CHAPTER 1

1 Introduction to the Study

Change alone is eternal, perpetual, immortal.

-- Arthur Schopenhauer

1.1 Introduction

There is increasing evidence that frequent fires at short intervals can reduce plant biological diversity (Gill and Bradstock, 1995). Fire and inappropriate fire regimes have the potential to threaten species' existence if not suitably managed (Williams and Gill, 1995; Keith, 1996). The potential for inappropriate fire regimes to threaten species existence is possible because fire can reduce plant biomass to the extent that regeneration is dependent on the internal capacity of the plant to regenerate from vegetative material, or fire can kill the plant outright, making it rely on germination from seed. Frequent fires at short intervals limits the time available for plant regeneration. Hence, persistence of plant species in fire-prone environments is determined by the nature of the fire regime and the capacity of plants to persist in these conditions.

Fire ecology integrates the physical aspects of fire, the fire regime and fire behaviour, and the ecology of disturbance that fire initiates. Fire as a disturbance has varying repercussions related to the nature of the disturbance and the aptitude of the species to tolerate the disturbance. Conservation of plant species and vegetation communities requires all species to be managed to avoid extinction (Gill and Bradstock, 1995). Due to the interactions between fire and the composition and structure of vegetation, the fire manager requires information on the effects of fire regimes and the resulting impact on vegetation. This study aims to address both aspects, to provide information on the fire regime to form the basis to study the interaction between the fire regime and vegetation composition and structure.

The fire regime, which varies spatially and temporally, creates a heterogeneous history of disturbance in a community. The fire regime is comprised of frequency, intensity, season and type (Gill, 1975) all of which can affect the ongoing persistence of plant species. As a complex mosaic of varying fire frequencies, intensities, season of occurrence and type, fire produces a heterogeneous vegetation community. Recent studies have demonstrated the significant impacts of components of fire frequency, such as inter-fire interval, on vegetation (Cary and Morrison, 1995; Morrison et al., 1995a). These studies have provided research on other aspects of the fire regime, beyond a more traditional focus on time since last fire (e.g. Russell and Parsons, 1978; Bell and Koch, 1980; Wark et al., 1987). Yet, research in the area of fire and vegetation effects has lacked longer-term fire history data to place studies in the context of a fire regime. The lack of data over time on the fire regime has highlighted the need for investigations into alternative sources, specifically satellite imagery, that is available retrospectively in areas where the fire history is incomplete or inadequate.

This study focuses on plant species and vegetation communities and the impacts of the fire regime. Studies have shown that the impact of the fire regime on vegetation can result in lasting changes in species composition and structure (Kruger, 1984; Norland and Hix, 1996).

Woody plant species, specifically trees and shrubs (McDonald et al., 1990), have been found to be more severely impacted by changes in the fire regime (Reid et al., 1996) than grassland communities (Gross and Pisanu, 1996) and therefore, were the primary focus of this study. Yet, the interactions between fire and vegetation composition and structure are not limited to the above-ground vegetation, information on the below-ground vegetation potential, lying dormant as seed in soil, in relation to the fire regime can provide important clues to future vegetation development.

Fire can have a significant effect on vegetation potential, as many plants in Australia retain seed for long periods of time (Cavanagh, 1980; Auld and O'Connell, 1991) and dormancy-breaking mechanisms released in fire, such as heat and smoke (reviewed in sections 1.5.2 and 1.5.3), can stimulate germination of the below-ground seed. By studying the soil seed bank and its responses in relation to fires and dormancy-breaking cues such as heat and smoke, more information is gained on the below-ground potential vegetation and the differing impacts of the fire regime. The ecology of seed bank dynamics, plus that on the fire response mechanisms of plant species, provide input into fire management planning.

Fire response mechanisms of plant species and their juvenile time periods, have been recognised as vital requirements for predicting the ongoing persistence of plants (Gill, 1975). Noble and Slatyer (1980) defined 'vital attributes' for plant persistence following fires. This involved, at the most fundamental level, the separation of species that regenerate following full crown scorch from vegetative material (resprouters) or seed (seeders) (Gill and Bradstock, 1992). Further vital attributes were defined as the method of persistence following fire, the conditions for establishment and growth to maturity and the timing of critical life stages (Noble and Slatyer, 1980). This information varies between species and through time, but is required for an understanding of species responses to fire. The management of fire to retain plant biodiversity requires information on these aspects. Thus, while our knowledge of the complexity of ecosystem processes remains incomplete and our understanding of the fire regime lacks detail, currently there are biologically-based fire management approaches that synthesise fire ecology and fire management principles.

Biologically-based approaches to fire management for the conservation of plant species (expanded in Section 1.7) are not common. The more traditional focus for fire management has been on prescriptive approaches. These have focused on fire behaviour and fuel management in vegetation, rather than the ecological effects of the fire regime. More recent adaptive management approaches for fire (Bradstock et al., 1995) have demonstrated the potential for an agreed framework for fire management planning for the conservation of plant species and vegetation communities in natural areas. The Bradstock et al. (1995) framework developed fire management guidelines with the specific aim of defining appropriate fire intervals and fire intensities for areas where the primary goal is biological conservation (e.g. NSW NPWS, 1998a; 2000a). Due to a lack of suitable data at an appropriate scale on the responses of plants to fire, as well as aspects of the fire regime, this management framework had not been implemented in the study region. This project aimed to address these gaps, research the fire ecology of Guy Fawkes River National Park (GFRNP) and provide data to implement biologically-based fire management guidelines.

The GFRNP was chosen as the site of this study due to the need for information on the fire ecology of plant species, identified by the local National Parks and Wildlife Service. There was concern that the Park had had a fire regime that threatened the persistence of some plant species. A large fire in the Park in 1994 highlighted the need for more information on specific responses of plant species to aspects of the fire regime. The Park was also large in area and steep in terrain providing the opportunity to assessing mapping techniques and it contained a flora of diverse and varied species. Thus, the requirement for data and information, and the size and nature of the Park made it a suitable location for this research.

The study was undertaken using a 25-year fire history, developed from satellite imagery and existing maps, to provide data on the number of fires and interval between fires. This fire history provided the basis for investigating the ecological aspects of fire, specifically the above and below-ground vegetation, to derive quantitative data on fire and plant interactions. The information derived from these ecological studies was used to demonstrate how fire ecology principles could be incorporated into a practical framework for management guidelines of a conservation area based on biodiversity goals.

1.1.1 Study objectives

The aim of this study was to develop fire management guidelines for the conservation of plant species and vegetation communities in GFRNP, based on quantitative, locally relevant, verifiable and, where relevant, experimental fire ecology data. Experimental fire ecology is defined as the experimental determination of fire responses of extant plants and soil seed banks. At the start of the project, key information requirements relating to fire ecology were identified: the recent fire history, the distribution and composition of present vegetation and 'vital attribute' information on plant responses to fire. These information requirements formed the basis of the first four objectives of the study. The fifth objective was to use the data and any other existing information to develop an adaptive management framework for the conservation of plant species and vegetation communities in GFRNP. This was aimed to demonstrate how ecological principals could be incorporated into practical applied management guidelines. The specific objectives of the study can be summarised as to:

(1) Compile the recent fire history of the study region, specifically in relation to fire frequency and its categories;

(2) Investigate the variation in composition and structure of the present vegetation in relation to fire frequency;

(3) Experimentally contrast the stored soil seed bank in areas subjected to a recent history of low and high fire frequency;

(4) Document the vital attributes of woody plant species in GFRNP;

(5) Synthesise the information into fire management guidelines, in a framework based on thresholds of the fire regime, for future fire management; and

(6) Make recommendations for future research to assist in the continued management of fire in the region.

1.1.2 Thesis outline

The thesis is structured into the four main topic areas: the recent fire history, vegetation responses to fire frequency, experimental fire ecology and fire management guidelines. These topic areas are dealt with in five main data chapters and three supporting chapters. The flow of chapters is outlined in Figure 1.1.

This chapter examines some of the recent theories on vegetation change, succession and disturbance plus related aspects of fire ecology relevant to this study. The focal points of each of the following chapters are then discussed, specifically in relation to the mapping of the fire regime, investigating fire frequency and vegetation, the soil seed bank and fire frequency, compiling vital attributes of species responses to fire and developing fire management guidelines.

Chapter 2 is a brief introduction to the physical location and biophysical characteristics of the study region. The fire history (Chapter 3) provides the context for the present vegetation and experimental fire ecology studies.

The second part of the thesis, the vegetation response to fire frequency (Chapter 4), interprets the present vegetation of the study region in relation to the fire history attributes of number of fires, shortest inter-fire interval and time since last fire. This established the broad patterns and processes of vegetation change due to fire in the study region.

The third part of the thesis (Chapters 5 and 6) experimentally contrasts the present vegetation and soil seed bank of areas of differing fire history. This addresses the question of the potential for regeneration of woody species in areas of high fire frequency. Experimental burning of plants (Chapter 6) adds to the information on species' responses to fire.

The fourth and final part of the thesis (Chapter 7) combines the above information to derive fire thresholds for the plant species and communities in this study for input into fire management guidelines. It demonstrates how this and other studies can be integrated into a framework to derive practical guidelines for the future management of fires in the region.

The thesis concludes with a synthesis of the study, a discussion of the need for future monitoring to enhance our current knowledge on species' responses to fire in an adaptive management framework and the need for future research on plant fire effects.

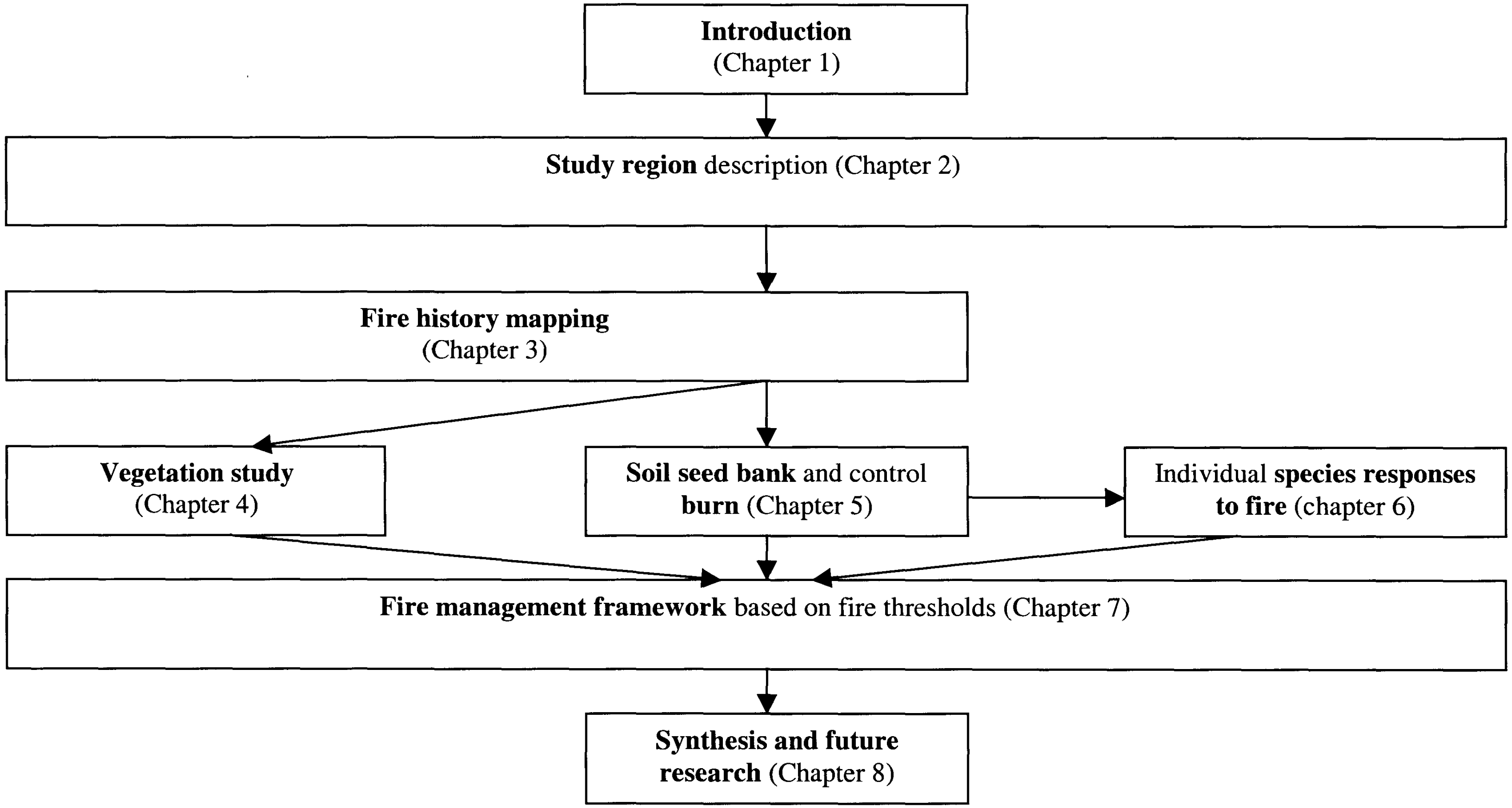

Figure 1.1. Thesis outline and chapter sequence. Except for Chapters 1 and 8, the breadth of the boxes indicate the information flow to following chapters.

1.2 Literature synopsis - Fire and vegetation change

Fire has long been a part of the Australian landscape as a result of natural phenomena such as lightning and some Aboriginal land management practices (Haynes, 1985; Kohen, 1996). Many studies have investigated the response or survival of individual species to one or a small number of fires (e.g. Beadle, 1940; Baird, 1977; Purdie, 1977a; 1977b; Bell and Koch, 1980; Fox, 1988; Hamilton et al., 1991). Only a few studies have addressed longer term (> 20 years) effects of repeated fires on vegetation (e.g. Cary and Morrison, 1995; Morrison et al., 1995a).

Generalisations on the response of vegetation to frequent fires have been reported. (Catling, 1991; 1994) suggested that, in the forests of south eastern Australia, low fire frequency and high-intensity fires enhance the complexity of forest structure by increasing the density and diversity of woody plants in the understorey and midstorey, while high fire frequency and low-intensity fires reduce complexity. He suggested that frequent fire converted a multi-layered understorey to a single-layered structure, with sites burnt frequently having a grassy or herbaceous understorey dominated by monocotyledons and fern species (Catling, 1994). This contrasted with sites burnt less frequently having an understorey of increased shrub abundance. In *Eucalyptus* dominated woodland in Kosciuszko National Park, New South Wales (NSW), high fire frequency, low-intensity fires were found to reduce shrub cover, reduce total biomass of shrubby and herbaceous species and stimulate grass-seed production (Leigh et al., 1987). Similarly, in northern NSW, the frequent burning (at 2-year intervals) of Blackbutt (*Eucalyptus pilularis*) forest changed the understorey from predominantly woody shrubs to grass (Birk and Bridges, 1989).

Where frequent fire is coupled with grazing, woody understorey has been found to change significantly in composition (Henderson and Keith, 2002). In forests managed for timber and livestock production, burning and grazing impacts were investigated and while statistically inseparable, the increased disturbance caused a reduction in shrub and litter cover and an increase in groundcover (Smith et al., 1992). Evidence is increasingly demonstrating that any one fire regime only favours a subset of the potential plant species that could occur at a site (Gill and Bradstock, 1995). These studies support the hypothesis that different fire frequencies will favour particular vegetation types, with high fire frequencies leading to grass-dominated vegetation and low fire frequency promoting rainforest (Figure 1.2). Chapter 4 examines the evidence for this hypothesis in relation to the vegetation of the GFRNP.

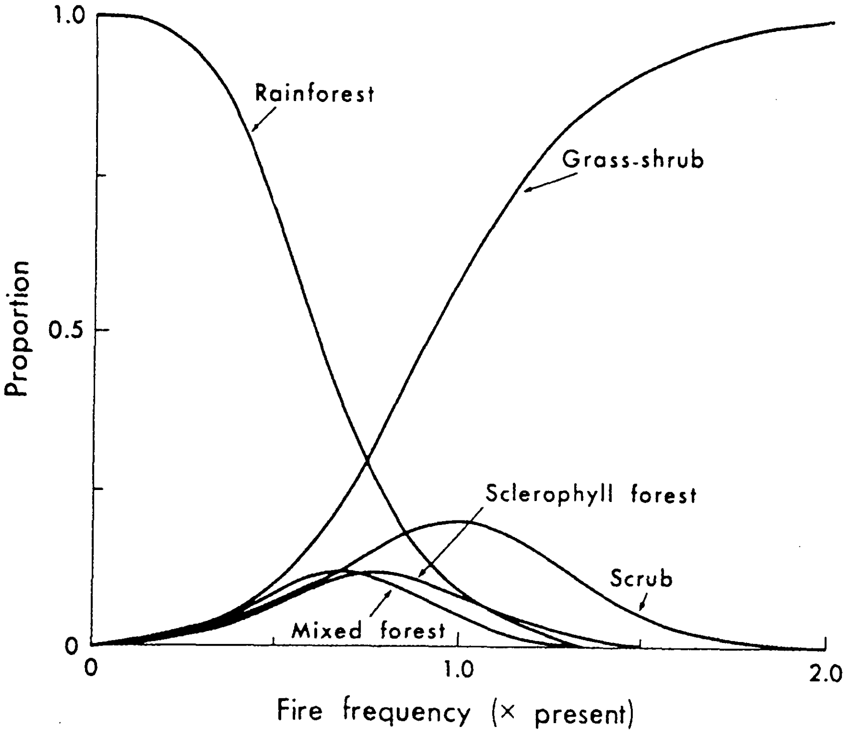

Figure 1.2 Suggested proportions of vegetation types under different fire regimes (Taken from Noble and Slatyer, 1981).

1.2.1 Succession

Fire as a disturbance mechanism is inextricably linked with plant succession and any study of vegetation dynamics must consider both succession and disturbance (Peet, 1992). Succession is the change in vegetation composition over time in response to external change (McCook, 1994). The development of theories of succession date from the early 1900s, which is surprising considering their significance to an understanding of vegetation dynamics. The early theories of succession were grounded in the work and observations of Cowles (1899). He studied the development of vegetation on sand dunes in Lake Michigan and observed some of the basic principles of primary succession. Clements (1904; 1916) integrated these and other observations into one theoretical framework. The Clements theory of succession was based on the concepts of equilibrium, stability and climax. Succession (vegetation change) was thought to progress towards a stable, climax vegetation type in equilibrium with the regional climate. A scheme summarising succession progressed from nudation (the creation of bare or partially bare areas by disturbance that initiates succession), migration (the arrival of organisms at the site), ecesis (the establishment of organisms at the site), competition (the interaction of organisms at the site), reaction (the modification of the site by the organisms inducing change relative to the species' ability to establish and survive) and finally to stabilisation (the development of a stable, climax vegetation) (Glenn-Lewin et al., 1992).

Critics of the Clements theory of succession (Gleason (1917) cited in Glenn-Lewin et al. (1992)) stressed the role of individual species within the vegetation community, and the role of disturbance events (Gleason, 1927). The concept of a climax vegetation community was also criticised as other, often non-climatic factors, were considered part of the process of vegetation development before reaching a climax community (Tansley, 1935).

By the early 1970s, a differing successional paradigm had been accepted. This recognised that climate and vegetation were not always in equilibrium, that disturbance was part of the succession process and the combined responses of many species, through individual characteristics and life history attributes, determined successional sequences (e.g. Pickett, 1976; Peet and Christensen, 1980; Tilman, 1985; Pickett et al., 1987). Thus a more mechanistic approach to succession was advocated.

Glenn-Lewin and van der Maarel (1992) summarised 'theories' of succession under four main approaches: 1) progression and retrogression, 2) primary and secondary succession, 3) autogenic and allogenic and 4) pathways. Progression implies a forward transition to a mature, stable, climax community as envisaged by Clements (1904; 1916). In contrast, retrogression is the reverse, a movement towards an earlier state of fewer species with less community productivity. Woodwell (1970) used the example of the impact of pollution on various ecosystems as an example of retrogressive succession.

The concepts of primary and secondary succession are based on the severity of the disturbance. Primary succession is identified as vegetation development on newly formed or exposed substrates where disturbance removes all previous biotic material. The redevelopment of vegetation on substrate where some prior biotic material remains, defines secondary succession (Purdie and Slatyer, 1976). There are numerous examples of primary succession on seashores (Cowles, 1899), following land slips (Guariguata, 1990), mining (Wagner et al., 1978) and many other areas (see Glenn-Lewin and van der Maarel (1992) for an extensive list). However fire as a disturbance mechanism is mainly associated with secondary succession as biota usually remains at the site following the burn.

The theories of autogenic and allogenic succession relate to the internal, self-modifying change associated with succession. Autogenic successions are internal processes of successional change, whereas external processes drive allogenic successions.

The concept of successional pathways denotes succession as proceeding by various options that differ according to the nature of the disturbance and type of vegetation. Connell and Slatyer (1977) synthesised many of the theories of succession into three main types of pathways. The first is the 'facilitation pathway' where early successional species modify their environment and facilitate the establishment of later successional species. This is essentially the Clements model of relay floristic composition (Pickett et al., 1987). The second is the 'tolerance pathway' where species that can tolerate the initial environmental conditions can establish and grow to maturity, due to their life history traits. The third is the 'inhibition pathway' where initial species at the site regulate the succession so later species cannot grow to maturity in the presence of early successional species.

The tolerance and inhibition pathways of Connell and Slatyer (1977) emphasise the importance of the initial floristic composition immediately following disturbance. The 'initial floristic composition model' proposed by Egler (1954) suggests that the composition of a vegetation community following disturbance is directly related to the composition of species present immediately following disturbance. This model was based on the life history characteristics of individual species and their dominance over time. The initial floristic composition model has been found to apply in a number of dry sclerophyll communities in Australia following fire (Bell and Koch, 1980).

The study of fire as a disturbance mechanism has generated its own coterie of succession models. In the early 1980s the emerging concepts of succession that built on individual species' attributes, rather than community properties of an ecosystem, resulted in the development of a framework for understanding vegetation communities' response to fire (Noble and Slatyer, 1980). Their 'vital attributes' scheme was based on three main plant attributes: (1) method of arrival or persistence of a species at a site, (2) ability to establish and grow to maturity in the community, and (3) time taken to reach critical life stages. This model provided both a framework for succession in disturbance prone environments, and a functional framework where individual traits could be grouped functionally for species demonstrating the same response in relation to the disturbance. By linking succession to a workable framework, Noble and Slatyer (1980) demonstrated the potential to develop a management framework for the vegetation community based on individual plant traits.

1.2.2 Disturbance and succession

Externally induced change in vegetation often comes in the form of a disturbance and therefore disturbance and succession are inextricably linked (Glenn-Lewin and van der Maarel, 1992). The succession of a community can be halted, sometimes temporarily, by the influence of disturbance. Disturbance as a determinant of vegetation change is hard to define due to variation in the spatial and temporal scale of disturbance and in the type of disturbance. These issues have been discussed by a number of authors (e.g. Pickett et al., 1987; Peet, 1992; White and Harrod, 1997). Disturbance has been defined as any relatively discrete event in time that disrupts ecosystem, community or population structure and changes resources, substrate availability or the physical environment (White and Pickett, 1985). Invariably disturbance will vary with spatial and temporal scale. The distinction between community regeneration and succession-initiating disturbance depends on the scale of investigation (Peet, 1992). For example, the death of a tree in a forest is a disturbance that locally redefines the environment for the community of tree seedlings, herbs and bryophytes beneath the tree, but it is only part of the normal regeneration process for the community of trees (Peet, 1992).

Disturbances of many types are part of the ecological and evolutionary setting of all ecosystems and are sources of variation in ecosystem structure and composition (White, 1979). Disturbance will have positive and negative effects on any species in any environment. Some species will exploit the post-disturbance conditions and other species will be unable to recover and survive, with all grades between these extremes.

The impact of the disturbance will vary in relation to the frequency of its occurrence, its spatial extent, particularly in relation to the organism being disturbed, the type of disturbance, the intensity of disturbance and the interval between successive disturbances. These components together define the disturbance regime.

1.2.3 Fire as a disturbance

The disturbance regime with its components of frequency, severity, size, timing and type, affects successional patterns and species distribution at a landscape scale (Menges and Hawkes, 1998). Fire is one of many types of disturbance and the fire regime comprises the frequency, intensity, season and type of fire (Gill, 1975), as defined at any point in the landscape. These components combine to define the impact that fire will have on a plant or ecosystem over time. In the components of the fire regime (Gill, 1975), 'fire type' is the division of above and below-ground (peat) fires. Almost all fires in mainland Australia are above-ground vegetation fires. This study focused on the fire regime as defined by Gill (1975) and primarily the aspects of frequency and intensity. Other aspects of fire, such as patchiness, that do not comprise the fire regime but can influence vegetation community development, were not directly researched in this study, but will be discussed where relevant.

Fire frequency can be subdivided into several categories; the number of fires, the range of intervals between fires (the inter-fire interval) and the time since last fire. Fire frequency is important to the long-term survival of plant species as plants vary in the length of time taken to reach reproductive maturity. By interrupting the plant reproductive cycle, frequent fires with short inter-fire intervals can lead to a decline in some plant species (Bradstock et al., 1995). The different categories of fire frequency, particularly inter-fire interval and time since last fire, have been shown to have significant but varying impacts on plant communities (Cary and Morrison, 1995; Morrison et al., 1995a).

Fire intensity is a measure of the heat released by the fire front. Poor germination of some species following fire, especially in the Fabaceae, has been linked to low intensity burns (Shea et al., 1979). Some species require higher intensity fires to crack hard seedcoats or break dormancy in some other way for germination to commence (Auld and O'Connell, 1991). Fire intensity is also a significant factor in plant survival and regeneration. Higher intensity fires can kill plants outright (e.g. Haidinger and Keeley, 1992), especially those not large enough to have sufficient protective tissue.

Fire season is the season of occurrence of fires. Fire season has the dual effect of changing the behaviour of fire as well as influencing plant reproduction and vegetative phenology. A study of seed bank dynamics and their seasonality for *Hakea sericea* and *Petrophile sessilis* showed variation throughout the year in seed stores, suggesting that a varied season of prescribed burning would optimise diversity (Brown and Whelan, 1999). However, studies on the impact of season of burn are not common and other factors such as site and yearly seasonal conditions can have a greater impact on post-fire germination than the season of the burn (Whelan and York, 1998).

1.3 Mapping the fire regime

Although knowledge of the fire regime is important for understanding long-term plant survival and persistence, fire history records are inadequate in most regions. Some studies do have fire history data available. These include observational or mapped records, or those determined remotely from satellite imagery. In Switzerland (Tinner et al., 1998) and Canada (Larsen, 1997), yearly records of the spatial extent of fires have been kept and now constitute long-term fire history databases. In Australia, fire records in National Parks around Sydney have been maintained since the 1960s (Benson, 1985) and a recent satellite-based fire history has been developed for Kakadu National Park (Russell-Smith et al., 1997). However, in general, fire histories are not common. Some databases contain gaps in the time sequence or errors in the spatial location of the fires (Rollings and van der Lee, 1995). This unreliability makes their application in ecological studies problematic. If all fire areas were ultimately mapped, the data would provide future researchers with an accurate, consistent fire history. Unfortunately, this is presently not the case so current fire ecology studies require techniques for deriving retrospective fire histories.

1.3.1 Fire frequency

Several data sources have been used to record fire frequency information. They fall into two categories: records from point sources where fire boundaries are extrapolated to larger areas, and records that include full spatial boundaries. The first category includes pollen and charcoal analyses from soil cores and dendrochronological recording. The second includes observational records of mapped fire boundaries recorded on maps or determined from satellite imagery.

Point-source fire information has been compiled in many environments around the world and include soil cores from lakes that have been analysed to detect peaks in pollen and charcoal related to fire activity (Clark, 1983; Larsen and MacDonald, 1998; Tinner et al., 1999). Radiocarbon dating techniques have been used to assign time periods to changes in charcoal density related to fire. Dendrochronological interpretation, the analysis of tree growth rings, has been used to detect basal fire scars or damage in the rings due to fire. This technique was used in Kosciuszko National Park (Banks, 1989) to document an increase in fire frequency from the mid-1800s, which peaked around 1900 and then declined. This was correlated with European land-use in the area. The advantage of these point-based techniques are that they can provide very long fire histories often over hundreds of years. The disadvantages are that the source data are from point localities and need to be extrapolated to other areas of the study region, hence the data quality is variable or unknown over most of the region.

The second category of fire frequency information records boundaries of fires. Mapped fire boundaries are often recorded on maps and saved as hardcopy fire records. Satellite imagery can map fire boundaries with specific satellite bands that detect the electromagnetic reflectance of plant chlorophyll. The sudden decrease in chlorophyll due to the combustion of vegetation in a fire is detected in satellite imagery. A number of satellite systems have been used to record aspects of the fire regime. These include the Advanced Very High Resolution Radiometer (AVHRR) with a pixel size of 1.1 km^2, Landsat Multi-spectral scanner (MSS, pixel size of 57 x 79 m), Landsat Thematic Mapper (TM, pixel size of 30 m) and radar. Data from the AVHRR have been used to detect fire occurrence and 'hot spots' in forest fires (Matson, 1981; Stephens and Matson, 1987; Smith et al., 1998). The daily repeat pass and large pixel size make it appropriate for mapping fires over large areas (Pereira and Setzer, 1993a; Chuvieco and Martin, 1994). Data from the Landsat MSS, collected since 1972, have been used to map fires and post-fire successional changes in vegetation (Richards and Milne, 1984). In Kakadu National Park, Landsat MSS was used to map fires (Graetz, 1990a) and hard-copy Landsat MSS images used to compile a fire history from 1980 to 1994 (Russell-Smith et al., 1997). Other studies have used Landsat TM, with its smaller pixel size for greater accuracy. These data have been used for forest fire and risk mapping (Chuvieco and Congalton, 1989; Maselli et al., 1996) and post-fire vegetation successional analysis (Milne, 1986).

The advantage of using imagery for mapping fires is that it covers large areas and can provide information on landscapes that are inaccessible. Satellite images are available at frequent intervals over the past 25 years and thus can fill gaps in existing records. Aerial photography is available for many areas over a longer history but at much longer intervals between images and smaller areas. A disadvantage of using satellite imagery is that the data are only available from 1972, and so provide only a medium-term fire history. The Kakadu National Park fire study (Russell-Smith et al., 1997) demonstrated the potential to compile a satellite-derived fire history in relatively flat terrain and open-forest where the fires are large. The utility of satellite imagery for mapping fire boundaries has not, prior to this study, been tested under the variable terrain conditions found in parts of south-eastern Australia, along the Great Dividing Range.

1.3.2 Fire intensity

There are a number of methods for estimating fire intensity. These include fire descriptions such as the heat per unit area, total fire energy and flame residence time (Burrows, 1984). Alternatively, fire intensity can be calculated from fire properties such as flame height, rate of spread of the fire front and the fuel load. The Byram fireline intensity equation calculates the fire intensity from measured fuel-load and flame rate-of-spread (Byram, 1959). Fire intensity is defined as:

$$I = Hwr \qquad \ldots (1.1)$$

where I is the fireline intensity (kJ m^{-1} or kWm^{-1}), H is the heat yield of the fuel (kJg^{-1}), w is the weight of available fuel (gm^{-2}) and r is the rate of fire spread (m s^{-1}) (van Wilgen, 1986). The required inputs of fuel load and rate-of-spread can be difficult and sometimes dangerous to measure in large high-intensity fires. In addition, this information is not available for retrospective studies.

For plant survival, of greater significance than fire intensity is the residence time of heat, as it is related to the amount of heat transferred into the soil (Bradstock and Auld, 1995) and the total loss of biomass. An alternative term, fire severity, has been adopted that integrates the physical and biological changes at a site due to fire (White et al., 1996). Fire severity is related to factors such as the fuel, meteorological conditions and vegetation (Gill, 1981). While fire intensity is a measure of the heat output as energy, fire severity is a relative measure of the degree of impact of the fire on vegetation.

Satellite imagery has been used to map fire severity as it detects the relative loss of the vegetation canopy and exposure of the soil. In the United States, Jakubauskas et al. (1990) used Landsat MSS and investigated the differing burn severities related to differing vegetation types in a Michigan pine forest. Turner et al. (1994) mapped fire severity over Yellowstone National

Park using field calibration data gathered after a fire to classify Landsat TM data into burn severity categories. White et al. (1996) mapped burn severity in a 1988 fire over two National Parks in Montana USA, using predominantly Landsat TM Band 7 and the normalised difference vegetation index (NDVI). In Australia, Milne (1986) identified the utility of band 5 and band 7 for deriving fire severity classes in the Blue Mountains region of eastern Australia. The study, however, lacked adequate ground-truth to evaluate the severity classes. In GFRNP, Rollings and van der Lee (1995) used principal components analysis and mapped varying fire severity. Likewise, their study lacked ground validation. Clearly there is scope for testing and validating methods to remotely map fire severity in *Eucalyptus*-dominated vegetation in Australia, especially in terrain where access is difficult and topographic variation can confound the interpretation of remotely sensed electromagnetic data.

1.3.3 Fire season

Fire season is the timing of the fire and has the dual effect of changing the behaviour of fire as well as influencing plant phenology. Fire behaviour is closely linked to fuel load (equation 1.1) and fuel moisture. Fire season is the timing of the fire in relation to the reproductive period of a plant's annual cycle. If a fire occurs when plants are flowering or prior to seed maturation, it reduces the seeds available for future regeneration of the species. Repeated fires in the same fire season can thus lead to a decline in the long-term persistence of species that flower at that time.

When fire history data are collected, the date of burn is generally recorded for the fire record. However, like other components of the fire regime, season of burn will be lacking where gaps in the fire history occur. When records have not been kept, satellite imagery can be used to record fire occurrence from the timing of the image pass. In Kakadu National Park, the satellite imagery used to map fire history was obtained at regular intervals throughout the fire season. The season of occurrence of each fire was mapped. This enabled a seasonal analysis of fire occurrence that highlighted the majority of fires were occurring in the late dry season and were larger and of higher intensity when compared to early-season fires (Graetz, 1990a; Russell-Smith et al., 1997). This demonstrated the utility of seasonal fire analyses.

1.4 Terminology - fire history and vegetation

Throughout the thesis the following terminology will be used to refer to the fire regime and its component aspects. 'Fire regime' will be used to refer to all components comprising the frequency, intensity, season and type of fire (Gill, 1975). A number of aspects of fire frequency are investigated and will be referred to individually as: number of fires (NOF) being the number of fires to have occurred in the recent (25-year) history, and shortest inter-fire interval (SIFI) being the shortest period in years between any two fires in the recent fire history. Time since last fire (TSLF) is a related aspect of fire frequency, and will be incorporated in the categories of fire frequency and is defined as the years since the last fire occurred. These acronyms are summarised in Appendix 1.1 and are used throughout the thesis.

For vegetation, 'structure' will refer to the community structure as defined by structural formation classes qualified by height classes (McDonald et al., 1990) and 'plant structure' will refer to the structure of the individual plant based on height and diameter. The classification of vegetation structural formation classes such as open forest and forest are as defined by McDonald et al. (1990).

1.5 Vegetation and fire frequency - Australian studies

There are numerous fire-related studies of Australian vegetation. Many focus on a particular habitat type and the specific impacts of fire. These include studies in differing habitats such as heath (Posamentier et al., 1981; Keith and Bradstock, 1994; Adams et al., 1994) or mallee (Noble et al., 1980; Bradstock, 1990). These studies have highlighted particular characteristics of communities, such as the regeneration requirements for high intensity fires in heath, or increased species richness in the seasons after fire followed by a gradual decline in richness through time (e.g. Specht et al., 1957; Specht and Specht, 1989). Studies in heath communities have also highlighted the vulnerability to repeated low-intensity burning of species that rely solely on seed for regeneration (obligate seeding species).

Fire ecology studies in Australia have tended to focus on one or two species of particular interest in the community, such as 'indicator' species representing the fire response of other species in the community. Bradstock and Myerscough (1988) compared two resprouting species to identify the age at which plants became fire tolerant. This work complements studies of seeder species, particularly the time to reproductive maturity (Enright et al., 1998b).

These studies of particular habitats and species have derived a broad collection of information on plant responses to fire that have contributed to the development of a national fire response database (Gill and Bradstock, 1992). However, there remain many locations and species for which studies have not been undertaken and for which information is not available.

Some studies have investigated the effects of one or two fires, particularly comparing time since last fire on plant regeneration (Purdie, 1977a; Russell and Parsons, 1978; Curtis, 1998). There is growing recognition that population responses to fire should be examined over a sequence of fires, not just a single fire (Whelan, 1995). Thus, to study the effects of fire on ecosystem composition and structure, one needs to consider the impacts of successive fires (i.e. the fire regime).

Cary and Morrison (1995) and Morrison et al. (1995a) undertook one of the more recent studies using a sequence of many fires and the combined effects of frequency, inter-fire interval and time since fire to study changes in floristic composition. They found that fire frequency accounted for approximately 60% of the floristic variation in the recent (< 30 years) fire history and that TSLF and inter-fire interval had significant but differing effects on the floristic composition. Habitat complexity has also been modelled with an 18-year fire history, demonstrating that time since last fire is highly significant for forest structure (Coops and Catling, 2000). These studies demonstrate the importance of studying the impact of a regime of fires. The characteristics of the disturbance can dictate the species composition and richness of the community as a function of time since the last disturbance and the nature of the disturbance. Increasingly, fire ecology data will be required in the context of a regime of fires, preferably for as long a fire history as possible, and more than just the last one or two fires. The growing awareness of the importance of components of the fire regime including fire frequency and inter-fire interval point to the need for further studies dealing with these variables to contribute to an increased understanding of fire-induced vegetation dynamics. The limitation is that in most areas, the data on the frequency and intervals between fires are not readily available.

1.6 Fire and germination - seed banks and germination treatments

While vegetation studies describe the patterns in present above-ground vegetation, the potential for vegetation change, particularly in response to disturbance events, also depend on the seeds in the soil. The soil seed bank has great importance in plant population dynamics (Whelan, 1995). The fate of many plant populations can be determined by the nature and patterns of mortality manifest in its seeds (Cavers, 1983).

1.6.1 Seed germination and dormancy

Most fire-prone plant communities contain species that possess innate seed dormancy. Dormancy can be due to the physical or chemical microenvironment of the seed (Whelan, 1995). Dormant seeds in the soil require the appropriate environmental conditions to break dormancy and initiate germination. These may include various combinations of temperature, light, moisture, scarification or stimulation from chemical compounds such as smoke, nitrogen oxides or ethylene. Other ‘serotinous’ species store seed in tough woody capsules (e.g. *Hakea* and *Banksia* species). They generally require heat from a fire to open the woody capsule for seed release, although studies have shown this varies among *Banksia* species (Whelan et al., 1998). Some plant species have no innate dormancy: they flower and release seeds that germinate immediately, decompose or are eaten. These species do not develop a seed bank.

1.6.2 Heat

Temperature is probably the most important environmental factor affecting the permeability of the seed coat and entry of water into the seed (Leck et al., 1989). Heat weakens hard seed coats, particularly the cuticle and other localised cell regions like the hilum or strophiole, allowing imbibition and germination (Keeley and Fotheringham, 1997). Once the coat is permeable to water, germination can proceed (Cavanagh, 1980). The role of heat in breaking seed dormancy has been determined for a number of plant families (e.g. Fabaceae, Lamiaceae, Rhamnaceae) in different fire-prone environments throughout the world (Keeley and Bond, 1997).

In relation to Australian species, research has established the importance of heat for plant germination, especially for the hard-seeded *Acacia* species and others in the Fabaceae (e.g. Shea et al., 1979; Auld, 1986a; Auld and O'Connell, 1991). In Western Australia, Shea et al. (1979) studied the abundance of leguminous seeds in relation to high intensity fires, noting that broad-scale regeneration of legumes followed high intensity fires. Portlock et al. (1990) studied *Acacia pulchella* and found germination rose to above 60% when seeds were exposed to temperatures between 55-60°C, compared to 4% with no heat treatment. For the Sydney flora, Auld (1986b) documented heat effects in *Acacia suaveolens* and found the optimal temperature for germination to be between 60°C and 80°C. Similarly, Auld and O'Connell (1991) studied 35 species of Fabaceae and found seed dormancy to be broken in over half the species at a temperature above 60°C and in all species at exposures above 80°C. In northern NSW there are a number of species (*Acacia* spp., *Kennedia rubicunda*, *Dodonaea triquetra* and *Phytolacca octandra*) that require heat to stimulate germination (Floyd, 1976).

1.6.3 Smoke

Since the discovery in South Africa of the increased seed germination of *Audouinia capitata* with the addition of smoke (de Lange and Boucher, 1990), a number of studies have tested the effects of smoke, or smoke derivatives, on germination (Roche et al., 1997; Keeley and Fotheringham, 1998). In the South African study, de Lange and Boucher (1990) investigated the effects of ethrel, GA and smoke on seed germination and found smoke produced the highest germination rates. In Western Australia, Dixson et al. (1995) found smoke had a positive influence on 45 out of 94 native species. Several studies have used both heat and smoke for seed bank analysis of bauxite mine rehabilitation sites (Koch et al., 1996; Ward et al., 1997;

Grant and Koch, 1997) and in the Great Basin scrub of Utah, smoke was found to trigger germination of some species (Baldwin et al., 1994).

The active chemical within smoke that causes germination to occur is still unknown. Keeley (1993) found the South African fynbos fire-lily (*Cyrtanthus ventricosus*) was stimulated to flower by smoke but not ethylene. The combustion of fuels in a fire releases 71 compounds, none of which has been found to stimulate germination in its pure form (Baldwin et al., 1994). Keeley and Fotheringham (1997) investigated the components of smoke that cause germination. They found nitrogen oxide (a product of combustion of fuels) triggered germination in a number of species, particularly *Emmenanthe penduliflora.*

1.6.4 Gibberellic acid

Gibberellic acid (GA) is a growth hormone that stimulates germination. Moore et al. (1998) summarised its role in the germination process: imbibition (the absorption of water into the internal surface of the seed); gibberellins then stimulate genes in the aleurone layer (protein rich tissue, two to four cells thick, in the outer endosperm, just inside the seed coat), which promote the production of an enzyme called alpha-amylase. Alpha-amylase is a catalyst for the conversion of starch to sugar, the energy source for seedling growth. GA weakens the endosperm cells around the radicle tip enabling germination.

The majority of work with GA is with herbaceous and forb species and was found to be particularly successful in those species requiring light for germination (Plummer and Bell, 1995). Bunker (1994) investigated scarification, light and GA in the germination of Asteraceae. The study found that GA promotes germination, breaks embryo dormancy and overcomes inhibitions imposed by the testa and pericarp in various Australian native daisies. For eight of the 17 species studied, a pre-sowing treatment of GA was recommended. GA was found to improve germination of two *Schoenia* species, but inhibited germination in *Rhodanthe.* An upper limit to the appropriate level of GA application was found, too much inhibiting germination (Plummer and Bell, 1995). In Western Australian understorey species, GA was found to overcome the inhibition resulting from exposure to light (Bell et al., 1995). However, although GA could overcome dormancy in some species, it was found to limit germination in *Brachyscome iberidifolia* (Bunker, 1994).

For woody shrub and tree species, studies have used GA often in association with heat and smoke treatments. An early study by Bachelard (1967) found GA assisted the germination of *Eucalyptus pauciflora.* A number of light-sensitive *Eucalyptus* species were tested and GA was found most effective in stimulating the germination of light-sensitive seeds. *Eucalyptus pauciflora* normally requires a cold (4-5°C) period of approximately four weeks to induce germination; the application of GA was found to overcome this cold requirement. GA promoted positive germination in *E. regnans, E. dumosa, E. lindleyana* and *E. delegatensis* but made no difference to *E. obliqua* and *E. fastigata.* More recently, Bell et al. (1995) tested the effects of temperature, light and GA on the germination of 43 native western Australian species of all structural types. The seeds were tested for viability using tetrazolium chloride, and for germination under two light and temperature conditions plus the addition of GA. No combination of treatments resulted in germination of all viable seed. The greatest germination rate was 71%. The dominant *Eucalyptus* tree species (*Eucalyptus calophylla, E. diversicolor, E. erythrocorys, E. gomphocephala* and *E. patens*) were indifferent to any of the conditions of temperature, light and GA. For *Allocasuarina campestris, Regelia ciliata, Xanthorrhoea gracilis* and *X. preissii,* GA resulted in higher germination.

The germination response to GA can vary between species within the same genus. Sukhvibul and Considine (1994) studied the germination requirements of Kangaroo paws (*Anigozanthos manglesii*) and other *Anigozanthos* species. They found that *A. flavidus* showed no response to GA, whereas *A. viridis* and *A. humilis* showed a small germination response. Although germination of *A. manglesii* was increased using GA, germination never exceeded 50%. Willis and Groves (1991) examined the germination of seven native forbs under varying temperature and light conditions with the addition of GA. Of these species, GA was found to have no effect on *Helichrysum apiculatum* and *Wahlenbergia stricta,* but increased germination in *Stylidium graminifolium.* The addition of GA to one species, *Vittadinia muelleri,* dramatically decreased germination from 77% in the controls to 33%.

Other dormancy-breaking mechanisms have been assessed. Bell (1993) investigated light regimes in relation to eight native Western Australian species and found increased germination with red light.

1.7 Fire response mechanisms

Attributes resulting in plant survival or mortality following fire have been categorised in a number of ways. Early studies (Jepson, 1922; Horton and Kraebel, 1955) identified two adaptive strategies in American chaparral communities; those plants that are killed by fire but produced large amounts of seed, and those that survived the fire and resprouted. These two adaptive strategies were also identified in Australia (Gill, 1975; 1981). Noble and Slatyer (1980) expanded this approach to encompass vital attributes, identifying 14 life stage parameters for plant persistence. Gill and Bradstock (1992) incorporated the available Australian information into a National Fire Response Database of plant responses to fire for use in fire management. They categorised species as either 'seeders' (mature plants subject to 100% leaf scorch from fire die) or 'resprouters' (mature plants subject to 100% canopy scorch survive). These categories have been identified as significant for the long-term persistence of species at a site. Species that regenerate from seed are more susceptible to a decline in density should fire occur prior to the time that plants reach reproductive maturity (Bradstock et al., 1995). Adequate time is required for both the seeder species to re-establish seed stores and for the resprouting species to become fire-tolerant and little information is known for these periods for most plant species and populations.

1.8 Fire management and conservation

Fire has long been used as a land management tool, but only more recently (circa. 40-50 years) as a fire management tool for nature conservation. In conservation areas there is the added requirement to manage fuel loads and fire threats with the balance of nature conservation of plant and animal species. Approaches to fire management on nature conservation lands have been primarily divided into prescriptive and adaptive fire management approaches (Bradstock, 2001).

1.8.1 Prescriptive fire management

Prescriptive fire management is the use of a formula or recipe to control fire (Bradstock, 2001) and is the more traditional approach to managing fire. It includes techniques such as fire suppression, mosaic burning and "event" management.

Fire suppression adopts the premise that all fire is extinguished. This was a common approach in the early part of the twentieth century in Australia (Whelan, 1995), the USA (Jolly, 1995) and Canada (Woodley, 1995). It was also more recently suggested as a management approach for Australian conservation reserves (Good, 1981). Fire suppression can result in high fuel loads, increasing the risk of large and extensive high-intensity fires and can result in significant changes in forest structure (Parsons and Botti, 1996). A move away from this approach began when high-intensity fires were found to cause large economic losses particularly to forestry operations often surrounding the conservation area, negating the original aim of the management approach that was to conserve timber resources (Whelan, 1995). An adaptation of fire suppression, implemented in Sequoia and Kings Canyon National Park in 1968, was 'natural fire management' based on the suppression of human-ignited fires, but leaving fires ignited by natural causes, such as lightning, to burn. This approach required substantial commitment, and from 1988 this approach was revised to include management-ignited prescribed fire (Kilgore and Nichols, 1995). The combination of fire suppression and managed burns for ecological purposes is now used as an integrated fire management approach. Examples of this approach in Australia are found in the Mallee Parks of Western Victoria

(Victorian Department of Conservation and Natural Resources, 1995) and the Tasmanian wilderness and world heritage area (Tasmania Parks and Wildlife Service, 1999).

Mosaic burning aims to subdivide the landscape into compartments that are burnt at varying times, providing a spatial "mosaic" of individual fire events to maximise abundance of a range of species. Diversity in the fire regime provides opportunities for the majority of species to survive fire. The mosaic burning approach, also called the patch burn strategy, has the benefit of varying the application of fire over a landscape and thus, breaking the pattern of fuel. Mosaic burning has been adopted as a management strategy in Uluru National Park to manage predominantly Spinifex grasslands (Saxon, 1984). However, Bradstock et al. (1995) outlined three problems with the approach (1) the lack of attention to non-target species, (2) unexpected outcomes for target species due to the interactions with non-target species, and (3) the difficulty of imposing target regimes of fire in landscapes prone to stochastic events of unplanned fire. These problems highlight the overall lack of a focused conservation aim in mosaic burning, that the application of fire is not targeted to known species conservation goals and the lack of spatial and temporal variability in all aspects of the fire regime.

"Event" management aims to protect biodiversity from intense wildfires, recognised as unique "events". Generally event management recognises the perceived destruction of large, high-intensity fires and implements management strategies to adapt these threats (Bradstock, 2001). "Event" management can also focus on specific elements of biodiversity such as "fire-sensitive" species or the management of single species or small groups of species, generally rare and threatened in the community. Event management focuses on often singular and restrictive conservation goals, without considering the range of species in the community or the other aspects of the fire regime, such as intensity and season of burn. Strict adherence to a narrow range of fire intervals, based only on a restricted suite of species can lower diversity in other species. The importance of varying the fire regime for ensuring continued species coexistence has been highlighted by a number of authors (Cowling, 1987; Hobbs and Atkins, 1988; Howe, 1994; Williams and Gill, 1995).

1.8.2 Adaptive fire management

Adaptive fire management recognises that conditions and features of ecosystems will vary and that no single formula or prescription can be applied across many areas (Bradstock, 2001). Adaptive management of fire is based upon the unique conditions of each area and adaptations are made through time when conditions change or when additional information is available. Most importantly "the fire regime requirements of the biota themselves, within the context of differing landscapes must drive the choice of options for management actions at any given time" (Bradstock, 2001). The elements of an adaptive system have been defined as: (1) having a biodiversity objective that is neither a platitude or surrogate, (2) knowledge of the distribution and condition of biodiversity, (3) knowledge of attributes and responses of biodiversity to fire regimes in a pragmatic form, (4) assessment of landscape condition (i.e. fire regimes), (5) regular (e.g. annual) and ongoing evaluation of condition of fire regimes and biodiversity with reference to the biodiversity objective, (6) consequent adjustment of strategies and actions, and (7) evaluation of performance in terms of both resultant fire regimes and changes to biodiversity (Gill et al., 2001).

The need to adopt ecologically-based approaches to fire management are increasingly being recognized (Andersen, 1999). An area that has combined a number of management approaches is Kakadu National Park where there is an aim to maintain the traditional aboriginal burning regimes, but with specific objectives such as mosaic burning in the early dry season to break fuel patterns and to protect fire-sensitive heath and rainforest communities in areas of the Park (Russell-Smith, 1995). Early indications are this control of the fire regime is providing effective and conservative use of fire as a management tool. In south-west Tasmania, options for fire management strategies have been identified and an integrated strategy of broad-scale ecosystem-management burns with some hazard-reduction burning and fire suppression are considered the appropriate approach for maintaining ecological values in button-grass moorlands (Marsden-Smedley and Kirkpatrick, 2000).

Bradstock et al. (1995) proposed a management framework for using the fire response of functional groups of plants, to define thresholds of fire intervals to be used as guidelines for fire management to conserve plant species. The development of this framework was based on the adaptive management framework and was possible due to the derivation of a considerable amount of species response information in the heaths and shrublands of the Sydney sandstone. This enabled the identification of species that responded in a functionally similar way to other species in the community. The framework recognised that management of vegetation communities needed to consider the amalgamated responses of many plant species.

As an ecological paradigm, the fire interval threshold approach recognised that community responses to fire were built on the individual responses of plants, which paralleled the current successional theories. The threshold approach reflected these successional theories and worked towards developing the concepts into an applied management framework. The Bradstock et al. (1995) schema described in Figure 1.3, outlined an approach to flexible fire management emphasising feedback (as monitoring) between the fire regime and the biota plus the iterative and flexibility of an adaptive approach based on the existing knowledge. It led to a framework for developing fire management guidelines based on biological principals. The guidelines (Bradstock et al., 1995), discussed in more detail in Chapter 7, were based on identifying life-history traits of plants and applying these to functionally similar plant groups. The life-history traits included the mode of regeneration following disturbance, length of juvenile period, longevity, mode of seed dispersal and seed bank longevity (Noble and Slatyer, 1980; van Wilgen and Forsyth, 1992; Whelan, 1995). An example of fire guidelines for coastal heaths and associated shrublands and woodlands is shown in Table 1.1. demonstrating the targeted but flexible nature of the guidelines.

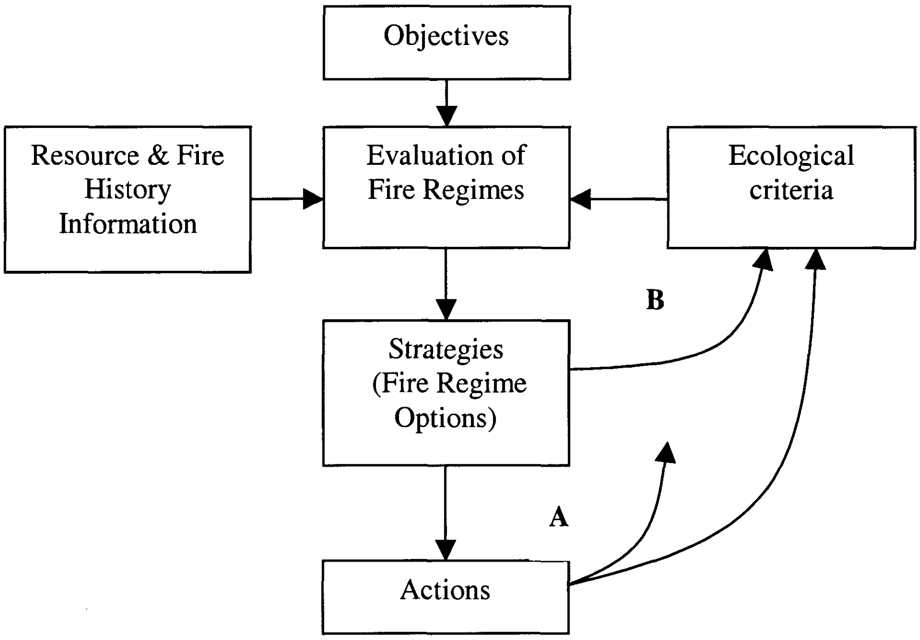

Figure 1.3. An outline of the way in which fire management for conservation can be planned in a flexible manner. Pathways denoted by A and B involves independent steps in the assessment of the outcome of planned actions. Path A assesses how fire management actions influence fire regimes. Path B assesses how fire regimes affect biota and whether these effects are in accordance with predictions based on existing knowledge (taken from Bradstock et al., 1995).

Table 1.1. Fire management guidelines for coastal heaths and associated shrublands and woodlands (taken from Bradstock et al., 1995).

A decline in populations of plant species can be expected when:

- there are more than two consecutive fires less than 6-8 years apart (fire-sensitive shrubs decline);
- intervals between fires exceed 30 years (herbs and shrubs with short-lived individuals and seed banks decline);
- three or more consecutive fires occur at intervals of 15-30 years (sub-dominant herbs and shrubs decline);
- more than two consecutive fires occur which consume less than 8-10 t ha^{-1} of surface fuel (species with heat-stimulated seed banks in the soil decline).

1.8.3 Current NSW NPWS fire management

In NSW, the management of fire in conservation reserves has been developed to include the goals of adaptive fire management for NSW National Parks and Wildlife Service (NPWS) managed land. The recent NPWS fire management policy has reiterated that the Service will manage fire based on the principals of adaptive fire management (NSW NPWS, 2001). Recent fire management in the NPWS has aimed to develop fire management plans for all reserves under the NSW NPWS jurisdiction. The fire management plans include a biodiversity conservation goal that complements the primary biodiversity conservation goal of the Service, to avoid the extinction of any native species known to occur naturally within management areas (NSW NPWS, 1996; 2000b). In GFRNP the current fire management has been based on the latest fire management plan (NSW NPWS, 1998b) that identified zones for conservation and zones for burning. Some recent controlled burns hve been undertaken with the aim of breaking fuel loads at strategic locations throughout the Park (Greg Watts, pers. comm.).

In this study, the Bradstock et al. (1995) framework was adopted as the approach to test as it specifically addressed biological criteria in fire management goals. The problem, however, was the lack of fire ecology data specific to NPWS managed land to address these biodiversity goals. In northern NSW, and specifically GFRNP, some of the ecological principles of fire had not been tested and fire response information on most plant species and populations was not available. It was from this premise that this study arose and from this baseline that the aims of this study were formulated.

CHAPTER 2

2 Guy Fawkes River National Park - the study region

I love a sunburnt country,
A land of sweeping plains,
Of rugged mountain ranges,
Of droughts and flooding rains.
I love her far horizons,
I love her jewel-sea,
Her beauty and her terror,
This wide brown land for me!

-- Dorothea Mackellar

2.1 Location

2.1.1 *Study region*

The study was undertaken on the eastern edge of the New England Tablelands in northern NSW, Australia. The area includes GFRNP and surrounding land. The area is located approximately 500 km north of Sydney and approximately 80 km inland from the closest coastal town, Coffs Harbour (Figure 2.1). The surrounding towns are Ebor to the south and Glen Innes to the west.

The study region comprises both National Park and private land. The original park area was gazetted as National Park in 1972 under the management of the NSW NPWS. In 1992 most of the Park and surrounding area was identified as having significant wilderness qualities, and was nominated for listing as a wilderness area NSW NPWS (1992). Since that time Crown leasehold and freehold land surrounding the Park has been purchased by the NSW State Government and added to the Park, significantly increasing its area. The boundaries of the nominated wilderness area and National Park (as at August 1999) were combined and whichever was greatest, defined the study region (Figure 2.1). Figure 2.2 shows the separate boundaries of the nominated wilderness and the National Park areas. The area of the study region defined by the nominated wilderness area is 121 316 ha (identified under the Wilderness Act 1987).

2.1.2 *Topography*

The study region is steep and rugged (Figure 2.3). Recognised as Northern Tablelands gorge country, there are sharp variations in elevation. At Ebor Falls in the south, where the Guy Fawkes River descends from the Tablelands, the elevation is approximately 1200-1300 m above sea level. At Broadmeadows Station, at the north of the study region, the elevation is 200-300 m. The variation in elevation occurs over short distances as seen in the digital elevation model (DEM) of the study region (Figure 2.5). The dominant physiographic feature of the study region is the north-south flowing Guy Fawkes River that drains from the New England Tablelands at Ebor Falls in the south, forming a steeply dissected gorge. Guy Fawkes River merges with the Aberfoyle River in the centre of the study region and with the Sara River (Figure 2.4) in the north. Where the Sara and Guy Fawkes Rivers converge becomes the Boyd River that within 10 km veers sharply to the east and flows through the Nymboida river system to the eastern Australian coast. The erosive actions of the Sara, Aberfoyle and Guy Fawkes Rivers flowing east and northwards across the New England tablelands has produced a landscape of plateaux and gorges with steep slopes and ridges.

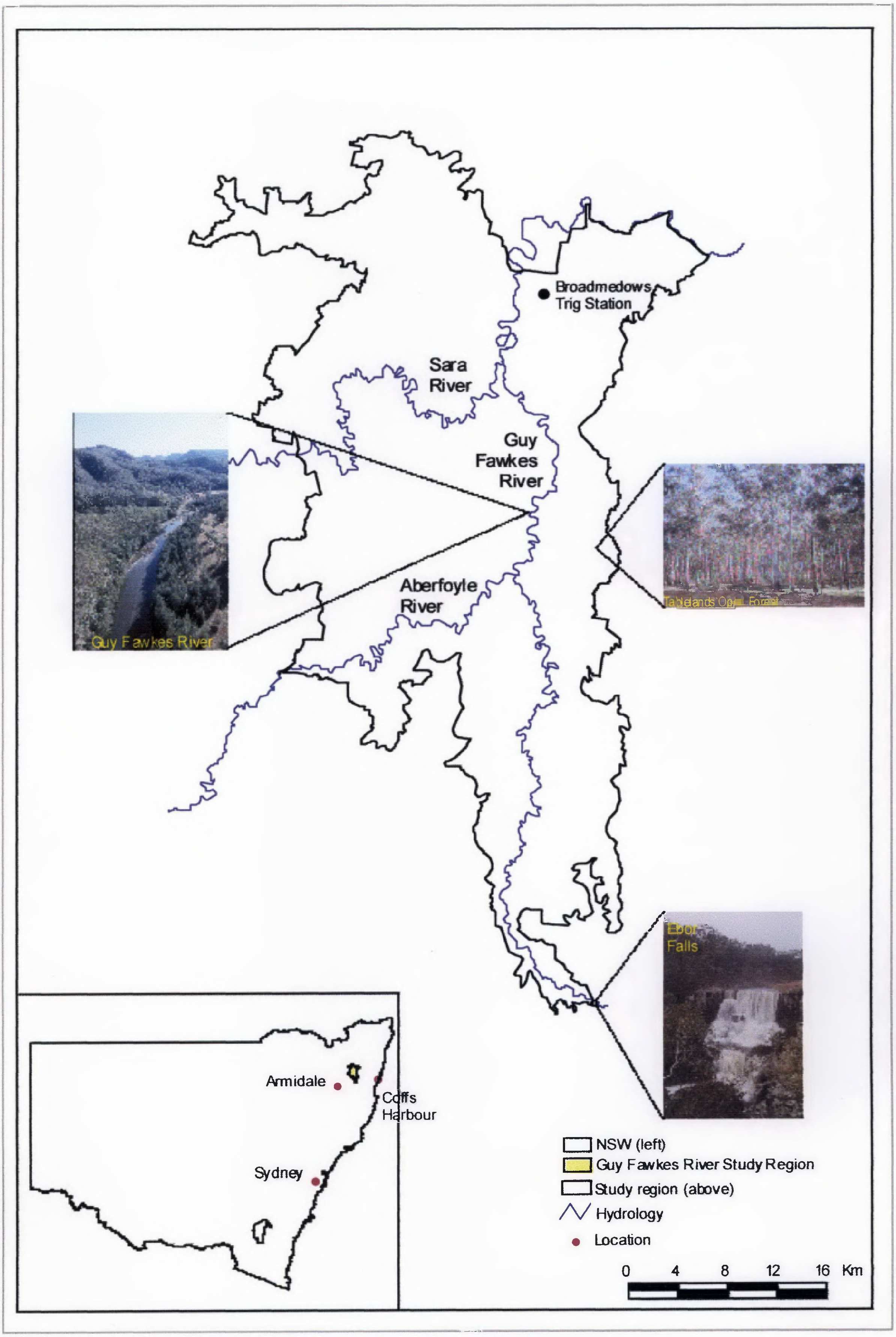

Figure 2.1. Guy Fawkes River National Park study region in the north-east of NSW, Australia.

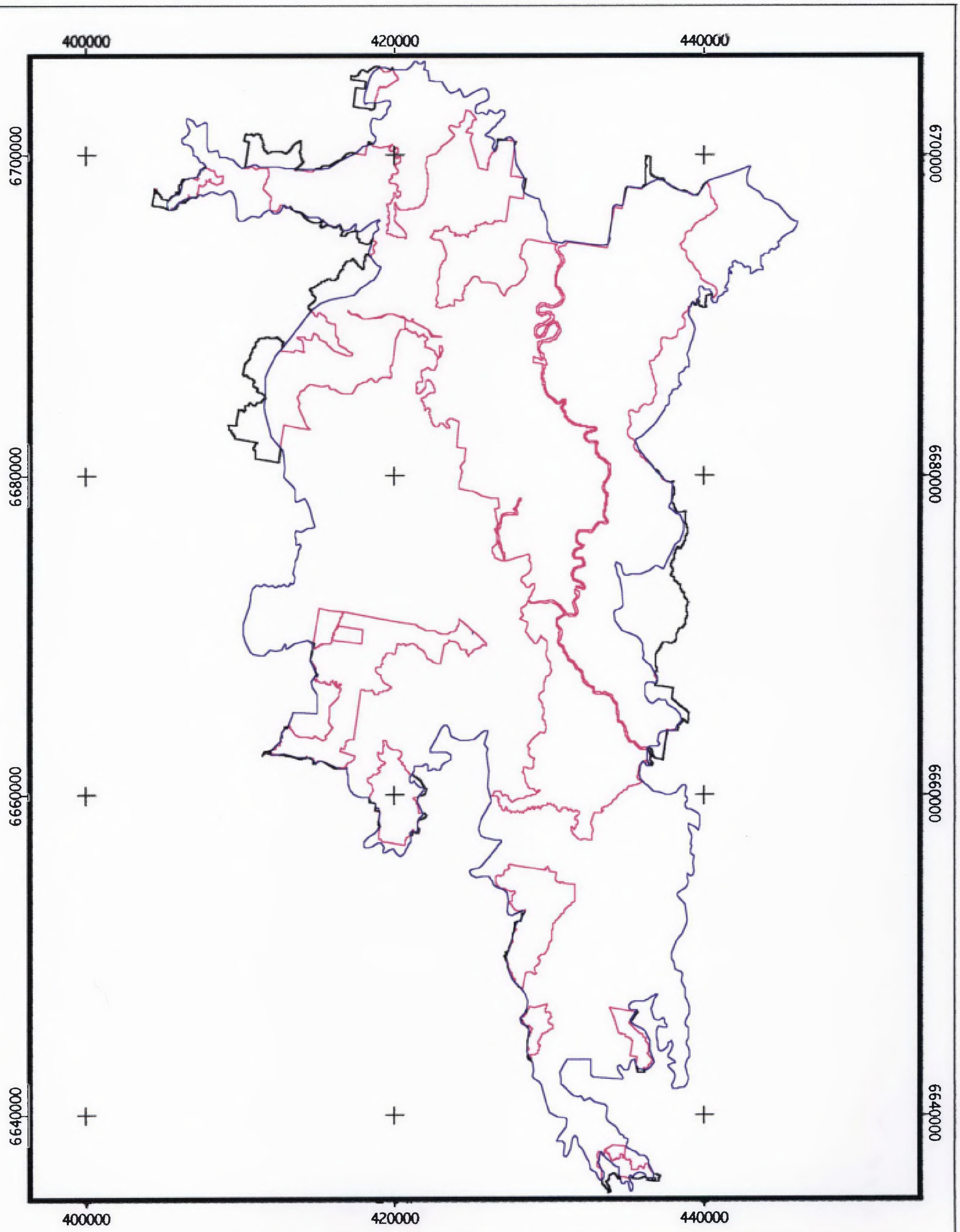

Figure 2.2 Boundaries including the nominated wilderness area, the National Park and the combined study region.

Figure 2.3. The Guy Fawkes River National Park gorges, viewed from south to north.

Figure 2.4. The Sara River with gallery forest along the banks.

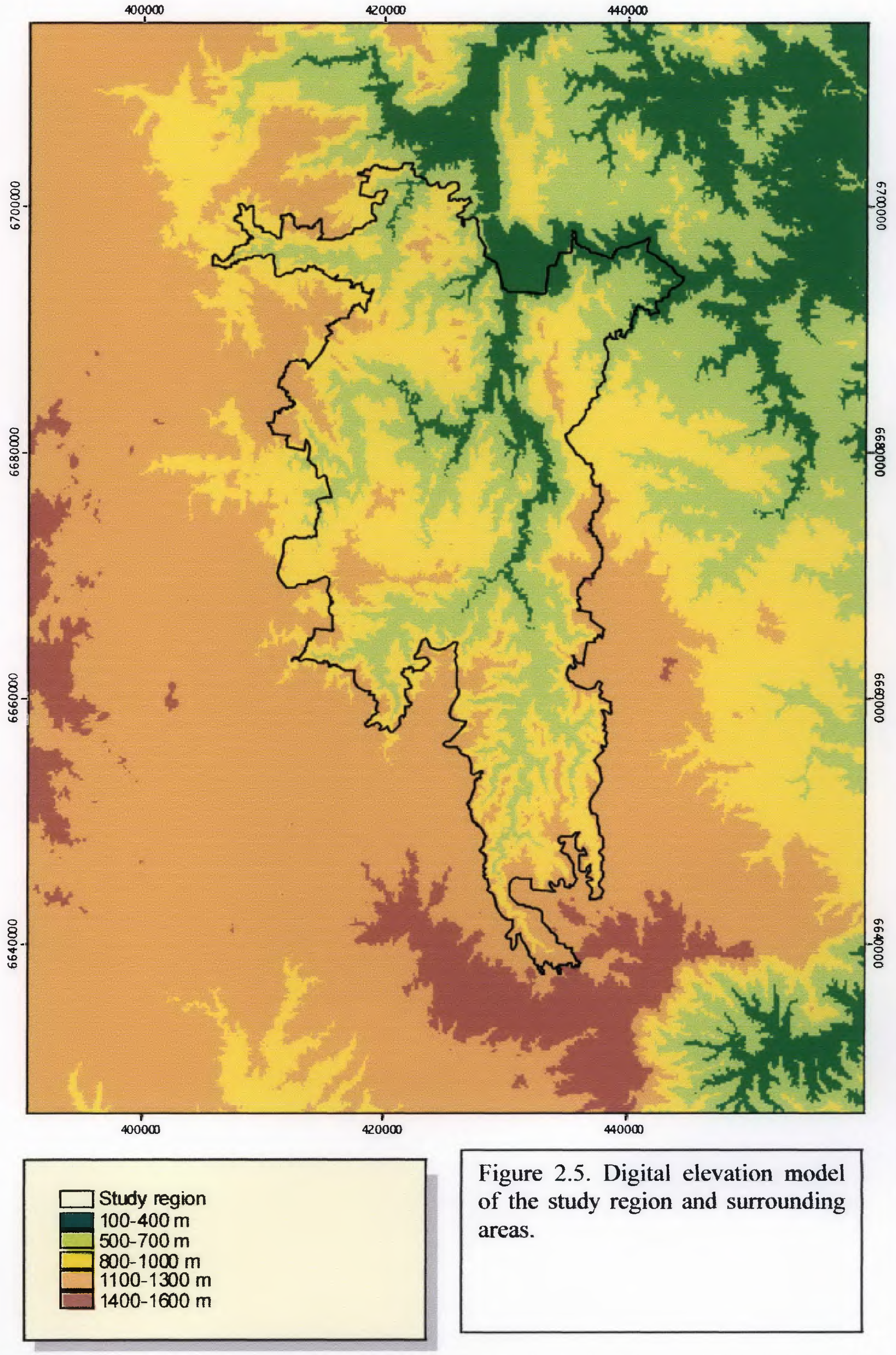

Figure 2.5. Digital elevation model of the study region and surrounding areas.

2.2 Slope

The slope in the study region varies from flat to steep drops of over 40 °. The Tablelands area is flatter, with steep slopes in the gorges away from the rivers and flatter area adjacent to the rivers along the valley floors. Over 50% of the study region has a slope of 20 °or greater (Figure 2.6).

2.3 Aspect

Like the other terrain variables, aspect varies considerably in the study region. The dominant aspect is the west-facing slope of the eastern side of the Guy Fawkes River gorge. The western side of the study region has a more varied aspect due to the Aberfoyle and Sara River Gorges. The aspect of the study region is shown in Figure 2.7.

2.4 Climate

2.4.1 Rainfall

GFRNP occurs in the summer rainfall, subtropical climatic zone of Australia (Colls and Whitaker, 1990). It is characterised by summer rainfall and low winter temperatures. In the study region, the rainfall and temperature gradients are sharp, reflecting the topographic variation. Monthly average rainfall recorded at Glen Innes, the closest town to the study region with a long-term (> 50 year) climatic record, varies from a maximum of 113 mm in January to a minimum of 43 mm in April (Figure 2.8). The average rainfall is low through the winter from April until September when it begins to increase, with a summer maximum rainfall pattern in December and January. Within the study region, climatic surfaces derived from the digital elevation model and climate stations outside of the Park, show the variation in rainfall (Figure 2.9). The majority of the study region has low to moderate rainfall, with some areas of higher rainfall occurring on the eastern Tablelands.

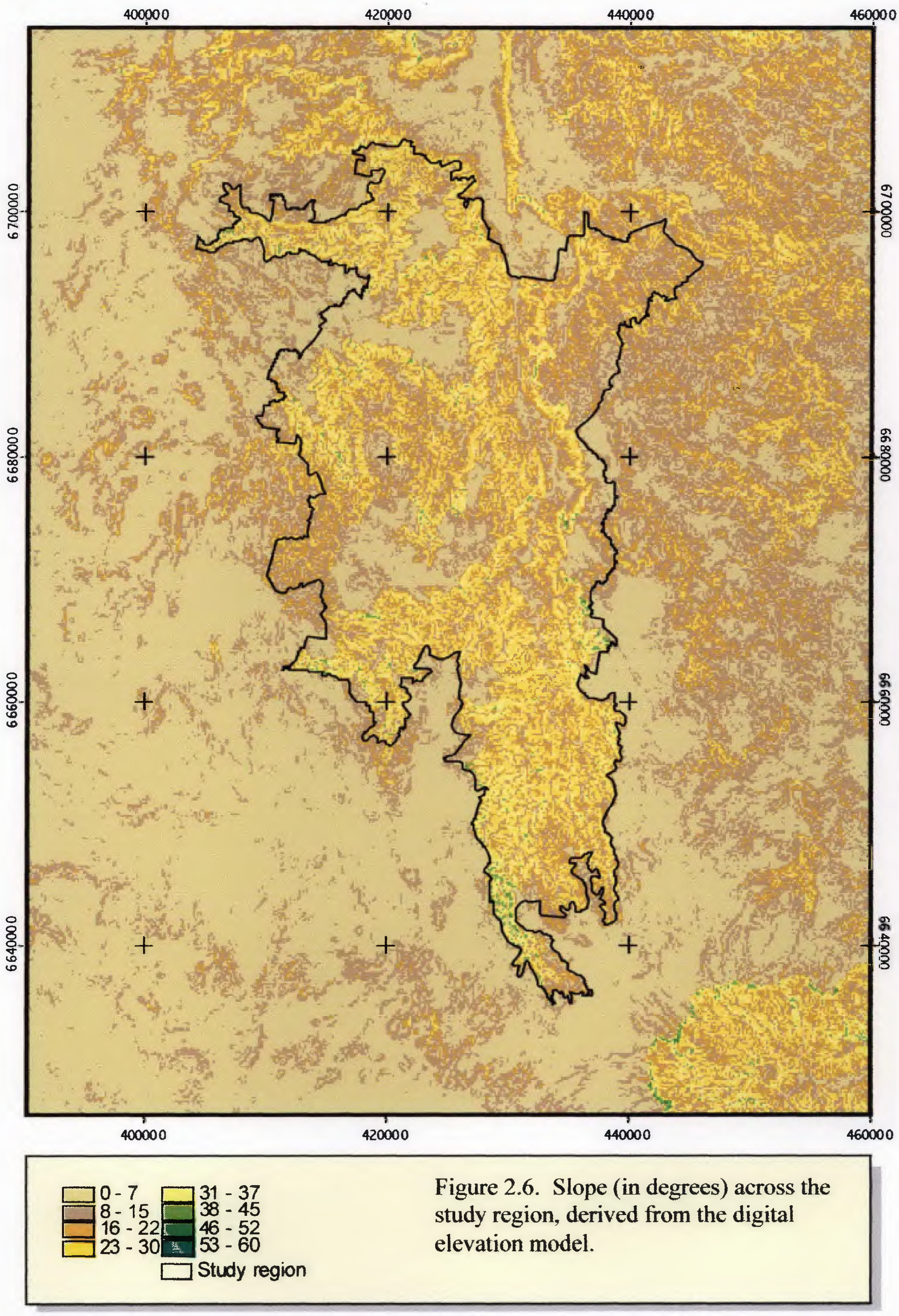

Figure 2.6. Slope (in degrees) across the study region, derived from the digital elevation model.

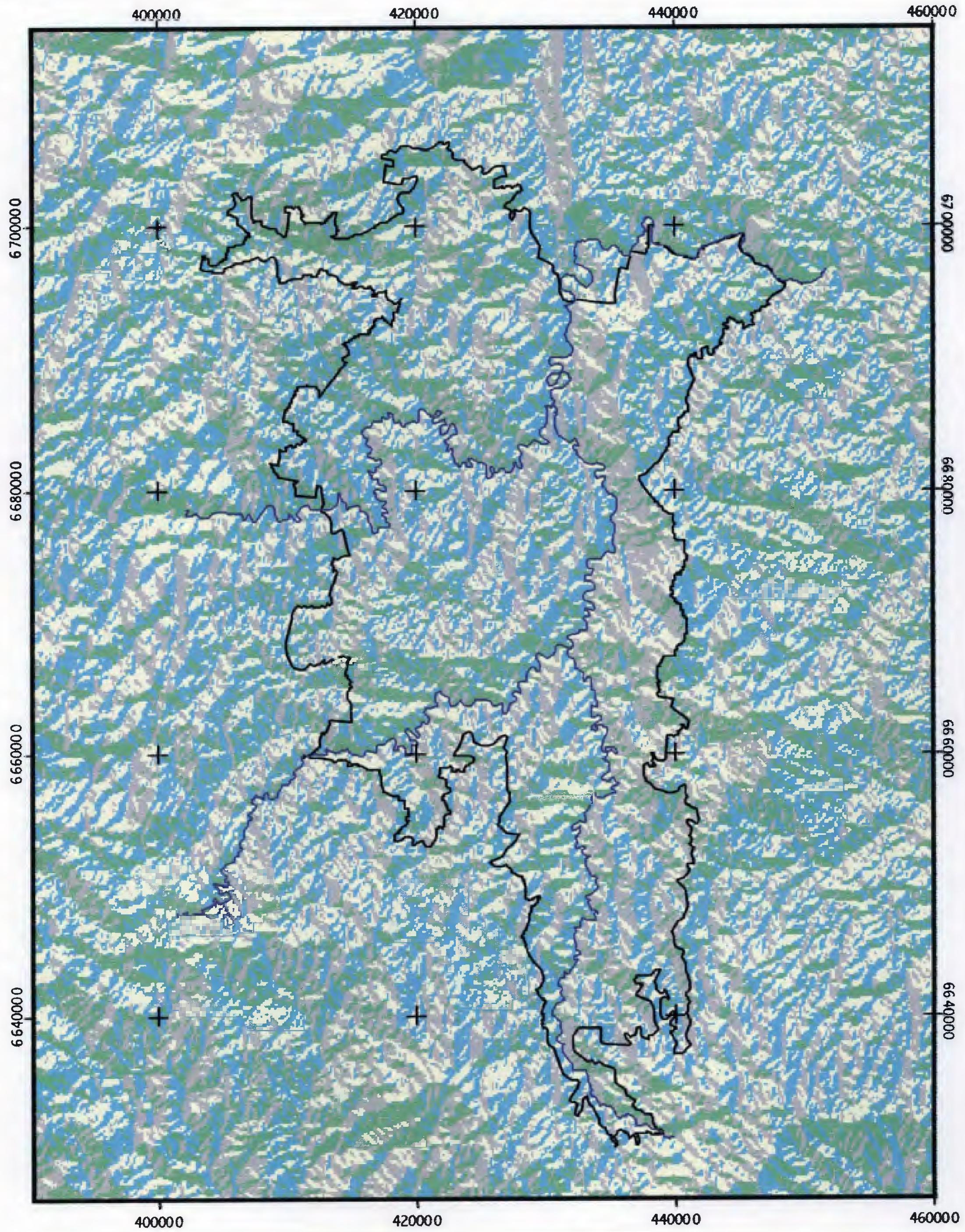

Figure 2.7. Aspect of the study region classified from the digital elevation model

2.4.2 Temperature

Temperature peaks in January with an average monthly maximum of 26.4°C. The coldest month is July with an average monthly minimum of 0.4°C (Figure 2.8) and frosts are often recorded on the Tablelands. The average annual temperature over the study region was coldest on the Tablelands with an increase of over 5°C between the Tablelands and lower Gorge regions along the Guy Fawkes River (Figure 2.10).

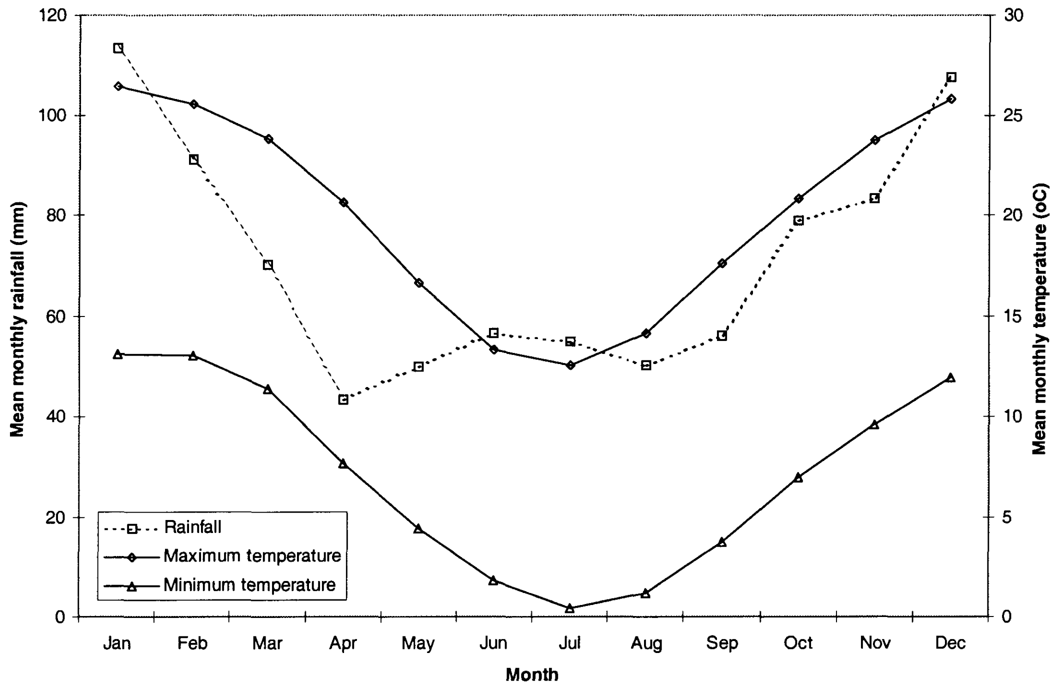

Figure 2.8. Variation in average monthly rainfall, minimum and maximum temperature for Glen Innes at the Post Office (Station number 56011), at an elevation of 1062 m with records from January 1881. Glen Innes is the closest town to Guy Fawkes River National Park, located on the New England Tablelands. Data supplied by the Bureau of Meteorology, Melbourne.

2.5 Geology

The dominant tectonic feature of the study region is the Demon Fault that trends north-south and is largely congruent with the Guy Fawkes River. The fault is the junction of two major geological units, the Dyamberin Block to the west and the Coffs Harbour Block to the east (NSW NPWS, 1992). The most common lithology is the lower Permian metasediments, primarily greywacke, slate, siliceous argillite, pebbly mudstone, siltstone and silicified mudstone (Geological Survey of NSW, 1969a) (Figure 2.11). It occurs mainly to the west of

Guy Fawkes River, with the eastern extent controlled by the Demon Fault. Lithologies on the east of the Demon Fault include the (1) upper Permian Chaelundi Complex, comprising primarily leucoadamellite, adamellite, diorite and gabbro, and (2) Carboniferous Moombil beds (siliceous, dark, generally massive, argillite) (Geological Survey of NSW, 1969a). The Moombil beds have been intruded by rocks associated with the Chaelundi Complex including ademellite, diorite and gabbro. The northern boundary of the study region includes a small area of the carboniferous Brooklana Formation (siliceous argillites, slates and rare siliceous greywacke) and a small area of the Mt Mitchell adamellite (porphyritic medium-grained hornblende-biotite adamellite) (Geological Survey of NSW, 1969b). In the southern section of the study region around Ebor falls, there are intrusions of tertiary basalts, primarily tholeiitic and alkaline basalts with minor trachyte and dolerite. Columnar jointing within the basalt is well developed at Ebor Falls. Isolated remnant patches of basalt occur on the western metasediment. These represent relics of more extensive basaltic cover that have been largely eroded during the Tertiary.

The most recent geological developments are quaternary alluvium along the banks of the Boyd River in the northern area of the park and gravel alluvial deposits, particularly through the broader valleys in the region of Broadmeadows Station (NSW NPWS, 1992). Over the study region, the two dominant rock types are the lower Permian metasediment and the Chaelundi Complex (primarily granite). These comprise approximately 94% of the region.

The digital geology data were obtained from the NPWS who compiled them from the 1:250 000 Australian geological map series of Dorrigo-Coffs Harbour (SH 56-10 and 11) and Grafton (SH 56-6) (Geological Survey of NSW, 1969a; 1969b). The data had been converted from hardcopy maps to digital data (Figure 2.11).

2.6 Soils

The soil type and depth across the study region is largely a reflection of the variation in dominant slope and lithology, respectively. The metasediments, coincident with a large proportion of steep slopes, generally weather to skeletal clay soils. Soils developed on the Tablelands, with gentler slopes and granite-dominated lithology, are generally deeper duplex soils.

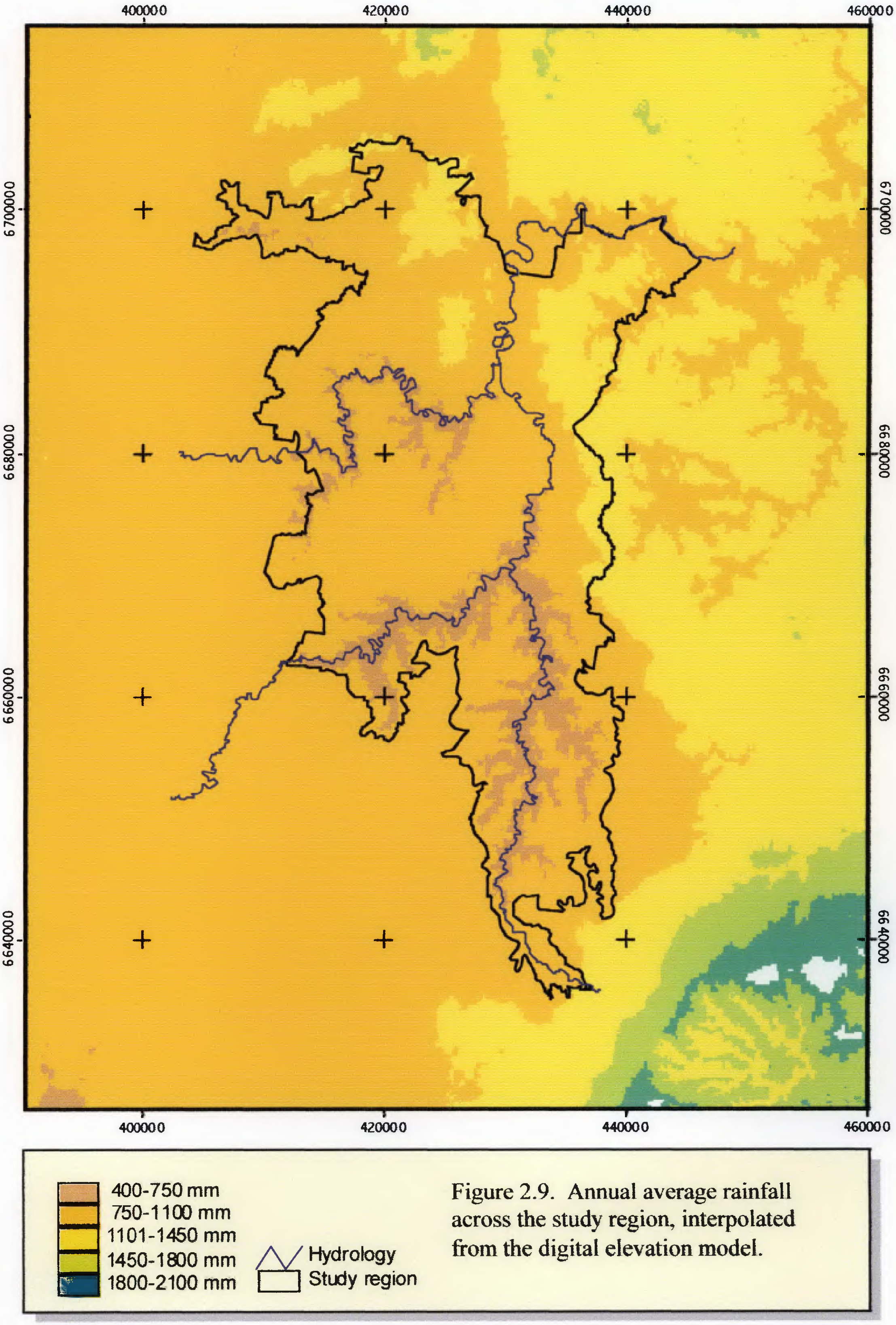

Figure 2.9. Annual average rainfall across the study region, interpolated from the digital elevation model.

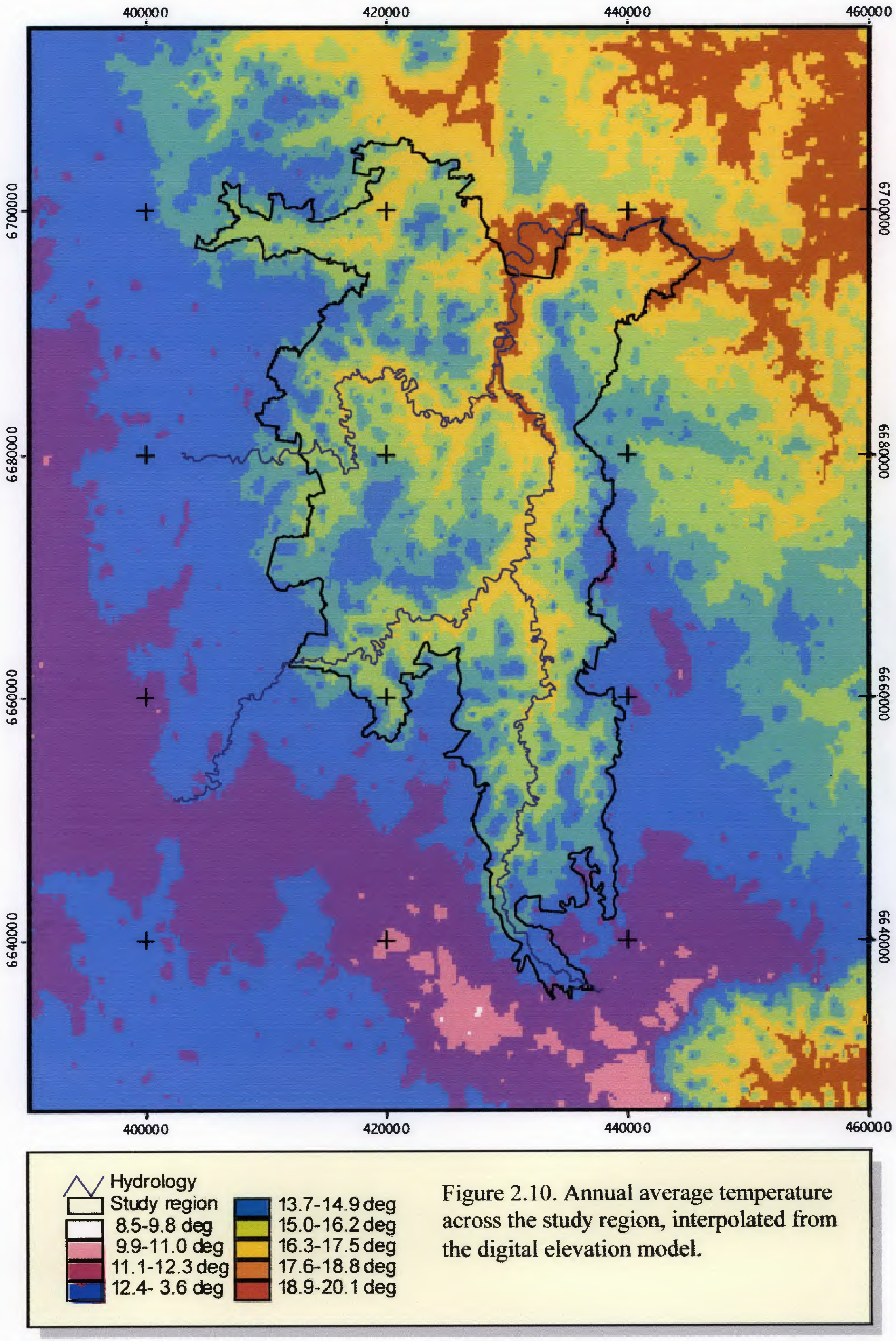

Figure 2.10. Annual average temperature across the study region, interpolated from the digital elevation model.

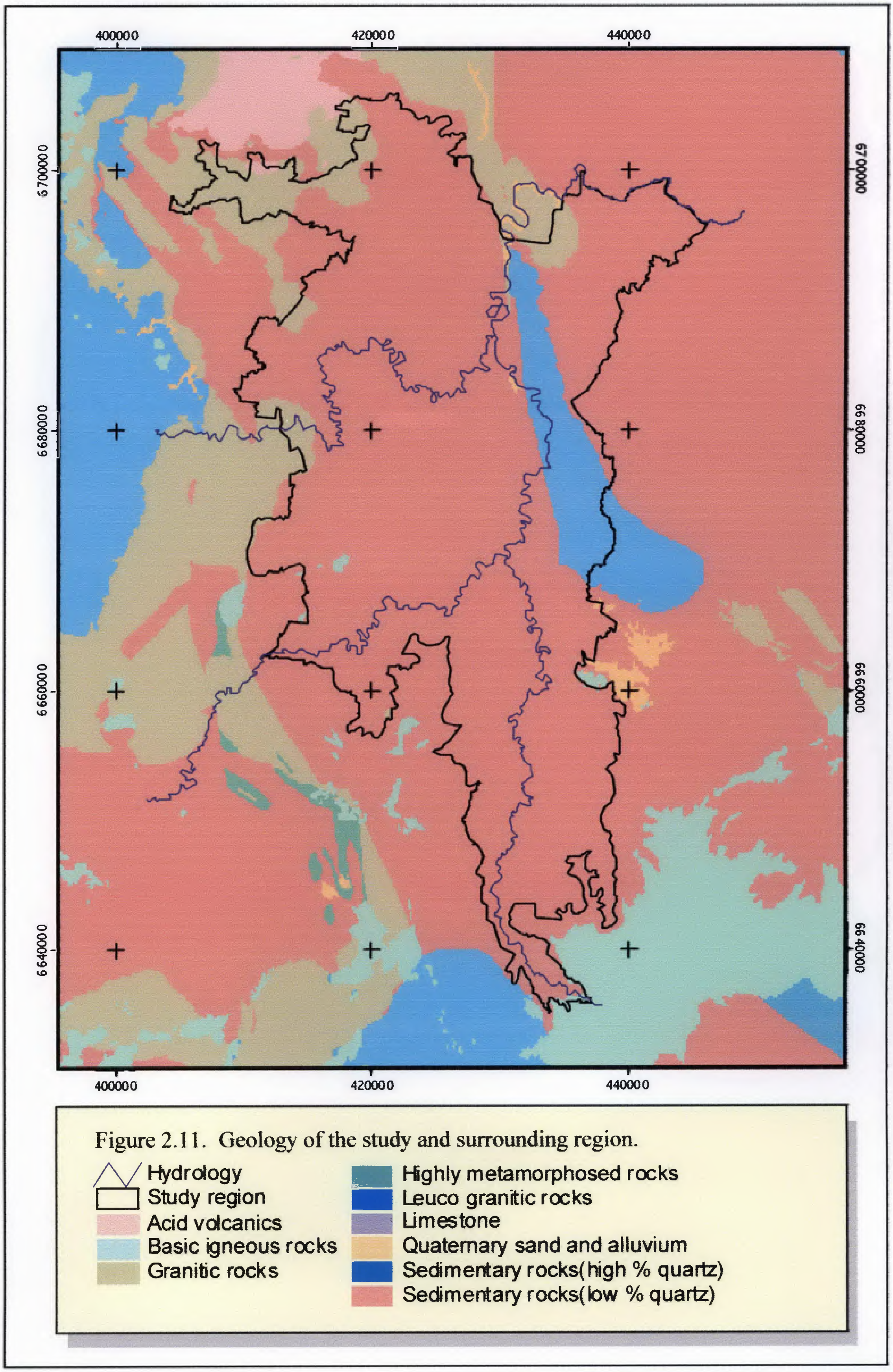

Figure 2.11. Geology of the study and surrounding region.

2.7 Vegetation

The vegetation is predominantly *Eucalyptus*-dominated open-forest and woodland. This varies from complex multi-layered forest to grassy open-forest on the slopes. There is a moderate shrub or small tree midstorey in some areas, comprised predominantly of *Persoonia*, *Allocasuarina* and *Acacia* species. There are intermittent patches of dry rainforest in steep sheltered gullies and on scree slopes, C*asuarina cunninghamiana* gallery forest along the Guy Fawkes and Sara Rivers, and wet sclerophyll forest with a subtropical-warm temperate forest understorey on the eastern boundary.

Records of the floristic composition of the New England Tablelands are scarce up to 1963 when Williams (1963) documented the main floristic changes from the eastern escarpment to the western slopes. More recently, studies have focused on specific habitats such as the dry rainforests (Floyd, 1983; 1990a; 1990b). In 1994-95, the North East Forests Biodiversity Study (NEFBS), was undertaken by the NSW NPWS for the Natural Resource Audit Council (NRAC) (NSW NPWS, 1995). The output was a collation of existing floristic survey data sets, the addition of gap filling surveys and the development of predictive models for 2394 vascular plant taxa in north-east NSW (NSW NPWS, 1995).

For GFRNP, the NEFBS survey collated over 100 vegetation plots, with the majority occurring on the eastern side of the Park. Over 2000 polygons classified into 337 unique combinations of vegetation overstorey structure and floristic variation were identified. The attributes recorded were floristic composition, height (< 10 m, 10-20 m, 21-30 m, > 30 m) and crown cover classes (0-10%, 10-20%, 20-50%, 50-80%, 80-100%) (NSW NPWS, 1995). Due to the complexity of the data set (Reid et al., 1996) aggregated unique combinations into 36 vegetation types based on the floristic association of the dominant overstorey. However, due to additions to the Park area, their study did not cover the full area of the National Park in 1998.

Another vegetation survey was undertaken in Guy Fawkes River in 1999 for the Comprehensive Regional Assessment (CRA) program (NSW NPWS, 1999). The survey completed in 1999, was not available at the initiation of this study. It was conducted in the National Park and surrounding areas and added 101 vegetation plots, describing floristic composition and cover, to the existing data. The full data set, containing 263 vegetation survey sites, covering the section of the park managed by the Dorrigo District of NSW NPWS, was then analysed using numerical techniques of classification and ordination (Austeco Environmental Consultants, 1999). On the basis of this analysis and the vegetation communities identified from aerial photography, 28 vegetation communities were recognised in the park (Figure 2.12).

The vegetation of the north-west section of the park managed from the Glen Innes District of NSW NPWS, was surveyed in 1998-99 and ten communities identified based on PATN analysis and aerial photo interpretation (Hunter and Alexander, 1999). Similarly, this survey recorded floristic composition and canopy cover.

Both of these most recent surveys had the primary goal of mapping vegetation communities to use in management planning by NSW NPWS. Both reports included fire response information for the individual species sampled in the surveys. The majority of this information was collated from work undertaken in other areas of NSW or Australia.

The plant species nomenclature follows (Harden, 1990; 1991; 1992; 1993), unless listed as a recent update in Appendix 2.1. Only infraspecific taxa have been named in the text where required, but are listed in Appendix 2.1.

2.8 History

Relatively little is known about the Aboriginal history of the study region. The Banbai people occupied the Tablelands and Gorges east of Glen Innes, and made annual visits to the Guy Fawkes Valley (Bennett, 1989). The area was considered a good place to hunt and ceremonies were held in the area. Significant stone arrangements and artefacts remain a high priority for conservation (NSW NPWS, 1992).

Guy Fawkes River National Park is named after the River that dissects the Park. The River was thought to have been named in 1845 by Major Parke who camped on the southern banks of the River near Ebor on November 5, Guy Fawkes night (NPWS, unpub.). The area has a long history of European settlement, with early records of grazing on the Tablelands. European entry into the area began in the 1800s when local Aboriginals guided a squatter called Coventry into the region. At the same time the station at the northern end of the study region, Broadmeadows, was being established. Occupation leases were being established over large areas of the Tablelands, and the river flats and valley bottom became increasingly attractive as pasture and grazing land (Boyd, 1991).

The first European establishment in the Gorge occurred around the turn of the 20th century when David (Pardy) Brown, son of the first owner of Marengo Station, established a hut in the centre of the Guy Fawkes Gorge. The hut was located near the junction of the Aberfoyle and Guy Fawkes Rivers and the ruins remain today. Brown carted wool to Marengo Station by bullock dray along the six km spur known as McDonald's ridge that in 1900 was gazetted as a Travelling Stock Route (TSR) (Boyd, 1991). The TSR was extended along various parts of the River and remains a popular horse track for visitors to the region.

Gold was discovered at Ballard's Flat on the Sara River in 1858. The discovery was gazetted under the *Mining Act 1874* as the Oban Gold Field (NSW Gazette 1888 cited in Hagen and Hockey (1991)). The discovery of gold brought prospectors to the area and small-scale alluvial mining was conducted along the Sara River in the late 1900s, 1930, 1960, and 1988-90.

The first part of the study region identified for conservation was Ebor Falls. A popular local picnic spot, the area was made a Reserve of Public Recreation in 1895 (Bennett, 1989). The first part of the National Park was gazetted in 1972. This identified an area of approximately 35 630 ha incorporating the main Guy Fawkes River section. In 1980, the Ebor Reserve was incorporated into GFRNP. The nomination for wilderness listing of the GFRNP and surrounding area highlighted the significant natural values of the region (NSW NPWS, 1992). Of particular note were the floral and faunal diversity, the geological complexity, the relatively undisturbed examples of sclerophyll communities including tall open forest, open-forest and woodland communities, the examples of tall old-growth forest and rainforest, the number of vulnerable, inadequately conserved and previously undocumented plant associations, habitat for many endangered and threatened species, the significant geological features such as the Demon Fault and the Great Escarpment, and the sweeping scenic beauty of the vistas covered by natural vegetation (NSW NPWS, 1992). It is a truly beautiful, rugged and remote region.

2.9 Fire and Guy Fawkes River National Park

The history of fire in the region, prior to management by the NPWS, largely consists of observations and local knowledge. Bennett (1989) undertook a study of the management of fire by 74 landowners in the New England tablelands. It was found 90% of managers actively used fire to (1) regenerate pasture for grazing, (2) reduce bushfire risk, (3) burn remaining biotic material, (4) maintain fire breaks and (5) burn regrowth after clearing. Managers in the gorge country were found to burn every 1-3 years from June to March, but mainly from August to October (Reid et al., 1996), principally to promote grass regeneration for grazing. Fire was thought to be a common and regular occurrence in the region, however records are scarce.

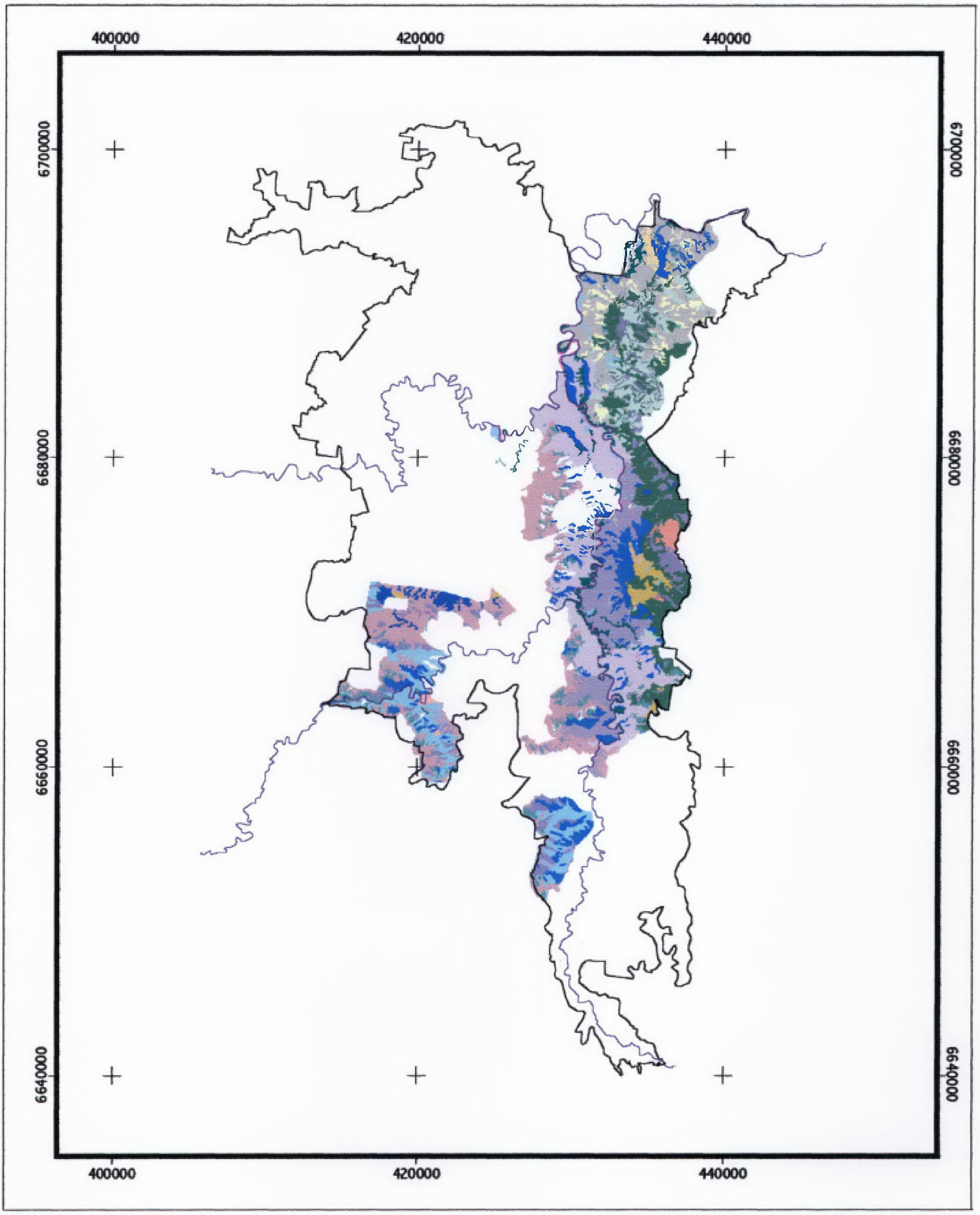

Figure 2.12. Vegetation of the area of National Park in the study region. Represents the most recent vegetation mapping for this area. Detailed legend over page (Source: Austeco Environmental Consultants, 1999).

╱╲╱ Hydrology
▭ Study region
Vegetation map
🟥 Angophora, redgums and E. eugenioides
🟦 Angophora, redgums, +/- E. laevopinea, E. biturbinata, boxes
🟫 Dry brushbox L. confertus +/- grey gums, ironbarks, redgums, E. carnea
🟦 Dry rainforest
🟦 E. biturbinata and E. microcorys, some L. confertus/E. laevopinea/box, Southern slopes
🟪 E. biturbinata, E. caliginosa, +/- boxes
🟧 E. biturbinata, E. laevopinea, boxes +/- some redgums
🟦 E. biturbinata, redgums, E. microcorys, boxes
🟥 E. campanulata +/- stringy, E. obliqua, on granite
🟩 E. campanulata, E. brunnea, E. cameronii +/- E. obliqua
🟨 E. campanulata, E. caliginosa/E. cameronii, &/or E. bridgesiana, E. dalrympleana, E. dorrigoensis, E. nobilis
🟪 E. campanulata, E. cameronii , A. littoralis
⬜ E. carnea, C. intermedia, Angophora, redgum, brushbox
🟨 E. carnea, E. siderophloia, E. propinqua +/- L. confertus, E. eugenioides - dry grassy on North aspect
🟩 E. crebra, C. intermedia, Angophora, redgum
🟦 E. laevopinea with redgum, E. melliodora or other stringy
🟪 E.laevopinea/E.caliginosa, E.campanulata, E. bridgesiana, +/- E. dalrympleana, E. fastigata, E. nobilis
⬜ E. microcorys, L. confertus & E. saligna, &/or E. laevopinea, moist shrubby u/storey
🟧 E.pilularis, E.microcorys +/- C intermedia, E. propinqua, L. confertus etc, grass & shrubs (dry mixed hardwood)
🟫 E. williamsians, E. laevopinea/E. caliginosa, A. littoralis
🟦 Grassland or cleared
🟦 Redgum & grey box, A. littoralis, high altitude
🟪 Redgum super group (composite)
🟥 Riverbed complex
🟦 Subtropical rainforest +/- Araucaria