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The vegetation of the Ettrema and Northern Budawangs wilderness areas, Morton National Park, NSW

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University of Wollongong

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The Vegetation
of the Ettrema and Northern
Budawangs
Wilderness Areas
Morton National Park, NSW

A thesis submitted in fulfilment of the requirements for the
award of the degree

Honours Master of Science

from

University of Wollongong

by

Denise Elizabeth Black B.Sc., M.Sc. (Syd. Uni.)

Departments of Geography and Biology,
1995
Declaration

I hereby declare that the work contained in this thesis is, except where otherwise acknowledged, entirely my own original work and has not previously been submitted for any degree at any University.
Acknowldgements

I would like firstly to acknowledge the caring attitude of people in the Geography and Biology Departments, who have helped where possible, despite the fact that their own individual research areas are rather different from the type of work undertaken for this thesis.

To my Supervisors:

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To all those who prayed for me, knowingly or unknowingly.

In Memory of:

Carol Virtue, whose assistance on many field trips and friendship helped me greatly.

Your deep love of the bush enhanced those trips. Like the rare plants that we found, you struggled to survive, and finally lost your battle when you took your own life in March 1995. I grieve your passing.
Explanatory Notes

The fieldwork for this thesis was largely conducted in the period 1982-1983. This period was prolonged, as I determined to cover the area as thoroughly as possible. I worked in close co-operation with the land managers, and all information passed on was instantly utilised.

There was then a long interruption, following the birth of my son, who had most of my attention for 7 years.

As explained in the section on "Change Through Time", a decade is unlikely to be long enough to cause a major change in vegetation patterns, short of catastrophe, which (apart from the usual bushfires, see ch.8), has not happened. I felt that it was still important to write this work up, despite the long delay, and was kindly accepted for enrolment at Wollongong University a second time around in 1991.

All names of plant species mentioned in the text are cited with their nomenclatural authorities in Appendix 1.
ABSTRACT

This is an analysis of the vegetation of the Ettrema and Northern Budawangs areas. These are the two core wilderness areas of the Morton National Park. The distinctive sandstone landscape of these two areas covers approximately one and one half thousand square kilometres. The vegetation communities, previously undocumented, are defined and then analysed in terms of their environmental interrelationships, both spatial and temporal.

The analysis began with the mapping and classification of plant communities. They were classified differently according to vegetation formation. Heathland and rainforest were subdivided on the basis of location and species composition. *Eucalyptus* forest was defined in terms of associations (*sensu* Beadle and Costin 1952) and gradients of change. The vegetation was mapped onto a series of topographic maps covering the area. These maps have been reproduced at a reduced scale in this thesis (Figs 3.3-3.12). A full-scale set of 9 1:25,000 map sheets covering the area are lodged in the map library in the Geography Department at Wollongong University. Mapped vegetation units often equate with "land systems" (*sensu* Keith & Benson 1988), containing the classified communities in short spatial sequence.

The defined communities were then described in terms of their place in the landscape. The majority of communities were found to occupy more than one habitat. This was interpreted as the vegetational response to the changing balance of basic plant growth factors. It was found that communities could be statistically grouped in relation to plant macronutrients, whereas the extent to which communities could be grouped statistically according to topography was found to be relatively low.

Temporal changes were examined from the three perspectives of (i) stability of *Eucalyptus* associations (ii) evolutionary significance of rare species (iii) relationships between vegetation distribution patterns and fire.

(i) It was found that co-occurring groups of eucalypts are frequently composed of species which can (theoretically) interbreed, since they occur in the same subgenera. It was
hypothesised that taxonomic distances amongst co-occurring species is a reflection of the stability of these associations through time.

(ii) Rare plants make up about 7% of the species collected during the course of this survey. These were categorised into a number of morphological and distributional groups. Some are closely similar to related species, while others are more taxonomically isolated. Some are consistently distributed through a particular habitat, whilst others are erratically distributed. A third and large group are disjunctly distributed over their entire range. The possible significance of these morphological and distributional differences in evolutionary terms was considered. The conclusion was reached that some may be more recently evolved than others, with at least one, *Eucalyptus dendromorpha*, possibly showing an adaptational response to recent increased fire frequencies. Others, as indicated by their distribution, may well have diminished as a result of changes following the arrival of man on this continent. Support for these hypotheses was drawn from the literature on evolutionary theory, climatic change and plant evolution as deduced from the macro- and micro-fossil records.

(iii) Broad relationships were observed between the high frequency of fire, its most usual direction of travel, and the pattern of distribution of fire-sensitive vegetation. Fire-sensitive vegetation was found to be in the least fire-prone locations. Eucalypts in the Ash Group are often killed outright by fire and are less likely to regenerate from lignotubers or by means of epicormic sprouting. The representation of this group in the area is high, compared to its representation in the State as a whole. Evidence that some species may be rare, or their rarity may have been accentuated, as a result of fire, comes from the chance observation of erratic distribution of rare species in different habitats.
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1. Introduction

1.1 Vegetation Communities, Continua and Beyond

"Community" and "continuum" are two concepts of vegetation distributions dating back to the early part of this century. They have often been set up in apposition to each other as hypothetical extremes of interpretation of vegetation distribution pattern. On the one hand, vegetation is seen to be made up of independently distributed individual species, which differ with differing environments (Gleason 1926), while the second view assumes that species group together in communities interdependently and change as a group with changing environment (Clements' 1936 "organismal" view of community).

Despite the fact that these concepts are often set up in apposition to each other, noted pioneers in the application of one or other concept have acknowledged the alternative. For example, Beadle and Costin (1952), trailblazers in adapting the European phytosociological association/alliance terminology to the Australian vegetation, acknowledged the independent distribution of species as follows: "Vegetation, soils and animal communities usually vary continuously and in several directions; accordingly, any attempt to classify a continuously varying system into several categories must necessarily be somewhat arbitrary...classification is essentially a compromise between the desire to preserve these natural groupings as continuously varying entities and the need to subdivide them for more utilitarian purposes".

The existence of plant communities was acknowledged by Whittaker (1967). He defined a meeting point between the continuum and community approaches to vegetation distributions by explaining that sequences of community types can be recognized along environmental gradients and that each can be described in terms of the other.

Although plants may be distributed independently relative to the physical environment, they do, nevertheless, occur in associations, at least of dominant species, which can be classified, described and mapped.
The nature of the difficulty in categorizing the Australian vegetation into communities was illustrated by the results of the South Coast survey (Austin et al. 1978). They found that extensive floristic data collected from naturally vegetated areas of the Eurobodalla Shire, when subjected to statistical classification, did not sort into the "obvious variations caused by aspect." However, when these data were subjectively divided, "based on the known combinations of the dominant eucalypts (data supplied by J. Duggin)", it proved possible to "achieve a classification which provided toposequence differentiation and geographical distinctness while allowing easy recognition of the communities in terms of dominant canopy species." Two problems appear to have been highlighted by this South Coast Survey. Firstly, the difficulty of quantifying the visible relationships between vegetation and environment, and secondly, the difficulty of matching the understorey with the dominant species, *Eucalyptus*, by which the communities were finally defined.

More recently, Austin (1989) propounded the idea that communities are a "landscape" concept of vegetation, since combinations of species change with the changing landscape. Austin maintained that gradients of species changes in relation to habitat gradients could be abstracted from the landscape, whereas communities could not. Yet if communities (albeit classified by dominants) can be defined in relation to the landscape, then it follows that it ought to be possible to abstract their relationship with that landscape as well.

### 1.1.1 Communities: Simple and Complex

In some areas of eastern Australia, communities of dominants have been easily defined. For example, Costin (1954) defined alliances and associations in the Monaro Region, although noting that some Tablelands associations were more complex than others. Associations were readily defined in the montane Barrington Tops (Fraser & Vickery 1939). Black (1977) found that associations of *Eucalyptus* were readily defined on the montane Boyd Plateau.

Pidgeon (1937, 1941), found that the *Eucalyptus* forests on the Sydney sandstone were bewilderingly complex, so much so that all forest was grouped together as one association: "mixed *Eucalyptus* forest association." Writing about these forests,
Pidgeon (1937), commented on their "extremely low integration...characterised by a large number of dominants in any one stand". Observing that some species were widely distributed and others narrowly, Pidgeon attempted to define gradients in the occurrence and change of species with climate and topography. The limits of distribution of species were attributed to climatic variables within their geographic range and to microclimatic variables within their local habitat.

In mapping the vegetation of the Sydney Basin, Benson and Keith (1986-1990) confirmed Pidgeon's assessment of the bewildering complexity of Eucalyptus forest on sandstone.

It appears, then, that the associations of Australian eucalypt vegetation may vary in ways which have not yet been fully defined or explained, with some associations being more complex than others.

1.1.2 Gradients of Change in Complex Associations

Benson and Keith (1986-90) described the "Hawkesbury sandstone complex" as being one which "contains considerable local structural and floristic variation depending particularly on topographic position, drainage and aspect. Various sub-units and topographic sequences can be recognised (which are) not practical to map." This is almost a repetition of the comments made by Pidgeon (1937) fifty years earlier.

Both Pidgeon and later Benson sought explanation for the complexity of distribution of eucalypts on the Sydney sandstone in terms of change from one species to another, in accordance with changing environment. Individual species of Eucalyptus, although thought to be extremely sensitive in their responses to the changing environment were not seen to be in association with one another, with the Eucalyptus forests as a whole displaying "extremely low integration." (Pidgeon 1937).

1.2. Vegetation and Environment: Interrelationships

The potential interrelationships between vegetation and features of the environment are modelled in Fig.1.1. This model illustrates the complex ways in
which the features of the physical environment can influence the spatial arrangement of factors which directly affect plant growth and hence vegetation distribution patterns. It also points to a means of interpreting the relationships between vegetation patterns and the environment. This can be done by considering the factors which directly influence plant growth, and which are therefore likely to be of primary significance in determining plant distributions. These "basic plant growth factors" (categorised as "resource gradients" by Austin and Cunningham 1981) are few in number and largely encompassed in the following list : nutrients, moisture balance, light, temperature.

It seems reasonable to expect that the factors of the environment such as physiography, geomorphology, climate and soil type ("indirect gradients" of Austin & Cunningham 1981), complex as they are in character, will influence plant distributions via the basic plant growth factors.

Thus, although the relationship between physiography and plant communities may be constant over a small area, over a larger area, it will vary in a predictable way which may nevertheless be difficult to describe, either qualitatively or quantitatively, since the actual relational constancy is amongst plants and plant growth factors, not amongst plants and aspect or any other physiographic feature.

Similarly, the impact of particular geomorphological features on plant distribution patterns, is likely to depend upon the way in which the balance of basic plant growth factors varies with geomorphology. Thus, if two different rock types produce soils of similar texture and nutrient balance, and if other factors remain within a similar range of variability, the same vegetation might reasonably be expected to occur on both.

The principles outlined above have previously been stated in various ways (summarised in Austin et al. 1984, referred to in Austin 1980, Austin & Cunningham 1981, Austin et al. 1983, Austin et al.1989, Fitzpatrick & Nix 1970), but not widely applied. Their application may assist in the interpretation of the often complex distributional patterns of vegetation observed in the Sydney Basin vegetation.
1.3. Change Through Time

1.3.1 Effects of Change Through Time on Vegetation

Precise spatial patterning of vegetation in relation to the distribution of plant growth factors would only occur if vegetation was left undisturbed by change through time. Changes such as climatic change or fire, can be expected to disturb existing species and communities. Likely effects are summarised in Fig 1.2. Changes can be expected to result in the contraction of the distribution of some species and communities, resulting in rarity of some species and fragmentation of distribution patterns. Other species may be favoured, resulting in their diversification and initiating natural selection and speciation. Distributional expansions may result in the overlapping of species and communities formerly separate. This may be followed by a period of instability and increased diversity and complexity.

1.3.2 Changes Through Time Which May Cause Disturbance

Changes through time may be caused by frequently recurring events, such as fire, flood and landslide, disturbances which are anthropogenic, such as clearing, logging and grazing and disturbances occurring over a longer period of time, such as climatic change and landform evolution.

1.3.3 The Community Concept in Relation to Stability through Time

There is an evolutionary rationale for the circumscription of community as more than the mere co-incidence of species with overlapping habitat tolerances. This is based on a knowledge of the speciation pathway. Darwinian evolutionary theory, as put forward by Charles Darwin in the Origin of Species last century, propounds the evolution of species from one another over time and space by means of the natural selection. According to the geographical theory of plant speciation (well explained in Grant 1981), geographical races are the precursors of species in a continuous process of evolutionary divergence. The speciation pathway starts with polymorphic variation within a species and continues through local races, followed by geographical races and then species. Isolation at the
racial stage enables separate populations to develop and maintain the gene combinations determining their distinctive morphological and physiological characteristics. Inevitably, then, the co-occurrence of taxa which are able to interbreed can only be a temporary phenomenon.

1.3.4 Pryor's Rule

This knowledge can be seen to underlie a generalisation put forward by Pryor (1959) concerning associations of *Eucalyptus*. *Eucalyptus* is the dominant species of most Australian open forests. There are about seven hundred species of *Eucalyptus*, which are placed in six subgenera. Within subgenera, hybridisation can occur, although in undisturbed forests, hybridisation is not regularly observed, and thus, it is thought, is maintained the separateness of taxonomic species. Only 15% of expected hybrids have been recorded in nature (Griffin *et al.* 1988). Pryor advanced the idea that different eucalypts in associations come from different subgenera. He noted that, in most of south-east Australia each available habitat is occupied by a stand made up of trees of *Eucalyptus* of at least two species. In such mixed stands, he claimed, the species do not interbreed, and are always derived from different subgenera. Pryor noted that there were many minor exceptions, but that the rule generally held at the 1000 acre scale.

Pryor's observations imply, firstly, that eucalypts occur in communities in a sense that stretches the limits of the "landscape" concept of Austin 1989. Secondly it implies that they display a degree of interrelationship, which extends beyond the mere overlapping of habitat tolerances and is meaningful in terms of stability of co-occurrence through time. Pryor's rule was tested for the South Coast (Austin *et al.* 1983) and was confirmed for the montane region, but not for the coastal areas of the Eurobodalla Shire. Given the significance of Pryor's generalisation in relation to a major theme of plant ecology, viz., the community-continuum debate, it is surprising to find that it does not appear to have been put widely to the test.
1.3.5 Rare Species

Australian rare species, which are currently being catalogued, partly because of the urgent need to see to their conservation, have not yet been widely interpreted in terms of their status in present and past communities. Categories of rareness have been previously proposed (for example, Stebbins 1942, Rabinowitz 1981, Main 1982). The potential value of rare species as indicators of temporal change in spatial patterning has not yet been explored. However, given that:

(i.) The environmental factors to which vegetation relates may vary over time, and:
(ii.) Adaptation of vegetation to environmental changes will be slowed by intrinsic (genetic) and extrinsic factors (e.g. rates of seed dispersal), the diminished components of current day vegetation may reflect the past. Hence, those rare species which can be identified as probable relics (e.g., many of the rare eucalypts listed by Pryor 1981), may be useful indicators of vegetation change through time.

1.4. Australian Plant Communities: Mapping

Many areas of the Australian vegetation have now been mapped. Vegetation has been systematically surveyed and mapped at a broad level in Western Australia, which has been mapped at the 1:1,000,000 scale, with the Southwest Province mapped to 1:250,000 scale; (Beard 1972-80). In Tasmania the vegetation has been mapped at the 500,000 scale (Kirkpatrick and Dickinson 1984) and major vegetation communities described (Duncan & Brown 1985, Kirkpatrick et al. 1988, Whinam et al. 1989, Pannell 1992). Tasmanian wilderness areas are being mapped at a scale of 1:25,000 under a Department of Parks, Wildlife & Heritage mapping program. As part of this program, the Central Plateau area of Tasmania, including the Lake St. Clair- Cradle Mountain National Park, has now been mapped (pers. comm. J. Balmer 1992). Victoria is being mapped area by area, as conservation and other considerations dictate, much of this work being done under the auspices of the Victorian Department of Conservation, Forests and Lands. Mapping scales have varied, depending on the area mapped (Kirkpatrick & Dickinson 1984). Floristic data for Victoria's wet sclerophyll forests is available in a variety of
published and unpublished forms (Kirkpatrick et al. 1988). This work follows a series of land use reports produced in the 1970's (eg Land Conservation Council 1974), in which areas were examined from the perspective of landuse and vegetation was classified and mapped at the structural level. The Northern Territory has been mapped and classified at the 1:100,000 scale (Wilson et al. 1990). Most of Queensland has been mapped at the 1:1,000,000 scale (Tracey & Webb 1976, Neldner 1984, 1991, Boyland 1984, Young & McDonald 1989, Elsol 1991). The Sydney Basin vegetation has now been mapped at the 1:100,000 scale, from 1:25,000 compilation maps (Benson & Keith 1986, 1988, 1990), building on the early work of Pidgeon (1937, 1941). The vegetation of some of the natural areas around Ettrema/Northern Budawangs (NSW) has been mapped, (the Eurobodalla Shire on the South Coast (CSIRO 1976, 1978) and the Budawang Ranges, (Gilmour & Plumwood 1982).

1.4.1 System of Classification used in Mapping

The difficulty of relating the understorey and canopy species in the Australian vegetation has been noted (Austin et al. 1978, Westman 1978, Rice & Westoby 1985, Wilson et al. 1990, Neldner 1991). Mapping is therefore usually based on the distribution of the canopy species. Plant communities defined by dominant canopy species equate with associations and alliances as defined by Beadle and Costin (1952).

Definition of Association/Alliance

Beadle and Costin (1952) defined the association as: "a climax community of which the dominant stratum has a qualitatively uniform floristic composition and which exhibits a uniform structure as a whole". The authors explained that this definition "does not insist upon quantitative uniformity of the dominants, which rarely occurs". The alliance was defined as: "a group of floristically related associations of similar structure". The associations of an alliance are linked by characteristic dominant species.
1.4.2. Level of Detail of Mapping

The level of detail at which an area can be mapped and its vegetation communities accurately defined can be seen to be a function of

1. Size of area being surveyed
2. Time taken.
3. Complexity of the vegetation patterns.

J.S. Beard (1981), recapitulating from many years of vegetation mapping, noted the part played by scale in relation to vegetation classification, with the level of detail necessarily being progressively reduced with increasing size of area of vegetation being classified. Beard and his associates mapped Western Australia mainly at the scale of the plant formation and in areas to the more detailed scale of the plant association. Costin, taking twelve years to study the vegetation of the Monaro region, was able to classify and map the vegetation into alliances of associations. Plant communities defined in the Northern Territory equated with Beadle & Costin's association and alliance (Wilson et al. 1990). Benson and Keith mapped many of the Sydney Basin vegetation communities as land systems rather than to the level of detail of the association. Mapping of the Sydney Basin is made more difficult by the complexity of the vegetation of this landsurface (see 1.1.1).

1.5. The Ettrema and Northern Budawangs Wilderness Areas

1.5.1 Potential for a Case Study

The vegetation of this area of approximately one and one half thousand square kilometres of relatively undisturbed wilderness was unmapped prior to this survey. Encompassing climatic changes from near coastal to tablelands, this large natural area is internally consistent in terms of its Permian geology and distinct from surrounding areas in this sense. Nevertheless, the area displays a wide range of variation in topography from the flat-topped mountains of the Northern Budawangs to the steep-sided gorges of the Ettrema creek system. Although the landscape is dominated by ancient sandstone, there is a wide range of rock types, producing soils which vary from fertile to extremely
infertile. The Shoalhaven River which borders the area to the north and west, the Budawang National Park which adjoins to the south and State Forests to the east, ensure that the area is buffered not only from urban influences, but also from the effects of many rural practices, a major exception being fire.

Northwards, the Northern Budawangs and Ettrema Wildernesses link with other remaining Wilderness Areas of the Sydney Basin, including the Blue Mountains to the west and the Colo Wilderness to the north-west. With these, they share in common large areas of infertile sandstone supporting heath and sclerophyll forest. A considerable variety in plant species and communities is encompassed within the varying environment of the Ettrema and Northern Budawangs (Fig. 1.3) This situation offers great opportunities to examine a large area of natural vegetation in terms of:

(i) The plant communities and gradients of change over an entire landscape;
(ii) Contrast between the vegetation communities and gradients of two adjacent, geologically similar areas;
(iii) Departures from the observed widespread pattern of communities and gradients;

In order to gain an appreciation of the vegetation as a whole, it was necessary to do the following:

(i) Map the vegetation patterns
(ii) Analyse vegetation patterns and gradients of change
(iii) Analyse relationships between vegetation and environment
(iv) Analyse departures from the observed pattern of communities and gradients and seek explanations in terms of disturbance factors, such as fire, human interference, and climatic change on vegetation patterns.
1.6 Aims of this thesis

1. To describe and map the vegetation communities of the Ettrema and Northern Budawangs areas.

2. To describe the gradients which occur within these communities.

3. To describe and analyse the relationships between communities, gradients and environment.

4. To seek explanations for vegetation distribution patterns, including the observed communities and rare species, in terms of temporal changes in relation to long and short-term disturbance factors, in particular, climate and fire.
Figure 1.1

Vegetation and Environment: Some Important Interrelationships

Physical Environment

- Temperature
- Moisture Balance
- Light
- Nutrients
- Climate
- Geomorphology
- Topography

Factors and Interactions:
- Temperature
- Rainfall
- Wind
- Soils
- Altitude
- Aspect
- Slope
Figure 1.2

Vegetation Dynamics: Ettrema - North Budawangs

Altered Distribution Patterns

Distributional Expansions

→ Contractions

↑ Dominance & Diversity

↓ Extinction

Species Increase/Decrease

↑ Change through Time

Climatic

Anthropogenic

Vegetation Distribution Patterns

Physical Environment

Plant Species
Figure 1.3

Etrema - North Budawangs:
Patterns of Vegetation Distribution
2. Physical Environment

2.1 Introduction

The Northern Budawang Ranges and Ettrema areas are the two core wildernesses of the Morton National Park, which is situated in south of Sydney, NSW (Fig. 2.1). They are similar geologically but geomorphologically distinct. The Permian sandstone of which both areas are composed has weathered to form a striking landscape of flat-topped mesas in the Northern Budawangs. Equally visually striking are the flat, rocky plateaux and deeply-dissected gorges of the Ettrema wilderness.

The antiquity of these landscapes, little changed since the mid-Eocene (Young & McDougall 1985), is reflected in the poverty of the skeletal and yellow earth soils which cover much of the area. These form a contrast to the rich, red krasnozemic soils, weathered from scattered basalt emplacements.

Climatically, the area is characterised by waning coastal influence and progressively increasing tableland climatic characteristics westwards. These features combine to form a great diversity of habitats.

Aims of This Chapter

The purpose of this chapter is to outline the geological, geomorphological, soil and climatic characteristics of this area, to provide a background for the vegetation study which follows.
2.2 Summary

2.2.1 Geology

The Ettrema and Northern Budawangs wilderness areas are at the southern edge of a major geological subdivision, the Sydney Basin. The Permian sedimentary sequence which dominates the Ettrema and Northern Budawangs landscapes underlies the younger Triassic sequences of the Sydney Basin which are exposed throughout the Sydney region to north of Newcastle and the western edge of the Blue Mountains. Although the landscape is dominated by ancient sandstone, a wide range of rocks outcrop here.

2.2.2 Geomorphology

The predominant stratum of the Permian sedimentary sequence, the Nowra sandstone, is the base material of contrasting landforms in the two wilderness areas. This sandstone is extremely hard and, as a consequence, slow to weather. In the Northern Budawangs, Permian sandstone caps a chain of flat-topped mountains, or mesas, whereas, in the Ettrema area, the sandstone forms a series of flat plateaux.

The mesas of the Northern Budawangs are isolated from one another by valleys, which are sometimes shallow and flat-bottomed, and at other times steep-sided and deep. Sharply demarcated boundaries between geological strata on the Northern Budawangs mesas present an abruptly changing physiography (Fig. 2.2). This is in contrast to the Ettrema area, where, on the one hand, the flat monotony of the plateaux, and on the other, the steep slopes of the Ettrema creek and its tributaries, are both landsurfaces dominated more by variations within the sandstone than by changing rock type (Fig. 2.3). Further contrast is provided by a number of volcanic emplacements, at Sassafras, Endrick and Tolwong.

2.2.3 Soils

The wide range of rock strata in these areas produce soils which vary from extremely infertile to fertile. The various Permian strata have weathered to produce soils of varying texture and depth. The large areas of sandstone rockland across the Ettrema Plateaux and
on the mesa-tops frequently have only a skeletal soil cover of poor nutrient status, while in other areas, deep yellow earths have been formed. The basalt emplacements have weathered to form rich, red krasnozems. Alluvium and colluvium occur along the Ettrema creeks, and old alluvium in the north-western corner of the Ettrema plateaux system, above the major north to east bend in the Shoalhaven River.

2.2.4 Climate

The one and one half thousand square kilometres of the Ettrema and Northern Budawangs wildernesses extends from the coastal hinterland to the edge of the southern tablelands. This area is large enough for climatic gradients to occur, from temperatures and humidity moderated by the coastal influence to greater extremes inland.

2.2.5 Diversity of Habitats

The geology, geomorphology and climatic variations combine to form a great diversity of habitats in the Ettrema and Northern Budawangs, from exposed surfaces subjected to climatic extremes, to sheltered positions where moisture is retained; from steep, unstable slopes to flat, ancient, unchanging rocklands.
2.3 Geology

The Ettrema and Northern Budawangs areas are at the southern edge of the Sydney Basin, a major geological subdivision characterised by generally conformable sediments ranging in age from Carboniferous to Triassic, which are thought to have been laid down in a depositional basin or basins (Herbert & Helby 1980). They form part of the Sassafras Plateau and the Boyne Mount Plateau, which are major structural subdivisions of the Sydney Basin.

The strata most important in forming the physiography of the Ettrema and Northern Budawangs areas are the Berry, Nowra, Wandrawandian and Snapper Point strata. These are thought to have been laid down as marine sediments during the Permian period (Herbert & Helby 1980).

2.3.1 Sequence of Permian Sedimentary Strata

(i) Berry Formation

The uppermost of these is the Berry formation, which consists of soft, relatively fast-weathering silt and sandstones. These form the rounded knolls which occur on Tullyangela Labyrinth and Ettrema and Galbraith Plateaux and which cap Island and Talaterang Mountains in the Northern Budawangs. These knolls are the residue of a once more widespread covering of these softer strata. The westernmost knolls would have been closer to an ancient shoreline, and the rock here is a silty sandstone. Further eastwards, the Berry becomes a finer-grained siltstone, accordant with its offshore deposition (R.W.Young pers. comm.1992). Foo (1969), in studying the Bulee Brook-Red Ground-Endrick River area, observed that joint patterns in the Nowra sandstone did not "permeate" into the topmost sandstone and by means of this characteristic feature, re-mapped this as Berry formation from air photos.

(ii) Nowra Sandstone

The physiography of both areas mainly stems from the slow-weathering characteristics of the massive, thick, hard sandstones of this Formation. The lithological characteristics of the Permian strata and their importance in landscape development were described by
R.W. Young (1977). Differential stripping of the softer Berry, Wandrawandian, Ordovician and Devonian strata has occurred, leaving the extensive plateau areas of the Ettrema wilderness and the flat-topped, benched mesas of the Northern Budawang Range. Numerous joint planes are visible in the Nowra sandstone on the air photographs. These trend in a north-west direction on Mts.Cole, Owen, Tarn, Bibbenluke, in an east-west direction on Endrick and Sturgiss Mts and north-east on Island Mt. They are obscured on Mt. Talaterang.

(iii) Wandrawandian Siltstone

The softer, more rapidly weathering siltstones of this Formation form the upper slopes of mesas and gorges, typically sloping at an angle of between 10 and 45 degrees. These moderately-angled slopes contrast with the vertical clifflines formed by the Nowra sandstone above. A single cliffline and slope occur on the western mesas: Endrick Mt., Sturgiss Mt., Mt. Bibbenluke and the western side of Mts. Tarn and Hoddle (see Plate 2.1). This is attributed to the lensing out of the Wandrawandian strata westwards (R.W. Young 1977). The Nowra sandstone cliffs are often undercut at their junctions with the Wandrawandian siltstones, forming caverns which may extend under the sandstone to a maximum of about ten metres. These caverns occur around all the mesas and along the clifflines of the Ettrema gorges.

(iv) Snapper Point

The relatively hard Snapper Point sandstones form extensive secondary plateaux around the easternmost mesas in the Northern Budawang Range (Mt. Talaterang, Pigeon House Mt.). These diminish to clifflines around Mts.Cole and Owen. The Snapper Point intergrades with the Wandrawandian on the slopes of Mts.Tarn, Bibbenluke, Hoddle, Haughton and Endrick. It becomes difficult to distinguish one from the other. In the Ettrema Gorge, the Snapper Point Formation is distinguishable as a second cliffline (see Plate 2.2).
(v) Talaterang Group

These conglomerates and siltstones discontinuously underlie the Snapper Point. They are exposed on the lower slopes of the Corang massif and also appear on the northern side of Mt. Bibbenluke. They are thought to be riverine in origin.

There is a discrepancy between earlier and later mapped interpretations of the stratigraphy in the Mt. Corang area. According to the more recent geological map (Ulladulla 1:250,000), the top of Mt. Corang is Berry formation, with the lower slopes being Nowra sandstone. Valley floors in the vicinity (including Corang River, Yadboro and Viney Creeks) are upper Devonian Merimbula Formation, eastwards to the Comerong volcanics (a dyke which runs east-west.) On the old 1-inch-to-the-mile geological series sheet, the top of Mt. Corang and slopes are indicated to be Nowra sandstone, with the lower slopes being Snapper Point.

2.3.2 Devonian and Ordovician Strata

A number of different rock types of these Periods shape parts of the landscape in Ettrema and Northern Budawangs.

(i) Northern Budawang Range

Folded Devonian Quartzites form the shallow valleys in the western half of the Northern Budawang Range. Ridges of quartzite occur frequently throughout this area. Further westwards and southwards, sharp divisions occur between surface outcroppings of Devonian and Ordovician strata. These are visible west of Mt. Corang and south of Monolith Valley, on the slopes above Yadboro Creek.

(ii) Ettrema Creeks

Devonian and Ordovician strata of diverse lithology outcrop along the Ettrema creeks. Rocks of both periods are folded (see Plate 2.3) and the unconformity between these strata and the overlying horizontally-bedded Permians is exposed in many places along the gorges. Where observed in the field, the geology of these creeks did not always correspond with that as marked on the available Geological Survey Sheets.
Most of the lower part of Ettrema Gorge is Ordovician quartzose sandstone, as indicated on the 1:250,000 geology map. Near the junction of Ettrema and Jones' Creeks, Silurian limestones occur. In this the area, there are small ore-bodies, which have been mined in the past.

Metamorphosed Ordovician sediments predominated at places where the Ettrema creeks were transected during field trips. On Bundundah Creek, exposures of Devonian granite were observed along the mid-slope below Smallest Plateau. These are recorded as Devonian basalt or dolerite on the geology map. Devonian sandstone and conglomerate were both observed on Boolijah Creek. The conglomerate contains pebbles of volcanic rock indicating the Middle or Upper Devonian age of this exposure. Matson (1969) studied Devonian strata in the Danjera Creek Dam area. He described the Middle Devonian rocks as occurring in the form of a large/wide anticline west of Danjera Creek, plunging northwards at 20°, with the Upper Devonian rocks gently folded into an asymmetric anticline and symmetric syncline tending north. Danjera Creek runs down the western limb of the anticline, which dips at 60-70° to the west.

The Middle Devonian rocks are interbedded rhyolites, basalt, conglomerate, siltstone, and sandstone, while the Upper Devonian rocks are interbedded basic volcanics, tuffs, ignimbrites, sandstone, siltstones, mudstones and conglomerates. Love (1965) studied the Ordovician and Devonian strata in the Yalwal area. He found that the Ordovician rocks in the Yalwal area consisted mainly of interbedded schist, semi-schist, phyllite, slate, quartzite and sporadic conglomerate, with semi-schist the most dominant rock-type. He found that rocks south-east along Yarramunmun Creek are lithologically identical with those west of Danjera Creek, and although mapped otherwise, it appears that the rocks outcropping to the north-east, south-east along the Yarramunmun, south in the upper reaches of Jinkbilly Creek, south-west along the Danjera and west of the Yalwal township site are of Ordovician age.
2.3.3 Basalt Flows

Basalt emplacements in this area, at Endrick, Sassafras and Tolwong, have been mapped by Young & McDougall (1985). The Sassafras and Tolwong basalts are slightly elevated above the plateau surface and are rounded intrusions. A thin, elongated tongue of basalt extends south-eastwards along the northern side of Endrick Mt., forming an area here referred to as the "Red Ground". It extends southwards along the eastern side of Endrick Mt., forming a long, low, tree-covered lump on the Devonian valley floor (see Plate 2.4).

2.4 Geomorphology

2.4.1 Ettrema

(i) Plateaux

The series of plateaux forming the Ettrema wilderness become progressively smaller from west to east. The largest plateau, Tullyanga Labyrinth, is bounded by the Shoalhaven River on its western and northern edges, and by the Ettrema Gorge on its eastern edge. Southwards, it is continuous with the Galbraith Plateau at the northern edge of the Northern Budawang Range. Eastwards from the Tullyanga Labyrinth, the plateaux are Ettrema Plateau, to its north-east, Danjera Plateau, and to the east, Yarramunmun Plateau. The smallest plateau included in the wilderness is north of Danjera Plateau and is unnamed. In the text it is referred to as "Smallest Plateau". These plateaux range in elevation from 800 metres to 400 metres and slope gently north-eastwards to the coastal plain. (see Figs 2.4 a, b and c, diagrammatic transects across the centre of the plateaux). This gradual decline has been termed the "Yalwal Ramp" (Young 1977). To the west, Nerriga, at 620 metres, is approximately 150 metres below the western elevation of the sandstone.

Large areas of Tullyanga Labyrinth, Ettrema and Danjera Plateaux consist of flat to gently sloping more or less unbroken sandstone. These areas of sandstone are either bare, or may be clad with a shallow to quite deep mantle of soil. Patterning in the
sandstone over much of these areas is visible on the air photographs (see Plate 2.5). Parallel bands follow the contours, extending downwards from high points in the sandstone. This "quasi-concentric" patterning is most conspicuous on the southern parts of Tullyangela Labyrinth and Galbraith Plateau, on the Ettrema Plateau and on top of Endrick Mt. Areas of flat, unbroken sandstone are interrupted by belts of broken rock. The flat areas vary from exposed bedrock (rockland) to areas with a skeletal soil cover.

(ii) Creeks

The series of creeks in the Ettrema wilderness (Ettrema, Bundundah, Boolijah, Danjera and Yarramunmun) flow north-eastwards into Yalwal Creek, which empties into Ettrema Creek. Upstream, these creeks are characteristically steep-sided and rocky. Downstream, the gorge slopes fan to gentler colluvial slopes at the base and alluvial flats. The creek courses generally coincide with the strike of fault lines in the sandstone (Young 1978).

(iii) Knolls

Rounded knolls of residual Berry siltstone rise above the plateau surfaces, particularly on the Ettrema Plateau, for example Ettrema, Sturgiss, and Rolfe's Hill. Others occur to the west of Sassafras, on Tullyangela Labyrinth and on the Galbraith Plateau (for example, Bhundoo Hill). Seepage areas often occur at the base of these knolls.

2.4.2 Northern Budawang Range

(i) Mesas

The Northern Budawang Ranges are characterised by a series of flat, sandstone-capped mountains, or mesas. The largest of these mesas are Endrick Mt. in the north-west and Talaterang Mt. in the east. The smallest mesa, Pigeon House Mt. is also the southernmost. The westernmost mountain, Mt.Corang, which is not capped with sandstone, is pimple-shaped at its highest point. The average elevation of the central mesas of the Northern Budawang Ranges (Endrick, Hoddle, Tarn, Sturgiss, and those ringing Monolith Valley) is approximately 860 metres, with Mt. Hoddle (917m.) being the highest. There is a decrease in elevation eastwards from this central line to Mt. Talaterang (779m.). The average elevation of the shallow valleys which divide the central
mesas is approximately 660-620 metres. Situated to the east of Mt. Talaterang, Little Forest Plateau conforms stratigraphically with the mesas of the Northern Budawang Range. Some of these mesas (Island Mt., Mt. Talaterang) are capped by rounded knolls of residual Berry siltstone.

(ii) Galbraith Plateau

This plateau surface drains eastwards into the Endrick River via the Newhaven and Vines Creeks and Bulee Brook and into the Clyde River at its southern extremity via Camping Rock Creek. Foo (1969) found that there are two well-defined vertical joint sets in the Nowra sandstone in the Endrick River area and observed that these joint patterns control the drainage of creeks in the area. The Galbraith Plateau is separated from the Tianjara Plateau to the east by the deeply-dissected gorge of the Clyde River. The Tianjara Plateau rises centrally to Mt. Tianjara (768 metres) and drops 4-500 metres via a scarp to forested coastal hinterland.

(iii) Valleys and Gorges

The centrally situated mesas (Mts Tarn, Hoddle, Haughton, Bibbenluke, Sturgiss) are separated from one another by shallow valleys. These valleys are continuous with, and drain into, the relatively flat land to the west of the Northern Budawang Range. The average elevation of the flat land to the west (660-620 metres) is approximately the same as the floor of the shallow valleys which divide the mesas.

On the southern and eastern side of the N.Budawangs, the landsurface drops steeply from mesas and shallow valleys to deeply-dissected tributaries of the Clyde River, including Kilpatrick Creek, Hollands Gorge and Angel Creek. At the southern end of the N.Budawangs, Corang Peak, Mt. Renwick (Owen), the Castle and Byangee Walls are elevated 730 to 360 metres above the Yadboro River, which joins the Clyde River to the east of Pigeon House Mt..
2.5 *Age of the Landscape*

This is an ancient landscape. Basalts, dated as Eocene by Young (1978) and Young & McDougall (1985), not only cap the top of the Sassafras mesa, but extend down into the upland valleys. Moreover, Mid-Miocene basalt on the coastal plain below the main escarpment, which is of erosional rather than tectonic origin (Young & McDougall 1985), shows that the tableland has been at its present elevation for more than 30 million years. Except for the slow headward extension of gorges, the landscape has changed little since this time. The rate of retreat of the Nowra sandstone clifflines was calculated as less than 200 metres per million years (Young & Macdougall 1985). Their research has confounded the earlier "Davisian synthesis" that the Sydney Basin and the Permian sandstone area to the south were the outcome of cyclical uplift and erosion during the Tertiary and Pleistocene (R.W. Young 1978). Notions of late Tertiary uplift and accompanying soil rejuvenation have been widely used to interpret not only the eastern Australian landscape, but also the evolution of the vegetation. For example, Pidgeon (1941) suggested that the variety of forest stands on Hawkesbury sandstone could be attributed to "immature physiography and soils, and consequently a mosaic of microclimates and habitats." The impact of these ideas still influences botanical thinking (see for example Specht 1977, Beadle 1981, Smith, J.M.B. 1981, 1986).

2.6 *Soils*

The soils of this ancient landscape vary from very deep to almost skeletal. The majority of soils have extremely low nutrient status. A series of profiles were examined and samples analysed. The field characteristics of these samples are summarised in Table 2.1. Chemical soil analyses are discussed in Ch.4 (Table 4.3). The occurrence of major soil types in Ettrema/ Northern Budawangs is briefly outlined below.
2.6.1 Major Soil Types

The great soil groups (Stace et al. 1972) are represented in Ettrema/North Budawangs by yellow earths, krasnozems, skeletal soils, podzols, alluvium and acid swamp soils.

Yellow Earths.

Yellow earths occur in coastal eastern Australia from southern NSW to Cape York, and in NW Australia and N. Northern Territory. In many areas, they are associated with old land surfaces, but the parent materials vary. They are massive, porous soils with weak profile differentiation and gradual horizon boundaries (Stace et al. 1972).

This is the predominant soil group in the area, being common on parts of the Ettrema and Galbraith Plateaux and the Devonian valleys separating the mesas. Across the Ettrema Plateaux, yellow earths are progressively better developed from west to east. As the plateau surfaces decrease in altitude, the depth of soil increases. The Yarramunmun Plateau is mantled with yellow earth.

At soil sampling sites, yellow earths varied in depth from five centimetres to an unknown depth in excess of four metres (observed near Endrick Mt.: a drillhole of unknown origin, four metres deep, yellow earth profile continuing beyond this depth.) Such a great depth tallies with the mid-Eocene age of this landscape deduced by Young & McDougall (1985), from dating of the nearby Endrick basalt, and presuming the origin of these soils by in situ weathering (as summarised in Stephens 1962, Stace et al. 1972).

Yellow earths in the study area are acidic and low in nutrients (Table 4.3).

Krasnozems

These rich red soils have weathered from the basalt emplacements in the Morton wildernesses.

These soils are widely distributed through eastern Australia, being confined to basic igneous rocks south of the subtropics. They are characteristically red, strongly structured clay soils with weak profile differentiation below the A1 horizon, which is darkened by organic matter (Stace et al. 1972).

The surface layers of the Ettrema/ Northern Budawangs krasnozems are loam to clay-loam in texture and were found to have a high organic matter content (12-18% volatile
matter). Laboratory analysis confirmed that these soils are relatively rich in nutrients, and with a high moisture-holding capacity (Table 4.3).

**Acid Swamp Soils** are found in poorly drained areas, often near the headwaters of creeks which drain the flat sandstone. Those examined were found to be deeper than could be fathomed with field equipment, peaty, acidic and relatively high in phosphate compared with other soil types except kraznozems (Table 4.3).

**Skeletal Soils** extremely low in nutrients, are widespread across the sandstone plateaux and on mesa-tops. These are sandy, structureless and often peaty in texture.

**Podzols, Yellow Podzols and Peaty Podzols**

Podzols have a strongly differentiated profile, with a distinct subsurface horizon. Podzols, with distinct sandy A horizon and clayey B horizon, were observed on hill slopes in Wandrawandian strata. Alternating sandstone and claystone bands on the Galbraith Plateau have skeletal soils on the rocky parts and deeper yellow podzols on the clay bands. In more poorly drained bands, yellow podzols are replaced by peaty podzols.

**Alluvium**

Beds of alluvium have built up along the lower reaches of the Ettrema Creek system.

**Ancient Alluvium**

A large area of sandy soils in north-west Ettrema is thought to be ancient alluvium, of unknown origin (R.W. Young Pers. Comm. 1982.) This soil was observed to be deep, with no marked horizon in the uppermost 0.5 metre, only a slight colour gradation.

**Other**

Since the Ordovician strata are exposed on the steep slopes of the Ettrema creek system, physiography tended to be the dominant force in shaping soils on these strata. Stony regoliths on upper slopes are replaced by colluvium and old alluvium on lower slopes.
2.6.2 Distribution of Soils

(i) Ettrema

Whilst large expanses of plateau have barely any soil, some areas are covered in deeper soils. These are:

1) The area north-west of Tullyangela Labyrinth, beyond the "Tolwong" property, where large, flat areas covered with sandy soil occur, cut by deeply dissected creeks (Tryer's Creek and its tributaries). This sandy soil is thought to be an ancient alluvium (R.W. Young pers. comm.).

2) The central part of the Yarramunmun Plateau, and smaller areas of the other plateau surfaces, are covered with yellow earths. The areas of exposed sandstone lessen and the areas of plateau surface covered with soil increase eastwards across the Ettrema Plateaux.

(ii) Northern Budawangs

1) Bare rock, skeletal soils on mesa-tops.

2) Silty soils on Wandrawandian slopes.

3) Sandy, structureless soils in shallow Devonian Valleys.

3) East of Endrick Mt. on the plateau surface which drains into the Endrick River, there are areas of yellow earth soils, which were observed to be extremely deep in places.

2.7 Climate

2.7.1 General Characteristics

Ettrema and Northern Budawangs, are situated from 34 to 36 degrees south of the equator, in the temperate climatic zone. The anticyclones which move eastwards across the continent and dominate the weather pattern of the whole Australian continent (Linacre & Hobbs 1977), are a predominating influence in these areas. These pressure belts cross the east coast to the south of the study area in late summer (approximately 37° S) and to the north of the study area in late winter and spring (approximately 29° S). Places to the north of the anticyclones receive easterly winds and to the south, westerly. Hence, in the
study area, in winter and spring, westerly winds are more frequent, whereas in summer, a greater proportion of winds come from the north, north-east and south-east (see Fig. 2.8). Consistent with the pattern for eastern NSW, conditions tend to be less windy in autumn. Rainfall may be convectional, especially in summer, when moist coastal air is borne inland on the prevailing winds, or it may be borne on cold-fronts travelling from west to east, especially in winter, when westerly winds are more frequent.

2.7.2 Data

Rainfall and temperature data were obtained for nearby areas (see Figs 2.5 and 2.6). Rainfall data available from several locations within and closer to the study area has been graphed (see Fig. 2.7). Minimal wind data available for Nowra and Braidwood has been graphed (Fig. 2.8). These data are discussed below.

2.7.3 Major Causes of Climatic Variation within the Study Areas

Major causes of climatic variation are: I. Coast to inland climatic gradient II. Variations in topography III. Temperature inversion.

I. Coastal - Inland Climatic Gradient

(i) Temperature

There are variations in temperature with increasing distance from the coast. Thus, at Nowra weather station (14km to the east of the Yalwal Plateau), annual mean maximum and minimum temperatures are 21°C and 11°C respectively, whereas at Nerriga, at the western edge of the study area, they are 19°C and 6°C respectively. In the south-east, Woodburn State Forest's annual mean maximum and minimum temperatures of 20°C and 11°C respectively, are very similar to those recorded at Nowra. Braidwood in the south-west has lower annual mean maximum and minimum temperatures (19°C and 6°C) than at the coastal stations, these being similar to those at Nerriga (north west). Monthly temperatures also show little variation between these two locations. Low temperature are more extreme at inland than coastal stations, whereas summer mean
maximum temperatures are similar (Fig.2.5). Temperatures are similar latitudinally throughout the study area.

(ii) **Rainfall**

Rainfall decreases inland (see Figs 2.6 and 2.7). A seasonal bias in rainfall distribution is evident at the coast, with winter and spring being consistently drier, whereas rainfall is more evenly distributed inland. The relatively higher rainfall in summer and autumn on the coast can be attributed to the moisture-bearing onshore winds.

(iii) **Winds**

Limited data available (Fig. 2.8) indicates that onshore winds are more prevalent at Nowra than at Braidwood. While there is some diminution in westerly winds, they still influence the coast. At both locations, the most wind-sheltered aspect appears to be north. Onshore winds diminish in winter, when the westerly winds are strongest.

II. **Influence of Topography**

(i) **Temperature**

The Ettrema wilderness slopes gently eastwards, with the plateau surfaces averaging about 700m. west of Sassafras (see Fig 2.4). A temperature drop accompanies the rise from the coast to the Sassafras basalt. Temperature records are unavailable for Ettrema, but lapse rates calculated for SE Australia (Young 1982) indicate an average decrease in temperature of approximately 0.65° C for each 100 metre rise. At this rate, the temperatures at Sassafras (760m) would be expected to be approximately 4.3° C lower than at Nowra Armed Forces Base (107.9m). In the Northern Budawangs, the mesas, at over 800 m., are elevated approximately 200 m above the surrounding valleys. Assuming that the average lapse rate applies, temperatures on mesa-tops could be expected to be 1.3° C cooler than in the valleys.

(ii) **Rainfall**
At any particular place rainfall is influenced by topography. Orographic effects, combined with progressive loss of moisture in coastal winds, would explain the higher rainfall at Ettrema, causing a peak in the otherwise consistent diminution of rainfall westwards. This is depicted in Fig. 2.7, which is based on the mean annual rainfall over the ten year period from 1962 to 1972.

The effects of both distance inland and altitude are shown in a rainfall map constructed by R.W. Young (1968). He demarcated a zone of high rainfall running northwards along the slopes of the Budawang Range from the headwaters of the Mongarlowe River to Sassafras, with a drier belt along the Shoalhaven Gorge. The decrease in rainfall from the coast was shown to be more abrupt in the south than in the north of the Shoalhaven River catchment. Young delineated an east-west gradient in rainfall across the Ettrema Plateaux from 1200mm to 800mm, rising to about 1400 mm in the Sassafras-Tianjara Falls area. Tullyangela Labyrinth and Ettrema Plateau lie between the 800 and 1000mm isohyets, while the easternmost Yarramunmun Plateau has a higher rainfall, between the 1000-1400mm isohyets. The Northern Budawang Ranges receive a higher rainfall, generally falling between the 1200-1600mm isohyets.

### III. Temperature Inversions

Cold-air drainage is caused by the advection of cold air from higher ground (Linacre & Hobbs 1977), resulting in temperature inversions. Cold air would roll from mesa-tops to surrounding valleys, particularly at night. Similar temperature inversions may occur across the Ettrema plateaux as a result of height variations between Berry Knolls and lower-lying sandstone. This effect would be at its most extreme on sites where the flow of cold air, once it reaches lower ground, meets a physiographic barrier and where there is shelter from wind, such as on north-facing aspects.

### 2.7.4 Conclusions

The climatic data available clearly indicate a diminishing maritime influence across the Ettrema/ Northern Budawangs. This is evident in decreasing convectional rain
westwards, and increasing extremes of cold in winter months. Although climatic data from within the park are sparse, an increase in rainfall paralleling the rise in altitude from the coast to the basalt at Sassafras is evident (Fig. 2.7). Temperatures would predictably vary by several degrees as a result of elevation, with this pattern being reversed at night in low hollows by entrapment of cold air draining off high points.
<table>
<thead>
<tr>
<th>Rock</th>
<th>Vegetation</th>
<th>Soil Types</th>
<th>Munsell Colour</th>
<th>pH</th>
<th>Depth (cm)</th>
<th>Texture</th>
</tr>
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<tbody>
<tr>
<td>Basalt</td>
<td>E.fastigata <em>et al.</em></td>
<td>krasnozem</td>
<td>10YR 3/1-10YR 3/4</td>
<td>4.8-5.8</td>
<td>&gt;50</td>
<td>loam, clayloam</td>
</tr>
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<td></td>
<td>Rainforest</td>
<td>krasnozem</td>
<td>2.5YR 3/4</td>
<td>4.6-5.2</td>
<td>deep</td>
<td>clayloam</td>
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<td>Berry</td>
<td>E.sieberi</td>
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<td>5YR 4/3</td>
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<td>20</td>
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<td></td>
<td>E.agglomerata</td>
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<td>7.5R 2/0</td>
<td>4.2</td>
<td>~10</td>
<td>sandyloam</td>
</tr>
<tr>
<td>Nowra</td>
<td>Heath</td>
<td>skeletal</td>
<td>5YR 2.5/1</td>
<td>3.4</td>
<td>16</td>
<td>sandyloam</td>
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<tr>
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<td>skeletal</td>
<td>10YR 6/3-5/2</td>
<td></td>
<td>3.5-4</td>
<td>12</td>
<td>peaty</td>
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<tr>
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<td>skeletal</td>
<td>10YR 6/2</td>
<td></td>
<td>4.4</td>
<td>30</td>
<td>sand</td>
</tr>
<tr>
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<td>skeletal</td>
<td>10ZYR 5/4</td>
<td></td>
<td>4.5</td>
<td>22</td>
<td>sandyloam</td>
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<tr>
<td></td>
<td>E. <em>piperita ssp. urceolaris</em></td>
<td>yellow earth</td>
<td>10YR 5/4</td>
<td>4</td>
<td>5</td>
<td>sandy</td>
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<tr>
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<td>10YR 5/1</td>
<td>5.5</td>
<td>75</td>
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</tr>
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<td></td>
<td>Sedgeland</td>
<td>acid swamp &amp; skeletal</td>
<td>5YR 2.5/1-10YR 3/1</td>
<td>3.4-4.5</td>
<td>16-100</td>
<td>sandyloam</td>
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<tr>
<td></td>
<td></td>
<td>peat</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>yellow earth</td>
<td>7.5YR 4/4</td>
<td>3.6-5</td>
<td>~50</td>
<td>sandy-silty loam</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7.5YR 2/0</td>
<td></td>
<td></td>
<td>sand, silty, silty sand</td>
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<td></td>
<td>Wandra-wandian</td>
<td>E.fraxinoides/</td>
<td>hill mantle</td>
<td>4.1</td>
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<td>peat</td>
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<td></td>
<td></td>
<td>E.fastigata</td>
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<td>130cm</td>
<td>sandyclay-peatey</td>
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<td></td>
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<td></td>
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<tr>
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<td>10YR 7/3</td>
<td>4.7-4.8</td>
<td>&gt;30</td>
<td>sandy-sandyloam</td>
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<tr>
<td>quartzose</td>
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<td></td>
<td>10YR 5/4</td>
<td></td>
<td>~300</td>
<td>sandy-loamyloam</td>
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<tr>
<td>sediments</td>
<td>Rainforest</td>
<td>profileless</td>
<td>2.5YR 3/0</td>
<td>4.4</td>
<td>~30-50</td>
<td>sandy peatloam</td>
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<td>Devonian</td>
<td>E. <em>punctata/ E. imitans/Ironbarks</em></td>
<td>stony regolith</td>
<td>5YR 3.2-10YR 6/3</td>
<td>4.7-6.5</td>
<td>20-350</td>
<td>sandyloam</td>
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<td>volcanics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>loamysand</td>
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<tr>
<td>Ordovician</td>
<td>E. <em>tereticornis</em></td>
<td>colluvium</td>
<td>5YR 4/2-10YR 5/2</td>
<td>4.5-6.5</td>
<td>~300</td>
<td>sand</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-?</td>
<td>sandyloam</td>
</tr>
<tr>
<td></td>
<td>E. *imitans/ Angophora</td>
<td>alluvium</td>
<td>10YR 3/3</td>
<td>5.5-6.5</td>
<td>&gt;300</td>
<td>loamysand</td>
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<tr>
<td>floribunda</td>
<td></td>
<td></td>
<td>5YR 2.5/2</td>
<td></td>
<td></td>
<td>sandyloam</td>
</tr>
</tbody>
</table>
FIGURE 2.1: LOCATION DIAGRAM

SYDNEY

MOSS VALE

GOULBURN

FITZROY FALLS

ETREMA WILDERNESS AREA

NORTHERN BUDAWangs WILDERNESS AREA

BRAIDWOOD

CURROCKBILLY MT.

NAHAA CREEK RIVER

LITTLE FOREST PLATEAU

PIGEON HOUSE MT.
Fig. 2.2: Schematic Diagram of Rock Strata: Northern Budawang Ranges

Permian
- Nowra sandstone
- Wandawangan siltstone
- Snapper Point sandstone

Devonian
- folded sediments

Ordovician
- folded sediments

Stylised mesa
- Approximately 860 metres A.S.L.

- Approximately 640 metres A.S.L.
Fig. 2.3: Schematic Diagram of Rock Strata:

Ettrema Wilderness Area

Tullyangela Labyrinth

Sassafras

Yalwal Plateau

Eocene
basalt

Permian series
Berry
siltstone

Nowra
sandstone

Wandrawandan

Snapper Point

Devonian
folded sediments

Ordovician
folded sediments

W

← approximately 20 kilometres →

E
Fig. 2.4: West to East Transects of Ettrema

2.4 a

![Graph showing altitude (metres) against distance (kilometres).]

2.4 b

![Graph showing altitude (metres) against distance (kilometres).]
Fig. 2.4c

Altitude (Metres)

Distance (Kilometres)
A general trend towards decreasing rain inland is evident, with a marked departure from this trend at Ettrema. This can be interpreted as an orographic effect due to the higher altitude at this location.

**Stations:**
- Series across Ettrema plateaux: ■
- East and west of Northern Budawangs: ◆
Plate 2.1: Landscape of the Northern Budawangs Wilderness

**Left Front:** Endrick Mt. (note single cliffline and joint planes in sandstone). Mt. Sturgiss middle left.

**Middle:** Styles Ck, flowing through shallow valley of Devonian age.

**Background:** Mt. Tarn and Monolith Valley massif (note double cliffline).

**Distance:** pimple-shaped Pigeon House Mt., the smallest mesa.
Steep-sided gorge of Ettrema Creek dissects the flat Ettrema plateau surface and is bounded by cliffs of Nowra sandstone.

A second cliffline of Snapper Point sandstone is visible on right hand side, middle ground.
Plate 2.3: Permian / Ordovician Unconformity on Yalwal Creek, Ettrama Wilderness
Plate 2.4: Basalt Emplacement

**Middleground:** Endrick basalt: a long, low, tree-covered lump on the Devonian valley floor.

**Foreground:** Endrick Mt.

**Background:** Mesas surrounding the Monolith Valley.
Plate 2.5: Patterning in Permian Sandstone

2.5a: Galbraith Plateau: Jointing and banding in sandstone.

2.5b: Ettrema Plateau: Contour banding north-east of Ettrema Hill.
Plate 2.6: Typical Yellow Earth Profile
Location: Heathland, Galbraith Plateau

Profile undifferentiated in A and B horizons
Light yellowish brown
Munsell colour: 10YR 6/4

C horizon:
Yellow clay

Geological hammer is 33 centimetres in length.
3. Vegetation Communities and Gradients

3.1 Introduction

3.1.1 Definition of Communities: Association/Alliance Classification: Terminological and Conceptual Limits

Vegetation may be categorised into communities of species at varying levels of detail, from the combinations of overall dominant species (i.e., those which dominate both in size and numbers) to the most dominant species (physically and numerically) at a particular scale. The phytosociological terminology in use in Australia (Beadle & Costin 1952) does not exactly specify the scale, permitting ambiguity in its application. Beadle and Costin (1952) defined the plant association as "a climax community of which the dominant stratum has a qualitatively uniform floristic composition and exhibits a uniform structure as a whole". An "alliance" was defined as "a group of floristically related associations of similar structure". This appears to be in general use, but this definition is ambiguous in the sense that it could be applied at varying scales. Thus, it may be possible to subdivide vegetation which is uniform at a smaller scale into larger scale sub-units which are uniform in relation to a proportion of the dominant species used to characterise the smaller scale unit. The "association" as defined by one vegetation classifier may thus correspond to the "alliance" of another researcher classifying vegetation at a more detailed level, over a smaller area. Since some species of *Eucalyptus* are characteristically widespread and others have narrower distributional ranges, associations may be described as those units dominated by a widespread species irrespective of changes in co-dominants over smaller areas, or as each of those sub-units in which the widespread species co-occurs with various other eucalypts.

The comparative use of phytosociological terminology in vegetation studies in eastern NSW is summarised in Table 3.1 and discussed in the following pages.
Table 3.1: Comparative Use of Classificatory Terminology in Vegetation Surveys in Eastern NSW

<table>
<thead>
<tr>
<th>Author</th>
<th>Use of Association or Equivalent Term</th>
<th>Use of Alliance or Equivalent Term</th>
<th>Habitat Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraser &amp; Vickery</td>
<td>units dominated by a widespread species but with changing co-dominants</td>
<td></td>
<td>montane</td>
</tr>
<tr>
<td>1939</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pidgeon</td>
<td>units dominated by widespread species but with changing co-dominants. Smaller unit: &quot;forest type&quot;</td>
<td>not used</td>
<td>sandstone, coastal</td>
</tr>
<tr>
<td>1941</td>
<td></td>
<td></td>
<td>plateau</td>
</tr>
<tr>
<td>Beadle &amp; Costin</td>
<td>dominant stratum has qualitatively uniform structure &amp; floristics</td>
<td>group of structurally &amp; floristically related associations</td>
<td>abstract</td>
</tr>
<tr>
<td>1952</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Costin</td>
<td>units of co-occurring dominants which cannot be further subdivided</td>
<td>groups of related associations</td>
<td>montane-tableland</td>
</tr>
<tr>
<td>1954</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>unit of co-occurring dominants which cannot be further subdivided called &quot;unit&quot; (pending further investigation)</td>
<td>not used</td>
<td>montane</td>
</tr>
<tr>
<td>1977</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austin</td>
<td>unit of co-occurring dominants which could not be further subdivided called a &quot;community&quot;</td>
<td>~ &quot;group&quot;</td>
<td>coastal-tableland-montane</td>
</tr>
<tr>
<td>1978</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gilmour &amp; Plumwood</td>
<td>&quot;where there was sufficient similarity in eucalypt dominants within a vegetation type&quot;</td>
<td>not used</td>
<td>montane</td>
</tr>
<tr>
<td>1982</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benson &amp; Keith</td>
<td>map units are variable, may be: (i) unsubdividable or (ii) subdividable units of co-occurring dominants or (iii) land units</td>
<td>not used</td>
<td>coast to mountain, sandstone and other</td>
</tr>
<tr>
<td>1986, 1990, 1992</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benson &amp; Benson</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td></td>
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Vegetation studies which may exemplify the use of the term "association" to describe a unit which is more general than every occurring combination include Fraser and Vickery (1939 - Barrington Tops), Pidgeon (1941 - Sydney Basin) and Gilmour and Plumwood (1982 - Budawang Ranges). Broad definition of associations is more likely to occur in vegetation surveys covering a large area (such as those of Wilson et al., 1991 and Benson 1986, 1992, Benson & Keith 1990, Keith & Benson 1988), where time, resources and vastness of area do not permit extensive collection of detailed data. Examples of studies where the defined communities appear to be "first-order" eucalypt co-occurrences (i.e., those combinations of eucalypts which occur in immediate spatial connection) are the detailed qualitative study of the Monaro Region by Costin (1954) and the quantitative CSIRO South Coast Survey (Austin 1978).

Extensive collection of quantitative data in the CSIRO South Coast Survey (Austin 1978), enabled the classification of eucalypt communities at a detailed level. Vegetation was sorted into "groups", containing varying numbers of "communities". Austin maintained that this system differed from the alliance/association hierarchy, because the latter was subjectively based. The vegetation units in the South Coast Survey were defined as those communities "which best differentiate the vegetation found in the area." Austin's claim that the alliance /association classification relies on subjective procedures was not valid, since the original definitions of these plant groupings (Beadle & Costin 1952) specifically stated that data on the qualitative and quantitative interrelationships in plant communities may be determined either "approximately by visual semi-subjective methods, which in themselves provide sufficient basic information at least to recognise the most abundant species, or by detailed statistical methods...". Although there appears to be little difference in this grouping of vegetation and that of the alliance-association system of Beadle and Costin, the use of numerical methods does hold the potential to address the problem of ambiguity of scale in the definition associations, since first-order co-occurrences can be defined within an hierarchical classification of dominant species.

Gilmour and Plumwood (1982) described the vegetation of the Budawang National Park, SE NSW, in terms of the "dominant eucalypts occurring in the major
physiographic subdivisions". The ambiguity of this phrase rests in its failure to define scale. On the basis of occurrence of eucalypts other than dominants, along with understorey variation, Gilmour and Plumwood suggested that the majority of their sites could be considered as separate communities. Where there was "sufficient similarity in eucalypt dominants within a vegetation type", they used the term association to group these different communities. It appears, therefore, that they used the term community to describe every different combination of tree and understorey species, and reserved the term association for a broader scale unit.

3.1.2 Variations in Patterning in Different Communities

Kirkpatrick and Dickinson (1986) pointed out that mapping units are not actually defined by prescribed structural and physiognomic schema, but by the features which characterise spatial variation of vegetation in any particular place. This can be seen to apply not only to mapping units, but also to classificatory units. Any descriptive system, while clarifying some aspects of difference between different vegetation communities, may fail to highlight other real differences. Apparent discrepancies in use of the association /alliance terminology by different researchers may be a reflection of actual variations in the nature of patterning in communities which are not distinguished from one another in this classification system.

Such basic differences in spatial patterning occur between the major formations of rainforest, heath and eucalypt forest.

Differences in patterning between the major vegetation formations:

(i) Heathland

Spatial variation over short distances (i.e. small scale pattern) is typical of heathlands of the Sydney Basin. Often, many species are involved. The patterns within heathland lend themselves to study by means of transects or quadrats followed by quantitative analysis, but are less easily categorised qualitatively, especially when describing the vegetation of a large area.
(ii) Rainforest

In rainforest, there are numerous tree species and relatively few shrubs and herbaceous species. The rapidity and complexity of spatial variation in tree species composition renders rainforest more suited to classification by quantitative means than by eye. For example, Mills (1986) used numerical classification to define floristic types within the Illawarra rainforest. Webb et al. (1985), in their comprehensive floristic classification of Australian rainforests and monsoon forests, used an asymmetric divisive monothetic program based on a binary similarity index (sums of squares) to categorise hierarchically spot-listings of tree species from as many sites as possible.

(iii) Eucalyptus Forest

In the Eucalyptus forests of south-eastern Australia, spatial variation is based on this single genus which most often dominates the canopy layer. The complexity of the variations in eucalypt forest is a result of the sublety in the changes of Eucalyptus across the landscape and the difficulty in distinguishing the species of this vast and diverse genus. Associations can often be visibly defined without recourse to numerical analysis once the pairs or small groups of Eucalyptus dominating particular places in the landscape have been accurately identified. Eucalyptus communities often lend themselves to categorisation as associations, because of a characteristic pattern of distribution. This pattern was defined by Pryor (1959a) as being "the regular occurrence on closely circumscribed micro-habitats of Eucalyptus populations made up of a pair or even three or four species as equal co-dominants."

Despite this compatibility with the association/alliance system, variations in patterning within eucalypt associations may be contained within and obscured by this classification. One such variation is the occurrence of particularly complex eucalypt associations on the sandstones of the Sydney Basin. These are referred to by Specht et al. (1974) in an Australia-wide summary of vegetation alliances and associations as the "Sandstone complex", which is further defined as "part of a vegetation continuum on very nutrient deficient sandstones". Beadle (1981) classified this vegetation as the the E. gummifera-E.
*sieberi*-E. *racemosa* Alliance and referred to the great diversity of xeromorphic species which it contains. The Ettrema and Northern Budawangs vegetation communities are compared with those of Specht and Beadle in Table 3.2. The complex sandstone forests were originally described by Pidgeon (1941). In describing the vegetation of the Central Coastal area of the Sydney Basin, Pidgeon categorised all of the "bewildering variety of forest stands" on the Hawkesbury sandstone as one association, the "Mixed *Eucalyptus* Forest". Benson (1986) defined the widespread vegetation complex found on coastal areas of the Hawkesbury sandstone as the Sandstone Complex and referred to its considerable local and structural floristic variation. He listed approximately fifteen tree species as being dominant in different places within this complex. In the Blue Mountains and Wallerawang areas, Keith & Benson 1988 listed two sub-units within the Sandstone Complex, with fewer (approximately ten), dominant species. This is still many more than the number described by Pryor (1959a) as being typical of stands of *Eucalyptus*.

### 3.1.3 Quantitative versus Qualitative Survey

After many years of experimentation with quantitative methods in plant ecology, standardisation of methods has still not been established. That qualitative methods still have their place was exemplified by the comparative study of intuitive and numerical classifications of the vegetation of Brian Pastures Research Station in south-east Queensland by Neldner (1991). In this study, a numerical classification of tree and woody plant data supported an intuitive mapping classification of the same area. It was concluded that the extra effort in obtaining quantitative data may not be justified in large-scale phytosociological studies, although these data may well be important for other purposes (such as monitoring vegetation changes). It was noted that the intuitive process utilises a larger amount and variety of data, i.e., data from continuous ground-truthing.

Kirkpatrick and Dickinson (1986), in comparing classifications based on collection of quantitative plot data versus those derived from remotely-sensed patterns and field observations, pointed out fallacies in the argument that the former approaches are more accurate, since they usually require subjective site choices.
Table 3.2: Comparison of Ettrema - Budawangs Vegetation with Alliances of (Specht *et al.* 1974) and Beadle (1981).

<table>
<thead>
<tr>
<th>Structure</th>
<th>Alliance (Specht <em>et al.</em> 1974)</th>
<th>Alliance (Beadle 1981)</th>
<th>Ettrema/ N.Budawangs</th>
</tr>
</thead>
<tbody>
<tr>
<td>tall open-open forest</td>
<td><em>Eucalyptus fastigata-</em>&lt;br/&gt;<em>E. viminalis</em></td>
<td><em>E. fastigata-</em>&lt;br/&gt;<em>E. obliqua</em></td>
<td><em>E. fastigata-</em>&lt;br/&gt;<em>E. radiata</em></td>
</tr>
<tr>
<td></td>
<td><em>E. saligna-</em>&lt;br/&gt;<em>E. resinifera-</em>&lt;br/&gt;<em>E. pilularis</em></td>
<td><em>E. botryoides</em></td>
<td><em>E. saligna-</em>&lt;br/&gt;<em>E. botryoides</em></td>
</tr>
<tr>
<td>open-low open forest (wet-dry sclerophyll forest)</td>
<td><em>E. gummifera-</em>&lt;br/&gt;<em>E. racemosa-</em>&lt;br/&gt;Angophora costata suballiance</td>
<td>discussed as a &quot;community associated with rivers&quot;</td>
<td>Creekbed society in Ettrema wilderness.</td>
</tr>
<tr>
<td>open forest, fringing woodland.</td>
<td><em>Casuarina cunninghamiana</em></td>
<td><em>E. macrorhyncha-</em>&lt;br/&gt;<em>E. rossii</em></td>
<td><em>E. macrorhyncha &amp; E. rossii</em> (Tableland influence, W.edge)</td>
</tr>
<tr>
<td>open -low open forest-tall-low woodland</td>
<td><em>E. moluccana-</em>&lt;br/&gt;<em>E. crebra</em></td>
<td><em>E. tereticornis &amp; E. drepanophylla-</em>&lt;br/&gt;<em>E. crebra</em></td>
<td>Associations of lower Ettrema gorge slopes</td>
</tr>
<tr>
<td>open forest</td>
<td><em>E. stricta</em> (containing as well <em>E. apiculata</em>, <em>E. ligustrina</em>, <em>E. multicaulis.</em>) &amp; <em>E. luehmanniana-</em>&lt;br/&gt;<em>E. obtusiflora-</em>&lt;br/&gt;<em>E. multicaulis.</em></td>
<td>Eastern mallee-heaths (not classified into Alliances).</td>
<td><em>E. dendromorpha</em> &amp; <em>E. multicaulis</em></td>
</tr>
<tr>
<td>open scrub: mallee</td>
<td><em>Allocasuarina nana</em></td>
<td><em>Allocasuarina nana</em></td>
<td><em>Allocasuarina nana</em> small patches nr Wog Wog</td>
</tr>
<tr>
<td>montane shrubland or open heath</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>open heath</td>
<td><em>Banksia ericifolia</em> &amp; sedge-heaths</td>
<td><em>Banksia ericifolia</em> &amp; sedge-heaths</td>
<td>-</td>
</tr>
</tbody>
</table>
3.1.4 Discrepancy between Mapped Patterns and Classificatory Units

Beard (1981), on the basis of many years of work, drew the following conclusions on the part played by scale in relation to vegetation classification:

"A vegetation map of the largest possible conceivable scale would be a diagram of a quadrat on which all the individual plants and their coverage were marked. For the mapping of more extensive areas, the scale has to be reduced. It then becomes impossible to represent individual plants, and they have to be grouped into communities whose boundaries are mapped. At progressively smaller scales, fewer communities can be represented and there has to be a progressive generalisation of the map".

Kirkpatrick and Dickinson (1986), in discussing Australian small-scale vegetation mapping, alluded to the difficulty of mapping vegetation communities which exhibit complex spatial variation. They argued for the recognition of the importance of information from both classificatory units and mapping units. This problem has been recognised and dealt with in recent surveys, such as those of Benson (1986, 1992), Benson & Keith (1990), Keith & Benson (1988), Wilson et al. (1990), variably.

Benson and Keith (1985-1991) classified the Sydney Basin vegetation into communities characterized by dominant species, but found that it was not possible to map all of the plant communities which were defined. Many of the mapped units were defined more by geomorphology than by vegetation and referred to as "land units". As this was a mapping exercise, emphasis was placed in the explanatory notes on the mapped units rather than the classified communities, and the extent to which the classified communities corresponded to associations was not always clear. Wilson et al. (1990) classified Northern Territory plant communities at the association level, but indicated that their mapping units varied from being relatively homogeneous to complexes representing several different associations.

The term "land unit" was defined in the CSIRO (1983 unpubl.) survey of the Tianjara area as "a type of land, rather uniform in landform, rock, soil and vegetation". Land units were grouped together to form "land systems", defined as "areas with recurring patterns of landform, vegetation and soil". The potential difficulty pointed out by Kirkpatrick &
(1986) in the reconciliation of mapping and classification was exemplified in this earlier study. Poor reconciliation was found amongst landform, soils and vegetation. In this complex environment, no fewer than 57 landform types, 28 soil families and 29 plant communities were defined. If the association between classes of landform, soil and vegetation had been perfect, only thirty land units would have resulted. The final reconciliation distinguished one hundred and twenty three land units. This was fewer, on average, than two sites per unit. Nineteen land units, covering nearly forty percent of the total area, were found to have four or more field sites each. This was taken as an indication that, for these units, the data justified "some confidence in the stated values of land characteristics and in the association between particular classes of landform, soil and vegetation". This system of classification, used effectively by Benson and Keith for the Sydney basin flora, did little to elucidate the vegetation patterns in the Tianjara area.

The vegetation of the Ettrema and Northern Budawangs wildernesses is heterogenous at varying scales in the different structural formations and across different landscapes. It provides a challenge in the interpretation of the complexities of its spatial variation.

3.1.5 Ettrema/Northern Budawangs Vegetation: Classification Units

In mapping and describing the vegetation of Ettrema/North Budawangs, the association system has been utilised in classifying eucalypt forest, while the more rapidly spatially varying heath and rainforest vegetation has been initially defined by location in a manner similar to that of Benson and Keith. Both heath and rainforest were subsequently sorted into broad groups on the basis of differing species composition.

3.1.6 Ettrema/Northern Budawangs Vegetation: Map Units

It was not possible to map separately all of the classification units in all areas. Particularly rapid changes from heathland to sedgeland and bands of stunted eucalypts occurred across parts of the Ettrema Plateaux, and these are often mapped together as "Quasi-concentric complex", which is, in effect, a land-unit similar in scale to some of the map units of Benson et al. (1986 - 1991) and Wilson et al. (1990).
3.2 Aims of This Chapter.

1. To outline the methods employed in finding out what the vegetation communities are in the Ettrema and Northern Budawangs wilderness areas.

2. To discuss the vegetation patterns visible on the map.

3. To describe the vegetation communities and gradients.

4. To draw attention to specific features which raise major problems to be dealt with in later chapters.

5. To briefly compare the vegetation communities with that found in other areas.
3.3 Methods

The area is encompassed within nine topographic map sheets (Fig. 3.1). Black and white air photo coverage of the area at a scale of 1:50,000 (available from the NSW Lands Department) was used.

In a series of preliminary reconnaissance trips, the area was surveyed along all major fire trails, and vegetation variations recorded kilometre by kilometre. During this phase, an aerial survey by helicopter also became possible. Set-downs were made on a number of relatively inaccessible mesa-tops, such as Byangee Walls (Plate 3.1), Island Mt. and Mt. Talaterang. On both vehicular and helicopter preliminary reconnaissance trips, plants were extensively collected for identification. The occurrence of heath, sedge and rainforest communities was noted. Widespread eucalypts and their patterns of co-occurrence were recorded.

Sites visited were located on air photos and the tone and textural appearance of heath, sedgeland and rainforest communities and eucalypt associations used to draw boundaries onto the air photos (Plate 3.2). These were successively modified following further ground reconnaissance.

Vehicular reconnaissance was followed up by a series of trips on foot into areas not adequately sampled from the road. Foot trips were designed to cover the area and the different types of terrain as evenly as possible, given the limits of accessibility. Details of the vegetation occurring in all areas visited were recorded directly onto the air photographs. It became possible to more clearly define the repeating patterns of vegetation in the area after each successive field trip.

Intensity of Sampling

The area is covered by forty nine air photos. On average, 1.6 field trips were conducted within the effective area of each air photo, with a range from 6 to 0 (Fig. 3.2). Sampling bias was caused more by topography than accessibility, i.e., some areas were visited more because of a greater diversity of environments there. For example, the
The central mesas of the Northern Budawangs are clustered around the Monolith Valley, and are mostly encompassed within one air photo effective area (1U, 7), which is recorded as having been visited six times (Fig. 3.2).

Bias in sampling caused by accessibility was minimised by a series of overnight camping trips, in which the more remote areas were visited, and by access to a helicopter on three occasions. However, sampling on the steepest gorge slopes was very limited.

Classification units were finalised and the final map boundaries drawn after some forty field trips into the area varying in time from one to four days. Even after forty field trips, it can be said that accuracy was still limited by the amount of sampling. On each successive field trip, unexpected (as well as increasingly well predicted) combinations of dominant species were located.

A final series of field trips was conducted in which return was made to communities which had already been defined to obtain detailed species and habitat information. Soil samples were taken at these sites.

**Level of Detail of Observations**

In view of the size of the area being surveyed and time limitations, emphasis was placed on the recording of dominant species. Understorey species were listed only in order to gain a general appreciation of differences from community to community. General structural changes were noted and categorised according to the system of Specht (1981a).

**Map Reliability.**

As is typical with broad area vegetation mapping (e.g. Benson & Keith 1990), the reliability of the map produced varies, being most accurate in areas actually surveyed. Accuracy is a function both of the amount of ground truthing done, and of the complexity of the vegetation. Here, as in many other areas in eastern Australia, the vegetation is complex.
Reliability has been indicated on the series of vegetation maps, which are reproduced in Figs 3.3-3.11. The original maps are lodged in the map library at the Wollongong University Geography Department. Routes of ground traverses are marked on the maps. Where typing (i.e., the identification of species combinations/map units) is considered completely reliable, the coded types have been underlined on the maps. In areas where the vegetation patterning is fairly simple, such as across the flat areas of the Ettrema plateaux and on the mesas and adjoining shallow valleys, the typing of areas adjoining field traverses proved (following further trips) to be fairly reliable. Typing becomes more hypothetical in steeper areas of both Ettrema and Northern Budawangs and around the extreme margins of the larger plateau areas. Uncertainty in typing has been indicated by bracketing the vegetation code.

Photo-interpretation has inherent in it variations in reliability. Whereas sedge and heathland, for example, can be separated from forest with a high degree of reliability, the boundaries between different eucalypt communities is less certain. Structural types are more readily determined on air photographs, with differences in vegetation heights and spacing being perceived as changes in tone and texture. For example, denser, taller vegetation appears darker. Sedgeland is darker than heath. Heathland and low, open forest is light in tone and texturally relatively smooth, while large-crowned trees have a rougher texture. Confusion can occur where one type of vegetation assumes a variety of structures (as happens, for example, with Grey Gum-Yertchuk-Red Bloodwood complex association), where adjoining vegetation types have a similar structure or where changes are rapid, as, for example, on gorge slopes.

Species patterning in *Eucalyptus* is very sensitive to topographic variation. The types of habitat occupied by a particular community became clearer as a result of fieldwork. Different communities are associated with different types of topography, aspect and rock type. These observations, when linked with textural and physiographic information from air photos, provided the means of predicting vegetation in areas not covered by field reconnaissance.
Example 1 *Eucalyptus sieberi*-E. *piperita* ssp. *urceolaris* forest. After a number of field trips, it became apparent that these two tree species occur together frequently in the Northern Budawangs, on exposed aspects of mesa-slopes and on rocky areas in heathlands. Tone and textural differences on air photos enable the ready separation of this forest from heathland and from the taller forest growing on sheltered aspects of mesas.

Example 2 *E. globoidea* forest, NW Ettrema. Air photographs indicated continuous, extensive forest in this area, by comparison with the areas of plateau to the east, which are covered by heath and low open forest. This north-eastern corner, when transected diagonally on foot, proved to be an extensive area of White Stringybark, with a mixture of different tree species dominating in the gullies. Field trips east and south indicate a "petering out" of this community, rather than a sharp cut-off. On the basis of these observations, a large area was mapped as White Stringybark Forest, with variations in gullies and overlap with adjacent types of vegetation to the east and north.

One way in which the level of accuracy in mapping large areas of vegetation can be increased is by conducting more field trips, until the area has been covered at a sufficient level of detail for every different combination of dominants to have been recorded. In an area of diverse vegetation, it may not be possible to reach this target within the constraints of time available. In Ettrema/Northern Budawangs, it is expected that if the number of field trips could have been doubled from forty to eighty, then the map would be more accurate (but not doubly so). However, for practical purposes, a cut-off point had to be made somewhere.

**Map Units/Classification Units**

As a result of on-ground differences in the rate at which vegetation varies from one community to another across these areas, the scale (in terms of species complexity) of the communities mapped varies. Sometimes classified communities are mapped separately, but over large areas, the vegetation varies over such a short distance from heath or sedgeland to bands of trees, that it has not been possible to map them separately. In this case, although separately classified, they have been mapped together as a unit. The
concordance between map units and classification units is indicated in Table 3.6. These map units may be equivalent to the 'land unit' used by Benson and Keith in their series of maps of the Sydney Basin (Benson 1986, 1992; Benson & Keith 1990; Keith & Benson 1988). This in turn appears equivalent to either the 'land system' or the 'land unit' of the CSIRO (Christian & Stewart 1953). It is difficult to distinguish which of these two is equivalent, because of ambiguity of scale. Assessment of what constitutes a 'land unit' is in the former case made by botanists and is oriented primarily towards an integrated map of the vegetation of the Sydney Basin, not its other physical features. By comparison, in CSIRO land system studies, such as that carried out in the Tianjara Firing Range (1983, unpubl.), other aspects of the physical environment, such as soils and geology were given equal priority.

Problems of a different nature were encountered in defining communities and mapping vegetation on very steep slopes, for example, the slopes of the Ettrema Gorge system. Here, it was difficult to find consistently recurring associations between two or three tree species and every reconnoitre produced a different set of profiles. The rapidly changing composition of dominants found here made mapping more difficult.

The following section 3.4, is a brief general description of the vegetation of the Ettrema and Northern Budawangs wildernesses. Following this (3.5), the vegetation variations are described map by map. In section 3.6, the classified communities are documented.
3.4 General Description.

Heathland, sedgeland and open forest are the predominant forms of vegetation, with smaller areas of tall open forest, open forest and rainforest.

Heath and Sedgeland

These formations are widely distributed across the flat plateau surfaces of the Ettrema area and on the mesa-tops and interconnecting shallow valleys in parts of the Northern Budawang Range. This vegetation varies from open scrub to low open shrubland. Structure is classified according to the system of Specht (1981a), outlined in Table 3.3. Open heath, dwarf heathland and sedge-heathland are the most abundant forms. Heathlands may be dominated by tall shrubs such as Banksia ericifolia, Kunzea ambigua, Allocasuarina distyla, Leptospermum rotundifolium, low shrubs (e.g. Banksia paludosa, Allocasuarina nana), or dwarf shrubs, such as Baeckea brevifolia or B. imbricata.

Sedgelands are often dominated by Button Grass (Gymnoschoenus sphaerocephalus) or Restio fastigiatus. On flat plateau areas, a thicket of Leptospermum, Melaleuca and Hakea species may overtop a thick bog-cover of sedges and node-sedges (Empodisma minus, Ptilanthelium deustum, Schoenus villosus etc.). The boundary between heath and sedgeland is often indistinct, there being a noticeable component of sedgy species in many heathlands.

Forest

Forty different species of tree (excluding rainforest species) have been identified in the Ettrema and Northern Budawangs Ranges during the course of this study. These are listed in Table 3.4. Seventeen associations have been defined within this group. These are listed in Table 3.5. The concordance between map units described in the section 3.5 and the classification units described in section 3.6 is summarised in Table 3.6. The most widespread tree associations across the Ettrema plateaux are Scribbly Gum (E.
sclerophylla) and Snappy Gum (E. mannifera), commonly forming a low, open forest or woodland community and Grey Gum-Yertchuk-Red Bloodwood low open forest. The former is a simple association in which the distributions of the two species consistently overlap, whereas the latter is a much more complex association involving overlapping distributions of about six species.

Silvertop Ash -Ur-n-fruit ed Peppermint is the most widely occurring open forest association in the Northern Budawangs, with a less frequent occurrence in the Ettrema area. An extensive area of open forest, in which White Stringybark is the main eucalypt, covers the north-western part of Ettrema around Tolwong. Other open forest associations include areas of Forest Red Gum along Ettrema Creeks, Ironbark-Grey Gum in north-east Ettrema and Snow Gum at the western edge of the area surveyed.

Tall, open forest may be dominated by E. piperita ssp. urceolaris -Syncarpia glomerulifera on the upper slopes below the easternmost Ettrema plateaux, E. imitans and Angophora floribunda along the Ettrema creek flats, E. fastigata, E. cypellocarpa and E. viminalis on parts of the Sassafras and Endrick basalt flows and E. fastigata and E. fraxinoides on the sheltered slopes of the Budawangs mesas.

Rainforest is a relatively minor component of the vegetation, occurring mainly as an understorey in eucalypt forest, as a canopy in gullies, on sheltered slopes and along parts of the tributary creeks of the Clyde River and Ettrema Creek, in ravines in the Monolith Valley and on parts of the Sassafras and Endrick basalt flows. Predominant trees in the Northern Budawangs rainforests include Coachwood (Ceratopetalum apetalum), Plumwood (Eucryphia moorei), Sassafras (Doryphora sassafras) and Possumwood (Quintinia sieberi). Sassafras dominates rainforest where it occurs on the basalt flows. The species composition on the slopes of creeks in the Ettrema area is noticeably different from that in the Northern Budawangs, with Cabbage Palms (Livistona australis), Bastard Rosewood (Synoum glandulosum), Black Plum (Diospyros australis), Grey Myrtle (Backhousia myrtifolia) and Coachwood being the trees which were most commonly observed.
Simple and Complex Associations

In the Ettrema and North Budawangs areas, some eucalypt associations were found to be relatively simple and others more complex. For example, *E. sieberi* showed a strong tendency to associate with *E. piperita* ssp. *urceolaris* and *E. sclerophylla* with *E. mannifera*, whereas in the group of trees amongst which *E. punctata* is the most abundant, referred to as the "*E. punctata- E. consideniana- E. gummifera complex association*", the composition of eucalypts was observed to change continuously across the area investigated. Within these pairs and groups of eucalypts, which are defined and mapped as associations, gradients in the distribution of the individual species are often readily identified. Brief analysis of these gradational changes are included as part the community descriptions.
Plate 3.1: Air Photo Map (overleaf)

Vegetation community boundaries were drawn directly onto the air photos covering the area. NE Ettrema, the area bounded by the Shoalhaven river and Ettrema Creek is shown within the "effective area" (i.e., central area of the photo, where distortion caused by camera lens is least), of this photo.

Reconnoitres in this area included several trips up Ettrema Gorge, the Timboolina Trail which traverses the centre of the area (visible as a white line), and short reconnoitres indicated by dotted lines.

Eucalypt associations in this area include eucalypt combinations classified as part of the *Eucalyptus punctata - E. consideniana- E. gummifera* "sandstone complex" on the plateau areas (e.g. *Eucalyptus ligustrina-E. gummifera- E. sclerophylla* (lggmscl) and *E. sieberi- E. gummifera- E. sclerophylla* (igmscl)). Red ink indicates occurrence of the uncommon *Eucalyptus ligustrina* (lg). *Eucalyptus eximia* (x), *E. punctata- Ironbark* (pclb) are common on slopes and *Angophora floribunda- Eucalyptus imitans* (Afob) on creek flats.
3.5 An Inventory of Map Units

In this section, the vegetation is described map sheet by map sheet. The latitudinal and longitudinal position of the map sheets in relation to each other is shown in Fig.3.1.

**Table 3.7: Summary of Map Units**

<table>
<thead>
<tr>
<th>Map Unit</th>
<th>Area km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heath-Sedgeland-Scribbly gum (hsg-scr)</td>
<td>188.5</td>
</tr>
<tr>
<td><em>E. punctata</em> Sandstone complex (pcygm)</td>
<td>21.6</td>
</tr>
<tr>
<td>Quasi-concentric hst-sg-scrm&lt;&gt;pcygm (Q)</td>
<td>90.7</td>
</tr>
<tr>
<td><em>E. punctata</em>-Ironbark-Stringybark (pclbob)</td>
<td>86</td>
</tr>
<tr>
<td><em>E. globoidea</em>-<em>E. punctata</em></td>
<td>58</td>
</tr>
<tr>
<td><em>E. sieberi</em>-Stringybark&lt;&gt;<em>E. sclerophylla-heath</em> (istr&lt;&gt;sclh)</td>
<td>&gt;100</td>
</tr>
<tr>
<td>residual Berry (iu-h, iu-r)</td>
<td>4.8</td>
</tr>
<tr>
<td><em>E. sieberi</em>-<em>E. piperita</em> ssp.urceolaris</td>
<td>68.1</td>
</tr>
<tr>
<td><em>E. piperita</em> ssp.urceolaris - <em>Syncarpia glomerulifera</em> (ut)</td>
<td></td>
</tr>
<tr>
<td>Rainforest (Ettrema Gorges)</td>
<td>27.4</td>
</tr>
<tr>
<td>Rainforest &lt;&gt; <em>E. fraxinoides</em>-<em>E. fastigata</em></td>
<td>68.4</td>
</tr>
<tr>
<td><em>E. fastigata</em> (bbrcyvim)</td>
<td>17.3</td>
</tr>
<tr>
<td><em>Angophora floribunda</em>-<em>E. imitans</em></td>
<td>20.2</td>
</tr>
<tr>
<td><em>E. tereticornis</em></td>
<td>16.8</td>
</tr>
<tr>
<td><em>E. multicaulis</em></td>
<td>5.6</td>
</tr>
<tr>
<td><em>E. eximia</em></td>
<td>5.5</td>
</tr>
<tr>
<td>Riverine complex (bo)</td>
<td>2</td>
</tr>
<tr>
<td><em>E. triflora</em></td>
<td>0.2</td>
</tr>
<tr>
<td>Clearing, regeneration</td>
<td>5.5</td>
</tr>
<tr>
<td><strong>Total Area</strong></td>
<td><strong>816.1</strong></td>
</tr>
</tbody>
</table>
1. Caoura

(i) Area encompassed

This flat, north-western section of the Tullyangela Labyrinth, sits five hundred metres above the north to east bend in the Shoalhaven River. The Tolwong basalt outcrop is demarcated by a small cleared patch near the centre of this north-western section.

(ii) Nature of Vegetation Patterns on this Map Sheet

1. *Eucalyptus* *globoidea* open forest (gl)

The deep, sandy soils of the north-west corner of Tullyangela Labyrinth support *E. globoidea* - *E. punctata* open forest association.

Gullies A contrasting selection of species is found in gullies, including *E. dives* (div), *E. dalrympleana* (dal), *E. cinerea* (cin), *Leptospermum subglabratum* (La). The varying combinations of these species are mapped as one unit.

Shallow Slopes above Gullies in the north-west corner support *E. rossii* Scribbly gum open forest. Further east, this is replaced by *E. sclerophylla* Scribbly Gum which co-occurs with *E. mannifera*.

Tolwong Basalt *Eucalyptus radiata* grows around the margins of the cleared basalt.

NE Plateau margins Here, *E. sieberi* occurs with stringybarks and/or *E. piperita* ssp. *urceolaris*.
2. Burrier

(i) Area encompassed

In the north-east corner of the Ettrema wilderness, the northern tip of Ettrema Plateau and the eastern end of Tullyangela Labyrinth drop via steep slopes dissected by creeklets into the Ettrema Creek, which flows into the Shoalhaven River.

(ii) Nature of Vegetation Patterns on this Map Sheet

Patterns are complex, in consonance with the complex environment.

**Gorge Slope** associations include *E. punctata* - Ironbarks- *E. imitans*, *Angophora floribunda* - *E. tereticornis*, *E. eximia*, *Acacia glaucescens* and *E. agglomerata*.

**Alluvial Flats** along the creeks support *Angophora floribunda* - *E. imitans* association.

**Colluvium** on the lowest slopes supports *E. tereticornis*.

**Eastern Extremities of Tullyangela Labyrinth** A variety of eucalypt combinations and *E. sclerophylla* - *E. dendromorpha* mallee/heath occur where the Tullyangela Labyrinth narrows into a series of ridges and between Yalwal Creek and the Shoalhaven River. These combinations are mapped, but do not sort readily into the major defined map units. Of particular note is the occurrence of the uncommon eucalypt, *E. ligustrina* in combination with *E. gummifera*, *E. eximia* and *E. punctata*. 
3. Touga

(i) Area Encompassed

The part of Tullyangela Labyrinth and corner of the Ettrema Plateau on this map are separated by a deeply dissected section of the Ettrema Gorge.

(ii) Nature of Vegetation Patterns on this Map Sheet

About 70% of the area is mapped as *E. rossii*-heath-sedgeland.

**Tullyangela Labyrinth** Here, *E. dendromorpha* mallee-heath, sedgeland and *E. rossii*-*E. mannifera* communities often occur in sequences too rapidly changing to map separately. Two basalt outcroppings have largely been cleared, but a fragment of their former covering of *E. fastigata*- *E. radiata* open forest remains around the margins. Knolls of Berry siltstone support *E. sieberi*, *E. piperita ssp. urceolaris*, heath and (tentatively) stringybarks. Stringybarks (*E. agglomerata* and *E. globoidea*) occur to the north and in gullies along the western plateau margin.

**Ettrema Plateau** supports *E. punctata* sandstone complex alternating with *E. dendromorpha* mallee-heath, with a complex sequence of species on the residual Berry knoll (Rodgers Hill), separately mapped and differing from the classified *Eucalyptus* associations, with the observed species combinations overlapping *E. punctata* sandstone complex and *E. sieberi*-*E. piperita ssp. urceolaris* association.

**Ettrema gorge** The steep sides of the gorge were inspected at one site on this sheet. The trees observed were unexpected (*E. globoidea*, *E. viminalis*). They were stunted, probably as a result of fire, slope instability or both. It is predicted that the vegetation of these steep slopes would be variable and not easily classified, because of slope instability, as well as the rapidly changing environmental gradients caused by slope steepness.
4. Yalwal

(i) Area Encompassed

The steep slopes of Yalwal, Danjera, Bundundah, Ettrema and subsidiary creeks dissect the northern reaches of the Ettrema, Danjera and Yarramunmun Plateaux of the Ettrema wilderness area.

(ii) Nature of Vegetation Patterns on this Map Sheet

The vegetation patterns on this map sheet are complex and rapidly changing, coincident with the rapidly changing environmental gradients provided by steep gorge slopes, dissected plateau margins and a prominent residue of Berry siltstone (Ettrema Hill).

Creek slope vegetation patterns are complex, with eucalypts on ridgelets differing from those in gullylets a few metres distant. The main recurring communities identified were *Eucalyptus eximia*, *E. punctata*- Ironbark, *Syncarpia glomerulifera*- *E. piperita* ssp. *urceolaris* associations and rainforest.

Alluvial Flats characteristically support *Angophora floribunda*- *Eucalyptus imitans* association.

Colluvium on the lowest creek slopes characteristically supports *E. tereticornis* open forest.

Plateau Areas carry *E. punctata* sandstone complex and *E. dendromorpha* mallee-heath in rapidly changing sequence. These are mapped together. Large areas of the rare and endemic *E. sturgissiana* occur in areas mapped as heathland.

Ettrema Hill, a large knoll of Berry siltstone, supports complex sequences of species which are mapped but not encompassed in the classified communities.
5. Nerriga

(i) Area Encompassed

The sandstone plateau areas at the western edge of the Ettrema and Northern Budawangs wildernesses represented on this map sheet are traversed by the main track through this wilderness, the Nowra-Braidwood Rd. Quasi-concentric patterning in the sandstone dominates the landscape. The headwaters of Ettrema Creek divide Tullyangela Labyrinth from Ettrema Plateau. A clearing outlines the Sassafras basalt flow. Knolls of residual Berry silstone form the highest points across the plateau surfaces.

(ii) Nature of the Vegetation Patterning on this Map Sheet

The three different rock types (sandstone, Berry siltstone and basalt) represent three different major controls on vegetation. The vegetation patterns resulting from each influence are interrupted by each other where the different geological strata abut. Further complexity is added by the influence of the tableland areas immediately to the west of this map sheet.

Quasi-concentric patterning in the Permian sandstone governs rapid changes between *Eucalyptus dendromorpha* mallee-heath, sedgeland and Scribbly Gum across the plateau surfaces. On this western part of the plateau, *E. sieberi* and *E. agglomerata* occur as part of the quasi-concentric sandstone sequence. These trees may co-occur with *E. punctata* or *E. consideriana* and are classified as combinations of the *E. punctata-* *E. consideriana-* *E. gummifera* sandstone complex, although *E. gummifera* reaches its distributional limit to the east of the Sassafras basalt. Vegetation following the quasi-concentric patterning covers approximately 75% of this map sheet.

Tableland influence is evident in the limited occurrence of *Eucalyptus macrorhyncha* (Red Stringybark), a tree which is much more common to the west of the study area. *E. rossii*, the tableland scribbly gum, occurs with *E. sclerophylla* at this western edge of the plateau.
Knolls of Berry siltstone support a similar range of species to the quasi-concentric sandstone, but in differing sequence and proportion, there being larger areas of *E. sieberi*-*E. agglomerata* open forest and smaller areas of heath - Scribbly Gum.

The Sassafras Basalt is ringed by *E. radiata*-*E. fastigata* open forest. This overlaps with the forest sequence occurring on the Berry siltstone knolls, which, includes *E. sieberi*, *E. piperita ssp.urceolaris* and *Baeckea brevifolia* heath.

The uppermost part of the Ettrema Gorge is represented on this map sheet. Minimal fieldwork was done in this section of the gorge and this area is not represented in the mapped or classified units.
6. Sassafras

(i) Area Encompassed

This map includes the plateau areas at the western edge of the Ettrema wilderness, eastwards from Yarramunmun Plateau across to the the south-eastern part of the Ettrema Plateau from which drain Boolijah, Danjera, Bundundah and Moore Creeks. The southern part of Danjera Plateau and the eastern outskirts of the Sassafras basalt also appear on this map.

(ii) Nature of Vegetation Patterns on this Map Sheet

_Eucalyptus punctata_ sandstone complex and heath- scribbly gum- sedgeland cover the major part of the plateau areas, amounting to approximately half of the area mapped.

**Deeper soils on the Yarramunmun Plateau** support two main combinations of the _E. punctata_ sandstone complex (i) _E. consideniana- E. gummifera-E. sclerophylla_ in the central portion of the plateau and (ii) _E. agglomerata- E. punctata- Syncarpia glomerulifera_ along the plateau margins.

**Skeletal soils of the Ettrema Plateau** support _E. dendromorpha_ mallee- heath, in rapidly changing sequence with sedgeland and _E. mannifera- E. sclerophylla_ woodland and varying eucalypt combinations of the _E. punctata_ sandstone complex. Residual knolls of Berry siltstone cap the high points in this corner of the Ettrema Plateau, and most frequently support _E. sieberi, E. piperita ssp.urceolaris_ and _Baeckea brevifolia_ heath.

**Creek slopes** support moister, open forest of a variety of species, difficult to define as either map units or associations. _E. piperita ssp. urceolaris- Syncarpia glomerulifera_ was mappable on upper western slopes below the Yarramunmun Plateau. The variety of eucalypts occuring along the lower western and eastern slopes of Boolijah Creek, include _E. elata, E. muellerana_, Ironbarks and _E. agglomerata_. These defied separation into map units, because of the diversity of species and complexity of changes. Rainforest species frequently occur as an understorey and form the canopy in places along the creeks.
The margins of the Sassafras basalt, mapped by R.W. Young, are marked on the map. Much of the basalt has been cleared. The remnant basalt vegetation of rainforest and *E. fastigata- E.viminalis- E. radiata- E. cypellocarpa* forest changes to *E. radiata- E. sieberi- E. piperita ssp.urceolaris* as one crosses from basalt-derived soils to sandstone-derived yellow earths.
7. Endrick

(i) **Area Encompassed**

Mapped are the northernmost mesas of the Northern Budawang Ranges, in particular Endrick (Quilty's) Mt., Island Mt. and Mts. Hoddle, Haughton and Sturgiss. These are separated by the shallow valley of Styles Creek and the deeper valleys cut by Camping Rock and Kilpatrick Creeks and part of the Galbraith Plateau outside of the Australian Military Forces Firing Range. The Endrick basalt flow is emplaced between the Endrick River and the northern side of Endrick Mt. and curves around the eastern side of this mountain.

(ii) **Nature of Vegetation Patterns on this Map Sheet**

**Mesas** are heath-covered on top, with the exception of Island Mt., which supports an open forest of *E. sieberi, E. piperita* ssp. *urceolaris* and *E. fastigata*. The slopes of the mesas support forest, with species segregated quite sharply into two groups, *E. sieberi-E. piperita* ssp. *urceolaris* open forest growing on aspects exposed to the west and north and *E. fastigata-E. fraxinoides*, with rainforest understorey sometimes canoping, on the south-easterly aspects (see Fig. 3.8).

**Styles Creek Valley** The shallow valley through which this creek flows is heath-covered.

**Kilpatrick and Camping Rock Creeks.** These steep-sided gorges appear from air photo patterns to support tall open forest, which is tentatively mapped as *E. fraxinoides* and *E. fastigata*. This is interspersed with rainforest, readily distinguished on air photos by its canopy characteristics.

**Galbraith Plateau** The dissected surface of this plateau supports *E. dendromorpha* mallee-heath in rocky areas and *E. sieberi-E. piperita* ssp. *urceolaris* open forest on deeper soils. The rare eucalypts *E. dendromorpha* (tree-form) and *E. triflora* occur in sheltered crevices and creeks and on rocky outcrops respectively, but these could not be distinguished as mapping units.

**The Endrick basalt flow** supports *E. fastigata* tall open forest and rainforest.
8. Corang

(i) Area Encompassed

Most of the mountains of the Northern Budawang Ranges are on this map sheet, extending from Mt. Corang in the west via Bibbenluke Walls and Mt. Tarn to the mesas surrounding the Monolith Valley, Mts. Roswaine (Cole), Renwick (Owen), Pataird (Shrouded Gods), Irambang (Nibelung), The Castle and Byangee Walls. To the south beyond the dissected sandstone plateau and its mountains, the land slopes steeply to Yadboro Creek. The Clyde River drains the eastern side of the Monolith Valley group. the Corang River runs north-west from the Corang Plateau, through a shallow, swampy valley.

(ii) Nature of the Vegetation Patterning

A large proportion of the total mapped area is rainforest and *E. fraxinoides- E. fastigata* forest.

Slopes below the mesas on the Permian strata support *E. sieberi-E. piperita* ssp. *urceolaris* association.

Sheltered south-facing slopes both within and below the sandstone plateau and deep ravines, for example, those in the Monolith Valley area support rainforest and tall open *Eucalyptus* forest (*E. fastigata-E. fraxinoides* association).

Crevices in the craggy rocks of the mesas provide a niche for the rare endemic *Eucalyptus triflora*.

Secondary sandstone benches of the mesas are the habitat for some large populations of the uncommon mallee, *E. multicaulis*.

Yadboro Creek and the Clyde River are bordered by tall open forest in which grow a variety of trees, including *Eucalyptus elata* (River Peppermint), *E. botryoides* (Bangalay), *E. saligna* (Sydney Blue Gum), *E. piperita* ssp. *urceolaris* (Urn-Fruited Peppermint), *Casuarina cunninghamiana* (River Oak) and *Angophora floribunda* (Rough-Barked Apple).
9. Milton

(i) Area Encompassed

This eastern section of the Northern Budawangs sandstone plateau is dissected by Pigeon House Creek, Jindelara Creek and Porters Creek, which drain Pigeon House Mountain and Little Forest Plateau.

(ii) Nature of the Vegetation Patterning on this Map Sheet

*Eucalyptus* sandstone complex, heath, *E. sclerophylla* scribbly gum and sedgeland cover most of the sandstone plateau areas.

Sandstone benches below Pigeon House Mountain support *Eucalyptus consideniana*-*E. gummifera* in sequence with heathland. These communities are mapped as a single unit.

Little Forest Plateau supports large areas of heath, sedgeland and *E. sclerophylla* woodland.

Summary of Map-to-Map Vegetation Variations

A large area of open forest dominated by White Stringybark (*Eucalyptus globoidea*) is the conspicuous feature of the vegetation of the north-west corner of the Tullyangela Labyrinth, overlooking the north to east bend in the Shoalhaven River (Fig. 3.3). This open forest association has developed on sandy soils thought to be an ancient alluvium.

To the north-east, the vegetation patterning becomes more complex as the area of plateau surface narrows between the east to south bend in the Shoalhaven River and the lower reaches of the Ettrema Creek (Fig. 3.4). Changes on the ridge and gullylet system on the gorge slopes and the alluvium and colluvium of the creeksides were deciphered. The sequence of associations found here, in which Ironbarks, Yellow Bloodwoods and the narrow-leaved stringybark *Eucalyptus imitans* are prominent, is peculiar to this part of the Ettrema wilderness.

Much of the Tullyangela Labyrinth represented on the Touga sheet (Fig. 3.5) is covered by open forest in which *Eucalyptus sieberi* and stringybarks (*E. globoidea* and
E. agglomerata) are prominent. This reflects better soil conditions supplied by two basalt emplacements and outcrops of Berry siltstone. At the western plateau margin, E. rossii scribbly gum replaces E. sclerophylla. E. dendromorpha mallee-heath and E. rossii outline the contours of the quasi-concentrically patterned sandstone exposed at the southern end of this map sheet.

The complex gorge slope vegetation on the Yalwal map (Fig. 3.6) contains areas of rainforest of mappable size (about 24% of the area mapped), as well as a diverse assortment of eucalypts. The area of plateau is smaller here in the east of the Ettrema wilderness and the deeper soils support taller open Eucalyptus punctata sandstone complex in rapidly changing sequence with heath, E. sclerophylla scribbly gum and sedgeland. Large Berry siltstone knolls at the northern tip of Ettrema Plateau interrupt the quasi-concentric patterning with their own unique sequencing of eucalypts. Species typical of the E. punctata sandstone complex and on both sheltered and more exposed gorge slopes recombine.

On the Nerriga map (Fig. 3.7), quasi-concentrically patterned sandstone dominates the landscape. Here, the heath-scribbly gum-sedgeland sequence interchanges rapidly with E. punctata sandstone complex. Variations in eucalypt composition are caused by the overlapping of three rock types (residual Berry, Sassafras basalt and sandstone). For example, E. radiata, typical of the basalt margins, laps onto the Berry siltstone.

The deeper soils of the smaller easterly plateaux represented on the Sassafras map (Fig. 3.8) support open forest of the E. punctata sandstone complex. On the Yalwal Plateau, this can be separated into two recurring "sub-associations", one at the margins of the plateau, (E. punctata- E. agglomerata- Syncarpia glomerulifera) and the other centrally located (E. consideniana- E. gummifera- E. sclerophylla). The upper reaches of the creeks of the Ettrema system represented on this map proved, where transected, to have a great variety of trees and patterns (if present) were not well-deciphered. The margins of the Sassafras basalt support a gradational sequence of changes from E. fastigata through E. radiata to E. sieberi, giving way to the heath- E. sclerophylla scribbly gum sequence on the concentric sandstone.
Quasi-concentric patterning of mallee-heath and sedgeland on the Galbraith Plateau (Endrick map, Fig. 3.9) is continued on the largest of the mesas, Endrick Mt. *E. sieberi-* *E. piperita* ssp. *urceolaris* on exposed mesa-slopes gives way to *E. fastigata-* *E. fraxinoides* on sheltered slopes, with an understorey of rainforest which canopies in the most sheltered places of slope and gorge. *E. sclerophylla* scribbly gum forms part of the patterning of both plateau and shallow Devonian valley, interchanging with mallee-heath-sedgeland.

The central mesas of the Northern Budawangs, represented on the Corang map (Fig. 3.10), support heath-sedgeland, rainforest in ravines, *E. fastigata-* *E. fraxinoides* on sheltered mesa-slopes and patches of whipstick mallee-ash (*E. multicaulis*) on secondary benches. A number of rare species survive on the rocky mesas.

The Pigeon House plateau on the Milton sheet (Fig. 3.11) supports a variant of the eucalypt sandstone complex without the species most common elsewhere (*Eucalyptus punctata*). Heath, sedgeland and scribbly gum interchange on the Little Forest Plateau and rainforest canopies in the depths of the gorges of the tributaries of the Clyde River.
3.6 An Inventory of Communities

This section of the thesis is an inventory of the vegetation associations, communities and patterns which were observed in the Ettrema and Northern Budawangs wildernesses. The communities are placed in structural groups, using the system of Specht et al. (1974) and separately described. Some eucalypt associations varied in structure, as mentioned in the descriptions.

Index to Communities

3.6.1 Heath/Sedgeland
3.6.2 Closed Scrub
3.6.3 Closed Forest
3.6.4 Open Forest

3.6.4a Eucalyptus sclerophylla - E. mannifera
3.6.4b E. sieberi - E. piperita ssp. urceolaris
3.6.4c E. punctata - E. considieniana - E. gummifera complex
3.6.4d E. globoidea
3.6.4e E. imitans - Angophora floribunda
3.6.4f Eucalypt associations of the slopes of the Ettrema Creek system
3.6.4g Eucalypts at the western margins

3.6.5 Tall Open Forest

3.6.5a E. fastigata - E. fraxinoides - E. triflora
3.6.5b E. fastigata - E. radiata - E. cypellocarpa - E. viminalis
3.6.5c Riverbank Vegetation, Northern Budawang Range

3.6.6 Discrepant Eucalypt Patterns
3.6.1 Heaths and Sedgelands

Occurrence

Heathland is widespread in both Ettrema and North Budawang Ranges, being the predominant form of vegetation across the Permian sandstones of the Ettrema plateaux and the mesa-tops in the Northern Budawang Range. The broad, shallow valleys in the western half of the Budawangs are mostly heath-covered, and in the eastern half, heath is common on sandstones of the Snapper Point strata. Dominant species within the heath vary from location to location.

Variations within the heath are discussed within the major subdivisions of its occurrence:

1. Permian sandstones of the Ettrema Plateaux
2. Northern Budawangs mesas
3. Northern Budawangs valley floors and lower slopes of mesas

Species composition data from various sites was analysed by means of a cluster analysis, in order to see if groups could be defined within the heathlands on a species basis.


Heath, sedgeland and bands of stunted eucalypts are the predominant vegetation in the western half of the Ettrema area.

Species composition.

1. *Baeckea brevifolia* (Plate 3.2b)

Large areas within the heath are characterised by the dwarf, nanophyll shrub, *Baeckea brevifolia*, which forms a dwarf heathland. This species was uncommon in heaths in the Northern Budawangs.
2. *Eucalyptus dendromorpha* mallee - shrubby heath (Plate 3.2a)

In other areas, open heathlands are characterized by scattered mallees (*Eucalyptus dendromorpha*) and shrubs, including *Allocasuarina distyla*, *Kunzea ambigu*, *Kunzea sp. nov. "B"*, *Leptospermum rotundifolium*, *Acacia suaveolens*, *A. hamiltoniana* and *Grevillea baueri*. Patches of heath are usually ringed by bands or patches of stunted Scribbly Gums, Grey Gums, Red Bloodwoods or Yertchuk. These patterns are depicted in the Transect diagram of western Ettrema Plateau: Plains Creek-Moore Creek (Fig. 3.12). These vegetation types predominate across the broad expanses of Tullyangela Labyrinth and Ettrema Plateau and have a lesser distribution on Smallest, Danjera and Yarramunmun Plateaux. It proved to be impractical to map discrete units within this broad area, as the vegetation varies over short distances.

**Sedgeland**

This occurs in flat, poorly drained areas in the headwaters of creeks in Tullyangela Labyrinth and on Ettrema Plateau, for example in the headwaters of Tallowal, Rotten and Ettrema Creeks. The most frequently occurring sedges and node-sedges are *Ptilanthelium deustum*, *Schoenus villosus*, *Lepyrodiia scariosa*, *Restio fastigiatus*, *Hypolaena fastigiata* and *Lepidosperma squamatum*, *L. limicola* and *L. urophorum*. *Eucalyptus mannifera* usually occurs in and bordering sedgeland. *E. ovata* has an infrequent occurrence near sedgelands. This tree is found bordering sedgelands at the base of knolls of Berry sandstone (Plate 3.5b). The infrequent occurrence of this tree suggests that its distribution is contracting, possibly as a result of climatic change accentuated by the effects of human intervention via increased fire frequency or grazing. Here, it is at the northern end of its current day geographical distribution, but occupies similar habitats at the southern end of its distribution in Tasmania (Jackson 1981).

Creeks on the Ettrema Plateaux are often bordered by a dense thicket of Tea Trees, in particular, *Leptospermum squarrosum* and *L. polygalifolium*, forming a closed heath.
Sturgiss' Mallee (*E. sturgissiana*)

This rare mallee occurs only on Ettrema (Plate 7.1a), Danjera, Unnamed and Yarramunmun Plateaux in the Ettrema area, being distributed patchily through some areas of heathland. The largest populations occur on Danjera and the northern end of Ettrema Plateau. Patches vary in numbers from a few to several hundred individuals.

2. Heath on Mesas

Flat areas of Permian sandstones forming the tops of mesas and benches around Mt. Talaterang, and mesas surrounding Monolith Valley, support heath.

Structure and Species Composition.

There is a suite of heathland structural types, including closed and open heath (Plate 3.1), sedge-heathland (Plate 3.3b), sedgeland and dwarf heathland. Although a common group of species occurs on all the mesa-tops, both the predominant species and structural types vary from mesa to mesa.

Comparison with the Ettrema Area

Although borne on similar soils from the same parent material, the total species composition of the mesa-top heaths and sedgelands varies considerably from that of the heath-sedgeland on the Ettrema Plateaux, with only about 23% of species recorded in Ettrema also having been recorded on the Budawangs mesa-tops. Species which particularly characterise the mesa-tops include shrubs such as *Leptospermum rotundifolium*, *Allocasuarina distyla*, *Melaleuca capitata*, *M. squarrosa*, *Banksia ericifolia*, *B. paludos* and *Hakea teretifolia*, and sedges such as *Restio fastigiatus*, *Lepyrodon scariosa* and *Empodisma minus*.

Rare species characteristic of the mesa-tops

These include *Goodenia glomerata*, *Leptospermum crassifolium*, *Boronia subulifolia*, *Dillwynia* sp. aff. *stipulifera* and *Eucalyptus triflora*. Forty-eight percent of the rare
species recorded for the Ettrema and Budawangs areas are located on the tops and slopes of the mesas of the Northern Budawangs Range. Possible reasons for this interesting concentration of rare species on the mesas are discussed in chapter 7.

3. Sedgelands-Wet Heath/Mallee-Scribbly Gum of the Valley Floors in the Northern Budawang Range.

Occurrence

This set of structural types interchanges across the shallow valleys in the Northern Budawang Range, around Styles Creek (Plate 3.3a), Burrumbeet Brook (between Mt. Corang and Mt. Bibbenluke) and the headwaters of Angel Creek (between Mts. Tarn and Bibbenluke).

Species Composition.

Species typifying the heath include *Epacris obtusifolia*, *Sprengelia incarnata*, *Kunzea sp. nov. "D"* and *"B"*, *Baeckea imbricata*, scattered *Eucalyptus dendromorpha* mallee and *E. mannifera*. Scattered clumps of the rare mallee *E. gregsoniana* were located along Burrumbeet Brook. The uncommon small tree *E. moorei* was found at Styles Creek and in the headwaters of Angel Creek.

Typical sedgeland species are *Lepidosperma* spp., *Ptilanthelium deustum*, *Schoenus villosus*, *Entolasia stricta*, *Hakea teretifolia* and *Gymnoschoenus sphaerocephalus* (Button Grass).

Comparison with other Heaths.

The species composition of the Devonian heaths is distinctly different from that of other types of heath, having, for example, only 24% of species in common with the heaths of the Nowra sandstone (see Tables 3.8 and 3.9).
Anomalous Distribution of Valley Heaths.

In central areas of the North Budawangs, heaths of the valley floors in some places show a curious distribution, being oddly extended onto the lower slopes of the mesas (Plate 4.2). The boundaries between heath and forest in these areas are very sharp and do not appear to consistently coincide with stratigraphic changes.


The residual "Berry knolls", common on Ettrema Plateau, sometimes support heath on flat areas on top or on benches subject to seepage, which sometimes occur on the sides of the knolls.

Species Composition.

Frequently occurring species in these heathlands are Baeckea brevifolia, Allocasuarina nana, Melaleuca thymifolia and Acacia hamiltoniana, with dense, shrubby patches of Kunzea ambiguа and Leptospermum juniperinum.


This area is distinct from the Northern Budawang mesas and also from the Ettrema plateaux, being an expanse of low-lying sandstone. Heath and sedgeland occur over most of this area, interspersed with bands, belts and patches of Eucalyptus sieberi-E. piperita ssp. urceolaris in gullies and on slopes and E. mannifera around watercourses.

Species Composition.

Heath is in some places dominated by tall shrubs (Banksia ericifolia, Allocasuarina distyla, Melaleuca capitata, Eucalyptus dendromorpha) and in others by low shrubs (Banksia paludosa, Leptospermum rotundifolium, Eriostemon scaber). Sedgelands dominated by Button Grass or Leptocarpus tenax and Leptospermum juniperinum occur near creeks and in peat-filled gullies.
Table 3.8: Most Abundant Heath Species

(i) Nowra Sandstone Mesa-Tops (Sturgiss Mt., Byangee Walls, Mt. Talaterang, Quilty’s Mt., Mt. Corang, Mt. Tarn, Monolith Valley)

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<th>Species</th>
<th>No.Obs./7</th>
<th>% Sites</th>
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<tr>
<td>Leptospermum rotundifolium</td>
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<td>71.4</td>
</tr>
<tr>
<td>L.squarrosum</td>
<td>5</td>
<td>71.4</td>
</tr>
<tr>
<td>Eucalyptus dendromorpha</td>
<td>5</td>
<td>71.4</td>
</tr>
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<tr>
<td>Leptospermum trinervium</td>
<td>3</td>
<td>42.9</td>
</tr>
<tr>
<td>Baeckia imbricata</td>
<td>3</td>
<td>42.9</td>
</tr>
<tr>
<td>B.linifolia</td>
<td>3</td>
<td>42.9</td>
</tr>
<tr>
<td>Schoenus villosus</td>
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<td>42.9</td>
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</table>

(ii) Ettrema Heath

<table>
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<th>11 Most Common Species</th>
<th>No.Obs./9</th>
<th>% Sites</th>
</tr>
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<td>Baeckea brevifolia</td>
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</tr>
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<td>Lepyrodiad scariosa</td>
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<td>Grevillea baueri</td>
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<td>55.5</td>
</tr>
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<td>Kunzea ambigua</td>
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<tr>
<td>Leptospermum arachnoides</td>
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</tr>
<tr>
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<tr>
<td>Persoonia mollis</td>
<td>3</td>
<td>33.3</td>
</tr>
<tr>
<td>Cryptandra propingua</td>
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<tr>
<td>Laxmannia gracilis</td>
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(iii) Northern Budawangs

<table>
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<th>14 Most Common Species</th>
<th>No.obs/12</th>
<th>% Sites</th>
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<tr>
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<tr>
<td>Baeckea imbricata</td>
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</tr>
<tr>
<td>Eucalyptus dendromorpha</td>
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</tr>
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<td>Isopogon anemonifolius</td>
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<td>Hakea teretifolia</td>
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<tr>
<td>Schoenus villosus</td>
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<td>Lepyrodiad scariosa</td>
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<tr>
<td>Dampiera stricta</td>
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<td>41.7</td>
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<tr>
<td>Acacia hamiltoniana</td>
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<tr>
<td>Baeckea linifolia</td>
<td>5</td>
<td>41.7</td>
</tr>
<tr>
<td>Leptospermum trinervium</td>
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<td>41.7</td>
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<tr>
<td>Leptospermum rotundifolium</td>
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Table 3.9: Comparison of Heathland Species

<table>
<thead>
<tr>
<th>21Most Common Species</th>
<th>N.Bud. /12 sites</th>
<th>N.Bud.%</th>
<th>Ettrema /9 sites</th>
<th>Ettrema %</th>
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<tr>
<td>Acacia hamiltoniana</td>
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<td>Banksia paludosa</td>
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<td>Casuarina distyla</td>
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<tr>
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<td>8.3</td>
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</tr>
<tr>
<td>Dampiera stricta</td>
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<td>41.7</td>
<td>1</td>
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<td>Eucalyptus dendromorpha</td>
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<tr>
<td>Hakea teretifolia</td>
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<td>50</td>
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<tr>
<td>Kunzea ambiguа</td>
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<td>4</td>
<td>44.4</td>
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<tr>
<td>Laxmannia gracilis</td>
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<td>Leptospermum rotundifolium</td>
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<tr>
<td>Lepyrodia scariosa</td>
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<tr>
<td>Persoonia mollis</td>
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<td>8.3</td>
<td>3</td>
<td>33.3</td>
</tr>
<tr>
<td>Schoenus villosus</td>
<td>6</td>
<td>50</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Species Common in both Areas: 4/21 or 19%

Consensus Very few species were observed to be common in both the Ettrema and Northern Budawangs heathlands. It is concluded that the heathland species composition is distinctively different in these two areas.
Cluster Analysis of Heath Sites

Aim

To see if sites could be grouped in terms of species composition.

Methods

Presence/absence species data was collected from a total of twenty-four sites of different sizes. These included eight mesa-tops, seven other sites in the Northern Budawangs (in Devonian valleys and on Berry siltstone) and nine sites across the Ettrema Plateaux, on both Nowra sandstone and Berry siltstone.

Site lists were reduced to the twenty-five most abundant species. They were then compared with each other using the Cluster Analysis program from Statistical Package for the Social Sciences (Nie 1975). The Jaccard Coefficient of Similarity (defined below) was calculated for each pair of sites and used to construct a similarity matrix. Sites were then clustered using average linking, that is, the average similarity between each sample and an existing cluster. This is computed using the arithmetic mean of similarities between the sample and all the members of the cluster.

Results

The results of the cluster analysis are figured as an Icicle dendrogram (Fig.3.12). In this graph, the greatest similarity is represented by the longest "icicles". As can be seen, the sites cluster into three distinct groups, which corresponded to one hundred percent of the Northern Budawangs plateau and valley sites versus seventy-five percent of the mesa-top sites versus one hundred percent of the Ettrema Plateaux sites.

The Northern Budawangs Devonian valley sites in the catchment of Styles Creek cluster with the siltstone site (Site thirty-two: Bhundoo Hill on the Galbraith Plateau). Of this group, the site showing the greatest similarity to the mesas is Site thirty, which was recorded on Snapper Point sandstone below one of the mesas, Mt. Bibbenluke. This site has the highest similarity with the nearest mesa species listed, Mt. Tarn (Site seven). The
mesas show little similarity to the Ettrema sites, linking only on the first subdivision of the data between Site two (Sturgiss Mt.) and Site forty two (Smallest Plateau). Site one, Island Mt., differs from the other mesas in that it is capped with siltstone which supports open forest. It is not surprising, therefore, that the sedge-heath found only on the margins does not link with other sites.

**Discussion**

The cluster analysis illustrates the fact that the heathlands of Northern Budawangs mesa-tops, the Northern Budawangs plateaux and valleys and the Ettrema plateaux differ from one another. The fact that the species compositions in the three areas of heathlands differ from one another is clearly depicted in Fig.3.12. However, in view of the limited data collected, these results are considered to give only a preliminary indication of differences between the three areas, not as an accurate quantification of the extent of differences either within or between these areas.

**Coefficient of Jaccard**

\[ S_j = \frac{a}{a+b+c} \]

where \( S_j \) = Jaccard's similarity coefficient

\( a = \) number of species in sample A and sample B (joint occurrences)

\( b = \) number of species in sample B, but not in sample A

\( c = \) number of species in sample A, but not in sample B

The matrix of Jaccard coefficients was used as the basis for a Cluster Analysis of the sites.
### Figure 3.12: Heath Cluster Analysis: Icicle Dendrogram

| ▼  | dev 35 | dev 37 | dev 34 | dev 32 | dev 33 | dev 36 | sst 30 | me 7 | me 4 | me 8 | me 3 | me 6 | me 5 | me 2 | ett 42 | ett 44 | ett 43 | ett 46 | ett 45 | ett 41 | ett 38 | ett 40 | ett 39 | me 1 |
|-----|--------|--------|--------|--------|--------|--------|-------|-----|-----|-----|-----|-----|-----|-----|-------|-------|-------|-------|-------|-------|-------|-------|------|
| 1   | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 2   | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 3   | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 4   | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 5   | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 6   | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 7   | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 8   | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 9   | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 10  | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 11  | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 12  | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 13  | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 14  | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 15  | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 16  | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 17  | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 18  | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 19  | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 20  | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 21  | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 22  | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
| 23  | ***    | ***    | ***    | ***    | ***    | ***    | ***   | *** | *** | *** | *** | *** | *** | *** | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   | ***   |
Figure 3.12:
Icicle Dendrogram of Heath Cluster Analysis

Key:

dev: Devonian valley floor sites in the Northern Budawangs (catchment of Styles Creek)

silt: Siltstone site in the Northern Budawangs (Bhundoo Hill)

sst: Sandstone site in the Northern Budawangs (below Mt. Bibbenluke)

me: Mesa top sites in the Northern Budawangs (Island Mt., Sturgiss Mt., Byangee Walls, Mt. Talaterang, Endrick Mt., Mt. Corang, Mt. Tarn, Monolith Valley).


Axes:

Vertical axis: This displays increasing similarity between sites from top to bottom.

Horizontal axis: The most similar sites are placed adjacent to each other, based on twenty three subdivisions of the data.

Cluster Groups

Three groups are evident:

(i) Sites 35, 37, 34, 32, 33, 36 and 30. Site 7 links this cluster to the next.

(ii) Sites 4, 8, 3, 6, 5 and 2.

(iii) Sites 44, 43, 46, 45, 41, 38, 40, 39 and 1.

The third group of sites is linked to the other groups only at the last subdivision of the analysis. See text pages 98-9 for interpretation.
Comparison with other Areas

Species diversity of Australian heathlands reaches its peak in the warm temperate zone, with the proportion of the total Australian heath species occurring in the tropics being 3-6% and in the cool-temperate areas, 9-14% (Specht 1981b).

Specht (1979) classified heath floristic data from sites all over Australia into six groups. These coincided with climate types. Specht's Groups C (warm-temperate to subtropical eastern Australia) and D (temperate areas of south-eastern Australia extending into the highlands of eastern Australia) appear to overlap in Ettrema and Northern Budawangs.

In the two Australia-wide summaries of vegetation which are available (Specht et al. 1974 and Beadle 1981), heath is classified into associations and alliances in terms of dominant species. In these classifications, some species which very clearly dominate certain areas of heathland in Ettrema/North Budawangs are named as dominants or co-dominants of alliances, but not all the variations of heathland found in Ettrema and Northern Budawangs are encompassed in either classification. For example, Banksia paludosa, which was the only species listed from all types of heath in Ettrema and Northern Budawangs, is not mentioned as a dominant in either the Beadle or Specht classification. Neither is the dwarf Baeckea brevifolia, which characterises much of the heathland across the Ettrema plateaux.

Heathland:

Comparable Specht Alliances

Open scrub (i) Eucalyptus stricta mallee

   (ii) E.luehmanniana-E.obtusifolia-E.multicaulis mallee

Montane shrubland (i) Allocasuarina nana

Closed heath (i) Banksia spp.

Open heath  (i) South coast heath (containing Casuarina spp.,Epacridaceae, Myrtaceae, Proteaceae, Rutaceae)

   (ii) Sprengelia incarnata -Sedge
Sedgeland  (i) *Gymnoschoenus sphaerocephalus*

Worthy of note amongst the above is the alliance "south coast heath", clearly here defined by place rather than by species, as have been the Ettrema-Northern Budawangs heaths.

**Comparable Beadle Alliances**

Beadle classified eastern Australian heathland communities into Alliances "when possible". Recognisable in Ettrema/Northern Budawangs from the Beadle list are:

- *Banksia ericifolia* Alliance
- *Leptospermum flavescens* (now *L. polygalifolium*) - *L. attenuatum* (now *L. trinervium*) Alliance
- Sedge-heaths (defined as heathlands in wet areas in which sedges dominate)
- *Allocasuarina distyla* Alliance
- *Allocasuarina nana* Alliance

This list does not comprehensively encompass all of the dominant species variations in the Ettrema/North Budawangs heathlands. The difficulty in classifying heathlands may be seen as a by-product of their species diversity and composition which varies over short distances. In Ettrema/North Budawangs as elsewhere, Australian heathlands less readily lend themselves to an association-type classification than eucalypt forest.

The heathlands in Ettrema/Northern Budawangs are floristically related to heathlands in adjacent areas, both to the north (Sydney Basin), to the east (Jervis Bay) and to the south (Budawang Ranges, South Coast). Brief comparison is made with data available from these areas.
(i) Sydney Basin Heath and Sedgeland

Fifty percent of 3700 species typical of Australian heathlands are found on the sandplain and lateritic soils of SW Western Australia, while the Triassic sandstones of the Sydney Basin support another twenty percent of the Australian heath flora (Specht 1981b). The heathlands of the Morton wildernesses share many species in common with heathlands of the Triassic sandstones. This is shown, for example, by comparison of the Ettrema/ Northern Budawangs species list with a comprehensive list available for the Barren Grounds (eds R. & P. Jordan 1987).

Benson (1986, 1992), Benson & Keith (1990), Keith & Benson (1988) subdivided the Sydney Basin heath communities mainly on a physiographic basis. As in the survey reported here, there was no detailed floristic separation, only a listing of dominant species. Comparison of these species listings indicates that a proportion of the abundant species are similar to both areas, but many are different. Of the fifteen species found to occur on at least 44% of sites in Ettrema and Northern Budawangs areas, eight are included in listings of the most common species (and one superspecies) in the various heathland units by Benson and Keith. These include Eucalyptus superspecies stricta (on the Triassic sandstones represented by E.stricta), Hakea teretifolia, H.dactyloides, Lepyrodia scariosa, Isopogon anemonifolius, Schoenus villosus, Allocasuarina distyla, Leptospermum arachnoides, and Baeckea brevifolia (on shallow, humic soils on Kanangra Tops). Allocasuarina nana, which characterises much of the open heath in the Blue Mountains, is of marginal occurrence at the south-westernmost corner of the Nth.Budawangs.

Species common in Ettrema/ Northern Budawangs may become uncommon in other areas of sandstone. For example, Banksia paludosa, the only species listed for all Northern Budawangs heath sites, becomes a "species of particular conservation importance" in the Gosford-Lake Macquarie region (Benson 1986), where it reaches its northern limit of distribution. Of particular interest, because of shared rare species, are the Newnes Plateau "Shrub Swamps" (closed heath and sedgeland), reported in Benson & Keith (1990). These share some dominant species (e.g. Baeckea linifolia,
Gymnoschoenus sphaerocephalus, Epacris paludosa), in common with Ettrema/Nth.Budawang swamps. At least three rare species with disjunct distributions (Morton NP and Blue Mts.), E. gregsoniana, Boronia deanei and Dillwynia stipulifera sens. lat. grow in these swamps. E. gregsoniana was also found in "Montane Heath" on the southern half of the Newnes plateau. This heath unit shares some species in common with heathlands in the Northern Budawangs, for example, Allocasuarina nana, Banksia ericifolia, Leptospermum trinervium, Hakea dactyloides, Isopogon anemonifolius and localised patches of Eucalyptus stricta.

(ii) Budawang Ranges (Gilmour & Plumwood 1982)

Heath occurs on the mountain peaks in this area. Allocasuarina nana, which dominates some areas of heath (e.g., the top of Mt. Budawang), occurs as the dominant in small heath patches in the Wog Wog area at the western edge of the Northern Budawangs wilderness and as a component of heath in the Corang area, thus linking these two adjacent wildernesses. Heath on the jagged peak of Currockbilly Mt. is redolent with rare species, dominant amongst which is Boronia subulifolia. Also common on the mesas in the Northern Budawangs, this species links the heath of these mountaintops. Two other rare species which occur in the Mt. Currockbilly heath, Boronia rhomboidea and the rare grass Plinthanthesis rodwayi, are disjunctly distributed here and in southern Tasmania. Boronia rhomboidea also occurs in the Northern Budawangs. Possible reasons for the occurrence of rare species on mountaintops and for the disjunct distributions of the aforementioned species, are discussed in ch.7.

The majority of heath species listed as occurring in the Budawangs were also found in the Northern Budawangs.
CSIRO South Coast Survey

Heath Complex

The majority of species listed in a floristic summary of the prevalent heath species on the South Coast (Austin & Sheaffe 1978) are also found in the Ettrema and Northern Budawangs wildernesses. Five communities were defined and named by dominants. Of these five, only two (Allocasuarina nana and Banksia ericifolia) are recognisable as dominating some areas of the Ettrema and Northern Budawangs. Hence it appears that, although floristics may be similar, dominant species differ.

Jervis Bay heath communities were briefly described by Ingwersen (1976). He defined four heath types, which, in terms of dominant species, superficially appear to bear similarities and differences to the heathlands of the study area. Banksia ericifolia is listed as a dominant species in two heath types, along with Melaleuca squarrosa and Allocasuarina distyla. Eucalyptus (superspecies) stricta mallee-heath occurs here. All of these species occur also in the Ettrema area. However, a more meaningful comparison would depend on the collection of data for this purpose.

Conclusions

About half of the heath species common in Ettrema/ Northern Budawangs appear common also in the Sydney Basin areas to the north. Others which were found to be common in the study area, become rare further north (e.g. Banksia paludosa). There are striking disjunct distributions in some rare heath species which occur in both the Blue Mts and the Ettrema/ N. Budawangs. Equally striking is the commonalty of some rare species between the mountaintops of the Budawang ranges to the south and the mesa-tops of the Northern Budawang Ranges.

There is much similarity in species composition with adjacent heathlands to both north and south but dominant species may differ. Elucidation of differences and similarities awaits further study.
Plate 3.2a: Heath on the Ettrema Plateau

Foreground: *Acacia hamiltoniana*
Background: *Eucalyptus punctata* (Grey Gum) sandstone complex

b. *Baeckea brevifolia* Heath on Tullyangela Plateau

Skeletal peat soils damaged by vehicle. Burnt *Eucalyptus sieberi* in background.
Plate 3.3 : Heath in the Northern Budawangs

a. : Devonian valley floor of Styles Creek

Background, left to right : Endrick Mt., Sturgiss Mt., Mt. Hoddle

b. : Heath - Sedgeland on top of Mt. Bibbenluke
3.6.2 Closed Scrub

Introduction

Only one eucalypt association is described here. One other (*E. eximia*) may assume closed scrub structure. This may also occur as low open forest and its occurrence is described in 3.6.4f. Heath may form a closed scrub in certain locations. This is described as part of the heathlands in 3.6.1.

*Eucalyptus multicaulis* (Whipstick Mallee-Ash) Closed Scrub

Map Symbol: mt

Occurrence

Extensive stands of this uncommon mallee grow on west-facing slopes on the sides of the Castle. Other known localised occurrences are at Folly Point, Sluice Box Falls (Pickard 1982), Mt. Tarn and Mt. Corang. It is predicted (from air photos) that this species occurs more widely in the eastern sector of the North Budawang Ranges than has yet been surveyed (see Fig. 3.10). A patch predictively mapped on the eastern side of Shrouded Gods Mt (Mt Pataird) has now been confirmed (I. Smith per. comm. 1992).

Structure

Where observed, this mallee forms a dense thicket or closed scrub, with no co-dominant species and little in the way of understorey vegetation.

Adjacent Vegetation

Heathland often occurs adjacent to, or intermingling with *E. multicaulis*.

Comparison with Vegetation of Other Areas.

The coastal "wet mallees" mallees are encompassed within one open scrub alliance by Specht et al. (1974). *E. dendromorpha* mallee, *E. ligustrina*, and *E. multicaulis*, are all listed as part of the *E. stricta* alliance. This categorisation is meaningless from the point
of view of the occurrence of these mallees in the Morton wildernesses, as they occur in different communities and do not form any gradational sequence in relation to each other. In his listing of the mallee species and communities of the east coast, Beadle (1981) did not record an *E. multicaulis* alliance or suballiance.

*E. multicaulis* is recorded as occurring in the Sydney Basin (Benson 1986, Benson & Keith 1990, Keith & Benson 1988) and in the Budawang Ranges (Gilmour & Plumwood 1982). Ingwersen (1976) described the major occurrence of *E. sieberi* at Jervis Bay as an "emergent mallee-like tree". This species was not recorded by Austin & Sheaffe (1976) in the South Coast survey.

*Eucalyptus multicaulis* is disjunctly distributed, with scattered occurrences in the Sydney Basin to the north and in the Budawangs and Northern Budawangs to the south. It is uncommon throughout the Sydney Basin, occurring in scattered localities in the lower Blue Mountains, the Gosford area and in the Royal National Park (Hall & Brooker 1980). Its distribution in the Sydney Basin was not mapped by Benson (1986, 1992) Benson & Keith (1990), Keith & Benson (1988).

Gilmour & Plumwood (1982) located several areas of *Eucalyptus multicaulis* in the Budawang Ranges, occurring as a community on exposed conglomeratic slopes. This appears to be a southern extension of its occurrence in the Northern Budawangs. It is not known whether the mallee-like *E. sieberi* recorded as being scattered through heathland at Jervis Bay (Ingwersen 1976) is another population of *E. multicaulis*, or whether its form here is induced by fire or its coastal habitat.

**Conclusion**

This species was listed as one which "could be endangered in the near future" by Pryor (1981). Its distribution is not well mapped, because of its scattered occurrence in small populations.
3.6.3 Closed Forest (Rainforest)

**Introduction**

The overall changes in structure and species composition which occur along the south coast of NSW have been described by Baur (1965), Webb (1959) and Webb, Tracey & Williams (1985) for NSW and Australia respectively. The species composition of the Illawarra rainforest has been inventoried by Fuller (1982) and Fuller & Mills (1985), structurally grouped by Bywater (1978) and floristically clustered by Mills (1986). The rainforest of the South Coast of NSW has been the subject of an inventory analysis by Helman (1983). Rainforest immediately to the south of the study area, in the Budawangs, was described by Gilmour & Plumwood (1982).

Detailed inventory analysis of rainforest species composition in the Ettrema and Northern Budawangs was limited to a small number of sites. Therefore the conclusions reached are considered to be only a preliminary, but do provide a basis for comparison, both within the study area and with the changing composition of rainforest in NSW.

**Main Occurrences**

Rainforest is found in a variety of locations within the Ettrema and Northern Budawangs wildernesses.

1. **Ettrema**
   a. Parts of the Sassafras basalt
   b. Parts of the Danjera, Boolijah and Bundundah Creeks on Devonian strata.
   c. In sheltered locations in the headwaters of creeks and in gullies on gorge slopes.

2. **North Budawang Ranges**
   a. Endrick basalt
   b. East to south-facing slopes of mesas
   c. In sheltered locations in the headwaters of creeks and in gullies.
   d. In ravines in and around the Monolith Valley.

The best development of rainforest in these two areas would once have been on the Endrick and Sassafras basalt flows. The major part of the Sassafras basalt has been
cleared and is now grassed. The rainforest on the Endrick basalt has been subjected to logging in the past.

Rainforest species occur in moist locations in both Ettrema and Budawangs, across the full range of rock strata.

**Description**

All rainforest observed falls (more or less) into the climatic classifications of temperate rainforest (Baur 1957) or humid cool subtropical to humid cool temperate (Webb, Tracey & Williams 1985). It is of low structural complexity and can be structurally classified as simple notophyll forest (Webb et al. 1959). The rainforest can be placed in Site Groups A1, A2 and A3 of a more recent comprehensive Australia-wide floristic classification of rainforests (Webb, Tracey & Williams 1985).

**Details of Occurrences.**

a. Sassafras and Endrick basalt flows

The largest stands of rainforest mapped occur in sheltered locations on these two basalt flows. The Tolwong basalt, a third basalt flow in the area, does not now support rainforest, but may once have done before clearing.

**Dominant Species Composition.**

The most abundant species in the notophyll forest on the Endrick and Sassafras basalts are Sassafras (*Doryphora sassafras*), Coachwood (*Ceratopetalum apetalum*), Plumwood or Pinkwood (*Eucryphia moorei*), Possumwood (*Quintinia sieberi*) and Tree Ferns. The dominance of these species places this rainforest in Baur’s (1965) classification as Cool Temperate Rainforest Leaugue, Forest Type 18 (Pinkwood) and in Webb’s (1985) classification as a humid cool-subtropical (mesotherm) element of Site group A1, the core area of which is centred on subtropical coastal south Queensland.
Structure

Low closed or closed forest, with only one tree stratum. Vines may be present. The simplicity in structure and species composition of much of this forest probably indicates that it is regenerating following logging at some stage.

Understorey

A ground layer of litter scattered with tree ferns forms the understorey.

b. Ettrema Creeks.

Air photo interpretation suggests that areas of rainforest occur on Devonian strata along parts of Bundundah, Danjera and Boolijah Creeks (see Fig. 3.6, Yalwal map). These areas have not been examined closely.

c. Rainforest in Headwaters of Creeks and in Gullies on Gorge Slopes in the Ettrema Area.

Typically, the upper gorge slopes of the Ettrema Creeks may support rainforest in gullies, alternating with Grey Gum-Ironbark forest on the ridges. This ridge and gully system is found on parts of Ettrema, Bundundah and Danjera Creeks.

Dominant Species Composition.

Rainforest species most often observed were *Backhousia myrtifolia*, *Elaeocarpus reticulatus* and *Acacia elata*. Other species are recorded in Table 3.10. *Backhousia myrtifolia* (Grey Myrtle) is characteristic of rainforest in relatively dry locations throughout NSW. This rainforest can be encompassed in Baur's Dry and Depauperate Rainforest League, Forest Type 23 (Myrtle). It is difficult to place in Webb, Tracey & Williams 1985 classification.
d. Rainforest Occurring as an Understorey.

Turpentine-Um-fruited Peppermint forest found on upper Wandrawandian slopes below Yarramunmun, Danjera and Unnamed Plateaux has a conspicuous rainforest component in the understorey, with the most frequently observed species being Livistona australis, Synoum glandulosum, Eupomatia laurina, Baloghia lucida and Ficus rubiginosa. Rainforest replaces Turpentine-Urn-Fruited Peppermint as the canopy in the wettest locations, e.g., in the headwaters of Yarramunmun Creek below Tianjara Falls (see Plate 3.4b).

These rainforest patches are difficult to place in Baur's (1965) classification but could be included in the Webb et al. (1985) classification as part of the humid cool-subtropical element of Site group A1. It is suspected that the unusual species composition may be a result of selection by fire (further discussed in Ch.8).

North Budawang Ranges

a. Sheltered Slopes of Mesas.

The east to south-facing slopes of the mesas support wet sclerophyll forest in which the dominant eucalypts are Eucalyptus fraxinoides, E. triflora and E. fastigata and the most commonly occurring mesic species are Eucryphia moorei, Emmenosperma alphonoides, Dicksonia antarctica, Todea barbara and Ceratopetalum apetalum (Plate 8.4). Tristaniopsis collina characteristically occurs around the "dripline" of mesas. Rainforest canopies in gullies (Plate 3.13) and along creeks, for example, along Angel Creek between Mt.Tarn and Donjon, where there is a luxuriant growth of Ceratopetalum apetalum, Doryphora sassafras, Quintinia sieberi, Acmena smithii and Eucryphia moorei. The understorey includes Tree Ferns (Dicksonia antarctica and Cyathea australis) and the shrub Tasmannia insipida.

The occurrence of Eucryphia moorei (Plumwood or Pinkwood) here links this to the cool temperate rainforest occurring in the Budawang Ranges to the south (Gilmour & Plumwood 1982). It is encompassed in Baur's Cool Temperate Rainforest League, Forest Type No.18, Pinkwood. It is included in Webb, Tracey & Williams' 1985
classification as an element related to site group A3, the core area of which are the humid cool temperate zones of central and western Tasmania and central and western Victoria.

b. Rainforest-Wet Sclerophyll Forest in Sheltered Locations in the Headwaters of Creeks and in Gullies.

1. Headwaters of the Clyde River.

*Eucalyptus fraxinoides*-*E.fastigata* forest with a rainforest understorey is common in the headwaters of the Clyde River, including Hollands Gorge as well as below Mt. Tianjara and Little Forest Plateau, with rainforest forming the canopy in the most sheltered gullies.

2. Yadboro Creek

Rainforest canopies in gullies on south-facing slopes below Mts.Corang, Bibbenluke, Owen and the Castle.

c. Ravines in the Nowra sandstone in and around the Monolith Valley.

These ravines become very dark, deep, moist and mossy at their lowest ends and here are found tree ferns and rainforest trees, most often Sassafras, Coachwood, Plumwood, Water Gum and Possumwood. This can be classified as cool temperate rainforest, encompassed in Baur's forest type no.18 (Pinkwood) and as a related element of site group A3 (Webb *et al.* 1985).

Structure

Very small areas of closed forest (simple notophyll fern forest) occupy the widest parts of the ravines, with little in the understorey to disturb the carpet of leaf litter apart from scattered ferns and tree ferns.

Human Influence.

The formerly popular camping area, alongside the creek in the Monolith Valley, supports a stand of trees dominated by Coachwoods. Absence of seedling regeneration
was noted here in 1983. This was probably a result of compaction of the ground by campers (now forbidden in Monolith Valley by NPWS).

Discussion

A significant feature of the rainforest is the differing species composition in Ettrema and Northern Budawangs. Although this is similar on the two basalt flows, it otherwise differs markedly in the two areas. The most frequently observed trees in the rainforest in the Northern Budawang Range were *Eucryphia moorei*, *Quintinia sieberi*, *Ceratopetalum apetalum* and *Doryphora sassafras*, whereas along the Ettrema creeks and gorges and gullies, the most frequently observed rainforest species were *Livistona australis*, *Synoum glandulosum*, *Diospyros australis* and *Stenocarpus salignus*. Of a total of fourteen species recorded in the Ettrema Gorges and twenty-one in the Northern Budawangs, only four were observed in both areas (Table 3.10).

The rainforest of the basalt flows is most floristically similar to the Illawarra rainforest, whereas the rainforest of the Northern Budawangs is more floristically similar to that occurring in the Budawangs to the south. Plumwood (*Eucryphia moorei*), which is a characteristic species in the Northern Budawangs, links this rainforest to the Budawangs and to the remnants of the Robertson Brush to the west above the Illawarra escarpment. *Backhousia myrtifolia*, which characterises the rainforest in the Ettrema Gorges, is the most characteristic species of dry, depauperate rainforests throughout NSW (Baur 1965).

Conclusions

It can be seen that the Ettrema/Northern Budawangs rainforests form part of the sequence of gradational changes in species composition occurring north to south along the east coast of NSW. Within the area, floristic changes are evident from the Ettrema rainforests to those of the Northern Budawangs and those of the basalt flows. These differences are probably determined by features of the environment such as soil fertility and moisture-holding capacity and climatic characteristics such as rainfall, temperature, and snowfall.
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Plate 3.4a: Remnant Rainforest at Sassafras

Plate 3.4b: Rainforest in Yalwal Creek below Tianjara Falls (visible as brighter green crowns).
3.6.4 Open Forest and Woodland

Introduction

These two structural classes of vegetation are here considered together, because of the overlap in structure of forest associations which are grouped together floristically. Nine different associations which were identified are described.

Comparison with other Areas

Open forest and woodland in Australia has been broadly classified into associations and alliances by Specht et al. (1974) and Beadle (1981). Some of the forests of Ettrema/Northern Budawangs can be encompassed within these classifications (Table 3.2).

Most notable amongst these are the 'Sandstone complex' associations of the Central Sydney Basin (defined by Pidgeon 1937, 1941, and mapped by Benson (1986, 1992), Benson & Keith 1990, Keith & Benson 1988). This is comparable with the *Eucalyptus punctata- E. consideniana- E. gummifera* 'sandstone complex' of the Ettrema Plateaux.

"Sandstone Complex"

Open forest, low open forest and woodland of Ettrema/Northern Budawangs may be included in five of the forty four alliances listed by Specht. Three of these alliances are included in "Sandstone complex", which is further defined as "part of a vegetation continuum on very nutrient deficient sandstones". These three alliances are separated mainly on this structural basis and have an overlapping and difficult to define composition of dominant eucalypts. This equates with the *E. gummifera- E. sieberi- E. racemosa* Alliance of Beadle, who refers to the great diversity of xeromorphic species which it contains. Beadle's alliance is subdivided on a species basis into three suballiances, which can be related to the complex sandstone vegetation in the Ettrema and Northern Budawangs. These are the *Eucalyptus gummifera- E. racemosa- Angophora costata* suballiance, within which the *E. punctata* complex association may be encompassed. The *E. sieberi- E. piperita- E. racemosa* suballiance, which may be seen to encompass *E. sieberi- E. piperita* ssp. *urceolaris* association and the *E. eximia- E. punctata*
suballiance which could include *E. eximia* and *E. punctata* complex association. This is placed within a north-south sequence of east coast woodlands and forests on poor soils.

The recognition that the eucalypt communities on the Sydney Basin sandstone are complex is attributable originally to Pidgeon (1937,1941), who studied the vegetation of the Central Coast. Pidgeon included all of the forests found on the poor sandy soils of the Hawkesbury sandstone as one association: "Mixed *Eucalyptus* Forest association" and referred to it as a "distinctive and unique association, differing from most of the coastal forests in its extremely low integration". Pidgeon noted the large number of tree species, which resulted in a "bewildering variety of forest stands". Observing that some species were widely distributed and others narrowly, Pidgeon attempted to define gradients in the occurrence and change of species with climate and topography. The limits of distribution of species were attributed to climatic variables within their geographic range and to microclimatic variables within their local habitat. Whilst Pidgeon's "bewildering variety of forest stands" is reminiscent of the Ettrema *E.punctata-E. considendiana- E. gummifera* complex association, the number and variability of species included in Pidgeon's Mixed *Eucalyptus* Forest association (regrouped as alliances by Specht, in keeping with definitions of Beadle and Costin 1952), is much greater. Ettrema/Nth.Budawangs associations, if present, were not defined. Despite these difficulties in comparison, Pidgeon's observation that the Sydney sandstone forest is bewilderingly complex is paralleled by my observations on the complexity of eucalypt forest across the Permian sandstone plateaux of the Ettrema wilderness.

The "sandstone complex" of Benson (1986, 1992), Benson & Keith (1990), Keith & Benson (1988), is described as being "essentially land units made up of several plant communities", occurring at lower altitudes in the Blue Mountains, overlapping with the higher altitude *E. sieberi- E. piperita* forest, on sandstone ridgetops in the Colo wilderness and widespread on Hawkesbury sandstone areas of the Gosford and Lake Macquarie map sheets. Consistent with Pidgeon's 1937, 1941 account of this eucalypt open to low open forest, woodland or scrub, species combinations are not well defined. Benson and Keith described the "Hawkesbury sandstone complex" as being one which
"contains considerable local structural and floristic variation depending particularly on topographic position, drainage and aspect. Various sub-units and topographic sequences can be recognised (which are) not practical to map". This is almost a repetition of the comments made by Pidgeon fifty years prior to this survey.

**Jervis Bay "Sandstone Complex" Woodland Associations.**

*E. sieberi - E. gummifera*

*E. sclerophylla - E. gummifera*

*E. gummifera - E. piperita*

These three woodland associations listed by Ingwersen (1976) as occurring on sandstone at Jervis Bay overlap in species composition with the Ettrema/Northern Budawangs *E. punctata - E. consideriana - E. gummifera* sandstone complex and *E. sieberi - E. piperita ssp. urceolaris* association. *E. gummifera* is clearly more dominant in this coastal situation, occurring as the co-dominant in the three woodland associations. The distributions of *E. sieberi* and *E. piperita*, which overlap in the Northern Budawangs and sometimes in Ettrema, are separated at Jervis Bay. The fact that these are listed as woodland associations, whereas they are often open forest in Ettrema/ Northern Budawangs, suggests a generally more stunted vegetation in this near-shore environment.

**South Coast "Sandstone Complex"**

The majority of communities identified in the CSIRO South Coast survey (Austin & Sheaffe 1976) which are recognisably comparable with Ettrema/ Northern Budawangs vegetation appear to be combinations which in Morton NP are part of the "sandstone complex". These are:

(1) *E. muellerana* Group

Of the ten communities listed by Austin and Sheaffe in this group, four are recognisable, three as combinations encompassed in the *E. punctata - E. consideriana - E. gummifera* complex association (*E. sieberi - E. agglomerata, E. sieberi - E. consideriana,
E. agglomerata- E. punctata and the fourth, E. sieberi- E. piperita, as a commonly occurring association in the Northern Budawangs.

(2) **E. gummifera Group**

Three "types" can be related:

(i) **E."globoidea"- E. gummifera- Angophora costata type**

Three of five communities in this group are recognisable eucalypt combinations from the Ettrema E. punctata - E. consid eniana- E. gummifera complex association, including E."globoidea"- E. gummifera, E."globoidea"- E. sieberi and E. consid eniana- E. gummifera.

(ii) **E. gummifera- E. piperita- E. botryoides type**

Of the five communities recognised, one, E. agglomerata- E. gummifera, is a combination included in the E. punctata- E. consid eniana- E. gummifera complex association. On the basis of a limited number of samples (five, only three of which contain E. gummifera) Austin & Sheaffe (1976) suggested that this community is characteristic of crests, upper slopes and warm midslopes, possibly being more common at higher altitudes.

(iii) **E. gummifera- E. sieberi- Syncarpia glomulifera type**

All four communities listed by Austin & Sheaffe (1976), i.e., E. gummifera-E. consid eniana, E. sieberi- E. gummifera, E. gummifera- E. piperita and Syncarpia glomulifera- E. piperita, are amongst combinations of eucalypts recorded in Ettrema, the first three being part of the E. punctata complex association. They were identified by Austin & Sheaffe (1976) in the area of overlap between the South Coast study and this study. They describe the first three communities as being characteristic of the Permian sediments in the north of the study area, forming a complex mosaic with heath communities. From their small sample (ten E. gummifera- E. consid eniana, three each of the other two), they suggest that there is an altitudinal separation, with E. gummifera- E. consid eniana at the lowest altitudes, E. gummifera- E. piperit a at intermediate altitudes and E. sieberi- E. gummifera at the highest altitudes. The Syncarpia community occurs along the north-east edge of the study area.
**Same Eucalypts, Different Combinations**

Often, the eucalypt species combinations listed appear different from those located in Ettrema/North Budawangs. For example, in the central Sydney Basin open forest (Benson & Keith 1986-1992), only one species combination, *Eucalyptus sieberi*-*E. piperita*, is recognisably similar to that found in Ettrema/North Budawangs (although subspecies *urceolaris* is replaced by *ssp.piperita*). Other Benson and Keith open forest units have species which are present but in different combinations in Ettrema/North Budawangs. For example, *E. punctata* and *E. sieberi*, which are recorded as occurring together in a number Benson and Keith's land units, were found to be distributed separately in the Morton National Park wilderness areas.

**Open forest to the South**

**Budawangs**

Vegetation communities documented by Gilmour & Plumwood (1982) display many links with those of the Northern Budawang Ranges, and some connection with the vegetation of the Ettrema wilderness. There appears to be no vegetation comparable to the *Ettrema E. punctata*- *E. consideniana*- *E. gummifera* complex association.

Three open forest associations are comparable:

1. *Eucalyptus radiata*- *E. rubida* ridge association. There appears to be continuity between this vegetation and that located at the western edge of the Ettrema/Nth Budawangs, in the area north of Wog Wog station, but it is not the same as any of the widely occurring associations identified in the Ettrema and Nth.Budawangs.

2. *E. sieberi* here, as in the Morton wildernesses, occurs on more exposed aspects. *E. piperita* *ssp. urceolaris*, a common associate of *E. sieberi* in Morton NP and the central Sydney Basin, reaches its southern limit of distribution in the far north-east corner of Budawang NP.

3. *E. agglomerata*- *E. sieberi* association occurs on west and north-facing slopes, crests and ridges, with *E. sieberi* typically occurring in pure stands on the crests and *E.*
agglomerata appearing slightly lower down and becoming co-dominant. The altitudinal limit of *E. agglomerata* was found to be about 420 metres in the south of the park and 780 metres in the north-east. *Angophora floribunda* occurs at every site. These species occur on the western margins of Tullyangela Labyrinth.

**Links with Southern Tableland Alliances and Associations:**

Two of the eight alliances listed by Costin for the Monaro Tablelands have a marginal occurrence in Ettrema/Northern Budawangs and one occurs in both.

The open forest associations of the Ettrema/Northern Budawangs may be related to the following Monaro alliances and their contained associations:

(i) *E. macrorhyncha* - *E. rossii* Alliance

Four of the twenty nine associations listed for the Monaro can be related to vegetation having a marginal distribution at the western edge of the Ettrema/Northern Budawangs. These are:

1. *E. dives* - *E. pauciflora* association. *E. pauciflora* and associates occurring at the western margins of the field area appear to be an outlier of this tableland tract alliance and can be related to this associations. This can be cross-referenced with the "*E. pauciflora* group" of Austin & Sheaffe (1978).

2. *E. macrorhyncha* - *E. rossii* The very marginal occurrence of these species at the western edges of the field area can be recognised as an eastern extension of this association.

3. *E. mannifera* ssp. *maculosa*

4. *E. rossii*

These two abovementioned associations recorded by Costin can be related to the occurrence of *E. mannifera* and *E. rossii* at the western margins of the field area, although here they were interpreted as being gradational to the widespread *E. sclerophylla* - *E. mannifera* association.
Conclusions

The independently identified "sandstone complex" of the Ettrema plateaux parallels similar open forest vegetation found in nearby areas of sandstone, both in complexity and species composition. This links the Ettrema open forests with those to the north (Sydney Basin) and east (Jervis Bay).

Open forest at the south-western edge of the Northern Budawangs displays links with that found in the Budawang Ranges to the south and the Monaro Tablelands to the south-west.

The majority of eucalypt associations classified and described in this study are not recorded in studies of comparable areas. *E. sieberi- E. piperita*, also recorded from the Central Sydney Basin (Benson & Keith 1988, 1990), is an exception.
3.6.4 Open Forest

a. Scribbly Gum Forest (Eucalyptus sclerophylla - E. rossii) and Snappy Gum Woodland (E. mannifera)

Map Symbols:

E. sclerophylla : scl
E. rossii : rss
Scribbly Gum : scr
E. mannifera : m

Occurrence

Scribbly Gum forest is widespread on the Ettrema plateaux, in the Tianjara and Newhaven Gap areas and in the valleys of the North Budawang Range. It grades into areas of woodland dominated by Snappy Gum in many locations. This association is generally contiguous with heath or sedgeland.

Variations in Dominant Species Composition

Eucalyptus sclerophylla is the dominant Scribbly Gum over most of the area, with an increasing component of E. rossii westwards. E. rossii has been identified as far east as Churinga Head on the western side of Ettrema Gorge and all Scribbly Gums collected for positive identification from the Tolwong area have proved to be E. rossii. Here, the Scribbly Gums form an open forest adjacent to White Stringybark Forest.

Gradients occur within this community in the proportional occurrence of Scribbly Gum versus Snappy Gum. E. mannifera occurs as a sub-dominant tree, becoming dominant around swamps and watercourses.

E. ovata has a limited distribution in this association. Small numbers of individuals occur around some swamps, for example, at the southern end of Ettrema Plateau and at the Sassafras end of the Endrick River Trail. Its fragmentary occurrence within this community may represent a gradient of change through time, since this species is here near its northern limit of distribution.
**Understorey**

Understorey species typically include sedges (*Ptilanthelium deustum*, *Schoenus villosus*, *Lepyrodia scariosa*, *Lepidosperma limicola*), grasses (*Eragrostis brownii*, *Stipa pubescens*) and a variable composition of scattered shrubs, such as *Leptospermum trinervium*, *L. juniperinum*, *Grevillea parviflora*, *Banksia spinulosa* and *B. paludosa*, *Hakea dactyloides*, *Acacia hamiltoniana* and *Lambertia formosa*.

**Gradients**

The most commonly occurring adjacent community is heathland, which is clearly distinguishable structurally. Overlap does occur, with heath interspersed, forming a woodland community.

Scribbly Gum-Snappy Gum form a clearly distinguishable, apparently stable community. The above defined gradients are most easily interpretable in relation to this community, as gradients within it and as ecotones with the adjacent heathland.
Plate 3.5a: *Eucalyptus mannifera* woodland near Sassafras

Plate 3.5b: *Eucalyptus sieberi* on Berry knoll with *E. sclerophylla* - *E. mannifera* woodland in background
3.6.4 Open Forest


**Occurrence**

Forest community dominated by one or both of these trees occurs over large areas of the Northern Budawang Range and the Ettrema wilderness. They are the predominant trees in the dry sclerophyll forest throughout the North Budawang Ranges. In the Ettrema area, these trees are less common, occurring on knolls (e.g. Ettrema Hill), where they are part of a more complicated and variable sequence of species and in gully-heads.

**Structure**

This forest varies from dry and open with trees of medium height (20-27m.) to moist open with taller trees (to 30m.).

**Understorey**

In dry forest, the understorey is generally shrubby; for example, on the north-facing slopes of Mt. Bibbenluke, *Acacia obtusifolia, Banksias paludosa* and *B. spinulosa, Leptospermum polygalifolium* and *Persoonia mollis* predominate. In moist phases of this forest, the understorey is ferny and sedgy e.g. on the lower slopes of Mt. Bibbenluke, massed areas of fern (*Culcita dubia* and *Gleicheina dicarpa*) occur and scattered clumps of *Gahnia subaequiglumis*.

**Gradients of Change in Dominant Species Composition.**

Gradients of change in the proportions of *Eucalyptus sieberi* and *E. piperita*, are readily visible within this association in the Northern Budawangs. In the different landscape of the Ettrema area, the distribution of these two species is more often than not separate.

In some stands of this forest in the Northern Budawangs, Silvertop Ash is the predominant species and in others, Urn-fruited Peppermint. At any one site, the
dominant species composition can be seen to vary from predominantly *Eucalyptus sieberi* through mixed *E. sieberi - E. piperita* ssp. *urceolaris* stands to predominant *E. piperita* ssp. *urceolaris*, along environmental gradients. Silvertop Ash may occur without Urn-fruited Peppermint and vice versa.

In a "moist phase" of this association, *Euxalyptus fastigata* or *E. saligna - E. cypellocarpa* may occur as co-dominants. The former combination was observed on Island Mt. in the Budawangs, and the latter in the headwaters of creeks on the Ettrema Plateau. Urn-fruited Peppermint occurs as part of a moist forest with Turpentines (*Syncarpia glomerulifera*) on the slopes of Yarramunmun Plateau.

In contrast to their co-occurrence in the Northern Budawangs, throughout the Ettrema area, the distributions of Silvertop Ash and Urn-fruited Peppermint are more commonly separate than overlapping. On the knolls, these two trees are part of a more complicated and variable selection of species.
Plate 3.6: *Eucalyptus piperita* ssp. *urceolaris* - *E. sieberi* open forest, Galbraith Plateau

Foreground: *Leptocarpus tenax* sedgeland
This transect shows a typical pattern of alternation between heath, sedgeland and *Eucalyptus punctata* - *E. considensiana* - *E. gummifera* "sandstone complex" across the quasi-concentrically patterned sandstone of the Ettrema Plateau.
3.6.4 Open Forest

c. *Eucalyptus punctata* (Grey Gum)-*E. consideniana* (Yertchuk)-
*E. gummifera* (Red Bloodwood) Complex Association.

Map symbol: pcygm

Occurrence:

These trees and a series of others, including *E. agglomerata* (Blue-leaved Stringybark), *E. sclerophylla* (Scribbly Gum) and *E. sieberi* (Silvertop Ash) intermingle in the eastern half of the Ettrema area. In the Northern Budawang Ranges, this group of trees was observed on the plateau below Pigeon House Mt. and on ridges descending south from the Castle to Yadboro Creek.

Structure:

Structural variability is a feature of this association. Whilst on the easternmost plateaux (i.e. Yalwal, Danjera and Smallest Plateaux), Grey Gum, Yertchuk, Red Bloodwood and Scribbly Gum form a low, open forest, on the sandstones of Ettrema Plateau, they occur as bands of stunted trees alternating with heathland. In gullyheads and upper gorges of the Ettrema Creeks, these trees grow taller, forming an open forest. On the western edge of the sandstone (Tullyangela Labyrinth-Bulee Brook area), Yertchuk, Silvertop Ash and Blue-Leaved Stringybark form an open forest.

Variations in Dominant Species Composition:

The species changes which occur are complex: these trees may occur singly or with one or more of the other trees. *E. punctata*, *E. consideniana* and *E. gummifera* are the three most commonly occurring trees in a group of species which consistently and complexly overlap in their distributions. Twenty four combinations of a possible one hundred and forty of six tree species were observed on thirty four sites, and, of these, only five combinations were recorded from more than one site. The two species most commonly found together were Yertchuk and Red Bloodwood (observed together on 13 of 34 sites,
that is, approximately 38%). The other combinations were observed less frequently, with the least frequently observed pair being Grey Gum-Silvertop Ash. The eucalypts in this community overlap complexly in their distributions. It differs from other associations in the greater number of eucalypts involved, and in this feature, it is reminiscent of the eucalypt forests of the Triassic sandstone of the central Sydney Basin (Pidgeon 1937, 1942, Benson 1986, 1992, Benson & Keith 1990, Keith & Benson 1988). Although this group of trees can be described as an association at a broad level, the changes in species composition are numerous. The composition of the complex changes noticeably from place to place, for example, Red Bloodwood occurs only in the eastern half of the Ettrema area. *E. sclerophylla* Scribbly Gum consistently occurs with Yertchuk and Red Bloodwood on the central area of the Yarramunmun Plateau (see Fig. 3.8, Sassafras map), while Grey Gum occurs with Blue Leaved Stringybark, Turpentine and other species along the edges. The uncommon Privet-leaved Stringybark (*E. ligustrina*) occurs with the complex along the western end of the Timboolina Trail and on Smallest Plateau. *Angophora bakeri* was observed as part of the complex on Smallest Plateau. Grey Gum is very abundant on Ettrema Plateau, while Yertchuk, Silvertop Ash and Blue-Leaved Stringybark predominate on the western edge of the area.

**Gradients**

Because of the floristic complexity of this association, the variations in dominant species composition described were not always readily interpretable in terms of gradients of change. East-west distributional limits of individual species occur (see Table 4.1).

**Understorey**

Generally shrubby, with abundant species being *Lambertia formosa, Leptospermum trinervium, Banksia spinulosa* and *Acacia obtusifolia*. The ground layer may be composed predominantly of leaf litter or of sedges, such as *Ptilanthelium deustum, Schoenus villosus, Leptocarpus tenax, Lepyrodia scariosa* and *Restio fastigiatus*.
Table 3.11: Observed Combinations in *Eucalyptus punctata* - *E. consideniana* - *E. gummifera* Complex Association

<table>
<thead>
<tr>
<th>Combination</th>
<th>Subgenus</th>
<th>Pryor's Rule?</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>E. punctata</em></td>
<td>S</td>
<td>-</td>
</tr>
<tr>
<td><em>E. punctata</em>-<em>agglomerata</em></td>
<td>S, M</td>
<td>yes</td>
</tr>
<tr>
<td><em>E. punctata</em>-<em>e.sclerophylla</em></td>
<td>S, M</td>
<td>yes</td>
</tr>
<tr>
<td><em>E. punctata</em>-<em>gummifera</em>-<em>e.sclerophylla</em></td>
<td>S, C, M</td>
<td>yes</td>
</tr>
<tr>
<td><em>E. punctata</em>-<em>agglomerata</em>-<em>e.sieberi</em></td>
<td>S, M, M</td>
<td>no</td>
</tr>
<tr>
<td><em>E. consideniana</em>-<em>e.gummifera</em></td>
<td>M, C</td>
<td>yes</td>
</tr>
<tr>
<td><em>E. consideniana</em>-<em>gummifera</em>-<em>e.ligustrina</em></td>
<td>M, C, S</td>
<td>yes</td>
</tr>
<tr>
<td><em>E. consideniana</em>-<em>agglomerata</em></td>
<td>M, M</td>
<td>no</td>
</tr>
<tr>
<td><em>E. consideniana</em>-<em>e.sieberi</em></td>
<td>M, M</td>
<td>no</td>
</tr>
<tr>
<td><em>E. consideniana</em>-<em>e.sclerophylla</em></td>
<td>M, M</td>
<td>no</td>
</tr>
<tr>
<td><em>E. consideniana</em>-<em>punctata</em>-<em>e.gummifera</em></td>
<td>M, S, C</td>
<td>yes</td>
</tr>
<tr>
<td><em>E. consideniana</em>-<em>gummifera</em>-<em>e.agglomerata</em></td>
<td>M, C, M</td>
<td>no</td>
</tr>
<tr>
<td><em>E. consideniana</em>-<em>gummifera</em>-<em>e.sieberi</em></td>
<td>M, C, M</td>
<td>no</td>
</tr>
<tr>
<td><em>E. consideniana</em>-<em>agglomerata</em>-<em>e.sieberi</em></td>
<td>M, M, M</td>
<td>no</td>
</tr>
<tr>
<td><em>E. gummifera</em>-<em>e.agglomerata</em></td>
<td>C, M</td>
<td>yes</td>
</tr>
<tr>
<td><em>E. agglomerata</em></td>
<td>M</td>
<td>-</td>
</tr>
<tr>
<td><em>E. agglomerata</em>-<em>e.sieberi</em></td>
<td>M, M</td>
<td>no</td>
</tr>
<tr>
<td><em>e.sieberi</em>-<em>punctata</em>-<em>e.agglomerata</em></td>
<td>M, S, M</td>
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<tr>
<td><em>e.sieberi</em>-<em>e.gummifera</em>-<em>e.agglomerata</em></td>
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<td><em>e.sclerophylla</em>-<em>punctata</em>-<em>e.gummifera</em></td>
<td>M, S, C</td>
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<td><em>punctata</em>-<em>e.consideniana</em>-<em>e.sieberi</em>-<em>e.sclerophylla</em></td>
<td>S, M, M, M</td>
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<tr>
<td><em>punctata</em>-<em>e.agglomerata</em>-<em>e.gummifera</em></td>
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<td><em>punctata</em>-<em>e.gummifera</em>-<em>e.consideniana</em>-<em>e.gummifera</em></td>
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<tr>
<td><em>punctata</em>-<em>e.sclerophylla</em>-<em>e.consideniana</em>-<em>e.gummifera</em></td>
<td>S, M, M, C</td>
<td>no</td>
</tr>
<tr>
<td><em>gummifera</em>-<em>e.consideniana</em>-<em>e.sieberi</em>-<em>e.sclerophylla</em>-<em>punctata</em>-<em>e.ligustrina</em></td>
<td>C, M, M, M, S</td>
<td>no</td>
</tr>
<tr>
<td><em>gummifera</em>-<em>e.agglomerata</em>-<em>e.sieberi</em>-<em>e.piperita</em></td>
<td>C, M, M, M</td>
<td>no</td>
</tr>
<tr>
<td><em>e.sclerophylla</em>-<em>punctata</em>-<em>e.agglomerata</em>-<em>e.sieberi</em>-<em>e.piperita</em></td>
<td>M, C, M, M</td>
<td>no</td>
</tr>
</tbody>
</table>

Subgenus Code: S = Symphyomyrtus  M= Monocalyptus  C= Corymbia

Observed Combinations Conforming to Pryor's Rule:

Yes: 9 No: 17  i.e. Majority of combinations (65.4%) do not conform to Pryor's Rule.

N.B. *E. punctata* was the only species from subgenus Symphyomyrtus observed in this complex, apart from the very fragmentary occurrence of *E. ligustrina*. 
Plate 3.7 *Eucalyptus punctata* "sandstone complex"

a: *Eucalyptus sieberi* - *E. sclerophylla* in band of broken rock on Ettrema Plateau

b. *Eucalyptus punctata* - *E. agglomerata* on Yalwal Plateau
There is NO p. 137 in original document
3.6.4 Open Forest

d. *Eucalyptus globoidea* (White Stringybark)

Map Symbol: gl, glpc

Occurrence

White stringybarks cover an extensive area in north-west Ettrema (see Fig. 3.3) and extending eastwards on the plateau above the Shoalhaven River.

*Eucalyptus punctata* (Grey Gum) is the main co-occurring species. *E. sieberi* (Silvertop Ash) sometimes occurs.

Adjacent Vegetation

Stringybarks are replaced by *E. rossii* forest in the headwaters of creeks and by a quite diverse and unpredictable mixture of eucalypts along creeks, including *E. cinerea, E. dalrympleana, E. dives, E. radiata* and *E. viminalis*.

Structure

Open - Tall open forest.

Understorey

The understorey is open, with a ground layer of leaf litter and sparsely scattered forbs such as *Hibbertia* sp. and scattered shrubs, including *Acacia obtusifolia, A. jonesii, A. rubida, Hakea dactyloides, Persoonia mollis* and *Banksia spinulosa*.

Gradients

White stringybark, with its associate Grey Gum, form a clearly definable association, whose boundaries are set by the limits of the sandy ancient alluvium occurring in north-east Ettrema. Species occurring along creeks in this area were found to be quite diverse and relatively unpredictable in their occurrence.
Plate 3.8: *Eucalyptus globoidea* open forest
3.6.4e Open - Tall Open Forest

*Eucalyptus imitans* (Narrow leaved stringybark) - *Angophora floribunda* (Rough-barked Apple)

Map Symbol: Afob

Occurrence:

These trees consistently co-occur on flats along the Ettrema Creeks, sometimes extending onto lower slopes. Occasionally present are *Eucalyptus elata*, *E. cypellocarpa* and *Brachychiton populneum* (Kurrajong Tree).

Gradients of Change in Dominant Species Composition

The joint dominance of these two species on alluvial creek flats is very consistent. However, gradients become apparent in the distribution of these two species on the slopes above the creeks where they become separated. *Eucalyptus imitans* extends upslope considerably further than *Angophora floribunda*. The latter hugs the water's edge, and is often found on rocky blocks, with roots growing down rock joints into the water.

Structure

Open - tall open forest.

Understorey

The understorey is usually open and grassy with patches of Bracken Fern and scattered shrubs such as *Clerodendrum tomentosum*, *Acacia pubescens*, *Leucopogon juniperinus* and cycads (*Macrozamia communis*). Grasses, otherwise unusual throughout Ettrema and North Budawangs, are a prominent feature. Many flats which would formerly have supported this vegetation along Ettrema and nearby creeks have in the past been cleared and are now open and grassy with regeneration being limited to clumps of wattle (*Acacia pubescens*) and occasional trees.
Gradational Overlap with Adjacent Association

_Eucalyptus punctata_- Ironbark community commonly occurs upslope of Rough-Barked Apple- Narrow-Leaved Stringybark. Along the steep slopes of the Ettrema Gorge, _E. imitans_ frequently occurs at the lower end of distribution of the Ironbark community and may extend through a considerable distance of it.

The occurrence of _E.imitans_ at lower altitudes in Ironbark community may be interpreted either, (from the community perspective) as an ecotone or, (from the continuum perspective), as an overlapping of species gradients. In either case, it reflects an order in the distribution of this eucalypt.
Plate 3.9: Ettrema Creek Vegetation

a. *Eucalyptus imitans* - *Angophora floribunda* on Ettrema Creek

3.6.4f Eucalypt Associations of the Slopes of the Ettrema Creek System.

A great diversity of eucalypt species and complex changes were observed on the slopes of these creeks. Many of the eucalypt species combinations observed were not repeated sufficiently to consider categorising them as associations. The most frequently observed combinations are described in the following section.

_Eucalyptus punctata_ (Grey Gum) - Ironbarks (_E. fibrosa_, _E. beyeriana_, _E. paniculata_) Open Forest

Map Symbol : pclb

Occurrence:

Ironbarks co-occur with grey gum in the north-eastern Ettrema area, on the slopes of the Shoalhaven River and Ettrema, Bundundah, Danjera and Boolijah Creeks and their tributaries. _Eucalyptus imitans_ frequently co-occurs over part of the range of this association.

Dominant Species Composition

Three species of Ironbark have been identified. These include _Eucalyptus beyeriana_ , here at the southern limit of its distribution. This species, once common in the Sydney basin, has now a reduced occurrence as a result of urbanisation.

The broad-leaved _E. fibrosa_ frequently occurs in this type of forest. _E. paniculata_ was also identified from the Ettrema forests during this survey.

Understorey

The understorey is of low diversity. Species include cycads (_Macrozamia communis_), scattered clumps of _Lomandra filiformis_ and scattered shrubs such as _Helichrysum argophyllum_. 
Adjacent Vegetation

At the moistest extremes of their distribution, Ironbarks may overlap with *E. imitans*, Turpentines or *Angophora floribunda*. On rocky slopes, Ironbarks may extend into patches of Yellow Bloodwood. In other locations (e.g. Smallest Plateau), Ironbark - Grey Gum type co-occurs with *E. agglomerata*.

Gradients

Additional tree species were frequently observed, as outlined above. Although mappable as a community, there are many variations in dominant species composition.

*Eucalyptus piperita ssp urceolaris* (Urn-fruited Peppermint) -
*Syncarpia glomulifera* (Turpentine) Open-Tall Open Forest

Map Symbol : ut

Occurrence

These trees associate on upper gorge slopes on Wandrawandian strata below Danjera, Smallest and Yarramunmun Plateaus.

Gradients of Change in Dominant Species Composition

Turpentines were not observed west of these plateaux (see Table 4.1). This reflects the overall geographical distribution of this tree -"rarely more than 50-100 miles inland" (Hall *et al*. 1970). Trees which may co-occur include *Eucalyptus elata*, *E. saligna* and *E. agglomerata*. *E. muellerana* was observed above Boolijah Creek. Scattered Kurrajong trees and Cabbage Palms occur. Port Jackson Figs cling to exposed sandstone boulders. *E. piperita* and *Syncarpia glomulifera* form a loose association, as can be deduced from the variety of co-occurring species which were observed.
**Understorey**

The understorey is typified by scattered mesophyllous species such as *Synoum glandulosum*, *Indigofera australis*, *Pimelea ligustrina*, *Goodenia ovata* and *Commersonia fraseri*. Ground cover is generally herbaceous (*Hydrocotyle*, *Viola*, *Pterostylis* etc) with clumps of *Gahnia* sp. and patches of Bracken Fern. On Boolijah Creek, this unit had been burnt and sapling regrowth of *E. agglomerata*, *E. muellerana*, *E. piperita* ssp. *urceolaris* and *E. elata* was evident.

**Eucalyptus eximia** (Yellow Bloodwood) Closed Scrub - Low Open Forest

**Map Symbol : x**

**Occurrence**

This species has a limited distribution in north-east Ettrema, where it occurs on exposed, rocky slopes and ridgetops above the Shoalhaven River and Ettrema Creeks.

**Structure**

On some sites, Yellow Bloodwood is stunted and shrub-like, forming a closed scrub. On other sites, it develops to a small tree, forming a low open forest.

**Gradients of Change in Dominant Species Composition**

Yellow Bloodwood often occurs as the single dominant, with Ironbark overlapping narrowly at the margins of patches. Where a low open forest is formed, Ironbark (*E. fibrosa*) may be a co-dominant species (e.g. ridge above Danjera Dam). *Eucalyptus ligustrina* (Privet-Leaved Stringybark) was observed as a co-dominant at the north-eastern end of the Timboolina Trail, above the Shoalhaven River.

This eucalypt often occurs in monospecific stands, but was also observed with co-dominants. One of these, *Eucalyptus ligustrina*, is a species of limited and quite probably diminishing distribution, and therefore this combination may reflect a change occurring
through time, with Yellow Bloodwood replacing Privet-Leaf Stringybark, or both being replaced by adjacent species, for example, Ironbark. If both are being replaced by Ironbark, then the observed co-dominance of Yellow Bloodwood with Ironbark could also be a reflection of a change occurring through time.

**Adjacent Vegetation**

Bands of *Acacia glaucescens* occur adjacent to Yellow Bloodwood along Ettrema Creek. Adjacent units are *Eucalyptus punctata* - Ironbark and *E. tereticornis*.

**Understorey**

Where *Eucalyptus eximia* occurs as a closed scrub, there is practically no soil and no understorey species. Where it forms a low open forest with Ironbark (ridge above Danjera Dam), the understorey consists of scattered Burrawang Palms with a ground layer of leaf litter and rocks interspersed with clumps of *Lepidosperma squamatum*, *Lomandra multiflora* and *Patersonia sericea*.

*Eucalyptus tereticornis* (Forest Red Gum)

**Map Symbol**: te

**Occurrence**

This tree grows on gentle slopes alongside creeks in north-east Ettrema.

**Structure**

It is commonly the single dominant in an open forest with trees of medium height.

**Understorey**

The understorey is generally open, consisting of leaf litter with scattered clumps of grass and few shrubs.
Ecotones

Its distribution may overlap with that of *Angophora floribunda* - *Eucalyptus imitans*, the forest most likely to be found adjacent.

**Community versus Continuum**

In the Ettrema gorge environment, Forest Red Gum forms a clearly distinguishable monospecific community, which conforms to the association concept as defined by Beadle and Costin (1952). Overlap with adjacent communities is interpretable as ecotonal.
Plate 3.10: *Eucalyptus punctata* - Ironbark open forest, Yalwal
Plate 3.11: Sapling Regrowth of *Eucalyptus agglomerata* on Boolijah Creek
3.6.4 Open Forest

g. Eucalypts at the Western Margins

*Eucalyptus pauciflora* (Snow Gum) - *E. dives* (Broad-Leaved Peppermint) - *E. rubida* (Candlebark) - *E. mannifera* (Snappy Gum)

(2) *E. radiata* (Narrow-Leaved Peppermint) - *E. dives* - Small-fruited Stringybarks

Map Symbols:

(i) pdivrum

(ii) rdivstr

Occurrence

This series of species are found on the western edge of Morton National Park, beyond the sandstone plateaus and mesas (see Fig. 3.10, Corang map). *E. viminalis* (Manna Gum) and *E. cypellocarpa* (Yellow Gum) occur in gullies.

Structure

Open - low open forest.

Discussion

These western vegetation types have not been looked at in detail. They belong to the suite of species more typical of the drier, more inland tableland areas of southern NSW, and are probably related to the associations and alliances identified by Costin (1954) as occurring in the Monaro region.
3.6.5 Tall Open Forest

Introduction

In the following section, three associations which generally occur as tall open forest are described. The structure of some other associations varies from tall open forest to open forest. These associations (Angophora floribunda-Eucalyptus imitans, E. piperita-Syncarpia glomulifera and Eucalyptus piperita-E. sieberi), are described in 3.6.4.

a. Eucalyptus fastigata (Brown Barrel) - E. fraxinoides (White Ash) - E. triflora (Budawangs Ash)

Map Symbol : bbfr,tri

Occurrence

These trees were observed growing adjacent to one another on the east to south-facing Wandrawandian slopes of the following mountains: Endrick, Owen, Bibbenluke (Plate 3.13), Tarn, Hoddle and Haughton. Brown Barrel and White Ash tend to be distributed in adjacent groves rather than as co-occurring species. E. triflora is typically seen leaning precariously out from the sandstone cliffs, where it is rooted in crevices. It was observed on lower Wandrawandian strata on east-facing slopes of Mt. Tarn and Mt. Owen and has been reported from a similar location near Mt. Tianjara.

Structure

Open forest, with a discontinuous small tree-shrub layer.

Understorey

Scattered rainforest trees such as Plumwood, Water Gum, Tree Ferns and Coachwood form a discontinuous lower stratum. Zieria caducibracteata, a fire-sensitive, highly aromatic, rare shrub, occurs in association with E. fraxinoides and E. triflora and has not been observed anywhere else. Large areas of the ground layer are densely covered in ferns.
Adjacent Vegetation

Rainforest canopies occur in gullies within this forest. It is replaced by Silvertop Ash - Urn - Fruited Peppermint forest on north and west-facing slopes

Gradients of Change in Dominant Species Composition

As noted above, *Eucalyptus fastigata* and *E. fraxinoides* tend to occur in adjacent stands rather than mingled together. They are nevertheless mapped as a community at the 1:25,000 scale. *E. triflora*'s rare co-occurrence with the former two species is possibly a relictual distribution pattern, reflecting a former habitat regime (further discussed in Section 2 of this thesis).

b. *Eucalyptus fastigata- E. radiata- E. cypellocarpa- E. viminalis* Forest

Map Symbol: bbrcyvim

Occurrence

This forest occupies relatively exposed, flat parts of the Sassafras and Endrick basalts. Much of it has previously been cleared.

Structure

These species form an open to tall open forest.

Gradients of Change in Dominant Species Composition

Although the dominant species vary from place to place, this group of species do form a community. The boundaries of this community in this area appear to be set by the occurrence of basalt.

There are gradients of change at the margins of the basalt emplacements, where *E. radiata* frequently replaces *E. fastigata* as the dominant species. *E. sieberi* may form an ecotone at the junction between the basalt with surrounding sandstone. Species changes overlap, an observed sequence at the edge of the Sassafras basalt being
Each of the abovementioned species has been observed to be the most abundant at one or more sites, for example, *E. fastigata* dominates most of the southern part of the Endrick flow, with *E. cypellocarpa* being a sub-dominant. *Eucalyptus viminalis* dominates areas of this forest on the northern side of Endrick Mountain. *Eucalyptus radiata* is dominant towards the margins of the Sassafras basalt and occurs around the margins of the Tolwong basalt. *E. cypellocarpa* dominates some areas of this forest at Sassafras.

**Understorey**

This is usually open and grassy. Shrubs may be present.

c. Riverbank Vegetation, Northern Budawang Range

**Map Symbols**: el,bo,sal,u,cas,Af

**Occurrence and Dominant Species Composition**

A variety of trees, including *Eucalyptus elata* (River Peppermint), *E. boytryoides* (Bangalay), *E. saligna* (Sydney Blue Gum), *E. piperita* ssp. *urceolaris* (Urn-Fruited Peppermint), *Casuarina cunninghamiana* (River Oak) and *Angophora floribunda* (Rough-Barked Apple) grow along the banks of the Clyde River and its tributaries, including Yadboro and Jindelara Creeks.

**Understorey**

Small trees and tall shrubs such as Water Gum (*Tristaniopsis laurina*), Cabbage Palms, Black Wattle, Native Peach (*Trema aspera*), *Leptospermum polygalifolium* and *Lomatia myricoides* occur as a discontinuous lower layer. Rainforest replaces eucalypts in the heads of gullies and on upper slopes of the Clyde River gorge.
Here, *E. triflora* is in its typical habitat: leaning out from cliffs.
Plate 3.13: *Eucalyptus fastigata* - *E. fraxinoides* on south-facing slope of Mt. Bibbenluke

Looking west towards Mt. Corang and beyond to the folded rocks of Budawang NP.

Emerald green patches of rainforest are visible below the plateau-line to Mt. Corang.
Plate 3.14: *Eucalyptus fastigata* - *E. cypellocarpa* at Sassafras
3.6.5 Tall Open Forest continued

d. Comparison with Vegetation of Other Areas

Tall open forests in NSW were encompassed in five alliances by Specht et al. (1974). The Ettrema-Nth.Budawangs *E. fastigata* associations can clearly be included in the *Eucalyptus fastigata-E. viminalis* alliance. This appears to be equivalent to the *E. fastigata-E. obliqua* alliance of Beadle (1981). An alliance can be clearly defined around *E. fastigata* and *E. obliqua*, because, in the case of these two species, the factor limiting their distribution, viz. good soils (Hall, Johnston & Chippendale 1970) can be clearly defined. With the majority of eucalypts, not only are the limiting factors more obscure, but the environmental correlates of their spatial patterning are not as obvious as that of good soils derived largely from volcanic rocks.

The riverine tall open forest in which *Eucalyptus saligna* and *E. botryoides* are found can be grouped under the *E. saligna-E. resinifera-E. pilularis* Alliance of Specht et al., but fits more clearly into Beadle's *E. botryoides* alliance. From the Illawarra southwards to Bateman's Bay, *E. saligna* and *E. botryoides* overlap distributionally and frequently hybridise (Beadle 1981, Fuller 1982).

A. Comparable Occurrences of *Eucalyptus fastigata* Forest

(i) Sydney Basin

Tall open forest in which *Eucalyptus fastigata* is a prominent species is recorded from the Sydney Basin (Benson 1986, 1992, Benson & Keith 1990, Keith & Benson 1988), the Budawangs (Gilmour & Plumwood 1982), South Coast (Austin & Sheaffe 1976) and the Monaro Tablelands (Costin 1954).

In Benson and Keith's Sydney Basin vegetation maps, tall open forest is encompassed in the following map units:

"Moist basalt cap forest", "Montane Gully Forest", "Montane Moist Forest" :
Tall open forests occurring both on basalt and in some sheltered gullies in the Blue Mountains has a similar list of dominant eucalypts to that found on the basalt emplacements and on sheltered Wandrawandian slopes in Ettrema/North Budawangs. *E. oreades*, a smoothbark related to *E. fraxinoides* and *E. triflora*, may occur with or near *E. fastigata*. Similarities can be seen in its distribution to its two N.Budawangs relatives.

*E. oreades* is associated with the cliff-lines in the Blue Mountains, a habitat preference which is indicative of fire sensitivity. The distribution of *E. oreades* was mapped in detail by Glasby (Glasby et al. 1988). They found that it occurs on steep, sheltered slopes, around the heads of valleys and around cliffs. It was found that the age structure of populations could be related to fire history.

(ii) **Budawangs**

Gilmour & Plumwood found *E. fastigata / E. cypellocarpa* in sheltered locations on both the eastern and western slopes. *E. fraxinoides* was found, often in pure stands, at higher altitudes and along the crest of the range in sheltered aspects and in the heads of gullies along the west face of the range. These appear to be continuations of the *E. fastigata* associations recorded in the N. Budawangs and on the Sassafras basalt. However, Gilmour & Plumwood did not find *E. triflora* in this area.

A similar altitudinal separation of *E. fraxinoides* and *E. fastigata* was observed in the Northern Budawangs, for example, between Mt.Owen and Yadboro Creek.

On sheltered eastern lower slopes and gullies, they found *E. fastigata* and *E. muellerana* in association, with other commonly occurring eucalypts being *E. cypellocarpa, E. pellita* and *E. smithii*. No similar association was observed in Ettrema-Nth.Budawangs, where both *E. muellerana* and *E. pellita* are very uncommon.

(iii) **South Coast**

Five communities containing *E. fastigata* were identified by Austin & Sheaffe (1978). There is consensus with one association identified in Ettrema/Nth.Budawangs, viz. *E. fastigata- E. fraxinoides* association. Other combinations listed as communities by Austin
& Sheaffe are recorded as gradational changes within either the *E. fastigata*-*E. radiata*-*E. cypellocarpa*-*E. viminalis* or the *E. fastigata*-*E. fraxinoides* association in the Ettrema and Northern Budawangs areas.

**(iv) Monaro Tablelands**

Four of twenty five associations listed as part of the *E. fastigata*-*E. viminalis* Alliance (Costin 1954) encompass the *E. fastigata* associations of the Ettrema and Northern Budawangs. These are the *E. fastigata*-*E. viminalis*, *E. fastigata*, *E. fraxinoides* and *E. radiata*-*E. sieberi* associations. Although *E. radiata* was not widespread enough in Ettrema/Northern/Budawangs to have been classified as a separate association, its occurrence at the margins of basalt, sometimes with *E. sieberi*, can be related to this Monaro association. Costin described the position of the *E. radiata*-*E. sieberi* association in this alliance as part of a temperature cline, whereas in the Morton wildernesses, *E. radiata* occurs near the margins of the basalt flows. The preference of *E. radiata* for more fertile soils, such as those found at the edges of rainforest or on river flats, is recorded in Hall et al. 1970.

**B. Comparable Occurrences of Riverine Complex**

This occurs along the Clyde River and its tributaries below the Northern Budawang Ranges, with a mixture of species including *Eucalyptus saligna* and *E. botryoides*. There is consensus with the South Coast riverine forest, *E. saligna* community complex classified by Austin & Sheaffe (1976). *E. botryoides* forest occurs at Jervis Bay (Ingwersen 1976) and *E. saligna* and *E. botryoides* co-occur and hybridise in the Illawarra (Fuller 1982). Gilmour & Plumwood recorded the occurrence of *E. elata* along streams in the Budawangs and the occurrence of *E. saligna* on Yadboro Creek in the northern section of the Budawang National Park, but noted that the vegetation here was "substantially different from the rest of the park".
Conclusions

The *Eucalyptus fastigata* associations found in Ettrema/Northern Budawangs can be readily related to *E. fastigata* associations defined in other areas of NSW. This is seen to be a result of the strong relationship between this species and better quality soils and its relatively limited distribution (Hall *et al.* 1970). Most other eucalypts, including *E. fastigata* associates, form a wider variety of combinations with other eucalypts over a wider distributional range.

The *E. saligna*-*E. botryoides* riverbank vegetation can be identified with the *E. botryoides* alliance described by Beadle, and with the South Coast riverine forest community complexes listed by Austin & Sheaffe (1976). The tendency for riverine forest to be defined by location rather than by dominant species can be attributed to the diversity and variability of species in this habitat.
3.6.6 Discrepant Eucalypt Patterns

On Berry Knolls and slopes of the Ettrema creek system in particular, species and species sequences were often observed which did not fit into the described communities. Some species were observed in these locations which were not observed elsewhere. Separations in the distributions of eucalypts elsewhere associated were observed. Species such as *Eucalyptus piperita* ssp. *urceolaris*, *E. sieberi*, *Angophora floribunda*, *Eucalyptus imitans* are found in gradational sequence.

(i) Berry Knolls

The species composition was observed to vary from knoll to knoll. East to west gradients were evident, as well as aspect changes and altitudinal clines. There were some species which were unexpected, because of their absence in adjacent areas.

The knolls characteristically display rapid changes in eucalypt composition, consistent with the rapidly changing topography (aspect, altitude and slope all change more rapidly here than across the plateaux.) *Eucalyptus sieberi* and *E. piperita* ssp. *urceolaris* are usually found on these knolls, but separately distributed, with *E. sieberi* found on west-facing aspects and *E. piperita* on east-facing. They frequently co-occur with a other species.

Species which did not otherwise occur across the plateaux were observed on Berry knolls in combination or sequence with species typical of the sandstone complex association. For example, *E. smithii* was found on the lower south-west facing slope of Rolfe's Hill (near Sassafras) and *E. cypellocarpa* co-occurred with *E. consideniana* and *E. radiata* on the east-facing slope of this knoll. Otherwise, this species was only observed on the western edge of the plateau expanse. It is speculated that *E. smithii* may have been distributed more extensively across the plateau in former environmental regime(s).

*E. ligustrina* was found on the west-facing slope of Ettrema Hill with sandstone complex (*E. consideniana*, *E. gummifera* and *E. punctata*). The only other located
occurrence of this uncommon species was at the eastern end of the Timboolina Trail. *E. saligna* was found on the east-facing slopes with *E. piperita*, *Angophora floribunda*, *E. fibrosa* and *E. globoidea*. The other occurrence of Sydney Blue Gum in the area is on sheltered slopes of the Ettrema creek system.

(ii) Slopes of the Ettrema Creek System

The gorge slope vegetation is characteristically rapidly changing and highly diverse (see for example, Fig. 3.14, Bundundah Creek and Fig. 3.15, Boolijah Creek). A wide variety of species were observed in the gorge system, with many species appearing to have a limited distribution. For example, *E. muellerana* and *E. elata*, which were located on Boolijah Creek, were not found elsewhere. The ironbarks *E. fibrosa*, *E. paniculata* and *E. crebra* are largely limited in their distribution to the gorge slopes, as are *E. saligna* and *Syncarpia glomulifera*.

In the Ettrema Gorge, associations were deciphered, but in other areas, where the geology, as well as the topography, changes rapidly (e.g. upper Boolijah and Danjera Creeks), the on-ground species co-occurrences may not always reflect those occurring away from the transects.
3.7 Conclusions

3.7.1 Mapping of Plant Communities

In the process of mapping heath, rainforest and eucalypt communities (Figs 3.4-3.12), it was found that the rate of spatial variation from one community to another differed in different habitats. For example, the vegetation varies over short distances of the sandstone plateaux from heath to sedgeland to open forest or woodland, as illustrated in Fig. 3.14. In other plateau areas, and on the slopes of the mesas of the Northern Budawangs, a single association may predominate on a particular aspect. This has resulted in map units of varying scale, analogous with the definition of mapping units in the vegetation of the Sydney Basin (Benson 1986, 1992, Benson & Keith 1990, Keith & Benson 1988).

3.7.2 Classification of Plant Communities

Heath and rainforest were classified by location and found to have differing species composition in the different types of habitat in Ettrema and Northern Budawangs (3.6.1 & 3.6.3). Eucalypts were classified into associations in which 2 or 3 species consistently co-occur in particular habitats of the wildernesses, bearing out the observations of Pryor 1959a (3.6.4 & 3.6.5).

3.7.3 Eucalypt Associations

The following conclusions are drawn from this mapping and classification of the vegetation of the Ettrema and Northern Budawangs wildernesses concerning the distribution of eucalypt species:

(i) Eucalypts often co-occur in groups of 2 or 3 species

In many habitats, eucalypts were observed to be distributed either singly, or in pairs or trios. The species involved are often co-distributed over a sufficiently large proportion of the landscape to be recognised, and classified into associations. This bears out the
observations of Pryor (1959a) and defends the classification of eucalypts into communities, using the terminology established by Beadle & Costin (1952).

(ii) Gradients of species change are always apparent

Within any particular association, differing proportions of the member species coincident with site differences, are always apparent. For example, changes from one species to another along topographic gradients were readily observed in *Eucalyptus sclerophylla- E. mannifera, E. sieberi- E. piperita* and *Angophora floribunda- Eucalyptus imitans* associations, as outlined in 3.6.4 and 3.6.5. This actualises the continuum (Gleason 1926, Whittaker 1967, Austin & Smith 1989).

(iii) Some associations are more complex than others.

Patterns of eucalypt distributions departed from the assemblage of 2 or 3 species into associations across the sandstone plateaux of the Ettrema wilderness. Here, *Eucalyptus punctata - E. consideniana - E. gummifera* were the most abundant amongst a group of species, whose distributions and patterns of co-occurrence varied across the plateaux. This is defined as a "complex association", parallelling the 'sandstone complex" of the Sydney Basin eucalypt forests (Pidgeon 1939, Specht *et al.* 1974, Benson 1986, 1992, Benson & Keith 1990, Keith & Benson 1988).
Table 3.3 Structural Formations*

<table>
<thead>
<tr>
<th>Life form and height of the tallest stratum</th>
<th>Foliage projective cover of tallest stratum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100-70%</td>
</tr>
<tr>
<td>trees &gt;30m.</td>
<td>tall closed forest</td>
</tr>
<tr>
<td>trees 10-30m.</td>
<td>closed forest</td>
</tr>
<tr>
<td>trees &lt;10m.</td>
<td>low closed forest</td>
</tr>
<tr>
<td>shrubs &gt;2m.</td>
<td>closed scrub</td>
</tr>
<tr>
<td>shrubs 25cms-2m</td>
<td>closed heath</td>
</tr>
<tr>
<td>shrubs &lt; 25cm</td>
<td>fellfield or dwarf heathland</td>
</tr>
<tr>
<td>hummock grasses &lt;2m</td>
<td>hummock grassland</td>
</tr>
<tr>
<td>graminoids, herbs, ferns etc</td>
<td>closed grassland</td>
</tr>
</tbody>
</table>

*Specht, R.L. (1981b)

Additional Terms used in text:

**Sedgeland**: Areas dominated by sedges and node-sedges (Families Cyperaceae and Restionaceae).

**Sedge-heathland**: Areas with sclerophyllous shrubs and sedges and node-sedges co-dominant.
## Table 3.4 Trees of the Etten and Northern Budawangs

<table>
<thead>
<tr>
<th>Map code</th>
<th>Botanical name</th>
<th>Common name</th>
<th>Ett Where</th>
<th>Bud Where</th>
<th>Abundance</th>
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</thead>
<tbody>
<tr>
<td>Ab</td>
<td><em>Angophora bakeri</em></td>
<td>narrow-leaved apple</td>
<td>+ plateau</td>
<td>-</td>
<td>very rare</td>
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<td>Af</td>
<td><em>Afloribunda</em></td>
<td>rough-barked apple</td>
<td>+ creeks, sheltered slopes</td>
<td>+ riparian</td>
<td>common</td>
</tr>
<tr>
<td>ag</td>
<td><em>Eucalyptus agglomerata</em></td>
<td>blue-leaved stringybark</td>
<td>+ upper slopes, gully-heads</td>
<td>-</td>
<td>common</td>
</tr>
<tr>
<td>be</td>
<td><em>E.beyeriana</em></td>
<td>ironbark</td>
<td>+ exp.NE slopes</td>
<td>-</td>
<td>common</td>
</tr>
<tr>
<td>bo</td>
<td><em>E.botryoides</em></td>
<td>bangalay</td>
<td>+ riparian</td>
<td>+ riparian</td>
<td>restricted</td>
</tr>
<tr>
<td>cin</td>
<td><em>E.cinerea</em></td>
<td>argyle apple</td>
<td>+ Tolwong</td>
<td>-</td>
<td>restricted</td>
</tr>
<tr>
<td>y</td>
<td><em>E.consideniana</em></td>
<td>yertchuk</td>
<td>+ plateau</td>
<td>+ exposed mesa slopes</td>
<td>common</td>
</tr>
<tr>
<td>cy</td>
<td><em>E.cypellocarpa</em></td>
<td>monkey gum</td>
<td>+ alluvial</td>
<td>+ riparian</td>
<td>less frequent</td>
</tr>
<tr>
<td>dal</td>
<td><em>E.dalrympleana</em></td>
<td>mountain gum</td>
<td>-</td>
<td>+ west slopes</td>
<td>marginal</td>
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<tr>
<td>de</td>
<td><em>E.dendromorpha</em></td>
<td>Budawang mallee</td>
<td>+ plateau</td>
<td>+ heaths</td>
<td>very common</td>
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<td>div</td>
<td><em>E.dives</em></td>
<td>broad-leaved peppermint</td>
<td>+ western margin</td>
<td>-</td>
<td>marginal</td>
</tr>
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<td>el</td>
<td><em>E.elata</em></td>
<td>river peppermint</td>
<td>+ some slopes, creeks</td>
<td>+ riparian</td>
<td>patchy</td>
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<td>eu</td>
<td><em>E.eugeniodes</em></td>
<td>thin-leaved stringybark</td>
<td>+ NW plateau</td>
<td>+ riparian</td>
<td>less common</td>
</tr>
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<td>x</td>
<td><em>E.eximia</em></td>
<td>yellow bloodwood</td>
<td>+ dry NE slopes</td>
<td>-</td>
<td>restricted</td>
</tr>
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<td>bb</td>
<td><em>E.fastigata</em></td>
<td>brown barrel</td>
<td>+ basalt</td>
<td>+ basalt</td>
<td>common</td>
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<td>f</td>
<td><em>E.fibrosa</em></td>
<td>broad-leaved ironbark</td>
<td>+ dry NE slopes</td>
<td>-</td>
<td>common</td>
</tr>
<tr>
<td>fr</td>
<td><em>E.fraxinoides</em></td>
<td>white ash</td>
<td>-</td>
<td>+ basalt sheltered Wandr.</td>
<td>common</td>
</tr>
<tr>
<td>Map code</td>
<td>Botanical name</td>
<td>Common name</td>
<td>Ett</td>
<td>Where</td>
<td>Bud</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------------</td>
<td>------------------------------------</td>
<td>-----</td>
<td>---------</td>
<td>------</td>
</tr>
<tr>
<td>gl</td>
<td><em>E. globoidea</em></td>
<td>white stringybark</td>
<td>+</td>
<td>nw of plateau</td>
<td>-</td>
</tr>
<tr>
<td>gr</td>
<td><em>E. gregsoniana</em></td>
<td>Wolgan Snow Gum</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>gm</td>
<td><em>E. gummifera</em></td>
<td>red bloodwood</td>
<td>+</td>
<td>dry plateau</td>
<td>+</td>
</tr>
<tr>
<td>ob</td>
<td><em>E. imitans</em> (= oblongifolia)</td>
<td>narrow-leaved stringybark</td>
<td>+</td>
<td>alluvial flats of creeks</td>
<td>-</td>
</tr>
<tr>
<td>lg</td>
<td><em>E. ligustrina</em></td>
<td>privet-leaved stringybark</td>
<td>+</td>
<td>dry plateau in ne</td>
<td>-</td>
</tr>
<tr>
<td>mac</td>
<td><em>E. macrorhyncha</em></td>
<td>red stringybark</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>mn</td>
<td><em>E. mannifera</em></td>
<td>snappy gum</td>
<td>+</td>
<td>sedgeland</td>
<td>+</td>
</tr>
<tr>
<td>mo</td>
<td><em>E. moorei</em></td>
<td>narrow-leaved sally</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>mt</td>
<td><em>E. multicaulis</em></td>
<td>whip-stick mallee-ash</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>ov</td>
<td><em>E. ovata</em></td>
<td>swamp gum</td>
<td>+</td>
<td>sedgeland</td>
<td>+</td>
</tr>
<tr>
<td>p</td>
<td><em>E. pauciflora</em></td>
<td>snow gum</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>u</td>
<td><em>E. piperita ssp. urceolaris</em></td>
<td>urn-frt'd pepp.</td>
<td>+</td>
<td>Berry silt. sheltered</td>
<td>+</td>
</tr>
<tr>
<td>r</td>
<td><em>E. radiata</em></td>
<td>narrow leaf pepp.</td>
<td>+</td>
<td>basalt</td>
<td>+</td>
</tr>
<tr>
<td>pc</td>
<td><em>E. punctata</em></td>
<td>grey gum</td>
<td>+</td>
<td>dry plateau</td>
<td>+</td>
</tr>
<tr>
<td>rss</td>
<td><em>E. rossii</em></td>
<td>scribbly-gum</td>
<td>+</td>
<td>western plateau</td>
<td>(+)</td>
</tr>
<tr>
<td>ru</td>
<td><em>E. rubida</em></td>
<td>candlebark</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>sal</td>
<td><em>E. saligna</em></td>
<td>Sydney blue gum</td>
<td>+</td>
<td>riverine</td>
<td>+</td>
</tr>
<tr>
<td>scl</td>
<td><em>E. sclerophylla</em></td>
<td>scribbly gum</td>
<td>+</td>
<td>plateaux</td>
<td>+</td>
</tr>
<tr>
<td>i</td>
<td><em>E. sieberi</em></td>
<td>silvertop ash</td>
<td>+</td>
<td>plateau margins, Berry knolls</td>
<td>+</td>
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</table>
### Table 3.4 cont.

<table>
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<tr>
<th>Map code</th>
<th>Botanical name</th>
<th>Common name</th>
<th>Ett</th>
<th>Where</th>
<th>Bud</th>
<th>Where</th>
<th>Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>sm</td>
<td><em>E.smithii</em></td>
<td>gully peppermint</td>
<td>+</td>
<td>Berry silt.</td>
<td>-</td>
<td>-</td>
<td>not common</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>sheltered</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>gullies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ss</td>
<td><em>E.sturgissiana</em></td>
<td>Sturgiss’ mallee</td>
<td>+</td>
<td>plateau</td>
<td>-</td>
<td>-</td>
<td>restricted</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>te</td>
<td><em>E.tereticornis</em></td>
<td>forest red gum</td>
<td>+</td>
<td>lower slopes</td>
<td>-</td>
<td>-</td>
<td>marginal</td>
</tr>
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<td></td>
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<td>tri</td>
<td><em>E.triflora</em></td>
<td>Budawang ash</td>
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<td>+</td>
<td>mesa-cliffs</td>
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<td></td>
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<td>restricted</td>
<td>restricted</td>
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<tr>
<td>vim</td>
<td><em>E.viminalis</em></td>
<td>manna gum</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>west, in</td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>gullys</td>
<td>restricted</td>
</tr>
<tr>
<td>t</td>
<td><em>Syncarpia glomerulifera</em></td>
<td>turpentine</td>
<td>+</td>
<td>sheltered</td>
<td>(+)</td>
<td>Tianjara</td>
<td>restricted</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>gorge slopes</td>
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<td></td>
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<td>Botanical Name</td>
<td>Common Name &amp; Map Code</td>
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</tr>
<tr>
<td><em>Eucalyptus sieberi</em>- <em>E.piperita ssp.urceolaris</em></td>
<td>silvertop ash(i)-urn-fruited peppermint(u)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E.piperita ssp.urceolaris</em>-Syncarpia glomerulifera</td>
<td>urn-fruited peppermint(u)-tarturpentine(t)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td><em>E.fastigata</em>- <em>E.radiata</em>- <em>E.cypellocarpa</em>- <em>E.viminalis</em></td>
<td>brown barrel (bb)-narrow leaved peppermint (r)-monkey gum (cy)-manna gum (vim)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E.fastigata</em>- <em>E.fraxinoides</em></td>
<td>brown-barrel (bb)-white ash (fr)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E.punctata</em>- <em>E.consideniana</em> - <em>E.gumnifera</em></td>
<td>grey gum (pc)-yertchuk (y)-redbloodwood (gm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><em>E.punctata</em>- <em>E.fibrosa</em> - <em>E.beyeriana</em></td>
<td>grey gum (pc)-ironbarks (lb) (f,be)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E.globoidea</em>- <em>E.punctata</em></td>
<td>white stringybark (gl)-grey gum (pc)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Angophora floribunda-<em>Eucalyptus imitans</em></td>
<td>rough barked apple (Af)-narrow leaved stringybark(ob)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Angophora floribunda-<em>Eucalyptusbotryoides</em></td>
<td>rough barked apple-bangalay (bo)-Sydney blue gum (sal)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E.saligna</em>- <em>E.piperita ssp.urceolaris</em>- <em>E.elata</em> - Casuarina cunninghamiana</td>
<td>Sydney blue gum-urn fruited peppermint-river peppermint (el)-river oak (Cc)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Eucalyptus tereticornis</em></td>
<td>forest red gum (te)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E.sclerophylla</em> (E. rossii) - <em>E.mannifera</em></td>
<td>scribbly gum (scl) - snappy gum (mn)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E.eximia</em></td>
<td>yellow bloodwood(x)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E.multicaulis</em></td>
<td>whipstick mallee ash (mt)</td>
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<tr>
<td><em>E.pauciflora</em>- <em>E.dives</em> - <em>E.rubida</em>- <em>E.viminalis</em></td>
<td>snow gum (p)-broad-leavedpeppermint (div)-candlebark (ru) -manna gum (vim)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>E.radiata</em>- <em>E.dives</em> - Small-fruited Stringybark (E.globoidea, E.eugeniodies or E.agglomerata)</td>
<td>narrow-leaved peppermint (r)-broad leaved peppermint (div)-stringybark (str)</td>
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<td></td>
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</table>
Table 3.6:
Concordance of Map Units and Classification Units
(Note: refer to Table 3.4 for map codes of individual species).

<table>
<thead>
<tr>
<th>Map Codes</th>
<th>Map Unit</th>
<th>Classification Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>h,hst-sg</td>
<td><em>Eucalyptus stricta</em> mallee-health</td>
<td><em>E. dendromorpha</em> mallee-health (hst)</td>
</tr>
<tr>
<td>h-sg-scr</td>
<td><em>E. stricta</em> mallee-health</td>
<td><em>E. mannifera</em> scribbly gum</td>
</tr>
<tr>
<td>h-scl,h-scr</td>
<td><em>E. stricta</em> mallee-health</td>
<td><em>E. sclerophylla</em> <em>E. mannifera</em> (sclm)</td>
</tr>
<tr>
<td>h-sg-scrm</td>
<td><em>E. stricta</em> mallee-health</td>
<td><em>E. sclerophylla</em> <em>E. mannifera</em> (sclm)</td>
</tr>
<tr>
<td>scl,ss</td>
<td><em>E. stricta</em> mallee-health</td>
<td><em>E. sclerophylla</em> <em>E. mannifera</em> (sclm)</td>
</tr>
<tr>
<td>hst-scrm-pcygm</td>
<td>overlap pcygm &amp; hst-sg-scrm</td>
<td>pcygm, hst, scrm</td>
</tr>
<tr>
<td>pcygm-h, ygm-h</td>
<td>overlap pcygm &amp; h</td>
<td>pcygm, h</td>
</tr>
<tr>
<td>pcygm gmlg</td>
<td><em>E. punctata</em> sandstone complex</td>
<td><em>E. punctata</em> <em>E. consideniana-</em> E. gummifera</td>
</tr>
<tr>
<td>Q</td>
<td>hst-sg-scrm&lt;-&gt;pcygm</td>
<td>hst-sg-scrm, pcygm</td>
</tr>
<tr>
<td>iustr&lt; sclh</td>
<td>iustr&lt; sclh</td>
<td>scrm, sg, hst, pclbstr</td>
</tr>
<tr>
<td>rB: scrm-sg-hst</td>
<td>residual Berry knolls (rB):</td>
<td>scrm, sg, hst, iu</td>
</tr>
<tr>
<td>rB : iur</td>
<td><em>Angophora floribunda-Eucalyptus imitans</em></td>
<td><em>E. tereticornis</em></td>
</tr>
<tr>
<td>rB : iu-h</td>
<td><em>Angophora floribunda-Eucalyptus imitans</em></td>
<td><em>E. tereticornis</em></td>
</tr>
<tr>
<td>Afob</td>
<td><em>E. fastigata-E. fraxinoides</em></td>
<td><em>E. fastigata-E. fraxinoides</em></td>
</tr>
<tr>
<td>te</td>
<td><em>E. fastigata-E. fraxinoides</em></td>
<td><em>E. fastigata-E. fraxinoides</em></td>
</tr>
<tr>
<td>bbfr</td>
<td><em>E. fastigata-E. fraxinoides</em></td>
<td><em>E. fastigata-E. fraxinoides</em></td>
</tr>
<tr>
<td>bbfr-RF</td>
<td><em>E. fastigata-E. fraxinoides</em></td>
<td><em>E. fastigata-E. fraxinoides</em></td>
</tr>
<tr>
<td>bbvim,bbrvim,bbcrey,bbr,rvim,r</td>
<td>*E. fastigata-E. radiata-<em>E. cypellocarpa-E. viminalis</em> (bbcreyvim)</td>
<td>bbcreyvim</td>
</tr>
<tr>
<td>RF</td>
<td>rainforest</td>
<td>rainforest</td>
</tr>
<tr>
<td>RFt,ut-RF</td>
<td>not established</td>
<td><em>E. piperita ssp. urceolaris-</em> Syncarpia glomerulifera (ut)</td>
</tr>
<tr>
<td>ustrrf+-Afsal</td>
<td>overlap pclb &amp; RF</td>
<td>pclb, RF</td>
</tr>
<tr>
<td>pclb-RF</td>
<td>overlap pclb &amp; RF</td>
<td>pclb, RF</td>
</tr>
<tr>
<td>pclb,pclbob</td>
<td>*E. punctata-Ironbarks-Stringybarks (pclbstr)</td>
<td>*E. punctata-Ironbarks (pclb)</td>
</tr>
<tr>
<td>iaglb,iagscr,iagistr</td>
<td>*E. punctata-Ironbarks-Stringybarks (pclbstr)</td>
<td>*E. punctata-Ironbarks (pclb)</td>
</tr>
<tr>
<td>glpc</td>
<td>glpc</td>
<td>glpc</td>
</tr>
<tr>
<td>clng, regen.</td>
<td>cleared land</td>
<td></td>
</tr>
</tbody>
</table>

Where separate classification units change rapidly across the landscape, they have been combined to form map units. This applies particularly to vegetation on the quasi-concentric sandstone plateau areas (i.e., heath, sedgeland, scribbly gum and *Eucalyptus punctata* "sandstone complex"). Map codes may reveal more detail than map units, indicating changes at particular locations visited and the occurrence of uncommon species. Additional symbols found on maps can be decoded using Table 3.4.
Figure 3.1: Key to Map Sheets

Caoura
34°45'N

Burrier
35°22'N

Shoalhaven

Touga
Shoalhaven

Yalwal

to Nowra

Nerriga

Sassafras

Turpentine Road

Endrick

Nerriga

N.Budawangs

Corang

Milton

Firing Range
(not mapped)

Area mapped (boundaries sketched)
Fig. 3.2 : Air Photo Reliability Diagram

(i) Ettrema Wilderness Area

<table>
<thead>
<tr>
<th>Run</th>
<th>Photos</th>
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</thead>
<tbody>
<tr>
<td>5</td>
<td>90 +</td>
</tr>
<tr>
<td>6</td>
<td>61 +</td>
</tr>
<tr>
<td>7</td>
<td>41 +</td>
</tr>
<tr>
<td>1T</td>
<td>67 -</td>
</tr>
<tr>
<td>2T</td>
<td>29 ++</td>
</tr>
</tbody>
</table>

Plus signs + indicate the number of reconnoitres conducted in each air photo effective area. In the Northern Budawangs, the most visited area was 1U,7: Castle, Monolith Valley, Byangee Walls. Next most visited, 4T,15 is Endrick Mt-Styles Ck area.

In Ettrema, the most visited areas were Yarramunmun Plateau and Boolijah Creek (2T,34) and lower Ettrema Gorge (6, 56-7).

Average number of field trips per air photo effective area : 1.7.
Figure 3.14: Profiles of Bundundah Creek

a. Headwaters

![Graph showing profiles of Bundundah Creek Headwaters]

- E. sieberi
- E. piperita
- E. punctata
- E. muellerana

in varying proportions on both creek slopes

b. Twelve Apostle Spur and Atkinson Spur

![Graph showing profiles of Twelve Apostle Spur and Atkinson Spur]

- E. smithii
- E. gummifera
- Angophora floribunda
- (Wandrawandian silstone)

- E. smithii
- E. gummifera
- Angophora floribunda

- E. agglomerata
- E. gummifera

- <Eucalyptus punctata-E. agglomerata-ironbarks>

- E. tereticornis
- Angophora floribunda

- SE slope cleared on creek
- NW slope
Figure 3.15: Transect of Upper Boolijah Creek
There are NO pp. 175-176 in original document
4. Vegetation and Environment: Interrelationships

4.1 Introduction

4.1.1 The Complexity of Interrelationships amongst Vegetation and Environment

The interrelationships between vegetation and the features of the environment are potentially extremely complex (Fig. 1.1). Since vegetation depends upon the physical environment, changes in vegetation communities can be expected to follow changes in environment. Where abrupt changes occur, the vegetation can be expected to change abruptly. Likewise, gradual changes in vegetation can be expected in accordance with gradual changes in landscape.

Changes imposed by one feature of the environment may dominate over changes caused by another feature. For example, gradual changes in relation to altitude or latitude may be masked by abrupt changes in relation to geological strata. Alternatively, abrupt changes in relation to small-scale environmental patterning may be encompassed within gradual changes in relation to a gradual environmental change, for example, deepening soil. Such changes may result in the same species and communities recurring across a landscape in relation to different combinations of environmental variables.

While changes in vegetation along a single transect may be consistent with topographic changes, such as aspect, it may not be possible to extrapolate the plant gradient or community results obtained for any great distance afield from that particular transect. The actual species and communities involved may vary from hill to hill or mountain to mountain.
4.1.2 Abrupt and Gradual, Superimposed and Distance Vegetation Changes in Ettrema and Northern Budawangs

**Abrupt changes** in stratigraphy in the Northern Budawangs and Ettrema areas are accompanied by abrupt changes in vegetation. For example, the alternating strata of soft and hard rocks, exposed on all the Budawangs mesas, underlie abrupt changes in vegetation from forest to heath. Across the Ettrema Plateaux, residual Berry knolls mark an abrupt change from the gently undulating plateau surfaces. Again, the change is accompanied by a sharply demarcated vegetation boundaries. At a smaller scale, the quasi-concentric patterning in the sandstone across the Ettrema Plateaux is accompanied by abrupt small-scale vegetation changes, such as those defined by Pickard & Jacobs (1983).

**Gradual changes**, such as latitudinal and altitudinal changes in species composition occur in the vegetation in this area. These changes may be secondary to the sharply demarcated changes along geological boundaries. At Sassafras, for example, which is high relative to that part of the Ettrema area to the east, the vegetation community boundaries are visibly related to the nutrient-rich soils derived from the basalt capping (see Table 4.3). Although the vegetation would undoubtedly also be affected by the cooler temperatures here as a result of higher altitude, any such changes are masked by the dramatic effect of the basalt on the type of vegetation.

**Superimposed Change**

Gradually deepening soils from west to east across the Ettrema Plateaux are accompanied by noticeable overall changes in the vegetation, both in structure and composition. This change is superimposed on the smaller-scale changes occurring in response to contour banding in the sandstone.
Change with Distance

Vegetation changes with aspect around the slopes of mesas in the Northern Budawangs, and around the slopes of knolls of Berry sandstone on the Ettrema Plateaux. Whilst these two separate sets of changes in vegetation with aspect are similar in that they are a change from vegetation more tolerant of dryness to vegetation requiring higher moisture levels, most of the plant species involved in the two places are different, and even at the formation level, the changes are not the same, with the change on mesa-slopes being from dry eucalypt to moist eucalypt forest and rainforest, while the change around the Berry Knolls is from one community of dry eucalypt forest to another.

4.1.3 Control by the Distribution of Plant Growth Factors: Unravelling the Complexity

As depicted in Fig.1.1, the features of the environment act on plants via their requirements for growth. It is predictable that vegetation distribution patterns will be found to relate more precisely to the most important plant growth factors than to the features of the environment, which act on the plant only through its growth needs. The main "basic plant growth factors" (categorised as "resource gradients" by Austin & Cunningham 1981) are nutrients, moisture balance, light and temperature. The complexities of relationships between vegetation community distributions and the environment (such as those outlined above) may be more readily interpreted if the distribution of basic plant growth factors can be determined.

The impact, for example, of the striking geomorphological features of the Ettrema and Northern Budawangs wildernesses on plant distribution patterns, is likely to depend upon the way in which the balance of basic plant growth factors varies with geomorphology. Thus, if two different strata produce soils of similar texture, nutrient balance and water-holding capacity, and if other factors remain
within a similar range of variability, the same vegetation might predictably occur on both.

Further to this, features of the environment can be ordered according to the directness or indirectness of their effect on plants, depending on how closely they affect plant growth factors. For example, soil type is closer in its effect on soil nutrients and soil moisture than is rock type and as a consequence, one could expect intricacies in vegetational variation to relate more closely to soil type than rock type.

**Environmental features ordered in terms of their effects on plant nutrients:**

Rock type governs physiography, which governs—Soil catena, which influences—Soil nutrients

Rock type governs—Soils, which govern—Soil nutrients

**Ordering of environmental features in terms of moisture balance:**

Rock type governs—Soils, which affect—Soil texture and depth, which affect—Soil moisture

Physiography governs—Soil catena, which affects—Soil depth, which affects—Soil moisture

Physiography governs—Aspect and Slope

Aspect and Slope both affect—Sunlight, which affects—1. Rate of Evaporation, which affects—a. Atmospheric moisture b. Soil moisture

2. Available light

3. Temperature

It can be seen that physiography is a complex feature of the environment, affecting all four listed basic plant growth factors, via its major components, aspect and slope, which are also complex in their effects on plant growth factors. Slope can be further subdivided into position on slope and degree of slope, both of
which in turn affect soils, moisture, light and temperature. Consequently, it may be difficult to relate plant communities to physiography, since the effects of physiography on plant growth factors will vary complexly. Although the relationship between physiography and plant communities may be constant over a small area, over a larger area, crossing landscape boundaries, the relationship will predictably vary in a way which may be difficult to describe, either qualitatively or quantitatively, since the actual relational constancy is amongst plants and plant growth factors, not amongst plants and aspect or any other physiographic feature.

4.1.4 Distribution of Australian Vegetation in Relation to Plant Growth Factors

The relationship between heathland and poor soils is well established (Specht 1979). Heathland sites may be seasonally waterlogged, seasonally droughty or extremely cold. The uniting factors are their presence on sites which suffer climatic extremes on soils low in nutrients (Specht 1979). Closed forest is generally associated with both better soils and wet conditions (Webb & Tracey 1981, Fig. 4.3). In their descriptions of the occurrence of rainforest (e.g., p.70-71), the complexity of interacting factors is evident. Tall open forests are associated with with high rainfall (Ashton 1981c) and open forest with moderate conditions (Gill 1981a). Woodland tends to occur in drier areas (Hall et al. 1970). For example, the most widespread form of woodland is characterised by Eucalyptus populnea, which is (Ibid) "a typical species of the hot, low rainfall pastoral and wheat country of New South Wales."

Early emphasis was placed on the distribution of Australian vegetation in relation to phosphates and nitrates (Beadle 1954, 1962 &1967), with little mention of other plant nutrients. Beadle proposed that rainforest, wet sclerophyll forests and sclerophyllous woodlands, scrubs and heaths of eastern Australia could be delimited by the phosphate content of the soil, with the last group occupying soils of of extremely low phosphate content. This hypothesis has been widely accepted, although it had not attracted much research in eucalypt ecology by 1981 (Florence 1981).
Burrough et al. (1977) studied variations in vegetation and soil across the Hawkesbury sandstone from Barren Grounds to Fitzroy Falls. A parallel was found between changes in vegetation and decreasing rainfall moving westwards, in an area thought to be of uniform lithology. The major conclusion reached by Burrough et al. was that on well-drained middle to upper slopes on Hawkesbury sandstone, the regional gradient in rainfall is the main factor controlling soil morphology, vegetation formation and species composition.

Many complexities in vegetation and physical environment appear to have been overlooked. For example,

(i) variations in species composition as a result of differences in soil texture or fertility or variations in soil drainage impedance were thought to be minor. A selection of soils were analyzed for total cations sodium, magnesium, calcium, potassium and phosphorus. Although their results suggested that there were recognisable differences in soil nutrients and texture over the plateau, which matched by differences in species composition of the vegetation, no major conclusion was reached as to the relationship between vegetation and soils. They appear to have dismissed potentially significant results relating to soil nutrient levels.

(ii) The high moisture content peats found across the Barren Grounds were not in this paper in any way related to a greater occurrence of flat-lying massive, impervious sandstone and the drainage impedance that this could cause, there than westwards. They claimed that there was no evidence to suggest that the sandstones in the east were less permeable than those in the west. In seeming contradiction, this very explanation was given for the patchy areas of heathland occurring on the Budderoo Plateau further west: "there are many areas on the Budderoo Plateau where the soil drainage is impeded by massive sandstone. These sites support a closed heath and shallow peaty soil resembling the sites further east on Barren Grounds". If this explanation was sufficient to explain the presence of heathland on Budderoo Plateau, why was it not also sufficient to explain the extensive presence of heathland across the Barren Grounds?
(iii) Further west, the potential influence of other rock strata on soil fertility was ignored. Most of Burrough et al.'s western sites (Fitzroy Falls and Hindmarsh Ridge) were very close to the extensive outcrop of basalt in the Robertson area. The soils here could easily have a basalt influence.

(iv) From my own casual observations, both shale and basalt outcroppings are more widespread on Budderoo than has been mapped by Burrough et al. (1977).

(v) As indicated in their paper, rainfall does display a decreasing trend westwards, however, as shown in their rainfall tabulations, there is no major variation in rainfall from Hindmarsh Ridge to Fitzroy Falls, whilst across this area they map a change in vegetation from open to closed E. piperita ssp.urceolaris forest.

(vi) The majority of their sites which displayed higher nutrient levels were forested, and included the only closed forest site for which nutrient data was presented. This suggests that a higher sampling density would have revealed a more definite relationship between vegetation type and height and soil nutrient levels. Given that a range of nutrient levels was obtained, and given the dependence of plants on soil nutrients as a basic plant growth factor, it seems appropriate to hypothesise that there would be a strong relationship between vegetation and soil nutrients here, and that these would, in turn, in similar topographies, reflect lithological variations.

Although the trend of decreasing rainfall westwards would undoubtedly affect the vegetation patterns, it appears that the final conclusion reached by Burrough et al. 1977 may be a gross oversimplification.

The complexity of interactions underlying the vegetation patterns in the Barren Grounds are well illustrated by the findings of biogeography students at Wollongong University (A.J. O'Neill pers. comm. 1989). In a study of the vegetation of a small area of Barren Grounds, marked changes were found in vegetation over time. Air photos taken over a thirty five year period showed a marked decline in open and low open forest and an increase in closed heath. It was hypothesized that the fire was followed by the rapid expansion of heath, due to raised water tables. Its presence would be perpetuated by
the conditions which it fostered, i.e., acid, waterlogged soils resulting from reduced evapo-transpiration.

In the CSIRO South Coast Survey (Austin & Sheaffe 1976), community distributions were plotted against aspect and altitude for the major geological strata in the area. Major vegetation changes with the major lithological differences across the survey area were noted, but no detailed relationship with soils was established. Although a relationship between communities and soils was indicated, it was considered that statistical analysis would have been "extremely cumbersome and probably unjustified".

These examples illustrate the complexity of the interactions between vegetation community distributions and their environment, the need to consider primary causes (plant growth factors) and the danger of oversimplification.

4.1.5 Aims of this Chapter

1. To describe the placement of the observed vegetation communities in the environment.

2. To ascertain the underlying reasons for the observed distributions. To this end, relationship between the distribution of plant communities and basic plant growth factors, in particular soil nutrients, is analysed.
4.2 General Description

4.2.1 Visible Relationships between Vegetation Formation and Rock Type

There is a clearly visible relationship between rock type and vegetation in the Northern Budawangs and this is most obvious at the formation or structural level of vegetational variation. The most conspicuous changes are those on the mesas of the Northern Budawangs. These changes are graphically displayed in Fig. 4.1. This is in contrast to the Ettrema wilderness, where there are several complex patterns occurring on quasi-concentric patterning in the sandstone, residual outcrops of Berry siltstone and slopes of the Ettrema creek system. In addition, there are gradational changes in vegetation from east to west in association with changes in climate, soil depth, and lithology. The vegetation patterns at the formation level are diagrammed in Fig 4.2.

Distribution of Heathlands

The widespread relationships between heathland and harsh conditions (Specht 1977) and exposed siliceous rock (Beadle 1981) are well illustrated in these areas. Heath predominates on all hard sandstone surfaces in both Ettrema and Northern Budawangs, for example, on the hard sandstones of the mesa-tops and on Ettrema Plateau, and also in those parts of Tullyangela Labyrinth where hard sandstones predominate. Similarly, secondary benches and plateau surfaces of hard Snapper Point sandstone around the mesas support heathlands. Secondary cliff lines of Snapper Point sandstone, visible in the Ettrema Gorges form a break in the tree cover above and below, and sometimes support small areas of heath, but not conspicuously so. Heathland is not limited to hard sandstones however, with valley slopes composed of Ordovician and Devonian rocks in the Northern Budawangs being mainly heath-covered, often interrupted by patches of trees clustered on quartzite ridges.
Fig. 4.1: Schematic Diagram of Rock Strata and Vegetation Formations: Northern Budawang Ranges

Permian series:
- Nowra sandstone
- Wandrawandian siltstone
- Snapper Point sandstone

Devonian folded sediments

Ordovician folded sediments

open forest
rainforest
heath-sedgeland
mallee-heath
open forest
mallee-heath/sedgeland
Fig. 4.2: Schematic Diagram of Geomorphology and Vegetation Formations: Ettrema Wilderness Area

- Quasi-concentric sandstone
- Sassafras basalt
- Ettrema gorges
- Yellow earth

**Eocene**
- Basalt

**Permian series**
- Berry siltstone
- Nowra sandstone
- Wandrawandian
- Snapper Point

**Devonian**
- Folded sediments

**Ordovician**
- Folded sediments

W←approximately 20 kilometres→

- Mallee-heath
- Sedge
- Open forest (heath)
- Open forest
- Closed scrub
- Tall open forest
- Rainforest
- Heath
Variations within the heathland are associated with the quasi-concentric patterning which is a conspicuous feature of the Permian sandstones of the Ettrema Plateaux, the Galbraith Plateau and the top of the largest mesa, Endrick Mt.. Pickard and Jacobs (1983), in a transect analysis of the relationship between contour banding and variations in heath and scrub vegetation near Sassafras, found that *E. dendromorpha* mallees were in deeper soil in rock crevices than heath species dominating a quasi-concentric sequence from tall closed scrub through tall and dwarf shrubland to open sedgeland. They believed that variations in soil moisture-holding capacity was a probable causal factor for the observed vegetation distribution patterns.

**Distribution of *Eucalyptus* Open Forest and Woodland**

Areas of silty sandstone on mesa-tops and plateau surfaces support mainly open forest to woodland vegetation, with occasional heath patches. Likewise, the softer weathering Wandrawandian siltstones, which form the upper slopes of mesas and Ettrema gorges, support wet to dry sclerophyll forest. Devonian and Ordovician strata exposed on the lower Ettrema Gorge slopes, and on the lower slopes of the Clyde River gorge and tributary gorges, are tree-covered, with forest varying from closed Yellow Bloodwood scrub at one extreme, to rainforest at the other. In the deep gorges, the effect of differences in rock type is combined with variations in gorge microclimates. Ordovician and Devonian strata north of Mt Corang are mainly tree-covered, with sharp changes in species composition from one strata to the other.

**Distribution of Rainforest**

In the Ettrema wilderness, rainforest is closely associated with rocks of volcanic origin, where it occurs in the moistest locations, sheltered from westerly winds and strong sunlight. It occurs on basalt emplacements at Endrick and Sassafras, and on Devonian volcanic strata sometimes exposed along the Ettrema Creek system.
In the Northern Budawangs wilderness, rainforest occurs in deep ravines in the Permian sandstone and in the moistest, most sheltered locations on the Wandrawandian slopes of the mesas.

**Position in the Landscape**

Although plant formations and rock types are conspicuously related in the Ettrema and Northern Budawangs areas, plant communities defined at a more detailed level, i.e., that of species composition, may not be limited to one rock type, nor are they, in most instances, limited to one physiography or geomorphology.

In 4.3, the places occupied by individual communities in the landscape are described. Territorial limits are sought out. Specific factors assessed as being the most likely major causes of the observed plant community distributions are analysed in 4.4.
4.3 Position of Plant Communities in the Landscape

Index

4.3.1 Heath/ Sedgeland

4.3.2 Closed Scrub

4.3.3 Closed Forest (Rainforest)

4.3.4 Open Forest

   a  *Eucalyptus* *sclerophylla* - *E. mannifera*

   b  *E. sieberi* - *E. piperita* ssp. *urceolaris*

   c  *E. punctata* - *E. consideniana* - *E. gummifera* 'sandstone complex'

   d  *E. globoidea*

   e  *E. imitans* - *Angophora floribunda*

   f  Eucalypt associations of the slopes of the Ettrema Creek system

      (i) *E. punctata* - Ironbarks

      (ii) *E. piperita* - *Syncarpia glomerulifera*

      (iii) *E. eximia*

      (iv) *E. tereticornis*

   g  Eucalypts at the western margins

4.3.5 Tall Open Forest: *E. fastigata* and associates
4.3.1 Heath-Sedgeland

General Occurrence (Fig. 4.3)

(i) Ettrema

On the Ettrema and Galbraith plateaux, heath is found on flat to gently sloping plateau surfaces, chiefly on hard, coarse-grained sandstone, which frequently has only a skeletal soil cover. It may also occur on deeper soils (e.g. below Rolfe’s and Bhundoo Hills). On the plateau surfaces, heath usually occurs in bands around contours, alternating with bare rock and belts of trees. Flat areas at the tops of silty sandstone knolls (e.g. Bhundoo and Rolfe’s Hills) are the other main type of landform on which heath is found.

(ii) Northern Budawang Ranges

Here, the chief occurrences of heath are on the hard, coarse-grained sandstones of the mesa tops and secondary benches, on skeletal soils, and on shallow to deeper soils of the Devonian quartzite valleys. In both these locations, the land surface is flat to gently sloping. Around Mts Tarn and Bibbenluke, heath extends upwards onto steeper slopes on exposed north to west aspects. An odd-looking "pocket handkerchief" patch of heath occurs on the northern aspect of the slopes of Mt Hoddle (Plate 4.2). A heath patch also occurs on the west-facing secondary bench of the Castle.

Heath is found on the hard, coarse-grained Snapper Point sandstones westwards around Mt Corang and eastwards on the secondary benches of Mt Talaterang and on the secondary plateaux around Pigeon House Mountain, where it is interspersed with a stunted Yertchuk- Red Bloodwood- Privet-leaved Stringybark Woodland.

Sedgeland

In both areas, heath grades into sedgeland in places where soils are more frequently waterlogged.
Fig. 4.3: Distribution of Heath

(i) Northern Budawangs

(ii) Ettrema wilderness
Common Features of Heathland Habitats

Heathlands occur on sandstone (Berry, Nowra, Snapper Point) or on siliceous rocks (Devonian quartzites).

They mostly occur on flat or very gently sloping land. The occurrence on more steeply sloping land around Mts Tarn and Bibbenluke is relatively minor, and appears to be associated with the occurrence of the Snapper Point sandstones (Plate 4.1).

Soils may be skeletal or of some depth (e.g. Bhundoo Hill, below Rolfe's Hill), but all are consistently low in nutrients, not only nitrates and phosphates, but cations as well (Table 4.3). Soil types are most often skeletal, being peaty where drainage is poor. Heath was observed on yellow earths and podzols in the Galbraith Plateau area.

Heaths are often in poorly drained locations, e.g. on mesa-tops and Ettrema plateaux, where drainage is impeded over large areas of unbroken sandstone. The low-lying heath-covered areas of the Devonian valley floors can stay soggy for months during wet periods. The Snapper Point heathlands have in general slightly more slope, and may be better drained.

However, these areas which are subject to waterlogging may also be extremely dry for long periods. As the majority of my field trips for this thesis were conducted during the drought, heathlands were invariably seen in a very dry condition. It is expected that the range of soil moistures observed would be considerable extended if soil samples were taken just after wet periods (Fig.4.4).

Waterlogging may influence vegetation composition in heathlands by further reducing soil nutrient availability as a result of anaerobic soil conditions and increased acidity. Many areas of heathland have a high Cyperaceous and Restionaceous component, as well as dicotyledonous genera which show widespread association with wet conditions, e.g *Baeckeaa* and *Kunzea*. 
4.3.2 Environmental Interrelationships:  
*Eucalyptus multicaulis* Closed Scrub

**Distribution Pattern**

This uncommon mallee has a patchy distribution centrally in the Northern Budawangs on secondary benches of Snapper Point sandstone.

**Topography.**

(i) **Slopes**

This species occurs on a wide range of slopes, varying from flat to steep.

(ii) **Aspect**

The distribution of this species in the eastern Budawangs has been mapped largely on the basis of air photo interpretation, with limited ground truthing. From the air photo patterns, it appears that this species occurs mainly on exposed, west-facing aspects.

(iii) **Altitude**

Its range of occurrence, about 400-800m, coincides with the rock type on which it occurs.

**Rock Type**

This species occurs only on the Snapper Point sandstones in this area.
4.3.3 Environmental Interrelationships: Closed Forest (Rainforest).

Rainforest was observed to grow in the following locations:

(i) On sheltered aspects and in gullies on the Endrick and Sassafras basalts.

(ii) In the Ettrema Gorges:
   a. moist, sheltered locations in the headwaters of creeks and in gullylets on gorge slope
   b. Devonian basic volcanic exposures on parts of Danjera, Boolijah and Bundundah Creeks.

(iii) In the Northern Budawang Ranges:
   a. sheltered slopes of mesas and plateaux.
   b. sheltered locations in creeks.
   c. ravines in and around the Monolith Valley.

(i) Sassafras and Endrick Basalt Flows.

There is a noticeable connection between aspect, rock type from which soil is derived and the occurrence of rainforest in both Ettrema and Northern Budawangs. The largest stands of rainforest occur in sheltered positions on the Sassafras and Endrick basalt flows. The Tolwong basalt, the third flow in the area, does not now support rainforest, but may once have done before clearing. The major part of the Endrick flow is not covered by rainforest, but by *E. fastigata* forest. The major occurrence of rainforest is in gullies on the eastern side of Endrick Mountain.

Most of the Sassafras basalt has been cleared and used for agriculture, with remnants of *E. fastigata* forest surrounding cleared areas. *Doryphora sassafras* dominates rainforest on sheltered east and south-facing slopes of the Sassafras basalt, much of which is probably regeneration following logging or clearing.
The original pattern of distribution of rainforest and eucalypt forest may have been altered by the extensive clearing and logging which has taken place on both basalt flows.

(ii) Ettrema Creeks

Areas of rainforest occur on Devonian strata along parts of Bundundah, Danjera and Boolijah Creeks. For example, rainforest is extensive on the lower east-facing slope of Boolijah Creek adjacent to the southern part of Yarramunnun Plateau, in an area of Upper Devonian rocks of the Merimbula Formation (sandstone, conglomerate, siltstone). Air photo interpretation suggests that rainforest becomes more extensive further downstream, where Devonian basalts and rhyolites are indicated on the geology map. It appears from air photo interpretation that the most extensive areas of rainforest in the Ettrema Creeks may be associated with Devonian basalts and rhyolites. The most extensive occurrence indicated from air photo interpretation is on Danjera Creek near Danjera Plateau in an area of Devonian rhyolite.

Rainforest is common in small gullies along the Ettrema Creeks, with wider patches on sheltered aspects. It forms an understorey in wet sclerophyll forest on sheltered upper Wandrawandian slopes.

The array of mesic species in these locations differs from those species typically occurring on the Endrick and Sassafras basalt flows, or from those typifying rainforest well in the Northern Budawang Ranges. This may involve geographic cut-offs, different soil nutrient and moisture regimes and/or tolerance to fire. On the upper Wandrawandian slopes of the Ettrema Creeks, Bastard Rosewood, Native Laurel and Bolwarra were all observed regenerating from the base following burning to ground level, indicating, contrary to popular opinion, that some rainforest trees have the ability to survive fire. This is further discussed in Ch. 8.
Northern Budawang Ranges.

Rainforest replaces wet sclerophyll forest in the moistest locations on the east to south facing slopes of mesas and plateaux. *Tristaniopsis collina* characteristically occurs around the "dripline" at the base of the Nowra sandstone cliffs of the mesas. Rainforest forms the canopy in moist locations in ravines in the Nowra sandstone in the Monolith Valley area, in gullies, and along deeply incised creeks and gorges.

Common Features of Rainforest Habitats.

(i) Topography

Rainforest consistently occurs on sheltered south and east facing aspects, being more common where the shelter provided is increased by adjacent mesas or deep gullies, for example, rainforest occurs on Wandrawandian strata in gullies of Kilpatrick Ck on the eastern side of Endrick Mt, but not on the southern side, which opens out onto the Devonian plains around Styles Creek.

The occurrence of rainforest bears no constant relationship to altitude or slope. At Sassafras and in Monolith Valley, it grows at relatively high altitudes on flat to moderately sloping land, while in the Clyde River Gorge it is at low altitudes on steep slopes. Local topographies form specific niches suitable for the growth of rainforest.

(ii) Geology

Rainforest occurs on Devonian, Ordovician, Wandrawandian and Nowra strata, with its best development on Tertiary basalts.

(iii) Soils

These are rich red Krasnozems on the Sassafras and Endrick basalt flows, having high nutrient levels (see Table 4.3) and a high moisture holding capacity. Elsewhere soils were generally sandy with a high loam content.
4.3.4 Environmental Interrelationships: Open Forest

a. Scribbly Gum Forest and Snappy Gum Woodland.

*(Eucalyptus sclerophylla- E. mannifera- E. rossii)*

**Distribution Pattern**

Scribbly Gum Forest and Snappy Gum Woodland occupy wide expanses of flat to slightly sloping land in the headwaters of creeks, above sedgelands, on the Ettrema, Tianjara and Galbraith Plateaux on Tullyangela Labyrinth and in the Devonian valleys of the Northern Budawang Range. Snappy Gum lines creeks in the Galbraith Plateau area. Scribbly Gum may occupy rocky bands between patches of heathland where contour patterning occurs across the Permian sandstones.

**Topography**

(i) **Slope**

Scribbly Gum and Snappy Gum occur on flat to slightly sloping land, being replaced by *Eucalyptus sieberi- E. piperita* ssp.urceolaris where slopes become more pronounced in the Northern Budawangs, by *E. punctata- E. consideniana- E. gummifera* complex on flat land away from creek headwaters in Ettrema, and by *E. globoidea* forest further away from creeks in the Tolwong area.

(ii) **Aspect**

Scribbly Gum- Snappy Gum is found on all aspects. For example on the western edge of Tullyangela Labyrinth, it extends from west facing slopes, to flat land around Tolwong and eastwards downslope to the swampy headwaters of Ettrema Creek. Similarly, at the eastern extremity of Ettrema Wilderness, Scribbly Gum extends both east and west onto gentle slopes below the southern end of Yarramunmun Plateau.
(iii) Altitude

This association does not extend below the plateau surfaces in Ettrema nor into steep gorges of the Clyde or Shoalhaven Rivers. This is probably a topographic rather than an altitudinal control, dependent upon the localised habitat preferences of these species.

Rock Strata

These trees occur on siliceous rocks, i.e., on Permian sandstones (Nowra and Berry) and on Devonian quartzites. They are absent from the Snapper Point sandstones where they form plateaux around Pigeon House Mt and Mt Corang.

Soils

These are generally yellow earths. Those examined in detail were found to be low in nutrients, being similar in overall paucity to those soils which support heath. Soils may be shallow or deep.

Moisture Balance

Scribbly Gum and Snappy Gum typically occur in locations where soil drainage could be expected to be slow, with the water table rising into the root zone during wet periods.

Gradients of Change

A gradational change from Scribbly Gum to Snappy Gum is evident as one moves downslope towards creeks. For example, in the headwaters of Ettrema Creek, there is a gradual change from Scribbly Gum forest to Snappy Gum woodland. Snappy Gum lines creeks in the Mt Endrick area and forms a woodland near Styles Ck.

A second gradient is seen in the increase in the occurrence of *Eucalyptus mannifera* westwards. This species extends onto the Ordovician strata west of Mt
Corang, where it occurs with Snow Gum and Broad-Leaved Peppermint on sites which appear drier. This geographical distribution factor, plus the tendency of Snappy Gum to occur closer to creeks than Scribbly Gum, implying a different optimal moisture regime, partly explain the distribution difference between the two species.

The occurrence of *E. rossii* in the Tolwong area adjacent to *E. globoidea* and *E. sclerophylla* further eastwards is a geographic distribution change, rather than a response to local habitat variation. It reflects the overall distribution patterns of these two species of Scribbly Gums.

The tendency of Snappy Gum to occur closer to creeks than Scribbly Gum may imply a different optimal moisture regime, or it may be related to temperature inversion effects, that is, the downslope movement of cold air, resulting in the formation of frost at the bottom of the slope (Linacre & Hobbs 1977). A greater tolerance of cold may be the common factor uniting these two apparently different distributional patterns.

The Scribbly Gum *E. rossii* occurs in the Tolwong area adjacent to *E. globoidea* whereas the Scribbly Gum *E. sclerophylla* occurs eastwards, over most of the area investigated. This is a reflection of the overall distribution of these two species, with *E. sclerophylla* being the coastal species and *E. rossii* the tableland Scribbly Gum.

Forests of these two trees occur in several different places in the landscape of the Northern Budawang Ranges:

(i) North-east to west-facing (or exposed) slopes of the mesas on Wandrawandian Formation.

(ii) Gently sloping Devonian valleys in the western half of the Budawangs, adjoining heathland.

(iii) On the Galbraith Plateau, on the Permian sandstone, adjoining heathland.

(iv) On areas of residual Berry sandstone on some mesa-tops (Island Mt, Mt Tianjara, Mt Talaterang).

It can be seen that this type of forest occurs in on a variety of rock types and in varying physiographies. What, then, are the common features of these habitats? A consistent feature in the occurrence of this type of forest is its definite preference for sloping land. The Wandrawandian strata of the mesas all have considerable slope. In the Newhaven Gap area and the Devonian valleys, these trees characteristically replace heathland where the topography changes from flat to sloping. In their relatively minor occurrence in the Ettrema area, they tend to occur on sloping land. In terms of moisture balance, slopes are likely to be better drained than flat land.

These trees grow in the midst of heathland on ribs of Devonian quartzite which rise out of the landsurface in the Styles Ck- Mt Corang area. Similarly, they replace heathland where bands of broken rock occur on the Permian sandstones on Galbraith Plateau. This structural change from heath to trees also occurs on the Ettrema plateaux, however, the tree species which occur here are usually Grey Gum, Yertchuk and Red Bloodwood. This relationship between the distribution of heath and trees is not limited to this area, but is more widely observed. For example, the occurrence of Snow Gums on rocky outcrops amongst alpine heathland in the Kosiusko area. Observation suggests that ribs and bands of rock
are better drained than adjoining heathland, which may stay waterlogged for a prolonged period after rain. Trees on rocky bands may be in shallow or deep soil e.g. soil depth in an *E. sieberi- E. piperita* ssp. *urceolaris* patch at Camp Rock were measured at only a few centimetres depth, whereas the depth of peat in the adjoining sedgeland exceeded one metre. At other locations, it appears that the reverse is the case, with deeper soil in the rocky bands and shallower soil in the adjoining heath.

**Moisture Balance**  (see Fig. 4.4).

These trees tend to occupy drier sites than most other vegetation communities in the Northern Budawangs. This shows up most clearly in their occurrence on the exposed north to westerly aspect of the mesas.

Contrastingly, the majority of dry forest sites across the Ettrema plateaux are occupied by Grey Gum- Yertchuk- Red Bloodwood forest to woodland. The restriction of Silvertop Ash- Urn-Fruited Peppermint to gullyheads, Berry knolls and upper gorge slopes may relate partly to the fact that these habitats would have higher moisture balances that the plateau surfaces.

**Soils**

These vary from shallow, skeletal soils directly overlying hard Permian sandstone to deep yellow earths or hill mantles of varying depths and structure. Soil textures are predominantly sandy, with or without loam or silt fractions.

**Nutrient Regime**

Sites examined had nitrate and phosphate levels similar to those in heathland, with values for other nutrients being consistently higher than those for heathland and Grey Gum- Yertchuk- Red Bloodwood complex, but lower than those obtained for other forest communities (see Table 4.3 and Fig. 4.5). Hence the restriction of Silvertop Ash- Urn-Fruited Peppermint to gullyheads, knolls and
upper gorge slopes in the Ettrema area undoubtedly bear a negative relationship to the low soil nutrient regimes of the impoverished plateau soils.

Summary of Common Habitat Features

These tree species occur together on:

(i) Sloping land 
(ii) Poor soils (but not as poor as those on which heathland occurs.) 
(iii) Exposed aspects (Northern Budawangs.) 
(iv) Sheltered aspects (Ettrema) 
(v) Well-drained soils 
(vi) Sandy soils

Gradients of Change

Although the ranges of these two species overlap, particularly in the Northern Budawangs, their extremes of distribution are observably different, with Urn-fruited Peppermint occupying moister sites and Silvertop Ash occurring in drier, more exposed situations. Urn-fruited Peppermint is found at the wettest end of its range where it occur in skeletal Permian sandstone soils on the exposed edges of the Budawangs mesas and on the edges of the Ettrema plateaux. These differences in distribution may be explained by differences arising from the contrasting landscapes of the Ettrema and Northern Budawangs.

Three habitat features distinguishing Ettrema from Northern Budawangs are:
1. An overall tendency to lower soil nutrients and 
2. A flatter landscape. 
3. Lower rainfall generally on the Ettrema plateaux (see ch.2).

Where slope values, nutrients and moisture balances are higher in the Ettrema area, the distribution of Silvertop Ash and Urn-Fruited Peppermint are usually separated, implying that there are more "niche spaces" here than in the Northern Budawangs.
Species observed to occur with *E. sieberi* include *E. agglomerata*, *E. sclerophylla* and *E. gummifera*. *Angophora floribunda*, *Syncarpia glomerulifera* and *E. cypellocarpa* or *E. saligna* occur with or adjacent to Urn-Fruited Peppermint.

Mowatt & Myerscough (1983) in examining the ecological differences between scribbly gums and *Angophora* spp., found that *Angophora floribunda* responded to an increased supply of nutrients in pot trials, whereas scribbly gums and *Angophora* spp. found naturally on poorer soils, responded best at lower nutrient levels. Since it co-occurs with *Angophora floribunda*, *E. sieberi* may also tolerate lower nutrient conditions.

Species compositional changes reflect the overall geographic distributions of species. Hence, Red Bloodwood and Turpentine, both restricted to the eastern side of Morton National Park (see Table 4.1) are coastal in their distribution throughout their natural range. Urn-Fruited Peppermint, which does not occur on the Western side of the Budawangs, is restricted to the coast and adjacent tablelands at lower altitudes throughout its range (Hall, Johnston & Chippendale 1970). These distributional limits would be related to the loss of the coastal influences (warmer temperatures and higher rainfall) on climate as one moves westwards. The absence of *Angophora floribunda* from the mesa- shallow valley- sandstone plateau areas reflects the absence of its known habitat preference for "alluvial soils and deep sandy loams along river and creek flats and along watercourses" (Ibid). *E. cypellocarpa* and *E. agglomerata* occur with *E. sieberi* on Devonian strata west of Mt Corang, where the habitat changes from that of the mesas and shallow valleys of the Budawangs. These changes coincide with the observed western limit of Urn-Fruited Peppermint (Table 4.1) in this area. Flatter topography, lower nutrient values, and climatic differences are habitat variations parallelling variations in the distribution of *E. sieberi*- *E. pipenta* ssp.urceolaris forest in the Northern Budawang Ranges and Ettrema areas.

**Distribution Pattern**

This group of trees occurs across the Ettrema plateau surfaces, forming a geomorphologically-related pattern with heathland and scribbly gum-snappy gum woodland. Overall similarities in the habitat occupied by this complex are outlined below, followed by a discussion of within-complex habitat and species variations.

**Physiography**

These trees are most common on flat Permian sandstone land surfaces, sometimes extending onto slopes of gorges and Berry Knolls. For example, the whole complex extends up onto the west-facing slopes of Sturgiss, Putt and Ettrema Hills, on Ettrema Plateau. Gorge slope occurrences were observed along the upper reaches of Bundundah Creek.

**Geology**

The complex occurs across a wide range of geological types. Permian sandstones, either Berry or Nowra are the favoured rock strata. *Eucalyptus agglomerata* has a major occurrence in gully heads and on upper gorge slopes on Wandrawandian siltstones, lapping onto the Nowra sandstone plateau edges. It occurs also on Ordovician slopes to the west and south. Along Bundundah Creek, the complex was observed on soils derived from pink Devonian granite, Ordovician quartzose sandstones, Snapper Point sandstone, conglomerate and chocolate shale, and Wandrawandian siltstone.
Soils

These are predominantly yellow earths and skeletal soils where this group of trees occurs across the Ettrema plateaus. Textures vary from sand to sandy loam or sandy clay.

Moisture balance

Sites may vary in their water-holding capacity, as a result of variations in the depth and draining qualities of soils. For example, the replacement of *E. punctata* by *E. sclerophylla* on the deeper yellow earth may relate to the water-holding characteristics of these clay-based soils.

Gradients of Change

The variations in species composition of this complex across the Ettrema plateau could be explained by the combined effect of climatic variations and differences in local habitat on basic plant growth factors, in particular, moisture balance.

(i) *E. punctata.*

On Ettrema Plateau, where contour banding occurs in the sandstone, *E. punctata, E. consideniana* and *E. gummifera* grow on bands of broken rock, alternating with areas of heath on flat, unbroken sandstone.

On Danjera and Yarramunmun Plateaux, where contour banding and areas of flat, exposed rock diminish and large areas of moderately deep yellow earth occur, *E. punctata* diminishes and *E. sclerophylla* consistently associates with *E. gummifera* and *E. consideniana.* These yellow earths are distributed centrally on Yarramunmun Plateau and overlie a layer of harder sandstone, which is exposed at the plateau edges. Here, skeletal soils support *E. punctata* and *E. agglomerata.*

Hence, the occurrence of *E. punctata* on the easterly Ettrema plateaux coincides with areas of exposed rock and shallow soil, and that of *E. sclerophylla* with deeper yellow earths.
In seeming contradiction, *E. punctata* is associated with *E. globoidea* on deep sandy soils in north-west Ettrema, but is absent from rocky areas of yellow earth immediately to the south. It also occurs on rocky edges around the Tolwong *E. globoidea- E. punctata* forests. These two apparently disparate occurrences may be similar in that the soils are less prone to waterlogging.

*Eucalyptus punctata* is noticeably absent from the Northern Budawangs in locations where *E. gummifera*, *E. consideniana* and other members of this overlapping group of species occur. This southward disappearance of *E. punctata* can be seen to be related to its overall distribution pattern (Hall et al. 1970), which is centred on the Sydney Basin sandstones and shales, particular favouring the junction between these two rock types. Its preference for these rock types could explain its absence from the Snapper Point sandstone plateaux around Pigeon House Mt and the Ordovician sediments between the Castle and Yadboro Creek, both of which habitats accommodate *E. gummifera*. Its absence from sandstones at the western edge of Tullyangela Labyrinth south of Tolwong, suggests that some local habitat variation, such as altered drainage patterns, or a habitat variation in conjunction with climatic variation causing increased exposure to wind or increased severity of floods may render this area unsuitable for *E. punctata*.

(ii) *E. gummifera*

Although habitats apparently geomorphologically similar to those on the eastern plateaux occur on Tullyangela Labyrinth, *E. gummifera* is absent. This is a reflection of the overall coastal distribution of *E. gummifera* (Hall et al. 1970) and is probably related to the east-west climatic trends of decreasing temperature and rainfall. Its relative insensitivity to geology over climatic variables is shown by its presence on Ordovician sediments and Snapper Point sandstones to the south.

(iii) *E. consideniana*

This species, a close relative of *E. sieberi*, predominates across the Ettrema plateaux, whereas *E. sieberi* occurs to a limited extent here, mainly along plateau margins and on hilltops or slopes. By contrast, *E. sieberi* predominates across
Galbraith Plateau and the Northern Budawangs. The explanation of this interesting distributional change is not obvious but may relate to differences in soil nutrients, with *E. sieberi* having a higher requirement for some or all nutrients.

*(iv) E. agglomerata*

This species frequently occurs with *E. sieberi* around plateau edges, and on Ordovician strata west of Mt Corang. It occurs with the complex in locations which may observationally be described as moister, more sheltered, and having better soil development.

*(v) E. sclerophylla*

Elsewhere forming a woodland with *E. mannifera* on low-lying sites likely to retain moisture in wet periods, this species is a consistent member of the complex on Yaramunmun Plateau and in other areas. Its association with yellow earths here suggests that the water-retaining capacity of these soils may have some bearing on its distribution.

**Summary**

Limits of distribution are reached east to west across the Ettrema plateau in *E. gummifera* and from north to south in *E. punctata*. The former is most likely to be sensitive to climatic variables of decreasing rainfall and temperature away from the coast, while the distribution of the latter is related to the Sydney Basin sandstone and shale strata. The cutoff in these two species explains much of the complex species changes which occur within this vegetation type.

The replacement of *E. punctata* by *E. sclerophylla* on Yarramunmun Plateau and in other areas appears, on this broad scale of observation, to be related to the occurrence of yellow earths, these being preferred by *E. sclerophylla*, whereas *E. punctata* is distributed on two rather different types of substrate, these being rocky areas in the east, and deep sandy soils in the west.
d. *Eucalyptus globoidea* (White Stringybark Forest.)

**Distribution Pattern**

White Stringybark forest occurs in the north-west corner of the Ettrema area, on the plateau above the bend in the Shoalhaven River where its direction of flow changes from south-north to west-east. This area is characterised by deep, sandy soils of unknown origin (Young, R.W. Pers.Comm.1982).

**Topography**

(i) **Slope**

The area is predominantly flat to very slightly sloping.

(ii) **Aspect**

No particular aspect is preferred, and the forest in generally is sheltered.

(iii) **Altitude**

The plateau surface varies from 600-1000m. Altitude range is different from that over most of the range of White Stringybark elsewhere. Its major occurrence, throughout the coastal areas of NSW (Hall *et al.* 1970) is at much lower altitudes.

**Latitude/Longitude**

Although this forest has its best development in the north-western corner of Ettrema Wilderness, the distribution of both species extends eastwards across the Ettrema Plateaux and onto the adjacent coastal lands. Both species are at or near their western limits of their distribution (Blakely 1965, Hill 1991) where one would expect a diminution of their occurrence. Hence the climatic regime resulting from geographical position is probably secondary to habitat in determining the predominance of these species here.

**Rock Type**

Exposures of bedrock are not common in the White Stringybark forest.
Soils

These are deep, with a sandy/silty texture in the A horizon, and a gradational profile with a slight increase in clay with depth and becoming very gravelly at about half metre deep. Nutrient levels were not tested.

Moisture Availability

Deep soils and sheltered location would result in reasonably good moisture regimes in White Stringybark habitat. The sandiness of the soils suggests that they would be free-draining.
e. *Angophora floribunda* - *Eucalyptus imitans*.

**Distribution Pattern**

Rough-barked Apple and Narrow-leaved Stringybark occupy young alluvial flats along the Ettrema Creeks, extending onto lower colluvial slopes on sheltered aspects. Narrow-leaved stringybark extends upslope onto drier sites in Ironbark-Grey Gum forest. Rough-Barked Apple has a limited occurrence on sheltered aspects of Berry Knolls on the Ettrema plateaux.

**Topography**

(i) **Slope**

Although these two species occur together on flat sites, neither is restricted to such sites. This is shown by the occurrence of Narrow-Leaved Stringybark on lower gorge slopes and of Rough-Barked Apple on slopes of Berry Knolls.

(ii) **Aspect**

Both species extend further upslope on sheltered aspects of the gorges. Specimens of Rough-Barked Apple become stunted at the top edge of its distributional range. During the 1982-83 drought, dead or very severely affected Rough-Barked Apple were observed on the driest sites of its occurrence, revealing moisture balance as the limiting factor in the upslope distribution of this tree here.

Rough-Barked Apple occurs only on sheltered aspects of Berry Knolls.

(iii) **Altitude**

Both species generally occur at low altitudes in this area, with Rough-Barked Apple having a relatively high altitude recurrence on Berry Knolls.

**Rock Types**

Neither species is restricted to a particular rock type, since they occur on Ordovician to Snapper Point rocks on the gorge slopes. Rough-Barked Apple on Berry sandstone on Ettrema plateaux.
Soils

Deep, sandy alluvium is the preferred soil. Those tested were low in nitrates and phosphates, but high in potassium and calcium (see Table 4.3).

Moisture Balance

These trees display a definite preference for the moistest habitats in the Ettrema area.

Geographical Trends (Table 4.1)

Neither species was recorded from the Northern Budawang Range. This reflects the known distribution pattern of both species (Hall et al. 1970). *Angophora floribunda* is coastal in the southern half of its distribution. *Eucalyptus imitans* has its centre of distribution in the Central Coast and Tablelands. Here in the Ettrema gorges, it is at its southernmost known limits of distribution.
f. Eucalypt Associations of the Slopes of the Ettrema Creek System

(i) *Eucalyptus punctata* (Grey Gum)- Ironbarks

(*E. fibrosa* and *E. beyeri*) - *E. imitans*

**Distribution Pattern**

These trees form an association in the north-east of the Ettrema Wilderness Area, on the slopes of the Ettrema Creeks and the Shoalhaven River. In this gorge slope environment, they grow on ridges, being replaced in small gullies and on lower slopes by *Angophora floribunda- Eucalyptus imitans* or *E. tereticornis*. Upstream along the creeks, the occurrence of Ironbarks diminishes.

**Topography**

(i) **Slope**

Ironbarks generally occur on moderate to steep slopes (53.1 degrees- 3.2 degrees). *Eucalyptus punctata* and *E. imitans* extend onto flat land, the former onto plateau surfaces and the latter on alluvial creek flats. In these separate slope environments, their distributions overlap with those of different species.

(ii) **Aspect**

Ironbarks do not consistently occur on any particular aspect on gorge slopes. For example, they occur on both sides of Ettrema Gorge from its junction with the Shoalhaven, upstream beyond Mt Edwards, on north, south, east and west facing aspects. They occur on both north-west and south-east facing slopes above Danjera Dam. On Bundundah Creek below Smallest Plateau (Fig.3.14b), they grow in the middle of the east and west facing slopes, on ridges. Aspect differentiation was observed on Boolijah Creek below Yarramunmun Plateau, with stands of Ironbark and Stringybark occurring on ridges on west-facing slope being replaced in gullylets and on east-facing slopes by *E. elata, E. saligna*, and *E. piperita ssp.urceolaris*. Ironbarks are here at the upstream, and possibly, the moister end of
their range of distribution, with sunlight and wind exposure generally decreasing as the gorge narrows upstream.

Rock Strata

Ironbarks display no restriction to any particular rock type or stratum, although they are absent from the particularly impoverished soils of the Nowra sandstone. They were observed on Ordovician, Devonian, Snapper Point and Wandrawandian strata. Bedrock types include quartzite, sandstone, basalt and shale. However, at any particular site, restriction to, or absence from, certain strata is apparent. This is probably related to its occurrence on soils of intermediate nutrient values.

Soils

These are often quite dark, seemingly rich soils, and those sampled (stony regoliths on the slopes of Ettrema Gorge, Table 2.1) were found to be higher in most nutrients than heath, sedgeland, *E. punctata- E. considenia- E. gummifera* complex and *E. sieberi- E. piperita ssp.urcelolaris* forest but lower in most nutrients than *E. fraxinoides- E. fastigata- E. tereticornis- Angophora floribunda- E. imitans* and rainforest (Table 4.3). This could explain its replacement by *E. tereticornis* on Devonian basalts and siltstones on the lower slopes of Danjera and Bundundah Creeks, and the continuation of its distribution onto the lower slopes of Ettrema Creek, where Ordovician quartzose sandstones prevail. Here it is replaced by *E. tereticornis* on colluvium at creek entrances. An interaction between soil nutrients and soil moisture balance in determining the relative distributions of Ironbark and *E. tereticornis* is suggested by the observed patterns on the south-east ridge of Smallest Plateau. Here, *E. tereticornis* occurs on basalts and quartzite sandstone on the lower slope with *E. punctata- Ironbark* forest showing a notable preference for the deeper, better quality soils derived from the Devonian basalts on the middle slopes.
Hence, although there is no consistent co-occurrence with any particular rock type, it appears that where these species occur, soil nutrients are likely to be reasonably high.

**Moisture Balance**

Ironbark forest occurs on fairly dry slopes, being replaced by other trees in moister parts of slopes. Its diminished occurrence further upstream on gorge slopes is probably explained by higher soil moisture balances, since upstream variations in the other basic plant growth factors of temperature and nutrient levels are likely to be less pronounced.
f. (ii) *Eucalyptus piperita* ssp. *urceolaris* - *E. saligna*- *Syncarpia glomerulifera*.

**Distributional Pattern**

In Wandrawandian slopes immediately below the sandstone plateaux of Ettrema, Um-fruited peppermint, Sydney Blue Gum and Turpentine are the dominant species. They grow on both eastern and western sides of the plateaux.

**Topography**

(i) **Slope**

These trees group on the flat benches immediately below the sandstone cliffs of the plateaux and on moderate slopes below the benches.

(ii) **Aspect**

The habitat is sheltered, being close under clifflines on both eastern and western sides of the plateaux.

(iii) **Altitude**

These trees occur as a group only on upper gorge slopes. This is likely to be related to the occurrence of a particular habitat at this altitude, but may also relate to lower frost frequency at the top of slopes due to cold air sinking to the bottom of gorges at night.

**Rock Type**

The habitat is on Wandrawandian strata at its junction with Nowra sandstone clifflines. Enormous sandstone blocks are littered about at this level of the gorge slope.
Soils

Are grey, sandy and loamy, with the appearance of being relatively fertile and well-watered. Two samples from Boolijah Creek had relatively high cation levels, although being typically low in nitrates and phosphates.

Moisture Balance

Although showing no strong aspect preference, these trees grow in the shadow of cliffs, where they would be sheltered from strong winds and direct sunlight for much of the day. Additional moisture may be present as a result of seepage at the junction of the Nowra sandstone cliffs. Moisture balance is therefore likely to be high.

Geographic Location

Turpentines are restricted to the eastern side of the Ettrema and North Budawang areas. This reflects the overall distribution of this tree, which is generally within 80-100 km of the coast (Hall et al. 1970). It also coincides strongly with the westerly disappearance of Wandrawandian siltstones from the gorge slopes, being found on the lower reaches of Ettrema Creek, but not on the upper, where Eucalyptus piperita ssp. urceolaris and E. saligna still occur.
f. (iii) *Eucalyptus eximia* (Yellow Bloodwood).

**Distribution Pattern**

This species is distributed in irregular patches on steep, rocky slopes and ridgetops above the west to east flowing arm of the Shoalhaven River and the lower reaches of Ettrema, Bundundah and Yalwal Creeks.

**Topography**

(i) **Slope**

Yellow Bloodwood often occurs on very steep slopes.

(ii) **Aspect**

North-facing mid-slopes above the Shoalhaven River are favoured. It occurs on north-facing lower, mid and upper slopes above Ettrema Creek, with west-facing mid-slope patches common along south to north-flowing side creeks (e.g. Leyden Creek) and on north-west to east facing slopes on the wedge of land between Reynolds and Clarke Saddles and the curve of Yalwal Creek and Danjera Dam.

(iii) **Altitude**

Occurrence is between about 30m and 370m in this area. This reflects the overall coastal distribution pattern of *E. eximia* (Hall *et al.* 1970).

**Latitude/Longitude**

Yellow Bloodwood is here at its southernmost known limit of distribution.

**Climate**

The restriction of this species to the NE suggests that there may be climatic factors, such as low frost tolerance, limiting its spread into colder areas west and south. Frosts are unusual in the area in which it is naturally distributed.
Rock Types

Along the lower slopes of Ettrema Gorge, this tree clings to soil-less, rocky screes of Ordovician quartzose sandstone blocks. On mid to upper slopes, it occurs on Snapper Point sandstones. Throughout its patchy occurrence in the Ettrema area, it appears to be restricted to either of these two rock types on rocky exposures.

Soils

These were practically non-existent on sites where this species was closely examined.

Moisture Balance

Lack of soil, steepness of slope and exposed aspect indicate that this species has the capacity to tolerate extreme dryness probably beyond the limits of tolerance of most other trees in the area. Sites on Ordovician scree slopes were characterised by bedding planes which dipped into the creek. This would serve to drain all the moisture away from these sites.

Summary

This species tolerates the driest, poorest, steepest, most inhospitable sites in Morton National Park. Its limited distribution in the north-east corner of Ettrema suggests that it may not tolerate frosts and colder conditions occurring on the plateau surfaces to the south and west. It is patchily distributed within the area of its occurrence.
f. (iv) *Eucalyptus tereticornis*

**Distribution Pattern**

This tree, widespread on good soils in adjacent coastal areas (for example, on Milton Monzonite and Berry siltstone) has a limited occurrence on the lower slopes of creeks in the north east of the Ettrema Wilderness area. It occurs here on soils derived from a variety of rock types.

**Topography**

(i) **Slope**

*Eucalyptus tereticornis* shows a preference for gentle lower slope and old alluvial flats along the Ettrema Creeks.

(ii) **Aspect**

There is no clear aspect preference. Along Ettrema Gorge, it occurs on both north and south facing sides of the creek. Along Bundundah Creek, it occurs on east facing slopes and is absent from the adjacent west facing slopes. However, this is probably coincidental with a greater occurrence of Devonian basalts on the east facing side of the creek. Around Danjera Dam, it occurs on both south-east and north-west facing lower slopes.

(iii) **Altitude**

Its occurrence is limited to the lower slopes above creeks, extending to about one third of the distance upslope on basalt on Bundundah Creek. It occurs upslope of *Angophora floribunda* - *Eucalyptus imitans* and downslope of *E. punctata* - Ironbark forest.

**Rock Strata**

*Eucalyptus tereticornis* occurs on Ordovician quartzose sandstones along Ettrema Gorge. Here its occurrence is restricted to the lowest parts of slopes and to sheltered gorges of side creeks where it may extend upslope onto Snapper Point.
sandstone. On Bundundah Creek, it occurs on Devonian siltstones and basalts, being replaced by *E. punctata* - Ironbark upslope on Snapper Point sandstone and Wandrawandian siltstone. Above Danjera Dam it was observed on Devonian quartzitic sandstone and siltstones, being replaced by *E. punctata* - Ironbark on Devonian basalts. It has a more pronounced occurrence along the Ettrema Creeks where exposures of Devonian volcanic rocks occur.

**Soils**

It occurs on colluvium, old alluvium and basalt-derived soils. These soils share the common features of depth and high nutrient levels. Those tested were, apart from rainforest, the only soils which contained a measurable quantity of nitrogen, and they also contained relatively high levels of potassium, calcium and magnesium.

**Moisture Balance**

*Eucalyptus tereticornis* forest occurs near creeks and on lower gorge slopes in deep soils, i.e, in habitats which would maintain a relatively high moisture balance. Its failure to show a clear aspect preference may indicate that its moisture balance requirement is less of a limiting factor in the Ettrema area than its requirement for soils with high nutrient levels.
(i) *Eucalyptus pauciflora*- *E. dives*- *E. rubida*- *E. mannifera*

(ii) *E. agglomerata*- *E. sieberi*- *E. consideniana*- *E. dives* -Scribbly Gum- *E. mannifera*.

**Distribution Pattern**

These two groups of species occur west of the Northern Budawangs and are sharply demarcated from one another. The Snow Gum group were observed on Ordovician strata west of Mt Corang and Mt Endrick, the Blue-leaved Stringybark group on Devonian strata below the Mt Corang sandstone massif and Scribbly Gum- Snappy Gum woodland west of Endrick Mt.

**Topography**

Distribution patterns within these groups have not been worked out in detail. Within the Blue-leaved Stringybark group, this species and Silvertop Ash occur on exposed slopes and Narrow-leaved Peppermint on sheltered slopes. Scribbly Gum- Snappy Gum grow around swamps and on flat or slightly sloping areas above creek headwaters. Yertchuk dominates on north-facing rocky slopes immediately below the Mt Corang conglomeratic sandstone.

**Rock Type**

The transition from Blue-leaved Stringybark forest on Devonian strata to Snow Gum- Candlebark on Ordovician strata is noticeably abrupt.

**Climate**

The occurrence of Snow Gum and Candlebark west of the Northern Budawangs is indicative of the cooler climate here than across most of the Northern Budawangs. These two species have a westerly and often montane distribution over their entire range.
4.3.5 Environmental Interrelationships: Tall Open Forest

*Eucalyptus fastigata* and *Eucalyptus fraxinoides* - *E. triflora* and *E. radiata* - *E. cypellocarpa* - *E. viminalis*.

**Distribution Patterns**

*Eucalyptus fastigata* grows on sheltered slopes of mesas and interconnecting plateaux in the Northern Budawangs with *E. fraxinoides* and *E. triflora*. It occupies the major part of the Endrick and Sassafras basalt flows with *E. radiata*, *E. cypellocarpa* and *E. viminalis*.

**Topography**

(i) **Slope Range**

This varies from flat to moderately steeply sloping for all species in these two communities.

(ii) **Aspect**

Brown Barrel - White Ash - Budawang Ash occur on the sheltered east to south-facing slopes of mesas. The basalt community occurs on all but the most sheltered aspects of the basalt, where it is replaced by rainforest. *Eucalyptus radiata* concentrates on the edges of these two basalt flows and also occurs around the edges of the largely cleared basalt emplacements at Tolwong and at Quiera and Tullyangela clearings.

(iii) **Altitude**

*Eucalyptus fastigata* has a wider altitudinal range than *E. fraxinoides* growing at 750 m at Sassafras, to 400 m along Angel Creek and probably to lower elevations than this along the gorges of the Clyde and its tributaries. White Ash was observed at elevations of about 650-800 m, with Budawang Ash extending to slightly higher elevations. *Eucalyptus cypellocarpa* extends below the distribution of *E. fastigata* onto river and creek flats in both Ettrema and Northern Budawangs, which are less than 100 m above sea level. These altitudinal ranges reflect the distribution patterns.
of the species concerned over the whole of their ranges, as outlined in Hall, Johnson & Chippendale (1970). All typically grow at high altitudes on mountains and escarpments at these latitudes, to high coastal escarpments at their lowest altitudinal limit. *Eucalyptus cypellocarpa* also occurs at lower altitudes over most of its range from Victoria to Southern NSW.

**Climate**

The harsh effects of winter westerly winds become much more pronounced once one climbs onto the Sassafras basalt along the Nowra to Braidwood Rd. In winter, the air temperature becomes noticeably lower from here westwards. These climatic changes coincide with the western limit of distribution of Urn-fruitied Peppermint and the eastern most distribution of Narrow-leaved Peppermint and also with the occurrence of montane trees on the basalt flows. These flows, being higher than the surrounding plateaux, would receive the full force of the wind. On the sheltered upper slopes of the mesas, where White Ash occurs, greater wind protection would be experienced. Winter temperature patterns may vary from those on the basalts, for example, there would probably be fewer frosts, as cold air would drain into the valleys below.

**Rock Types**

The distribution of Brown Barrel and one set of associates (Monkey Gum, Manna Gum and Narrow-leaved Peppermint), coincides well with the occurrence of basalt flows. With its other associate (White Ash), it grows on sheltered aspects of mesas and interconnecting plateaux, on Wandrawandian and Snapper Point strata. Budawang Ash has its most conspicuous occurrence on the Nowra sandstone, in cracks and crevices, extending onto Snapper Point sandstone in some places.
Soils

Both the hill mantle soils of the mesas and the basaltic Krasnozems supporting *Eucalyptus fastigata* associations were found to have high nutrient status (Tables 4.4 and 4.5, sites 45 - 51). Soils in both locations tended to have a loamy texture. The restriction of *E. fastigata* to rich soils in Morton National Park reflects its overall preference for better quality loamy soils (Hall *et al* 1970). Its associates may also grow on poorer soils, although perhaps not as poor as most of the soils which prevail on the sandstones and quartzites of this area. Its tolerance for poorer soils than *E. fastigata* would explain the occurrence of *E. radiata* around the edges of basalt flows.

Moisture Balance

The basaltic krasnozems were found to have extremely high moisture contents, indicating the ability of these soils to retain large amounts of water. Hence Brown Barrel and associates grow in high moisture regimes, on mesa slopes because of shelter from westerly winds and sun, and on basalts because of high moisture retaining ability of the soil.

Fire

*Eucalyptus fastigata, E. fraxinoides* and *E. triflora* are members of the Ash Group, and do not regenerate from lignotubers following fire (or destruction by whatever cause.) Occurrence of *E. fraxinoides* on sheltered slopes of mesas may bear some relationship to fire sensitivity. As with other Ash Group species, regeneration following fire is from seed. The even-aged stand on the eastern sides of Endrick Mt. may be the result of fire, or of heavy logging during the time when this took place, here. The unusual distribution pattern of *E. triflora*, clinging to cliff edges, suggests that extreme fire sensitivity may be contributory. In these locations, surrounded by expanses of bare rock, *E. triflora* is likely to escape fire which engulfs the surrounding slopes. As a species such as *E. fraxinoides* is likely
to take 20 years to return to seeding following fire, its distribution pattern, if at all influenced by fire, would relate to fire regimes other than those which the area has experienced under white settlement, these averaging a much greater frequency than one in twenty years.
4.4 Vegetation Distribution Patterns and Plant Growth Factors

4.4.1 Introduction

In the preceding section, the way that environmental features such as topography, geology, soils and geographical location influence the distribution of vegetation communities and gradients of change within and between communities has been described. Distribution patterns are now interpreted in terms of the factors which directly affect plant growth.

It is predictable that vegetation distribution patterns will be found to relate more precisely to the most important plant growth factors than to the features of the environment, which act on the plant only through its direct requirements.

The "basic plant growth factors" (categorised as "resource gradients" by Austin & Cunningham 1981) are few in number and largely encompassed in the following list: nutrients, moisture balance, light, temperature. It seems reasonable to expect that the factors of the environment such as physiography, geomorphology, climate and soil type, complex as they are in character, influence plant distributions primarily, or most significantly, via these basic plant growth factors.

The impact, for example, of particular geomorphological features on plant distribution patterns, is likely to depend upon the way in which the balance of basic plant growth factors varies with geomorphology. Thus, if two different rock types produce soils of similar texture and nutrient balance, and if other factors remain within a similar range of variability, the same vegetation might predictably occur on both.

Further to this, features of the environment can be ordered according to the directness or indirectness of their effect on plants, depending on how closely they affect plant growth factors. For example, soil type is closer in its effect on soil nutrients and soil moisture than is rock type and as a consequence, one could expect intricacies in vegetational variation to relate more closely to soil type than rock type.
Environmental features can be ordered in terms of their effects on plant nutrients as follows:

Rock type governs physiography, which governs—Soil catena, which influences—Soil nutrients

Rock type governs—Soils, which govern—Soil nutrients

Ordering of environmental features in terms of moisture balance:

Rock type governs—Soils, which affect—Soil texture and depth, which affect—Soil moisture

Physiography governs—Soil catena, which affects—Soil depth, which affects—Soil moisture

Physiography governs—Aspect and Slope

Aspect and Slope both affect—Sunlight, which affects—1. Rate of Evaporation, which affects—a. Atmospheric moisture b. Soil moisture

2. Available light

3. Temperature

It can be seen that physiography is a complex feature of the environment, affecting all four listed basic plant growth factors, via its major components, aspect and slope, which are also complex in their effects on plant growth factors. Slope can be further subdivided into position on slope and degree of slope, both of which in turn affect soils, moisture, light and temperature. Consequently, it may be difficult to relate plant communities to physiography, since the effects of physiography on plant growth factors will vary complexly. Although the relationship between physiography and plant communities may be constant over a small area, over a larger area, crossing landscape boundaries, the relationship will predictably vary in a way which may be difficult to describe, either qualitatively or quantitatively, since the actual relational constancy is amongst plants and plant growth factors, not amongst plants and aspect or any other physiographic feature.

In Ettrema and Northern Budawangs, vegetation was observed to change with aspect around the slopes of mesas in the Northern Budawangs, and around the
slopes of knolls of Berry sandstone on the Ettrema Plateaux. Whilst these two separate sets of changes in vegetation with aspect are similar in that they are a change from vegetation more tolerant of dryness to vegetation requiring higher moisture levels, most of the plant species involved in the two places are different, and even at the formation level, the changes are not the same, with the change on mesa-slopes being from dry eucalypt to moist eucalypt forest and rainforest, while the change around the Berry Knolls is from one community of dry eucalypt forest to another. While changes in vegetation along a single transect may be consistent with topographic changes, it may not be possible to extrapolate the plant gradient or community results obtained for any great distance afield from that particular transect.

**Altitude**

Altitudinal changes in species composition are not a marked feature of the vegetation in this area except those coincidental with changes in geological strata. Species changes with altitude would predictably be gradational coincident with temperature changes, however, in this area any such changes are secondary to the sharply demarcated changes along geological boundaries. At Sassafras, for example, which is high relative to that part of the Ettrema area to the east, the vegetation is primarily determined by the nutrient-rich soils derived from the basalt capping. Although the vegetation would undoubtedly also be affected by the cooler temperatures here as a result of higher altitude, any such changes are masked by the dramatic effect of the basalt on the type of vegetation.

The effect of altitude on moisture balance is difficult to predict, as there could be contrary effects: increased exposure to winds with altitude would lead to higher rainfall when these winds were rain-bearing and a greater drying-out effect when dry conditions prevailed, ie, accentuation of the extremes of dryness and wetness. Contrarily, decreased temperature with altitude would predictably lead to a lower
rate of evaporation and consequently, an increase in moisture. One effect may cancel out the other.

**Slope**

Apart from an overall tendency for flat areas to be dominated by heath and sloping areas by forest, changes in angle of slope do not appear to be critical in determining the distribution of most vegetation communities at the broad level at which they have been analysed in this thesis. An exception is *E. sieberi-E. piperita ssp.urceolaris* community, with most of its various habitats in Ettrema and Northern Budawangs being unified by their tendency to be sloping, rather than flat. (see next section of this chapter.)

Overall, the effects of topography on vegetation distribution patterns are not as consistently obvious as the effect of geology in the Ettrema and Northern Budawangs areas. The effects of changes in rock strata are visibly obvious.

If soils are derived from the underlying rock types, as appears to be the case across most of the Ettrema and Northern Budawangs areas, it may be possible to see a relationship between rock type and vegetation, since soils are the major factor governing plant nutrients.

This relationship will predictably not be as strong or as constant as that between vegetation and soil types, which in turn will predictably not be as strong or as constant as that between vegetation and soil nutrients.

**Nutrient Levels**

Over much of the Ettrema-North Budawangs area, nutrient levels were expected to be low, as this is an ancient, well weathered sandstone landscape. Generally low nutrient status is characteristic of many Australian soils, particularly those derived from sandstones (discussed by Beadle 1981, Nix 1981).
In the Ettrema and Northern Budawangs areas, the observed relationships between geology, physiography and plant distribution were thought likely to operate primarily via soil nutrient levels.

Soil nutrient levels will predictably vary with:

1) **Change in geological stratum**

A likely sequence from least to highest nutrient levels is as follows:

Sandstone and Quartzite ≤ Siltstone ≤ Alluvium & Colluvium ≤ Basalt

2) **Physiography**

R.W. Young (1982) described the widespread catenary pattern on the sandstones of the Illawarra region (both Permian and Triassic) as being one of skeletal soils across the plateaus on both flat surfaces and very steep slopes (where rapid erosion removes weathered material ). These skeletal soils are replaced by yellow earths where there is a higher clay content in the sandstone, or where the weathering extends well below the surface (as for example in the deep sandy soils in the Tolwong area and outcrops of Berry siltstone.) In areas of poor drainage, acid peat soils, with a high organic content are found. Podzols may be present on deep, well-drained sands. Deep red, clayey kraznozemic soils occur on the basalt emplacements.

A likely sequence from least to highest nutrient levels in soil types is:

Skeletal ≤ Peat ≤ Yellow Earths,Podzols ≤ Colluvium,Alluvium ≤ Kraznozems

Consequently, a likely sequence of vegetation communities from least to highest nutrient levels is:

Heath ≤ Sedgeland ≤ Scribbly Gum, *E.punctata* complex ≤ *E.tereticornis* ≤ Rainforest, *E.fastigata*-*E.fraxinoides*

**General Prediction**: Vegetation distributions are observably related to geology and physiography, but are expected to be even more strongly related to soil nutrient levels.
4.4.2 Assessment of the Effects of Soil Nutrient Levels

(i) Methods

Soils were sampled from the major community types for analysis. Samples were taken at ten centimetres depth, or just under the surface in soils shallower than ten centimetres. Two samples were taken at each site and mixed to ensure evenness of sampling.

Available nitrates, phosphates and potassium were analysed by Australian Fertilizers Ltd., using the Colwell (CSIRO) method (Colwell 1965). In this method, nitrates and phosphates are extracted from the soil by being tumbled in sodium carbonate solution at pH 8.5 over a sixteen hour period. This enables an estimation of freely available phosphorus and nitrogen, as opposed to the total soil content of these nutrients. A similar extraction procedure was used for potassium, but substituting barium chloride solution. Available calcium, magnesium, manganese and zinc were extracted using a weak acid (0.5 normal acetic acid) and measured on the Atomic Absorption Spectrophotometer at Wollongong University.

(ii) Results

These are summarised below and on the accompanying graph.

Nitrates

The majority of soils contained negligible freely available nitrates. The exceptions were rainforest on basalt and *Eucalyptus tereticornis* forest (Table 4.3).

Phosphates

Values of readily available phosphates were low (under 10 ppm) in all soils except *E. fastigata* forests, in which levels were above 14 ppm in all samples, and in sedgelands, in which three of four samples had values above 10 ppm.

Potassium and Calcium

Readily available quantities of these nutrients were relatively low in heath, sedgeland, scribbly gum, silvertop ash - um-fruited peppermint and yertchuk-red bloodwood units
and relatively high in brown barrel, ironbark, forest red gum, rough-barked apple and rainforest (Table 4.3).

**Magnesium**

Freely available magnesium was low in heath, scribbly gum, sedgeland (under 20 ppm), intermediate in silvertop ash and red bloodwood- yertchuk (about 30 ppm) and relatively high in brown barrel, ironbark, forest red gum, rough-barked apple and rainforest (65-90 ppm).

**Zinc**

Levels of this nutrient were similar throughout the various communities, and ranged from averages of 2 to 5 ppm.

(iii) **Analysis of results**

**Soil Nutrients and Rock Type**

The expected nutrient sequence from the least fertile sandstone to the most fertile basalt was obtained, viz.:

Sandstone and Quartzite ≤ Siltstone ≤ Alluvium, Colluvium ≤ Basalt

The soils overlying Permian sandstones and Devonian quartzites were low in nutrients, whereas those overlying siltstone (Berry or Wandrawandian) tended to be higher in nutrients. Highest levels of nutrients were found in soils overlying basalt, with levels of most nutrients being next highest in alluvial and colluvial soils (Table 4.3).

(iv) **Conclusions**

As predicted, nutrient levels were found to vary from community to community. The expected general trend in nutrient levels from lowest to highest: Heath ≤ sedgeland ≤ Scribbly gum/ *E. punctata* complex ≤ *E. tereticornis* ≤ Rainforest, *E. fastigata- E. fraxinoides* was confirmed.

Extremely low levels of nutrients were consistently measured in heathland soils. Sedgelands had extremely low levels of all nutrients except phosphate, which was found to be higher in sedgeland than in all other vegetation communities except *E. fastigata*..
Scribbly gum forest had low levels of all nutrients. Levels of most nutrients in *E. sieberi- E. piperita ssp.urceolaris* and *E. punctata- E. consideniana- E. gummifera* forest, although still low, are slightly higher than those in the preceding communities. Relatively high levels of nutrients were found in Ironbark, *E. tereticornis, E. fastigata, Angophora floribunda* forests and in rainforest. Phosphate levels were consistently higher in *E. fastigata* forest than in other types of forest. Extremely high levels of calcium were recorded at four of the five *E. tereticornis* sites. Levels of manganese tended to be higher in basaltic soils supporting *E. fastigata* forest or rainforest. However, not all of the sites occupied by either of these two communities had high manganese levels.

**Statistical Analysis**

Discriminant analysis was applied to the soil nutrient data. This is an ordination technique in which the discriminating variables are mathematically weighted and linearly combined to render them as statistically distinct as possible (Klecka 1975). One or more linear combinations of the discriminating variables are formed, called "discriminating functions". These are of the form

\[ D_i = d_{i1} Z_1 + d_{i2} Z_2 + \ldots + d_{ip} Z_p \]

\( D_i = \) score of the discriminant function
\( d's \) are weighting coefficients
\( Z's \) are standardised values of the \( p \) discriminating variables

The discriminant functions can be thought of as axes in geometric space and can be used to study the spatial relationships amongst the groups.

For the analysis, vegetation communities were grouped into the classes shown in Tables 4.4 & 4.5. The analysis was used primarily as a classification technique, in which the set of variables which are found to most satisfactorily discriminate the cases (plant communities) are used to predict the membership of all plant communities. A separate linear combination of the discriminating variables is used for each plant community. This produces a probability of membership in the respective community and each case is assigned to the community in which it has the highest probability of belonging. The analysis used Fisher's linear discriminant function (Fisher 1936). In the classification
test, the appropriate group membership of the separate communities is predicted on the basis of the results of the discriminant analysis. All communities showed a 60-100% correct classification on the basis of soil nutrients taken as a whole, meaning that the distribution of the vegetation communities could be explained to this considerable extent by soil nutrients alone. These results are summarised in Table 4.7. Given the small sample sizes (between 10 and 2, a total of 62 samples, see Tables 4.4 & 4.5) and the number of environmental parameters to which vegetation may relate, this is considered to be an extremely successful prediction rate, proving the general prediction that the vegetation distributions in this area are strongly related to soil nutrient levels.

The correct classification based on any single nutrient was 18 - 31%. This indicates that, while nutrients taken as a whole are a good explainer of vegetation distribution patterns, no single nutrient explains all of the observed variations. The results suggest that the synergistic interaction of all available plant nutrients affects the distribution of vegetation much more than variations in any single nutrient.
4.4.3 Moisture Availability

(i) Introduction

Most of the fieldwork for this thesis was conducted during drought conditions and it was possible to observe the extremes of dryness to which the area is subject. Areas of sedgeland and "wet" heath were dry underfoot. Probably all of the vegetation of this area suffers water-stress at some time and must therefore be able to survive this condition. Moisture availability must limit plant growth in all habitat types throughout the area, to a greater or lesser extent. As a factor which is at times scarce, it is likely to be an extremely significant pattern determinant, with different plant species reaching the limit of their tolerance of water stress in differing habitat types.

At the other extreme, waterlogging during wet times and the resultant anaerobic soil conditions and acidity (pH 3.5-4) may strongly influence vegetation distribution patterns in these areas.

Vegetation patterns likely to be influenced by moisture regime:

(i) Vegetation changes with aspect observed on the slopes of the Northern Budawangs mesas and the Ettrema "knolls".

(ii) Changes sedgeland » heath » scribbly gum which occur around watersheds.

(iii) Variations within the vegetation of the Nowra sandstone of the Ettrema plateaux from high point (heath) to gullyhead (*Eucalyptus agglomerata*, *E. piperita* ssp.*urceolaris*).

(iv) The ridgelet and gullylet patterns on the slopes of the Ettrema gorges.

(v) Gradients in vegetation from top to bottom of slopes are (where there are no geological changes) likely to be related to a soil moisture gradient [e.g. on Wandrawandian strata of mesas, *E. sieberi* (upslope), *E. piperita* ssp.*urceolaris* (downslope)].

(vi) Parallel banding of heath/scribbly gums- grey gum- yertchuk- red bloodwood on parts of the Ettrema plateaux may be attributable to moisture balance variations.
(ii) Assessment of the Effects of Moisture Regime

Soil moistures were measured for the sixty two samples collected (Fig. 4.4). However, because of the variability of results, only limited conclusions can be drawn from this data.

General Indications

The soil moisture averages and ranges of variation give a general indication of higher values in sedgeland, rainforest and *Eucalyptus fastigata* forest. This is as predicted. They also show values clustered at two levels of moisture in heathland: this supports the prediction that some of these areas are subject to periodic waterlogging, as well as extremes of dryness.

It is expected that the range of values displayed by all of the vegetation communities would be larger with an increased sample size.

Data from Individual Field Trips (Table 4.8)

Data collected within two or three consecutive days with constant weather conditions probably gives a more reliable indication of the relative soil moistures of the different vegetation types than averages of data collected on different field trips in differing weather conditions.

A number of samples were collected on two field trips in the Northern Budawangs:
1) Galbraith Plateau - Endrick Mt. - Styles Creek (twelve samples)
2) Monolith Valley - Mt.Bibbenluke (eight samples)

The results consistently indicate a close relationship between soil moistures and topography, in particular aspect, distance from creek and position on slope. Vegetation association is generally consistent with aspect on the mesa-slopes, but is not always consistent with soil moisture regime throughout its range. For example, on Mt.Endrick, *Eucalyptus piperita* ssp.*urceolaris* occurs on moist south-facing slopes and at the other extreme, on dry soils at Camp Rock. A strong connection between aspect, soil moisture and vegetation type was observed on Mt. Owen and Bibbenluke, with soil moistures in the order SE > E > N slopes, with vegetation varying accordingly. There is a gradient in soil moisture from top to bottom of slope, those at the top being driest, and those at the bottom moistest. The relationship between vegetation and position on slope is not as
sensitive as that between soil moisture and position on slope, at least at the level of change in tree species. Devonian quartzites near Styles Creek gave a moderate soil moisture reading adjacent to the creek and a low reading three metres from the creek. Both sites support heath, although the species composition differs between the two sites. For example, the near-creek site supports two rare species: *Boronia rhomboidea* and *Kunzea* sp.nov."B", both absent from the drier site. The distributions of heath versus Silvertop Ash cannot be separated relative to soil moisture alone, with both occurring on soils with moderate to low moisture levels. This is a variation from prediction, as it was expected that heath sites (other than wet heath) would be drier than Silvertop Ash sites.

(iii) Discussion of Results

The findings reported here, although sketchy, support a separation of vegetation communities into two groups:

i) those with high soil moistures, which are:
Rainforest, *E. fastigata* and Sedgeland

ii) those with lower soil moistures.

Although the relationship between aspect, soil moisture and vegetation community on mesa-slopes is consistent, communities which occupy a particular aspect/moisture regime range on mesa-slopes do not consistently occupy those ranges throughout the area surveyed.

These data may best be considered as a preliminary to further investigation.

4.4.4 Temperature

This affects germination and growth rates of plant species. Hence the east-west temperature gradients across this area are likely to influence vegetation distribution patterns.

Assessment of the Effect of Temperature

Average temperatures on the western side of Ettrema-North Budawangs are lower than those on the coastal side, as assessed from available climatic data (see 2.5). There are
many species whose distribution is restricted either to the east or to the west of the Morton wildernesses, such as *E. eximia*, *E. gummieresa*, *E. piperita ssp. urceolaris*, and *Syncarpia glomerulifera*, which are restricted to the east) and *Eucalyptus rossii*, *E. pauciflora* and *E. dives*, which are restricted to the west (see Table 4.1). These distributional limits may well be related to variations in temperature tolerance. In many cases, their distribution pattern is also linked with a particular rock stratum (e.g. *Syncarpia glomerulifera* on Wandrawandian strata), indicating that moisture availability and nutrient levels are also factors determining distributions.

Actual assessment of the effect of temperature would include plant growth trials for frost tolerance and precise in-field measurements of diurnal temperature ranges over a period of years. Both were considered to be beyond the scope of this thesis.

**4.4.5 Vegetation Distribution Patterns and Topography**

To test the prediction that vegetation distribution patterns would be more precisely related to plant growth factors than to the features of the environment, the topographic parameters of aspect, slope and altitude were measured at the sixty two sites at which soil were sampled.

These data were included in a Discriminant Analysis with soil nutrients. The subsequent classification based on topography was relatively low. Whereas soil nutrients as a whole led to a sixty percent correct classification, topography as a whole resulted in only a thirty-five percent classification. Correct classification on aspect alone was seventeen percent, on slope ten percent and on altitude twenty percent.

To further test the extent to which vegetation distribution could be related to topography, data from all field trip routes was compiled from the available 1:25000 topographic maps and analysed in a separate discriminant analysis. Data from a total of three hundred and five sites was included. Again the percent correct classification based on topography was low. Topography (plus latitude and longitude) as a whole gave a twenty eight percent correct classification. The correct classification on aspect alone was four percent, on slopes (maximum and minimum) was eleven percent and on altitude six
percent. The correct classification on the basis of latitude and longitude was eleven percent.

Conclusions

Although vegetation distribution patterns are always related to topography, with the connection being observably strong in places (e.g. mesa-slopes), over the whole of Ettrema-Northern Budawangs, the relationship between vegetation and topography was not consistent. A particular vegetation community will occur in a particular topographic location in one area and in different topographic locations in areas nearby. The relationship between vegetation and soil nutrients proved to be a lot more consistent.

4.4.6 Final Conclusions: Vegetation Distribution Patterns and Plant Growth Factors

Vegetation can be expected to assort primarily according to the most important plant growth factors, which are nutrient levels and moisture balance.

In the Northern Budawang Ranges and in the Ettrema area, the major vegetation distribution patterns are observably subject to geological control, which it was thought would act mainly through variations in soil nutrient levels. The expected correlations were found.

Soil moisture levels (as well as nutrients) are thought likely to be important in determining variations within a single geological stratum. The number of sites sampled was not large enough to draw many firm conclusions concerning moisture balance.

Broad climatic changes in temperature, rainfall and wind patterns which occur across the latitude and longitude of the area will also influence vegetation patterns according to their effects on plant growth factors. The numerous distributional cut-offs in the area are probably a result of climatic changes in most instances.

It was expected that vegetational distributions would vary more consistently according to basic plant growth factors than to environmental features such as topography. This proved to be true when aspect, altitude and slope were compared with soil nutrients as discriminators of vegetation.
Table 4.1: Limits of Distribution of Eucalypt Species

(i) Ettrema

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Air Photo Number</th>
<th>Species</th>
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<tbody>
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<td><em>E. rossii</em></td>
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<td></td>
<td>91</td>
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</tr>
<tr>
<td></td>
<td>92</td>
<td><em>E. punctata?</em> <em>E. punctata?</em> Turpentine?</td>
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<td>93</td>
<td><em>E. gummifera</em> <em>E. piperita</em> <em>E. imitans?</em> Turpentine <em>A. floribunda</em></td>
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<td><em>E. eximia</em> <em>E. gummifera</em> <em>E. piperita?</em> <em>Ironbarks</em> <em>E. imitans</em> Turpentine <em>A. floribunda</em> <em>A. bakeri</em> <em>E. punctata?</em></td>
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Table 4.1: Limits of Distribution of Eucalypt Species (i) Ettrema cont.

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Table 4.1: Limits of Distribution of Eucalypt Species

(ii) North Budawang Range

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Table 4.3: Summary of Soil Analyses

Mean values of available nutrients, soil moisture and organic matter

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<th>P ppm</th>
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Table 4.4: Soils: NPK: Vegetation Classes
(Values are available nutrients in parts per million)

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<td>2</td>
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| BB2   | 2 | 40 | 190 | 23 | 50 | 8.3 | 5.7 | 140 | 0.5 | 671 |
| BB3   | 2 | 26 | 220 | 94 | 20 | 11.8 | 5 | 90 | 0.4 | 730 |
| BB4   | 2 | 18 | 100 | 84 | 96 | 22 | 4.3 | 140 | 0.1 | 735 |
| BB5   | 2 | 16 | 180 | 128 | 100 | 59 | 5 | 0 | 0 | 750 |
| BB6   | 2 | 14 | 160 | 12 | 50 | 17 | 3.8 | 270 | 0.2 | 620 |
| BB7   | 2 | 20 | 100 | 232 | 200 | 88 | 5.3 | 0 | 0 | 700 |

| I1    | 2 | 5 | 80 | 5.5 | 21 | 5.5 | 3.8 | 180 | 0.2 | 720 |
| I2    | 2 | 5 | 50 | 0 | 19 | 5 | 4.5 | 360 | 0.5 | 839 |
| I3    | 2 | 10 | 30 | 5 | 50 | 5 | 18.3 | 90 | 0.1 | 732 |
| I4    | 2 | 5 | 70 | 0 | 21.5 | 5 | 5.2 | 320 | 0.2 | 717 |
| I5    | 2 | 8 | 30 | 7 | 24 | 1.5 | 2 | 180 | 0.25 | 680 |
| I6    | 2 | 5 | 120 | 6.5 | 23.5 | 5.8 | 3.5 | 360 | 0.25 | 630 |
| I7    | 2 | 5 | 40 | 2.5 | 15 | 5.5 | 3.8 | 270 | 0.67 | 700 |
| I8    | 2 | 8 | 60 | 27.5 | 24 | 5 | 2.5 | 360 | 0.125 | 700 |
| I9    | 2 | 5 | 30 | 3 | 72 | 2.6 | 2.5 | 360 | 0.125 | 700 |
| I10   | 2 | 5 | 170 | 256 | 92 | 9.3 | 3.3 | 90 | 0.25 | 160 |
| I11   | 2 | 5 | 170 | 168 | 200 | 14 | 5 | 270 | 0 | 400 |
| I12   | 2 | 4 | 100 | 162 | 92 | 38 | 4.3 | 270 | 0.2 | 650 |

| Sg1   | 2 | 12 | 30 | 0 | 21 | 5 | 3.8 | 0 | 0 | 869 |
| Sg2   | 2 | 5 | 120 | 5 | 14 | 3.6 | 3.8 | 0 | 0 | 824 |
| Sg3   | 2 | 16 | 50 | 0 | 8.5 | 0 | 2 | 360 | 0.1 | 700 |
| Sg4   | 2 | 22 | 30 | 0 | 17 | 0 | 0 | 270 | 0.1 | 680 |

| Y1    | 2 | 5 | 30 | 2.5 | 21 | 2.6 | 3 | 0 | 0 | 440 |
| Y2    | 2 | 10 | 70 | 0 | 19 | 3.8 | 2.8 | 0 | 0 | 440 |
| Y3    | 2 | 5 | 20 | 5 | 20.5 | 0.5 | 2 | 0 | 0 | 440 |
| Y4    | 2 | 28 | 160 | 69 | 58 | 7.3 | 4.8 | 0 | 0 | 480 |
| Y5    | 2 | 5 | 20 | 2 | 12.5 | 3.8 | 2 | 270 | 0.1 | 550 |
| Y6    | 2 | 5 | 90 | 2 | 21.5 | 2.5 | 2 | 0 | 0 | 700 |
| Y7    | 2 | 10 | 50 | 6.5 | 25 | 5.3 | 2.8 | 0 | 0 | 765 |
| Y8    | 2 | 10 | 110 | 9.5 | 55 | 6.5 | 4.5 | 360 | 0.1 | 750 |

| Af1   | 2 | 5 | 90 | 99.5 | 44 | 7.8 | 2.3 | 0 | 0 | 200 |
| Af2   | 2 | 10 | 200 | 172 | 88 | 13.5 | 4.5 | 0 | 0 | 200 |
Table 4.6: Discriminant Analysis Data  
continued

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<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Mn</th>
<th>Zn</th>
<th>Aspect</th>
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Table 4.7: Discriminant Analysis:
Summary of Re-Classification Results

Predicted Group Membership: Percent of Grouped Cases Correctly Classified

Table 1a: Nutrients

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Correctly classified: 61.67%

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Correctly classified: 38.33%

Table 1c: Reclassification by Nutrients plus Topography

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Correctly Classified: 73.33%
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</tr>
<tr>
<td>Endrick Mt.</td>
<td>S slope</td>
<td>37</td>
<td><em>Eucalyptus piperita</em></td>
</tr>
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<td>Endrick basalt</td>
<td>flat</td>
<td>31.79</td>
<td><em>Doryphora sassafras</em></td>
</tr>
<tr>
<td></td>
<td>flat</td>
<td>25.37</td>
<td><em>Eucalyptus fastigata</em></td>
</tr>
<tr>
<td>Styles Ck</td>
<td>creek bank</td>
<td>6.41</td>
<td>Heath</td>
</tr>
<tr>
<td>Endrick Mt.</td>
<td>E slope</td>
<td>4.22</td>
<td><em>Eucalyptus fastigata-</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><em>E.fraxinoides</em></td>
</tr>
<tr>
<td>Camp Rock</td>
<td>flat, shallow soil</td>
<td>4.04</td>
<td><em>Eucalyptus piperita</em></td>
</tr>
<tr>
<td>Endrick Mt.</td>
<td>N slope</td>
<td>3.99</td>
<td><em>E.sieberi</em></td>
</tr>
<tr>
<td></td>
<td>W slope</td>
<td>3.92</td>
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<td></td>
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<td><em>E.consideniana</em></td>
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<td>Bhundoo Hill</td>
<td>slope to creek</td>
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<td>Heath</td>
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<td>Styles Ck</td>
<td>23m. upslope</td>
<td>1.65</td>
<td>Heath</td>
</tr>
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Fig. 4.4  % Moisture : Ranges of Variation

Plant Community

% Moisture
Fig. 4.5: Average Nutrients in Plant Communities

Nutrients (p.p.m.)

- **Mg**
- **Mn**
- **Zn**
- **K**
- **Ca**
- **P**
- **N**
Plate 4.1: Mt. Tarn viewed from the N.W. slope of Mt. Cole

Middle Ground: Heathland on sloping surface of Snapper Point sandstone
Plate 4.2: Extension of heath upslope

(i) Mt. Hoddle

(ii) Mt. Bibbenluke
### Abbreviated Contents: Volume II

**Section 2: Change through Time**

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5. Effects of Environmental Disturbance on Vegetation

5.1 Introduction

In the first part of this thesis, the spatial patterns of vegetation and the relationships between vegetation and environment were considered as if they were static phenomena. Yet, since the environmental factors to which vegetation relates vary over time, vegetation will also vary. Temporal responses of vegetation to disturbance can be expected to be complex, since they are governed not only by change in the environment, but also by intrinsic factors, such as the rate at which a genotype pre-adapted to a changed environment can be dispersed, or the rate at which adaptation can take place within existing species to an environmental change. If dispersal rates are slower than rate of environmental change, if changes have occurred recently, or in a cyclic fashion, then current day vegetation must reflect previous regimes to a greater or lesser extent.

The aim of this chapter is to assemble information concerning environmental disturbance and the effects of disturbance on vegetation. This information provides a basis in later chapters for interpreting the influence of temporal disturbances on the observed spatial patterns in the Ettrema/Northern Budawangs vegetation. The possible sequence of effects of disturbance in the environment on vegetation are modelled in Fig. 5.1, which is discussed in 5.2. Types of disturbances which are known to have occurred are outlined in Section 5.3. In 5.4, the question of the time periods involved in the sequences of events depicted in Fig. 5.1 is examined. In Section 5.5, it is shown how Connell's 'Intermediate Disturbance' hypothesis in conjunction with a knowledge of the general trends of climatic change can be used as a means of deciphering the imprint of time in current vegetation patterns. In 5.6, an outline of relevant aspects of climatic change is drawn from the mass of literature on this subject. A more detailed review of the literature on this subject is included as an appendix at the end of this thesis (Appendix 2).
5.2 A Theoretical Model of the Effects of Disturbance in the Environment on Vegetation

Disturbance will predictably set off a chain of events in any plant community. Predictable sequences of events following disturbance are modelled in Figure 5.1. The impact of change is twofold: natural selection will be initiated, as well as changes in the distribution of species and the composition of communities. The speciation pathway is depicted on the right-hand side of the model, while the sequence of distributional changes is modelled on the left-hand side.

Changes at the Evolutionary Level

Some species will be favoured by a particular change and increase in numbers. As depicted on the right hand side of Figure 5.1, the speciation pathway may be initiated, with an increase in variability being followed by the formation of local and geographical races and possibly new biological species, depending on the length of the period of disturbance and whether it effectively creates a situation equivalent to geographic isolation. Other species may be disadvantaged by a particular disturbance with the result that their distribution contracts and they become rare and eventually extinct. The rate of changes at the species level will depend on intrinsic rates of speciation and how these are influenced by the disturbances which occur. The effect of disturbances will vary, depending upon the type, magnitude and pattern of disturbance, in particular, whether disturbance is unidirectional (e.g. anthropogenic disturbances, such as change in fire frequency) or cyclic (e.g. climatic fluctuations). If cyclic, the duration of disturbances and the time interval between them will affect the extent to which the selection process proceeds in one direction before being reversed. Cycles of long or short duration might result in the loss of the adaptations produced by one or other element of the cycle of change, while cycles of intermediate duration may result in the retention of adaptation to both aspects of the disturbance cycle. For example, taxa exhibiting a bimodal distribution of morphological characters, such as the mallee/tree pairs of closely related eucalypts,
could be interpreted as a response to selection pressures resulting from alternating cyclic disturbance.

Changes at the Distributional Level

There is a sequence of distributional changes likely to occur as a result of disturbance. These are depicted on the left-hand side of Fig. 5.1. Any disturbance will result in the expansion in the distribution of some species and contraction in the distribution of others. Community boundaries may shift altitudinally or latitudinally or in relation to other spatially continuous or discontinuous environmental variables. Some species /communities may react rapidly to change, while others may react slowly.

Distributional expansions may result in overlap of species which were previously separate. Greater complexity in distributional patterns will be one result of such overlap. Greater instability in communities is another predictable result of distributional expansions. This will occur when species previously separated are brought into distributional overlap as a result of disturbance. These species may have the potential to hybridise, and, should their distributional overlap be perpetuated, such a community could be expected to change in composition. Depending on the time interval between disturbances, species and communities may have time to readjust, or alternatively, their complexity and instability may be further accentuated by each successive disturbance. Palynological evidence suggests that just such a process has taken place. For example, Peters (1988) cites examples from North America of past vegetation contractions and expansions and uses this evidence to make general predictions about vegetation changes into the future, as a result of anthropogenic global climatic change (i.e., the "Greenhouse effect").

Connell's "Intermediate Disturbance" hypothesis (discussed in 5.5) interprets community diversity in relation to levels of disturbance.
5.3 Types of Disturbance

In the Ettrema/Northern Budawangs, disturbances may be categorised as either climatic or anthropogenic. It appears at this point that instability of landsurface can be eliminated as a disturbance factor across the sandstone due to the ancientness of the landscape (this point is elaborated in (ii) below).

Relevant details of climatic changes are briefly summarised in Section 5.6 of this chapter. Of disturbances associated with the arrival of firstly, aboriginal man and much more recently European man, fire may be of particular importance. This is discussed in Chapter 8. Other disturbances include logging, clearing and alterations in grazing regimes, following the disappearance of the mega-marsupials in the late Quaternary and the introduction of cattle, sheep and goats in the last two hundred years.

(i) Climatic Change as an Intermediate Disturbance

Although there have been variations in the Australian climate during the Quaternary, these have been of a lesser magnitude than those in other parts of the world which have been subjected to repeated glaciation (Bowler et al. 1976, Frawley & Semple 1988, Colhoun 1991) and, as gauged by pollen records (Martin 1978, Kershaw 1981, Kershaw 1988), have resulted in change, but not in the destruction of whole floras. These changes might therefore have functioned as an intermediate level of disturbance through time.

(ii) Landform Evolution as a Disturbance Factor: Ancient Sydney Basin Landscape

In the area studied in this thesis, it is now believed that the landsurface is particularly stable. It is thought that the sandstone landscapes of the Sydney Basin are ancient and have not been subjected to uplift, rapid erosion or other disturbance for a long period of time (Young 1978, 1982). In the Ettrema/Northern Budawangs, Young & McDougall (1985), on the basis of dating and emplacement of basalt flows in relation to topography, estimated that the landsurface has been stable since the mid-Eocene at least. It appears
therefore that landform change is unlikely to have been a factor disrupting the equilibrium of vegetation in the study area.

(iii) Fire as a Disturbance Factor

The pollen record for eastern Australia shows increases in scleromorphic taxa in the current interglacial period which are not synchronous with glaciation and are accompanied by an increase in charcoal (Kershaw 1988, Head 1989). This seems to be a fairly definite indication of uni-directional change in vegetation in response to increased fire frequency. It follows that fire sensitive species would have diminished or have become contracted in their distributions from about this time and expansion of fire-resistant species would have been initiated. This apparently marked change in fire frequency would also have stimulated the commencement of a period of rapid selection of fire-resistant characters within plant species, from pre-existing adaptations, such as those found in scleromorphic genera (lignotubers, epicormic sprouting, large woody seeds, microphyll etc.).

Many species are able to survive fire, and display various response mechanisms to and rates of recovery following fire (Benson 1985, Muston 1987, Whelan 1986, Fox 1988, Bradstock & Myerscough 1988, Glasby et al. 1988). Bowman et al. (1988), reported the results of a thirteen year experimental annual burning study in an area of coastal forest and woodland in the Northern Territory. They found that there was little difference in structure and floristics after this period and concluded that the eucalypt communities there have had a sufficiently long history of dry season burning for vegetation patterns to be primarily determined by edaphic factors.

These research results suggest that, as a result of high fire frequencies in Australia in the last one hundred years, fire sensitive vegetation may already be confined to fire-sheltered locations. As long as high frequency burning regimes are maintained, the vegetation in many areas may not proceed past a fire climax to the stage of (interpreted according to Connell's hypothesis) maximum diversity, where the fire climax vegetation overlaps with the climatic climax vegetation. However, viewed in terms of the slow rates at which evolution and dispersal occur, it seems unlikely that vegetation could have
already reached a static level in terms of its adaptation to the suspected increased fire frequencies in the last interglacial period (from 130,000 BP). Although Connell’s hypothesis may be less applicable in relation to this factor, diversity in relation to higher fire frequencies may be proceeding in a unidirectional fashion, as adaptation to this change proceeds. The fragmentary distributions of some rare species may be related to altered fire regimes.

5.4 Time Taken for a Vegetation to Adapt to Environmental Change

The times taken for the processes depicted in Fig. 5.1 to occur following an environmental change would vary considerably. There is no such thing as the rate of evolution (Simpson 1949). Patterns of distributional expansion, as evidenced by the analysis of succession (Daubenmire 1968) or by palynological analysis (Peters 1988), differ from habitat to habitat. The information below provides a theoretical basis for estimating the orders of magnitude of times involved.

The geographical theory of plant speciation in its modern form is well explained by Grant (1981). Geographical races are the precursors of species in a continuous process of evolutionary divergence. The speciation pathway, starting with polymorphic variation within a species and continuing through local races, followed by geographical races and then species, is well documented (examples in Grant 1981). Isolation at the racial stage enables separate populations to develop and maintain the gene combinations determining their distinctive morphological and physiological characteristics. The isolation necessary for speciation to occur can be caused by environmental disturbances.

Fluctuating disturbance, such as climatic change, may cause populations to alternately contract, causing reproductive isolation and then expand, causing overlap. The timing of the fluctuations is relevant. Speciation may only occur if periods of contracted distribution (and hence reproductive isolation) are of sufficient duration (Boucot 1978).

The geological record indicates that evolution has been episodic, with long stable periods during which individual species underwent little modification, and relatively short
periods of rapid diversification (Darwin 1872). Similarly, communities of fossil taxa display a remarkable constancy through time, with rapid change generally occurring only after there have been significant changes in the environment (Boucot 1978). High rates of evolution may occur at the middle, beginning and/or end of the radiation of any particular group of animals (Simpson 1949).

The stages in the evolutionary life of a biological species include a period or periods of radiation, followed by decline. Hybridisation is a characteristic feature of plant evolution. Grant (1981) described the phylogeny of plants as being reticulate or anastomosing, rather than dichotomous, as in animals. This is a result of cyclical phases in plant evolution: divergence and hybridisation. Hybrid progeny better suited to a changed environment than their parents may become stabilised as new taxa as a result of genetic isolation. Many (but not all) methods of perpetuating particularly favourable gene combinations (that is, genetic events which effect reproductive isolation) in plants accomplish this end by imposing strong restrictions on gene recombination. This pattern of evolution by initial polyploidy followed by disploidy has been documented in many Australian families, for example Rutaceae, Epacridaceae and Proteaceae and many others (James 1981). The resulting species may rapidly expand its population during the period when the environment is favourable. When the environment changes, however, they may be unable to adapt, and the species may then enter a period of decline. James (1981) emphasised the reduction in genetic flexibility and evolutionary potential of these increasingly restrictive genetic systems. He argued that the polyploid genetic systems would be preserved in a constant environment, but would have a high rate of extinction in a "situation of environmental dynamism" (= a changing environment).

The family Myrtaceae differs from many other Australian plant families in that polyploidy appears to have played a relatively minor role in the evolution of the family and none in the origin of its genera (Smith-White 1959). Polyploidy is unknown in Eucalyptus, the usual chromosome number being 2n=22 (Pryor & Johnson 1975). In contrast, Boronia, displays a range of chromosome numbers in different species (Smith-White 1959) by means of which its evolutionary radiations may be traced (Weston,
Carolin & Armstrong 1984). The relative flexibility of *Eucalyptus* may well be related to the absence of restrictive chromosomal evolution.

The significance of these ideas in this theoretical appraisal of the effects of change through time on vegetation is in the modification of the view of evolution as a series of single radiations and declines of species, or species groups. Particular plant groups (such as *Eucalyptus*) may retain sufficient genetic flexibility to continue radiating under changing environmental conditions, whereas others (such as *Boronia*), may have originated in similar environments, yet be nearer to extinction as the result of an evolutionary direction towards increasing genetic (and consequently environmental) inflexibility.

There would be time-lags between environmental disturbance and species change (both at a community level and, over longer time periods, at the level of species evolution). This is exemplified by the sequence of postglacial community changes documented from peat fossils for both North America and Europe, in which Taiga vegetation rapidly invaded bare areas and was then slowly replaced by steppe or temperate forest (summarised in Daubenmire 1968). The rarity of certain species in Ettrema and Northern Budawangs may well be a reflection of such time lags.

**Likely Pre-Adaptation**

Given the likely rarity of favourable new mutations, it can be deduced that the modern-day species are likely to have been formed predominantly from the pre-existing genetic pool contained within the various taxa. Selection of favourable genotypes from this pool would depend on the frequency of occurrence of that genotype, which would in turn depend on time since an environment favouring that genotype previously occurred and the genetic flexibility of the particular taxon.

The implications of this are that characters that we consider to be adaptations to modern disturbances, such as high fire frequency, may have initially evolved as a response to some other disturbance. For example, the occurrence of bud tissue either underground or beneath the bark of the woody stem or trunk is widespread in angiosperms (Raunkiaer
Sprouting may be evoked by a variety of agencies, and hardseededness may be associated with many environmental factors (Gill 1981b).

**Age of Existing Genera**

A major clue to the rate of speciation of the Australian plant genera comes from the hypothesised age of existing genera. Smith-White (1959) suggested that modern species in the autochthonous Australian flora have evolved post mid-Miocene when the east became cut off from the west by the development of aridity in the centre of the continent (about 16 million years ago). Many modern genera, thought to have come into existence before this time, as evidenced by their presence in both eastern and western Australia (e.g., the Myrtaceous *Eucalyptus*, *Leptospermum*, *Kunzea*, *Baeckea*, *Melaleuca*, Proteaceous *Banksia*, *Grevillea*, *Goodenia* and *Dampiera* from the Goodeniaceae, the Epacrids *Leucopogon*, *Brachyloma*, *Styphelia*, and Fabaceae *Pultenaea* and *Dillwynia*, to name a few from a long list, can thus be dated as in excess of 16 million years old). *Eucalyptus* and the other common genera in Ettrema/North Budawangs are included in this group. It appears then, that many of the existing genera are of great antiquity.

Substantiating information comes from the pollen and megafossil record. Both pollen and megafossil data suggest that the scleromorphic element of present-day Australian vegetation was probably present at least as far back as the early Tertiary. Martin (1978), in a review of over fifty Tertiary pollen assemblages, reported a remarkably high incidence of Proteaceous pollen in early Tertiary deposits. Eucalypt-type pollen has been identified as far back as the Oligocene (Martin 1981). Eucalypt leaf fragments have been found dating back to the Eocene (Chapman 1937), and full leaf and capsular ranges of fossil eucalypts have been found dating at least as far back as the Miocene, and possibly as far back as the Eocene-Oligocene (Lange 1978, Ambrose *et al.* 1979, Holmes *et al.* 1983).
Rates of Speciation

Nordal (1987) maintained that rates of speciation in herbaceous plants in post-glacial Scandinavia may have been rapid. He used a narrow concept of taxonomic species, i.e. with "a single mutation (?) with distinct phenotypic effect being enough to create a new species". As he explained, many of these species could have originated as a result of hybridisation facilitated by contact between the separate species following glacial retreat. He concluded therefore that these species may be of no more than post-glacial age, i.e., not older than about 15,000 years. In this case, where bare ground would have been available for colonisation, establishment of the renovated genetic population could have been very rapid.

Rates of speciation in *Eucalyptus* may be of a similar order of magnitude. For example, no significant speciation has occurred in Tasmania in species also found on the mainland, despite its isolation (Pryor 1959b). Clinal variation observed is of a degree which could be expected over the distance separating extant populations (Ibid). The last land bridge with Tasmania is thought to have been about eight thousand years BP.

Parsons (1970) found the same species of *Eucalyptus* disjunctly distributed on several isolated dune systems on the coast of the Great Australian Bight. These disjunctions he considered, dated from the last period of marine regression in the Late Pleistocene. These taxonomic species would equate with local or geographical races, indicating that this stage (RHS of Fig. 5.1) might take a minimum of 15,000 years to come about.

Rates of Dispersal

Available data on rates of gene flow suggest that the rate at which a favourable genotype, once selected, can become established in plant populations, is limited by the effectiveness of plant dispersal, whether by vegetative means or by the dispersal of seed and pollen. Grant (1981) concluded from available data on dispersal rates that known rates of gene flow are too small to have a significant homogenizing effect on variations over large areas during 10,000-year periods in outcrossing perennial plants. Therefore "in considering gene flow on the scale of geographical races and species, it is necessary to
employ a larger time-frame encompassing many generations." Grant cited the established dispersal rate of a perennial herbaceous plant, *Liatris aspera*, which has an average dispersal distance per generation of 3.5 metres and a generation length of five years. Consequently, the cumulative dispersal range would be only 0.7km in 1,000 years or 7km in 10,000 years. Wind-blown pollen of outcrossing species might lead to a more rapid dispersal of genetic material. The natural dispersal rate of the wind-dispersed seeds of Engelmann spruce has been calculated as 1 to 20 km per century (Seddon 1971, cited in Peters 1988), a considerably higher rate than that calculated for *Liatris aspera*.

Evidence on revegetation following volcanic eruptions, for example, Krakatau (Bush and Whittaker 1991), indicates that colonisation rates such as that calculated for *Liatris aspera* might not apply in the recolonisation of bare areas. On Krakatau, the rapid recolonisation which occurred can be seen as the outcome of absence of competition and existence of plants already adapted to the prevailing conditions.

Turnover of generations may (in theory) be slowed if a species (such as *Eucalyptus sturgissiana*) is out of phase with current climatic conditions, particularly if it regenerates from vegetative parts (such as lignotubers) following disturbance. Under these conditions, in the absence of competition from other individuals of the same species and prior to invasion by a more successful species, individuals might persist for a very long time, perhaps at least as long as the 1,000 years attributed to the Californian Redwoods.

**Conclusions**

(i) The order of magnitude of time involved in speciation in relation to recent environmental changes, may be measured in thousands to millions of years.

(ii) Where speciation is probably the revelation of pre-existing adaptations, minor changes in taxa in response to environmental disturbances (equivalent to the formation of local and geographical races, as shown in Fig.5.1), may be measured in the thousands of years.
(iii) That genera, once established, may persist for millions of years, is clear from the pan-continental distribution of the majority of the autochthonous Australian genera and the Gondwanic distribution of several.

(iv) Establishment of new distributional patterns in response to disturbance, is more likely to take thousands of years than hundreds of years to reach "equilibrium."

5.5 Distributional Changes: An Explanatory Mechanism

Connell's Intermediate Disturbance Hypothesis

Connell (1978), in the Intermediate Disturbance Hypothesis, suggested a natural mechanism for the maintenance of high species diversity in relation to disturbance. Connell hypothesised that the observed high diversity of coral reefs and tropical rainforests was a non-equilibrium state resulting from disturbances recurring at an intermediate time interval. According to this hypothesis, the ecosystem would progress towards lower diversity if left undisturbed. The high levels of diversity of corals and trees in reefs and forests respectively were interpreted as the intermingling of species suited to different successional stages following disturbance, with long-term stability resulting in a reduction of the number of species to those which are the most successful in competition for resources and which are the most long-lived. Connell argued that the same reasoning could be applied to variations in intensity or area of disturbance. He hypothesised that gradual change over a longer period of time, such as change in climate, might impose an additional order of cyclic change in species, operating at a different amplitude and that this might alter the pattern of changing diversity precipitated by the more rapid cycles of disturbance in the physical environment. This hypothesis may be useful in interpreting complex distribution patterns occurring in *Eucalyptus*.
5.6 Climatic Change: Major Recurring Disturbance

Summary of General Characteristics of Climatic Change.

The following information is drawn from the very large amount of literature that has been written on this subject. Evidence suggests that there have been a wide range of climates, in the millions of years from mid-Miocene to Pleistocene.

Climatic Changes During the Quaternary

Our current climates are seen as very temporary. For 90% of this time, the earth was affected by a series of glacial and interstadial periods (Hope & Kirkpatrick 1988). Climates in eastern Australia through most of the Quaternary are thought to have been colder and probably drier. The following changes are thought to have taken place (Colhoun 1991):

>40-35 ka BP: Most Australian environments cool and moist.
35-25 ka BP: Phase of inferred cooling and drying climate
25-15 ka BP: Cold and dry
20-16 ka BP: Peak of last glacial cycle, maximum ice advance; greater aridity in most areas than at present.
15-12 ka BP: Cool, relatively dry conditions
10-5 ka BP: Warmer, maximal moisture
5 ka - present: Cooler and drier

Viewed over a longer time-frame, (since the beginning of the radiation of Angiosperms in the Cretaceous), climates have fluctuated between extremes (at different times) of warm and wet, or cold and dry, with more of the former in the Cretaceous and Palaeocene and more of the latter since then, but with cyclical changes between these two extremes becoming increasingly detectable in more recent periods of the Tertiary. The Quaternary is marked by dramatic, short-term, glacial - interglacial fluctuations, these changes being
"extremely rapid in geological terms" (Galloway & Kemp 1981). Dryness is generally considered to be a consequence of coldness sufficient to cause ice accumulation and this is confirmed by data from independent sources, such as sea levels and sea temperatures (Galloway and Kemp 1981 summarised these data). Cool, moist periods may precede coldness sufficient to cause ice accumulation (Colhoun 1991, Nansen & Price 1992). Warmness and wetness are often thought to coincide in the long-term climatic record. Climate at any time appears to have varied from place to place.

**Climate as Deduced from the Pollen Record**

The pollen record appears to show an overall general concordance with indications of climatic change in Australia derived from other sources. These include indications of change from forest to grassland, herbfield (Singh et al. 1981, Kershaw 1981, 1988) or (inland) arid vegetation coincident with cold climates during the Quaternary (Dodson & Wright 1989) and the expansion of forest in warmer and wetter times, such as at present.

**Bias in Pollen Records**

Bias in pollen records comes from a number of sources, including different amounts of pollen produced by different plants, differential dispersal and the requirements for pollen preservation.

(i) Pollen is found preserved in particular types of locations, e.g. bogs, where anaerobic conditions preventing breakdown of organic matter prevail. Here, one would expect a bias towards pollen being preserved from vegetation favouring moist conditions.

(ii) The acid conditions which prevail in bogs may result in the differential preservation of pollens.

(iii) The characteristic dispersal pattern of pollen is often very limited, with the bulk of pollen being dropped near the parent plant. Grant (1981) cited a number of examples, including *Pinus coulteri*, which was found to drop the bulk of its pollen downwind at a distance of 3 to 10 metres from its source, with only small amounts of pollen being found beyond 50-130 metres. Dispersal of cotton pollen by bees diminished uniformly away
from the source, with pollen being found up to 80 feet away). Rose (1981), reported in Holmes et al. (1983) found that bloodwood-Angophora pollen is not dispersed widely from its source. One must conclude from these studies that fossil pollen is more likely to reflect the composition of the vegetation immediately adjacent and does not take into account the ever-changing pattern of vegetation across a landscape.

(iv) An additional problem is the bias caused by varying amounts of pollen shed by different species. In a particularly thorough survey, McPhail (1979) carried out a Tasmania-wide pollen-trapping program and found that certain pollen and spore types were consistently over-represented irrespective of not of their presence in the surrounding vegetation, while others, although abundant in the surrounding vegetation, were almost never present in pollen collections. The prominent and predominantly sclerophyllous families Proteaceae, Epacridaceae, Myrtaceae (except eucalypts) and Fabaceae were amongst those rarely encountered in pollen samples.

Kodela (1990), in a study of modern pollen rain in the Robertson Area near Wollongong, NSW, found that the pollen of many rainforest species was under-represented and that there were relatively high percentages of Eucalyptus, Casuarinaceae, Asteraceae, Poaceae, Pinus, Rumex and Plantago, with all of these except Eucalyptus and being from plant sources mainly outside the survey plots. Like McPhail, Kodela found lower values of Myrtaceae other than Eucalyptus. As Kodela pointed out, these findings probably reflect relatively low pollen production from rainforest taxa. It could be postulated that tall trees producing wind-dispersed pollen (such as Nothofagus and Casuarina) are the model species for maximum pollen representation, while at the other extreme, the model species for minimum pollen representation would be low-growing herbs or shrubs producing heavy, animal-dispersed pollen.

Discrepancies between Fossil Pollen and Megafossil Data

In a synthesis of Australian vegetation history, Kershaw (1988) deduced from the pollen record that early Miocene climates were much more homogenous than today. All records examined by Kershaw contained high percentages of Nothofagus brassii,
southern conifers and a significant representation of *Myrtaceae* and *Casuarinaceae*. He inclined to the view that the data suggested the predominance of closed forest in the early Miocene. Kershaw referred to the "relatively homogenous vegetation of Australasia in the early part of the Miocene", and inferred less contrasting climates from this tenuous fossil data. Significantly, a contrary view has been obtained from megafossils. Christophel (1989) reviewed the evolution of the Australian flora through the Tertiary on the basis of megafossils, in terms of key taxa and floras. Megafossil evidence suggests that a complex closed forest system existed across southern Australia during the middle and upper Eocene. In the Oligocene/Miocene, the high diversity Eocene leaf floras are replaced by a lower diversity, far more sclerophyllous group of taxa. Christophel generalised that the floras reflected climatic deterioration. This conflicts with Kershaw's conclusions drawn from fossil pollen data that homogenous closed forest predominated across Australasia during the early Miocene. Christophel particularly highlighted the discrepancy between the pollen and megafossil records of *Nothofagus*. The *N. brassii* group, which the pollen record suggests dominated the early Tertiary is completely unknown from mainland Australia as fossil leaves. *Nothofagus* megafossils are known from Tasmania, but are completely unknown from the mainland except at one Miocene site (Bacchus Marsh, Victoria). As Christophel said, "the myth that the continent was once covered by forests of that genus must be firmly laid to rest once and for all". Christophel's views on Eocene-Miocene climatic changes based on megafossil data support much earlier views. Crocker and Wood (1947), in reviewing the problem of the origin of the Australian autochthonous flora on the basis of climatic, pedological and floristic data to that date, concluded that in the Eocene, genera such as *Eucalyptus, Hakea, Banksia* and *Persoonia* were already established across Australia. In the Miocene, warmer climates pushed this Australian element southwards and at the same time there was an incursion of the sea northwards from the head of the Bight for a considerable distance. The isolation of the eastern and western elements of the autochthonous vegetation is thought to have been maintained since the Miocene.
5.7 Aims of This Section

From the foregoing, it is clear that many spatial and temporal factors may interact, at different spatial and temporal scales, to produce the current patterns of vegetation in a landscape.

The imprint of past events is likely to be embodied in the vegetation patterns, with the influence of recent disturbances being superimposed.

The objective of this half of the thesis is to attempt to untangle the influence of changes through time on current vegetation patterns.

(i) To define the observed *Eucalyptus* associations in terms of their stability through time.
(ii) To categorise rare species in terms of their morphological and distributional characteristics and interpret these categories in terms of disturbance.
(iii) To describe the observed distributions of fire-sensitive species and interpret these in terms of the fire regime.
(iv) To draw general conclusions concerning the effects of disturbance on plants and plant communities in Ettrema/Northern Budawangs.
Figure 5.1

Effects of a Change in Environment on Vegetation

Distributional Changes

Expansion

Overlap

Instability

Complexity

Altered Vegetation Patterns

Contraction

Fragmentation

Rarity

Evolutionary Changes

Natural Selection

Speciation

local race

geneographic race

New Taxa
6. The Imprint of Disturbance through Time on *Eucalyptus* Associations

6.1 Introduction

6.1.1 Temporal Explanations for Distributional Complexity

In Section 1, spatial explanations were sought for the observed distribution patterns of eucalypts and answers were found. The associations of *Eucalyptus* and their component species (ch. 3) were often seen to vary in their relative placement and proportions, depending on readily discernible environmental gradients, such as slope or moisture. There are many visible relationships amongst associations and features of the environment such as geomorphology. More precise relationships have been established between different associations and nutrient regimes (ch. 4), and the dominating influence of nutrients on the distribution of associations disclosed.

Nevertheless, many aspects of the current distribution patterns remain enigmatic. For example, why do eucalypt species occur together in pairs (or small groups) and what is the nature of this grouping? Further understanding of these patterns is here sought in terms of how changes in the environment through time may have impinged upon the peculiar characteristics of genus *Eucalyptus*.

In 6.1.2, the peculiarities of *Eucalyptus* are drawn together, as these provide a basis for understanding the dynamics of this genus. Following this (6.2), Pryor's Rule concerning subgeneric diversity is outlined, tested and then re-interpreted in the light of evolutionary theory. In 6.4, subgeneric diversity is used as a means of interpreting the stability of the Ettrema/Northern Budawangs associations. In 6.5 and 6.6, stability and instability (as reflected in subgeneric diversity) are placed in a time-frame, based on Quaternary climatic fluctuations and using Connell's hypothesis as a tool for interpretation.


6.1.2 Characteristics of *Eucalyptus*

(i) Dominant and Diverse

"My tables show that, in any limited country, the species which are the most common, that is abound most in individuals, and the species which are most widely diffused within their own country (and this is a different consideration from wide range and to a certain extent from commonness), oftenest give rise to varieties sufficiently well-marked to have been recorded in botanical works. Hence it is the most flourishing, or, as they may be called, the dominant species,...which oftenest produce well-marked varieties, or, as I consider them, incipient species. And this, perhaps, might have been anticipated; for, as varieties, in order to become in any degree permanent, necessarily have to struggle with other inhabitants of the country, the species which are already dominant will be the most likely to yield offspring, which, though in some degree modified, still inherit those advantages that enabled their parents to become dominant over their compatriots".

(Darwin 1872)

Darwin's observations that the most dominant and widely distributed species give rise most often to varieties clearly applies to Australia's most dominant genus, *Eucalyptus*. The seven hundred species of this genus are grouped into six subgenera, within which there are many very closely related groups, which are separated into sections, subseries and superspecies (Pryor & Johnson 1975, Hill, K.D., in Harden, ed. 1991). Hybridisation can occur between the great majority of species within subgenera, but not between (Pryor 1959a, Pryor & Johnson 1981, Griffin *et al.* 1988).

(ii) "Biological" and "Taxonomic" Species

A distinction important to the temporal interpretation of *Eucalyptus* is that between biological species (to which Darwin referred) and taxonomic species. Grant (1981) defined the biological species as the "reproductively isolated system of breeding populations, that is, the sum total of interbreeding individuals." He defined taxonomic species as "groups with morphological differences that are useful in formal classification". This is similar to Mayr's 1942 definition: "Species are groups of actually
or potentially interbreeding natural populations which are reproductively isolated from other such groups". Mayr's 1982 definition adds an ecological criterion: "A species is a reproductive community of populations (reproductively isolated from others) that occupies a specific niche in nature". Mayr (1982) attributed the first clear definition of the biological species to the entomologists Jordan (1896) and Poulton (1903).

**Eucalyptus: Seven Biological Species**

The seven subgenera of *Eucalyptus* recognised by Pryor and Johnston (1975), *Blakella, Corymbia, Eudesmia, Gaubea, Idiogenes, Monocalyptus* and *Symphiomyrtus*, equate approximately with seven biological species, falling as they do, more or less, into seven interbreeding groups. The various taxonomic species within subgenera probably frequently equate with the local and geographical races of the evolutionary theorist. It is vital to define and name all the variations within *Eucalyptus* in order that the full range of variability of the biological species may be conserved. However, there is a need to understand the evolutionary position of these taxa in interpreting distribution patterns.

(iii) **Variation in Species of Eucalyptus**

Many taxonomic species of *Eucalyptus* are not genetically isolated. Links with other species are displayed in two ways, (a) hybridisation and (b) clinal variation.

**Hybridisation**

The ability of species within subgenera to hybridise is a noticeable characteristic of this genus (Pryor 1959a, Pryor 1962, Johnson 1976, Pryor & Johnson 1975, Pryor & Johnson 1981). Griffin *et al.* (1988) amassed available data on naturally occurring hybrids in *Eucalyptus*. Only fifteen percent of expected hybrids were found to occur naturally. Manipulated hybrids can be produced between most members of a subgenus. More hybrids, both manipulated and natural, were found to occur between species in the same series than between species in different series (see Pryor & Johnson 1975 and Table 6.1) and between species in the same section (Ibid) than between species in different sections.
Clinal Variation

Eucalypt species frequently vary cli
cally. Similar species of *Eucalyptus* often merge 
where their ranges overlap, with the resultant intermediate populations variably 
resembling one species or another (Pryor & Johnson 1981). Complicated groups of 
superspecies, species and subspecies may be linked in certain areas, while the same 
component taxa may remain distinct in other places (e.g. patterns of variation described 
structure of such a group to an anastomosing tree of descent, indicative of past merging 
of groups and hybrid origins of some taxa.

(iv) Evolution in Action: the Syngameon

The syngameon, defined by Grant (1981) as "the sum total of species or semi-species 
linked by frequent or occasional hybridization in nature; a hybridizing group of species. . 
. ." aptly describes the status of *Eucalyptus*. Grant cited subgenera of *Quercus*, the 
black and white oaks of North America, as examples of syngameons. Johnson (1976) in 
discussing the complexity of genetically and variationally connected taxonomic species in 
*Eucalyptus*, made fleeting reference to this concept "call it a syngameon if you wish". 
These syngameonic genera obey the pattern for dominant species detected by Darwin so 
long ago, displaying stages of divergence in the evolutionary process, with stages of 
incomplete speciation (i.e. semi-species) also existing. Semi-species are defined by Grant 
as "population systems connected by a reduced amount of interbreeding and gene flow".

(v) *Eucalyptus*: Currently Radiating

It is clear that *Eucalyptus* is currently in a period of evolutionary radiation. They 
respond with great sensitivity to spatial variations in the environment. It can be expected 
that *Eucalyptus* would respond with similar sensitivity to changes of similar magnitudes 
and types occurring over time.
(vi) Antiquity of *Eucalyptus*

Eucalypt type pollen and wood have both been identified and dated back as far back as the Oligocene (Martin 1981 and Pryor 1959b respectively). Eucalypt leaf fragments have been found in inland Australia dating back to the Eocene (Chapman 1937), and full leaf and capsular ranges of fossil eucalypts have been found dating at least as far back as the Miocene, and possibly as far back as the Eocene-Oligocene (Lange 1978, Ambrose *et al.* 1979, Holmes *et al.* 1983). The existence of the Subgenera *Monocalyptus*, *Symphyomyrtus* and *Corymbia* on both sides of the continent suggests that these had evolved prior to the development of aridity in the centre of the continent in the mid-Miocene (Crocker & Wood 1947).

Although *Eucalyptus* has been in existence since at least the Miocene, the vicissitudes in its ecological status through these tens of millions of years are unknown. However, the discovery in inland Australia of full leaf and capsular ranges from the Miocene indicates that *Eucalyptus* may have had a past period or periods of expansion and dominance in what are now drier parts of the continent.

(vi) Summary of Characteristics of Eucalypts.

*Eucalyptus* is both ancient and modern, i.e., it has been in existence for a long time, yet is now the most prominent tree on the Australian continent. It is diverse in its species and plastic in the response of these species to environmental changes. The restriction of genetic flexibility which often occurs during evolution by means of hybridisation (see Grant 1981), has not occurred in *Eucalyptus*.

6.2 Interpreting the Stability of *Eucalyptus* Associations

6.2.1 Pryor's Rule

Pryor (1959a) discussed the diversity of the genus *Eucalyptus* and the propensity for hybridisation within subgenera. Noting the usually low frequency of hybrids in naturally occurring populations of *Eucalyptus*, he generalised that "interbreeding *Eucalyptus"
species form separate stands each occupying distinctly different ecological situations", and, further, that "in most areas of south-east Australia each available habitat is occupied by a stand made up of trees of *Eucalyptus* of at least two species. In such mixed stands the species concerned do not interbreed, and always each is derived from a different subgeneric group. A second rule may therefore be stated relating to the occurrence of *Eucalyptus* species which is that mixed stands of *Eucalyptus* are made up of species which are genetically isolated". Pryor further noted that there are many minor exceptions, but that "if looked at from the 1000 acre (405 hectares) scale the position is clear. In accordance with the topographic pattern, each species of any given pair gives way appropriately to other species...".

6.2.2 Compliance of *Eucalyptus* Associations of Ettrema and Northern Budawangs with Pryor's Rule

The extent to which the associations formed by species of Eucalyptus in the Ettrema and Northern Budawangs wildernesses conform to Pryor's Rule was examined (see Table 6.3). It can be seen that eucalypt associations in the Morton NP wildernesses do not conform wholly to Pryor's Rule. Only half of the communities defined are dominated by eucalypts from different subgenera. However, when considering the area as a whole, subgeneric diversity is apparent. About half of the eucalypts are from subgenus *Symphyomyrtus* and half from *Monocalyptus*. The two eastern Australian *Corymbia* also occur in the area.

6.2.3 Conformity of *Eucalyptus* Associations in other Areas with Pryor's Rule

In order to compare the results obtained in Ettrema/ Northern Budawangs, data from some other areas were checked for their concordance with Pryor's Rule.
(i) South Coast Survey Data

Another study in which Pryor's rule has been put to the test was that of Austin, Cunningham and Wood (1983). They tested data collected for the South Coast Survey for its adherence to Pryor's rule, by calculating the relative frequency of occurrence of first and second dominant species from the same subgenus and from different subgenera in different regions. They were able to confirm the rule specifically for the mountain region and found a statistically significant tendency over all regions (coastal, hill, mountain and granite) for dominant and sub-dominant to be from different sub-genera in *Corymbia* and *Monocalyptus*. In coast, hill and granite regions, only *Corymbia* was found to significantly co-occur with members of other sub-genera. This is a highly likely result, since there are only two *Corymbia* in the area (Red Bloodwood, *Eucalyptus gummifera* and Yellow Bloodwood, *E. eximia*), which would statistically bias the chances of this Subgenus being associated with another rather than the same. From their results, it appears that Pryor's rule applies in mountainous areas of Eurobodalla Shire, but it is not clearly confirmed for stands of eucalypts in other areas.

(ii) Boyd Plateau

Data from the Boyd Plateau (Black 1977) was checked for its conformity with Pryor's Rule (see Table 6.4.)

**Results**

Subgeneric diversity predominates in all three of the widespread eucalypt associations on the Boyd Plateau. In addition, there are some clearly unstable con-subgeneric distributional overlaps. Clinal variation from one con-subgeneric species to another were observed in two of these three associations, and intergradation between two closely related species. *S E. dalrympleana*, the most widely distributed species on the plateau, forms a cline with *E. viminalis*. Increasingly moist sites supported an increasing proportion of *E. viminalis* and diminishing proportion of *E. dalrympleana*. In areas that had been logged, hybrid swarms between *E. dalrympleana* and *E. viminalis* were
observed. *E. dalrympleana* was found to be difficult to distinguish from *E. rubida* and intergradation between the two at this location was suspected. These observations support the view that co-occurrence of eucalypt species from the same subgenus is likely to be unstable in the long term.
(iii) Monaro

Data from Costin (1954) is summarised in Tables 6.5.1 to 6.5.5

Eighty percent of the component associations of the most cold-tolerating alliance (E. pauciflora- E. stellulata) conform to Pryor's Rule. Ninety percent of the most warm-preferring alliance (tableland E. melliodora- E. blakelyi) do not conform to Pryor's Rule.

However, when the associations in the latter alliance are split into two groups (proposed by Costin as sub-alliances), viz., those associations occurring in colder areas versus those occurring in warmer areas, a noticeable difference in subgeneric diversity is apparent, with colder area associations tending to be display subgeneric diversity (75%) and warmer area associations tending to consist of species from the same subgenus (75%).

In four separate analyses of eucalypt associations in eastern NSW, it was found that Pryor's rule does not apply in the majority of associations, except in montane areas. Of the areas examined, Pryor's Rule appears to hold least well in the Ettrema/ Northern Budawangs and in the warmer tableland region of south-eastern NSW.

6.2.4 Why Doesn't Pryor's Rule Hold for All Environments?

It appears that either

(i) Eucalyptus associations are stable, whether or not their constituent members are from the same subgenus.

or

(ii) Eucalyptus associations may be unstable if their constituent members are from the same subgenus.

The Limits of Stability of Con-subgeneric Associations of Eucalyptus

If a pair of consubgeneric species (such as E. sieberi and E. piperita) co-occur with sufficient constancy to be described as an association, this per se suggests that this must be a stable combination. For such an association to occur, it would seem that there must
be breeding barriers, such as genetic separation, staggered flowering times (as discussed by Pryor 1959b, Rogers & Westman 1979, Gill 1981a), self-pollination, niche specificity (such as that described by Rogers & Westman 1979 for *E. signata* and *E. umbra* and by Noble 1989 for *Monocalyptus* versus *Symphyomyrtus* as a whole), or other as yet undefined mechanisms which inhibit cross-pollination.

However, if it is shown that two species can interbreed, (whether by the observation of natural hybrids or by manipulation), then it follows that they may eventually do so. Environmentally imposed breeding barriers such as those outlined above may sooner or later be lifted, not only along ecotones or following clearing or logging, but also within the association. This may happen as a consequence of environmental change. Logic suggests that an association between two species which can interbreed, such as *E. piperita*/ *E. sieberi*, has a high likelihood of being recent in origin, relative to widespread associations of species from different subgenera, such as *E. sclerophylla* (*E. rossii*)/ *E. mannifera* and *E. punctata*/ *E. globoidea*.

### 6.3 Using Subgeneric Composition as a Key to Interpreting Change Through Time: Re-Interpretation of Ettrema/ Northern Budawangs *Eucalyptus* Associations

Consideration of the implications of Pryor's rule in the light of evolutionary theory (as outlined in the introduction to this chapter), suggest that, whether or not it holds at the 1000 acre scale, it must have meaning in terms of the stability of co-occurrence of pairs of *Eucalyptus* species. It can logically be expected that sympatric species which can hybridise will eventually do so and that, therefore, if they continue to co-occur, the distinction between the species will be lost. It follows that associations of species from different subgenera are likely to have been in existence for a longer period of time than associations of species from the same subgenus.
It is therefore hypothesised that the consistent co-occurrence of species pairs or trios from the same subgenus of *Eucalyptus* implies temporal instability of these associations.

The converse of this hypothesis is that consistent co-occurrence of species from different subgenera implies stability. This need not necessarily imply association of a longer time than that taken to disperse a genotype compatible with an environment changed by disturbance, since species from different subgenera may, immediately following disturbance, co-occur by chance.

Viewed in this light, some of the associations of *Eucalyptus* observed in Ettrema/North Budawangs are genetically stable and others are potentially genetically unstable (Table 6.2). This outcome could have been predicted, for stability would only be expected to occur in the virtually impossible circumstance of no change in the environment through time.
Table 6.2.
Stability of Ettrema/Northern Budawangs *Eucalyptus* Associations

Genetically Stable Associations:

*Eucalyptus* sclerophylla-*E. mannifera*

*E. globoidea*-*E. punctata*

*E. eximia*-*Ironbarks*

*E. eximia*-*E. ligustrina*

Potentially Genetically Unstable Associations

*E. piperita* ssp.urceolaris-*E. sieberi*

*E. fastigata*-*E. fraxinoides*

Associations with Evidence of Both Stability and Change

*E. fastigata*-*E. cypellocarpa*-*E. viminalis*-*E. radiata*

*E. punctata*-*E. gummifera*-*E. consideniana*

Monospecific Communities

The stability of these cannot be interpreted by means of Pryor's Rule

*E. tereticornis*

*E. eximia*

*E. multicaulis*

6.4 Interpretation of Some Associations in Ettrema/N. Budawangs

(i) Genetically Stable

*E. punctata*-*E. globoidea* / *E. sclerophylla*-*E. mannifera*

These are imputed to be the most stable associations, since they are the only consistently co-occurring pairs from different subgenera. *S E. ovata* has a fragmentary occurrence in the *M E. sclerophylla*-*S E. mannifera* association. Its fragmentary occurrence here and centre of distribution further south, suggest that *E. ovata* may have been more widespread in the Ettrema/Northern Budawangs areas during cooler climatic
conditions. Its location next to drainage lines suggest that it requires moisture conditions at the wettest end of the range of those now occurring in the study area. During cooler and wetter climatic conditions (such as those described by Nanson & Price 1992), *E. ovata* may have replaced *E. mannifera* over much of its range in Ettrema/ Northern Budawangs.

(ii) Potentially Genetically Unstable

*E. piperita* ssp. *urceolaris* - *E. sieberi*

The distributions of these two species, although consistently overlapping in the Northern Budawangs, were more often than not separate in the Ettrema wilderness. Although both are in the subgenus *Monocalyptus*, these two species are in separate series (Pryor & Johnson 1975), reducing the chance of hybrids occurring (Griffin et al. 1988) and indicating that they have not evolved directly from one another (Pryor 1993, pers. comm.). has indicated that naturally occurring hybrids of *E. sieberi* are rare. I quote: ".....in looking with care at a lot of material my conclusion was that interspecific hybridising (in *E. sieberi*) is relatively uncommon or that the results of crossings do not thrive."

*E. sieberi* may have been favoured (in Ettrema/ North Budawangs) by the cooler, drier conditions which are thought to have prevailed during most of the Quaternary (Hope and Kirkpatrick 1988), and may have had a much wider distribution during this time. *E. piperita* ssp. *urceolaris* would have been favoured by the warmer, moister interglacial conditions which are thought to have peaked in the period 10-5 ka BP (Colhoun 1991). During this time, it may have spread south and west from the Central Coast, into the territory of *E. sieberi*. For the two species to have come into overlap during this time, the distribution of *E. piperita* must have expanded at a more rapid rate than the rate at which the distribution of *E. sieberi* contracted, implying a wider ecological tolerance in the latter species. The dynamics of this particular association could be further elucidated by investigation of the reasons for the lack of hybridisation between these two species, and by a closer examination of their separate eco-physiological tolerances.
(iii) Evidence of Both Stability and Change

**a. Eucalyptus punctata- E. gummifera- E. consideniana complex**

The majority of combinations (65%) do not conform to Pryor's Rule. However, the three most commonly occurring species, by which the complex has been named, do. Hence, it appears that for this association of eucalypts, Pryor's Rule applies, not for trees actually growing together, nor at the 1,000 acre scale as suggested by Pryor, but at the 100,000 acre scale, i.e., over the entire distribution of the defined association (i.e., the Ettrema Plateaux.)

**b. E. fastigata- E. cypellocarpa -E. viminalis**

Species of the same subgenus may occur together, e.g. all four species were observed together along the road verges near Sassafras. *S E. viminalis* co-occurs with *S E. cypellocarpa* near Sassafras adjacent to a long-abandoned logging settlement. However, *E. cypellocarpa* is consistently the subdominant tree in large areas of *M E. fastigata* forest on the Endrick and Sassafras basalts. *E E. viminalis* co-occurs with *M E. fastigata* on the Endrick basalt on the northern side of Endrick Mountain. The largest stands of *M E. radiata* around the margins of the basalt flows occur without a co-dominant tree. It can be seen that this association conforms to some extent to Pryor's rule. The mixing of trees from the same subgenera observed along road verges and in logged areas may be a result of disturbances which have taken place in this forest association and may be obscuring the natural order in the distribution of these species, whether or not it conformed to Pryor's Rule. Suspected hybrids were observed at some locations, for example, *E. viminalis x E. cypellocarpa* near Sassafras.

**6.5 The Significance of Pryor's Rule in Relation to Diversity in Eucalyptus**

There is an assumption of genetic stability in eucalypt associations, implicit in Pryor's Rule. As discussed in 6.2, the evidence supplied by *Eucalyptus* Australia-wide is contrary to the notion of genetic stability of species within this genus. The present-day
size and genetic flexibility of the genus *Eucalyptus*, its extraordinarily rapid response to environmental alteration by hybridisation, the presence of clines within species, large naturally occurring hybrid populations, and natural individuals and populations intermediate in dimensions between defined species (e.g. *Eucalyptus dendromorpha*-*E. stricta* in the Northern Budawangs) all point to the present as being a time of active evolutionary radiation in *Eucalyptus*.

It is not surprising, then, that this instability and complexity at the species level is often reflected in the fact that *Eucalyptus* associations possess the potential to hybridise.

How recent a con-subgeneric overlap can be before species variation occurs is a logical next question. As discussed in 5.3, the order of magnitude of time involved in speciation in relation to environmental change may be measured in thousands to millions of years, and that, even where speciation involves only minor changes in taxa, the response time may be measured in thousands of years.

However, re-examination of the data, in particular, the higher occurrence of subgeneric diversity (and imputed stability) in montane regions, provides the beginning of an answer.

### 6.6 Why is There Greater Stability in Montane Associations?

The stability of *Eucalyptus* associations in montane areas and instability in Tableland and Plateaux areas may be explained in terms of

(i) The likely effects of climatic fluctuations during the Quaternary on vegetation communities

(ii) Connell's Intermediate Disturbance Hypothesis

### 6.6.1 Effect of Climatic Fluctuations on the Stability of Associations

We are thought to be in a comparatively warm period of the Quaternary. Such climatic conditions are thought to have prevailed for only relatively short periods during the Quaternary, with the majority of the time having been colder (see 5.2). The implication is that cold preferring associations would have had a longer period of time in which to
stabilise than warmth-preferring associations. Snow Gum, *E. pauciflora*, is the species central to the majority of montane associations, and there are strong suggestions from its current-day distribution, that it was formerly more widely distributed. The potential extent of the distribution of *E. pauciflora* during the last glaciation was mapped by Williams (1991) on the basis of its current climatic envelope and estimated glacial temperature and rainfall values. It was predicted to have been widespread throughout the lowlands of south-east Australia, but absent from higher altitudes (except in refugia-Hope & Kirkpatrick 1988). However, its spread would probably have been limited by other environmental factors. For example, the extremely poor soils prevailing over much of the Sydney Basin may well have been outside the limits of tolerance of this species. Support for the predominance of edaphic factors over Holocene climatic variation as the limiting factor influencing plant species distributions was provided by the research of McPhail (1984). The influence of soil nutrient levels in eucalypt association distributions is shown in ch. 4 of this thesis.

### 6.6.2 Application of Connell's Intermediate Disturbance Hypothesis

The mechanism which was hypothesised by Connell to be operative in maintaining high diversity in tropical rainforest and coral reefs, can be adapted to explain the observed stability in montane *Eucalyptus* associations and the comparative instability of associations in warmer tableland and plateau areas.

(i) **Warm Periods as a Temporal Intermediate Disturbance**

The shortness of the warm periods (5.2) would mean that species and their distributions would have less time to adjust to these conditions than to cold conditions. Warm conditions, from the perspective of the vegetation, would amount to a disturbance of the 'norm', i.e., the usual prevailing cold conditions. Since we are presently in a relatively warm period, the vegetation prevailing over most areas of south-east Australia today may, then, be in the non-equilibrium state, with the remnants of former widespread associations being contracted to the coldest areas.
(ii) Tablelands and Plateaux: Areas of Spatial Intermediate Disturbance

Expansion of the montane associations would have occurred during colder times. Concurrently, a downslope migration would have been occurring in adjacent associations. Previously stable associations would overlap, forming unstable combinations. There would be no overlap on the uphill side of the uppermost montane associations, only a downslope migration of the tree-line. Hence the highest altitude association, would, over the upper part of its area, remain without overlapping species from different associations. Downslope and tableland associations, which would be in contact with a mosaic of others, would overlap in several directions with climatic change, resulting in a complex assortment of unstable eucalypt combinations.
6.6.3 Application of Connell's Hypothesis to the Dynamics of the Ettrema/ Northern Budawangs Eucalyptus Associations:

Con-subgeneric occurrences can be interpreted as either

(i) recent distributional overlap, dating at the earliest from the commencement of the post-glacial warming which peaked 10-2 ka BP (Colhoun 1991),

or

(ii) temporal speciation clines which can be dated within this same time frame.

The former would apply where it is probable that two related species are not sufficiently similar to have evolved from one another, (such as E. sieberi and E. piperita) and the latter where the degree of similarity is such that they may have (e.g., E. consideniana- E. sieberi).

Overall subgeneric diversity in Ettrema/ North Budawangs is apparent, with about half of the species belonging to Monocalyptus and half to Symphyomyrtus. Nested within this stable subgeneric 'supra-alliance', patterns of both stability and change can be identified, both at the base-level of species diversification and at the broader level of stable and unstable associations between species. The application of Connell's hypothesis enables the interpretation of the unstable forms and combinations in relation to the stable ones. Instability can be seen as an overlay on the stability resulting from the longer period or periods of cold conditions. Stable combinations thus become "the ghost of communities past", as opposed to the "ghost of competition past" (Connell 1980), while unstable combinations and difficult to define species are the changes superimposed on this stability since the commencement of post-glacial warming sometime in the period 15-10 ka BP.

The superimposition of stability on instability is apparent in the 'sandstone complex', with the subgeneric separation of the three most abundant species, E. punctata, E. consideniana and E. gummifera suggesting that their association could have extended
through the last Ice Age. Edaphic factors may have limited the spread of the *E. pauciflora* alliance across the Ettrema plateaux. The subgeneric similarity of other species identified as part of this complex suggests that they can be interpreted as a 'temporal overlay' dating from the time of post-glacial warming.

Species at the southern extremities of their distribution can be interpreted as the recent invaders, whereas those near the northern limits of their distribution are more likely to be the longer-term residents. In this light, the distribution of *E. piperita* can be seen as superimposed on that of *E. sieberi* and the observed variability in this species (ssp. *urceolaris* and *piperita*) can be viewed as part of the post-glacial expansion of this species. Conversely, the observed lack of hybrids in *E. sieberi* in south-east NSW may be viewed as an indication that this species is not well-favoured by current climates in this region.

### 6.7 Conclusions

Pryor depicted eucalypt communities as being stable combinations of two or three species of *Eucalyptus*, each from different subgenera. The Ettrema/ Northern Budawangs eucalypt associations were tested against Pryor's Rule. It was found that, although the eucalypts over the entire area conform, individual associations often do not. This held good for other areas (South Coast, Monaro, Boyd Plateau) except for montane, where associations more often than not conform to the rule. Reconsidered in the light of evolutionary theory, and environmental disturbance, as well as a knowledge of *Eucalyptus*, it is clear that eucalypt associations could be expected to be unstable and that Pryor's Rule must have meaning in this light.

It can be seen that the subgeneric composition of eucalypt associations is a key to their stability through time and that this in turn can assist in unravelling the path of change in eucalypt distributions. This, in conjunction with Connell's Intermediate Disturbance Hypothesis, has provided a rationale for placing observed instability in *Eucalyptus* associations in Ettrema/ Northern Budawangs into a broadly post-glacial time-frame (i.e., from approximately 15 thousand years before the present).
Table 6.1: Ettrema/Northern Budawangs
Taxonomic Relationships - *Eucalyptus*

<table>
<thead>
<tr>
<th>Subgenus</th>
<th>Section</th>
<th>Series</th>
<th>Super-species</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corymbia</td>
<td>Rufaria</td>
<td>Gummiferinae</td>
<td>gummifera</td>
<td></td>
</tr>
<tr>
<td>Ochraria</td>
<td>Maculata</td>
<td>Maculata</td>
<td>maculata</td>
<td></td>
</tr>
<tr>
<td>Eximia</td>
<td>Peltata</td>
<td>eximia</td>
<td>mueleriana</td>
<td></td>
</tr>
<tr>
<td>Monocalyptus</td>
<td>Renantheria</td>
<td>Capitellata</td>
<td>Macrorhyncha</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>agglomerata</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Obliquae</td>
<td></td>
<td>liguistrina</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Regnans</td>
<td></td>
<td>fastigata</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Consideniana</td>
<td></td>
<td>langleyi</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multicaulis</td>
<td></td>
<td>sieberi</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pauciflora</td>
<td></td>
<td>gregsoniana</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stricta</td>
<td></td>
<td>fraxinoides</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stellulata</td>
<td></td>
<td>moorei</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Piperitae</td>
<td>Amygdalina</td>
<td>radiata</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>elata</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>dives</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>piperita</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>sclerophylla</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>rossii</td>
<td></td>
</tr>
<tr>
<td>Symphyomyrtus</td>
<td>Transversaria</td>
<td>Salignae</td>
<td>Saligna</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>saligna</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>botryoides</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>punctata</td>
<td></td>
</tr>
<tr>
<td>Exsertaria</td>
<td>Tereticornes</td>
<td>Tereticornis</td>
<td>tereticornis</td>
<td></td>
</tr>
<tr>
<td>Maidenaria</td>
<td>Ovatae</td>
<td>Ovata</td>
<td>ovata</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mannifera</td>
<td></td>
<td>mannifera</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Viminales</td>
<td></td>
<td>sturgissiana</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cypellocarpa</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>smithii</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>viminalis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rubida</td>
<td></td>
<td>dalrympleana</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cinerea</td>
<td></td>
<td>rubida</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adnataria</td>
<td>Pruinosae</td>
<td>fibroa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paniculatae</td>
<td>Paniculata</td>
<td>paniculata</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>crebra</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>beyeriana</td>
<td></td>
</tr>
</tbody>
</table>
Table 6.3: Pryor's Rule- Summary of Taxonomic Similarity within *Eucalyptus* Communities of Ettrema/ Northern Budawangs

<table>
<thead>
<tr>
<th>Community</th>
<th>Pryor's Rule?</th>
<th>Sub-genus</th>
<th>How Distributed</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Eucalyptus sieberi</em>- <em>E. piperita</em></td>
<td>no</td>
<td>M-M</td>
<td>consistently overlap</td>
</tr>
<tr>
<td><em>E.fastigata</em>- <em>E.cypellocarpa</em>- <em>E.viminalis</em>- <em>E.radiata</em></td>
<td>yes</td>
<td>M-S-S-M</td>
<td>members of same subgenus often in separate stands</td>
</tr>
<tr>
<td><em>E.fastigata</em>- <em>E.fraxinoides</em></td>
<td>yes</td>
<td>M-M</td>
<td>adjacent stands</td>
</tr>
<tr>
<td><em>E.punctata</em>- <em>E.gummitfera</em>- <em>E.consideniana</em></td>
<td>no</td>
<td>S-M-C</td>
<td>complex, same subgenus often present.</td>
</tr>
<tr>
<td><em>E.punctata</em>- Ironbarks <em>(E.fibrosa, E.beyeriana)</em></td>
<td>no</td>
<td>S-S</td>
<td>consistently overlap</td>
</tr>
<tr>
<td><em>E.globoidea</em>- <em>E.punctata</em></td>
<td>yes</td>
<td>M-S</td>
<td>consistently overlap</td>
</tr>
<tr>
<td><em>E.sclerophylla</em>- <em>E.mannifera</em></td>
<td>yes</td>
<td>M-S</td>
<td>consistently overlap</td>
</tr>
<tr>
<td><em>E.eximia</em></td>
<td>no</td>
<td>C</td>
<td>monospecific stands</td>
</tr>
<tr>
<td><em>E.multicaulis</em></td>
<td>no</td>
<td>M</td>
<td>&quot;</td>
</tr>
<tr>
<td><em>E.tereticornis</em></td>
<td>no</td>
<td>S</td>
<td>&quot;</td>
</tr>
<tr>
<td><em>E.eximia</em>- Ironbarks</td>
<td>yes</td>
<td>C-S</td>
<td>limited occurrence</td>
</tr>
<tr>
<td><em>E.eximia</em>- <em>E.ligustrina</em></td>
<td>yes</td>
<td>C-S</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

Sub-genus Code: M=Monocalyptus S=Symphyomyrtus C=Corymbia

Table 6.4 Concurrence of Boyd Plateau Eucalypts with Pryor's Rule

<table>
<thead>
<tr>
<th>Vegetation unit</th>
<th>Sub-genera</th>
<th>Conforms to Pryor's Rule?</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Eucalyptus pauciflora</em> - <em>E.dalrympleana</em></td>
<td>S, M</td>
<td>Yes</td>
<td>Widespread association</td>
</tr>
<tr>
<td><em>E.fastigata</em>- <em>E.dalrympleana</em>- <em>E.viminalis</em></td>
<td>M, S, S</td>
<td>Yes/No</td>
<td><em>E.dalrympleana</em>- <em>E.viminalis</em>: drier &gt;&gt;&gt;&gt;&gt;&gt;&gt;&gt;&gt; moister hybrids observed where logged. Widespread association</td>
</tr>
<tr>
<td><em>E.radiata</em>- <em>E.dalrympleana</em></td>
<td>M, S</td>
<td>Yes</td>
<td>Abundant unit</td>
</tr>
<tr>
<td><em>E.dives</em>- <em>E.radiata</em>- <em>E.dalrympleana</em></td>
<td>M, M, S</td>
<td>Yes/No</td>
<td>Minor grouping</td>
</tr>
<tr>
<td><em>E.dives</em>- <em>E.dalrympleana</em></td>
<td>M, S</td>
<td>Yes</td>
<td>Minor grouping</td>
</tr>
<tr>
<td><em>E.sieberi</em>- <em>E.blaxlandii</em></td>
<td>M, M</td>
<td>No</td>
<td>Marginal occurrence</td>
</tr>
<tr>
<td><em>E.stricta</em></td>
<td>M</td>
<td>monospecific</td>
<td></td>
</tr>
</tbody>
</table>
Monaro Data (Costin 1954)

Table 6.5.1

*E. pauciflora-E. stellulata* Alliance (Montane and cooler tableland)

<table>
<thead>
<tr>
<th>Eucalyptus Association</th>
<th>Subgenera</th>
<th>Conforms to Pryor's Rule?</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>viminalis-dives</em></td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td><em>pauciflora-viminalis</em></td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td><em>pauciflora-rubida</em></td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td><em>pauciflora-bridgesiana</em></td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td><em>pauciflora-dives</em></td>
<td>M, M</td>
<td>no</td>
</tr>
<tr>
<td><em>pauciflora-ovata</em></td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td><em>pauciflora-aggregata</em></td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td><em>pauciflora-stellulata</em></td>
<td>M, M</td>
<td>no</td>
</tr>
<tr>
<td><em>stellulata-camphora</em></td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td><em>stellulata-parvifolia</em></td>
<td>M, S</td>
<td>yes</td>
</tr>
</tbody>
</table>

Total: 80% of associations support Pryor's Rule

Summary

10 species form 10 associations (out of a possible 50 combinations). Most associations are stable.

Table 6.5.2

*E. melliodora-E. blakelyi* Alliance (Tableland - warmer, subhumid areas)

<table>
<thead>
<tr>
<th>Eucalyptus association</th>
<th>Subgenera</th>
<th>Conforms to Pryor's Rule?</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>melliodora-blakelyi</em></td>
<td>S, S</td>
<td>no</td>
</tr>
<tr>
<td><em>melliodora-polyanthemos</em></td>
<td>S, S</td>
<td>no</td>
</tr>
<tr>
<td><em>melliodora-bridgesiana</em></td>
<td>S, S</td>
<td>no</td>
</tr>
<tr>
<td><em>melliodora-bridgesiana-gonioalyx</em></td>
<td>S, S</td>
<td>no</td>
</tr>
<tr>
<td><em>melliodora-viminalis</em></td>
<td>S, S</td>
<td>no</td>
</tr>
<tr>
<td><em>bridgesiana-gonioalyx</em></td>
<td>S, S</td>
<td>no</td>
</tr>
<tr>
<td><em>bridgesiana-polyanthemos</em></td>
<td>S, S</td>
<td>no</td>
</tr>
<tr>
<td><em>bridgesiana-dives</em></td>
<td>S, M</td>
<td>yes</td>
</tr>
<tr>
<td><em>bridgesiana-viminalis</em></td>
<td>S, S</td>
<td>no</td>
</tr>
<tr>
<td><em>bridgesiana-rubida</em></td>
<td>S, S</td>
<td>no</td>
</tr>
</tbody>
</table>

Total: 90% do not conform to Pryor's Rule

Summary

8 species form 11 associations (out of a possible 32 combinations.) These associations are, with one exception, all of Symphiomyrts and potentially genetically unstable.
Table 6.5.3
Eucalyptus macrorhyncha-E. rossii Alliance
(Tablelands and drier montane)

<table>
<thead>
<tr>
<th>Eucalyptus association</th>
<th>Subgenera</th>
<th>Conforms to Pryor's Rule?</th>
</tr>
</thead>
<tbody>
<tr>
<td>dives-pauciflora</td>
<td>M, M</td>
<td>no</td>
</tr>
<tr>
<td>dives-bridgesiana</td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td>dives-sieberi</td>
<td>M, M</td>
<td>no</td>
</tr>
<tr>
<td>dives-rubida</td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td>dives-maculosa</td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td>macrorhyncha-rubida</td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td>dives-goniocalyx</td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td>dives-polyanthemos</td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Subtotal (colder)</strong></td>
<td></td>
<td><strong>75% stable</strong></td>
</tr>
<tr>
<td>maculosa-rubida</td>
<td>S, S</td>
<td>no</td>
</tr>
<tr>
<td>macrorhyncha-maculosa</td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td>macrorhyncha-goniocalyx</td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td>polyanthemos-goniocalyx</td>
<td>S, S</td>
<td>no</td>
</tr>
<tr>
<td>maculosa-goniocalyx</td>
<td>S, S</td>
<td>no</td>
</tr>
<tr>
<td>maculosa-melliodora</td>
<td>S, S</td>
<td>no</td>
</tr>
<tr>
<td>macrorhyncha-rossii</td>
<td>M, M</td>
<td></td>
</tr>
<tr>
<td>polyanthemos-rossii</td>
<td>S, M</td>
<td></td>
</tr>
<tr>
<td>rossii</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal</strong> (warmer): 25% stable</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total:** 53% of associations conform to Pryor's Rule

Summary

Eleven species form twenty seven associations (out of a possible sixty six combinations). About half of these are potentially genetically unstable.

Table 6.5.4
Eucalyptus delegatensis-E. dalrympleana Alliance (Upper montane and Tableland).

<table>
<thead>
<tr>
<th>Eucalyptus association</th>
<th>Subgenera</th>
<th>Conforms to Pryor's Rule?</th>
</tr>
</thead>
<tbody>
<tr>
<td>delegatensis-dalrympleana</td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td>delegatensis-viminalis</td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td>delegatensis-radiata</td>
<td>M, M</td>
<td>no</td>
</tr>
<tr>
<td>dalrympleana-radiata</td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td>pauciflora-radiata</td>
<td>M, M</td>
<td>no</td>
</tr>
<tr>
<td>dalrympleana-pauciflora</td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td>pauciflora-viminalis</td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td>dalrympleana-dives</td>
<td>M, S</td>
<td>yes</td>
</tr>
<tr>
<td>pauciflora-dives</td>
<td>M, M</td>
<td>no</td>
</tr>
</tbody>
</table>

**Summary:** 67% of associations conform to Pryor's Rule

Of the three potentially unstable associations, Costin lists two of these (delegatensis-viminalis and pauciflora-radiata) as being rare. Hence it would appear that most of the area is occupied by stable associations.
Table 6.5.5
_Eucalyptus fastigata-E. viminalis_ Alliance (Upper montane and mountainous tableland).

<table>
<thead>
<tr>
<th>Eucalyptus association</th>
<th>Subgenera</th>
<th>Conforms to Pryor's Rule?</th>
</tr>
</thead>
<tbody>
<tr>
<td>radiata-dives</td>
<td>M,M</td>
<td></td>
</tr>
<tr>
<td>radiata-macrorhyncha</td>
<td>M, M</td>
<td></td>
</tr>
<tr>
<td>radiata-bridgesiana</td>
<td>M, S</td>
<td></td>
</tr>
<tr>
<td>radiata-dalrympleana</td>
<td>M, S</td>
<td></td>
</tr>
<tr>
<td>radiata-viminalis</td>
<td>M, S</td>
<td></td>
</tr>
<tr>
<td>viminalis-macrorhyncha</td>
<td>M, S</td>
<td></td>
</tr>
<tr>
<td>viminalis-dives</td>
<td>M, S</td>
<td></td>
</tr>
<tr>
<td>viminalis-dalrympleana</td>
<td>S, S</td>
<td></td>
</tr>
<tr>
<td>viminalis-fastigata</td>
<td>M, S</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal (cooler)</strong></td>
<td><strong>67% stable</strong></td>
<td></td>
</tr>
<tr>
<td>fastigata-obliqua</td>
<td>M, M</td>
<td></td>
</tr>
<tr>
<td>obliqua-viminalis</td>
<td>M, S</td>
<td></td>
</tr>
<tr>
<td>obliqua-goniocalyx</td>
<td>M, S</td>
<td></td>
</tr>
<tr>
<td>nitens-fastigata</td>
<td>M, S</td>
<td></td>
</tr>
<tr>
<td>fraxinoides</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>goniocalyx-fastigata</td>
<td>M, S</td>
<td></td>
</tr>
<tr>
<td>goniocalyx-radiata</td>
<td>M, S</td>
<td></td>
</tr>
<tr>
<td>radiata-sieberi</td>
<td>M, M</td>
<td></td>
</tr>
<tr>
<td>radiata-globoidea</td>
<td>M, M</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal (warmer)</strong></td>
<td><strong>67% stable</strong></td>
<td></td>
</tr>
</tbody>
</table>

Summary: 67% of associations conform to Pryor's rule.
7. Rare Species in Ettrema and Northern Budawang Ranges and their Relationship to Vegetation Change.

7.1 Introduction

"...there is a striking parallelism in the laws of life throughout time and space; the laws governing the succession of forms in past times being nearly the same as those governing at the present time the differences in different areas. We see this in many facts. The endurance of each species and group of species is continuous in time...so in space, it certainly is the general rule that the area inhabited by a single species, or by a group of species, is continuous, and the exceptions, which are not rare, may...be accounted for by former migrations under different circumstances, or through occasional means of transport, or by the species having become extinct in the intermediate tracts. Both in time and space, species have their points of maximum development. Groups of species, living during the same period of time, or living within the same area, are often characterised by trifling features in common, as of sculpture or colour..."

Extract from "The Origin of Species" by Charles Darwin 1872

7.1.1 Why are some species rare?

Darwin (cited above) suggested three alternative explanations, viz, that they may be the result of "former migrations under different circumstances", of occasional long-distance dispersal, or the remnants of former continuous distributions. These are still possibilities.

That rare species could be either a residue of previous regimes or the outrider of changes taking place has long been recognised [attributed to Engler (1882) by Kruckeberg and Rabinowitz (1985)]. More recently, a few authors have sought to categorise rare species in terms of their genetic potential (Stebbins 1942) or their distribution patterns (Rabinowitz 1981, Main 1982).

Stebbins (1942) categorised rare species in terms of their genetic constitution, suggesting that rare species were poor in biotypes, and homozygous or nearly so. This was seen to be in contrast to the most widespread and common species, which consist of
a large number of genetically different biotypes, which often differ widely in their ecological preferences. Stebbins further subdivided rare species into two possible types: "depleted" and "insular" species and pointed out that both palaentology and present distributions indicate that depleted species constitute a large proportion if not the majority of rare species. The insular rare species, its distribution circumscribed by its limited habitat, may have "a potential aggressiveness, but cannot spread because it has nowhere to go" (ibid). Its genetic diversity may be unexpectedly high, because of periodic hybridisation with surrounding species. This semi-isolated species may have the best potentialities for evolutionary progress (Ibid).

Rabinowitz (1981) divided types of rare species into seven possible categories, based on local population size (large or small), geographic range (large or small) and habitat specificity (wide or narrow).

Main (1982) classified rare species into five distributional categories (aggregated, disjunct, fragmented and dispersed) and suggested that some patterns may be indicative of either incipient or of relictual species. The resulting categories are similar to those of Rabinowitz.

Main listed six possible factors which could contribute to rarity. These were climatic fluctuations, predation, intra-specific competition, conditions inhibiting regeneration, disturbances such as drought, fire or storms, and physiological intolerance of changed conditions. Main likened an extant ecosystem to a "palimpsest, overwritten many times after imperfect erasures."

The categorisations of the above authors appear to have been a theoretical appraisal rather than being drawn from a comprehensive analysis of the characteristics of actual rare species. None of the categorisations noted above encompassed variations in morphology.

7.1.2 Disjunction: long distance dispersal or contracted distribution?

Disjunct occurrences of species may represent contraction from formerly more widespread distributions or may be the result of long-distance dispersal. It is important to
know about a plant's ecological amplitude, capacity for dissemination of propagules, mode of reproduction, and cytological stability in order to accurately interpret the origin of its distribution pattern (Fryxell 1967). Disjunct distribution patterns may sometimes be the result of recent long-range dispersal. Verifying evidence may include no demonstrable evolutionary divergence, impermeable seed coats permitting dormancy and longevity of seeds, self-compatibility and high reproductive potential, as in the case of three bicentric African species cited by Fryxell (1967). On the other hand, vicarious species pairs, which are taxonomically distinct, may occur when distribution is disrupted by disturbance such as climatic change.

Evidence suggests that many Australian autochthonous species are not adapted for long distance dispersal. For example, *Eucalyptus regnans*, one of the tallest eucalypts, was found to have a mean seed path equal to about the height of the tree (Barber 1955).

Nelson (1974) mustered evidence against long-range dispersal as the explanation of the disjunct distribution of "quonkan" species of the south-west botanical province of Western Australia on isolated dune systems of the south-western Nullabor Plains. He argued that species of *Banksia* and other members of the Proteaceae are not adapted for long distance dispersal, since seed is usually held on the plant until released by fire and then drops straight to the ground. Moreover, the mycorrhizal Proteaceae will not germinate in sterile soil.

7.1.3 Morphology: reflections of time and place

As Darwin pointed out, the species of a particular time or place tend to have a certain overall similarity, and may have "trifling features in common". Morphological features can provide a clue as to the position of species in time. Glaucousness, hairiness, overall size, leaf size and thickness vary with environmental conditions, although differently in different taxa and in adaptation to more than one set of environmental conditions. It is not easy to generalise as to the adaptive significance of a particular characteristic. For example, the lignotuberous condition which is a fire adaptation in eucalypts, may, in this same species, be an adaptation to mechanical damage (see photos of *Eucalyptus*
pauciflora sprouting in response to ice-damage, Pl.8.2). The development of accessory buds at the base of the stem must have occurred early in the evolution of the dicotyledons, since it occurs in the primitive angiosperm *Eupomatia laurina* (Endress 1983). It may have functioned effectively through time in relation to a diversity of hazards, including predators, other causes of mechanical damage and drought. The same early evolutionary development and multiple adaptive significance would apply to all of the general characteristics listed above. However, an overall trend (for example, high fire frequency) in a particular time or place could be expected to result in an overall tendency to the predominance of certain morphs over others and this (as Darwin pointed out) is manifested as a certain similarity about the vegetation of a particular place or time. This could be exemplified in Australia as a whole by the overall tendency of much of our vegetation at the present time to be sclerophyllous, lignotuberous, hard-fruited and aromatic.

### 7.1.4 A study of rare species in an environmental perspective

This study of the vegetation of a large area provided an ideal opportunity to place rare plants in perspective with the whole in terms of their distributional and morphological characteristics, thus enabling the categorisation of these species into types of rarity and the development of some hypotheses as to their evolutionary status.

### 7.1.5 Aims of this chapter:

(i) To describe the rare species found in Ettrema/Northern Budawangs wildernesses.

(ii) To outline the different morphological and distributional categories which were observed.

(iii) To seek explanations for these categories in terms of evolutionary theory, and the pattern of disturbance through time in this area.
7.2 Characteristics of Rare and Uncommon Species in Ettrema and Northern Budawang Ranges

7.2.1 Definition of Rare Species

Rare species discussed here are those located during this survey which have been given a rarity rating by the CONCOM Working Group on Endangered Flora (Leigh, Briggs & Hartley 1981, Briggs & Leigh 1988), or, in the case of *Eucalyptus*, by Pryor (1981), or recorded as unusual by taxonomists at the National Herbarium of New South Wales, Royal Botanic Gardens, Sydney, or at the Herbarium of the National Botanic Gardens, Canberra. Many of the eucalypts are not strictly speaking rare, having been classed as "those which may be endangered in the near future" (Pryor 1981). Rare species discussed here are not necessarily endangered according to the definition of Briggs & Leigh (1988), which is "at serious risk of disappearing in the next two decades if present land use and other causal factors continue to operate". Some have sufficiently large populations in Morton National Park (and possibly other reserves) to be considered rare but not endangered. Rare species may be represented by a relatively large population in a very restricted area or by smaller populations spread over a wider range (Ibid). Some species included in the 1981 CONCOM list have been removed from the 1988 list, and can only be rated as uncommon rather than rare. Nevertheless, they are included, as they assist in unveiling the reasons for the less frequent occurrence of some species than others.

The species discussed are listed in Table 7.1. This list is not expected to be fully comprehensive, as sporadically distributed rare species may still be located in future surveys.

7.2.2 Distribution of Rare Species Among Taxa

Ettrema and Northern Budawang Ranges contain an interesting variety of rare species, listed in Table 7.1. The major Australian plant families (*Epacridaceae, Fabaceae, Goodeniaceae, Mimosaceae, Myrtaceae, Proteaceae, Rutaceae and Restionaceae*) are
represented. *Eucalyptus*, the genus which displays the greatest diversity of species in NSW, likewise has the greatest diversity of rare species in the Morton wildernesses.

Significantly, the list of rare eucalypts includes all the mallee gums growing in the area. Sturgiss’ mallee is restricted in its distribution to the Ettrema plateaux, and has no closely similar relatives. Others, such as *E. multicaulis* and *E. triflora*, are closely related to nearby species (*E. sieberi* and *E. fraxinoides*/E. dendromorpha). The mallees are described in more detail in Appendix 3. Points drawn from this appendix are included in the body of the chapter where relevant.

The *Rutaceae* are represented on the list by three *Boronias* and one *Zieria*. *Boronia rhomboidea* is the most unusual of these, with its orbicular, stem clasping leaves. It has an oddly disjunct distribution, being found in the Northern Budawangs and in Tasmania. The terete-leaved *Boronia subulifolia* and *B. deanei* have differing distribution patterns, which show signs of fragmentation over smaller areas. *B. subulifolia* is concentrated on the mesa-tops, with sporadic occurrences at other locations within the Ettrema-Nth.Budawangs areas. *B. deanei* is disjunctly distributed from Clarence in the Blue Mountains to Nalbaugh NP near Eden on the far south coast of NSW. Located during the course of this survey along the Endrick River west of Endrick Mt., it is also found at Fitzroy Falls adjacent to the river, and on the Boyd Plateau along the Boyd River west of the Blue Mountains (Black 1977). It has been collected extensively in the Clarence area by staff of the National Herbarium of NSW. An isolated occurrence further south at Nalbaugh NP near Eden was also recorded by Weston (1990).

The *Fabaceae* is represented by several species of *Faboideae*, of which one (*Dillwynia sp. aff. stipulifera*) was located. Two rare *Mimosoideae* were located (*Acacia pubescens* and *A. subtilinervis*). *Hakea macraeana* (representing *Proteaceae*) was located only once in the Ettrema creek system and is rare in this area, although it no longer has this rating state-wide (Briggs & Leigh 1988).
Other families (*Epacridaceae*, *Goodeniaceae*, *Rhamnaceae*, *Restionaceae*) have single rare representatives, although more may be found if further, yet more detailed inspection is made.

### 7.2.3 Distinctive Forms

Many of the rare species are distinctive in general appearance. They may visually stand out as being different from the vegetation around them, or from related, more common taxa. For example, glaucousness and stem-clasping leaves in Sturgiss' mallee and orbicular leaves in *Boronia rhomboidea*. Amongst the rare eucalypts, leaf sizes are often noticeably smaller than those of the majority of extant species or than their more abundant relatives. For example, *E. ligustrina* (juvenile leaves), *E. moorei*, *E. gregsoniana*, *E. apiculata* and *E. recurva*. Contrastingly, *E. langleyi* is conspicuous for its unusually large, thick leaves. Whilst small leaves are distinctive in eucalypts, the same characteristic in other rare genera makes them similar in appearance to the surrounding vegetation. e.g. the needle-shaped leaves of *Boronia deanei*, renders it (at a distance) barely distinguishable from *Baeckia linifolia*, with which it tends to be associated in tall heath along creeks, both in the Northern Budawangs, at Fitzroy Falls and on the Boyd Plateau.

### 7.2.4 Distribution

Many rare species occur on mesa-tops, including *Leptospermum crassifolium*, *Eucalyptus triflora*, *Boronia subulifolia* and *Goodenia glomerata*. A number of species of limited distribution are found on sheltered mesa-slopes. In these locations, the rainforest tree *Eucryphia moorei* often dominates the canopy, with the Rutaceous shrub *Ziera caducibracteata* MS (J. Armstrong unpubl.) being a frequent understorey component. A number are found along creeks e.g. *Boronia deanei*, *B. rhomboidea*, *Eucalyptus dendromorpha* (tree-form), *E. moorei*. A few rare species were located in the Ettrema area, particularly the creek system in the north-east. These include *Acacia pubescens*, a shrub which has a continuous distribution along the lower Ettrema creekbanks, *Hakea*
*macraeana* on slopes higher up in the creek system and *E. ligustrina*, having a patchy distribution on the narrow ridge at the eastern end of the Timboolina Trail.

Several of these rare species have been located in more than one habitat type. e.g. *Goodenia glomerata* (mesa-top and occasional sheltered slopes and plateau occurrence), *Boronia rhomboidea* (mountain-top and Devonian valley-floor) and *B. subulifolia* (mesa-top and occasional plateau occurrence.)
7.2.5 Proportion of Rare Species Relative to Total Species

Thirty four rare or very uncommon species are recorded in Table 7.1. Of the species collected during the course of this work, 7% have a rarity rating (according to Leigh, Briggs & Hartley 1981). This compares with an Australia-wide rating of 10% rare species (Ibid). Hence, there is no evidence from this survey for a higher proportion of rare species in this area than the Australian average.

7.2.6 Distribution according to Habitat

Table 7.2: Distribution of Rare Species according to Habitat

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Rare Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. By Location</td>
<td>Number</td>
</tr>
<tr>
<td>Mesa-tops &amp; upper slopes</td>
<td>13</td>
</tr>
<tr>
<td>Mesa-tops only</td>
<td>8</td>
</tr>
<tr>
<td>Gorges in NE Ettrema</td>
<td>1</td>
</tr>
<tr>
<td>Ettrema Plateaux</td>
<td>6</td>
</tr>
<tr>
<td>N.Budawangs: open forest &amp; woodland</td>
<td>1</td>
</tr>
<tr>
<td>Bundanoon/Meryla/Fitzroy</td>
<td>3</td>
</tr>
</tbody>
</table>

| 2. By Vegetation Type               | Number       | % of Total |
|-------------------------------------|--------------|
| Heathland                           | 21           | 55.3       |
| Bogs                                | 1            | 2.6        |
| Rainforest                          | 1            | 2.6        |
| Riverine/Creekside                  | 2            | 5.2        |
| Open forest & woodland              | 3            | 7.9        |
| Nth.Budawangs, heaths of valley floors | 3         | 8.3        |
7.2.6 Distribution according to Habitat cont.

(i) Heathland

There is a definite bias towards heathland in the occurrence of rare species (55% of the rare species are in heathland), in particular to heathland on the tops of mesas (36% of rare species). As only 37% of the total species listed for the Morton National Park occur in heathland, it is clear that the relative proportion of rare species occurring in heathland is higher than in other structural types of vegetation. This figure may nevertheless simply be a reflection of the greater diversity of species generally growing in heathland compared to other types of vegetation, or it may relate to some historical phenomenon, such as contraction or expansion of heathland, and a lag in the total disappearance of those species now rare.

(ii) Mesa-tops

Rare species constitute approximately 11% of the species found on mesa-tops. The mesas, although similar to other heath-covered areas in terms of their very poor soils, are isolated from the surrounding valleys by Permian sandstone cliff lines. Some of the rare species characteristically cling to cracks in these cliffs (*Budawangia gnidoides*, *Eucalyptus triflora*), but the diversity and abundance of others (such as *Leptospermum crassifolium*, *Goodenia glomerata*, *Boronia subulifolia*) on the mesas when compared with adjacent heathland in the valleys is less easy to explain in terms of habitat differences. The relative inaccessibility of mesa-tops as a result of their sandstone cliff lines may well have played a part. For example, this would have limited or prevented altogether the use of these areas in the very recent past by cattle, which may have found some of the rare species particularly palatable. Alternatively, fire frequency and intensity would be reduced on the mesa-tops relative to surrounding areas. As a third possibility, the presence of rare species here may be a result of microclimatic differences, such as increased exposure resulting in colder temperatures and dryness (if this is in fact the case). Clustering of rare species is particularly pronounced on Mt. Currockbilly in the
Budawang Ranges to the south of the study area. Here, rare species (*Boronia subulifolia*, *B. rhomboidea*, *Eucryphia moorei*) visually dominate in both heath and rainforest. This mountain, which is composed of folded Ordovician metamorphics, producing different soils and physiography, is higher and more isolated from the surrounding area than the mesas of the Northern Budawangs, improving the case for the presence of rare species on the mesas being in some way connected with their inaccessibility.

(iii) Sheltered Slopes of Mesas

The sheltered slopes provide a moist, less fire-prone environment where rainforest and tall eucalypt forest can survive. *Eucryphia moorei* and *Zieria caducibracteata* commonly inhabit this environment. *Goodenia glomerata* was also observed in this environment (below Mt.Cole-Owen), a somewhat different habitat from its other observed occurrence in crevices in exposed sandstone on Quilty's Mountain.

(iv) Ettrema Creek System

The rare species noted in the Ettrema area were not confined to any particular habitat. Whilst *Acacia pubescens* is dominant and flourishing along lower Ettrema Creek flats on sandy alluvium, *E. ligustrina* is in an entirely different habitat on the rocky ridges.

(v) Other Creeks and Rivers

*Eucalyptus dendromorpha* (tree-form) grows along creeks in heathland. *Boronia deanei* occurs in tall heath alongside creeks in Morton NP and at other locations.

(vi) Diverse Habitats

Some species were observed in more than one habitat. For example, *Goodenia glomerata* was located both on mesa-tops and sheltered mesa-slopes. *Boronia subulifolia*, was found on mesa-tops and plateau edges. *Boronia rhomboidea* was found in valley-floor heath and on mountain-top.
7.3 Different Categories of Rare Species

As an outcome of observations made during this survey, it was noted that rare species fall into a number of different morphological and distributional categories. Some are morphologically quite distinct from the vegetation around them, and from their nearest relative, while others are more similar to, and may intergrade with, their nearest relatives, which are often located nearby. There are differences in the distribution patterns of different rare species. Some, such as *Eucalyptus gregsoniana* and (to a lesser extent) *E. sturgissiana* and *Leptospermum crassifolium*, are patchily distributed in the area surveyed. Some, such as *Boronia rhomboidea* and *Eucalyptus gregsoniana*, have widely disjunct distributions. Yet others, such as *Eucalyptus triflora* and *Acacia pubescens*, appear to be consistently distributed in their particular habitat. These observed morphological and distributional differences are categorised and discussed below:

7.3.1 Morphological Categories

Rare species broadly fall into two categories: those which are similar to their nearest relatives and those which are distinctly different.

(i) Those which are very similar to their nearest living relative.

Examples which fall into this first category include all the mallees except *Eucalyptus sturgissiana* and *E. recurva*. For example, *E. multicaulis* is very similar to *E. sieberi*. Likewise, *E. gregsoniana* and *E. moorei*, except for the mallee-form, differ little from *E. pauciflora* and *E. stellulata* respectively. Pryor (1981) said of *E. gregsoniana-E. pauciflora* that there are "some intermediate gradations" between the two. He offered the comment that, although the differences have been recognised by botanists as sufficient to constitute a separate species,"some would it regard as a subspecies". Similarly, *E. multicaulis* and *E. moorei* are the rarer mallee-forms of *E. sieberi* and *E. stellulata* respectively.

Downy wattle (*Acacia pubescens*) is a Mimosaceae which can be included in this group. Apart from its pubescence, is quite similar in its gross morphology to other
pinnate wattles, such as *Acacia mearnsii* and *A. decurrens*. *Dillwynia* sp. aff. *stipulifera* differs only minutely from related species.

(ii) Different from nearest living relative and/or from the majority of forms in that taxon.

Examples which fall into the second category are *Eucalyptus sturgissiana* and *Boronia rhomboidea*. Orbicular, stem-clasping leaves are a distinctive feature of *B. rhomboidea*. The foliage of *B. rhomboidea* is probably most reminiscent of that of *B. serrulata* amongst the *Boronia* species, although it is not closely similar. The chromosome number of this species has not been counted (Weston, pers. comm. 1991) and its nearest relative can only be guessed at. None of the other *Boronia* species are closely resemble this species.

The large leathery leaves of *E. langleyi* and, conversely, the small privet-like leaves and clavate buds of *E. ligustrina* render these two species morphologically distinct from the majority of other contemporaneous eucalypts on the east of the continent.

7.3.2 Analysis of Particular Morphological Characteristics

(i) The connection between glaucousness and cold climates

Glaucousness is a distinctive feature of Sturgiss' mallee. Evidence available suggests that this particular characteristic has a strong association with the occurrence of a species in cold climatic conditions.

The distribution of this characteristic in eucalypts was assessed by surveying Hall *et al.* 1970 and Hall *et al.* 1980. A list of glaucous eucalypts was drawn up (see Table 7.3). Glaucousness in eucalypts was found to be quite strongly associated with distribution in cold climates. Sixty six percent of eucalypts exhibiting glaucousness are recorded as occurring in cold climates characterised by frequent frosts and sometimes light snow. They often grow in montane or tableland habitats. Interestingly, a high proportion of eucalypts exhibiting glaucousness are also of rare, limited or disjunct occurrence (see Table 7.3) and one wonders whether, in former cold climates, such as those thought to
have occurred during the greater part of the Pleistocene, the bluish-grey tones of glaucous species, which contrast strongly with the olive-green tones of today's bush, were once more widespread.

The case for the association between glaucousness and coldness is further strengthened by the observations of Barber (1955) & Barber & Jackson (1957), who found increasing glaucousness in the leaves of several species of eucalypts with altitude in Tasmania. A similar clinal variation is recorded in *E. urnigera* (Hall *et al.* 1970). Yet another example comes from the Monaro region (Costin 1954). Costin described clinal variation in glaucousness in the Kosiusko area in the *E. glaucescens- E. moorei* wet mallee alliance.

The glaucous *E. perriniana* attains the highest elevations, growing where there are heavy snowfalls. *E. glaucescens*, which has glaucous juvenile and concolourous adult leaves, occurs at the next highest altitudes. At lower altitudes again, *E. moorei*, in which seedling and juvenile leaves are slightly glaucous, occurs. A non-glaucous mallee-form of *E. radiata* grows at the lowest altitudes.

(ii) Mallee-Form

Although a dominant feature of vegetation in drier inland parts of Australia (ch. 10 in Groves 1981), the mallee-form is quite strongly associated with rarity in eucalypts, both in the Morton NP wildernesses and elsewhere. This is indicated by the fact that, of the 9 rare eucalypts located in this survey, 5 are mallees (see Table 7.3). In addition, there is a high occurrence of mallees amongst rare eucalypts in all states: of a total of 515 eucalypts described, 108 are mallee eucalypts (i.e., approx. 21%). Of a total of 62 eucalypts listed as rare (Pryor 1981), 29 assume the mallee habit all or most of the time (i.e., nearly 50%). These rare mallees are, almost without exception, located in higher rainfall areas with average annual rainfall ranging from about 600 mm to in excess of 1000 mm. Contrastingly, the current core areas of mallee distribution, at the driest end of the range of distribution of eucalypts, in the 380- 250 mm rainfall zone (Parsons 1981).

The location of the Monaro *Eucalyptus glaucescens- E. moorei* (now *E. latiscula+E. moorei*) "wet mallee" alliance on the Monaro (Costin 1954) suggests possibilities as to
the optimal habitats of the Ettrema/ N. Budawangs "wet mallees", which include *E. moorei*. The Monaro mallee alliance occurs in sites which receive high rainfall and may or may not be subjected to heavy snowfall. Sites are too windy to support taller vegetation and are steep, rocky and subject to large daily temperature fluctuations. Costin (1954) interpreted the discontinuous distribution of this alliance in the montane tract of the Monaro and its recurrence in NSW, ACT, Victoria and Tasmania, as being indicative of the extension of "cool, windy, xeric conditions" in the past. The approximate average annual rainfall (700-1500 mm) of this alliance in the Monaro compares with that of the *E. delegatensis*- *E. dalrympleana* alliance (600-1400 mm) and is higher than that for *E. pauciflora*- *E. stellulata* alliance (460-1100 mm). However, the occurrence of the rare mallees in high rainfall areas does not of itself argue for their former distribution in more xeric conditions. However, the occurrence of the rare mallees in high rainfall areas does not of itself argue for their former distribution in more xeric conditions.

In fact, the distribution of *E. moorei* in Ettrema/ Northern Budawangs in sites which are moist relative to the range available argues against its wider distribution in former more xeric conditions. *E. moorei* was only located adjacent to creeks. This is a reflection of its overall distribution. Hall (1972) recorded that it is "locally dominant on small, damp, cold sites" in the disjunct locations of its occurrence in the Blue Mts, Morton NP, and Monaro areas. Conjecturally, in former cooler, moister climates (such as the pluvial periods described by Nanson & Price 1992), its disjunct patches would have been linked through damp areas of the Great Dividing Range.
Table 7.4: Distribution and Percent of Mallees amongst Rare Eucalypts

<table>
<thead>
<tr>
<th>Rare Eucalypts</th>
<th>N.S.W</th>
<th>Vic.</th>
<th>Qld</th>
<th>W.A.</th>
<th>S.A.</th>
<th>Tas.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>23</td>
<td>8</td>
<td>4</td>
<td>18</td>
<td>2</td>
<td>5</td>
<td>60</td>
</tr>
<tr>
<td>Mallees</td>
<td>9</td>
<td>4</td>
<td>3</td>
<td>11</td>
<td>1</td>
<td>1</td>
<td>29</td>
</tr>
<tr>
<td>% Mallee</td>
<td>39</td>
<td>50</td>
<td>75</td>
<td>61</td>
<td>50</td>
<td>20</td>
<td>47</td>
</tr>
</tbody>
</table>

Not all mallees in this area are relictual species, as can be seen from the widespread distribution of *E. dendromorpha*.

7.3.3. Distributional Categories of Rare Species.

(i) Distribution within the study area.

Some plant species fairly predictably occupy particular habitats. e.g. *E. triflora* (mallee-form) occurs in crevices in most mesa cliffs in the Northern Budawang Ranges (Plate 3.12). *Boronia subulifolia* occurs on most mesa-tops (Plate 7.2a). Downy wattle is consistently distributed along the banks of the lower Ettrema Creek system.

Other species are more or less patchily distributed within the survey area and do not always occupy their preferred habitat where it occurs. For example, there appears to be little constancy in the occurrence of *E. ligustrina* in small patches in north-east Ettrema, nor in the occurrence of *Boronia rhomboidea*. Locating patches of *E. sturgissiana* is rather a "hit and miss" exercise, although this species is more common in the area than either of the aforementioned. Other species in this category in this area are *Eucalyptus dendromorpha* (tree-form), *E. gregsoniana*, *E. langleyi*, *E. moorei*, *E. recurva*, *Boronia deanei* and *Hakea macraeana*.
(ii) Distribution Outside the Study Area (according to current distributional knowledge).

Some of the species are endemic (or nearly so) to the Ettrema-Budawangs area e.g. *Boronia subulifolia*, *Eucalyptus sturgissiana*, *E. triflora*, *Leptospermum crassifolium* and *Budawangia gnidoides*.

Others have contiguous populations in similar habitats to the north and south. e.g. *Eucalyptus dendromorpha* tree-form (Budawangs, Barren Grounds), *Eucryphia moorei* (Budawangs and isolated patches north to Dapto). Plumwood is no longer considered rare, although it is frequent only in habitats which can support rainforest in the Budawangs and Northern Budawangs. These habitats are of restricted occurrence.

Yet others have very odd widely disjunct distribution patterns e.g. *Boronia rhomboidea*, (Budawangs and Tasmania), *Eucalyptus gregsoniana* (two foci, one inland from south coast, with other southern populations at Mongarlowe, etc.; the other in the Newnes-Blue Mts. area west of Sydney, Pryor, 1981). *Boronia deanei* has a similar disjunct distribution, with populations recorded from Endrick River (this survey), Fitzroy Falls, Boyd Plateau (Black 1977) and extensively in the Clarence area and in Nalbaugh NP near Eden (Weston 1990). *Dillwynia stipulifera* has been recorded from the Clarence-Wolgan area (Thompson 1961). Specimens forwarded to the NSW Herbarium were identified as *Dillwynia* sp. aff. *stipulifera*. A number of rare species show disjunctions across the Sydney Basin, linking the Blue Mountains, Morton NP and the Sydney area. With the exception of the endemics *E. sturgissiana*, *E. recurva* and *E. triflora*, all the rare eucalypts (i.e. *E. gregsoniana*, *E. moorei*, *E. ligustrina*, *E. langleyi*, *E. multicaulis*, *E. dendromorpha*) are included in this group. This is thought most likely to be a by-product of the close links displayed between the Ettrema/ North Budawangs vegetation as a whole and the Sydney Basin.

(iii) Distribution of Related Species.

In the case of some rare species, there is a cluster of closely related species in the vicinity e.g. *E. triflora*, *E. fraxinoides*, *E. dendromorpha* in Ettrema-Budawangs.
In the case of others, the most closely related species grows at some distance. e.g. *E. sturgissiana*’s nearest relatives are in Victoria. These are *E. neglecta* and *E. kitsoniana* (Pryor 1981 and Pryor and Johnston 1975). *E. neglecta* is a small tree or bush restricted to the high mountain and subalpine regions of eastern Victoria. *E. kitsoniana* is a mallee distributed in the sub-humid climatic zone along southern coastal Victoria. Both are rare. The next nearest relatives, both rare species, are *E. parvifolia* which has populations at Nimmitabel and in the Deua-Tuross National Park and *E. recurva*, two plants only on private property at Wog Wog. These (except *E. recurva*, not then discovered) were grouped together taxonomically by Pryor & Johnston (1975) as Subseries Neglectinae and Parvifolinae within Series Viminales (which contains many other species which are not rare). The suggestion from distribution and taxonomic affinities is that these are remnants of a biological grouping within eucalypts which radiated over a more extensive area of south-east Australia during former times. These times were probably colder, i.e., the last Ice Age and possibly earlier Ice Ages as well.

7.4 Summary of Morphological and Distributional Categories

Rare species may be

1. Close to or distant from their nearest related extant species morphologically.

   For example, (i) *Eucalyptus dendromorpha* (tree-form) and *E. triflora* are part of a group of closely-related members of Series Obliquae in the Northern Budawangs. (ii) All the rare mallees except two are closely related to a tree species. The two exceptions are *E. sturgissiana* and *E. recurva*, which are not closely similar to any extant species.

2. Close to or distant from their nearest relatives spatially.

   For example, *Eucalyptus dendromorpha* (tree-form) occurs adjacent to the widespread *E. dendromorpha* (mallee-form) and *E. triflora* adjacent to the closely-related *E. fraxinoides*. In contrast, *E. sturgissiana*’s nearest relatives are in Victoria. The rare
mallees, such as *E. gregsoniana* and *E. multicaulis*, occur near their tree-form relatives (*E. pauciflora* and *E. sieberi* respectively).

3. **Consistently or patchily distributed in particular habitats.**

For example, the distribution of *E. triflora* appears consistent, whereas that of *E. dendromorpha* (tree-form) is patchy. The distribution of *E. gregsoniana* and *E. ligustrina* is very patchy, that of *E. sturgissiana* and *E. multicaulis* patchy, but less so than the former two species.

**Rare species may have populations which are:**

1. **Endemic to a very localised area.**

For example, *E. sturgissiana* is endemic to the Ettrema Plateaux, *E. triflora* to the cliffs and mesas of the Northern Budawangs and *Budawangia gnidioides* to dry ledges under overhanging cliffs (Telford 1981).

2. **Contiguous over a region.**

For example, *E. dendromorpha* (tree-form), *Eucryphia moorei* and *Acacia subtilinervis*, all of which have populations to the north and south of Morton NP.

3. **Disjunct**

There is a major pattern of disjunction, shared by a number of the rare species. Species in this group occur in various locations in the Morton NP and in the Blue Mountains. Included are the rare mallees (except *E. sturgissiana* and *E. recurva*), *Boronia deanei*, *Dillwynia* sp. aff. *stipulifera* and *Acacia pubescens*. *Boronia rhomboidea* is distantly disjunct, occurring in the Central Plateau area of Tasmania and in the Northern Budawangs and the Budawangs.
7.5 Evolutionary Implications

The observed morphological and distributional categories have significance in helping to understand the relationship between rare species, present-day environments and widespread plant communities. These are interpreted briefly below.

(i) Morphological Similarity and Difference

The more similar the taxa, the more likely they are to be closely related. The path of evolution involves the radiation of forms when the environment favours a particular taxon, and its decline in less favourable times. Many closely related forms indicates that that taxon (e.g. *Eucalyptus* as a whole) is favoured by current (or recent) environmental conditions. Taxa which are thought to be related but which display a greater degree of morphological difference, such as the *E. sturgissiana, E. neglecta, E. kitsoniana, E. paliformis* group probably evolved at an earlier time. The implication for the latter is that intermediate forms have become extinct and the species group is in a state of evolutionary stasis (at least in present environments), with a reduced rate of evolutionary change.

(ii) Distributional Continuity versus Disjunction

Distributional continuity implies that a species is adapted to and occupies a particular present-day niche. Discontinuity implies distributional contraction or expansion is taking place. Other data (such as morphological similarity versus difference or propensity for long distance dispersal) are needed to distinguish which of these two is taking place.

(iii) Widely Disjunct, Locally Disjunct or Continuous Small Populations

A new taxonomic species will arise out of another within the spatial population of that first species. It follows that if the same species is found at disjunct locations, sufficiently separate to render distance dispersal of any significance extremely unlikely (as in *Boronia rhomboidea, B. deanei, Dillwynia stipulifera* sens. lat. and *Eucalyptus gregsonianiana*), that this species must once have been distributed at suitable sites between these two locations, and that its distribution has contracted. This view was expressed for eucalypts by Pryor
and Johnson (1981), thus: "The persistence of taxonomically more or less isolated species on well-separated sites, with their close adaptation to highly restricted habitats, surrounded by other eucalypt species, implies that they once had much wider extent, presumably when habitats were available that were suited to them or to their immediate forbears. Such tiny populations are the mere fragmented remnants of species that have had a past heyday. This leads to the conclusion that many eucalypt species have become extinct as their habitats disappeared completely".

The implication is that species with disjunct distributions (which are not likely to be a result of long-distance dispersal) are not currently the fittest for sites which they may once have occupied between their extant populations. On the other hand, a single continuous small population may indicate that a species has always been rare, or (as in disjunctly distributed species) that it is a remnant of a formerly more widespread species.

**Conclusions**

Morphological distinctiveness is not in itself sufficient to indicate that a species is a relict. However, this characteristic in combination with the absence of closely related species suggests that a species is out of phase in an adaptive sense with the suite of species round it, and may no longer be well-adapted to the current environment.

Disjunct or irregular, limited distribution of species in Ettrema/ Northern Budawangs suggests more widespread distribution in previous times.

Conversely, morphological similarity to related species and continuous or consistent distribution suggest that a species is adapted to current environments.
7.6 Clues to the Age of Rare and Uncommon Species and when they may have been Dominant in the Plant Community

7.6.1 Reasons for Rarity

(i) Any disturbance

Change in any environmental factor which affects the basic plant growth factors (nutrients, moisture regime, temperature, light) will predictably result in changes in vegetation. All of these would have altered during the marked glacial-interglacial climatic cycles which have occurred during the Quaternary.

(ii) Climatic Change

Likely changes in vegetation over the two million years of the Pleistocene period relate to the fact that the climate has mostly been colder, (but not, as in the northern hemisphere, cold enough to wipe out whole floras), alternating with periods of warmer conditions (see 5.5).

The effects of these Quaternary climates on vegetation at any one place such as Ettrema-Northern Budawangs may be elucidated by considering them in relation to:

(i) The fact that the climatic extremes of the Quaternary had probably occurred previously and since the mid-Miocene. Consequently:

(ii) The likelihood of the pre-existence of vegetation adapted to the range of climates which occurred during the Quaternary.

This general idea is not new, having been put forward by Stebbins (1947) in discussing rates of plant evolution. Based on the thesis that rapid environmental change stimulates rapid evolutionary adaptation, he outlined four major periods of Angiosperm evolution:

1. Cretaceous, when all the major plant families were established.

2. The middle and latter Tertiary, in response to mountain building, global cooling and an increase in temperate habitats.
3. Accompanying the advance and retreat of the successive Pleistocene glaciations. He maintained that changes in plants during this epoch were of a lesser magnitude than those of the previous two periods of rapid expansion, firstly, because new climates which appeared were little different from those which had prevailed before the glacial period and secondly, because new habitats opened were little different from those already existing.

Therefore, it is likely that the influence of Quaternary climatic change on species, has involved the selection from pre-existing characters within taxa of those which are better suited to the return of a previous climatic regime, rather than the evolution of new characters to suit new regimes.

(iii) Human Occupation

The arrival of aboriginal people at least 40,000 years BP and of white people in the last two hundred years would have had several catastrophic consequences. Changes in fire regimes are likely to have occurred. Hunting, grazing, clearing and urbanisation of the Sydney Basin have affected the vegetation.

(iv) Altered Fire Regimes

Frequent and sometimes cyclic changes in vegetation are found in pollen profiles over longer periods of the Quaternary, extending over approximately the last 1-400ky. Increases in scleromorphic taxa in the current interglacial period which are not synchronous with glaciation and are accompanied by an increase in charcoal, seem to provide a fairly definite indication of uni-directional change in vegetation in response to increased fire frequency (Kershaw 1988, Head 1989). It follows that in the Ettrema and North Budawangs, fire-sensitive species would have diminished or have become contracted in their distributions from about this time and expansion of fire-resistant species would have been initiated. This apparently marked change in fire frequency would also have stimulated the commencement of a period of rapid selection of fire-resistant characters within species, from pre-existing adaptations, such as those found in
scleromorphic genera (lignotubers, epicormic sprouting, large woody seeds, microphyll etc.).

v) Geological Change

The Ettrema and Northern Budawangs landsurface is ancient and extremely stable. As outlined in 2.5, evidence from the dating of basalt emplacements indicates that there has been very little change in the landscape since at least the Eocene (Young, R.W. 1977, Young & McDougall 1985). Therefore, geological activity can probably be discounted as a cause of vegetation changes which have taken place in Ettrema/ Northern Budawangs since the mid-Tertiary.

7.6.2 Effects of Quaternary Climates on Rare Species

Since the majority of the Quaternary has been cooler than the present (see 5.5), disjunctly distributed species, are more likely to have been favoured by a colder climate than a warmer one. The suggestion of adaptation to colder climates is present in the morphology of some of the observed rare species, as discussed above, but is not clear in others. Disjunct distributions connected to other populations further south (such as those of *Boronia rhomboidea*, *Acacia subtilinervis*) indicate adaptation to cooler climates. However, southwards fragmentation of distribution is not very pronounced in the rare species occurring in Ettrema/ Northern Budawangs. The clearest disjunction is that north-westwards across the Sydney Basin to the western edge of the Blue Mts. This is probably a materialisation of the strong influence of soil nutrients in the distribution of plant species (see ch.4), combined with the effect of other disturbances, in particular, climatic change, and the various effects of the arrival of humans as outlined in (i) above.

7.6.3 Rates of Speciation and Dispersal

As discussed in ch.5, the order of magnitude of time involved in speciation is more likely to be measured in thousands to millions than in hundreds to thousands of years. It
may take thousands of years to establish a new taxon to its maximum distribution potential.

7.6.4 Application of these considerations to the Ettrema - Budawangs species.

Small variations, such as is shown between *Eucalyptus langleyi* and its Blue Mountains counterpart *E. burgessiana*, may have taken in excess of 10,000 years to become established, in the absence of environmental change great enough to create the equivalent of a bare ground situation. Conversely, where the equivalent of a bare-ground situation was created (as at Krakatau), establishment of new forms could take place quite quickly. For example, *Eucalyptus dendromorpha* mallee-form may have become established quite rapidly following recent (50,000/200 years) increases in fire frequency, given that the genetic potential for this taxonomic species was probably already present in the closely-related *E. dendromorpha* tree-form and that there is a high likelihood that this (and other species) would have been killed by fire.

The time since evolution of significantly more taxonomically isolated species, such as *E. sturgissiana* and *Boronia rhomboidea* is likely to be many multiples of this figure of ten thousand years. These species may even pre-date the Pleistocene.

7.7 Temporal Categories of Rare Species

As a result of the above observations, combined with evolutionary interpretation, a number of groupings of the Ettrema-Budawangs rare species are postulated. These are summarised in Table 7.5 overleaf and then outlined in more detail.
Table 7.5: Reasons for Rarity/Uncommonness in Ettrema/ N.Budawangs

<table>
<thead>
<tr>
<th>Relicts of Past Climates</th>
<th>Not Relicts</th>
<th>Radiating/contracting</th>
<th>Recent Cause/Accentuated by Loss Humans</th>
<th>Urban Devt.</th>
<th>Fire/Grazing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ancient</td>
<td>Less Old</td>
<td>Small Niche</td>
<td></td>
<td>Urban Devt.</td>
<td>Fire/Grazing</td>
</tr>
<tr>
<td>Eucalyptus sturgissiana, Boronia rhomboidea</td>
<td>Most mallees</td>
<td>Eucalyptus triflora, Budawangia gnidioides</td>
<td>Eucalyptus dendromorpha, mallee/tree</td>
<td>Eucalyptus beyeriana</td>
<td>Goodenia glomerata, Boronia subulifolia</td>
</tr>
</tbody>
</table>

(i) Relicts of former climates, with a long evolutionary history.

A. Evidence of adaptation to climates colder than at present:

*Eucalyptus sturgissiana, E. recurva, Boronia rhomboidea*

B. Climatic adaptation not clear:

*Eucalyptus langleyi, E. ligustrina*

(ii) Relicts of former climates, but with a more recent evolutionary history.

e.g. *Eucalyptus gregsoniana, E. multicaulis, E. moorei, Boronia deanei.*

(iii) Part of a rapidly evolving genetically mobile complex.

e.g. *Eucalyptus dendromorpha.* This species, is very closely related to *E. stricta* and hybrids between these two were found in the study area. This suggests that it is actively evolving now. *Eucalyptus dendromorpha* (mallee-form), being widespread and consistently distributed in the Ettrema and Budawangs areas, cannot be rated as a rare species in this area, whereas *E. dendromorpha* trees are very restricted in their distribution, sporadically distributed close to watercourses in heathland. *Eucalyptus*
dendromorpha (mallee-form) is well adapted to current fire regimes, regenerating (after having been burnt to ground level) from lignotuber to fruit production in three years (observed at Barren Grounds). This raises the possibility that its current widespread distribution has been promoted by very recent high fire frequencies.

(iv) Rare species evolved in a habitat of limited area or potential.

This may apply to species such as Eucalyptus triflora, which clings to rocky outcrops, or Budawangia gnidioides, also found in rocky locations and possibly to Leptospermum crassifolium, Dillwynia stipulifera (sens.lat.) and Boronia subulifolia. Kunzea sp.aff. capitata (sp. nov.B), found on the Ettrema Plateaux may also fall into this category, being a localised species. Most of these species might alternatively or additionally fall into category F.

(v) Species rare or uncommon as a result of urban development

   e.g. Acacia pubescens, Eucalyptus beyeriana

(vi) Species whose rarity may have been accentuated by recent local effects of man, such as increased fire frequency or grazing.

   There is a strong likelihood that the rarity of some of these species has either been caused or accentuated by the activities of man, in particular, grazing and increased fire frequency.

   Species which may be included here are Eucalyptus triflora, E. sturgissiana, E. dendromorpha (tree-form), Boronia subulifolia, B. rhomboidea, B. deanei, Goodenia glomerata, Dillwynia stipulifera (sens.lat.). Boronia subulifolia, found on mesa-tops on top of the inaccessible Mt.Currockbilly further south and also found along margins of Ettrema plateaux, may once have been more widespread across this area and have contracted to fire-safe and/or grazing-safe locations within its potential habitat. Goodenia glomerata may also fall into this category, having been located in two different habitats, both relatively sheltered from fire and grazing (mesa-top and sheltered mesa-slope). If
these two separate habitats are fragments of its previous distribution, then it may previously have been extensive in this area. To quote Darwin (1872): "As the tide leaves its drift in horizontal lines, rising higher on the shores where the tide rises highest, so have the living waters left their living drift on our mountain summits...". In this case, the elemental motivating force proposed is not the "living waters" (i.e. glaciation), but fire, rising high up the slopes of the mountains.
Table 7.1: Rare and Uncommon Angiosperms Occurring in the Ettrema and Northern Budawangs Areas of Morton National Park

Rare species which have been reported elsewhere but not found during this survey are bracketed.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Epacridaceae</td>
<td>Budawangia gnidioides (Summerh.) Telford</td>
<td>Budawang Ranges-st.rock ledges</td>
<td>endemic</td>
<td>2VC</td>
<td>consistent in special -ized niche</td>
</tr>
<tr>
<td>Eucryphiaceae</td>
<td>Eucryphia moorei F.Muell.</td>
<td>Frequent in RF around mesas-slopes</td>
<td>Budawangs, Victoria</td>
<td>-</td>
<td>frequent in habitat</td>
</tr>
<tr>
<td>Faboideae</td>
<td>Dillwynia sp. aff. stipulifera Blakely</td>
<td>Heath on mesas</td>
<td>W. Blue Mts &amp;Budawangs (Thompson 1961)</td>
<td>3RC</td>
<td>collected once</td>
</tr>
<tr>
<td></td>
<td>(Pultenaea bauerlenii F.Muell.)</td>
<td>(Burrumbeet Brook)</td>
<td>Currockbilly Mt.</td>
<td>2VCa</td>
<td>collected once</td>
</tr>
<tr>
<td></td>
<td>(Pultenaea sp.D)</td>
<td>(Hidden Valley)</td>
<td></td>
<td>2K</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Harden 1991</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pultenaea sp.H</td>
<td>Ettrema &amp; N. Budawangs</td>
<td>Judge Dowling Ra.- Lower Blue Mountains</td>
<td>2RC-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Harden 1991</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Goodeniaceae</td>
<td>Goodenia glomerata Maiden &amp; Betche</td>
<td>Rocky mesatops</td>
<td>Endemic</td>
<td>2RC</td>
<td>restricted</td>
</tr>
<tr>
<td>Mimosoideae</td>
<td>Acacia pubescens (Vent) R.Br.</td>
<td>Ettrema creek system</td>
<td>Lower Blue Mts, W. Sydney (Leigh et al. 1984)</td>
<td>2VCa</td>
<td>abundant in one habitat</td>
</tr>
<tr>
<td></td>
<td>Acacia subtilinervis F.Muell.</td>
<td>Ettrema plateaux</td>
<td>SC,Clyde Mt., nr.Goulburn</td>
<td>3V</td>
<td>collected once</td>
</tr>
<tr>
<td>Myrtaceae</td>
<td>Darwinia taxifolia Cunn.ssp. macrolaena B.Briggs</td>
<td>Ettrema Plateau</td>
<td>Nowra, Tomerong, Berrima</td>
<td>not listed</td>
<td>collected once or twice</td>
</tr>
<tr>
<td></td>
<td>(Eucalyptus apiculata R.Baker &amp; H.G.Smith )</td>
<td>Belmore Falls (Cosh) WogWog (Plumwood)</td>
<td>O'Hare's Ck catchment / Berrima Colliery</td>
<td>not seen</td>
<td></td>
</tr>
<tr>
<td></td>
<td>E.beyeriana L.Johnson &amp; K.Hill</td>
<td>N.E.Ettrema</td>
<td>Locally frequent Narrabri - Nowra (Harden 1991)</td>
<td>S.P.5</td>
<td>not known</td>
</tr>
<tr>
<td>Species</td>
<td>Location</td>
<td>Vegetation Type</td>
<td>Status</td>
<td>Notes</td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------------</td>
<td>-----------------</td>
<td>--------------</td>
<td>---------------------</td>
<td></td>
</tr>
<tr>
<td><em>E. dendromorpha</em></td>
<td>Heath in Ettrema, Nth. Budawangs</td>
<td>Barren Grounds, Budawangs</td>
<td>S.P.5 Endangered</td>
<td>Mallee: Very Abundant Tree: Rare</td>
<td></td>
</tr>
<tr>
<td><em>E. gregsoniana</em></td>
<td>Wog Wog</td>
<td>Wolgan Valley</td>
<td>3V</td>
<td>Rare</td>
<td></td>
</tr>
</tbody>
</table>
There is NO p. 331 in original document
Table 7.3: Glaucous Eucalypts
(Data from Hall et al. 1970 & and Hall et al. 1980)

<table>
<thead>
<tr>
<th>Species</th>
<th>Glaucous Parts</th>
<th>Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>wandoo</td>
<td>seedling&amp;juvenile leaves</td>
<td>temperate sw WA</td>
</tr>
<tr>
<td>blakelyi</td>
<td>&quot;</td>
<td>w. slopes NSW frosts</td>
</tr>
<tr>
<td>dealbata</td>
<td>adult &amp; juvenile &quot;</td>
<td>NSW, w. slopes frosts</td>
</tr>
<tr>
<td>camaldulensis</td>
<td>juv. &quot;</td>
<td>Along all Aust. seasonal watercourses</td>
</tr>
<tr>
<td>manifera ssp.maculosa</td>
<td>seedling leaves</td>
<td>central &amp; s. tablelands NSW, frosts</td>
</tr>
<tr>
<td>bridgesiana</td>
<td>juv. leaves subglaucous</td>
<td>w. slopes NSW frosts</td>
</tr>
<tr>
<td>gonioalyx</td>
<td>&quot;</td>
<td>w. slopes &amp; foothills of alps Vic., NSW</td>
</tr>
<tr>
<td>rubida</td>
<td>seedling &amp; juvenile leaves subglaucous</td>
<td>tabelands &amp; upper w. slopes NSW</td>
</tr>
<tr>
<td>gunnii</td>
<td>juv. leaves</td>
<td>Tas. limited distr. Central Plateau</td>
</tr>
<tr>
<td>globulus</td>
<td>seedl., juv. leaves, fruit</td>
<td>Tas., frosts</td>
</tr>
<tr>
<td>bicostata = St. Johnii</td>
<td>fruit</td>
<td>Vic.- NSW, frosts</td>
</tr>
<tr>
<td>maideni</td>
<td>seedl., juv. leaves</td>
<td>se NSW, frosts</td>
</tr>
<tr>
<td>cypellocarpa</td>
<td>juv. leaves</td>
<td>se NSW, Vic., temperate with frost &amp; light snow</td>
</tr>
<tr>
<td>nitens</td>
<td>juv. leaves</td>
<td>frosts numerous &amp; severe</td>
</tr>
<tr>
<td>cinberea</td>
<td>all leaves &amp; parts of inflorescence</td>
<td>s. parts central tablelands, frosts; disjunct distr.</td>
</tr>
<tr>
<td>patens</td>
<td>juv. leaves</td>
<td>sw WA, nr coast. Few frosts</td>
</tr>
<tr>
<td>sieberi</td>
<td>seedl. &amp; juv. leaves, stalks</td>
<td>Often in exposed locations</td>
</tr>
<tr>
<td>pauciflora</td>
<td>seedl. &amp; juv. leaves</td>
<td>alpine-montane</td>
</tr>
<tr>
<td>coccifera</td>
<td>adult leaves green or grey-green</td>
<td>Tas. snow gum. Distr. restr.</td>
</tr>
<tr>
<td>dives</td>
<td>juv. leaves</td>
<td>e. &amp; s. Vic. &amp; foothills of Divide etc. Frosts</td>
</tr>
<tr>
<td>albens</td>
<td>seedl. &amp; juv. leaves</td>
<td>w. slopes NSW, low rainfall</td>
</tr>
<tr>
<td>fibrosa ssp. fibrosa</td>
<td>juv. leaves</td>
<td>coastal NSW, Qld</td>
</tr>
<tr>
<td>fibrosa ssp. nubila</td>
<td>branchlets, inflorescence, leaves</td>
<td>n. NSW-S. Qld, cool, humid, 10-30 frosts, 6-700 mm rain</td>
</tr>
<tr>
<td>melanophloia</td>
<td>juv. &amp; adult leaves, inflorescence</td>
<td>semi-arid NSW, Qld; 10-20 frosts</td>
</tr>
<tr>
<td>nova-anglica</td>
<td>seedl., juv. ± adult leaves</td>
<td>n. tablelands, frosts±snow</td>
</tr>
<tr>
<td>polybracteata</td>
<td>seedl., juv. (slightly)</td>
<td>restricted, disjunct distr.: Wyalong, Bendigo</td>
</tr>
<tr>
<td>glaucescens</td>
<td>seedl., juv. leaves</td>
<td>limited distr., sub-alpine Vic., NSW, disj. nr Tamworth</td>
</tr>
<tr>
<td>malacoxylon</td>
<td>juv. &amp; intermediate</td>
<td>restr. n. central tablelands of NSW; frosts</td>
</tr>
<tr>
<td>dawsonii</td>
<td>juv. &amp; intermed. leaves</td>
<td>restr. n. central tablelands of NSW; frosts</td>
</tr>
<tr>
<td>pulverentula</td>
<td>all leaves &amp; inflorescence</td>
<td>cool temperate NSW; restr. &amp; disj.: Bowenfels, Bredbo</td>
</tr>
<tr>
<td>Species of <em>Eucalyptus</em></td>
<td>Glaucous Parts</td>
<td>Habitat</td>
</tr>
<tr>
<td>-------------------------</td>
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</tr>
<tr>
<td><em>moorei</em></td>
<td>seedling &amp; juvenile leaves slightly glaucous</td>
<td>NSW disj: Blue Mts, Jervis Bay, N. Budawangs, Kybean</td>
</tr>
<tr>
<td><em>pruinosa</em></td>
<td>adult leaves thick, glaucous</td>
<td>n. NT, WA, Qld Semi-arid on wide range topography &amp; soils</td>
</tr>
<tr>
<td><em>morrissyli</em></td>
<td>seedl., adult leaves</td>
<td>Tas., v. restr.; mild climate</td>
</tr>
<tr>
<td><em>cordata</em></td>
<td>most parts glaucous</td>
<td>se Tas., v. restr., frost, snow, damp</td>
</tr>
<tr>
<td><em>urnigera</em></td>
<td>altitudinal cline: leaves green to v. glaucous</td>
<td>Tas., restr. mod. to high alts</td>
</tr>
<tr>
<td><em>tenuiranis</em></td>
<td>juv. ± adult leaves</td>
<td>Tas.; frosts &amp; light snow</td>
</tr>
<tr>
<td><em>pseudo-globulus</em></td>
<td>young leaves, buds &amp; fruit</td>
<td>NSW &amp; Vic nr coast</td>
</tr>
<tr>
<td><em>gonylocarpa</em></td>
<td>seedl. &amp; juv. leaves</td>
<td>arid, occasional frosts</td>
</tr>
<tr>
<td><em>accedens</em></td>
<td>juv. leaves</td>
<td>sw WA; warm temperate, low rainfall</td>
</tr>
<tr>
<td><em>chapmaniana</em></td>
<td>young leaves, buds, fruits, twigs</td>
<td>Inland side of Australian alps, montane</td>
</tr>
<tr>
<td><em>crenulata</em></td>
<td>all leaves, buds, twigs</td>
<td>v. restr. nr. Melb.; humid, frosts</td>
</tr>
<tr>
<td><em>neglecta</em></td>
<td>other than adult leaves, twigs</td>
<td>high mt. 7 subalpine e. Vic. Disj. distr.</td>
</tr>
<tr>
<td><em>shirleyi</em></td>
<td>all stages of leaves, buds &amp; young fruit</td>
<td>ne Qld; sub-humid</td>
</tr>
<tr>
<td><em>microneura</em></td>
<td>adult leaves subglaucous</td>
<td>Cape York peninsula; sub-humid</td>
</tr>
<tr>
<td><em>argillacea</em></td>
<td>adult leaves glaucous to light green</td>
<td>n. Aust., semi-arid</td>
</tr>
<tr>
<td><em>sturgissiana</em></td>
<td>buds &amp; juv. leaves</td>
<td>Restr. Ettrema, frosts</td>
</tr>
<tr>
<td><em>perriniana</em></td>
<td>twigs, buds, fruits, seedl. &amp; juv. leaves</td>
<td>NSW, Vic.; alpine-montane Restr., snow common</td>
</tr>
<tr>
<td><em>debeuzevillei</em></td>
<td>buds, twigs, fruit</td>
<td>restr., Snowy Mts, subalpine</td>
</tr>
<tr>
<td><em>gillii</em></td>
<td>juv. ± adult leaves, twigs, buds, fruit</td>
<td>SA disj., arid, 1-5 frosts</td>
</tr>
<tr>
<td><em>andrewsii</em></td>
<td>int. &amp; adult leaves, twigs, buds</td>
<td>n. NSW-Qld, frosts ± snow</td>
</tr>
<tr>
<td><em>caleyi</em></td>
<td>all stages f leaves &amp; buds v. glaucous</td>
<td>s. Qld-w. NSW; warm, sub-humid, frosts</td>
</tr>
<tr>
<td><em>whitei</em></td>
<td>adult leaves (variably)</td>
<td>n. Qld, warm to hot, semi-arid</td>
</tr>
<tr>
<td><em>risdonii</em></td>
<td>juv. ± adult leaves, buds &amp; fruits</td>
<td>se Tas., rare, snow</td>
</tr>
<tr>
<td><em>apodophylla</em></td>
<td>buds &amp; younger leaves</td>
<td>SA, sub-humid, swamps</td>
</tr>
<tr>
<td><em>morrissii</em></td>
<td>adult leaves tending to sub-glaucous</td>
<td>w. NSW; warm, semi-arid</td>
</tr>
<tr>
<td><em>gamophylla</em></td>
<td>juv. &amp; int. leaves, twigs &amp; inflorescence</td>
<td>s. NT, Qld arid</td>
</tr>
<tr>
<td><em>pendens</em></td>
<td>young branchlets</td>
<td>WA, warm, sub-humid</td>
</tr>
<tr>
<td><em>kartzoffiana</em></td>
<td>juv. leaves, branchlets &amp; inflorescence</td>
<td>s. NSW, restr., frost &amp; snow</td>
</tr>
<tr>
<td><em>leucoxylon</em></td>
<td>all new leaves, twigs, buds, fruits</td>
<td>w. Vic. &amp; se S. Aust.; warm, sub-humid</td>
</tr>
<tr>
<td><em>stenostoma</em></td>
<td>branchlets &amp; inflorescence</td>
<td>s. NSW coast, restr.; mild</td>
</tr>
<tr>
<td><em>pyrocarpa</em></td>
<td>stems, leaves, buds, fruit</td>
<td>n. NSW-s. Qld; warm, humid</td>
</tr>
</tbody>
</table>
Table 7.3: Glaucous Eucalypts

Analysis

A total of 58 species are listed as having glaucousness in some anatomical parts. 38 (i.e. 66%) of these occur in cold climates. At least 21 (i.e. 36%) of the total are species of restricted occurrence. At least 13 species are both rare and occur in cold places, i.e., 61% of the rare glaucous species occupy cold habitats.
Plate 7.1: Rare Mallees


b. *Eucalyptus langleyi*, Yalwal Ramp
Plate 7.2: Rare Species on Mesa-Tops

a. *Boronia subulifolia*

b. *Leptospermum crassifolium*
8. The Role of Fire in Shaping Vegetation

8.1 Introduction

8.1.1 Raging controversies

The effects of fire on the Australian vegetation has been the subject of raging controversy amongst conservationists, foresters and researchers for nearly half a century. Numerous conferences have been held, for example, conferences organised by the National Parks Association, a large NSW conservation group (Catford 1967, 1970 & 1976) and for the Illawarra by Whelan & Spencer (1983).

Fire has been viewed by conservationists as a destructive agent introduced by Europeans, and by fire control authorities and foresters as a disturbance of such long-standing that much of the Australian vegetation must literally depend on fire for its survival. The scientific community appears to have widely accepted this view, with the uncritical conclusion that the Australian vegetation is fire-adapted often written.

8.1.2 Fire as a Force Shaping Vegetation

Witnessing the devastation caused by wildfire (for example, that described by Newsome et al. 1975), leaves one in no doubt that only those species with mechanisms enabling them to regenerate could survive even a single such occurrence, except by escaping the fire altogether, either by chance or in fire-sheltered locations. Such a "pattern of survival" will be dependent upon fire behaviour, which is in turn dependent upon a variety of environmental factors. These are briefly outlined and following this, key elements of fire behaviour in south-east NSW are described.

A. Determinants of Fire Behaviour in Eastern NSW.

Fire behaviour is determined by factors such as climate (wind patterns, seasonal occurrence of wind and rain), physiography and ignition source.
(i) Climate

The hot north-west and westerly winds originating from the hot air mass in the centre of Australia in spring and sometimes summer (Luke & McArthur 1978) are a major factor in determining the fire patterns in south-east NSW.

(ii) Physiography

Different types of physiography will produce different burn patterns. For example, Newsome et al. (1975) described the "coarse-grained" environment of the dry sclerophyll forest at Nadgee as burning unevenly, thus creating refugia. In contrast, the "fine-grained" physiography of the upland moors was thoroughly burnt. Wide rivers, deep gorges, steep clifflines and expanses of rock are some physiographic features which could be expected to slow the progress of a wildfire and provide refuges.

Fire intensity and rate of spread are affected by physiography. Fires travel faster up slopes than across flat country. The rate of forward spread of a fire on level ground doubles on a ten degree slope and increases almost fourfold travelling up a twenty degree slope and fire spread is considerably reduced on downslopes even when moving with the prevailing wind (Luke & McArthur 1978).

The least fire-prone locations are also often the moistest sites. Luke & McArthur recorded that the rate of acceleration of fires is influenced by litter moisture content and (to a lesser extent) of living vegetation. At litter moisture contents greater than fifteen percent, fire behaviour is very predictable and fire intensity is low. It becomes difficult to separate the effects of fire and moisture balance in determining the distribution of some of the different community types.

(iii) Ignition Source

A proportion of fires are caused by lightning strikes. Many bushfires result from deliberately lit fires which subsequently burn out of control. Irrespective of whether fires originate from natural or human causes in south-east NSW, the majority still travel in an east to south-easterly direction, born on hot, dry westerly winds.
B. Fire Behaviour

Fire behaviour may be described in terms of its frequency, direction of travel, intensity and seasonality.

(i) Frequency

Records show that major fires have been frequent in south-east NSW this century (Table 8.1)

<table>
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<tr>
<td>1915</td>
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<td>1925-6</td>
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<td>Jan. 1929</td>
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<td>1938-9</td>
<td>1938-9</td>
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<td>1951-2</td>
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<td>1968</td>
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<td>1968</td>
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<td>1972-3</td>
<td>1972-3</td>
<td>1975-6</td>
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<td>Jan. 1983</td>
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<td></td>
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<td>1988-9</td>
</tr>
</tbody>
</table>

(ii) Direction of Travel

The majority of bushfires in south-east NSW originate to the west and are borne towards the coast before these prevailing dry westerly winds.

(iii) Intensity and Seasonality

Wildfires generally become intensely hot. Intensity may be further heightened by fuel build-up, heat-wave and drought conditions and strong winds. Spring and sometimes summer are the most bushfire-prone seasons in south-east NSW.
8.1.3 Pre-European Fire Regimes in Australia and Changes Since Settlement

i) Evidence from Pollen Profiles

The frequency of fires through the tens of thousands of years of aboriginal occupation prior to the arrival of white man is unknown. As discussed in 6.3, charcoal deposits in pollen profiles indicate that there may have been periodic fires (Singh et al. 1981, Head 1989). An increase in fire frequency as evidenced by an increase in charcoal, is apparent at most major fossil pollen sites sometime during the Quaternary. At Lake George, this increase in charcoal is apparent at about 130,000 years BP, whereas at Lynch's Crater (Atherton Tableland) an increase in charcoal occurs at about 40,000 years BP (Singh et al. 1981). These higher charcoal levels continue through climatic and vegetation changes associated with the last Ice Age and are very suggestive of high fire frequency during aboriginal occupation.

(ii) Use of Fire by Aborigines

Information summarised by Nicholson (1981) records that aborigines used fire for the following:

(a) The maintenance of grassland in eastern Victorian river valleys and in north-west Tasmania. When this practice was stopped by white settlers, whole tracts of country reverted to forest. In these areas at least, the arrival of Europeans meant a reduction in fire frequency.

(b) Burning firebreaks around sacred sites and food source areas which they wished to protect. This is indicative of their ability to use fire as a tool and direct its path and also of their awareness that it could destroy their food plants.

(c) As a hunting tool. For example, the "almost daily" and skilful use by the Gidgingali tribe in the Northern Territory was witnessed by the anthropologist Rhys Jones when living with them (Jones 1975).
(iii) Fire During the Quaternary

Since glacial and interstadial periods, producing climates colder than at present are thought to have occupied ninety percent of the Quaternary, similar climates may not have been a frequent occurrence (see Ch. 5). The predominance of colder climates throughout most of the Quaternary suggests that high fire frequencies would have been an unlikely scenario.

(iv) Fire During the Tertiary

Although there is evidence for fire during the Tertiary (Kemp 1981), frequencies are unknown. On the basis of the proportion of fires attributed to lightning strikes (NPWS unpubl.) frequency was possibly as high as ten to twenty percent of current frequencies of larger fires during similar climatic regimes. Areas which now burn once every three years may have burnt only once every fifteen to thirty years.

Scant clues from which we may deduce the occurrence of fire in the Tertiary are summarised by Kemp (1981) and include:

a) The presence of pyrofusinite in coals. The value of this clue is limited by disagreement as to how much fusinite is actually pyrofusinite.

b) Alteration of rocks by fire. e.g. those adjacent to burning coal seams. Coal seams sometimes ignite spontaneously and this could have happened during the Tertiary.

c) Preservation of the record of lightning strikes as "fulgurites" (i.e. dendritic patterns) in sand.

d) The inevitability that volcanic activity would have started fires.

Possibly, during suitable climates of the Tertiary, fire was an occasional catastrophic event. However, in particular areas or climates, for one reason or another, it may have occurred more frequently. For example, in areas or times of high thunderstorm activity, fires could have occurred more frequently as a consequence of lightning strikes. It seems unlikely that fires would at any time during the Tertiary have occurred as frequently as they have in the last one hundred years.
(v) Conclusion

On the basis of scant clues, it appears that some fire did occur during the Tertiary, but its character remains a mystery. Fossil pollen records suggest that there was an increase in fire frequency coinciding with aboriginal occupation approximately 50,000 years BP. Fire frequency has been very high in south-east NSW in the last 50-100 years.

8.1.4 Fire-Sensitive Vegetation

Gill (1981b) summarised fire-adaptive traits in vegetation. These include subterranean bud tissue (e.g. lignotubers), bark protection of aerial buds, epicormic sprouting, stimulus of flowering, seed shed and germination by fire, on-plant seed storage, hardseededness, life cycles of duration in harmony with fire frequency. Fire-sensitive species may be regarded as those which do not possess such mechanisms and which are therefore, readily destroyed by fire. The following groups of vegetation contain many fire-sensitive species.

(i) Rainforest

Rainforest as a whole is fire-sensitive and many rainforest tree species are easily destroyed by fire (Francis 1970, Floyd 1989). Fire is probably an important factor controlling rainforest margins (Beadle 1981, Powrie 1981). Eucalypt forest, particularly tall open (wet sclerophyll) forest, has often been viewed as a "Fire Climax", with rainforest considered to be the potential climatic climax over much of Eastern Australia, its development prevented by repeated fire (Ashton 1981b, Newsome et al. 1975).

(ii) Fire-Sensitive Eucalypts

The majority of eucalypts have morphological features which enable established plants to regenerate rapidly following fire. These responses are epicormic sprouting of buds which survive fire beneath thick, heat resistant bark and basal sprouting from subterranean bud tissue protected by woody burls (lignotubers).
Some species (for example, *Eucalyptus regnans*), which are fire-sensitive, according to the criterion that they are killed outright by fire, have nevertheless been regarded as being fire-adapted because they are in harmony with a regime of wildfire recurring at well-spaced intervals (stated for example by Foster 1976). The stimulation of seed release and massive germination following fire ensures the regeneration of the species, even though the majority of mature plants are killed outright.

Nevertheless, these species are sensitive to high frequency fire regimes, i.e., burning at intervals shorter than time taken to develop seeds. Many magnificent *E. regnans* forests in Victoria have been reduced to scrub or bracken since the arrival of European man (Ashton 1981b & 1981c).

*E. regnans* belongs to a group of eucalypts which, on the whole, display a lower capability to survive fire by means of lignotubers, epicormic sprouting and thick bark. This is the Ash Group of eucalypts (Series Obliquae of Pryor & Johnson 1975). The majority of eucalypts in this group do not possess lignotubers. Some (such as *E. viminalis*, *E. obliqua* and *E. pilularis*) develop lignotubers in dry forest (dry sclerophyll), but not in moist forest (wet sclerophyll).

Despite the possession of characteristics which are traditionally assumed to be fire-adaptations, some species are still fire-sensitive. For example, Snow Gum (*E. pauciflora*), which has massive basal bud tissue (see Plate 9.2), may be killed outright by wildfire (Bryant 1971). The effects of fire on *E. luehmanniana*, a mallee species in Series Obliquae, were reported by Davies & Myerscough (1991). This species displayed rapid regeneration from basal buds following fire, but recruitment of new individuals following an experimental burn was zero, as a result of 100% mortality of seedlings within 200 days. It was concluded that the maintenance of *E. luehmanniana* populations is not solely dependent on low fire frequency (and high fire frequency was considered likely to diminish population size.) It appears that factors other than fire are responsible for the rarity of this species, since the species is neither killed outright by fire nor is its survival apparently enhanced by fire.
(iii) Smoothbarks and Roughbarks

Roughbark provides greater protection from the heat of fire and smoothbarks are more readily killed by it (Gill 1981b, Ashton 1981).

(iv) Rare Species and Fire

The rarity of some species may be caused or accentuated by altered fire regimes in the last two hundred years.

(v) Mallees and Fire

Variable data have come forth on the reactions of mallees to fire. Research suggests that some inland mallee vegetation may be maintained by fire occurring at well-spaced intervals (Wellington & Noble 1985), but may be extremely vulnerable to specific fire treatments. Noble (1982) found that two consecutive autumn burnings destroyed 90% of experimental plots of inland mallee near Pooncarie, western NSW. At least one of the coastal mallees (*E. dendromorpha* mallee-form) appears well-adapted to fire. Widespread in heathland of the southern Sydney Basin, individuals of this species regenerate rapidly to reproductive stage following burning to ground level in fire. *Eucalyptus luehmanniana*, another coastal mallee, has been observed to regenerate following fire at an equivalent rate (Davies & Myerscough 1991). These researchers concluded that more than fire was needed to ensure regeneration in the rare coastal mallee, *E. luehmanniana*, since seedlings (whose germination was stimulated by fire) did not survive beyond 200 days.

8.1.5 Adaptation of the Australian Vegetation to High Fire Frequencies

A. Rates of Adaptation

One hundred years of high fire frequencies is probably long enough to cause contraction in the distributions of fire-sensitive species. However, based on information available on rates of species differentiation of even small degree (see Ch. 5), it is unlikely to be long enough to allow the development and full distributional expansion of
forms adapted to high frequency fire regimes. Based on estimated rates of speciation (see Ch. 5) however, 50,000 years could be long enough to

(i) wipe out sensitive vegetation from fire-prone sites
(ii) begin the selection of "pre-adapted" characters, such as those previously developed in response to drought, low soil nutrients, mechanical damage or low frequency fire.

B. Origin of the Features of Vegetation which Enable it to Survive Fire.

Australian sclerophyll vegetation is thought to have evolved in relation to low nutrient status of soils (Beadle 1954 & 1962), not the probable increased fire frequencies since the arrival of man on this continent at least 50,000 years before present (Roberts et al. 1990). Aridity on this continent is thought to have originated following the separation from Antarctica. Beard (1977) hypothesised that aridity (and the development of arid-adapted vegetation) began in the north-west of Australia as early as the Eocene-Oligocene, becoming more widespread as the continent moved northwards. Many of the characters which enable plants to survive fire could have evolved initially in response to these and other stimuli, at much earlier times.

This view is supported by at least some of the data presented by Gill (1981b). For example, he summarised explanations of the significance of hardseededness (or more accurately, hardfruitedness), which have emerged in recent years. These include prevention of predation, delay of germination until after summer drought, survival of water transport and survival of fire.

That hard-seededness may be a multi-purpose adaptation is illustrated by the following example. The Cabbage Palm (Livistona australis) is common below cliff lines in Ettrema and its woody nuts may have the capacity to survive fire. However, the woody nuts of Cabbage Palms are not dependent on fire for germination, but have been observed to break down within three months in moist rainforest soil, (observed at Foxground, NSW, 1983), where prevention of predation or protection from the predator's digestive juices would be valuable advantage of hardfruitedness.
Further evidence for lack of specificity to fire of adaptations which enhance survival following fire is provided by experiments conducted by Gill and Ingwersen (1976), in which both fire and clipping were found to stimulate flowering in Xanthorrhoea australis. This suggests that mechanical damage, irrespective of source, would stimulate some flowering in this species (although possibly not as prolific as that stimulated by fire).

Similarly, mechanical damage of Snow Gums by ice and snow has been observed to stimulate lignotuberous sprouting of this species (Plate 8.2), suggesting a pre-fire origin of this character.

Siddiqi et al. (1976) described this characteristic in three species, Banksia serratifolia, B. oblongifolia (=aspleniifolia) and B. ericifolia. Their field observations indicated that "the follicles open and shed their seed only after branches bearing the inflorescences die or are burnt." They concluded that these Banksias demonstrate the ability to survive fire without there necessarily being any dependence on fire: "The main features of importance in seedling establishment after fire in Banksia serratifolia, B. oblongifolia and B. ericifolia appear to be the protection of the seeds within hard follicles during the fire, with their release immediately after it."

The notion of fire dependence was introduced by Gill (1981b), who attributed the finding of fire dependent dehiscence in Banksias to Siddiqi et al. thus: "Banksia species that show fire dependent dehiscence are Banksia ericifolia, B.serratifolia and B.oblongifolia of coastal heathlands of NSW."

Lignotuberous tissue is found in some members of primitive Angiosperm families, for example, Eupomatia laurina. Endress (1983) documented the protruberances which develop in the axils of the cotyledons of this species. This suggests that this character originated early in angiosperm evolution and has probably been part of angiosperm potential since the Cretaceous. Lignotubers were observed in some rainforest species (Hedycarya angustifolia and Acmena smithii) by Ashton (1981b). He noted that the heartwood of incompletely calloused individuals can catch alight, "thus killing the living
buds from within by a slow smouldering fire." About 20% of Illawarra rainforest species were observed to regenerate from stump or rootstock in one study (Powrie 1981).

On the basis of the above observations, it appears likely that, while many plants may be adapted to survive the occurrence of occasional catastrophic fire, adaptation to higher fire frequencies since, firstly, the arrival of aboriginals at least 50,000 years ago and secondly, Europeans 200 years ago, is an ongoing process.

8.1.6 Expected Distributions

Since fire is a frequent occurrence in Ettrema-Northern Budawangs, it was expected from the outset that fire-sensitive vegetation would be found mainly, if not exclusively, in locations sheltered from fire and where fire, if it occurs, is likely to be of lower intensity.

8.1.7 Aims of this Chapter

Because fire is clearly a force which can shape vegetation patterns rapidly, and the SE NSW forests have been subjected to frequent fires since the arrival of Europeans, vegetation patterns in Ettrema/ Northern Budawangs are likely to have been much affected.

The aims of this chapter are:

(i) To summarise what is known of fire patterns and frequencies in Ettrema and Northern Budawangs. (Section 8.2)

(ii) To discuss the likely effects of physiography on fire behaviour in Ettrema-Northern Budawangs. (Section 8.3)

(iii) To outline and discuss the observed distributions of fire sensitive vegetation in the Ettrema and Northern Budawangs.(Section 8.4)

(iv) To discuss the likely effect of fire on change in vegetation through evolutionary time.
8.2 Fire Patterns and Frequency

8.2.1 History of Fires in the Study Region

Fires are a frequent occurrence. On the many reconnoitres through the Ettrema and Northern Budawangs wildernesses, very few areas were encountered in which evidence of fire (as various degrees of blackening of trunks) was not observed. Available fire records confirm that most areas have been burnt within the last 3-20 years (NPWS, unpubl.).

8.2.2 Characteristic Direction of Travel

The fire pattern in Ettrema/ Northern Budawangs reflects that typical in eastern NSW, described in the introduction to this chapter. Fires characteristically commence to the west or north-west of the Park and travel through the Park in an east to south-easterly direction (NPWS unpubl.). Fires which commence within the Park are often in the vicinity of inholdings such as Tolwong and Sassafras, but still the predictable fire-path is in an east to south-easterly direction.


These records show that there was, on approximate average, one serious fire somewhere in the area every five years between 1915 and 1972, while recent detailed records indicate that there was fire somewhere in the Park nearly every summer between 1975-6 and 1992. There were at least 70 fires in the 19 year period between 1964 and 1992. 18 of these covered an area of more than one thousand hectares. Of these 18 fires, 6 occurred in the Ettrema area, 5 in the Pigeon House Mt. - Yadboro Ck. area, 3 north of the Shoalhaven, 2 in the Tolwong area and 2 commenced in freehold land to the north-west of the Park. It is striking that all fires travelled in an east to south-easterly direction. Of 61 fires to 1983, possibly four were the result of natural ignition (i.e. lightning
strikes), the remainder being either deliberately subsequently burning out of control, or hazard reduction burns. Three of the 18 fires covering areas of greater than one thousand hectares, (i.e. 17%), may have been caused by lightning strikes.

These records are not necessarily accurate for particular locations. For example, Danjera Plateau is recorded as having been burnt three times since 1964, i.e., in January 1976 (aerial hazard reduction), again in January 1977 (suspect local graziers as ignition source), and in January-February 1983 wildfire. The plateau was definitely not burnt in the 1983 fire: on a helicopter flight over this area in December 1983 the author observed that the fire had been stopped at the northern end of Danjera Plateau.
Table 8.2 Fire History in Morton NP 1964-1992

This table records fires burning in excess of 1,000 hectares.

<table>
<thead>
<tr>
<th>Year</th>
<th>Area (ha)</th>
<th>Area Burnt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964-5</td>
<td>&gt; 10,000</td>
<td>N.Goulburn to Tomerong</td>
</tr>
<tr>
<td></td>
<td>&gt; 10,000</td>
<td>Pigeon House area, E. towards coast</td>
</tr>
<tr>
<td>1968-9</td>
<td>&gt; 10,000</td>
<td>i) Carters Ck.-Clyde R.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ii) Pigeon House Ck.-N.Milton-S.Ulladulla</td>
</tr>
<tr>
<td></td>
<td></td>
<td>iii) Barren Grounds-Belmore Falls</td>
</tr>
<tr>
<td>1975-6</td>
<td>~ 6,400</td>
<td>Ettrema</td>
</tr>
<tr>
<td>Dec. 1976</td>
<td>1,000</td>
<td>Ettrema Ck./ The Jumps</td>
</tr>
<tr>
<td>Jan. 1977</td>
<td>1800</td>
<td>?Danjera Plateau/ Reynolds Saddle/ Clark Saddle areas</td>
</tr>
<tr>
<td>Jan. 1977</td>
<td>~ 1,000</td>
<td>Tallowal &amp; Tolwong areas</td>
</tr>
<tr>
<td>1977-8</td>
<td>11,700</td>
<td>Bungonia - Belmore Falls</td>
</tr>
<tr>
<td>1977-8</td>
<td>&gt; 10,000</td>
<td>W.Sassafras-Danjera Ck.</td>
</tr>
<tr>
<td>1979-80</td>
<td>1,350</td>
<td>many small fires</td>
</tr>
<tr>
<td>1980-1</td>
<td>&gt; 10,000</td>
<td>Tianjara, Corang &amp; Yadboro</td>
</tr>
<tr>
<td></td>
<td>~ 1,600</td>
<td>E. of Tullyangela clearing</td>
</tr>
<tr>
<td></td>
<td>~ 250</td>
<td>Jones Ck.</td>
</tr>
<tr>
<td>Oct. 1981</td>
<td>500 (part of 4,200)</td>
<td>Yadboro &amp; Pigeon House</td>
</tr>
<tr>
<td>June 1983</td>
<td>&gt; 20,000</td>
<td>Bundanoon-Kangaroo Valley</td>
</tr>
<tr>
<td>June 1983</td>
<td>17,023</td>
<td>Ettrema &amp; Colley Plateaux</td>
</tr>
<tr>
<td>1988-9</td>
<td>~ 2,500</td>
<td>Mt. Tianjara to Pigeon House Mt.</td>
</tr>
</tbody>
</table>
8.2.3 Fire Frequency During Aboriginal Occupation

The overall suggestion from the small amount of available data (see introduction) is that fire frequencies could have been high in areas frequently hunted by aborigines, but that they would have done their best to protect certain other areas (although it could be a difficult task to pick which these areas were). It can be imagined that The Ettrema and Northern Budawangs areas could well have been areas in which the aborigines did not camp in frequently. This may have been so because of the rugged terrain and (presumed) relative poverty as a food source for the coastal Walbanga and Wandandian tribes whose territory these wild places were (Hilder 1982). They may not, therefore, have been subject to as high a frequency of burning as areas around regular campsites on the coast. However, this is sheer speculation.

8.2.4 Fire Frequencies prior to Aboriginal Occupation in Ettrema/ Northern Budawangs

These are an unknown factor. On the basis of the proportion of fires attributed to lightning strikes in the study area, (NPWS unpubl.) frequency was possibly as high as ten to twenty percent of current frequencies of larger fires during similar climatic regimes. Areas which now burn once every three years may have burnt only once every fifteen to thirty years, i.e., long enough for the completion of the life-cycle of any eucalypts similar to E. regnans (fire relations described by Ashton 1981b). Species most likely to be similar are other members of the Ash Group (Series Obliquae), such as E. fraxinoides, E. fastigata, E. triflora and E. dendromorpha (tree-form).

8.2.5 Summary

Serious fires occurred somewhere in Morton National Park, on average, once every five years in the period 1915 to 1972. More detailed records kept since that time indicate that fires affecting more than one thousand hectares have occurred annually. The highest proportion (six i.e., close to one third) of these fires occurred in the Ettrema area, with
five in the Nth. Budawangs and two in the Tolwong area. Although the overall fire frequency may have been lower than it is now, higher frequencies may well have been maintained around areas in which aborigines regularly camped, such as the overhangs at the base of the Nowra sandstone cliff-lines of the mesas of the Northern Budawangs. Fire frequencies prior to the arrival of man were possibly as high as eighteen percent of current frequencies (this being the proportion of recent fires attributed to lightning strikes.) Using this percentage as a guide, one can speculate that serious fires may have occurred as often as every fifteen to thirty years in some places during suitable dry, hot climates.

8.3 Fire Patterns in Relation to Physiography

Since fire most frequently originates to the west of the Park and is carried on west and north-west winds, the hottest burn and the severest effects are likely to be on west and north-west facing slopes.

In the Ettrema wilderness, these slopes are found on Berry Knolls and in the creek systems at a lower level than the plateaux. In the Northern Budawangs, west and north-west facing slopes are found around the mesas. West facing slopes of mesas and gorges are likely to be the most fire-prone sites, while the bottoms of gorges and east to south slopes of mesas and gorges are likely to be the least fire-prone sites. As has already been noted (ch.4), fire-sensitive vegetation is found on the east and south facing slopes of mesas.

Slower and Less Intense Fire on Bare Rock

The tops of mesas, being relatively flat, isolated by cliff-lines and carrying areas of low-growing heath interspersed with areas of bare rock, are likely to carry less frequent fire and fire of less heat than west-facing slopes. The same may apply to parts of the Ettrema Plateaux, in which there are extensive areas of bare rock surface, which would serve to further reduce the intensity of fire, already travelling more slowly across the flat surface.
8.4 Fire Sensitive Vegetation in Ettrema/ Northern Budawangs

8.4.1 Distribution

With major fires occurring as frequently as once every five years over the past one hundred years, one major assumption which can be made with a reasonable degree of certainty, irrespective of fire frequencies prior to the last one hundred years, is that the distribution of vegetation in Ettrema and Northern Budawangs, as elsewhere, is affected by fire. It is not surprising that fire-sensitive species are found on sites which are sheltered from fire and in areas which are away from fire paths. In the Northern Budawang Ranges, these areas are the east to south facing quarter of the mesa-slopes, south-facing gully slopes and possibly the tops of mesas. In the Ettrema area, they are the east to south-facing deeper parts of gorges and probably the flattest, rockiest plateau areas. As the east to south-facing aspects are also the moistest locations, it is difficult at these sites to separate the effects of fire and moisture balance in determining the distribution of the community types which occur here.

If conditions are otherwise suitable, a pattern of expansion from these sites in between fires could be expected. This has been observed, for example, in Boronia spp. (e.g. Boronia thujona at Barren Grounds) which are killed outright by fire and depend on regeneration from seed to recolonize an area. Fire sensitivity of this nature could explain the sparse distribution of Boronias generally in the Ettrema and Northern Budawangs areas and in particular, the abundance of Boronia subulifolia on mesa-tops and its scarcity in heathlands elsewhere.

Different types of fire sensitive vegetation are found in different locations. Rainforest is found on the east to south facing mesa-slopes, in deep ravines in the Monolith Valley area and in deep gorges of the Ettrema Creek system and the Clyde River. Some fire-sensitive members of the Ash Group of eucalypts are located in fire-sheltered places. For example, E. triflora is typically perched precariously in cracks of cliff-faces and E. fraxinoides is
found on sheltered upper mesa-slopes. Many rare species are located in heathland on mesa-tops or at plateau edges or alongside watercourses (see Tables 7.1 and 7.2). The pattern of fire-sensitive vegetation around the slopes of the mesas in the Northern Budawangs is particularly distinctive (see Fig. 8.1).

8.4.2 Types of Fire-Sensitive Vegetation in Ettrema/ Northern Budawangs

(i) Rainforest

This occurs on moist sites with high nutrient soils (see ch.4), for example, on south-facing Wandrawandian mesa-slopes and on the upper parts of the Ettrema Creeks, being most extensive on Devonian rhyolites on east-facing gorge slopes. Rainforest grows only in the most sheltered locations on the Tertiary basalt flows at Sassafras and Endrick. The Ash Group eucalypt *Eucalyptus fastigata* dominates large areas of the basalt flows. *E. fraxinoides*, another member of the Ash Group, occurs on the Endrick basalt flow.

A rainforest understorey is found in moist eucalypt forest, for example, below clifflines on slopes of tributaries of Ettrema Creek and on sheltered east-facing aspects of mesas in the Northern Budawang Range. Some of these sites observed in Ettrema had been recently burnt. A number of species were observed regenerating from the base, including Blueberry Ash (*Elaeocarpus reticulatus*), Bastard Rosewood (*Synoum glandulosum*), Native Laurel (*Cryptocarya glaucescens*), Bolwarra (*Eupomatia laurina*) and Grey Myrtle (*Backhousia myrtifolia*).

These observations suggest that the more fire-sensitive rainforest species, at least in these locations, may have been selected out, leaving only those which have mechanisms for resisting fire.
(ii) The Ash Group of Eucalypts (Series Obliquae)

Members of the Ash group are well-represented in Ettrema and Northern Budawangs and include Brown Barrel (E. fastigata), Silvertop Ash (E. sieberi), Whipstick Mallee-Ash (E. multicaulis), White Ash (E. fraxinoides) and Pigeon House Ash (E. triflora). These species respond differently to fire, some being well adapted, others sensitive and possibly diminishing in population size. Pigeon-House Ash is fire-sensitive (Johnson and Blaxell 1973), and there is evidence that individuals are destroyed by hot fire (dead trunks observed on the south to east facing slopes of Mt.Owen). Pigeon-House Ash is very restricted in distribution, being mostly found on mesa-tops and cliff-lines. Possibly a contributing factor to this very restricted distribution is its sensitivity to fire. Chance observation of its presence on the lower Wandrawandian slopes of some mesas indicates that its rocky cliff-line habitat is not obligatory.

White Ash (E. fraxinoides) was recorded by Johnson and Blaxell (1973) as having no lignotubers and being readily killed by fire. This species grows on the east to south quarter of the mesa-slopes, accompanied by the rare endemic, Zieria caducibracteata MS and rainforest species, commonest amongst which is Eucryphia moorei (Plumwood). Patches of dead trunks are visible on the air photographs, indicating that the distribution of this tree may be in danger of further contracting as a result of frequent fire. Even-aged regeneration of White Ash has occurred on the basalt flow below Endrick Mt. This site has been subjected to both logging and fire (see Plate 8.1). Lignotubers have been recorded as present in White Ash (Ashton 1981b,Table 1), but coppicing was not observed in this species during the course of this survey, even where it had been subjected to fire. Fire-scarring was observed in E. fraxinoides and numerous fire-scarred fallen trees were probably indicative of the weakening caused by these scars.

E. sieberi is killed by hot fire, characteristically regenerating readily from seed, forming even-aged stands. Small, even-aged sapling stands of this species have been observed repeatedly in the Ettrema and Northern Budawangs areas during the course of this survey. E. multicaulis is very similar to E. sieberi except for the mallee-form, indicative of the presence of lignotuberous tissue. It is not beyond the bounds of
possibility that this mallee-form, although quite probably originally an adaptation to dry
conditions, could increase in abundance in response to the current high frequency fire
regimes.

*E. dendromorpha*, which has both a widespread mallee-form and a rare tree-form, is a
member of the lignotuberous Series Strictinae of the Ash Group. This contains a very
closely related group of species, all of which are mallees except for *E. dendromorpha*
tree-form. These are grouped together as Superspecies stricta (see Table 6.1) Wilcox
(1983, Pers. comm.) noted from specimens he had cultivated that *E. stricta* flowers and
seeds profusely from about four years of age onwards, and it also sprouts freely from a
cut stem. He suggested that this evident capacity to reproduce after fire could explain why
it is common, and that the lack of similar sprouting in *E. dendromorpha* (tree-form) could
explain its confinement to fire refuges.

*E. pauciflora*, which has a marginal presence at the western edge of the sandstone, is a
lignotuberous member of this group (Plate 8.2), which is nevertheless relatively fire-
sensitive. Multi-stem regeneration from lignotubers may follow destruction of trunks by
hot fires (Ashton and Hargreaves 1983, Barker 1988). Fire-scarring may occur (Barker
1988). Juvenile trees, including lignotubers may be completely destroyed by wildfire
(Bryant 1971). In this species, lignotuberous regeneration follows mechanical damage
from snow and ice (Plate 8.2b), insect damage or grazing (Barker 1988).

(iii) Smoothbarks and Roughbarks

The widespread distribution of the smoothbarked Scribbly, Snappy and Grey Gums
across the Ettrema Plateaux may be in part relate to reduced fire intensities across these
flat areas where there are large expanses of rock to further reduce the intensity of the fire.
In the woodland formation in which Scribbly and Snappy Gums occur over most of the
area, fire intensity and rate of spread would be reduced. A closer look at *E. punctata- E.
consideniana- E. gummiifera* complex in eastern Ettrema may reveal a relationship
between the component species, their barktype and fire patterns.
Major trunk-kill of the smoothbarked River Peppermint (*E. elata*) was observed at one location, with regeneration occurring from the base of the trunk. Smooth-barked *E. saligna* is not widespread and only occurs in locations which are sheltered from fire in the Ettrema area. These are amongst the moistest locations.

The effect of fire on rough and smoothbark tea-trees was observed on top of Quilty's Mt. Here, the rough-barked *Leptospermum subglabratum* was found growing adjacent to smooth-barked *L. rotundifolium* and near *L. polygalifolium*, also smoothbarked. Both of the smoothbarked Tea Trees had been burnt to ground level and were coppicing from lignotuber, whereas *L. subglabratum* stems had survived the fire and were resprouting from the trunk as well as coppicing from the base.

(iv) Rare Species and Fire

As discussed in Chapter 5, some species may be rare, or their rarity may have been accentuated, as a result of fire. These may include rare species found on mesa-tops, such as *Boronia subulifolia*, *Eucalyptus triflora*, *Dillwynia* sp. aff. *stipulifera* (Species C) and *Goodenia glomerata*. Others which may be rare or whose rarity may have been accentuated as a result of fire are *Zieria caducibracteata*, found on sheltered mesa-slopes, *Boronia rhomboidea* and *B. deanei*. *Goodenia glomerata* (Plate 8.3) is abundant on some mesas, for example, Endrick Mt., where it grows in crevices in the rock surfaces. By chance, this species was discovered growing in a different, but also fire-sheltered, habitat, viz., the sheltered south-east Wandrawandian slope below Mt. Owen, in *E. fastigata- E. fraxinoides* association (Pl. 8.4). The temperature, light, nutrient and moisture regimes in these two habitats would probably be quite different. In the rockland habitat, there would be greater extremes of temperature, higher light conditions, probably greater extremes of dryness and lower nutrient values. The occurrence of this species in two such remarkably different habitats, both fire-sheltered, suggests that it may have previously been more widespread and have contracted to these locations as a result of increased fire frequency.
(v) Mallees and Fire

The relationship between mallees and fire is not clear. All except one of the mallee-gums in these wildernesses are rare species (see section on mallees). This is a reflection of the status of a large proportion of mallee-gums Australia-wide (see ch.7). The disjunct distributions displayed by these mallees (mainly Blue Mts-Morton NP) suggest that they were formerly more widespread. The pattern of disjunction of the first two, with populations in colder areas of the western Blue Mts and the closely-related *E. latiscula* (formerly *E. moorei*) with populations south in the Monaro region, suggests that they were more widespread in colder times. The morphological similarity between these mallees and their closest relatives suggests relatively recent evolution, or a continuous oscillation from one form to another through the climatic fluctuations of the Quaternary. These mallees may have been more widespread during the cold climates of the glacial periods which occupied ninety percent of the Quaternary.

*E. dendromorpha*, the one common mallee, appears to be particularly well-adapted to survive the current high frequency fire regimes. It regenerates rapidly to reproductive stage from lignotuber following fire (observed at Barren Grounds following both control burn and wildfire in the period 1984 - 1990, three years from coppicing to flowering). Whether other mallees, such as *E. moorei*, *E. gregsoniana* and *E. multicaulis* have similar potential for surviving high fire frequency has not been observed. Given the probable recency of high fire frequencies, it is not impossible that some or all of these mallees may expand in their distribution as a result of this environmental change. It is even possible that the disjunct distribution of *E. multicaulis* represents a polytopic re-emergence of this genotype out of *E. sieberi* in response to increased frequency of fire. That is to say, the genetic potential for the mallee-form may have remained dormant and have re-emerged in response to suitable environmental conditions. On the other hand, the survival of some mallees, for example *E. sturgissiana*, may be jeopardised by high fire frequencies.

*E. sturgissiana*, as argued in ch.7, appears to be a much older species than, for example the majority of the other rare mallees, with its glaucousness suggesting that it
belonged to a group adapted to extremely cold climates. Although this species regenerates from lignotuber following fire (Plate 8.5a), it retains its juvenile foliage for some years before developing mature leaves. As the flowers are borne on the mature foliage, the life cycle of this mallee is probably considerably longer than that of *E. dendromorpha* and its survival may be jeopardised by continuing high fire frequencies. In areas where this species was closely examined during this survey, no seedling regeneration was observed. The distribution of this species on the rockiest plateau areas, distant from inholdings (Plate 8.5b), may be a result of its fire-sensitivity. More observations need to be made on this and other mallees to clarify their reactions to fire.

### 8.4.3 Conclusions

Two fire-sensitive vegetation groups, rainforest and Ash Group eucalypts, were identified and found to occupy locations which are relatively sheltered from fire. It is deduced from available evidence that many mallee-eucalypts may also be fire-sensitive and that this may be a factor contributing to their rarity. Evidence suggests the contrary for at least one mallee-form (*E. dendromorpha*): this species may be radiating in response to increased fire frequencies. The rarity of some species (e.g. *Goodenia glomerata*) may have been accentuated by increased fire frequency and intensity.
8.5 Seed Dehiscence Independent of Fire in *Banksia ericifolia*

This species has been cited as an example of fire-dependent seed dehiscence in the Australian vegetation (Gill 1981b). Seed dehiscence in *Banksia ericifolia* in the absence of fire was observed during fieldwork. My observations in Northern Budawangs indicated that the death of the mature bushes by fire enhanced seedling growth, but that seedling growth was also enhanced in the vicinity of adult bushes which had died from other unknown causes.

In parts of the Northern Budawangs, clumps of large (2-4 metres tall) *B. ericifolia* occur scattered irregularly through heathland. In March 1983, at one such patch near Endrick Mt., it was observed that:

(i) Cones on all bushes were splitting and shedding seeds, with only a small proportion (one or two) of the follicles on any one cone shedding seed (Plate 8.6). This suggests that in the absence of fire, seed release may occur slowly over a long period of time, thus increasing the chance that some seed release will coincide with weather conditions suitable for germination.

(ii) Young seedlings were observed to occur, infrequently, around mature, living bushes.

(iii) Occasional dead bushes occurred in most clumps and were invariably surrounded by many young bushes.

(iv) Some *B. ericifolia* clumps were burnt in a fire in this area about two years prior to these observations. All adult bushes had died and large numbers of seedlings were visible in the burnt patch. This supports the observation of Siddiqi *et al.* (1976) that this species is easily destroyed by fire but that survival of the species is enhanced by increased seedling production.
Conclusions

1. *B. ericifolia* does not depend on fire to cause splitting of woody follicles and seed release.

2. Death of clumps of this species was observed to result in a much higher frequency of seedling establishment than occurred around living bushes.

3. The presence of many mature bushes indicates that parts of the Budawangs heathlands have escaped fire for long periods of time.

8.6 Discussion

In 8.1 and 8.2, recent high fire frequencies (one hundred years of extremely high frequencies, with a further fifty to one hundred and fifty thousand years of quite high frequencies) have been described. The suggestion from scant evidence of fire for the Tertiary and early Quaternary, as well as from climatic reconstruction (ch.5) is that this pattern of high frequency is very recent and that, for most of the period of angiosperm evolution, fire would have been an infrequent but catastrophic event.

Data presented in 8.4 suggest that the recent high fire frequencies have caused contractions in the distribution of fire-sensitive species in the Ettrema and Northern Budawangs areas, as well as causing or accentuating the rarity of a number of species.

New adaptations to elevated fire frequency would probably take considerably longer than 100 years to be selected and dispersed. This deduction is based on the length of time needed for appearance and dispersal of new adaptations (discussed in ch.5).

Fire-Adaptation in Rainforest Species

The ability to coppice from lignotubers was a characteristic observed in at least seven of the rainforest species found in Ettrema and Northern Budawangs (see 8.4.1). This characteristic has also been reported elsewhere (Ashton 1981b, Powrie 1981). Powrie noted that approximately 20% of rainforest species at his study site in the Illawarra were regenerating from stump or coppicing. This infers that some rainforest species are relatively fire-tolerant. The proportion of rainforest species able to survive fire appears to
be much lower than the proportion of sclerophyllous species thus endowed. Benson (1985) noted that approximately 20% of sclerophyllous species are fire sensitive, i.e., about 80% of this group can survive fire by resprouting. It is possible that this group of rainforest species is adapting to current fire regimes.

Ash Group of Eucalypts

Many species in this taxon are characterised by lack of lignotuber (e.g. *E. regnans*, *E. delegatensis*, *E. fraxinoides*, *E. triflora*, and are killed by very hot fires. Surprisingly, this group also contains species which can survive frequent fire (*E. dendromorpha* -mallee). Adaptation to current high fire frequencies is thought likely to be a process just beginning. *E. dendromorpha*-mallee may be one species which is adapting to this regime.

8.7 Conclusions

Broad relationships were observed between the high frequency of fire, its most usual direction of travel, and the pattern of distribution of fire-sensitive vegetation. These relationships are defined.

Fires characteristically commence to the west or north-west of the Park and travel through the Park in an east to south-easterly direction.

Fire is a frequent occurrence. Records show that major fires have occurred in the region as frequently as once every five years over the past one hundred years. On the many reconnoitres through the Ettrema and Nth. Budawangs wildernesses, very few areas were encountered in which evidence of fire (as various degrees of blackening of trunks) was not observed.

Fire-sensitive vegetation is found in the least fire-prone physiographic positions. Locations likely to be less fire-prone and vegetation likely to be fire sensitive are defined below.

In the Northern Budawang Ranges, the east to south-facing quarter of the mesa-slopes and south-facing gully slopes are sheltered in relation to the most frequent direction of
travel of fire, i.e., from the north-east. In the Ettrema area, the east to south-facing deeper parts of gorges are sheltered from the direction of travel of fire.

The tops of mesas are separated from the slopes by cliffs and have large expanses of exposed rock. In the Ettrema area, large expanses of rock occur across the plateaus. Clifflines and expanses of rock such as these are likely to slow a fire.

**Fire-sensitive vegetation**

(i) **The Ash Group of Eucalypts (Subgenus Monocalyptus).**

Many (but not all) of the eucalypts in this group are fire-sensitive in the sense that they may be killed outright by fire. Many do not have the capacity to regenerate from lignotubers or by means of epicormic sprouting. The representation of this group in the area is high, compared to its representation in the State as a whole.

(ii) **Rainforest**

This is found only in the most fire-sheltered locations within soils of high nutrient status. In more fire-prone, moist locations, the more fire-sensitive rainforest species appear to have been selected out, leaving only those which have mechanisms for resisting fire. For example, rainforest species able to regenerate by coppicing from lignotubers following moderately intense fires such as Blueberry Ash (*Elaeocarpus reticulatus*), Bastard Rosewood (*Synoum glandulosum*), Native Laurel (*Cryptocarya glaucescens*), Bolwarra (*Eupomatia laurina*) and Grey Myrtle (*Backhousia myrtifolia*).

(iii) **Rare Species and Fire**

Some species may be rare, or their rarity may have been accentuated, as a result of fire. These may include rare species found mainly on mesa-tops, such as *Boronia subulifolia*, *Eucalyptus triflora*, *Dillwynia* sp. aff. *stipulifera* and *Goodenia glomerata*. Evidence for this comes from the chance observation of erratic distribution of rare species in different habitats. For example, *Goodenia glomerata*, mostly found on rocky areas of mesa-tops
was found at one location on sheltered mesa-slope. Similarly, *Eucalyptus triflora*, found mainly on rocky outcrops of mesas, was found at one location on sheltered mesa-slope.

(iv) Mallees and Fire

All except one of the mallee-gums in these wildernesses are rare species.

*E. dendromorpha*, the one common mallee, appears to be particularly well-adapted to survive the current high frequency fire regimes. It regenerates readily from lignotuber following fire and takes as little as three years from coppicing to flowering. In contrast, there are other mallee eucalypts which, although they can regenerate rapidly to reproductive stage following burning, are nevertheless rare (e.g. *E. luehmanniana*).

8.8 Future directions

1. Responses of Mallees to Fire

It would be interesting to know whether other mallees, such as *E. sturgissiana*, *E. moorei*, *E. gregsoniana* and *E. multicaulis* have similar or different responses to *E. dendromorpha* to high fire frequency. Is the mallee representative of closely-related tree/mallee pairs such as *E. moorei*/*E. stellulata*, *E. gregsoniana*/*E. pauciflora* and *E. sieberi*/*E. multicaulis* more or less fire sensitive?

Some of the mallees may be expanding in their distribution as a result of recent high fire frequencies. On the other hand, the survival of some mallees, for example *E. sturgissiana*, may be jeopardised by high fire frequencies. More observations need to be made on the mallees to clarify their reactions to fire.

2. Adaptation to Recent High Fire Frequencies

One hundred years of high fire frequencies is probably long enough to cause contraction in the distributions of fire-sensitive species. However, it is unlikely to be long
enough to allow the development and dispersal of fire-adapted forms. Adaptation to current high fire frequencies may be a process just beginning.

Recent high fire frequencies (one hundred years of extremely high frequencies, with a further fifty to one hundred and fifty thousand years of quite high frequencies) has probably caused contractions in the distribution of fire-sensitive species, as well as causing or accentuating the rarity of a number of species. However, new adaptations would probably take considerably longer than this to be selected and dispersed.

Based on estimated rates of speciation, 50,000 years could be long enough to wipe out sensitive vegetation from fire-prone sites and to begin the selection of "pre-adapted" characters, such as those previously developed in response to drought, low soil nutrients or mechanical damage.

What, then, is the origin of the features of our vegetation which enable it to survive fire?

It is postulated that the characteristics which enable plants to survive fire are the result of selection of "pre-adapted" characters, such as those previously developed in response to drought, low soil nutrients or mechanical damage.

Example 1

This view is supported by the observed rarity of mallee species, both in Ettrema-Northern Budawangs and Australia-wide, for if the lignotuber were primarily a fire-adaptation, then mallees, which characteristically re-sprout vigorously from the lignotuber, could be expected to be more widespread. The indication from the present day distribution of mallees, is that this form is primarily an adaptation to dryness.

Example 2

The Cabbage Palm (Livistona australis) is common below clifflines in Ettrema and its woody nuts may have the capacity to survive fire. However, the woody nuts of Cabbage Palms are not dependent on fire for germination, but break down within three months in moist rainforest soil where prevention of predation would be a valuable advantage of hardfruitedness.
3. Adaptations which Enable Survival of Fire in Rainforest Species

A number of rainforest trees have been observed to regenerate from basal bud tissue.

**Question:** Are rainforest trees with the capacity to survive fire by resprouting being selected in locations where fire frequency has been high in the last 50-100 years?

4. Responses of the Ash Group of Eucalypts to Fire in Ettrema/ Northern Budawangs

Observations indicate that there are a variety of responses, including distributional contraction (*E. triflora, E. dendromorpha*-tree form), even-aged regeneration (*E. sieberi, E. fraxinoides*) and resilience to high fire frequency (*E. dendromorpha*-mallee). The adaptive responses to fire in this group in this area would be an interesting further study.
Figure 8.1: Distribution of *Eucalyptus* on Slopes of Mesas, Northern Budawang Ranges

Key

<table>
<thead>
<tr>
<th>IU</th>
<th>E. sieberi/ E. piperita ssp. urceolaris open forest</th>
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<tbody>
<tr>
<td>BB</td>
<td>E. fastigata</td>
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<tr>
<td>FR</td>
<td>E. fraxinoides</td>
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<tr>
<td>RF</td>
<td>Rainforest</td>
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<tr>
<td>TR</td>
<td>E. triflora</td>
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Fire-sensitive

Mesas (represented by circles)

1. Endrick Mt.
2. Cole/Owen/Shrouded Gods/Nibelung
3. Tarn
4. Hoddle & Haughton
5. Bibbenluke

Fire-sensitive vegetation (black areas) consistently occurs on south to east facing slopes.
This Fire Map was provided courtesy of the NSW National Parks and Wildlife Service, Nowra District Office. It was produced from the ERMS Geographic Information System, into which all fire data for the Morton National Park is now registered.
Plate 8.1: *Eucalyptus fraxinoides*, Even-Aged Stand on Basalt at Base of Endrick Mt.
Plate 8.2a Dead Snow Gum, with Large Lignotuber at Base of Trunk
(Guthega area, Snowy Mts.)

Plate 8.2b Snow Gum Sprouting from Lignotuber,
Charlottes Pass Oct. 1982
Plate 8.3: *Goodenia glomerata*, a rare species.
Plate 8.4: Two Habitats of *Goodenia glomerata*

(i) Mesa-top Rockland (Endrick Mt.) in heath.

(ii) Sheltered Mesa-slope (SE slope of Mt. Owen) in *E. fraxinoides* / *E. fastigata* Moist Forest.
Plate 8.5a:
Regeneration of
_Eucalyptus sturgissiana_
10 Months after Fire
(Dec. 1983).

Plate 8.5b: Habitat of _E. sturgissiana_, Remote Parts of Ettrema Plateau
Plate 8.6: Seed Dehiscence in *Banksia ericifolia* Cones on Living Bushes
Conclusions

1. *B. ericifolia* does not depend on fire to cause splitting of woody follicles and seed release.

2. Death of clumps of this species was observed to result in a much higher frequency of seedling establishment than occurred around living bushes.

3. The presence of many mature bushes indicates that parts of the Budawangs heathlands have escaped fire for long periods of time.
9. Summary and Conclusions

This study has fulfilled a basic need for the mapping and classification of a small part of the Australian vegetation in a region that is complex topographically and floristically diverse. In addition to describing the vegetation community patterns, this study has provided an analysis of factors which might explain their distributions, in particular, nutrients, topography and change through time. The following conclusions are divided, as the preceding thesis was, into two major sections.

Section 1: The Spatial Organisation of Vegetation

9.1. Classification of Vegetation Communities

The majority of *Eucalyptus* communities could be classified into associations (*sensu* Beadle & Costin, 1952). In most of these associations, one, two or three species of *Eucalyptus* were observed to consistently co-dominate particular landscapes, thus confirming the observations of Pryor (1959a). One association of a more complex nature was described (*E. punctata- E. consideniana- E. gummifera* complex association). In this association, a group of species (predominantly six) were observed to form pairs in which the component members were seldom the same.

Sometimes, as for example, on the slopes of upper reaches of the tributaries of the Ettrema Creek system, it was observed that species of *Eucalyptus* changed over too short distances across a landscape to be classified into associations.

Continua of change in *Eucalyptus* species composition were always found to occur both within associations and between adjacent associations, bearing out the estimations of Beadle & Costin (1952) and Whittaker (1967), that both communities and gradients may be defined at any location. It appears, then, that the concepts of "continua" and "community" are complementary in the associations of *Eucalyptus* in Ettrema and Northern Budawangs. Both continuum and community may be considered as expressions of order in eucalypt distribution in relation to the landscape. Departures from
this order, such as observed on gorge slopes and in the sandstone eucalypt complex appear to relate to species variations over short distances and (as discussed in Section 2), temporal change.

Heathlands, in the major locations of their occurrence, i.e., sandstone plateaux, mesatops, and Devonian valley floors, were readily distinguished on the basis of species composition.

Rainforest was found to vary in species composition in relation to the major locations of its occurrence, i.e., basalt emplacements, Ettrema gorges and sheltered slopes and deep ravines in the Northern Budawangs.

9.2. Mapping of Vegetation Communities

9.2.1 Discrepancies between Map Units and Classification Units.

Communities of vegetation were mapped at the 1: 25,000 scale. Mapping units were often found to equate with "land systems" (sensu Christian and Stewart 1953), since the classified communities often interchange over such short distances that they cannot be mapped separately. This result corroborates the discrepancy between mapping and classification units identified by Kirkpatrick & Dickinson (1986) and grappled with in other small- scale vegetation surveys, e.g. Sydney Basin (Benson 1986, 1992, Benson & Keith 1990, Keith & Benson 1988), Northern Territory (Wilson et al. 199), Queensland (Boyland 1984, Neldner 1984, 1991, Young & McDonald 1989, Elsol 1991).

9.2.2 Landscape Units and their Vegetation Sequences

Broad-scale changes in vegetation pattern were found to parallel changes in landscape. Where landscape changes abruptly, so also does the vegetation. Gradational habitat changes are accompanied by gradational vegetation changes. Particular sequences of vegetation communities, were observed in relation to the following landscapes:
(i) The series of Permian rocks forming the mesas of the Northern Budawangs. Successive rocks are marked by different vegetation communities. These cover sufficiently large areas to have been separately mapped (see Fig. 4.1).

(ii) Quasi-concentric patterning across the sandstone of the Ettrema plateaux. Here, the vegetation sequence changes rapidly from heath to sedgeland to Scribbly Gum- Snappy Gum woodland or *E. punctata- E. gummifera- E. consideniana* complex association (Fig. 4.2).

(iii) A gradual deepening of soils eastwards across the Ettrema plateaux, with the quasi-concentric heath- sedgeland- woodland sequence giving over to open forest, grouped within the *E. punctata- E. gummifera- E. consideniana* complex association.

(iii) Slopes of the Ettrema Creek system. These support a greater diversity of species of *Eucalyptus*, changing rapidly with position on slope, up or down gorges and from one gorge to another.

### 9.3. Environmental Interrelationships

The classified communities were described in terms of their position in the landscape. It was observed that particular communities are associated with particular positions in the landscape. Geological control of the distribution of plant communities was visibly evident. This particularly applies in the Northern Budawangs, where the sharp demarcation of the geological strata is accompanied by sharp demarcation of the vegetation communities.

It was found possible to distinguish the communities from one another on the basis of soil nutrients. Using Discriminant Analysis, a higher level of discrimination was achieved on this basis (62% overall) than on the basis of topographic factors (35% overall). This result ratifies the theoretical consideration that plant distributions ought to be more closely related to the factors which directly influence their growth than to environmental variables such as physiography, which, as they vary, affect a whole range of other variables in complex ways.
9.4. Comparison with the Vegetation of Other Areas

The pattern of distribution described as being typical of eucalypts by Pryor (1959a) was of the regular occurrence on closely circumscribed micro-habitats of *Eucalyptus* populations made up of a two, three or four species. These, he stated, could be easily recognised and delineated as associations.

The ease with which much of the Ettrema/ Northern Budawangs eucalypt vegetation could be classified into associations is in full agreement with Pryor's observations. Similarly, in most other areas of comparable vegetation nearby which have been described, associations or association-equivalents (since the use of the association terminology has often been avoided), have been defined (Costin 1954, Ingwersen 1976, Burrough *et al.* 1977, Austin & Sheaffe 1976, Gilmour & Plumwood 1983, Benson 1986, 1992, Benson & Keith 1990, Keith & Benson 1988).

An exception is the 'sandstone complex' of the Central Sydney Basin (Pidgeon 1937, 1941, Specht *et al.* 1974, Benson & Keith 1986, 1988, 1992). The parallel identification of a 'sandstone complex' in the Ettrema wilderness (the *Eucalyptus punctata- E. consideniana- E. gummifera* complex association) of the Ettrema Plateaux is considered to be an important outcome of this vegetation analysis. Our understanding of the reasons for this complex eucalypt distribution pattern on sandstone may be furthered by a more detailed definition of its characteristics.
Section 2 : Change through Time

It may sometimes be assumed that, even if we cannot see the precise relationship between the vegetation and the spatial environment, it must nevertheless be there. Yet, one would only expect precise delineation of vegetation patterns in relation to features of the environment if there were no change through time, or if the vegetational response to change was instantaneous. Some clues to the extent to which change through time is represented in the Ettrema/ Northern Budawangs have been found in:

(i) an assessment and interpretation of the stability of associations amongst the diverse and rapidly changing array of species of *Eucalyptus* (Ch. 7).

(ii) interpretation of the status of rare species in relation to disturbance through time (Ch.7).

9.5. Stability of *Eucalyptus* Associations

A theoretical consideration of the implications of the subgeneric composition of eucalypt associations suggested that it could be used as a guide to their stability through time. This led to an analysis of data from a number of areas. It was found that eucalypt associations in montane areas consistently displayed a high level of subgeneric diversity, whereas those identified in Ettrema/ Northern Budawangs were frequently composed of species from the same subgenus.

An hypothetical explanation for this is presented, based on Connell's Intermediate Disturbance hypothesis. It is hypothesised that warm climatic conditions, which are thought to have prevailed through only approximately ten percent of the Quaternary, amount to a disturbance relative to the cool conditions which have prevailed through most of the Quaternary. This disturbance, it is hypothesised, would have been sufficient to stimulate distributional changes, but not widespread destruction (i.e. it was of intermediate intensity).

The subgeneric diversity of montane associations lends strong support to the notion that subgeneric diversity is an indicator of associations widespread during the Quaternary cold times. Thus, subgeneric diversity can be used as a sort of time-key which can
provide a clue to the rate of change through time of the pattern of *Eucalyptus* across the landscape of south-eastern NSW.

The observed lack of subgeneric diversity of many of the *Ettrema/ Northern Budawangs* eucalypt associations (see Table 6.2), then hypothetically places them in a late Quaternary time-frame, dating from the post-glacial warming which peaked at 10-2 ka BP. (Colhoun 1991). The 'sandstone complex' association can be interpreted as an 'temporal overlay', with the subgeneric separation of the three most abundant species (*E. punctata, E. consideniana* and *E. gummifera*) suggesting that their association could have extended through the last Ice Age. The subgeneric similarity of other species identified as part of this complex association, such as *M E. consideniana, M E. agglomerata* and *M E. sclerophylla* suggests that these may be distributional overlaps dating from the time of post-glacial warming. The fact that these three species are in *Monocalyptus* is in accord with the greater evolutionary activity current in this subgenus in *Ettrema/ Northern Budawangs*, as compared with *Symphiomyrtus* (see Fig.6.1).

**9.6. Categorisation and Interpretation of Rare Species in Terms of Change through Time.**

A small percentage of the species identified during this survey are classified as rare or uncommon (Table 7.1). This study of the vegetation of a particular landscape provided an ideal opportunity to place rare species in a perspective with the whole. It was found that rare and uncommon species can be grouped into a number of different morphological and distributional categories (7.4). The evolutionary implications of these morphological and distributional categories is analysed and used as a basis for defining the possible causes of rarity. A number of categories of rare species are proposed (7.7). Species are sorted into two groups on the basis of probable antiquity, with some of these grouped as species probably adapted to colder climates. Further investigation would be required to establish the climatic adaptation of the remaining species. It is suggested that at least one species (*E. dendromorpha* mallee) may have radiated in response to recent disturbance (altered fire regimes). A fourth group of species are defined as those adapted to a limited habitat.
Species rare or uncommon as a result of urbanisation of the Sydney Basin form a fifth group. The sixth group are those whose rarity may have been caused or accentuated by disturbances which were anthropogenic in origin, such as altered fire and/or grazing regimes. Support for this suggestion comes from their habitat preferences, which are relatively safe from intense fire or grazing.

9.7 Fire and its Effects on Vegetation Distributions

Broad relationships were observed between the high frequency of fire, its most usual direction of travel, and the pattern of distribution of fire-sensitive vegetation. The characteristic direction of travel of fires through the Park in an east to south-easterly direction could be related to the distribution of fire-sensitive vegetation the following locations:

(i) in the Northern Budawang Ranges, the east to south-facing quarter of the mesa-slopes and south-facing gully slopes.

(ii) in the Ettrema area, the east to south-facing deeper parts of gorges are sheltered from the direction of travel of fire.

It was found that the Ash group of eucalypts, which are often fire-sensitive, are highly represented in this area. Rainforest, generally considered to be fire-sensitive, is found only in the most fire-sheltered locations on soils of high nutrient status. Notably, in more fire-prone, moist locations, the more fire-sensitive rainforest species appear to have been selected out, leaving only those which have mechanisms for resisting fire.

The concentration of rare species found on mesa-tops may be related to the relative protection of these areas from intense fire. Chance observation of unpredictable distribution of some rare species in different habitats lent weight to the suggestion that their rarity has been caused or accentuated by fire.

On the basis of likely slow rates of evolutionary adaptation to new factors, it is hypothesised that adaptation of plants to current high fire frequencies may be a process just beginning.
It is postulated that the characteristics which enable plants to survive fire are the result of selection of "pre-adapted" characters, such as those previously developed in response to drought, low soil nutrients or mechanical damage.

9.8 Future Directions

The data presented here are only a beginning. This exploration of the vegetation communities and their environmental interrelationships has formed the basis for the generation of some hypotheses concerning:

(i) order versus disorder in plant distributions
(ii) the stability of eucalypt associations
(iii) the reasons for the rarity of some species

Further research is required to test these hypotheses. Some possible directions for this research are outlined below.

(i) Order versus Disorder in Plant Distributions

The perspective which has been emphasized in this thesis is that communities and continua both exist and that both are expressions of order in *Eucalyptus* distributions. These expressions of order are contrasted with disorder, which is apparent in certain locations. At this broad level of observation, this disorder is apparent as a greater variety of eucalypt species in a particular habitat and greater difficulty in discerning repeating patterns of eucalypt distribution in those particular locations. The hypothesis that vegetation at some locations is in a relatively disordered state could be tested against models of order and disorder.

Alternative hypotheses are that the greater complexity observed is a reflection of an equal degree of order in the responses of individual species to particular habitats, but a reflection of either (i) a greater diversity of niches or of (ii) a longer period of plant diversification.
(ii) The Stability of *Eucalyptus* Associations

The hypothesis that subgeneric diversity reflects stability of co-occurrence through time and that, conversely, subgeneric similarity is a reflection of instability, could be subjected to further testing. The finding that montane associations are on the whole composed of species from different subgenera supports this hypothesis. Further attention could be focussed in the region where the changeover from subgeneric diversity to similarity takes place (Southern Tablelands), as this (hypothetically) reflects a limit of climatic tolerance of *Eucalyptus* combinations which would have prevailed during colder climates of the Quaternary. It is here that we may possibly find the most recent evidence of disturbance of eucalypt distributions.

In the Ettrema area, the individual tolerances of the species which make up the "sandstone complex" could be looked at more closely, as a means of explaining the current pattern of overlapping distributions. The search for instability in these species could be entered upon at a number of different levels, for example, genetic (allozyme diversity, analysis of hybridism possibilities and testing of predictions), morphological (clinal variation, evidence of hybridism), or distributional (more detailed analysis of distribution of individual species in relation to other species or in relation to the environment). For example, do the "stable" species (*E. punctata, E. consideniana, E. gummifera*) display a more precise distributional relationship with environmental factors other than those affected by climatic change (e.g., position(s) in landscape, soil nutrients) than do the hypothesised "invading" species? (*E. sieberi, E. agglomerata, E. sclerophylla- E. rossii*).

(iii) Reasons for Rarity of Some Species

The proposed categories of rare species are considered to be hypothetical. More detailed research into the requirements of the separate species may either substantiate or invalidate them. Information from pollen cores would help to establish rates of change in vegetation in the study area.
Investigation of the physiological tolerances and fire sensitivity of rare species, would help to prove or disprove the proposed categorisations. Investigation of the cold-tolerance of species, for example, those disjunctly distributed across the Sydney Basin, would assist in determining whether the distribution of these species is contracted because of warmer conditions or other from the list of possible causal disturbances.

It would be particularly interesting to determine whether contraction or expansion is taking place in some species (*E. multicaulis, E. dendromorpha*) in response to recent human disturbance, in particular altered fire regimes.

Fire-tolerance of the "wet mallee" group as a whole could be investigated. Some, such as *E. sturgissiana*, may be sensitive to high frequency fire if (as preliminary observation suggests is possible), they are slow in regenerating to flowering stage following burning to ground level. Others, such as *E. dendromorpha*, clearly survive fire well.

There are numerous overhangs in Ettrema/North Budawangs which could be a potential source of fossil pollen profiles, preserved in dry rather than damp conditions. Swampy or boggy areas may provide alternative sites, providing profiles of pollen preserved in waterlogged, anaerobic conditions. Potentially, profiles from one location could provide a control on profiles from the other type. This information could help to establish to what extent rainforest is able to expand its distribution into areas of extremely infertile soil, such as those found across the Ettrema Plateaux and Devonian valley floors in the Ettrema and Northern Budawangs areas.
Appendix 1: Plant Species List

Family and Species

**Bryophyta**
*Sphagnum sp.*

**Pteridophyta**

**Fern Allies**
*Lycopodium deuterodensum* Herter
*Selaginella uliginosa* (Labill.) Spring

**Ferns**
*Asplenium flabellifolium* Cav.
*Cyathea australis* (R.Br.) Domin.
*Cheilanthes sieberi* Kunze ssp. *sieberi*
*C. austrotenuifolia* Quirk & Chambers
*Gleichenia dicarpa* R.Br.

**Gymnospermae**

**Zamiaceae**
*Macrozamia communis* L. Johnson

**Cupressaceae**
*Callitris muelleri* (Parl.) F. Muell.
*C. rhomboidea* R.Br. ex A. Rich & Rich
*Podocarpus spinulosus* (Smith) R. Br. ex Mirbel

**Dicotyledonae**

**Apiaceae**
*Actinotus forsythii* Maiden & Betch
*A. minor* (Smith) DC.
*Platysace lanceolata* (Labill.) Druce
*P. linearifolia* (Cav.) Norman

**Araliaceae**
*Polyscias murrayi* (F. Muell.) Harms
*P. sambucifolia* (Sieb. ex DC.) Harms

**Asteraceae**
*Bracteantha bracteata* (Vent.) Anderberg & Haegi
*Cassinia aureonitens* Wakef.
*C. quinquefaria* R.Br.
*Gnaphalium sphaericum* Willd.
*H. scorpioides* Labill.
*Lagenifera stipitata* (Labill.) Druce
*Olearia argophylla* (Labill.) F. Muell. ex Benth.
*O. stellulata* (Labill.) DC.
*Ozothamnus argophyllus* (Cunn. ex DC.) Anderberg
*Vernonia cinerea* (L.) Less.

**Bignoniaceae**
*Pandorea pandorana* (Andrews) Steenis
Casuarinaceae
Casuarina cunninghamiana Miq. ssp. cunninghamiana
Allocasuarina distyla (Vent.) L. Johnson
A. littoralis (Salisb.) L. Johnson
A. nana (Sieber ex Sprengel) L. Johnson
A. paludosa Sieber ex Sprengel) L. Johnson
A. turulosa (Aiton) L. Johnson

Cunoniaceae
Callicoma serratifolia Andrews
Ceratopetalum apetalum D. Don
C. gummiferum Smith

Dilleniaceae
Hibbertia empetrifolia (DC.) Hoogl.
H. obtusifolia DC. s. lat.
H. riparia (R. Br. ex DC.) Hoogl. s. lat.
H. rufa Wakef.
H. serpyllifolia R. Br. ex DC.

Droseraceae
Drosera binata Labill.
D. pygmaea DC.
D. spathulata Labill.

Elaeocarpaceae
Elaeocarpus reticulatus Smith

Epacridaceae
Astroloma humifusum (Cav.) R. Br.
Brachyloma daphnoides (Smith) Benth.
Budawangia grifoloides (Summerh.) Telford
Dracophyllum secundum R. Br.
Epacris longiflora Cav.
E. microphylla R. Br.
E. paludosa R. Br.
E. pulchella Cav.
Leucopogon sp. aff. appressus R. Br.
L. ericoides (Smith) R. Br.
L. fraseri Cunn.
L. juniperinus R. Br.
L. lanceolatus (Smith) R. Br.
L. microphyllus R. Br.
L. muticus R. Br.
Melichrus urceolatus R. Br.
Monotoca scoparia (Smith) R. Br.
Sprengelia incarnata Smith
Woollsia pungens (Cav.) F. Muell.

Escalloniaceae
Quintinia sieberi A. DC.

Eucryphiaceae
Eucryphia moorei F. Muell.

Euphorbiaceae
Amperea xiphoclada (Sieber ex Sprengel) Druce
Beyeria viscosa (Labill.) Miq.

Fabaceae
Aotus ericoides (Vent.) Don
Bossiaea heterophylla Vent.
B. kiamensis Benth.
Chorizema parviflorum Benth.
Dillwynia ramosissima Benth.
D. sp. "C" (sp. aff. stipulifera)
Kennedia rubicunda (Schneev.) Vent.
Mirbelia rubifolia (Andr.) G. Don.
Oxylabium cordifolium Andr.
O. ilicifolium (Andr.) Domin.
O. scandens (Smith) Benth.
Phyllota phyllicoides (sieber ex DC.) Benth.
Pultenaea altissima F. Muell.
P. daphnoides Wendl.
P. elliptica Smith

Goodeniaceae
Dampiera purpurea R. Br.
Goodenia bellidifolia Smith
G. glomerata Maiden & Betch
G. heterophylla Smith
G. paniculata Smith
Scaevola albida (Smith) Druce

Icacinaceae
Pennantia cunninghamii Miers

Lamiaceae
Plectranthus parviflorus Willd.
Prostanthera hirtula F.Muell. ex Benth.
P. saxicola R.Br.

Lauraceae
Cryptocarya glaucescens R. Br.

Lobeliaceae
Isotoma axillaris Lindley

Meliaceae
Synoum glandulosum (Sm.) A. Juss.

Menispermaceae
Stephania japonica (Thunb.) Miers var. discolor (Blume) Forman

Mimosaceae
Acacia amoena H.L. Wendl.
A. binervia (H. L. Wendl.) J. F. Macbr.
A. binervata DC
A. elata Cunn. ex Benth.
A. elongata Sieber ex DC
A. falciformis DC.
A. gunnii Benth.
A. hamiltoniana Maiden
A. jonesii F. Muell. & Maiden
A. leprosa Sieber ex DC.
A. mabelliae Maiden
A. melanoxylon R. Br.
A. obtusifolia Cunn.
A. parramattensis Tind.
A. penminervis Sieber ex DC.
A. pubescens (Vent.) R. Br.
A. rubida Cunn.
A. subtilinervis F. Muell.
A. suaveolens (Smith) Willd.
A. ulicifolia (Salisb.) Court

**Monimiaceae**

*Doryphora sassafras* Endl.

**Moraceae**

*Ficus coronata* Spin.
*F. rubiginosa* Desf. ex Vent.
*Hedycarya angustifolia* Cunn.

**Myrsinaceae**

*Rapanea howittiana* Mez.
*R. variabilis* (R. Br.) Mez.

**Myrtaceae**

*Angophora bakeri* C. Hall
*A. floribunda* (Smith) Sweet
*Backhousia myrtifolia* Hook. f. & Harvey
*Baeckea brevifolia* (Rudge) DC.
*B. diosmifolia* DC.
*B. imbricata* (Gaertner) Druce
*B. linifolia* Rudge
*Callistemon citrinus* (Curtis) Skeels
*C. linearis* (Schrader & Wende.) Sweet
*C. sieberi* DC.
*Calytrix tetragona* Labill.
*Darwinia campostylis* B. Briggs
*D. taxifolia* Cunn. ssp. *macrolaena* B. Briggs
*Eucalyptus agglomerata* Maiden
*E. amplifolia* Naudin
*E. beyeriana* L. Johnson & K. Hill
*E. botryoides* Smith
*E. cinerea* F. Muell. ex Benth.
*E. consideniana* Maiden
*E. crebra* F. Muell.
*E. cypellocarpa* L. Johnson
*E. dalrympleana* Maiden
*E. dendromorpha* (Blakely) L. Johnson & Blaxell
*E. dives* Schauer
*E. elata* Dehn.
*E. eugenioiodes* Sieber ex Sprengel
*E. eximia* Schauer
*E. fastigata* Deane & Maiden
*E. fibrosa* F. Muell.
*E. fraxinoides* Deane & Maiden
*E. globoidea* Blakely
E. gregsoniana L. Johnson & Blaxell
E. gummifera (Sol. ex Gaertner) Hochr.
E. imitans L. Johnson & K. Hill
E. langleyi L. Johnson & Blaxell
E. ligustrina DC.
E. macrorhyncha F. Muell. ex Benth.
E. maculata Hook.
E. mannifera Mudie ssp. maculosa
E. mannifera ssp. guliickii
E. moorei Maiden & Cambage
E. muellerana A. Howitt.
E. multicaulis Blakely
E. ovata Labill.
E. paniculata Smith
E. pauciflora Sieber ex Sprengel
E. piperita Smith ssp. urceolaris
E. punctata DC.
E. radiata Sieber ex DC.
E. rossii R. Baker & H. G. Smith
E. rubida Deane & Maiden
E. saligna Smith
E. sclerophylla (Blakely) L. Johnson & Blaxell
E. sieberi L. Johnson
E. smithii R. Baker
E. sturgissiana L. Johnson & Blaxell
E. tereticornis Smith
E. viminalis Labill.
Kunzea ambiguа (Smith) Druce
K. sp. nov "B"
K. sp. nov. "D"
K. capitata (Smith) Heynh.
Leptospernum arachnoides Gaertner
L. trinervium (Smith) J. Thompson (formerly L. attenuatum)
L. polygalifolium Salisb. ssp. polygalifolium
L. juniperinum Smith
L. morrisoni J. Thompson
L. obovatum Sweet
L. scoparium Forster & Forster f.
L. rotundifolium (Maiden & Betche) F. Rodway ex Cheel.
L. squarrosum Gaertner
Syncarpia glomulifera (Smith) Niedenzu
Tristaniopsis laurina (Smith) Peter G. Wilson & Waterhouse
T. collina Pter G. Wilson & Waterhouse
Melaleuca capitata Cheel
M. hypericifolia Smith
M. linariifolia Smith
M. parvistaminea Byrnes (formerly ternifolia)
M. thymifolia Smith

Oleaceae
Notelaea longifolia Vent.

Pittosporaceae
Citriobatus pauciflorus Cunn. ex Ettingsh.
Pittosporum undulatum Vent.

Polygonaceae
Muehlenbeckia axillaris (Hook. f.) Walp.
M. rhyticarya F. Muell.

Proteaceae
Banksia oblongifolia Cav. (formerly asplenifolia)
B. ericifolia L. f.
B. paludosa R. Br.
B. serrata L. f.
B. spinulosa Smith
Conospermum longifolium Smith ssp. angustifolium (Meissner) L. Johnson & McGillivray
Grevillea arenaria R. Br.
G. baueri R. Br.
G. linearifolia Siebr ex Spreng.
G.linearifolia (Cav.) Druce (formerly parviflora)
Hakea dactyloides (Gaertner) Cav.
H. macraeana F. Muell.
H. salicifolia (Vent.) B. L. Burtt.
H. teretifolia (Salisb.) Britten
Isopogon anemonifolius Knight
I. anethifolius (Salisb.) Knight
Lomatia ilicifolia R. Br.
L. myricoides (Gaertner f.) Domin.
L. silaifolia (Smith) R. Br.
Lambertia formosa Smith
Persoonia levis (Cav.) Domin.
P. lanceolata Andrews
P. linearis Andrews
P. microphylla R. Br.
P. mollis R. Br.
P. oxyccocoides Sieber ex Sprengel
Petrophile pulchella (Schrader) R. Br.
Stenocarpus salignus R. Br.

Ranunculaceae
Clematis aristata R. Br. ex DC.

Rhamnaceae
Cryptandra amara Smith
C. ericoides Smith
C. propinqua Cunn. ex Fenzl.
Emmenosperma alphtonoides F. Muell.
Pomaderris aspera Sieber ex DC.
P. betulina Hook.

Rosaceae
Acaena novae-zelandiae Kirk (Formerly anserinifolia)

Rutaceae
Boronia algida F. Muell.
B. anemonifolia Cunn. var. anemonifolia
B. Barkerana F. Muell.
B. deanei Maiden & Betche
B. floribunda Sieber ex Spreng.
B. rhomboidea Hook.
B. subulifolia Cheel.
Crowea exalata F. Muell.
Eriostemon scaber Paxton
Phebalium squamulosum Vent.
Zieria sp. "A" ['Z. caducibracteatas' J. Armstrong ' unpubl.]
Z. cytisoides Smith

Santalaceae
Exocarpus strictus R. Br.

Sapindaceae
Dodonaea multijuga Gaertn.
D. triquetra Wendl.

Smilacaceae
Smilax glyciphylla Sm.

Sterculiaceae
Brachychiton populneus (Schott & Endl.) R. Br.
Commersonia fraseri Gay

Stylidiaceae
Stylidium lineare Sw. ex Willd.
S. laricifolium Rich.

Thymelaceae
Pimelea ligustrina Labill.

Tremandraceae
Tetrapheca thymifolia Smith

Ulmaceae
Trema aspera (Brongn.) Blume

Verbenaceae
Clerodendrum tomentosum R. Br.

Violaceae
Viola hederacea Labill.

Vitaceae
Cissus hypoglauca A. Gray

Winteraceae
Tasmannia insipida Br. ex DC.

MONOCOTYLEDONAE

Arecaceae
Livistona australis (R. Br.) Mart.

Cyperaceae
Carex appressa R. Br.
Chorizandra cymbaria R. Br.
C. sphaerocephala R. Br.
Gahnia sieberana Kunth.
G. subaequiglumis S. T. Blkake
Lepidosperma flexuosa Labill.
L. laterale R. Br.
L. limicola N. Wakefield
L. squamatum Labill.
L.urophorum N. Wakefield
L. viscidum R. Br.
Ptilanthelium deustum (R. Br.) Kükenth.
Schoenus ericoretrum R. Br.
S. villosus R. Br.
Scirpus inundatus (R. Br.) Poir.

Iridaceae
Patersonia glabrata R. Br.
P. sericea R. Br.

Liliaceae
Arthropodium milleflorum (Red.) Macbride
Bulbine bulbosa (R. Br.) Haw.
Burchardia umbellata R. Br.
Dianella caerulea Sims
Laxmannia gracilis R. Br.
Sowerbaea juncea Sm.
Thysanotus tuberosus R. Br.

Lomandraceae
Lomandra filiformis (Thunb.) J. Britt. ssp. filiformis
L. longifolia Labill.
L. multiflora (R. Br.) J. Britt.
Lomandra obliqua (Thunb.) MacBride

Orchidaceae
Prasophyllum striatum R. Br.
Thelymitra ixioides Swartz.

Poaceae
Agrostis avenacea Gmel.
Aira cupaniana Guss.
Danthonia longifolia R. Br.
D. penicillata (Labill.) Beauv.
D. tenuior (Steud.) Conert
Entolasia stricta (R. Br.) Hughes
Eragrostis brownii Nees ex Steud.
E. leptostachya Steud.
Paspalidum radiatum Vickery
Poa labillardieri Steud.
Stipa pubescens R. Br.
S. ramosissima Trin.

Restionaceae
Hypolaena fastigiata R. Br.
Leptocarpus tenax (Labill.) R. Br.
Lepyrodia scariosa R. Br.
Restio fastigiatus R. Br.
R. fimbriatus L. Johnson & O.D. Evans

Smilacaceae
Smilax australis R. Br.

Xanthorrhoeaceae
Xanthorrhoea minor R. Br.
X resinosa Pers. ssp. resinosa

Xyridaceae
Xyris operculata Labill.
X. ustulata Nilss.
Appendix 2:

Climatic Change during the Tertiary and Quaternary

Data have been tabulated for the Tertiary as well as the Quaternary, because it is clear from the literature that much of the evolution of the Australian flora, at least to generic level, took place during this period. The fossil record indicates that all the main elements of the present-day flora were represented from the early Tertiary, including heathland and *Eucalyptus* open forest in northern Australia, rainforest, subtropical *Nothofagus* flora and montane ericaceous flora (Specht 1977).

Eucalypt-type pollen has been identified dating as far back as the Oligocene (Martin, 1981). Eucalypt leaf fragments have been found dating back to the Eocene (Chapman 1937), and full leaf and capsular ranges of fossil eucalypts have been found dating at least as far back as the Miocene, and possibly as far back as the Eocene-Oligocene (Lange 1978, Ambrose *et al.* 1979, Holmes *et al.* 1983).

Palaeographic data relevant to unpuzzling the present-day vegetation distributions in Ettrema-Northern Budawangs, are summarised below.

Tertiary and Quaternary Climates and Vegetation: Summary Generalisations

Reconstructions of past climates and vegetation recorded in the literature have been derived in a number of different ways. These include:


Site bias, resulting from vegetation favouring moist conditions growing adjacent to the wet area in which the pollen is preserved, is a factor to be considered in vegetation
reconstructions which are based on pollen profiles taken from peaty deposits, as the majority are. The characteristic dispersal pattern of pollen has proven to be limited, with the bulk of pollen being dropped near the parent plant. Grant (1981) cited a number of examples, including *Pinus coulteri*, which was found to drop the bulk of its pollen downwind at a distance of 3 to 10 metres from its source, with only small amounts of pollen being found beyond 50-130 metres. Dispersal of cotton pollen by bees diminished uniformly away from the source, with pollen being found up to 80 feet away. Rose (1981), reported in Holmes *et al.* (1983) found that Bloodwood-*Angophora* pollen is not dispersed widely from its source. Hence, preserved pollen may reflect the composition of the vegetation immediately adjacent, and is likely to present a biased picture of the ever-changing pattern of vegetation across a landscape.


(iii) **Sea surface temperatures** (Galloway & Kemp in Keast ed.1981). Data from marine sediments, O2 isotope analyses, foraminiferal faunas, etc.

(iv) **Sea level changes** (in response to the growth and decay of continental ice sheets.) Evidence exists for low sea levels coinciding with glacial peaks during the Pleistocene and late Tertiary (summarised in Ch.4 of Keast ed.1981).

(v) **Fluvial Geomorphology** Recent research indicates that peaks of glaciation during the last 300,000 years of the Quaternary may have been preceded by cool, pluvial periods (Nanson & Price 1992).
Characterisation of Climatic Changes

Climatic changes can be characterised as underlying gradual, progressive changes (for example, those associated with the northward drift of the Australian landmass), as relatively rapid change (even catastrophic) and as cyclic change. Rapid changes are recorded for the middle Eocene and middle Miocene, while cyclic changes, revolving around repeated glaciations, appear to be particularly pronounced in the Pliocene and Pleistocene.

More records have been preserved from more recent times and the reconstructions are consequently more detailed. As Galloway & Kemp (in Keast ed. 1981) point out, the repeated changes recorded for the Pleistocene may simply be a function of more data and may not, as has been suggested, be indicative of greater inherent variability in climate during this period than for the Tertiary, (which is generally held to be a period of more stable climates). When we reach the most recent parts of the record, pollen profiles and sea-level change data provide an even more detailed record of climatic variations (Colhoun 1991). It seems possible that these climatic intricacies, which can be traced for the later Pleistocene and the Holocene, occurred in every Age.

Tertiary Climate and Vegetation.

The very brief sketch below is drawn from major syntheses of available data, chiefly Kershaw 1988 and Galloway and Kemp 1981. Other sources are referenced through the text.

Climates in the Miocene

Sea temperatures and levels suggest that the early Miocene was warm. Early Miocene seas were warm in relation to the Oligocene and the present day. There was extensive transgression of seas over the southern margins of the Australian continent. At least locally, increased precipitation seems likely. Further inland, rainfall may have been seasonally distributed. There was renewed or continued warmth in the early part of the middle Miocene, with a sudden temperature drop in the middle Miocene and rapid
development of the Antarctic icecap. Cooling of surface waters would have led to a precipitation decrease, a consequence of this being increasing dryness of the Australian continent. Both palaeographic and palaeotemperature considerations suggest that Australia was dominated by westerly wind systems throughout the Miocene, with these being as strong as today in the late Miocene. There was a rise in sea-surface temperatures in the late Miocene, followed by a dramatic drop at the end of the Miocene.

Widespread deep weathering is evidence for wet climates during the first half of the Miocene, although periodic aridity is suggested at inland sites by the presence of dolomite beds.

There were two important phases of intense weathering, indicative of wet conditions. One of these was in the Palaeo-Eocene and another in the late Oligocene to early Miocene. Most available data indicate stream erosion as being most active on the ancient shield areas in the early Tertiary and dwindling progressively thereafter.

Kershaw (1988) deduced from the pollen record that early Miocene climates were much more homogenous than today. All records examined by Kershaw contained high percentages of *Nothofagus brassii*, southern conifers and a significant representation of Myrtaceae and Casuarinaceae. He inclined to the view that these data suggested the predominance of closed forest in the early Miocene. Kershaw referred to the "relatively homogenous vegetation of Australasia in the early part of the Miocene", and inferred less contrasting climates from this tenuous fossil data. Christophel (1989) reviewed the evolution of the Australian flora through the Tertiary on the basis of megafossils, in terms of key taxa and floras. Macrofossil evidence suggested that a complex closed forest system existed across southern Australia during the middle and upper Eocene. In the Oligocene/Miocene, the high diversity Eocene leaf floras are replaced by a lower diversity, far more sclerophyllous group of taxa. Christophel generalised that the floras reflect climatic deterioration. This conflicts with Kershaw's conclusions drawn from the fossil pollen data. Christophel highlighted the discrepancy between the pollen and megafossil records of *Nothofagus*. The *N.brassii* group, which the pollen record suggests dominated the early Tertiary, is completely unknown from mainland Australia as
fossil leaves. *Nothofagus* megafossils are known from Tasmania, but are completely unknown from the mainland except at one Miocene site (Bacchus Marsh, Victoria). As Christophel says, "the myth that the continent was once covered by forests of that genus must be firmly laid to rest once and for all."

An abundance of Myrtaceae found in diatomite in the Warrumbungles was dated as middle Miocene, 17 to 14 ky BP. This find coincides neatly with the sudden temperature drop of the mid-Miocene determined from sea temperature data, and concurs with the dryness considered likely to have accompanied the fall in temperature.

Kershaw noted geographical variations in the rate of decline in rainforest during the Miocene, (as indicated chiefly by the decline in *Nothofagus brassii*-type pollen.) According to this criterion, rainforest declined from the early Miocene in central Queensland and from the end of the Miocene in northern NSW with pollen profiles from a site in the La Trobe Valley, Victoria, showing a dramatic acceleration in the trend to elimination of rainforest at the end of the Miocene. This coincides with the dramatic drop in sea surface temperatures calculated for the end of the Miocene.

**Pliocene Climates.**

Data for this period are sparse. The sketchy picture painted for the Australian environment by Galloway and Kemp (1981) is mainly derived from knowledge of fluctuations in Southern Ocean and Tasman Sea temperatures. These indicate:

**(i) Marked warming of the early Pliocene seas 3.9-4.3 my BP**

This may have caused melting of part of the West Antarctic ice sheet and is likely to have been associated with high precipitation. This coincides with the documented reappearance of rainforest in western NSW (Martin 1978).

**(ii) Renewed cooling.**

**(iii) Rapid fluctuations in sea surface temperatures through the Late Pliocene and Pleistocene.**
The late Pliocene (2.6 my BP) was a time of relatively rapid accumulation of ice sheets in the northern hemisphere. In the latest Pliocene, the northern hemisphere ice sheets were one third to half their maximum Pleistocene volume. The severe global cooling which took place at the time of the ice sheets in the northern hemisphere would have been reflected in a widespread precipitation decrease.

**Clues from Faunal Record**

A Miocene to Pliocene change to a drier, more open vegetation is independently suggested by the faunal record (Rich and Thompson 1982). The grazing and browsing group of marsupials, the *Macropodidea*, first appear in the fossil record in the medial Miocene, about 15 my BP. At first there are small forms. It is not until the late Miocene that large forms begin to appear. Beginning at that time, the macropodids diversified with bewildering rapidity into a variety of genera and species. *Macropus* appeared in the Pliocene and diversified in 5 million years into at least 28 species.

Kershaw's general impression from the fossil pollen record was that eucalypt communities were widespread during the Late Tertiary, with the extinction of *Nothofagus brassii* -type in Australia and the fragmentation of rainforest.

**Pleistocene Climates**

The Quaternary was characterised by temperature and rainfall oscillations, with long glacial and short interglacial periods. The indications are that ice retreat began earlier than 20,000 years BP in the Kosiusko region and that from 20-10,000 BP, climate may have been warmer and wetter, but with increasing dryness for the last 10,000 years. The general climate was considerably drier and (in SE Australia) cooler than it was during much of the Tertiary. Recent evidence from both inland Australia (dune formation) and coastal (deposition of alluvium) (Nanson & Price 1992) indicates that there were pluvial peaks preceding the last two glaciations.

**Early-Middle Pleistocene**
Data for the Australian continent are sparse. Three widely separated glacial intervals in Tasmania imply cold phases. Climate seems to have been predominantly dry, with interglacial climates like the present and wetter at times. Aeolianite barrier systems are taken to indicate that strong winds have been a persistent feature of the coastal zone. Episodes of continental dune formation correlate with world glacial maxima.

Limited evidence suggests that there have not been major expansions of rainforest during Pleistocene interglacials. Charcoal deposits suggest probable increased levels of burning with the expansion of sclerophyll vegetation. Forest and woodland communities were probably restricted in their distribution during the height of the glacial periods. Alpine communities would have been correspondingly more widespread. Kershaw (1981) considered it necessary to invoke factors in addition to decreased rain and temperature, for example winds, to explain the absence of our already arid-adapted tree flora and the presence of a cool-steppe vegetation. He maintained that it is extremely difficult to locate the component plants in order to reconstruct this steppe vegetation, as there are a lack of cool, dry environments in the region today.

**Late Pleistocene and Holocene**

**80-40 ky BP**

Pollen analyses from Lynch's Crater, Lake George and Willandra Lakes all suggest drier and possibly cooler conditions than at present.

**40-30ky BP**

The pollen record suggests that NE Queensland was drier and cooler and that there was increased humidity in SE Australia. This suggests a northward migration of the subtropical high pressure belt or alternatively, reduced temperature. Increasing coolness towards the end of this interval is indicated by periglacial slope deposits in the mountains overlying *Nothofagus* remains.
30-26 ky BP

Dryness continued in north-east Queensland, while in the SE, glaciers developed in the Snowy Mountains. Continental dunes were active and closed lakes at high levels. Slope deposits extended to low altitudes. All these phenomena, according to Galloway and Kemp, can be explained by a dry, windy climate with low evaporation because of low temperatures. Disparate evidence includes comparatively high sea levels, indicative of global warming.

26-10 ky BP

North-east Queensland dry, with maximum exposure of the continental shelf. The south-east and south-west are also dry, with lake levels falling. Dryness reached its maximum 16-17,500 years ago, while glaciers worldwide advanced to their late Pleistocene maximum. Indications are that glaciers in the Snowy Mountains may not have been as extensive as in some earlier late Pleistocene advance. Alternative climatic hypotheses advanced by Galloway and Kemp are a cold, dry climate with strong winds and high summer radiation or west to north-west winds bringing warm, dry continental air to the south-east in summer, which would cause glacier retreat in the mountains, although ice-sheets were still developing in the northern hemisphere.

16-10 ky BP

Continuing dry, becoming warmer. Ice and snow retreats. North-east Queensland and the south-east are both dry (except for a brief rise in closed lakes around 14-15 ky BP). Tree-lines rose in New Guinea and Tasmania.

10 ky - Present

Higher temperatures and precipitation. Tropical rainforest returns to north-east Queensland after an absence of 70,000 years. This is followed by slightly drier conditions. There appear to have been only minor fluctuations in the last two thousand
years. Debate as to peak of Holocene marine transgression (Bryant, Young, Price & Short 1992).
Appendix 3:
Mallee Eucalypts in Ettrema/ North Budawangs

Introduction
Six mallee eucalypts were located in Ettrema/North Budawangs during the course of this survey. Notably, five of these six mallees are rare. Notable also are the distribution patterns, with four being distributed disjunctly across the Sydney Basin and the remaining two being endemic to the Ettrema/North Budawangs. In the following section, the characteristics and indications of evolutionary status of each of these mallees is explored. Following this, some general conclusions are drawn as to their possible evolutionary status as a group.

Distribution and Abundance of Mallees

<table>
<thead>
<tr>
<th>Species</th>
<th>Ettrema/Nth. Budawangs</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Eucalyptus dendromorpha</em></td>
<td>abundant in heath on s't. in deep cracks in rock (Pickard &amp; Jacobs 1983)</td>
<td>Budawangs NP, Barren Grounds</td>
</tr>
<tr>
<td><em>E. sturgissiana</em></td>
<td>patchy, Ettrema plateaux</td>
<td>endemic to Ettrema</td>
</tr>
<tr>
<td><em>E. multicaulis</em></td>
<td>patchy, slopes Corang, Castle, Bibbenluke</td>
<td>central coast, Lower Blue Mts., sandstone, poor soils open low forest or heath</td>
</tr>
<tr>
<td><em>E. gregsoniana</em></td>
<td>v.restricted: Devonian valley floor</td>
<td>Mt.Wilson to Newnes Jnctn &amp; Blackheath in Blue Mts., always on poor soils over s't. or other siliceous rock</td>
</tr>
<tr>
<td><em>E. moorei</em></td>
<td>large patch, Wog Wog</td>
<td>small, damp, cold sites in Blue Mts. above 2800 ft</td>
</tr>
<tr>
<td><em>E. langleyi</em></td>
<td>patchy, east Ettrema</td>
<td><em>E. burgessiana:</em> poor, shallow sand on s't., lower Blue Mts.</td>
</tr>
<tr>
<td><em>E. recurva</em></td>
<td>WogWog, 2 trees only</td>
<td></td>
</tr>
</tbody>
</table>
Occurrence and Indications of Evolutionary Status

*Eucalyptus dendromorpha*

The mallee-form of this species is widespread throughout heathlands in both the Ettrema and Northern Budawangs areas. It occurs in similar habitats immediately to the north, for example, at Barren Grounds (which is at the southern edge of the Sydney Basin Triassic sandstones) and to the south, for example on Budawang Peak and Mt. Currockbilly. It is recorded from further to the south on Sugarloaf Mt. (Pryor 1981). *E. dendromorpha* intergrades with *E. stricta* in the Blue Mts (Hill 1991).

In Ettrema, Northern Budawangs and Barren Grounds, the mallee-form is a thriving and vigorous species, consistently occupying sites within its preferred habitat on skeletal sandstone soils. It survives fire well, being able to recover to flowering stage within three years of being burnt to ground level (observations following both wildfire and control burn at Barren Grounds.)

The tree-form of *E. dendromorpha* is uncommon. Individuals have been observed along creekbanks at Barren Grounds and at similar sites in the Northern Budawangs. Tree-form *E. dendromorpha* is very similar to *E. fraxinoides*. In the field, separation may be possible on ecological grounds, with fairly stunted specimens along creekbanks being described as *E. dendromorpha*, while stands of tall forest timber in moist locations on good soils were identified (NSW Herbarium) as *E. fraxinoides*. However, these species are indistinguishable as Herbarium specimens (pers.comm., Johnson,L.A.S. Sydney Herbarium 1983).

Taxonomically, this species is complex. It is defined by Pryor and Johnson (1975) as being part of a "superspecies", i.e. a cluster of very similar forms, which have been separated out as species on very small differences in leaf and capsule dimensions. Other species in the cluster include *Eucalyptus stricta* (centre of distribution: Blue Mountains), *E. apiculata* (sporadic occurrences between Linden and Berrima -Harden 1991) and *E. obstans* (Kuringai Chase to Jervis Bay-Hill 1991). Some of the specimens collected in Ettrema-Budawangs were identified (NSW National Herbarium) as hybrids between *E.*
stricta and E. dendromorpha. Measurements were subsequently made on a selection of specimens (tabulated below) and they were found to fall within the dimensional range of E. dendromorpha, and on this basis, the entire mallee population in Ettrema-North Budawangs has been mapped as E. dendromorpha.

**Mean Dimensions of Eucalyptus ssp. stricta mallees in Ettrema/Nth.Budawangs**

<table>
<thead>
<tr>
<th>Location</th>
<th>Leaf (mm)</th>
<th>Capsule (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>length</td>
<td>width</td>
</tr>
<tr>
<td>Endrick R.on folded quartzites</td>
<td>89</td>
<td>0.35</td>
</tr>
<tr>
<td>Styles Ck.on folded quartzites</td>
<td>(i) 74</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>(ii) 99</td>
<td>0.66</td>
</tr>
<tr>
<td>Camp Rock on sandstone</td>
<td>(i) 87</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>(ii) 85</td>
<td>0.23</td>
</tr>
<tr>
<td>Mt.Talaterang on sandstone</td>
<td>92</td>
<td>0.36</td>
</tr>
<tr>
<td>Newhaven Gap</td>
<td>(i) 73</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>(ii) 74</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>(iii) 86</td>
<td>0.38</td>
</tr>
<tr>
<td>Quasi-concentric sandstone near Sassafras</td>
<td>(i) 80</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>(ii) 95</td>
<td>0.40</td>
</tr>
<tr>
<td>Tolwong Rd.</td>
<td>(i) 87</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>(ii) 90</td>
<td>0.20</td>
</tr>
</tbody>
</table>

* SEM : Standard Error of the Mean.

On the basis of (i) the close similarity between the different species and (ii) the occurrence of specimens with intermediate dimensions (putative hybrids), the suggestion is made that this superspecies is actively evolving now. At least one of its variations, the tree-form E. dendromorpha, appears diminished in its distribution over what it would
have been under some recently past environmental regime. The disjunction of *E. apiculata* suggests that its distribution has also contracted and that this species, which differs from *E. dendromorpha* mainly in its narrower leaves, may also have been better adapted to some past climate. Long distance dispersal seems unlikely, since there are almost certainly potential habitats in between these two sites.

**Summary**

*E. dendromorpha* appears to be well adapted to the habitat it occupies in the climate of today. Showing rapid regeneration from its lignotuberous base, it is well adapted to survive the high frequency fire regime to which it is often subjected. The presence of plants thought to be hybrids between this and the closely related mallee *E. stricta*, as well as the existence of a closely related but less abundant tree-form of *E. dendromorpha*, suggest that this species has undergone rapid evolution recently and that, in this species, the mallee-form is favoured over the tree-form in the current environment.

*Eucalyptus sturgissiana*

Large and small patches of this lanky, few-stemmed mallee occur across the Ettrema plateaux. In its general appearance, this species is strikingly different from the vegetation around it. Adult leaves are thick and glaucous. Juvenile leaves are retained for a longer period than on most eucalypts and are connate and perfoliate (i.e. stem clasping and fused together), a feature which is rare amongst eucalypts (Pryor 1981), but is reminiscent of the stem-clasping leaves of *Boronia rhomboidea*.

Unlike *E. dendromorpha*, Sturgiss's mallee does not have extant closely similar species. Its nearest relatives are *E. kitsoniana*, *E. neglecta* and *E. parvifolia* (Pryor and Johnson 1975, Pryor 1981) and the recently discovered "Robin's Gum" (*E. recurva* MS), located by Robin Jean in the vicinity of Wog Wog in 1985, and whose nearest relative is thought to be *E. parvifolia* (Crisp 1988). *Eucalyptus recurva* is the rarest of all the eucalypts, being known from only two individuals.
All four of these species, like *E. sturgissiana*, are rare. None are found growing in the vicinity of *E. sturgissiana*. The nearest is *E. recurva* Crisp near Wog Wog, then *E. parvifolia* which is found at Nimmitabel and in the Deua-Tuross National Park. *E. kitsoniana* is a coastal species of southern Victoria, while *E. neglecta* has disjunct occurrences in high mountain and sub-alpine regions of eastern Victoria. Pryor (1981) thought that its fragmentary occurrence and association with moist, damp sites suggested that it may have been more widespread in a cool, pluvial period in the past.

Two of these four related species share the mallee-form with *E. sturgissiana* (*E. kitsoniana* and *E. recurva* Crisp), while the other two are small, bushy trees. None of the four are as conspicuously glaucous as Sturgiss's mallee.

*E. neglecta* and *E. parvifolia* have proved to be very resistant to cold in SE United States plantings, surviving a weather pattern in which, during a period of normally mild temperatures, sudden freezing conditions can occur for two or three days. Such sudden freezing kills most eucalypts (Pryor 1981).

**Summary**

As outlined in 7.3.2, glaucousness in eucalypts is strongly connected with occurrence in cold climates. In the case of *E. sturgissiana*, its glaucousness suggests that it may have been more widespread in former colder climates. The rarity and dissimilarity of the different species in this group suggest that they are relicts of a former time and not now actively evolving. Although no thorough study has been conducted, there are strong suggestions that the group as a whole is adapted to colder climates than that of the present day.

**Eucalyptus multicaulis**

Whipstick mallee ash was listed by Pryor (1981) as a "species of relatively limited extent likely to be endangered in the near future." This species is very closely related to *E. sieberi*. Except for the mallee-form, it differs little.
Its distribution is limited to NSW, where it was originally found at Wondabyne, Hawkesbury River, Gosford and Kurrajong, being "confined to the cool sandstone slopes of the coast and Blue Mts" (Blakely 1965).

Its location in the western part of the Northern Budawangs reveals its disjunct distribution, and places it in a group of species, some classed as rare, others not, which have a similar distribution pattern, with some populations in the Blue Mts and others in the Nth Budawang Ranges.

**Eucalyptus gregsoniana**

This mallee is very similar to Snow Gum (*E. pauciflora*). Although classified as a species, "some would regard it as a subspecies" (Pryor 1981). This is indicative of its degree of similarity to Snow Gum.

It has two disjunct centres of occurrence, one south-west of Sydney, in the Budawangs and surrounding locations, and the other in the Newnes-Wolgan area of the Blue Mountains, west of Sydney. It has a patchy occurrence in both these areas.

**Eucalyptus moorei**

This species was listed by Pryor (1981) as a species of "relatively limited extent likely to be endangered in the near future". It is very similar, apart from its mallee habit, to *E. stellulata*, with a population (now extinct) with characters in between these two having been reported (Pryor & Johnson, 1981).

It shows a similar disjunction to the above two mallees, being distributed in the Blue Mts. and in Morton NP. *Eucalyptus latiscula*, a very closely related species, has a localised occurrence in the Kybean Trig area between Cooma and the coast.

*Eucalyptus moorei* is typically found in frost hollows on poorly drained soils.
**Eucalyptus langleyi**

Langley's mallee is found in the eastern side of the Ettrema area, on poor soils. It is very closely related to *E. burgessiana* (Hill & Johnston 1991), which is found in the Lower Blue Mountains.

**Eucalyptus recurva** Crisp (Robin's Mallee)

This mallee, which has not been sited by the author is recorded from two specimens on private property in the Wog Wog area (Crisp 1988)

**General Conclusions as to the Evolutionary Status of the Mallee Eucalypts in Ettrema/ Northern Budawangs**

(i) Distinctive Morphological Features

The group as a whole do not share any distinctive feature other than the mallee-form, although four of the five are individually distinctive. For example, glaucousness is a noticeable feature of *E. sturgissiana*, but is not a feature of the other mallees. Relatively small leaves separate *E. gregsoniana* and *E. moorei* from their nearest extant widespread relatives (*E. pauciflora* and *E. stellulata* respectively.) Conversely, Langley's mallee has distinctively large, very thick leaves.

(ii) Temporal Distribution

There are two noticeable features concerning the mallee-form in *Eucalyptus*, Australia-wide. Firstly, a high proportion of rare eucalypts are mallee-form. Secondly, mallees are distributed at the driest end of the current day range of distribution of eucalypts (Groves 1981).

There is a high occurrence of mallees amongst rare eucalypts Australia-wide: of a total of 515 eucalypts described, 108 are mallee eucalypts (i.e., approx. 21%). Of a total of sixty two eucalypts listed as rare, (Pryor 1981), 29 assume the mallee habit all or most of the time (i.e., nearly 50%). Of the nine rare eucalypts located in this survey, five or six
(if *E. dendromorpha* is included) are mallees (approx. 60-70%). As noted in 7.3.2, in Ettrema-North Budawangs, with the exception of *E. dendromorpha*, the mallees appear from their restricted and fragmentary occurrences to be poorly adapted to the current-day environment. The current day maximum distribution of mallees is in the low rainfall zone (178-762 mm, Groves 1981). This figure is an approximate halving of the existing rainfall in the Ettrema and Northern Budawangs, estimated as 1600-800 mm (R.W. Young 1974).

(iii) Possible Reasons for Rarity

The Ettrema/North Budawangs mallees which are now rare could have been more widespread during colder period(s) of the Quaternary, possibly replacing open forest across large areas of poor sandstone soils. An equally feasible alternative hypothesis is the destruction of mallee populations by fire.

(iv) Possible Former Distribution Pattern

It is possible that coastal climates were not as severely altered during the glacial-interglacial changes as those inland at higher altitudes, such as the Snowy Mountains. This suggestion comes from the work of A.R.M. Young (1986), who found that the same peats were being formed in the dells of the Woronora Plateau 17ky BP as today. The inference was drawn that the Last Glacial Maximum climate of coastal NSW was not significantly different from that of today for biogeographic and geomorphic thresholds to have been crossed. If this is true, it would explain the absence of rare species showing coastal links. Since about one quarter of the non-rare eucalypts are coastally distributed, relatively unaltered coastal climates could explain the apparent bias towards rare species with links across the Sydney Basin. The bias towards rare species distributed across the Sydney Basin thus becomes a by-product of the close links displayed between the Ettrema/North Budawangs vegetation as a whole and the Sydney Basin. It further suggests that former populations linking the Blue Mountains-Morton disjunct species are more likely to have been tableland than coastal.
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