CHAPTER 1 INTRODUCTION

1.1 Rainforest In Southern New South Wales

Rainforest in southern New South Wales exists in patches scattered over the rugged country between the coast and escarpment. It is clear from the literature that the extent of this rainforest vegetation and its component types has been a little known quantity (see Groves 1981; Webb and Tracey 1981; Beadle 1981). In particular, rainforest patches in New South Wales south of the Illawarra area have not been well studied, and are in fact not known to exist at all by many ecologists and geographers.

Since European settlement, activities associated mainly with agriculture and forestry have considerably reduced the total area of rainforest in Australia as well as leading to the establishment of exotic plant species. Baur (1964, 1981) estimates that over the whole of New South Wales rainforest has been reduced to less than a third of its original area, to now occupy only about 300 000 ha. The most significant reductions in the south of the state resulted from clearing for dairying in the Illawarra and Tilba areas. Changes in fire regime continue to affect the rainforests.

Increases in population and standard of living create pressures on all resources, and directly or indirectly bring about changes. An awareness of the enormity of such changes and the depletion of natural resources, has over recent decades led to a common concern for conservation, rainforest conservation becoming particularly topical over the last few years. The creation of National Parks as areas for biological conservation has increased in response to this concern, as shown by the dedication of large areas on the south coast of New South Wales to form the Deua and Wadbilliga National Parks. Large tracts of land in State Forests are under the management of the New South Wales Forestry Commission, which is increasingly recognizing its responsibility for management of land for purposes additional to timber production.

Conservation planning is most effective when based on an understanding of the resource in question. Resource inventories provide background information for decision-making on conservation priorities and appropriate management strategies. Since the importance of rainforest resources was recognized, studies of Australian rainforest have concentrated on northern New South Wales and Queensland, or on Tasmania and Victoria (as described in Chapter 2). The southern New South Wales rainforests, which fall between these two broad types, have been considered depauperate versions of them and thus virtually ignored.

Information is needed on the floristic and structural composition of different rainforest types in southern New South Wales and their environmental correlations, including dynamics and disturbance status. The problem of how best to collect such information stems from the patchy distribution of the rainforest types, which are scattered unevenly over the area. A survey of the southern New South Wales rainforests would therefore perform a number of important functions. It would:

i. provide the information to increase general awareness of the distribution and composition of rainforest in the area,

ii. provide information to contribute to our understanding of Australian rainforest ecology and biogeography,

iii. provide resource information for land management planners,

iv. provide an opportunity to develop appropriate survey techniques. This fourth, methodological function was introduced when it became clear that a survey of such patchy vegetation would present design problems for which conventional methods were considered inadequate.

1.2 Aims

With this background the present study has two main aims.

1. To produce an inventory of the distribution, composition and environmental correlations of southern New South Wales rainforests to fill a gap in our knowledge of Australian rainforest vegetation and provide resource information for management planning.

2. To develop appropriate methodology to survey rainforest patches and assess such methods with a view to their potential for other surveys of patchy vegetation.

The specific objectives of the study are:

a) to sample and measure the floristics and structure of rainforest vegetation,

b) to measure environmental variables within rainforests, and correlate these with floristics and structure, providing means for extrapolation and hence the potential for a resource inventory of rainforest types and their distributions,

c) to develop survey design methods appropriate for studying patchy vegetation,

d) through the survey and analysis to test these methods and evaluate their potential for other studies of patchy vegetation,

e) to make available for land management authorities in the area information regarding the rainforest resource as well as information on survey design.

In the present study it was assumed that overall rainforest development is dependent on a combination of factors (such as fire protection and reduced radiation and evaporation) resulting from topographic shelter. No attempt was made to clarify this problem, which would require measurement within and outside rainforests. This question of causal factors in distribution of rainforest versus sclerophyll forest is a potential study in its own right. Within the broad rainforest category, different rainforest types are found in different environments (Appendices 1 and 2). The study addresses itself to these correlations between rainforest tvpe and environment.

A study was therefore designed along the following lines, which are described in detail in later Chapters. After reduction of the area to be sampled by use of gradsects, (explained in Section 4.2.3), rainforest patches were mapped from air photographs. Stratification within gradsects ensured sampling in different combinations of altitude, geology and distance from coast. At randomly derived patches within these strata floristic, structural and environmental data were recorded. The data were subjected to numerical analyses by classification and ordination to determine relationships between rainforest patches and their environmental correlations.

CHAPTER 2 PREVIOUS STUDIES

This Chapter presents previous relevant studies in rainforest research and survey design, data collection and analysis methods.

2.1 Previous Relevant Rainforest Research

2.1.1 Introduction

Traditional methods of vegetation sampling and analysis were designed for temperate vegetation and may be considered inappropriate for study of complex and diverse rainforest (Webb and Tracey 1963; Greig-Smith et al. 1967; Williams 1968; Williams and Webb 1969). The problems these rainforest characteristics pose for sampling are immense.

The species richness and inaccessibility of specimens high in the canopy make taxonomic work difficult and time-consuming. There are hundreds of tree species alone to differentiate and identify, and this is complicated by the number of undescribed species which continues to be discovered (Tracey, pers. comm.). The complex structure of tropical rainforest with its numerous synusiae (life-forms), apart from adding to taxonomic problems and species differentiation, means that floristic studies involve an extremely large data set. It is difficult moving through some types of rainforest vegetation, and more often difficult getting into the rainforest.

Species richness and local distribution of species, resulting from environmental variation or dispersal and establishment factors, combine to produce extreme heterogeneity. "If a traveller notices a particular species and wishes to find more like it, he may often turn his eyes in vain in every direction...he may at length, perhaps, meet with a second specimen half a mile off..." (Wallace 1878, quoted by Richards 1952). Many species share in assuming dominance and one may find a "shifting mosaic of dominants" (Herbert 1960).

Partly as a result of these problems rainforest was largely neglected by researchers until relatively recently. Ecologists then turned to the development of computer technology and numerical analysis techniques and rainforest ecology was able to become an active research area.

One approach to the rainforest sampling problem was to reduce the size of the data set by sampling only trees (Ashton 1964), 25% of big trees only (Webb et al. 1976b), or 25% of the total tree flora (Austin and Greig-Smith 1968). Other approaches to reduce identification problems and data size were to sample only large trees (Poore 1968), or to use physiognomic and structural classification (Webb et al. 1970).

The problem of adequate sampling of the heterogeneity is not resolved yet. Plotless sampling methods (Cottam 1947; Mueller-Dombois and Ellenberg 1974) were developed for tree-dominated vegetation, but are considered inadequate for rainforest (see Section 2.2.1).

Use of qualitative instead of quantitative data has been suggested as a technique to reduce time spent collecting data (Austin and Greig-Smith 1968; Webb et al. 1970), but as pointed out by Noy-Meir (1970), once a site is located and the qualitative data obtained, extra time for obtaining quantitative data is comparatively small.

2.1.2 Rainforest research in Australia

Definition

Definition and classification of rainforest vegetation continues to be problematical. It is difficult to fit Australian rainforest into world vegetation classifications such as that of Walter (1979), because such classifications are based on northern hemisphere concepts. This was highlighted for the present author by the visit of a number of international plant ecologists to the International Botanical Congress (Sydney 1981). For these European, North American and South African ecologists 'rainforest', or indeed 'forest' did not really exist in Australia, mainly because of the form of the trees. This accentuates the problem of definition and classification over different continents. In Australia rainforests can certainly be differentiated from sclerophyll forests, and Webb (1959) suggested this negative approach to definition (i.e. as not being sclerophyll forest).

The use of precise definitions of rainforest is limiting in that it excludes certain rainforest types. For example, definitions based on broad leaves and diversity of life-forms may exclude the cool temperate rainforests. Whether these floristically and structurally simple forests should be lumped with the complex tropical is a different question, which will not be addressed in this thesis.

Classification of rainforests in Australia has been approached in a variety of ways, from Baur's (1957) New South Wales rainforest floristic alliances and associations, through Webb's (1959) structural types, to Walker and Hopkins (in press) descriptive approach. Table 9 presents a comparison of classification systems for the study area.

The classification by Floyd (1982b, 1982c) is based on the traditional climatic subformations, as is that of the New South Wales Forestry Commission (anon. 1981), but the latter does not cater for intermediate types. There is a problem in using climatic subformation terminology in that some of the differences in rainforests are not climatic. For example warm temperate and subtropical rainforests occur in the same area on different soil (Baur 1957). Nix (1982) has developed a classification of thermal regions, which can be useful in broad-scale classification, and combined with other criteria for more detail. Southern New south Wales rainforests fall into the mesotherm region (subtropical and warm temperate elements) and microtherm (cool temperate).

Early studies

Schimper (1903) describes rainforest in a world context in his general vegetation work, and Beard (1944, 1955) describes vegetation series in tropical America in relation to environmental gradients radiating from the "climax" rainforest vegetation. Richards' (1952) book 'The Tropical Rainforest' and Francis' (1929) 'Australian Rainforest Trees' both contributed to information on rainforest, but most of the information from these earliest rainforest researchers was based on subjective observation.

Rainforest in Australia, until recently, was not often studied in its own right, but included in general regional vegetation studies (e.g. Domin 1911; Cheel 1912; Davis 1936, 1941a, 1941b; Pidgeon 1937, 1938, 1940, 1941; Osborn and Robertson 1939; Blake 1947). These studies were strongly influenced by Clementsian theory and considered rainforest to be a "physiographic disclimax" (Davis 1936) or a "postclimax" (Pidgeon 1937) with sclerophyll forest the natural climatic climax. Davis (1941a, 1941b) considered physiographic shelter from insolation, desiccating winds and fire as the most significant factor in rainforest or "brush" distribution, followed by soil moisture availability. Soil conditions are partly dependent on topography through humidity, build up and decay of humus, moisture availability, leaching and accumulation of soil or nutrients. Soil parent material is also significant. Pidgeon (1937) stressed the importance of soil moisture and its interaction with physiographic shelter, and said rainforest is found on moderately fertile soils if these conditions are favourable.

A more detailed study of rainforest is that on the ecology of the Upper Williams River and Barrington Tops by Fraser and Vickery (1937, 1938, 1939). Prior to this, apart from works such as that of Francis (1929) and Brough et al. (1924), only species lists had been published for subtropical rainforest in New South Wales. Fraser and Vickery (1937) believed that the southern subtropical rainforests were only "depauperate" versions of the northern forests. They saw the subtropical rainforest as having affinities with the so-called "Indo-Malaysian" rainforest element and originating north of Australia (Fraser and Vickery 1937). Such a view has been repeatedly challenged since (e.g. Webb and Tracey 1981). Subtropical rainforest in their study area occurred from 1000 to 3000 ft (305 to 915 m) and above that subantarctic rainforest was found to 5000 ft (1525 m), both types occurring only in sheltered positions.

Species occurrences were seen as limited by temperature because of the southerly location, and by dryness because of its distance inland. Three species occurring in many subtropical rainforests elsewhere in New South Wales, but not occurring in their study were Ceratopetalum apetalum, Livistona australis and Archontophoenix cunninghamiana.

To sample the rainforest Fraser and Vickery (1938) chose an area of at least an acre (0.4 ha) at random and in it ten to 25 randomly distributed ten foot (3 m) radius plots were measured. All large plants were counted and height and diameter measured, while ferns were given an abundance rating.

Distribution of species was seen as a combination of habitat variation plus chance, but like Poore (1968) they concluded that chance was the major influence. They described three types of communities on the basis of specific light and moisture habitats - river banks, canopy breaks and soakage areas. Different types of rainforest margins and outliers were recognized. The subtropical rainforest was seen as advancing into the sclerophyll forest except at the highest altitudes where low temperature prevented its establishment. Subantarctic rainforest was seen as advancing into sclerophyll forest except at its lowest altitudes where it was too hot (Fraser and Vickery 1939). Low temperature was blamed for species poverty at high altitudes - subtropical seedlings would not be able to establish under an open canopy because of frost. Wind was considered an important limiting factor in rainforest distribution below 3000 feet (915 m) because of its desiccating effects.

More recent studies

After the early work of the late 1930's there was a gap in Australian rainforest work before a new period of interest in the 1950's. Burges and Johnston (1953) studied a transect in the Doyles River region of northern New South Wales from *Ceratopetalum apetalum*-dominated forest to sclerophyll forest, by felling and measuring all vegetation. They concluded that the transitional zone indicated the advance of rainforest up the slopes.

Herbert (1960) reviewed tropical and subtropical rainforest structure and distribution. He challenged the commonly accepted idea of the Indo-Malaysian origins of our northern rainforest element and suggested an ancient continent (and ancient widespread flora) linking Australia with India. This was a radical approach at the time but is becoming more accepted with recent work by Webb and Tracey (1981) and knowledge about continental drift.

In describing the diversity of the tropical rainforest Herbert used Aubreville's (1938) "shifting mosaic of dominants". He stressed the importance of the gradient in microclimate from above the canopy to ground level, and the consequent synusiae. Edaphic factors were seen as limiting distribution. He said the southern extension of tropical species was assisted by protection of seedlings from the cold by the rainforest canopy, as did Fraser and Vickery.

Changing climate and fire were seen by Cremer (1960) as contributing to "mixed forest" which is not a climax as its life is only as long as the longest-lived individual. Fire is required to regenerate eucalypts and maintain the mixed forest, otherwise rainforest is advancing with the current more humid climate (Cremer 1960). Thus two time scales are involved with climate and fire. Cremer described "mixed forest" as a forest of eucalypts with an understorey of potential rainforest canopy species. His definition of rainforest is a "climax vegetation of water-loving and shade-tolerant, very dense trees with vascular and/or non-vascular epiphytes". This definition is a broad one which encompasses tropical and temperate types. Fires rarely burn into true rainforest and eucalypts can not usually establish there because of the reduced light. The restriction to "climax" vegetation is limiting and indeed, it is being argued by some current researchers that rainforest, rather than being a climax vegetation, is successional in many situations, not yet having achieved stability since the most recent major climatic change

(Flenley 1979). Many of the rainforests in the present study which are in different stages of succession following disturbances, should be considered as mature communities (in the context of southern New South Wales, at least).

Fire in rainforest was reviewed by Ridley and Gardner (1961). Periods of drought may cause litter build-up, as trees lose leaves and dryness reduces litter decomposition. In these conditions rainforest can burn. The author observed such a build-up of litter and dying-off of trees near the rainforest margin under drought conditions during the study period. Scorching allows disease and pests to enter trees, and regrowth of exotic species such as Lantana camara is encouraged by fire, particularly in the subtropics.

In studies of New South Wales forests Florence (1963, 1964) suggested that the sclerophyll-rainforest continuum was restricted prior to man's presence by a) effects of eucalypts on the sites and b) irregular firing. He believed man has unbalanced these factors which restricted the continuum expression, through logging, grazing, different burning patterns and fire protection which has led to an invasion of sclerophyll forest by rainforest. Thus he saw current rainforest advance as a result of habitat disturbance on the inherent stability mechanisms.

Soil moisture availability was seen as the critical factor in rainforest distribution when others are not limiting (Florence 1964). Topographic rainforests can develop in areas of low inherent soil fertility through compensation by colluvial nutrient concentration or amelioration of conditions through high soil moisture because of the influence of accumulation of organic matter on soil texture. Florence discussed the comparative soil moisture requirements of Eucalyptus pilularis and some rainforest species, and claimed that because the latter mainly draw moisture from only zero to 40 inches depth (0 to 102 cm) they are subject to moisture stress unless rainfall is consistent. He said that the vegetation of a region is largely an expression of the edaphic environment, which is different from Cremer (1960), who said eucalypts are "fire-weeds" and mixed forest is a "fire sere in the succession towards rainforest climax". Florence questioned whether eastern Australian mixed forests would change to rainforest after senescence of the eucalypts because the secondary rainforest species are edaphically less demanding than the primary ones. However, Cremer claimed that mixed forest has an understorey of potential canopy species, so definition of "mixed forest" or "rainforest" species is inconsistent.

Baur (1957) reviewed the nature and distribution of rainforests in New South Wales in detail. He recognized four subformations as tropical, subtropical, temperate and dry, with two extra (littoral and gallery). Within these subformations six floristic alliances and a number of associations were recognized. Distribution of rainforest was accounted for mainly by moisture, either high average annual rainfall or supplementary moisture resulting from topography and soil. In later work Baur (1962) changed his formation category names to subtropical, warm temperate and cool temperate to coincide with other workers who did not believe New South Wales had any tropical rainforest.

Temperate rainforest was related by Baur (1957) to lower temperature and higher moisture than tropical. In northern New South Wales subtropical and warm temperate rainforests are found under similar climate but on soils of different fertility, which indicates that after temperature and rainfall tolerances soil fertility is important. Baur (1957) explains this by competitive factors. He listed the five major New South Wales rainforest areas as the MacPherson Range and Richmond-Tweed Valleys, Dorrigo Plateau and Bellinger River headwaters, Hastings River headwaters with extensions north to the Carrai Plateau and south to the Bulga and Comboyne Plateaux, Barrington Tops district, and The Illawarra and Robertson Highlands. He said rainforest also occurs on all alluvial floodplains and small areas of suitable sites, and is distributed discontinuously along the coast and ranges to 4000 ft (1220 m) altitude. Vast areas were cleared for agriculture and timber so now the state's rainforest is reduced to about a quarter its original area and "little rainforest is in virgin condition". There are no extensive areas south of the Shoalhaven River and few typical northern species survive in the south, where more Victorian temperate species are found (Baur 1957).

Factors involved in species distribution were listed by Baur as climate, soil, topography, history and biota. The main effect of temperature was suggested to be limiting the range of many species (de Beuzeville 1943, quoted in Baur 1957). In his early work Baur (1957) referred to "rain-forest" but later introduced "rainforest" as a single word to "give it importance as an independent plant formation" (Baur 1964a). This term, which has been widely accepted, is adopted by the present study.

The Webb era

The most detailed work on Australian rainforest has been done by L.J. Webb and his co-workers. In an effort to overcome the difficulties resulting from the floristic complexity and heterogeneity, a physiognomic-structural approach to rainforest classification was developed (Webb 1959, 1968, 1978; Webb et al. 1970, 1976; Williams 1968).

Webb recognised three independent rainforest formations, tropical, subtropical and temperate (with cool and warm facies). Webb (1959) believed that classification of the rainforest subformations would best be done on physiognomic-structural characteristics, which are more easily determined than floristic variation, and avoid climatic interpretation. Leaf size, height and extent of canopy closure, tree and shrub strata, type of emergents, whether evergreen or deciduous, life-forms and presence of araucarians were considered.

The term "notophyll" was introduced by Webb (1959) to incorporate the leaf size three to five inches (7 to 12 cm) between Raunkiaer's microphyll and mesophyll classes. The subformations correlate with environmental gradients of temperature (altitude and latitude), soil properties (moisture, drainage, fertility) and exposure. Webb (1959), unlike many earlier and current workers, believed that Australian subtropical rainforest has unique ecological features and should therefore not be dismissed as a depauperate version of tropical forest. "Ecological fitness" was defined as the volume of internal environment enclosed by mature rainforest. Twelve physiognomic-structural subformations were recognised (Webb 1959, see Table 1). The first division was into vine or mossy forests.

The subtropical notophyll vine forest is a mixture of tropical and temperate species. Climatic and edaphic changes have occurred and allowed the species to adapt to intermediate conditions (Webb 1959).

Webb (1963) found a gradient from eutrophic to oligotrophic soils between seasonal complex rainforest, evergreen simple rainforest and sclerophyll forest. He suggested that soils are more important than just at the climatic extremes as others had said (e.g. Fraser and Vickery 1938; Francis 1929; Richards 1952). However, in a later paper (Webb 1968) he said climate and topography outweigh nutrients at climatic extremes. This emphasized the complexity of environmental factors and in particular soil, which influences vegetation through a number of characters, including soil moisture and fertility.

Webb (1959) recognized the patchy distribution of rainforest, saying that within broad climatic limits it is associated with soil, fire and man. Even where protected from fire, complex evergreen rainforest only occurs on eutrophic soil, so there is a "nutrient barrier" within the bioclimatic region. Webb (1968) claimed the importance of the high mineral status in south eastern Australia is in the rate of recovery from

TABLE 1. Summary of rainforest subformations in Australia (Webb 1959)

Tropical rainforest region

MVF, SEVF, DVT (lowland and lower montane)
SMVF, NVF, SNVF, AVW (lower montane or montane)
MMT (montane)

Subtropical rainforest region

NVF, AVF, AVW, SEVT (lowland and lower montane)
AVF, SNVF (lowland and lower montane)
MMF, MMT (montane)

Temperate rainforest region

SNVF, MMF (lowland and lower montane)
MMF, MMT (montane)

Legend:

MVF - Complex Mesophyll Vine Forest
SEVF - Semi-evergreen Mesophyll Vine Forest
DVT - Deciduous Vine Thicket
SMVF - Simple Mesophyll Vine Forest
NVF - Complex Notophyll Vine Forest
SNVF - Simple Notophyll Vine Forest
AVW - Araucarian Microphyll Vine Woodland
MMT - Microphyll Mossy Thicket
AVF - Araucarian Notophyll Vine Forest
SEVT - Semi-evergreen Vine Thicket
MMF - Microphyll Mossy Forest

disturbance. Accordingly the limitation of rainforest to eutrophic soils is not a narrow nutrient tolerance, but fire sensitivity.

In a further study Webb (1978) compared rainforest sites in New Zealand, southeastern Australia and New Guinea, using the physiognomic-structural proforma. He concluded that New Zealand rainforests are warm temperate and cool temperate types with a marginally cool subtropical type in North Auckland. Affinities with tropical rainforest are very limited. Cool temperate rainforests in New Zealand and Australia are similar structurally, but New Zealand's warm temperate forest is closer to Australia's submontane.

Webb's work has long been the centre of interest in Australian rainforest ecology. With development in computer techniques his analyses became more sophisticated, but he maintains an overview. Webb and Tracey (1981) have more recently described Australian rainforest in terms of three floristic regions (A, B and C), which can be described very broadly as cool, hot/wet and hot/dry, and include eight ecofloristic provinces.

Recently Webb and Tracey (1981) have also presented a hypothesis of Australian rainforest origins being in ancient Gondwanaland rather than an invasion from Malaysia. In this they are in agreement with conclusions from recent palaeobotanical studies (Lange 1982). Webb and Tracey (1981) stress the importance of rainforest refugia where communities have survived climatic changes and are now able to reinvade broader areas. Arguments for the ancient origins of the rainforest flora in Australia when it was part of Gondwanaland revolve around these refugia, the number of primitive rainforest angiosperm families in Australia, incorporating genera such as Austrobaileyana, Idiospermum and the species Eupomatia laurina (which occurs in the present study area), and the number of endemic taxa, as well as affinities between the Australian and Indian rainforest floras (Webb and Tracey 1981). Webb and Tracey assumed that if the flora had evolved in Asia and migrated south the primitive forms would be found in Asia, and that the Australian flora, adapting to a very different environment, would have differentiated and had advanced features.

Contemporary studies

Modern rainforest studies have not all used numerical analysis. Ashton and Frankenberg (1976) studied Acmena smithii in Victoria, but used traditional methods only, and produced a mainly descriptive paper. They found this species in fire shadows, although because it is fire-resistant through its ability to coppice and development of a lignotuber, it is an important marginal species. It is extremely shade-tolerant and regenerates under the canopy or in gaps. A. smithii, which is common in the present study area, is at its southern limit in microphyll fern forest at Wilson's Promontory and is the only truly subtropical species there (Ashton and Frankenberg).

Turner (1979) used traditional methods to study an altitudinal transect through the ecotone of subtropical rainforest and subantarctic rainforest at Barrington Tops. He found decreasing species diversity and increasing dominance from the lower subtropical to the upper subantarctic forest, and suggested climatic change and the subsequent reduction of fires is causing a "retreat" upwards of the subantarctic forest. Nothofagus moorei is not regenerating at the lower margins, but spreading upwards into the sclerophyll forest. However, only one transect was used, with 37 plots of different altitude and a range of aspect, so there is no system of replication, and generalisations are made on little substantiating evidence.

A study of lowland and montane rainforest in east Gippsland was undertaken by D. Cameron (pers. comm.), who stressed the importance of these southern rainforests as distinct (rather than depauperate) relatives of northern types. Cameron developed a life-form spectrum for classifying the Victorian rainforests, which fall into the warm and cool temperate types. He says there are no subtropical forests in Victoria, the most southern occurrence of subtropical rainforest being on Mount Dromedary in southern New South Wales. This can now be updated by Floyd's documentation of subtropical rainforest at Mimosa Rocks National Park (Floyd 1982c).

In studying rainforest/eucalypt forest interactions at two sites in northern New South Wales, Smith and Guyer (1983) examined the relevance of the biological nomad concept (van Steenis 1958). They concluded that adaptations of species of tall open forests, which enable rapid post-burn regeneration "may have evolved initially in a fire free, prehuman rainforest environment in response to other types of disturbance." Much former rainforest in southeastern Australia was considered to have been replaced mainly by "nomads" after burning.

Bywater (1978) studied rainforest of the escarpment and lowlands in the Kiama area. He used numerical methods to elucidate vegetation patterns which he correlated with moisture supply and soil fertility.

A study of the rainforest vegetation of Beecroft Peninsula, at Jervis Bay, was carried out by Helman (1979). Classification and ordination complemented each other to indicate trends in the vegetation related to soil moisture availability, parent material, aspect and disturbance. This result is in contrast with that of Poore (1968) who claimed distribution on a local scale to be a matter of chance.

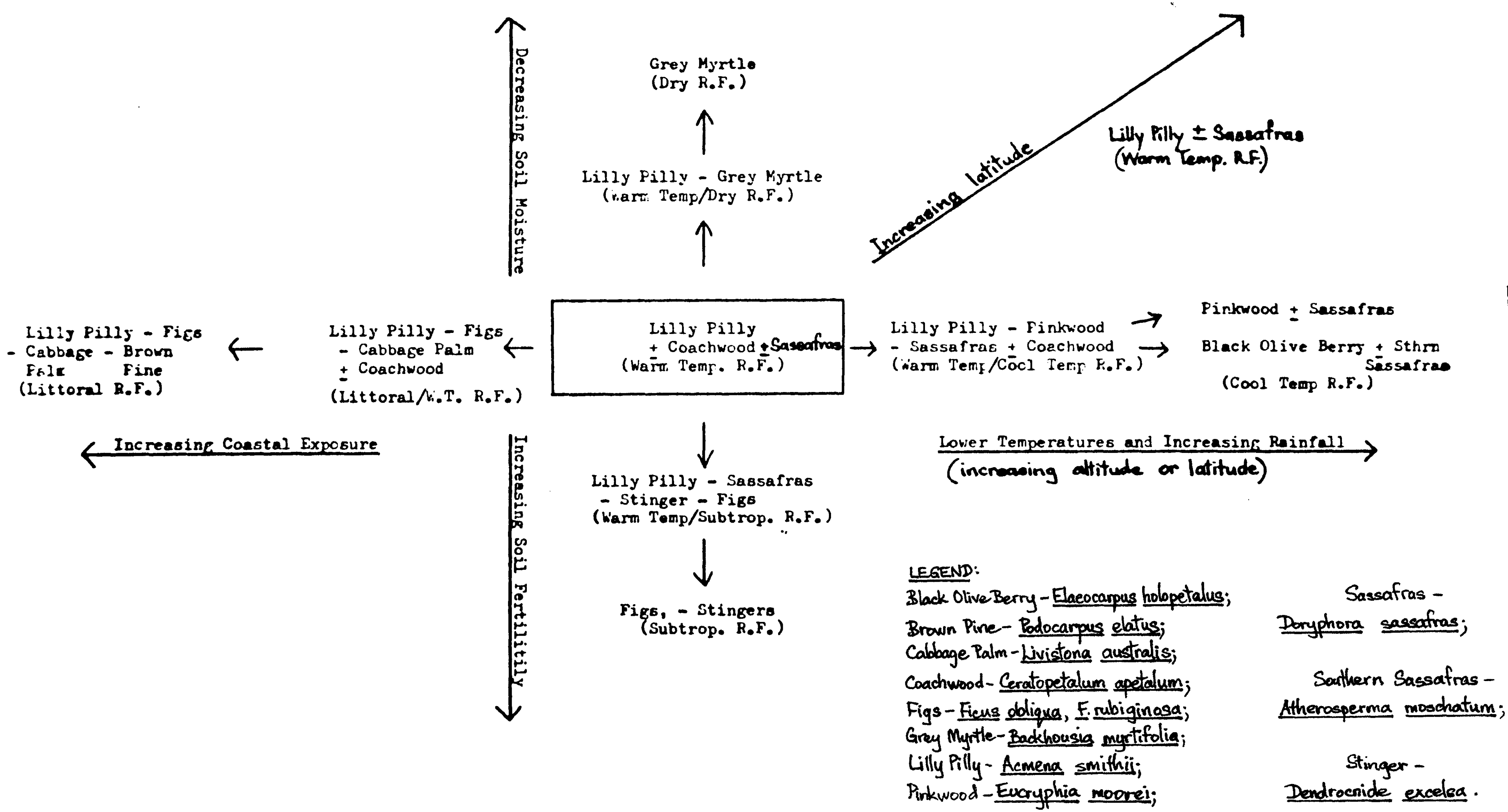
The New South Wales Forestry Commission mapped rainforest over the whole of the state in 1981 using aerial photography. Problems arose because of inconsistent interpretation in different areas. The level of rainforest types considered was very broad, with only six types recognized - Subtropical, Warm Temperate, Cool Temperate, Depauperate, Dry and Littoral. The survey identified 253 000 ha of rainforest over the State, of which it claimed 18% "is already preserved in National Parks and equivalent reserves". In southern New South Wales, species composition has been compiled for a number of rainforest areas in State Forests (D. Binns pers. comm.), although this is generally in the form of species lists for stands, and not measureable plots.

Floyd (1982b, 1982c) conducted a survey of New South Wales rainforests for the National Parks and Wildlife Service. His approach was to select particularly large or interesting examples of different rainforest types by using aerial photographs and local knowledge both from his own experience and from local people. Although the survey was of a very different nature from the present survey in that it selected 'good examples' of rainforest types and used only patch (rather than plot) species lists, it produced most informative results which complemented those of the present survey. This occurred particularly with regard to some unusual rainforest types which were not recovered by the more formal sampling of this study (which attempted to record representative rather than extreme examples). Floyd's work is a good example of the results that can be gained, with limited resources and very little time in the field, by a competent and experienced field ecologist. Floyd's interpretaton of the inter-relationships of south coast rainforests (with an addition from the results of the present survey) is presented in Fig. 01.

An Australian rainforest inventory is currently being undertaken (by G. Werren, P. Kershaw, and A. Dennis) to coordinate information from other sources for a nationwide perspective in relation to palaeogeography, botany, zoology and management. G. Werren is also currently working on an analysis of distributional overlap in rainforest taxa of eastern Australia.

Fig. 01

INTERRELATIONSHIPS OF SOUTH COAST RAINFORESTS (after Floyd 1982)



K. Mills is currently mapping the remaining rainforests between Port Hacking and the Shoalhaven River, and attempting to reconstruct the areas of original rainforest, their extent and type. He plans to examine current ownership status of rainforest in the area and make recommendations on conservation.

G. Aiken (A.N.U. Geography Dept., pers comm.) carried out a floristic similarity analysis of cool temperate rainforests of northern New South Wales, southern New South Wales and south-east Victoria, which are dominated by *Nothofagus moorei*, *Eucryphia moorei* and *Nothofagus cunninghamii* respectively. The Victorian and New South Wales rainforests were found to be most dissimilar, with southern New South Wales forests having more similarity to both of them.

Thus it can be seen that numerical methods are not being universally accepted for use in Australian rainforest studies. Studies which do not use them can certainly make a valuable contribution to information, as in Ashton and Frankenberg's (1976) study and the work of Floyd (1982b and 1982c). However, they can not be viewed in the overall context of efficient rainforest study if they can not be compared, or if their methods are not open to being repeated and extended.

If workers are to combine resources and information in order to achieve the most efficient study of rainforest, consideration should be given to a series of compatible methods. For the present study the benefits of numerical analysis are considered to outweigh any disadvantages.

Rainforest history

The current distribution of rainforest on the New South Wales south coast can not be fully understood without an understanding of the complex picture of Australia's vegetation history. Webb and Tracey's (1981) hypothesis suggesting ancient origins of rainforest in Australia during Gondwanic times has been described (Section 2.1.2).

Suitability of fossil pollen sampling sites has restricted the extent of palynological studies. Emphasis has been placed on particular areas such as north Queensland (e.g. Kershaw 1973, 1978; Kershaw and Sluiter 1982) the southern tablelands and western New South Wales (Martin 1973, 1978; Singh et al. 1981), and the Gippsland highlands (Ladd 1979). (Sediment studies other than palynological studies are also informative.) These studies, together with the increasing understanding of Australia's geological history in the light of recent wide acceptance of the plate tectonics theory, which "constitutes the greatest and most pervasive revolution in geological thinking" (Smith 1982), contributes to a general understanding of climatic change and Australian vegetation history.

It appears that hotter, wetter conditions dominated the early Tertiary (Kemp, 1981), a period when a mesic Austral vegetation, "with some of the floristic characteristics of modern rainforests" (Walker and Singh 1981) dominated most or at least the southern half of Australia (Lange 1982). This included a range of temperate and tropical rainforest types different from those present today. Nothofagus sp., brassii type, associated with gymnosperms, is generally accepted to have dominated many forests, with the family Proteaceae also being important. A study of Miocene deposits at Nerriga on the southern tablelands (Owen 1975, quoted in Lange 1982) suggests that high altitude forests were of this beech-conifer type, while at lower altitudes a Lauraceae-Myrtaceae type forest existed.

During the later Tertiary, as Australia drifted north towards its current position in proximity to south-east Asia and the south-west Pacific Islands, increasing aridity led to dominance by the beech-conifer type of rainforest and development of the sclerophyllous vegetation, while the more tropical types retreated to favourable sites, or "refugia" (Webb and Tracey 1981). After the mid Miocene the proximity with south-east Asia allowed for an exchange of species with enrichment from the Tropical Asian flora. "By the beginning of the Quaternary...it seems likely that the rainforests had become limited to the eastern fringe of the continent" and differentiation was occurring within these forests (Walker and Singh 1981).

The Quaternary was a period of severe climatic fluctuations associated with a series of glacial (cold, dry) and interglacial (warm, moist) intervals, during which rainforest distribution would have contracted and expanded many times (Singh 1982). Singh says that before the arrival of man the upper Pleistocene rainforest patches were delimited by these climatic changes. At Lake George on the southern tablelands such rainforest taxa as Cyathea, Tasmannia and Podocarpus continued to survive in sclerophyll-dominated communities and it seems that the rainforest/non-rainforest boundary was not as sharply defined as today.

In the Lake George area a marked change in vegetation and fire activity occurred at the start of the last interglacial 128 000 years ago (Singh et al. 1981). The replacement of a Casuarina-dominated flora by a eucalypt one is said to result from increased influence of fire on the vegetation after the arrival of Aboriginal Man. Since then the rainforest "contracted to small, especially favourable, but restricted patches as a result of increased fire frequency and intensity, or both, at south temperate latitudes in Australia...and its place has been taken by various shades of wet and dry sclerophyll forest and woodlands" (Singh 1982).

In contrast to the situation at Lake George, rainforest angiosperms thrived and dominated the rainforest at Atherton in north Queensland during the last interglacial, but with the cooling of temperatures at the onset of the last glacial they were partly replaced by gymnosperms (Kershaw 1978). The rainforest was then virtually eliminated from the vegetation at the peak of the last glacial 30 000 to 10 000 years ago and replaced by sclerophyll woodland because of reduced rainfall and increased fire (Singh et al. 1981). It seems that since the last glaciation there has been a high effective rainfall allowing (over the last 7000 years) the rainforest angiosperms to return to the Atherton Tablelands (Kershaw 1978). Kershaw (1973) believes the last 3000 years, with lower rainfall, experienced the development of drier facies of subtropical rainforest, and since then recent changes induced by European Man have led to an increase of disturbed rainforest species such as Macaranga tanarius, and exotic species such as Lantana camara.

Ladd's (1979) work on the Delegate river in eastern Victoria's highlands suggests that about 12 000 years B.P. temperature, and probably also rainfall, were lower than they are today, but that by 8000 B.P. both had increased. He correlates these changes with a change in dryland vegetation from alpine herbfield or grassland to forest with a shrubby understorey. As the present study area is close to Ladd's area, this suggests that suitability of climate for rainforest in the area increased between 12 000 and 8000 B.P.

2.1.3 Numerical studies of rainforest

Computer analysis of rainforest data was initiated over twenty years ago and allowed development of more sophisticated numerical techniques. A discussion of the overall advantages of numerical techniques can be found in Section 2.2.2. Suffice to say here that repeatability, explicit methods and the ability to handle large data sets are sufficient justification.

Three main schools were involved in this development. Ashton (1963, 1964) studied rainforests at Brunei and became part of a group in Bangor, Wales, comprising Greig-Smith, Austin, Ashton and Whitmore, which studied rainforest in the Solomon Islands, Malaysia and Borneo (Greig-Smith et al. 1967; Austin and Greig-Smith 1968; Austin et al. 1972). In Australia, Webb, Tracey, Williams, Lance, Lambert and Dale conducted a series of numerical rainforest studies (Webb et al. 1967a, 1967b, 1970a; Williams et al. 1969; Webb et al. 1970a and 1970b). Poore (1968) worked in Malaysia.

The Bangor school

Ashton's (1963 and 1964) early study of mixed Dipterocarp forest in Brunei was done without computers, because he felt that local workers would not have access to them for follow-up studies. At that stage numerical analysis was in its infancy and choice of available methods was limited. A manual calculation using a Bray and Curtis (1957) method of ordination by Euclidean distance was chosen.

One aim of Ashton's study was to determine whether the forest, apart from patterns from the "fortuitous random distribution of species" was a "floristically and structurally uniform climatic climax" or whether it changed "under the influence of non-climatic environmental factors...from place to place", and whether such change was continuous or created discrete communities. The other aim was to learn more about the ecological behaviour of the Dipterocarpaceae.

Selection of sites was based on geological variation, physiography, access and lack of disturbance. Plots of 0.4 ha were selected as "the largest reasonably physiographically homogeneous unit" (Ashton 1963a). Qualitative data and enumeration of trees over 12 inches (30 cm) girth were used, the latter because of the long flowering cycles (13 years), a short-term factor reflected by saplings and seedlings.

Ashton found the x axis of the ordination correlated with a humidity gradient from mesic to xeric soil conditions. It separated valley and ridge sites and correlated with increased physiological soil depth. Altitude played a part indirectly through its influence on soil. The y axis related to slope, depth of humus and other soil factors such as availability of nutrients.

It was concluded that the Dipterocarp forest is not just a "uniform climatic climax formation" but reflects environmental variation (Ashton 1963b). Ashton considered soil texture and soil depth as important and inter-related through the influences of parent material and physiography. These soil factors are critical in soil moisture availability.

The Bangor group tested the application of association analysis and principal components analysis to rainforest data from Kolombangara in the Solomon Islands (Greig-Smith et al. 1967). They found a combination of the two techniques successful. Data were analysed by association analysis and ordinated to identify the "mis-classifieds". Reclassification was then done and each forest type was ordinated to investigate vegetation-environment correlations. Plots were selected on northern and western altitudinal transects to include a variety of topographic positions. Vegetative data were collected for trees only, all tree species being considered qualitatively. Quantitative measurements were made on trees above 30 cm girth on a 1.8 ha plot, in subplots of 20 m.

Stands were first separated geographically into northern and western ones, then topography and altitude became important. It was concluded that classification is more suitable if heterogeneity is marked, while ordination is best when stands have similar composition. With marked heterogeneity they found the direction of the first axis leads to inefficient projection on other axes.

Analysis reflected the very features which had been selected for in environmental heterogeneity by plot selection, and this raises the problem of subjective selection of plots.

In a second study (using data from Sepilok Forest Reserve in Sabah) Austin and Greig-Smith (1968) considered in more detail the methodological problems of number of species needed for ordination, appropriate measurements and standardization.

They found that "rare species contribute little information on overall variation unless the vegetation is markedly heterogeneous", and this also applied to a study by Webb et al. (1967). Austin (pers. comm.) suggests inclusion of such rare species only adds "noise" to the data analysis. Orloci and Stanek (1979) defined rare species as having a single occurrence in any or all ecoregions. The removal of single species occurrences is discussed by Clifford and Stephenson (1975). The absence of common species is only a problem when the species have a very high percentage frequency. In Austin and Greig-Smith's data the highest was 62%. It was decided that the abundant species provide maximum information and that 25% of the flora (50 in 190 species) can give an efficient ordination. Because of the high diversity and low species dominance in tropical rainforest, qualitative data were seen as more satisfactory than quantitative.

Poore

In a study of lowland evergreen rainforest in Jengka Forest Reserve, Malaysia, Poore (1968) examined an area of "uniform" soil and topography to determine factors controlling species distribution. He suggested that the "rarer species" formed groups and were influenced by environmental factors such as soil, but that "common" ones were distributed by chance factors such as dispersal. This is in contrast to the findings of the Bangor group.

In a study block of one km sq. Poore set out a grid of two perpendicular but overlapping sites of six parallel belt transects. Working along the full transect lengths he covered an area of over 23 ha. Canopy trees were recorded (in plots of 0.12 ha) for basal area, number of individuals and identity. A second block of 24 ha was sampled for all individuals of the canopy in the 19 commonest species. He ranked the common families and measured basal area and constancy. Analysis by partition of variance was carried out to detect pattern, and showed the distribution of all species together was random for a 400 sq. m plot, but that some species were aggregated.

Poore discussed the problem of selecting a plot size which would be homogeneous but large enough to sample the floristic variation, and the need for minimum variance between stands for ordination. Although his grid covered a catenary sequence from well-drained slopes to swamps, he believed he had selected a uniform study area.

Poore dismissed the idea that distribution of vegetation is based on narrow specific tolerance, because young trees were spreading from areas stocked with old ones. Accordingly he argued that micro-distribution is not controlled by micro-climate or soil, but by chance of regeneration in large gaps. The composition of seedling/sapling flora is important and depends on such factors as parent trees, periodicity, dispersal and dormancy.

The results from association analysis and covariance analysis were less powerful than those from his use of traditional methods. Both Poore (1968) and Whitmore (1975) prefer more traditional methods for rainforest studies than the Bangor and Brisbane schools which advocate numerical techniques. Austin et al. (1972) explain the reasons for the poor performance of Poore's numerical analyses in terms of his choice of sampling and analysis methods.

Austin et al. (1972) re-examined Ashton's data using modern methods and detailed soil data. They supported his conclusion that floristic variation is correlated with environmental variation (soil and topography) rather than just a matter of chance. They challenged Poore's argument that there is no topographic correlation, saying his use of trees of 91 cm girth and over was inadequate because it led to large plots and increased heterogeneity. They stated "it may be that the large 'minimal area' commonly assumed for tropical rain forest is the area which provides an adequate sample of the environmental heterogeneity to be found in any given habitat". "Poore's analysis of nineteen species in 651 plots (area B) is likely to have contained insufficient information per plot for meaningful results to be obtained". Large numbers of rare species cause a skewed distribution in the 2 x 2 table. His data were therefore subject to abundance effects and chaining. If plot size is too large then the within plot heterogeneity masks that between plots, and the methods of numerical analysis used are not appropriate.

Vegetation in the study of Ashton's data differentiated into two main types based on soil - alluvial and hill. Within the alluvial, further divisions were made on fertility and amount of flooding. A "leaching gradient" was suggested to operate with a fertility gradient, giving a range from unleached rich soil to leached poor soil.

The Brisbane school

The third group carried out studies on Australian rainforest and was enthusiastic about application of numerical techniques. Webb et al. (1967a) found, in a study of site-species data that, a Gower ordination gave information over and above classification in site analysis. However, because of the lower cost of classification they suggested it be tried first, and ordination only be used if insufficient information is gained. For classification they used the agglomerative polythetic method of information analysis.

Their study recorded presence/absence data for 818 species (and enumerated all woody growth of trees over 45 cm tall) over 18 sites of 0.1 ha. The vegetation was correlated with environmental data. An interesting result was the "vertical integration" of the classification groups, each of which comprised most components of an entire forest. However, on reconsidering these groups at a later stage they decided thay were "in part at least, artefacts of the method of numerical analysis employed" (Webb et al. 1967b). This example highlights the problems of method selection and interpretation.

In a further study the data were split into synusial groups, and big trees reproduced the original classification perfectly (Webb et al. 1967b). These were then reduced to the most common big trees (25%) and again reflected the original classification closely. Properties of the species were important (not just size), and trees of the main canopy and emergents (not just 'big' trees) were important. It was therefore suggested that time is wasted in collecting unnecessary data if any more than the 25% of big trees are sampled. This also raised the question of the feasibility of doing rainforest analysis on physiognomic-structural instead of floristic data, and avoiding the high time cost and skill required for floristic work.

Large trees and lianes are more exposed to the macro-climate, therefore reflect climatic and other factors independent of the vegetation, whereas the understorey is dependent on the micro-environment (Webb et al. 1967b). Herbs and epiphytes are sensitive to local variations in canopy, and herbs to the upper soil layers. Thus understorey has little value in regional classification (Webb et al. 1967a).

An experimental study was done on rainforest succession by clearing of some sites and monitoring 12 times over seven years (Williams et al. 1969a). Of the various analyses carried out a single one, regarding sites at different periods independently, proved the most useful and formed successional species groups. Transition matrices also gave interesting results. This study described successional change and proposed a method for prevention of take-over by *Lantana camara* in disturbed rainforest. They did not support Gleason's (1926) argument that vegetation patterns are fortuitous, but believed, like Watt (1964), that they are a result of the combination of chance and environment.

The problem of sampling small scale forest pattern was examined by Williams et al. (1969b). Ashton (1963, 1964) had found a species area curve in the lowland tropics required plots of two ha, but he could not find large enough areas which were homogeneous, and Poore (1968) said that at least 0.4 ha was needed to sample interspecific association. Point sampling was approved of by Greig-Smith (1983), and Ashton (1965), but Williams et al. (1969b) believed that single nearest neighbour was too limiting on the scale of pattern which can be elucidated. They therefore used a system of "multiple nearest neighbours". There is a problem in symmetry as A and B are not necessarily consistently mutual nearest neighbours. Measurement of trees only is suggested as appropriate for different forests, but not for intra-forest structure, therefore all individuals should be measured.

A study of all trees in an area of only 0.4 ha was carried out (Williams et al. 1969b) using three plot scales - 15 x 13.5 m, 11 x 10m and 7.6 x 6.7 m. The data were subjected to information analysis, both normal and inverse. It was found that the smallest plots contained too few species to define meaningful contingency tables, and the largest ones were too coarse. Species groups were correlated with topography, and an idea of the dynamics was obtained.

The inefficiency of collecting floristic data became progressively apparent to Webb and his co-workers through this series of studies and in a fifth paper (Webb et al. 1970) they compared the properties of floristic data with those of physiognomic-structural data. A proforma which was designed for non-experienced observers to record data is discussed at length by Webb et al. (1976).

Agglomerative and divisive classification were both accepted as suitable for floristic data, but only agglomerative for structural data (Webb et al. 1970). Floristic analyses indicated geographical localization of habitat-types and historical availability. Structural analysis diagnosed the environment independent of geography. Polythetic structural analysis compared favourably with polythetic floristic analysis in defining habitat-types in terms of general parameters of temperature, rainfall and soil fertility.

The first split in the floristic analysis was strongly latitudinal and related to temperature, but the first in the structural analysis related to moisture. This was considered to be in agreement with both Good (1947), who said that temperature was the primary factor in individual species distribution, and Beard (1944), who claimed it was available moisture. It was suggested that both floristic and structural analyses are worthwhile, but that the latter has the advantages of rapidity and being applicable over a wider geographical range.

An important point made by Webb et al. (1970) is that "classification" of vegetation is informal - not like organism classification. The main problem is to develop a system for communication with others.

A comparison of the three major rainforest analysis schools was made by Austin (unpub. lecture notes), but it must be remembered that direct comparisons of results are not appropriate because of the different techniques used. Table 2 lists these differences. Austin summarized the comparison: "the Brisbane group did the most elegant and coherent analysis of possible methods while the Bangor group was more ecologically-oriented and Poore's work lacked the support of a good analyst".

2.2 Survey Design, Data Collection and Analysis Methods Review

2.2.1 Survey design and measurement

Introduction

Decisions on aims and methods made during the planning stage of a vegetation survey control the subsequent stages of sampling, analysis and interpretation. Noy-Meir (1970) discusses

TABLE 2. Comparison of rainforest studies (Greig-Smith *et al*. 1967, Webb *et al*. 1967, Poore 1968, (Austin unpub.))

	BANGOR	BRISBANE	JENGKA
Plot size	0.12 ha	0.1 ha	0.12 ha
shape	rectangle	?	rectangle
number	110	18	192
Species number	91	818	184
type	trees	all species	trees
size (girth)	1'	(2')	3'
Survey area	400 km^2	300,000 km^2	1 km^2
Sampling	unconstrained within strata	selected	systematic
Location	Solomon Is.	Australia	Malaya
Methods	Association-Analysis PCA	Association-Analysis Information Analysis PCoA	Association-Analysis
Data	Presence/Absence Density	Presence/Absence	Presence/Absence

clearly the stages necessary in observational analysis (Austin unpub. lecture notes) and the options within them. His large study area in semi-arid south-eastern Australia resulted in some similar survey design problems to those of the present study. The following sections refer to Noy-Meir's discussion on survey design, then compare his work with other large-scale surveys. Such considerations enable an appropriate design for the present study to be decided upon. Noy-Meir stresses the importance of appropriate data collection methods upon which numerical analysis can be performed, because results can only be as good as the original data. Bunce (1980) also raises this problem saying that it is of utmost importance to keep bias in data to a minimum, because bias can be accentuated by computer methods.

Noy-Meir (1970) lists the major stages in an observational approach to plant ecology as: 1) data collection; 2) exploratory data analysis; 3) interpretation; 4) generalization, and 5) prediction. Exploratory data analysis is useful in elucidating patterns and trends in data which can lead to generation of hypotheses about causal factors. As Gittins (1969) so aptly says "the aim of analysis is to reveal precisely those relationships between plants and environment which are most likely to repay closer investigation."

Domain definition and sampling frame

Following decisions as to aims and objectives, both areal and subject domains must be precisely defined. The subject domain is the set of vegetational and environmental variables to be measured in the study area, selection of which has been made from a wide range of variables on the basis of the study aims.

Noy-Meir's aim was to examine "vegetation and its relationship to environment". He therefore measured "the diversity of the plant component of the ecosystem, and those parts of other components (climatic, edaphic, biotic, human) which are coupled with it".

As it is generally impossible to make observations over the entire study area, a representative sample, consisting of sampling points, must be used (e.g. Goodall 1952; Noy-Meir 1970; Austin 1978; Orloci and Stanek 1979; Bunce 1980). In some studies limited resources, or lack of pressure to use mathematical procedures and produce unbiased results, led to less importance being placed on reducing the sample to a representative one. Whittaker's classical study of the vegetation of the Great Smoky Mountains (1956) used "typical" stands which were subjectively defined, and Curtis sampled all possible stands in the survey of the vegetation of Wisconsin (Curtis 1959). When a sample is reduced, the relationship between properties of interest in the sample and the whole domain must be known in order that results can be extrapolated to domain level with confidence (Noy-Meir 1970).

Measurement of properties in a sample will suffer from a degree of "sampling error" but this error declines with increasing number of observations (Noy-Meir 1970). Even a complete census has errors, but an advantage of large sample numbers is the increased chance of sampling rare communities or species. This was evident in Bunce's study and is important in the present study. Noy-Meir sees conscious or subconscious prejudices and technical convenience as two likely causes of bias.

Efficiency in terms of sampling time and cost has to be weighed against attempts to increase precision and reduce bias. Choice of an appropriate sampling design, plus the use of supplementary information, can increase both precision and efficiency. The minimal precision required by Noy-Meir "was such as to make possible meaningful statements about differences in species composition and environmental factors between groups of stands at least down to a level equivalent to 'associations' or 'types' recognized in previous studies". He anticipated the number of classes between 10 and 40, and estimated that 10 stands per class should sufficiently characterise a class to make reasonably reliable statements about it. Therefore, with stratification, he decided 100 stands should be adequate for major associations and 400 for minor ones, but no statistical reasons were given for this.

In multivariate studies different variables may have different requirements in precision and observation costs. A compromise is necessary to attempt to optimize all variables (Noy-Meir 1970).

Accessibility, time expenditure and disturbance to natural vegetation limit sampling, sometimes leading to use of completely subjective methods involving high levels of bias. In extensive surveys these seriously hamper "the quest for the ideal unbiassed, reliable and efficient sample" (Noy-Meir 1970). Noy-Meir decided sites had to be within 10 to 30 minutes walk from a vehicular track. This limitation to uniform coverage of an area introduces bias, particularly as roads tend to avoid certain landscape features and they also cause disturbance to vegetation. In the flat, open land of Noy-Meir's study this was not a serious problem.

Noy-Meir halved his original planned number of traverses in order to reduce travelling time to equal sampling time. Maximal use needed to be made of his field time because of the seasonality of the ephemeral vegetation, and repetition in sampling was necessary to record temporal variation.

Remnant vegetation such as rainforest often consists of small and scattered patches and is usually not accurately represented on vegetation maps. Because unbiased sampling may fail to record it, Noy-Meir suggests predetermined criteria can be developed to sample rare vegetation types outside the main sampling framework, but minimizing bias. He says a sampling design should be drawn on a map, and replacement rules for unacceptable sites, as well as rules for determining extra sites, be devised.

Stratification and random sampling

A number of options in survey design are listed by Noy-Meir.

a) Selection or objective sampling.

Ecological surveys often use selected "typical" stands which are recognized by surface properties such as physiognomy, but may not represent more subtle variation, such as floristic diversity. Vegetation dynamics (such as successional seres) and aesthetic value judgements inevitably lead to bias in such selection.

Random sampling allows estimation of the mean value, but also of the precision of this mean (Greig-Smith 1983). These significance tests can be used because any point within the area has an equal chance of being represented. However, random sampling is not necessarily a solution because vegetation patterns are rarely random (Goodall 1952; Curtis 1959). Goodall suggests restricted random sampling, where an area is divided into equal sized units, which are each allocated an equal number of randomly distributed sites. This method of stratified random sampling satisfies the conditions for statistical testing (Greig-Smith 1983). Random methods include use of a grid system to find sites by random coordinates, or random distances along a randomly located transect, as done by Orloci and Stanek (1979). Selection can take place at a number of levels in the survey scheme - sampling the whole area or a representative sample, and distribution of plots within that sample. Type, size, shape and number of sampling units and variables to be measured are all subjective decisions.

b) Random or systematic sampling.

Although Noy-Meir says that "systematic sampling at equal intervals along a line...is more economic than random sampling" he says periodic variations occurring in a similar pattern to the sampling interval can cause problems. By using airphotomosaics he was able to determine that no large scale periodic fluctuations in environment coincided with his transect system and decided that any undetectable pattern would be below the scale of interest, therefore a systematic method was acceptable.

c) Stratification.

Simple random sampling may result in chance under or over-representing of areas with distinct properties. In addressing this problem along with that of sampling a representative portion of the area a system of stratification can be developed. If prior information on size and distinctness of areas is available it "may be used to divide the area into strata" (Noy-Meir 1970). "Each stratum is allocated a number of sites relative to its size, and these sites are randomly located within the strata". Although such a sample is as unbiased as a simple random sample, quality and relevance of prior information determining stratification will dictate level of efficiency (Noy-Meir 1970).

Noy-Meir stratified on vegetation physiognomy from airphotomosaics, but studies by Bunce (1980) and Orloci and Stanek (1979), which will be discussed later in this chapter, stratified on environmental variables.

d) Allocation to strata.

Area-proportional allocation assumes that the user's interest covers the whole area equally, but it may omit sampling of rare communities. The possibility of weighting distinctness or importance must be considered. Noy-Meir suggests weighting can be based on "an informed guess of the intensity in each stratum of the criterion of interest." Estimates derived from the whole sample must take account of relative sizes of strata and allocation weights. This was a weakness in the study by Bunce discussed late in this Chapter. Noy-Meir decided that area-proportional allocation is the best method for examining distributional patterns, and was most appropriate to his study, as there were no particular areas which he required to be weighted and Austin (1978) also used this method.

e) Multi-stage and multiphase sampling.

The former may be useful to reduce time in travelling, and give a variation pattern over large areas, but may decrease accuracy, the latter to increase precision for some variables by using subsamples. Two phases were used by Noy-Meir - plant species lists, quantitative estimates and habitat descriptions, being relatively fast, comprised the 'outer' sample of 400 sites, while soil data and measurements in permanent plots were taken in 100 'inner' sites.

Measurement

Plotless methods (Cottam 1947) were developed in the Wisconsin school and used by Curtis (1959). They were developed as a technique to enable rapid, efficient sampling of a large number of sites in tree-dominated communities of variable density (Williams et al. 1969b), where random distribution is assumed. Because they do not require the actual setting-up of plots they are efficient in time and equipment. It is argued that because they are not of fixed size they do not suffer from the density-dependent problems of fixed plots (Mueller-Dombois and Ellenberg 1974). The density of the vegetation allegedly imposes appropriate size on them, whereas size of fixed plots, being selected by the user, may be quite inappropriate for the vegetation density. However, because of the small number of individuals per point, plotless sampling may inaccurately sample a very heterogeneous, or clustered type, unless enormous numbers of points are sampled, and is therefore inappropriate for rainforest. Lamacraft (1979) examines problems associated with point (plotless) sampling.

Some properties such as variance and frequency depend on dimensions of sampling unit, and results can therefore only be valid for units of these dimensions - not to the domain as a whole. Definition of a "representative area" for plot sampling is difficult. Goodall (1952) discusses the various approaches to determining "minimal area", and concludes that it is best based on vegetation homogeneity, "the smallest area for which the stand is homogeneous in those features by which the association is defined." The "species-area curve" was used by Braun-Blanquet and others to define the minimal area as that where no new species appear with increase in area (1965). Goodall believes this has been taken too literally and that it actually means the area where the curve is becoming horizontal. At this stage, he says, it can go from having 30 species in ten sq. km to only 34 in 100 sq. km.

Vestal (1949) examined minimal areas for different vegetation types, recommending an area of five to ten acres (2 to 5 ha) for tropical rainforest. His species-area curve shows additional species numbers still increasing considerably at this size, which may reflect the minimal area comments by Austin et al. (1972) presented in Section 2.1.3. Williams (quoted in Werger 1972) decided that one ha was generally the point below which environment was homogeneous, and that above that species numbers increase more rapidly because of new ecological conditions. A comparison of the Braun-Blanquet approach with that of Williams highlights the confusions in the minimal area concept. The former suggests a curve which tails off from the point of "minimal area", while the latter suggests a curve which steepens from this point. This reflects the problem of different scales of interest.

In reviewing the literature of the species-area relationship to plot size Werger (1972) concludes that "the use of the concept of 'minimal area' is impractical, mainly because it is impossible to define". He prefers the concept of "optimal plot size" which "can be expressed in terms of information required". As one ha plots are both uneconomic to sample and tend to be heterogeneous, he suggests a unit of one ha should be considered as 100% information, with decisions on percentage information required for a particular survey then dictating plot size. For tropical rainforest, however, he suggests plots larger than one ha may be required.

Noy-Meir subjectively selected the scale of interest after reconnaissance as of the order of 50 m for woody plants and five m for herbaceous, and says this corresponds roughly to ten times the canopy diameter of the larger individuals.

Actual location of plots in the field was achieved by Noy-Meir by driving the prescribed distance, then walking perpendicular to the road until out of the zone of influence of road disturbance to vegetation, with sites on alternate sides of the road. Distances from roads were subjective and quite variable, and this may be the weakest area in his technique. He raises the problem of bias at this stage, and also discusses the need for a prescribed list of criteria for relocation of sites, and the need for a system of microstratification in the field. The latter is relevant to the present study as areas with open understories or dense fern gullies can be encountered.

Quantity or 'importance' of species can be measured by a variety of variables such as density, cover, basal area, rooted or shoot frequency, and biomass. Noy-Meir chose to measure presence/absence of all vascular species, and to use cover as a measure of importance and density as a population parameter. They were chosen because they are both "visually estimated quickly without elaborate frames or measurement, both are applicable to almost all life forms, and both are conceptually simple." Height, basal area and vitality were also estimated but found of little use in the analysis.

Noy-Meir's approach of considering speed more important than precision is a valid one for large-scale surveys, where it is impractical to spend large amounts of time on detail. His use of "loose" plots and estimates of quantity are therefore appropriate. Smartt et al. (1976) carried out a study to test the use of different methods of variable measurement and concluded that "approximations in methods of field recording, unless exceptionally crude, have less effect on the results than changes in the nature of the measure." They were particularly interested in cover and used a method of subjective allocation to five cover classes, which they decided were adequate. They also concluded that for many purposes qualitative data are acceptable, and that quantitative data devalue the many uncommon species as opposed to the well-represented ones, but that this depends on data type, which may vary with environment. Some quantitative methods failed to register any marked improvement over qualitative data. Of the types which do make quantitative data assume importance, type selected depends on needs. For example the amount of plant material, and ecologically important habitat conditions, can be learnt by use of different data types. The latter needs a type sensitive to relatively permanent features and thus floristic diversity may be more useful than dominating species. They conclude that a compromise is appropriate - to use a "quantitative procedure which approaches performance of qualitative at upper levels and exceeds it below". The "loss in ecological definition at the top can be compensated by a gain at lower levels." The use of estimates is seen by Noy-Meir as sufficiently detailed, as he was looking for gross quantitative differences, and floristic diversity was of prime interest.

In a detailed breakdown of time involved in his field work Noy-Meir found that most of the sampling time (after stopping the car for each site) was spent on recording. He felt the increased time in making quantitative estimates over just species list compilation was not great, therefore well justified. After examining efficiency in travelling and sampling time he decided that increase in site numbers would be justified. The sample size could have been doubled for only 30% increase in time, or quadrupled by less than doubling of time.

If more sampling time had been available Noy-Meir would have done more detailed quantitative measurements on "dominants". There are problems with this method, unless it is done at a second stage, after "dominants" have been determined by an analysis of initial data. Other studies have used dominants (e.g. Orloci and Stanek 1979), but the present author believes subjective assessment of dominants is subject to extreme bias. This was evident in surveys by Hurrill (1971), and Coyne et al. (1978) where the dominants selected were not substantiated by quantitative data on the same area (Helman 1979). Dominants can easily be selected by false impressions based on size or outstanding appearance. Ease of identification in a flora such as rainforest, where the researcher is having difficulty with identification, or consistent proximity to patch margins, where species are noticeable, also influence choice of dominants.

Comparison of surveys

The preceding Section of this Chapter examined the stages of sampling and measurement listed by Noy-Meir as necessary for a vegetation survey. His thorough discussion succeeds in justifying his decisions, and leaves little room for criticism. However, several small points or possible alternatives have been raised. Other researchers have recognized similar stages, with some variations, and different options have been adopted depending on the nature and aims of the survey. This section will briefly discuss the different approaches of other large-scale studies.

The United Kingdom Ecological Survey (Bunce 1980) was planned as a computer-oriented study. The area was divided into km square grid cells, and using environmental data (climate, geology, human, topography) of observed land surface features, these cells were classified by multivariate analysis into 32 land classes. The classes could then be 'tested' by a field survey of the vegetation, and form a stratification for that survey. The survey chose to sample eight grid cells randomly in each class. Actual location of plots within cells would be by a random method. The stages identified in survey design by Bunce are: a) environmental stratification; b) strata used for site selection for field surveys; c) results of field survey used to check stratification, by looking at relationships between strata and field data; and e) predictions made about unsampled areas on the basis of known relationships between variables.

Despite the systematic modern approach there are problems with this survey. For example the equal allocation of samples to the land classes would result in unrealistic weighting of the small classes and under-representation of the large ones. Area-proportional allocation of sites would have therefore been worthwhile.

Another modern survey was that of Orloci and Stanek (1979) who surveyed the vegetation of the Yukon section of the Alaska Highway. This survey was written-up quite formally, with little space given to discussion of the methods used. A system of "nested stratification" was used through previously determined "ecoregions" and "terrain types" based on gross environmental factors. Allocation to strata was proportional to the distance of intercept with the road.

The method of calculating site number and distribution was effective and simple. Using known length of highway and dividing it into equal intervals for a minimum distance between sites (to prevent clustering), 5731 possible sites were determined. Within their strata and along the highway 323 sites were selected randomly (to give 5.6% sampling intensity). A random choice determined whether they were placed north or south of the road, but actual placement was subjective, according to road disturbance. This is the same problem as in Noy-Meir's study, where the careful avoidance of bias at earlier stages is abandoned at the final plot stage. The problem could have been solved by using a base distance from the road, and if it had to be rejected, having a predetermined system of prescribed distance pacing until a suitable site was found. It must be remembered, however, that 'suitable' site is still subjective.

Another study which explored the feasibility of regional stratification was the South Coast Survey of New South Wales by the CSIRO Division of Land Use Research (now Water and Land Resources) (Austin and Cocks 1978). This study set out to survey vegetation, along with many other variables, over a contiguous geographic area. The stages identified as necessary were: a) collect bio-physical information for survey area; b) map area into units on basis of air-photos, prior information and preliminary traverse, and identify their characteristic geology, terrain and vegetation; c) group units similar in those variables and design a sampling scheme; d) ground survey of detailed data collection and observation; e) check correlations between airphotographs and real attributes; f) group mapping units into "land systems" and describe "units" on basis of geology, landform, soil and vegetation, using correlations between attributes to extrapolate from sampled to unsampled areas (Austin and Basinski 1978).

Accessibility, and therefore time also, was a serious problem in more rugged parts of this area which has little road access, therefore a subjective method was inevitable. A two level spatial stratification was used , based on the 14 "Functional Districts" identified, and 800 "Unique Mapping Areas". Number of sampling sites per District was determined by its size, complexity and importance (Austin and Basinski).

The actual location of sites was done in a purposive manner, by selection of "typical" stands which were reasonably accessible. This can be criticized as open to bias as discussed by Noy-Meir, but with the constraints on the survey, no option was available. Where possible, sites were distributed along a topographic sequence to allow patterns of environmental correlation to emerge in the context of gradients. In areas of particular interest which had been unsampled, extra traverses were done, as with Noy-Meir's selection of extra sites.

Two earlier, but important studies are those done by Whittaker (1956 and 1960) in the Great Smoky Mountains and in the Siskiyou Mountains. Part of the aim for these surveys was research into theory of the "community unit" as Whittaker believed that the practice of classifying vegetation was artificial, and that it should be seen as a continuum along environmental gradients. "Gradient analysis" was developed to relate gradients of populations and community characteristics to gradients of environment.

Like Noy-Meir, Whittaker felt that precision was not of prime importance in the overall approach, and estimates of cover were acceptable. No systematic stratification of the area was done, and selection of gradients for transects, and of actual sites was subjective. Field transects were supplemented by site samples to attempt an "approach towards randomization" (Whittaker 1956). It was certainly only an "approach" as the sites were selected on the ground, although on the basis of topography.

The vegetation of Wisconsin was studied by a team over a period of years and is very well described by Curtis (1959). Like Whittaker he was looking for compositional gradients. The floristic provinces were subdivided on composition to give 21 major communities. A vast amount of time was spent sampling all "suitable stands". Criteria for suitability were minimum size 15 acres (6 ha), homogeneity, uniform topography and lack of disturbance. "Homogeneity" could not be applied to the present study because of the diversity and clustered distribution of rainforest species. Curtis mentions this problem of aggregation of tree species and suggests clustering is likely to be subject to sampling error.

After calculating the area of each stand on the map, its number of sites was allocated proportionally. Once the stand was found on the ground and still fulfilled requirements, the location of the first plot was determined by a 'random' toss of a quadrat stick, and a prescribed pattern of pacing from it located others. This is in contrast with Orloci and Stanek (1979) and Noy-Meir (1970), where "unbiased" methods were used until the final ground location stage but bias was introduced at the plot stage.

Curtis discusses the problem of validating interpretation of "rare" species and stresses the need for replication. Thus he chose 100 stands per major community, making a total of 1420 stands or 2.59 per ten sq. miles (25.6 km sq.).

A combined plot/plotless method was used for vegetation measurement. The "Importance Value" was developed as an index of species' total importance and derived from summing relative density, relative frequency and relative dominance by basal area (Curtis 1959). There are serious problems with this index. There is no valid reason why these three variables should be summed. They are very different measures and weight the Importance Value (I.V.) accordingly. An extreme example of this problem was discussed by Helman (1979). In this case a small number of large old eucalypts rated more or less equal to a large number of smaller trees of rainforest species. These two types provide very different information about the plant community. If the I.V. is seen as a measure of total physical presence in terms of competition for resources it is misleading. There is also the question of what role the frequency rating has in the index, because frequency rating is more relevant to a larger area than to a small location, and should be more important in describing distribution (aggregation and dispersal etc.) and competition. To force an artificial index from summation of these three values is questionable.

Curtis' study is well presented with clear discussion of results and vegetation description. However, the very subjective method of sampling is a serious problem, particularly relevant with current methods of numerical analysis as explained at the beginning of this Chapter.

A. Gillison and K. Brewer (pers comm.) introduced the term "gradsect" to mean transect maximizing the most important recognized environmental gradient. After incorporating the gradsect approach into survey design of studies at a range of scales, they conclude that it is an efficient method to ensure sampling major environmental gradients.

Conclusions

From examination of a range of large-scale vegetation surveys a design for the present survey could be produced. The stages seen as necessary to survey design are:

1) domain definition

2) reduction of sample through use of gradsects

3) stratification

4) location of sampling sites

5) measurement of variables.

This follows Noy-Meir's approach except that gradsects are introduced to reduce the sampling area and ensure sampling along the major recognized gradient, and stratification assumes increased importance because of the very different nature of the study area. Chapter 4 presents these methods in detail.

2.2.2 Data analysis

Introduction

The use of numerical data analysis with specific reference to rainforest studies has already been described in Section 2.1.3. This Section deals in a more general way with analysis methods, by examining the reasons for adoption of numerical methods, then the different methods available.

Results obtained from a survey are affected not only by the sampling methods selected, but also by the methods of analysis. After the early descriptive ecological surveys (e.g. Pidgeon 1937, 1938, 1940, 1941) simple statistics were introduced to validate results and test significance (e.g. Whittaker 1956). Whittaker (1967) states that mathematical complexity may be unnecessary and that "effort to understand a pattern of vegetation by the most direct and effective means" is worthwhile. He says that "quantitative techniques can, when ineptly or mechanically used, obscure ecological relations". "They can never substitute for effective observation, judgement, intuition, and scope of understanding; for only these can suggest which quantitative analyses are worth undertaking and provide evaluation and interpretation of the relations which emerge" (Whittaker 1967).

A number of problems associated with the earlier methods, combined with advances in computer technology led researchers to develop numerical methods, which have played a significant role in the evolution of survey design and analysis over the past two decades. Computers provide facilities for handling extremely large data sets which would otherwise be unmanageable. Numerical analysis overcomes the problems of consistency, explicitness and lack of repeatability (Austin, unpub. lecture notes). The latter means that they are subject to closer scrutiny than other methods. However, because choice from the wide range of available numerical methods rests on preconceived ideas about the data set and purpose of the analysis, the problem of subjectivity has not been removed. When first introduced, numerical methods were used only at the analysis stage as by Noy-Meir (1970), or by Goodall (1952) who introduced the term "ordination". However, recent developments have enabled their use at earlier stages, leading to totally computer-oriented modern studies such as the United Kingdom Ecological Survey (Bunce 1980, Section 2.2.1).

While standard statistics are based on prior assumptions and are hypothesis-testing, numerical analysis is hypothesis-generating - searching for patterns which stimulate questions and lead, if possible, to explanations (Austin, unpub. lecture notes).

Some opponents of numerical analysis have suggested that users choose methods to give a desired answer (Clifford and Stephenson 1975). Although it is true that judgements are involved in numerical methods as well as in traditional ones, this is not necessarily a valid argument. Because the computer can handle more data than the brain a precise and specific answer can not be known in advance.

Another argument against numerical analysis is that it only produces results which can be anticipated (Harrington et al. 1981). Recently Dale (1982) denied that this limitation exists and challenged a study on which it is based on a number of grounds.

Decisions concerning methods of numerical analysis to be adopted should be based on an understanding of different properties of the various methods, and interpretation should be done only in the light of these properties and biases. With rapidly expanding use of numerical methods, there is a real danger that inappropriate alternatives may be selected. Bunce (1980) suggests it is better to choose one method and accept its results than to try a variety and accept the "best" results. However, if the one method chosen is a bad choice for the particular study, results would be of dubious value.

In order to overcome these problems it is necessary to i) research the merits of available methods, ii) make a decision based on the purpose of the study, and iii) interpret results in the light of the methods used. An alternative, which is not always available because of shortage of time and computing resources, is to try a number of different methods, the properties of which are understood, and either compare results, or pursue the one which produces results most suited to the study aims. Results are to be considered robust if they are repeated in the results from different methods.

Classification versus ordination

A major decision in the use of numerical analysis is that between classification and ordination of data sets. In some instances they have been used separately but are probably most effective when used in conjunction, as each emphasizes different aspects of the data (Greig-Smith, Austin and Whitmore 1967).

Classification organizes individuals into groups on the basis of the similarity or dissimilarity between their attributes (Clifford and Stephenson 1975). It is useful in indicating sites (in the case of the present study) with something in common in their species assemblages, which may or may not be interpretable in terms of known environmental variables. The main argument against the use of this method is presented by the Wisconsin school (Curtis 1959) which sees vegetation as a continuum (Whittaker 1953) and suggests that imposing groups on a continuum is artificial and unjustified (Whittaker 1953, 1967, 1975). This would seem a valid argument, as the boundaries between groups are arbitrary and may vary from method to method. A second problem is that classification results can only be presented in one dimension, which is unlikely to resemble the real situation. By combining classification with ordination a more comprehensive result may be obtained.

A hierarchical classification optimizes the route between individuals and groups, thereby not optimizing the structure within the groups (Clifford and Stephenson 1975). Such a classification produces groups or 'clusters' whose relationships to one another are readily expressed in two dimensions in the form of a dendrogram.

Ordination places individuals (sites) in multi-dimensional space (but reduces presentation to the most significant planes), so that as well as seeing which sites form groups, the relationships between the groups are evident (Clifford and Stephenson 1975). Visually it is generally presented in two dimensions at a time, but information provided makes it possible to interpret in more than two. Entities are arranged in n dimensional space on the basis of their similarities. An axis (vector) which accounts for most of the variability is determined, then axes accounting for successively decreasing information are placed orthogonally (Clifford and Stephenson 1975). These vectors can be examined in relation to environmental variables, the distance of different sites along each vector indicating site similarities. However, because vegetation variation occurs in more than two dimensions, it is dangerous to interpret vectors in only one or two dimensions as representing particular environmental variables. Austin (1976a, 1976b; Austin and Noy-Meir 1971) shows that interactions between variables are often non-linear and may lead to curvilinear results, such as the familiar "horse-shoe curve" effect. By emphasizing specific axes ordination is likely to lose some of the detail which classification retains, therefore the combination of the two is advantageous. Principal coordinates analysis (Gower 1967, 1969) is computationally easier than principal components analysis, and it also has the advantage of providing euclidean representation of non-euclidean metrics. A principal coordinates analysis represents a "multidimensional space in which the entities are embedded in such a way that all are separated from one another by distances corresponding to their dissimilarities" (Clifford and Stephenson 1975). According to Clifford and Stephenson principal coordinates analysis is more powerful than principal component analysis because "the ability to ordinate a set of entities given only their dissimilarities is of particular value in many ecological studies". For example, through the combination of principal coordinates analysis and the Bray-Curtis dissimilarity measure, one can choose to emphasize dominance.

Similarity coefficients

According to Clifford and Stephenson (1975) the Jaccard and Czekanowski coefficients are reasonably simple, and the two most commonly used in ecology for binary data. They suggest it is wise to use these known and simple coefficients as the properties of others are not well understood. These two coefficients are presented below.

Jaccard $\left(\frac{a}{a+b+c}\right)$

Czekanowski $\left(\frac{2a}{2a+b+c}\right)$

Both measures ignore paired absences (when a species is absent from both the compared sites). Choice of a coefficient which excludes double zeros (paired absences) is often made in ecological studies, because paired absences make sites seem similar and classify them together just because they are species poor. On the other hand conjoint absences of ubiquitous species may provide significant information. The difference between these two coefficients is that the latter gives double weighting to conjoint presences. In situations with few conjoint presences it may be useful to stress them, but where there are many the Jaccard coefficient may be better because it gives a wider spread at the upper end of the range (Clifford and Stephenson 1975).

The quantitative extension of the Jaccard coefficient is the Canberra metric of Lance and Williams (1967) and that of Czekanowski is the Bray-Curtis measure (Bray and Curtis 1957) (Clifford and Stephenson 1975). They are expressed as follows:

Canberra metric $$\frac{1}{n}\sum_{1}^{n}\frac{|x_{1j} - x_{2j}|}{(x_{1j} + x_{2j})}$$

Bray-Curtis $$\frac{\sum_{1}^{n}|x_{1j} - x_{2j}|}{\sum_{1}^{n}(x_{1j} + x_{2j})}$$

Clifford and Stephenson explain the differences between them. The former is the sum of a series of fractions, of which an outstandingly high value can only dominate one, but the latter can be influenced by occasional outstanding values because it is fractionalized as a whole.

A problem in the Canberra metric is that of zero values, where the difference between 1000 and 0 is unity and therefore becomes equal to that between 0.1 and 0.0, thus reducing the significance of the larger value. Double zeros also influence the result because "comparisons of sites with few species in common will lead to small values of the Canberra metric suggesting the sites to be less dissimilar" (Clifford and Stephenson 1975). A further difference is that the Canberra metric is designed to be sensitive to ratios rather than to raw data score differences.

Raphael and Stephenson (1972, quoted in Clifford and Stephenson 1975), showed that "if the Bray-Curtis dissimilarity measure is used in preference to the Canberra metric, the site groups which are obtained are more homogeneous with respect to abiotic attributes. The implications of this appear to be that for their data set 'reasonable' stress on the dominant species is preferable to stress on the infrequently occurring ones if indications of the abiotic factors are required." However, degree of dominance varies with environment.

Sorting strategies

Clifford and Stephenson (1975) say that experience is needed to understand the properties of the clustering methods available. Weakly clustering, 'space-contracting' (Lance and Williams 1967) methods such as nearest-neighbour lead to poor dendrogram structure, while space-dilating methods such as incremental sum of squares (Burr 1970), or furthest neighbour force strong clustering. The latter are subject to strong group size dependence, because as a group grows it recedes in space (Clifford and Stephenson 1975). Weakly related entities would 'chain' (Williams, Lambert and Lance 1966) under space-contracting methods, but form "non-conformist groups of peripheral elements" (Lance and Williams 1967) under space-dilation, leading to the 'ragbag' effect (Goldsmith 1973, quoted in Austin, unpub. lecture notes). Space-conserving methods using group averages, such as UPGMA (Sneath and Sokal 1973) and centroid sorting fit somewhere between these two extremes. As centroid sorting has largely been avoided because it is 'non-monotonic' and suffers from 'reversals' (Clifford and Stephenson 1975), UPGMA was chosen as the sorting strategy for the present study.

CHAPTER 3 THE STUDY REGION

3.1 Introduction

The South Coast Study conducted by the CSIRO Division of Land Use Research (now Water and Land Resources) in the mid 1970's surveyed a large section of the New South Wales south coast, using the land systems approach (Austin and Cocks 1978). The present study was originally designed to include that area as well as to extend further to the north and south. For logistic reasons, which are explained in Section 4.1.4, the area studied was reduced initially in the north and later in the south. The final study area thus closely matched that of the South Coast Study as is evident in Fig. 1. Differences result because the present study area was not constrained by local government boundaries, and was designed to sample as wide a range of rainforest as possible south of the Illawarra area. Thus both northern and southern limits are located slightly south of those in the previous study, and the northern section extends to the coast. More details on the biophysical resources of this region are available in the numerous South Coast Study publications (Austin and Cocks 1978). The following summary is based mainly on those publications, and on personal observations.

3.2 Location

The study area covers the strip of the New South Wales south coast between Milton near Ulladulla and Mimosa Rocks National Park north of Bega (Fig. 1). It extends from 35 degrees

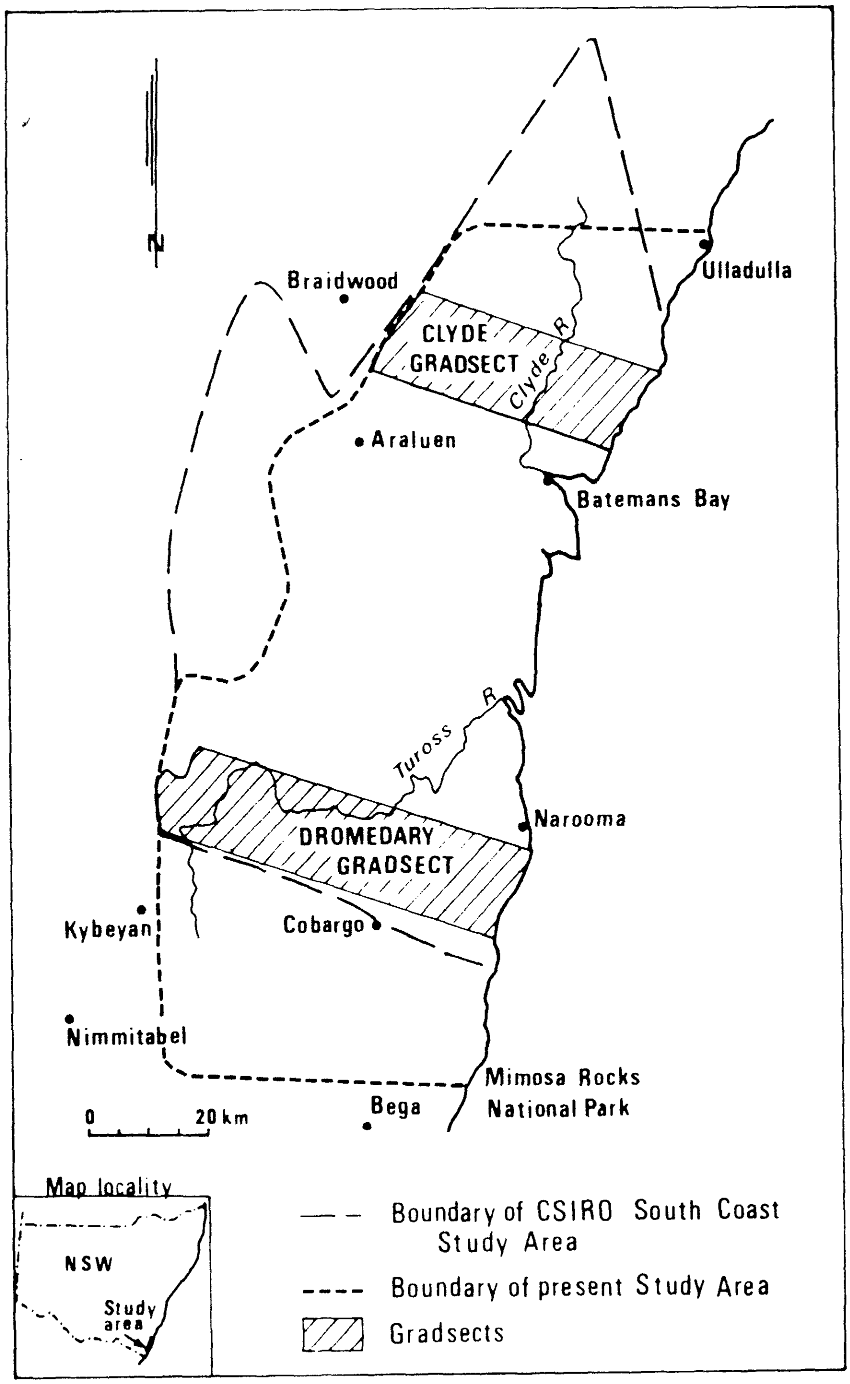

Braidwood
Ulladulla
CLYDE GRADSECT
Clyde R
Araluen
Batemans Bay
Tuross R
Narooma
DROMEDARY GRADSECT
Kybeyan
Cobargo
Nimmitabel
Mimosa Rocks National Park
Bega
0 20 km
N
Map locality
NSW
Study area
Boundary of CSIRO South Coast Study Area
Boundary of present Study Area
Gradsects

Fig. 1

24 minutes latitude in the north to 36 degrees 35, and from 150 degrees 30 longitude in the east to 149 degrees 30 in the west, incorporating coastal lowlands, the foothills and the escarpment.

3.3 Topography

The area is "that part of the eastern fall from the plateau of the Southern Tablelands to the coast, which is drained by the Clyde, Moruya and Tuross Rivers" (Gibson Turner and Alexander 1978). It consists mostly of uninhabited hilly or mountainous country, falling from the plateau rim at about 1000 to 1100 m altitude, to a narrow coastal lowland of less rugged terrain, where settlement and economic activity are concentrated (Galloway 1978).

Altitude ranges from sea level to over 1200 m on peaks of the Great Dividing Range, and includes a drop of about 600 to 800 m at the escarpment (Appendices 1 and 2 and Plates 2 and 3). The mountain belt of the escarpment presents "steep, rugged dissected mountains on folded sedimentary and low-grade metamorphic rocks and some volcanics. The western portion includes steep massive mountains on granite. All rivers flow in deep narrow valleys except where more open basins have developed on parts of the granite, notably at Yowrie and Araluen" (Galloway 1978).

The central hilly belt contains dissected forested hills on folded sedimentary rocks, with altitudes rarely exceeding 300 m. Granite masses at Buckenbowra, Mogendoura Creek and near Cobargo are now evident as cleared, rolling lowlands (Galloway 1978).

Plate 2. Northern escarpment (from east) showing south-easterly aspect of sheltered gullies in which rainforest occurs.

Plate 3. Terrain of northern area (looking east from Mt Currockbilly) showing escarpment and foothills.

In the gently undulating coastal lowland belt altitude rarely exceeds 100 m. Isolated mountainous enclaves associated with resistant rocks, such as Mount Dromedary, Durras Mountain and Mount Peak Alone are exceptions to this generally low coastal relief, providing 'islands' of local relief up to 1000 m.

3.4 Climate

The New South Wales south coast has a strongly maritime mesothermal climate characterized by a seasonally uniform distribution of rainfall, and a long, mild summer (Kalma and McAlpine 1978).

Climate stations are unevenly distributed in the region, being limited mainly to the coastal strip. For this reason, and because of climatic variability from the complex local topography, temperature and rainfall maps of the area are very generalized. Further details on climate are provided in the South Coast Study (Kalma and McAlpine).

A recently revised rainfall surface (Adomeit et al. pers. comm.) is presented in Fig. 2a. The main rainfall trends are decreases away from the coast and towards the south, but increase with elevation. Annual rainfall at recognized recording stations varies from 1300 mm on the northern coast to 750 mm at Kybeyan in the southwest, but the limited, recent records at Monga suggest a higher maximum for that area. The highest monthly falls occur in late summer and the lowest in late winter (Kalma and McAlpine 1978). The ranges of rainfall and temperature for the two sampling areas of the present study are presented in Table 3.

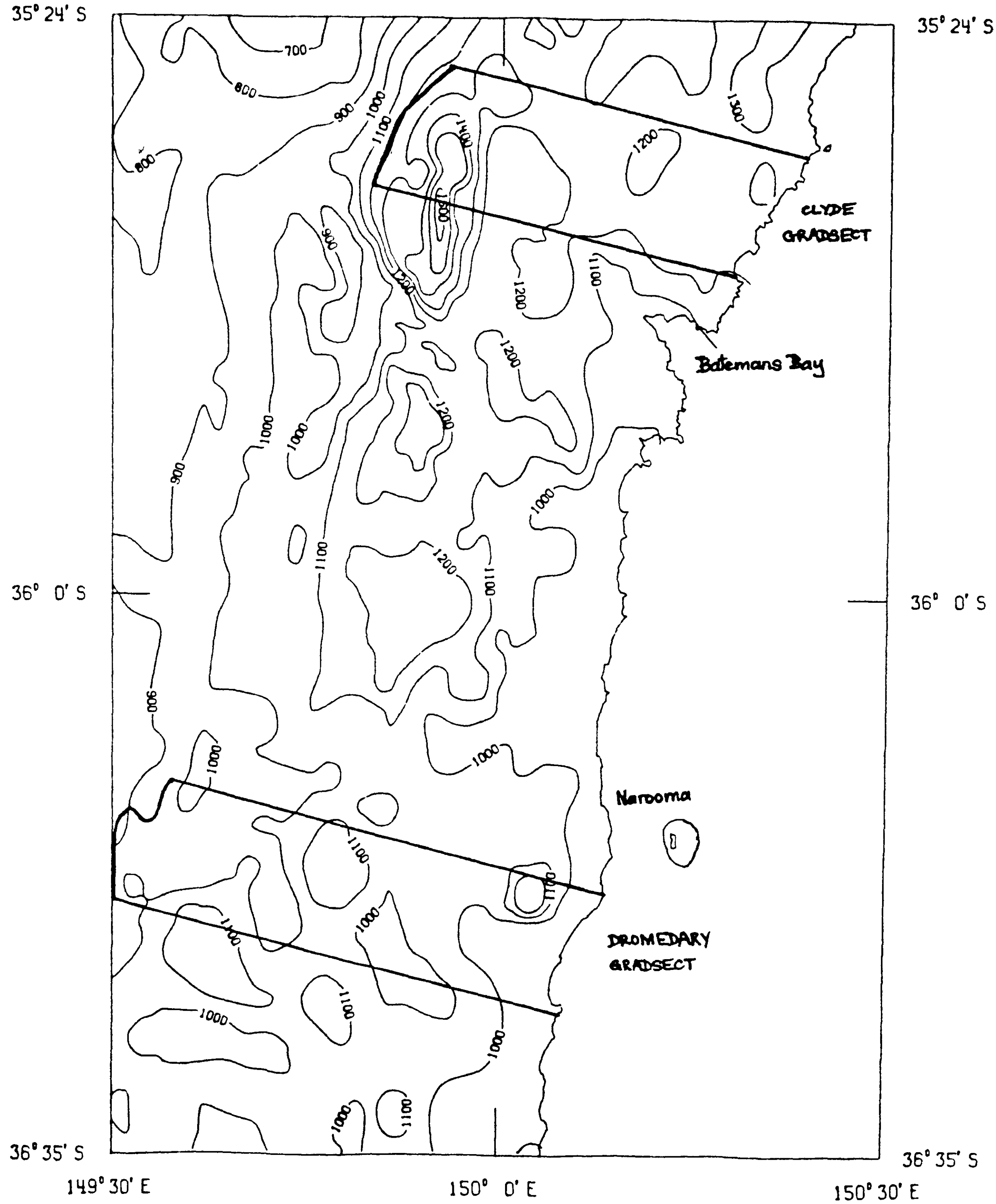


Fig. 2a Rainfall surface for study area (mm)

TABLE 3. Rainfall and temperature in study area (after Kalma and McAlpine 1978)

3a. RAINFALL - Mean monthly and annual rainfall (mm) for the standard period 1911-70

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Araluen	83	95	88	75	102	92	70	49	58	78	68	80	940
Bateman's Bay	100	95	105	103	112	100	70	51	64	77	83	91	1065
Braidwood	69	67	71	55	69	63	52	43	51	65	61	75	739
Cobargo	88	101	90	78	79	84	61	46	60	75	82	81	926
Milton	115	122	140	135	136	133	87	66	77	105	99	104	1318
*Monga	160	228	183	137	83	115	24	127	59	156	122	75	1832
Narooma	89	80	93	84	83	87	50	51	56	67	67	78	887
Nimmitabel	73	60	62	52	61	68	56	47	53	63	62	80	737

* Monga monthly figures obtained from local resident and only cover 1967 to 1977, whereas the annual figure is from the Monga sawmill and for the period 1955 to 1981.

TABLE 3 - Page 2

3b. TEMPERATURE - Mean maximum and minimum monthly and annual temperatures

Station		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Braidwood	Max.	25.1	25.8	24.0	20.5	15.7	12.7	11.7	13.2	15.9	19.9	21.6	24.2	19.2
	Min.	11.8	12.0	10.4	6.4	2.8	0.8	-0.7	1.2	3.1	6.3	8.1	10.2	6.0
Moruya	Max.	23.0	23.6	22.7	20.8	18.4	16.3	15.6	16.5	18.2	19.6	20.7	22.1	19.8
	Min.	16.2	16.7	15.4	12.8	9.8	7.5	6.5	6.9	8.8	11.2	13.1	15.0	11.7
Narooma	Max.	24.0	24.2	23.4	21.4	18.0	15.7	15.0	16.2	17.5	19.8	21.0	22.3	19.9
	Min.	14.8	15.8	14.8	11.7	8.6	6.5	5.2	6.4	7.6	10.7	12.0	13.8	10.7
Nimmitabel	Max.	22.4	22.9	20.7	17.0	11.8	9.0	8.0	9.6	11.9	16.2	17.8	20.7	15.7
	Min.	8.5	9.3	7.3	2.0	0.8	-0.9	-2.2	-1.3	0.2	3.2	5.0	7.0	3.2
Nowra	Max.	27.4	27.3	25.7	22.8	19.5	16.9	16.6	18.4	21.2	23.8	25.1	26.4	22.6
	Min.	15.8	16.6	14.8	11.9	9.9	8.3	7.4	7.5	9.4	11.1	12.6	14.8	11.7

Mean annual temperature in the region ranges from 9.5 degrees C at Nimmitabel (near the southwest corner of the study area) to 17.1 C at Nowra (in the north), with July the coldest month and February the warmest (Fig. 1). Frosts are frequent in valley bottoms and depressions (Kalma and McAlpine 1978). A rainfall surface is presented in Figure 2b.

In winter the dominant winds are morning westerlies. In summer northeast to easterly sea breezes are prominent, particularly in the afternoons, with early morning land breezes. The seasonal trend in the relative humidity index is influenced by distance from the coast. In coastal areas the highest humidities occur between December and March and the lowest between June and August, while further inland this trend is reversed. Moruya has 2690 hours of bright sunshine per year (8.1 per day in December to 5.8 in June) (Kalma and McAlpine 1978).

Climate must be considered in conjunction with topography. Temperature is closely related to elevation, distance from coast, latitude and local topography (e.g. aspect, position on slope, surrounding terrain). Similarly precipitation is a function of elevation, distance from coast, latitude and terrain.

In summer, frequent incursions of moist maritime air from easterly directions force orographic uplift against the coastal escarpment (Kalma and McAlpine 1978). Such local influences cause extreme and often isolated variations in climate which are generally not monitored, but which can be easily observed. For example, during field work in the northern area

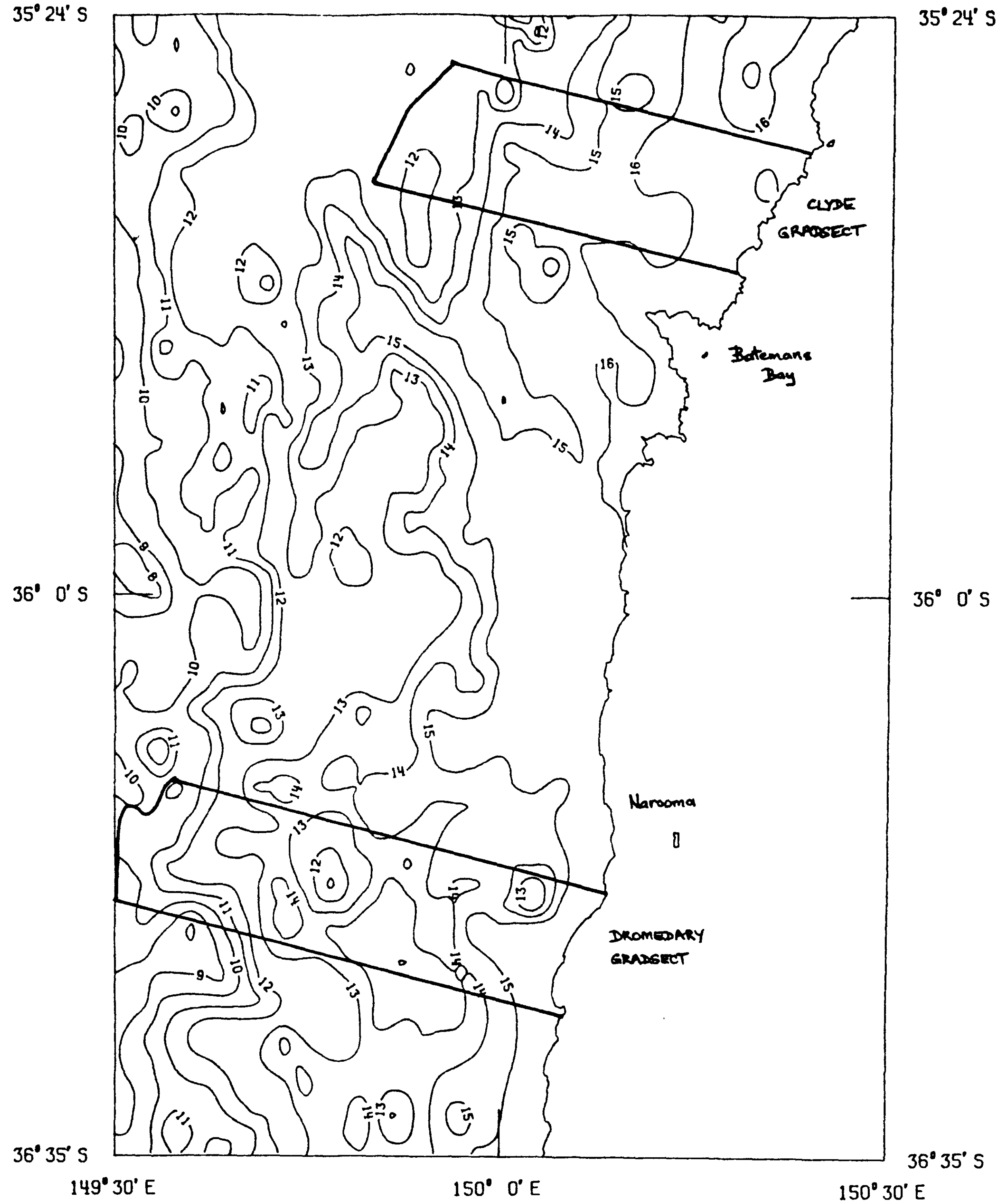


Fig. 2b Temperature surface for study area (degrees C)

Mount Budawang was observed to have a cloud cap for some part of most days (Plate 4). In the southern area Mount Dromedary at the coast is characterized by its almost constant cloudcap.

These interactions must be considered as important factors in vegetation distribution. The mountainous inland areas support more large rainforest patches than the coastal lowlands or broad river valleys (Appendices 1 and 2), except for isolated mountainous enclaves.

3.5 Geology and Soils

3.5.1 Parent material

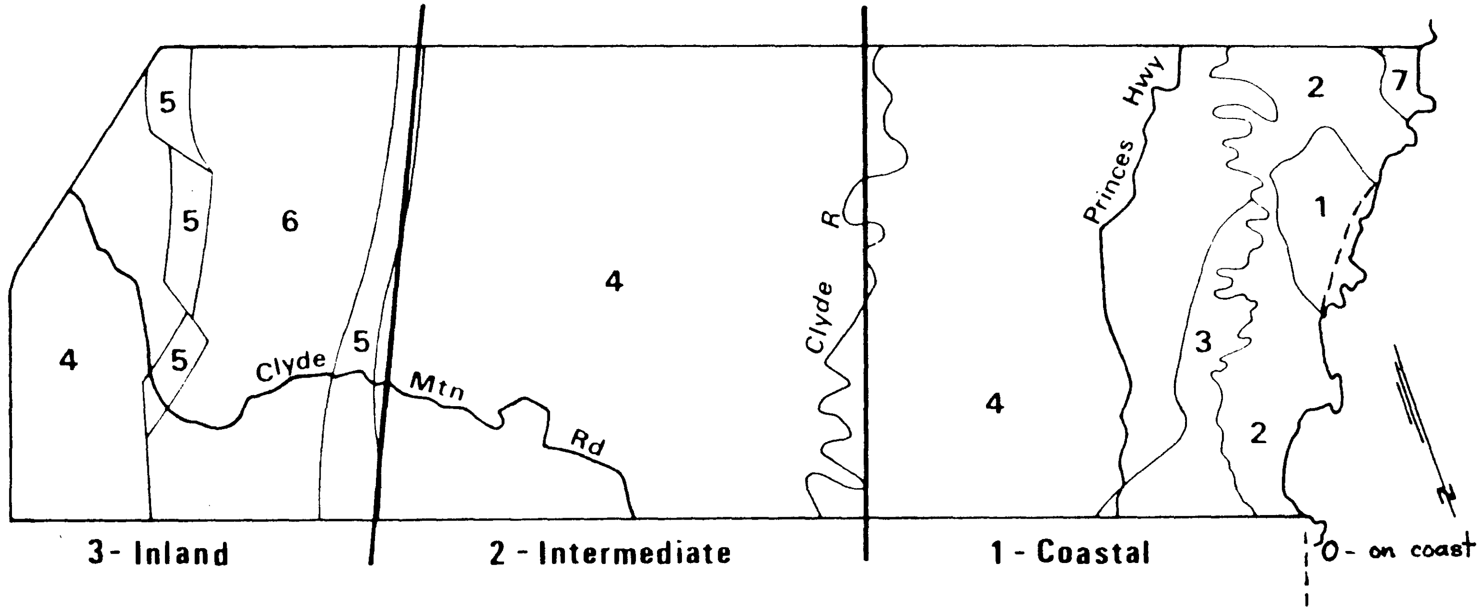
Geology in the sampled area was mapped from 1:250 000 geological maps (Geological Survey of New South Wales), 1:100 000 geological maps where available, and the South Coast Study results. Figs 3 and 4 show geological categories in the areas sampled (Section 4.2.4). The area is underlain mainly by tightly folded sediments and low grade metamorphic rocks (greywacke, shale, sandstone, chert, phyllite and schist) of Ordovician age that are generally associated with forested stony hills and mountains (Galloway 1978).

Intrusions of Devonian granite and Cretaceous monzonite and related rocks form both rolling basins under pasture and steep forested terrain in the south and centre. Subhorizontal sandstone, siltstone and conglomerate of Permian age form dissected plateaux and rolling to hilly country in the extreme north. The area is bisected by a mountainous belt of steeply-folded Devonian rocks, mainly red siltstone and sandstone but including some volcanics (Galloway 1978).

Plate 4. Mountain mist over Mt Currockbilly and Mt Budawang, creating an environment which supports microphyll mossy forest and microphyll fern forest.

Plate 5. Large coppiced specimen of the endemic Eucryphia moorei in microphyll fern forest of Monga State Forest.

Fig. 3 CLYDE GRADSECT - Geological types



1 ?Basalt enriched Permian sediments

2 Permian sediments (sandstone and silty sandstone)

3 Cambrian sediments (chert, conglomerate, slate and sandstone)

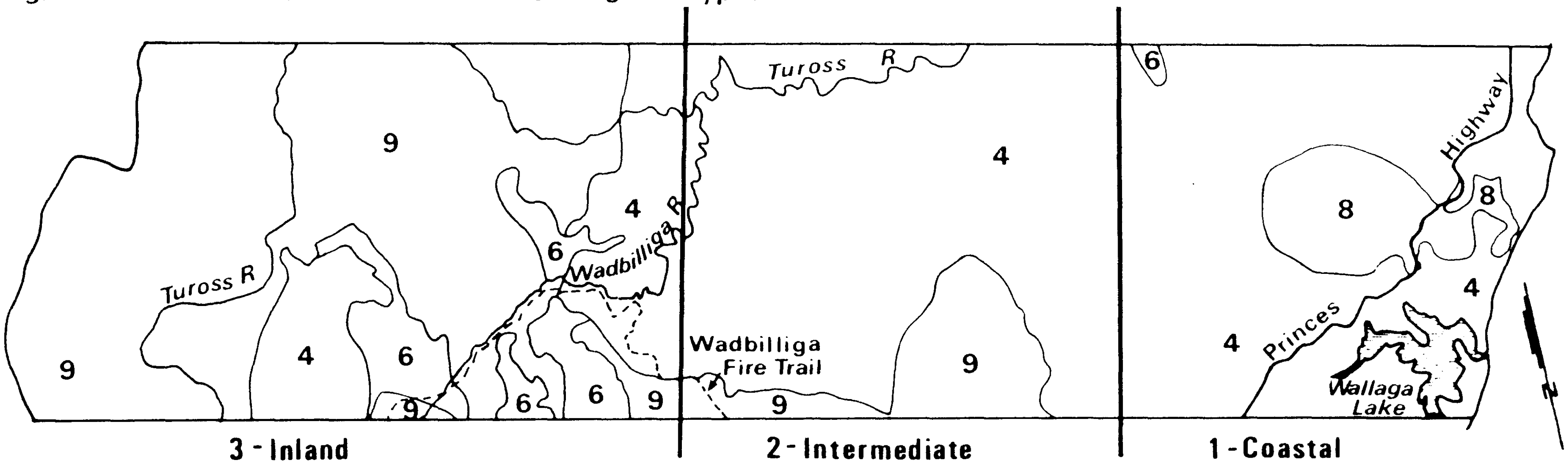
4 Ordovician sediments (greywacke, sandstone, slate)

5 Devonian volcanics

6 Devonian sediments (sandstone, conglomerate and siltstone)

7 Essexite

Fig. 4 DROMEDARY GRADSECT - Geological types



4 Ordovician sediments
6 Devonian sediments
8 Monzonite
9 Granite

The geology of the sampled area is summarized in Table 4. Ordovician sediments dominate both gradsects, granites play an important role in the southern one only, and Devonian/Silurian sediments and volcanics occur in both.

Geology affects rainforest distribution through its influence on topography, which in turn influences weather as described in Section 3.4. However the influence of geology, in terms of soil fertility, on rainforest distribution is only partially clear, and will be discussed in detail in Section 7.

3.5.2 Soils

The most extensive soils are massive earths and structured soils with gradational texture profiles, commonly with moderate to high gravel contents, which occur mainly in the hilly to mountainous terrain underlain by the folded sedimentary rocks covering about two thirds of the area (Gunn 1978).

Structured soils tend to be found where weathering and erosion results in clay accumulation and in certain environments where organic matter collects. Moderate to high organic accumulation occurs especially on hilly to mountainous sites above 500 m altitude on cool southerly aspects or on sheltered moist lower slopes. These sites have strongly developed humic surface horizons. There are lower erosion rates on the steeper slopes of cool aspects because of the dense canopy vegetation and ground cover, and accumulation of organic material increasing water entry and retention, thus reducing run-off rates. Organic matter accumulation depends on type, density and stability of the vegetation, and lower radiation and evaporation (Gunn 1978).

TABLE 4. Geological types (based on the Geological Survey of New South Wales and Galloway 1978)

Category	Clyde gradsect	Both gradsects	Dromedary gradsect
1	?enrichment of PERMIAN SEDIMENTS by TERTIARY BASALT		
2	PERMIAN SEDIMENTS Conjola Formation (in Shoalhaven Group) - conglomerate, sandstone, silty sandstone		
3	?CAMBRIAN SEDIMENTS Wagonga Beds - chert, conglomerate, agglomerate, slate, sandstone, phyllite		
4		?ORDOVICIAN SEDIMENTS - siltstone, claystone, sand-stone, quartzite, chert	
5	UPPER DEVONIAN VOLCANICS Comerong Volcanics - ryholite, rhyolite breccia, basalt, siltstone, claystone		

cont.

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Category	Clyde gradsect	Both gradsects	Dromedary gradsect
6		UPPER DEVONIAN SEDIMENTS Merrimbula Formation - sandstone, quartzite, conglomerate, siltstone, claystone	
7	MESOZOIC Termeil Essexite - essexite		
8			CRETACEOUS Mount Dromedary Monzonite Complex - monzonite, andesite, shonkinite, lamprophyres, ijolite, banatite, granite
9			LOWER TO MIDDLE DEVONIAN Bega Granite - granite, granodiorite, aplite, pegmatite

There are also texture-contrast soils on some granitic rocks, uniform sandy soils on beach ridges, and alluvial soils. Most soils are leached and moderately to strongly acid; kaolinite is the dominant clay mineral. Nutrient status and available water storage capacities are generally low, except for some humic soils formed on loamy alluvial deposits and fresh basalt.

According to Gunn (1978) parent material is the dominant influence on soil in the area. However, the vegetation-lithology relationship (as expressed by dominant eucalypts) "is less intimate than in drier parts of Australia" (Gunn 1978). Climatic and site factors such as rainfall, altitude, latitude, relief and aspect often play a relatively greater role than variations in rock (Gunn 1978). Intrusives do, however, support different soil and vegetation from sediments, as is evident at Mount Dromedary. "On the widespread fairly uniform Ordovician sediments, the relationship between soil and vegetation is obscured by the complexity of microclimates controlled by variation in altitude, aspect, distance from coast and latitude (Gunn 1978). Gunn's high altitude, cool aspect humic soils are distributionally related to rainforest.

3.6 Human Occupation and Use

3.6.1 Aboriginal

Knowledge and perception of humans in the Australian environment prior to European settlement has increased considerably over the past two decades (Tindale, 1981). Previously it was widely assumed that Aborigines had not played an influential role in Australian ecosystems.

It is likely that the ancestors of the Aborigines immigrated from or through the islands of southeast Asia at least 40 000 years ago, and this coincided with a climatic change to colder, drier conditions (Tindale 1981). Coastal environments, which provided a wide range of resources, may have been the first to be inhabited.

Tindale (1981) says that "for at least fifty millenia during the Late Pleistocene, and subsequently, man has ranked with climate as the arbiter of change in Australia." Although aboriginal tribes in different areas had varied diets, implements and habits in response to their surroundings, it is generally accepted now that fire was widely used as a hunting aid (Tindale 1981). The influence of this on the surrounding vegetation would vary according to the different environments, but one has to conclude that over many thousands of years the Australian vegetation has been exposed to a change in fire regime from that of purely natural lightning strike fires. This has probably resulted in reduced forested lands (Tindale 1981). Palynological evidence supports the notion of major vegetation changes having been caused by fires set by Aboriginal people (see Section 2.1.2).

Rainforests contributed to the diversity of environments which allowed the densest populations of Aborigines to survive on the east coast, with a far less nomadic life-style than those further inland. Many rainforest plants in the present study area have edible fruits, such as Eupomatia laurina, and Acmena smithii, thus providing a valuable resource for

Aborigines. More details on the use of rainforest by south coast Aborigines are provided by Lampert and Sanders (1973).

3.6.2 European

The most obvious changes to the natural environment brought about by European occupation are probably clearing, destruction of natural forests by logging, and changes in fire regimes.

The area was opened up early for purposes of timber extraction and mining, e.g. Mount Dromedary (Gibson Turner and Alexander 1978). Richer coastal sites, such as the Tilba area, were cleared early for dairying, which initiated much of the lowland rainforest destruction.

The area has provided a range of specialty rainforest timbers, mostly extracted by selective logging. Illawarra cedar cutters operated only in the northern section, as *Toona australis* may not have occurred south of Bateman's Bay. *Eucryphia moorei* and probably *Ceratopetalum apetalum* supplied timber for coachworks, such as that at Braidwood (V. Plumwood pers. comm.). More recently *Doryphora sassafras* at places like Mount Peak Alone, was cut for rifle butt manufacture in war time (K. Traise pers. comm.) as is evidenced by the extreme coppicing recorded in one stand in the present study.

In 1978 30% of the south coast study area was in State Forests. Of the rainforest which remains over the whole of the State, Prineas (1980) says two thirds is under Forestry Commission management. He also says the Foresty Commission has calculated that 300 000 ha of rainforest exists in the State (including heavily logged and lantana infested forest), and the National Parks and Wildlife Service says only 8.6% of this is in National Parks.

State Forestry Commission Forest Preserves, although less secure than the Commission's Flora Reserves, or the National Parks and Nature Reserves of the National Parks and Wildlife Service, are designed to maintain examples of communities. Some major rainforest types of the south coast are represented in such reserves, such as Ceratopetalum apetalum in Lyrebird Forest Preserve, Eucryphia moorei in Pinkwood and Milo Forest Preserves. The Mount Dromedary Flora Reserve offers more protection to stands of Eucryphia moorei and Doryphora sassafras. Austin (1978) states that "further detailed study is required before an adequate summary of rainforest variation in the study area can be prepared." "If plant communities are used as surrogates for ecosystems then decisions about ecosystem conservation are dependent on knowledge of the geographical distribution of communities and their current degree of conservation in reserves and National Parks" (Austin 1978).

The most obvious change in the area this century, other than the impact of forestry, is the development of holiday resorts along the coast, and associated increased recreational use. This places many stresses on the coastal environment. Vandalism for horticultural purposes is one of the impacts upon rainforests, as described by Austin (1978) and observed during the present study.

3.6.3 Fire

Southeastern New South Wales has a severe bushfire history for a number of reasons. The large tracts of forest, with dense understorey vegetation, in rugged mountainous terrain have severely limited vehicular access. The area is subject to frequent droughts, periods of hot, drying winds and electrical storms (Duggin 1978). According to the South Coast Study, areas are mostly burnt at least every 35 years and as often as every three to seven years (Austin and Cocks 1978).

After European settlement and Aboriginal depopulation, fire frequency changed and probably declined (Adamson and Fox 1982). However a further change in fire regimes has been associated with forestry practices, particularly in the extensive use of prescribed burning. The increased extent of habitation along the coast has also influenced the fire regime. Laut and Basinski (1978) state that most natural forest in the sections of the study area under agriculture, including rough grazing, "is seriously degraded by burning, clearing and timber harvesting".

All management authorities have favoured some prescribed burning to reduce intensity and rate of spread of fires. The vegetation may be significantly changing due to current burning regimes, the long-term consequences of which we do not understand. Subjective impressions suggest that in some parts of the south coast the regrowth following fires maintains the fire-prone nature of a vegetation, which if left alone may gradually change to a less fire-prone state. This seems likely to have an impact on the generally small patches of rainforest because of the possibility of continued attrition of margins by fire in the surrounding sclerophyll forest.

Being intolerant of fires by comparison with sclerophyll forest, rainforests appear to have been seriously affected by change in fire regime in a number of ways. As yet no study has documented this problem. Fire favours sclerophyll forest over rainforest by allowing sclerophyll species, which thrive in open situations, to invade, (Smith and Guyer 1983). The presence of sclerophyll species in such disturbed rainforest increases the chance of a major fire actually burning into the rainforest. Fire-affected rainforest boundaries tend to be abrupt, whereas those undisturbed are gradual because of the spread of rainforest species into the sclerophyll understorey.

Within the study area evidence of fire at margins of rainforest was common, in the form of recently burnt surrounding vegetation, burn scars on the bases of rainforest trees, or burnt logs which had fallen into the rainforest, damaging the canopy. The interior of small patches often showed evidence of burning, and some appeared to have been completely destroyed by prescribed burning. At Bolaro Mountain a patch had recently been burnt right through, probably during a backburn. "Management of fire has important implications for conservation, the long-term potential of forestry and the possible multiple use of forests for recreation etc" (Austin 1978).

3.7 Vegetation

3.7.1 General

Austin lists the history of vegetation research in the area (1978). It has been extremely limited, and definitely uncoordinated. This applies particularly to rainforest. Sclerophyll open forest dominates the region's vegetation. The South Coast Study (Austin 1978) describes 68 forest communities and a number of community complexes, such as swamps and rainforest, which form a small proportion of the total vegetation.

Altitude, latitude and geology are listed as the major environmental variables associated with variation in forest vegetation. A major latitudinal change in vegetation north and south of a line along Currowan Creek and the Clyde River was described. Lithology is reflected in vegetation differences between communities on granites and those on sediments below 500 m altitude (Austin 1978). Aspect was found to be associated with major changes in plant communities on a local scale. The communities recognised by Austin (1978) "are an abstraction from a continuum and likely to be superseded as more information becomes available." The need to gather detailed information on composition was stressed.

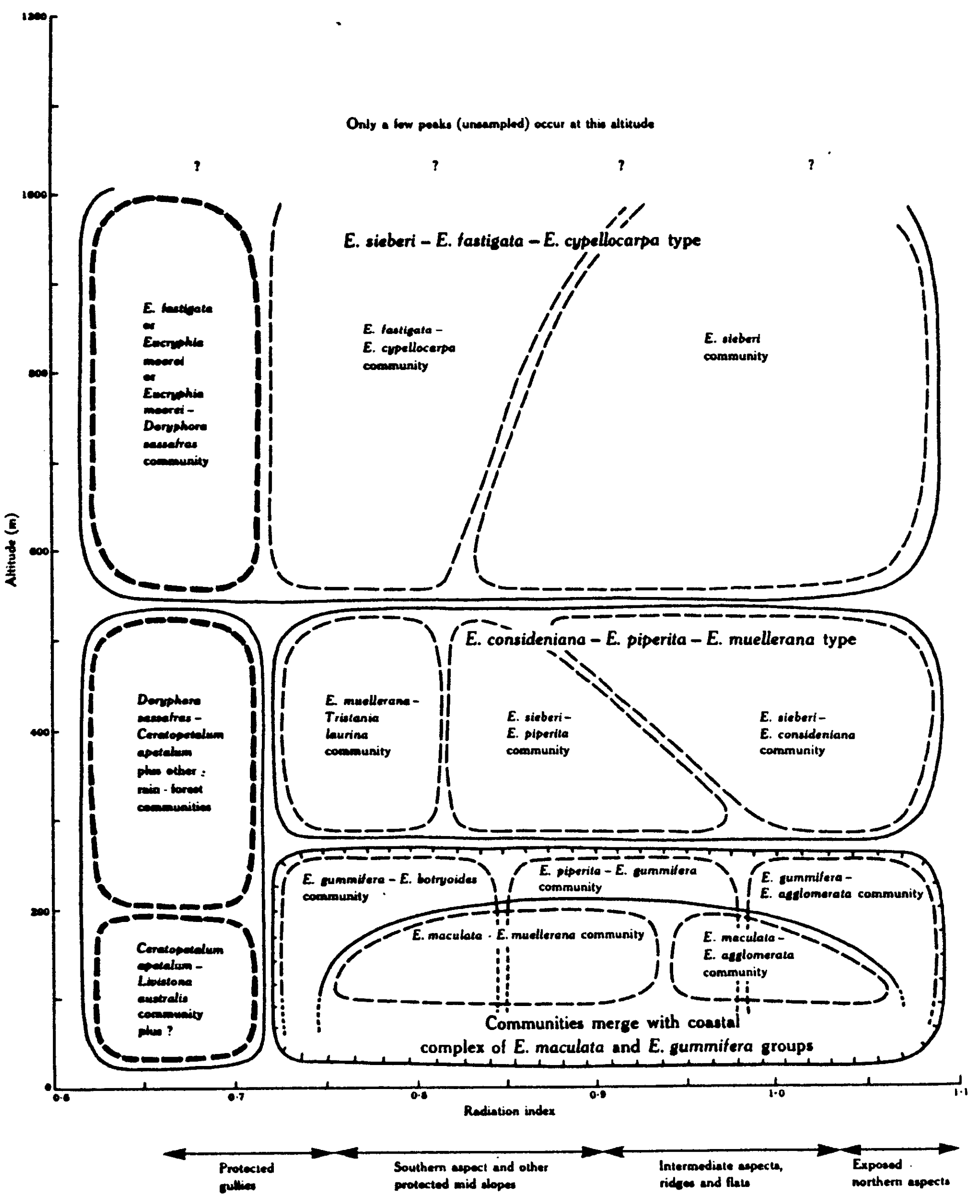
3.7.2 Rainforest

Rainforest occurs as scattered patches through the area, mainly along sheltered gullies and on protected lower slopes. Austin (1978) recognized aspect as important for rainforest development, with the majority of rainforest patches having a southeasterly aspect.

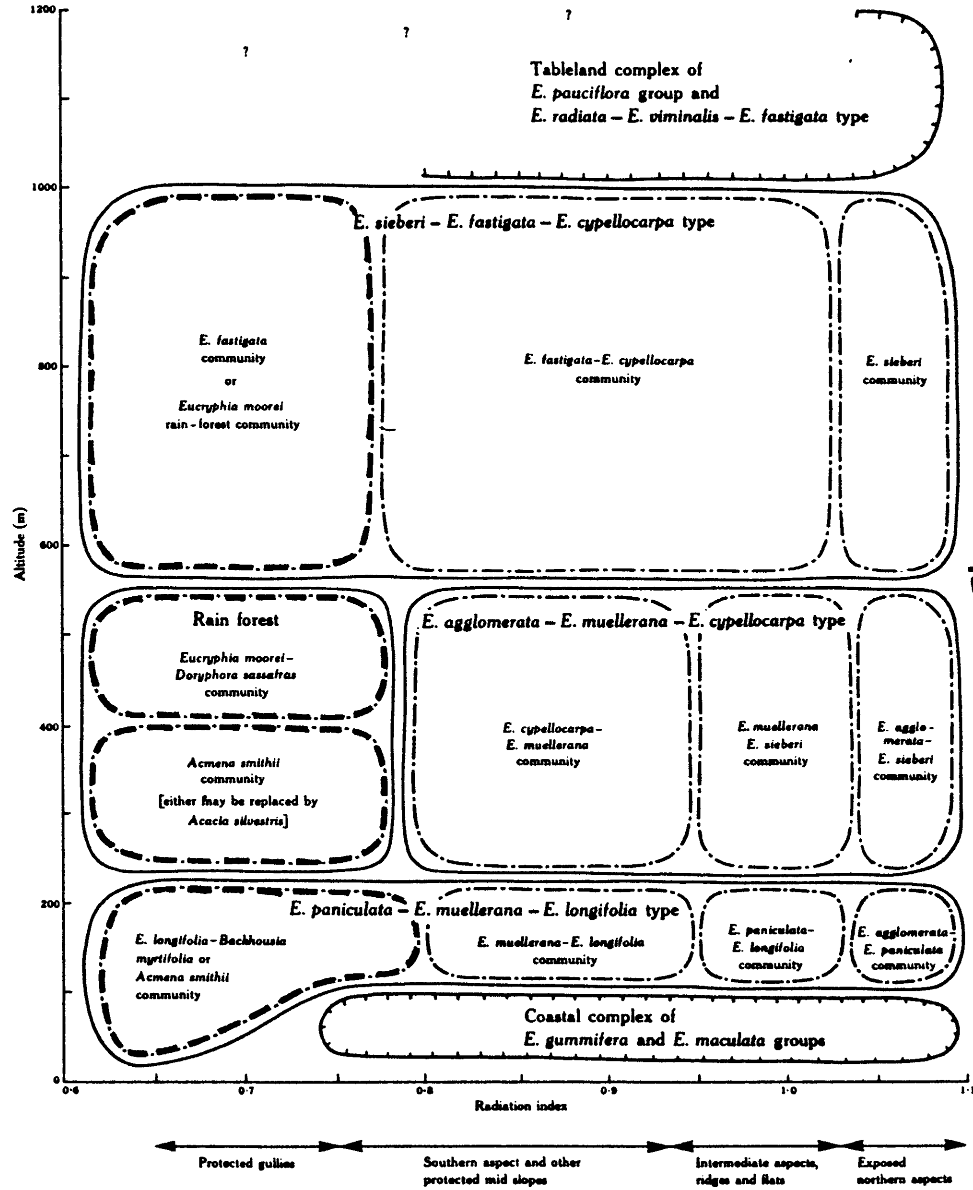
On the basis of the north-south floristic break, rainforest was recorded by Austin as two distinct latitudinal complexes, and those on sediments were considered different from those on granites (Fig. 5). In rainforests of all geological/ latitudinal combinations above about 600 m *Eucryphia moorei*-dominated forest was predicted.

In northern forests a mixture with *Doryphora sassafras* occurs at the lower end of the *Eucryphia moorei* altitudinal range, and rainforests between 200 and 550 m have mixtures of *D. sassafras*, *Ceratopetalum apetalum* and other tree species. Below 200 m forests would be of the *C. apetalum* and *Livistona australis* type (Austin 1978).

As *Ceratopetalum apetalum* does not extend south of Bateman's Bay, the composition of the mid to low altitude rainforests is different further south, as reflected in Austin's rainforest model (Fig. 5) and confirmed from personal observations. On sediments *Acmena smithii* joins *Doryphora sassafras* and *Eucryphia moorei* between about 240 and 400 m, below which rainforests are dominated by *Backhousia myrtifolia* or *A. smithii*. On granites *E. moorei* is listed as dominating rainforests over 580 m, but sclerophyll forest, rather than rainforest, takes over below that. Rainforest is listed as possible, but its occurrence and composition is uncertain between zero and 380 m on granites due to clearing.



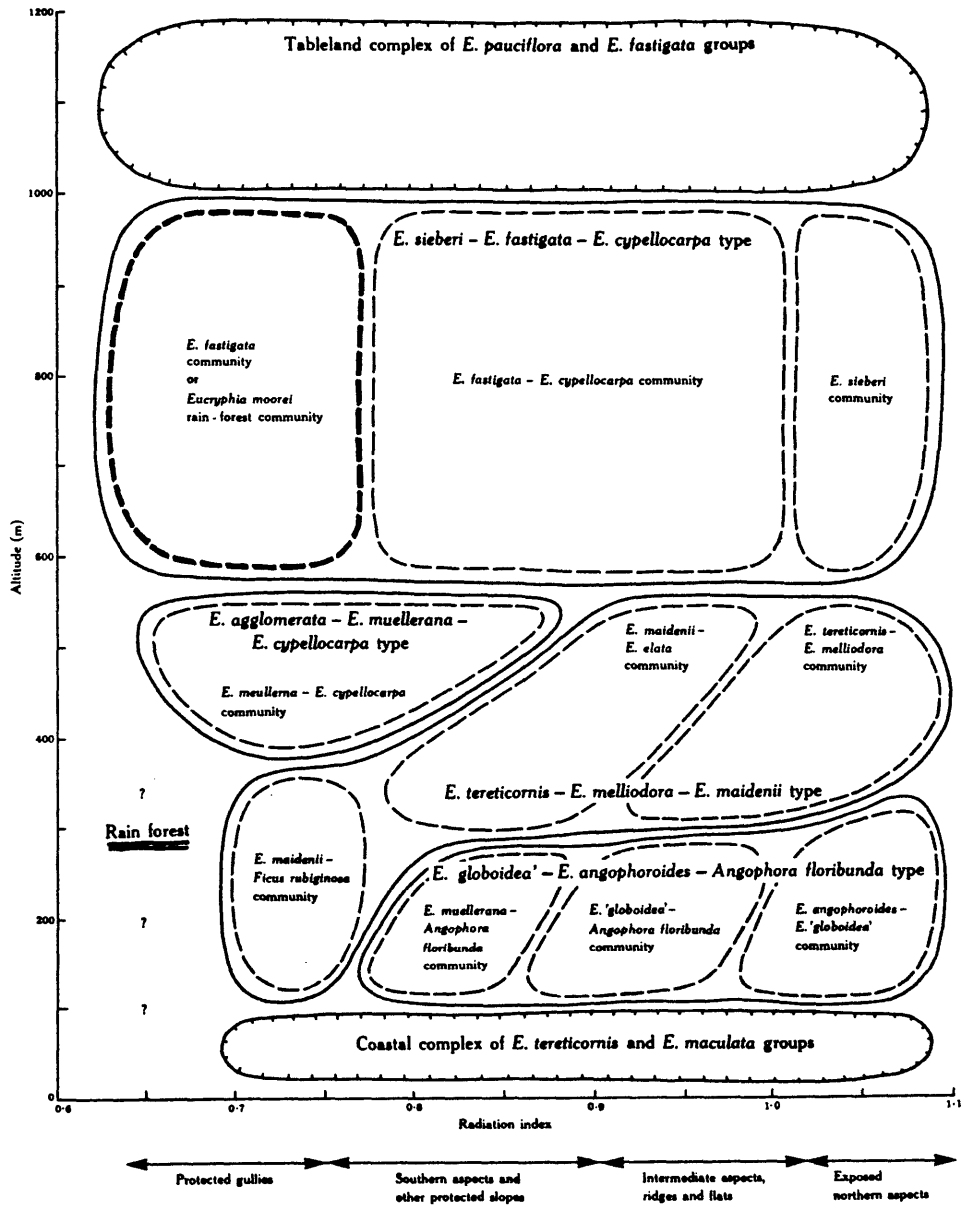
a. Idealized diagram of the relationships of forest vegetation to altitude and aspect for the northern forests occurring on sediments north of the Currowan Creek–Clyde River estuary line.



b. Idealized diagram of the relationships of forest vegetation to altitude and aspect for the southern forests occurring on sediments south of the Currowan Creek–Clyde River estuary line.

Fig. 5a – b South Coast rainforest model (Austin 1978)

Fig. 5c South Coast rainforest model (Austin 1978)



C. Idealized diagram of the relationships of forest vegetation to altitude and aspect for the southern forests on granite.

"The riverine forests are composed predominantly of eucalypts but frequently the rain forests behave as gallery forests and monospecific stands of *Backhousia myrtifolia* may occur on the banks of narrow streams particularly in the south" (Austin 1978 and personal observation), often with emergent eucalypts, e.g. *Eucalyptus smithii*, *E. longifolia*, *E. muellerana*, or *E. paniculata*. The rainforests of the area, though poorly sampled in the South Coast Study, showed a marked decrease in species richness going from north to south and from sea level to 800 m (Austin 1978). Austin also points to Mount Dromedary in the south as an exception, with "much larger numbers of species than the monospecific stands on the Ordovician sediments adjacent to the mountain."

Austin (1978) says the south coast "study area represents the southern depauperate extreme of the subtropical rainforest, usually said to finish at Kiama (Baur, 1956)". Many rainforest species reach their southern limit at Mount Dromedary. It is unique in having "a full sequence of altitudinal rainforest types" and well-developed higher altitude vegetation types close to the coast (Austin 1978).

The controls on vegetation imposed by long-term environmental conditions must be interpreted in the light of more recent changes brought about by man. Fire and logging appear to be the two most significant human influences.

Existing vegetation has to be considered in the light of previous forestry activity in the area. Despite the Forestry Commission's policy of protecting "brush" areas, clearfalling of large stands of sclerophyll forest (100 ha) exposes rainforest in gullies to drying winds (Austin 1978), and "the narrow strips of rainforest seem unlikely to be viable under these conditions." Direct damage to rainforest margins also occurs when surrounding forest is logged.

During the course of the present study Floyd (1982b, 1982c) carried out a survey of rainforest in the area as described in Section 2.1.2, and his framework of south coast rainforests can be seen in Fig. 01.