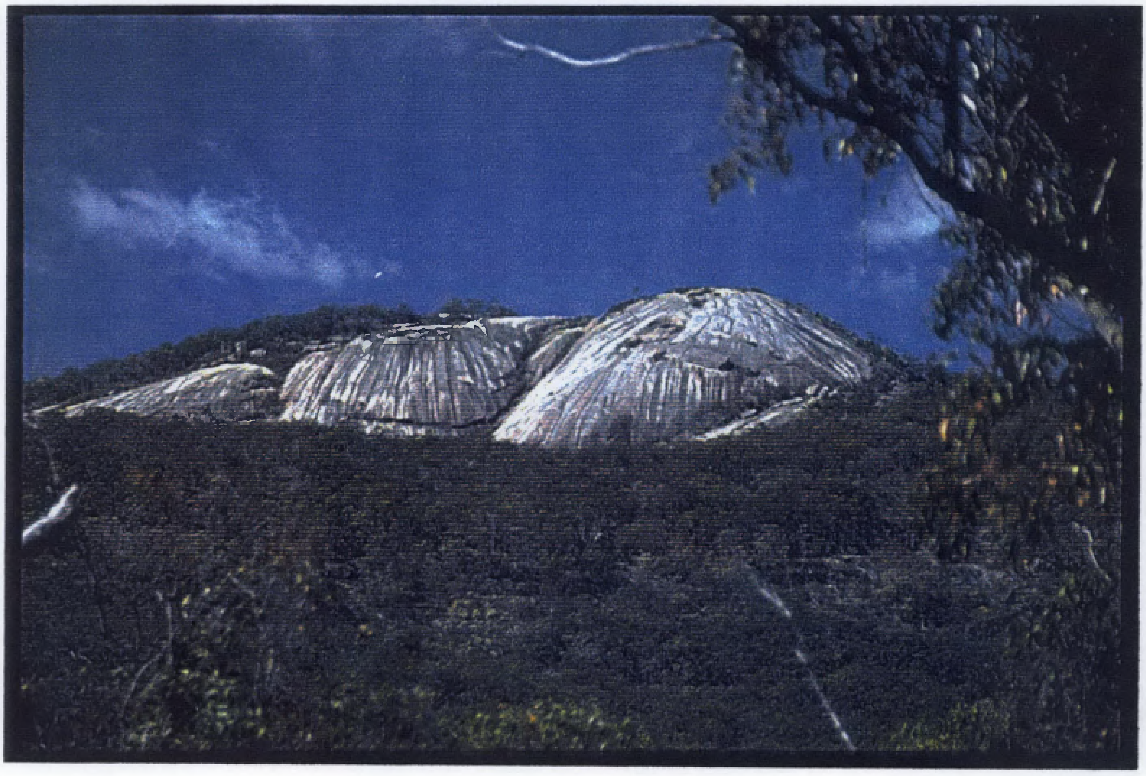
# Chapter 2: Stratification and Data Storage



*Bald Rock – the largest granitic monolith in Australia*

# Chapter 2

# Study Area, Stratification and Data Storage

## 2.1 Introduction

Very few data have been collected on granite outcrop floristic communities or their species composition, even of those most common and obvious plants. Stratified full floristic surveys have been conducted within the New England Batholith, particularly on the eastern side of the New England Batholith, yet data on the flora of granitic outcrops is scarce. Information on species has been derived from opportunistic recordings of species and floristic lists by local botanists involving less than 1% of known outcrops. The most significant surveys conducted on the eastern parts of the New England Batholith, the 'North East Forests Biodiversity Study' (NSW NPWS 1995) and the 'Natural Resources Audit Council' (NRAC) (1995), failed to include specialised tree-less vegetation communities (including those on granitic outcrops) in their stratification. The NRAC (1995) datum validation procedures excluded sites with fewer than two tree species present.

A survey of granitic areas of the Northern Tablelands and North Western Slopes of New South Wales involving collation of existing data with additional information from transects in forested areas was conducted by Roberts (1983). Hunter (1992) placed belt transects from a granitic outcrop and into the surrounding vegetation in three areas on the batholith, finding marked differences in species composition between outcrop and forested areas. In State Forests of New South Wales stratified floristic surveys (Binns 1992; Binns 1995a) a few sites were placed on outcrops. This was not always the case with forestry surveys, for example the Forestry Commission of New South Wales (1989) wrote of granitic outcrops 'Apart from lichens, mosses and some herbs established in crevices, they are usually unvegetated'. Benson and Ashby (1996) in a systematic survey of the Guyra district sampled six sites on granitic outcrops in the Backwater district. Only Bowlay (1992), Le Brocque and Benson (1995), Clarke *et al.* (1995), Clarke *et al.* (1998) and Hunter (1998d) have included rock outcrops in their systematically stratified surveys conducted on the western side of the New England Batholith. All of these researchers were working in the Severn River and Torrington areas (Figure 2.4). Overall, fewer than 50, 0.1 ha, quadrat based survey sites had been placed on granitic outcrops within the entire New England Batholith, and only the work conducted by Binns (1992) and Hunter (1992) had been conducted within outcrop vegetation prior to the commencement of this project. A fully stratified, regionally encompassing (NEB) field survey was necessary for the granitic outcrops of the entire New England Batholith in order to accomplish the aims of the investigation.

Appropriate survey methodology was needed to elucidate aspects of the ecological-biogeographical continuum of granitic outcrop vegetation communities and their constituent species as outlined in Chapter 1. A stratified, plot-based sampling strategy was considered the most appropriate method for answering these questions. A plot-based survey enables each site to be treated equally in analyses and the time spent at each site is equivalent. Only a plot-based sampling strategy would allow comparative quantitative data to be collected, allowing precise inter- and intra-outcrop comparisons. In addition, this type of data is necessary in evaluating rarity, which is dependent on context and scale (Austin 1984).

## 2.2 Description of the study region

### *2.2.1 Location and physiography of the study region*

The New England Batholith lies in the north east corner of the state of New South Wales and the south eastern corner of the state of Queensland within Australia (Figure 2.1). The batholith is part of the eastern highlands of Australia (Great Dividing Range) that run semi-continuously along the entire east coast of the continent. The study area included portions of four botanical divisions: the North Coast, Northern Tablelands and North Western Slopes of New South Wales and the Darling Downs of Queensland. Tenure of the land surveyed included State Forest, Crown Land, National Park, Nature Reserve, Traveling Stock Reserve, Forest Preserve, private reserve, and private and leasehold land. General attributes of the 24 areas investigated are given in Table 2.1. The batholith is broadly divided into east and west portions, which is more or less marked by a major traffic highway that joins the towns Armidale-Glen Innes-Tenterfield-Stanthorpe (Figure 2.4).

Rain falls mostly in the summer (60—70%) due to a predominantly easterly airflow from the Pacific Ocean and the effects of tropical cyclones from the north east (RACAC 1996a). Rainfall that falls on the western side of the batholith runs north and west, that on the east flows eastward towards the adjacent coast. Snow occurs occasionally at higher altitudes. Overall, rainfall ranges from 600—1000 mm annually in the west and 1000—2500 mm annually along the escarpment (RACAC 1996a). Great variability occurs in rainfall and one in every five years on average is drought declared (Division of National Mapping 1986).

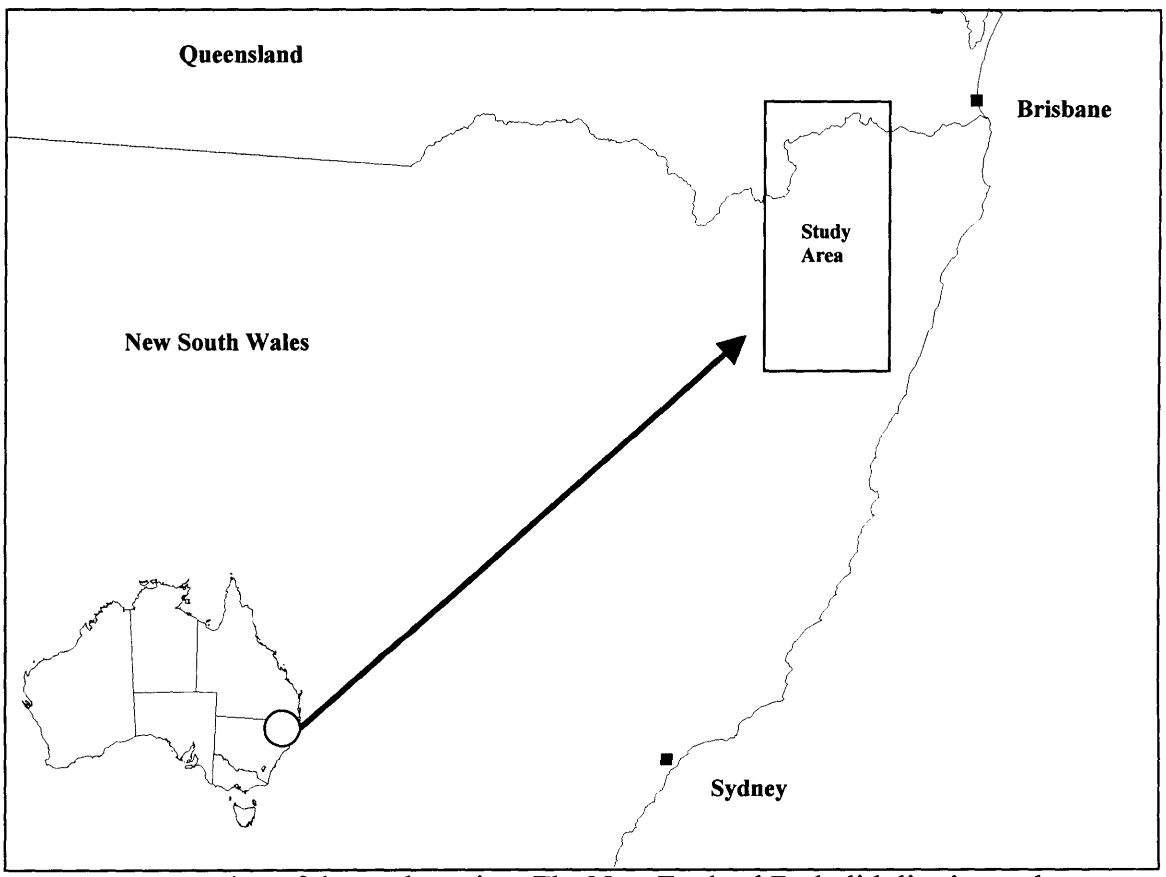



**Figure 2.1:** Location of the study region. The New England Batholith lies in north east of New South Wales and the south east of Queensland within Australia. A more detailed map of the study region is given in Figure 2.4.

Average temperatures are lowest at the higher altitudes at the top of the range and become warmer towards the west. The highest elevations are on the eastern escarpment and the lowest towards the west at the Kwiambal Terrain (Hunter 1998d). Kwiambal (KL) and Cathedral Rock (CR) National Parks represent extremes of climate (Table 2.1; Figure 2.2) and highly the gradients of climate that occur from the west to the eastern escarpment.

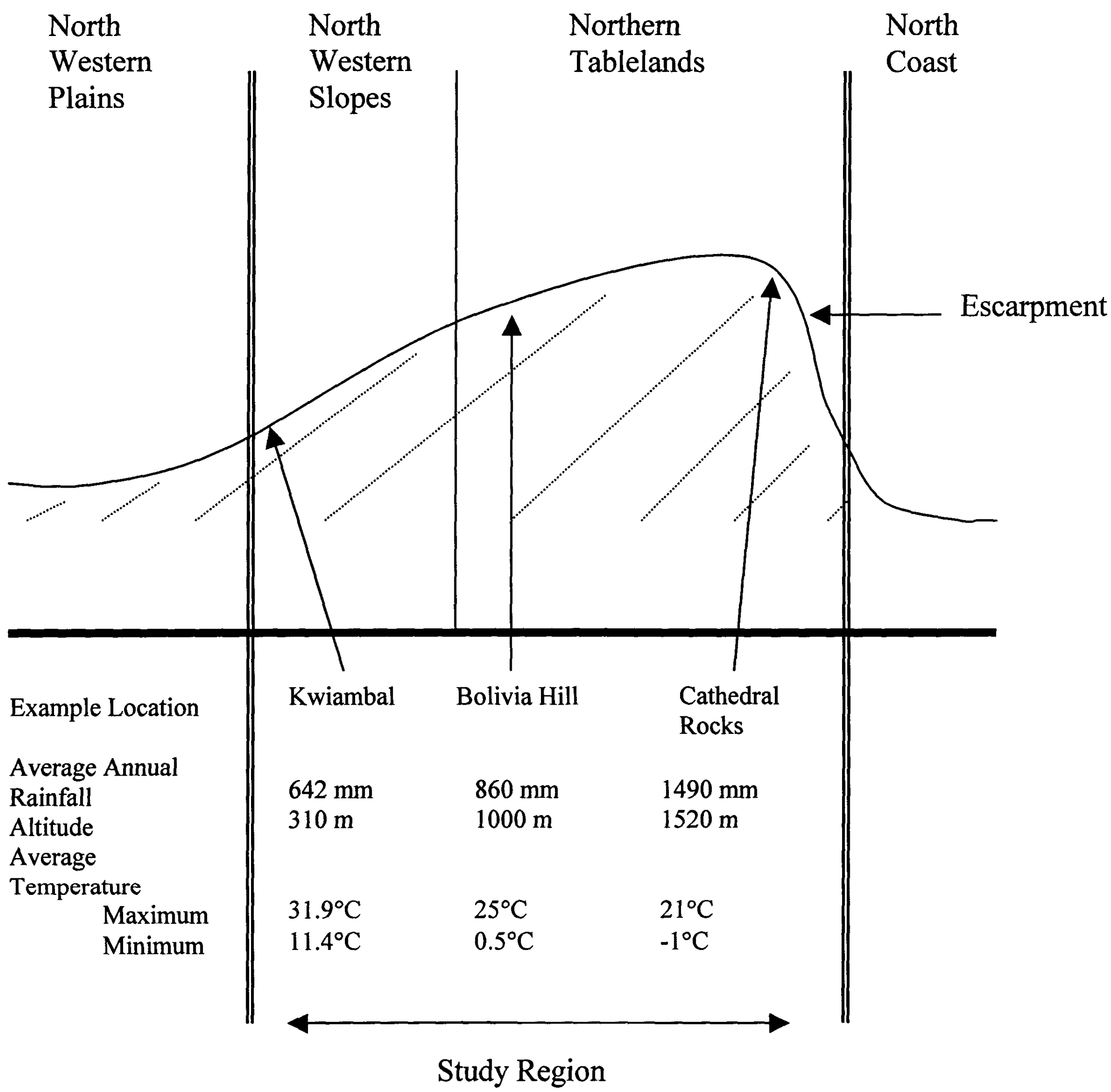



**Figure 2.2:** Cross section of the New England Batholith from east to west. Note the sudden rise in the east, which constitutes the New England escarpment and the gradual sloping to west known as the western slopes. Such a cross section is typical of the most of the east coast of Australia.

### 2.2.2 Granitic geology, landforms and the age and orogen of the New England Batholith

Granitic rocks are the main component of continents. Granite is an igneous rock comprising crystals of quartz, feldspar, mica and/or hornblende or pyroxene (Myers 1997). Quartz and feldspars make up 90% of the rock and it is the proportions of these and the kinds of feldspars that are used in dividing granitic rocks into different types (Myers 1997). A complex of related granitic bodies joined at the subsurface is termed a batholith (Twidale 1982; Myers 1997). The study region is located within the southern part of the New England Orogen and the group of granitic bodies under investigation is termed the New England Batholith (Leigh 1968; Barnes *et al.* 1988). The rock types within the study area include granite, leucoadamellite, adamellite, granodiorite and those that are currently undifferentiated. The names of each rock type and suite are based on relevant geological maps (New South Wales Geological Survey 1971, 1984, 1986, 1987a-c, 1988a-b, 1993; New South Wales Department of Mines 1971, 1973a-b, 1976; New South Wales Department of Mineral Resources 1974, 1987). In recent years the nomenclature and terminology of geological rock types has changed. Not all changes to the names of rock types have been published or are readily available therefore, the older terminology is retained in this current work due to its published coverage.

The New England Orogen (NEO), of the New England Fold Belt (NEFB), is a belt of complex geology interpreted to be a tectonic collage of a number of terranes which amalgamated with, and accreted to the eastern margin of Gondwana during the late Paleozoic-early Mesozoic (Flood & Fergusson 1984; Flood & Aitchison 1993) (Figure 2.3). It is the easternmost tectonic element in the Tasman Orogenic Zone of eastern Australia, and the youngest (Schreibner 1993). It extends for 1500 km from Newcastle in the south almost to Bowen in the north (Murray 1998) (Figure 2.3). The setting for the assemblage of the majority of these terrains was an active continental convergent margin (Flood & Aitchison 1993) which comprised three major morphotectonic features: The western magmatic arc (an Andean style volcanic chain concealed in the southern NEO); the forearc basin; and the subduction complex or oceanic trench (Day *et al.* 1978). The genesis of the NEO began in the Cambrian and extended through various phases of uplift and deformation to the Triassic, with igneous activity lasting through to the Jurassic (RACAC 1996).

With the culmination of the orogenic episode most of the granites formed from the melting of freshly deposited volcanic sediments (RACAC 1996a). These granites form the New England Batholith (Barnes *et al.* 1988). The batholith extends for 400 km in length and 110 km in width, from Stanthorpe in Queensland to Tamworth in New South Wales (Leigh 1968) (Figure 2.4). It formed during a major period of plutonism between 265—220 Ma ago (Barnes *et al.* 1988). These are some of the youngest granitic rocks within Australia, with those in Western Australia being around 3600 Ma (Willmott & Stephenson 1989). About 255 individual plutons form at least 20 aggregated outcrop areas (Barnes *et al.* 1988). These aggregated areas extend semi-continuously through the central New England Orogen (Leigh 1968; Barnes *et al.* 1988). This represents one of the most significant areas of granitic outcrops in Australia. Within the batholith is Bald Rock, the largest granitic rock and the second largest rock in Australia, being 150 m high, 750 m long and 500 m wide (400 ha in total) (Leigh 1968; Walker 1982) (Figure 2.12).

In northeast New South Wales, outcrops of granite have been called 'tors'. This term is ambiguous as it is used for all types of granitic landforms including single boulders to large massifs. Twidale (1982) has attempted to clarify the terminology used. This work along with a synopsis presented by Campbell (1997) and Main (1997a), describe the majority of features found in granitic landscapes. A precis of some of the more significant features as described within these works is briefly presented here. Reference should be made to these works for further detail or for definitions of additional terms.

- Massif: a large elevated feature formed from an orogenic belt that differs in topography and structure from the adjacent terrain.
- Inselberg: large steeply sided 'island' mountains that arise abruptly from their surroundings. They arise more abruptly than monadnocks.
- Monadnock: an isolated hill or mountain where surrounding areas are level to their limits.
- Bornhardt: is the basic inselberg feature. They are large dome-shaped monoliths, bald and steeply sided with few fractures whereas the surrounding landscape is

highly fractured. This feature is further divided. 'Whalebacks' are elongated and elliptical. 'Turtlebacks' are symmetrical with steeply sloping flanks. 'Elephant rocks' are symmetrical in profile. 'Domes' have plan axes of similar length and altitude. 'Sugarloaf' is high and narrow along the plan axis. A bornhardt is the basic positive relief landform from which nubbins and kopjes are formed.

- Nubbin: a block or boulder strewn, hill-sized inselberg.
- Kopje: also known as koppie, a feature comprising angular and blocky rocks in castellated form.
- Pediment: essentially flat or gently sloping rock platform, often grooved and dimpled and slightly included away from an adjacent upland.
- Gnammas: rock basins that are circular, elliptical or irregular depressions in solid bedrock.
- Pavement: a small exposure of low and relatively plain relief.
- Fugitive outcrop: a subsurface basement, high but not yet fully exposed.

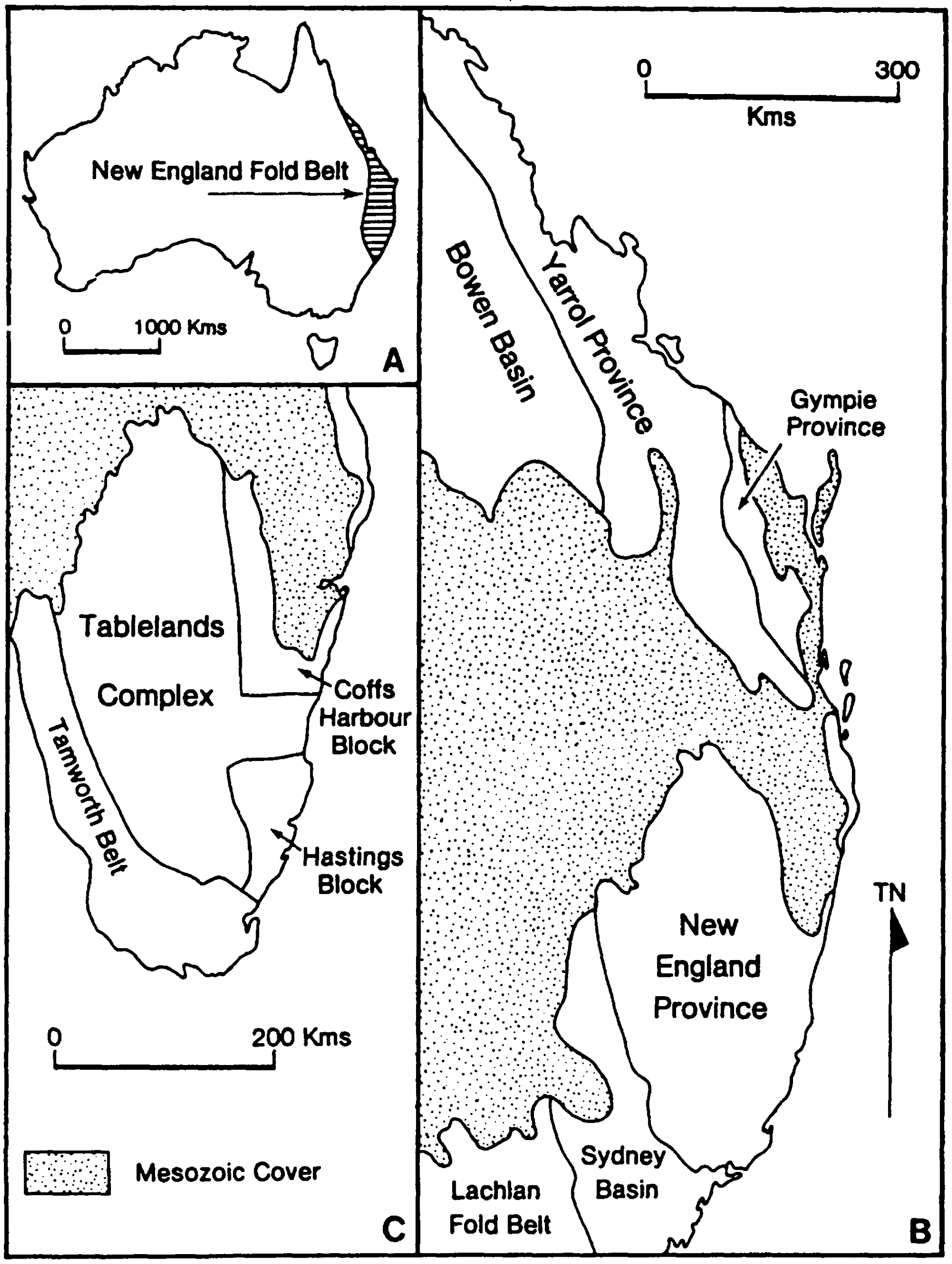



**Figure 2.3:** Geological setting. Taken from Flood and Fergusson (1984). A) Location of the New England Fold Belt (or Orogen). B) Subdivisions of the New England Fold Belt. C) Subdivisions of the New England Province.

### *2.2.3 European history and botanical exploration*

The initial settlement of the New England district of New South Wales probably occurred around 1839 to 1850. Early interest were mainly in cattle grazing (Gilmour &

Helman 1993). It wasn't until the 1860's that extensive clearing began after the introduction of the Robertson Selection Acts (Pearson 1992; RACAC 1996b). By 1890 *c.* 10% of the Northern Tablelands had been ring-barked or cleared (Benson & Ashby 1996). Pasture improvement with a range of exotic species commenced in the 1920's and by the 1970's, 19% of the region was sown to improved pastures (Benson & Ashby 1996).

Some of the earliest publications on the vegetation and flora of the north east of New South Wales are those of Turner (1903; 1906). Several collecting trips were made by Botanists from the Botanic Gardens in Sydney over many decades particularly by Maiden and Boorman. Many local professional and amateur botanists were also active on the New England namely, Rupp, Blakely, McKie and Youman to name a few. It was not until the late 1950's and early 1960's that any systematic effort was made to survey the vegetation and flora of the New England. Unfortunately, due to arguments amongst those carrying out the surveys, all site data was destroyed and the only record remaining of this work is the annotated checklist published by Gray (1961). Williams (1963) described the major changes in vegetation across the eastern escarpment to the western slopes (Figure 2.2). It is only in the last decade that a concerted effort has been made to survey the flora and communities that occur on the New England and the escarpment.

### 2.2.4 Aggregated plutons (virtual 'archipelagoes') selected for survey

At the outset of the project, the location of all outcrop areas ('archipelagos') was not known. Therefore, an extensive search was conducted to find all areas. Potential areas for investigation were identified from satellite and aerial photographs, local knowledge, and topographic and geological maps. Choice of areas for sampling was also influenced by practicalities such as available access (Austin 1984). Twenty-four separate aggregated plutons ('archipelagos') that included granitic outcrops ('islands') were chosen for investigation (Figure 2.1). These included all of the larger and a majority of the smaller known aggregated granitic plutons of the New England Batholith.

**Table 2.1:** Selected attributes of the 24 virtual 'archipelagos' (aggregated plutons) chosen for the survey. Precipitation is based on point location BIOCLIM modeling (section 2.5). Tenure: SF - State Forest, PR - Private Freehold, NP - National Park, SFP - State Forest Preserve, NR - Nature Reserve - SRA, State Recreation Area, TSR - Traveling Stock Reserve, LC - Leasehold. Data presented here based on appropriate topographic and geologic maps.

| Name | Geology | Altitude | Annual Precipitation | Area | Locality | Tenure |
|---|---|---|---|---|---|---|
| **Attunga (AT)** | Adamellite | 430—930 m | 703—705 mm | 900 ha | 16 km NW Tamworth | SF |
| **Backwater (BC)** | Leucoadamellite | 800—1372 m | 889—979 mm | 5000 ha | 40 km SE Glen Innes | PR, SF, SFP |
| **Bald Rock & Girraween (BR)** | Adamellite | 800—1277 m | 832—972 mm | 26000 ha | 20 km N Tenterfield | NP |
| **Bolivia Hill (BH)** | Leucoadamellite | 950—1225 m | 832—882 mm | 2000 ha | 15 km N Deepwater | PR |
| **Butterleaf (BL)** | Granite | 900—1300 m | 1002—1054 mm | 6000 ha | 40 km NE Glen Innes | PR, SF, SFP |
| **Cathedral Rock (CR)** | Leucoadamellite | 1000—1580 m | 1021—1490 mm | 3000 ha | 70 km E Armidale | NP |
| **Demon Nature Reserve (DM)** | Adamellite | 470—1090 m | 1250—1300 mm | 900 ha | 30 km E of Tenterfield | NR |
| **Mount Chaelundi (CH)** | Granite | 900—1377 m | 1168—1356 mm | 800 ha | 40 km N Ebor | NP, SF |
| **Eagle Creek (EC)** | Adamellite | 700—1118 m | 798—860 mm | 1500 ha | 12 km SW Tenterfield | PR |
| **Flaggy Range (FR)** | Adamellite | 750—1149 m | 753—838 mm | 5000 ha | 10 km N Bendemeer | PR |
| **Gibraltar Range (GR)** | Granite | 900—1175 m | 1118—1447 mm | 10000 ha | 60 km E Glen Innes | NP, SF, LC |
| **Howell (HC)** | Granite | 600—934 m | 752—866 mm | 6500 ha | 5 km SW Tingha | PR, LC, CR |
| **Ironbark (IB)** | Leucoadamellite | 640—1019 m | 780—840 mm | 2500 ha | 25 km SW Bundarra | NR, PR |
| **Mount Jondol (JB)** | Leucoadamellite | 1100—1210 m | 943—1041 mm | 800 ha | 22 km SE Tenterfield | SF |
| **Kwiambal (KL)** | Granite | 280—460 m | 642—672 mm | 2500 ha | 30 km W Ashford | NP, PR, SF |
| **Kings Plains (KP)** | Undifferentiated | 850—1009 m | 759—793 mm | 2500 ha | 40 km NW Glen Innes | NP |
| **Moonbi (MB)** | Adamellite | 550—980 m | 740—875 mm | 2500 ha | 5 km W Moonbi | PR, TSR |
| **Mount Balala (ML)** | Adamellite | 850—980 m | 765—784 mm | 500 ha | 16 km SW Uralla | PR |
| **Parlour Mountain (PM)** | Leucoadamellite | 1070—1200 m | 844—888 mm | 2500 ha | 35 km NW Armidale | PR |
| **Severn River (SR)** | Undifferentiated | 500—740 m | 678—709 mm | 5500 ha | 50 km NW Glen Innes | NR, PR |
| **Torrington (TT)** | Granite | 400—1220 m | 745—815 mm | 40000 ha | 60 km NW Glen Innes | SRA, LC |
| **Warrabah (WB)** | Leucoadamellite | 430—1042 m | 671—832 mm | 6000 ha | 15 km W Kingstown | NP, PR |
| **The Willows (WW)** | Undifferentiated | 700—850 m | 710—726 mm | 1500 ha | 40 km NW Glen Innes | PR |
| **Mount Yarrowyck (YH)** | Granodiorite | 800—1205 m | 812—758 mm | 1500 ha | 25 km W Armidale | NR, PR |

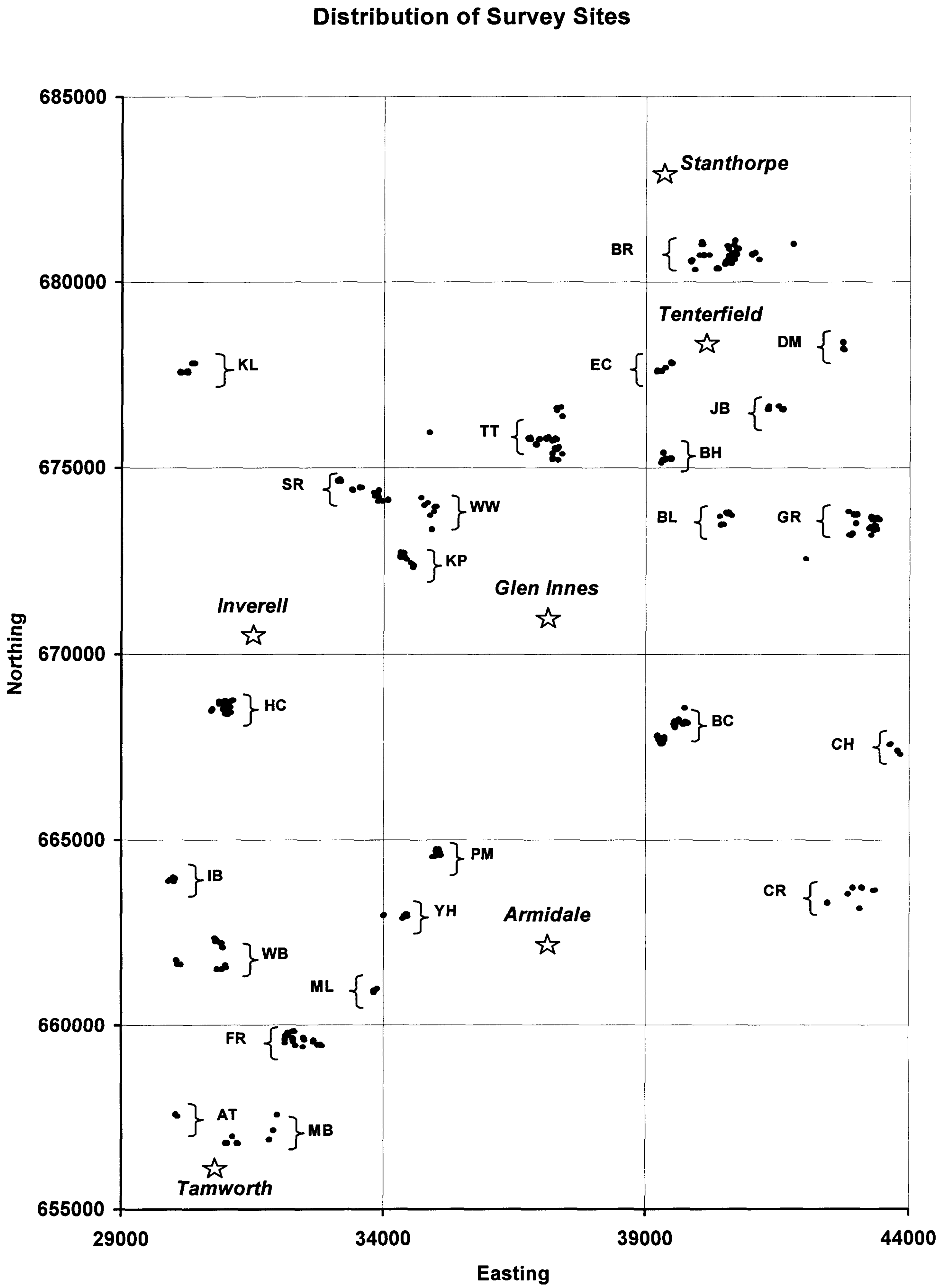



**Figure 2.4:** Distribution of the 24 granitic outcrop aggregated plutons ('archipelagos') of the New England Batholith. The scales of the axis are in AMG coordinates. Abbreviations are given in Table 2.1. Location of this section is given in Figure 2.1.

## 2.3 Survey methodology

### *2.3.1 Nested quadrat*

The survey was conducted between April 1994 and June 1996, using 32 m × 32 m (*c.* 0.1 ha) nested quadrats. The nested quadrat design first described by Bunce and Shaw (1973) and initially tested by Outhred (1984). This method is based on a series of smaller (nested quadrats) that decrease in size geometrically within a larger quadrat (Figure 2.2). Studies by Outhred (1984), Outhred, *et al.* (1985), Le Brocque and Buckney (1995), and Morrison, *et al.* (1995a; 1995b) have shown this method capable of detecting subtle community patterns by being functionally equivalent to frequency and directly related to plant density. The method was modified to enable approximately 0.1 ha to be surveyed and a frequency score of 10 be given to each taxon found. At the time of the survey, 0.1 ha was considered a standard size for vegetation surveys. Each quadrat was marked out by the placement of four 30 m measuring tapes marking the diagonals. Markings were placed on the measuring tapes at distances from the centre of the quadrat at 1, 1.4, 2, 2.8, 4, 5.7, 8, 11.2, 16 and 22.5 m. This divided the total quadrat into 9 subquadrats. The approximate cumulative areas are; 2, 4, 8, 16, 32, 64, 128, 256, 512 and 1024 $m^2$. All vascular plant species were recorded for each quadrat. The presence or absence of a taxon in each of the ten quadrats gave a frequency score out of ten for each taxon, providing a measure of relative abundance. This same alteration in design has been used by Clarke *et al.* (1998) and Hunter (1999) for vegetation surveys in the north east of New South Wales.

Boormann (1953) and Greig-Smith (1964) suggested that rectangular shaped plots are more efficient than square or circular shapes because of the tendency for vegetation to clump. The square shape has its advantages, as the distributions of the sub-quadrats are concentric in nature (Figure 2.5), the time spent (looking for species) arithmetically increases as the size of the sub-quadrat arithmetically increases. Therefore, the square shape of the plot and its sub-quadrats are important for equitable time-sharing of search effort. Additionally the nature of vegetation distribution on outcrop ('island') generally enables a number of vegetation patches to be sampled in a square plot.

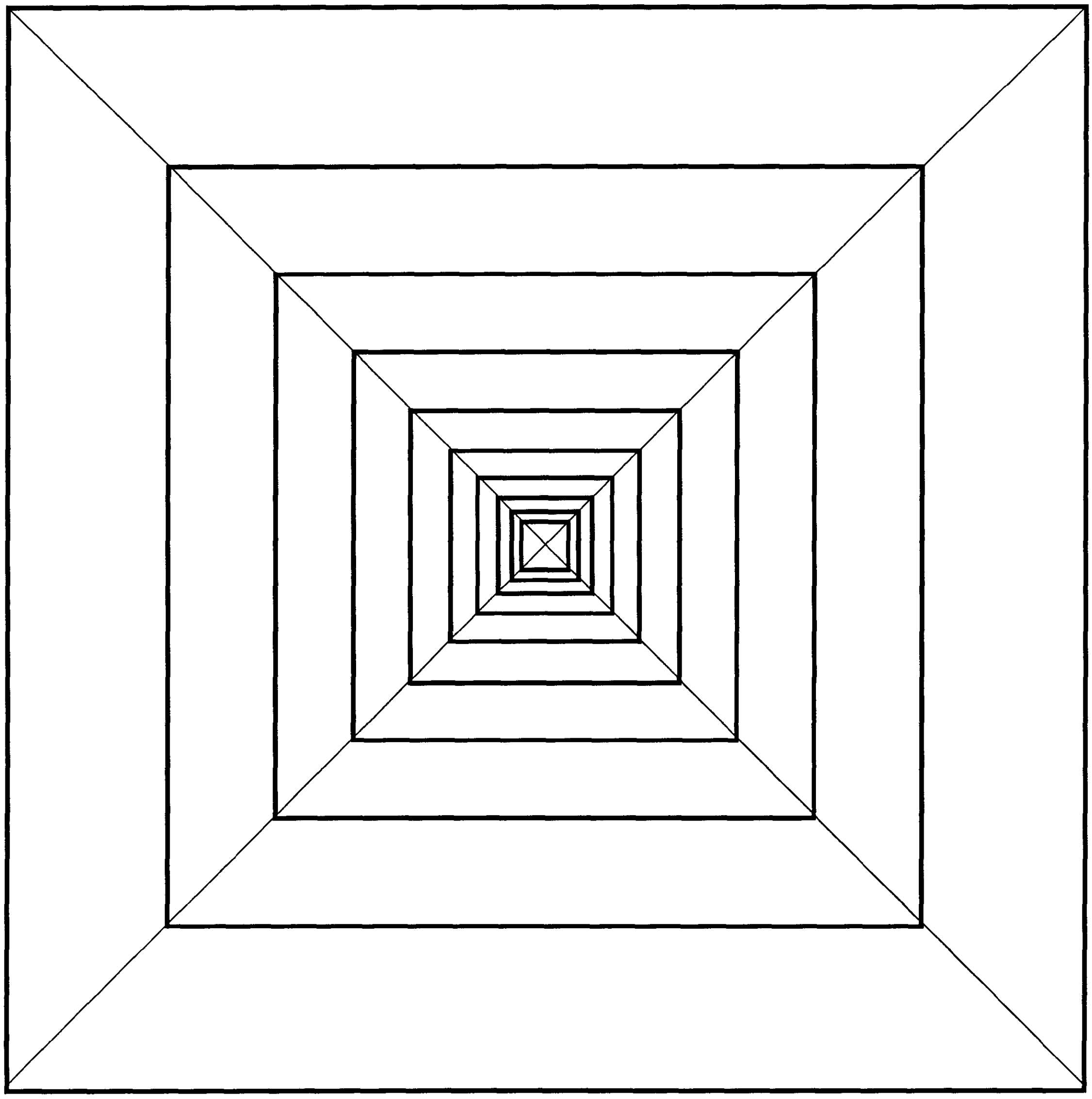


**Figure 2.5:** The 32 x 32 m (*c.* 0.1 ha) nested quadrat with nine sub-divisions developed by the author based on the design discussed by Outhred (1984). Four tape measures are reeled out 22.5 m from the centre of the quadrat forming the diagonals. The 10 quadrats have approximate cumulative areas of 2, 4, 8, 16, 32, 64, 128, 256, 512, and 1024 square metres.

### *2.3.2 Proportional allocation of quadrats to virtual 'archipelagos' (aggregated plutons)*

Based on an estimate of the number of days available for surveying, the potential number of quadrats that could be surveyed (after possible unforeseen delays) was 500. The distribution of the 500 quadrats (between the 24 aggregated plutons ('archipelago')) had to be equitable. Using aerial photographs and topographic maps, the extent of each 'archipelago' was mapped. The number of kilometre squares (cells) occupied on a topographic map was chosen as a measure of the relative size of each 'archipelago'. The smallest 'archipelago' occupied *c.* 500 ha and the largest *c.* 35000 ha. Due to the size difference in 'archipelagos' (two orders of magnitude) a simple linear distribution of quadrats was not appropriate. For this reason, the distribution of the number of quadrats to each 'archipelago' was based on a logarithmic scale. The number of quadrats assigned to each 'archipelago' is given in Table 2.2. This number was not achieved in all cases as detailed in Section 2.6.

**Table 2.2:** The number of cells (km squared) occupied by each of the 24 virtual 'archipelagos' (aggregated granitic plutons) and the number of quadrats assigned to each (see Section 2.3.2). See Figure 2.4 for location of the 'archipelagos'.

| *Region ('archipelago')* | *Number ha* | *Number of Quadrats Assigned* |
|---|---|---|
| **Mount Lookout (ML)** | 500 | 6 |
| **Demon (DM)** | 500 | 6 |
| **Chaelundi (CH)** | 800 | 10 |
| **Mount Jondol (JB)** | 800 | 10 |
| **Attunga (AT)** | 1000 | 12 |
| **Eagle Creek (EC)** | 1400 | 15 |
| **Yarrowyck (YH)** | 1400 | 15 |
| **Willows (WW)** | 1400 | 15 |
| **Moonbi (MB)** | 1600 | 16 |
| **Bolivia (BH)** | 2000 | 18 |
| **Parlour Mountains (PM)** | 2400 | 20 |
| **Kwiambal (KL)** | 2400 | 20 |
| **Kings Plains (KP)** | 2500 | 20 |
| **Butterleaf (BL)** | 2800 | 21 |
| **Cathedral Rocks (CR)** | 3000 | 22 |
| **Ironbark (IB)** | 3200 | 22 |
| **Flaggy Range (FR)** | 4500 | 25 |
| **Backwater (BC)** | 5000 | 26 |
| **Severn River (SR)** | 5500 | 27 |
| **Warrabah (WB)** | 6000 | 28 |
| **Howell (HC)** | 6500 | 29 |
| **Gibraltar Range (GR)** | 10000 | 32 |
| **Bald Rock\Girraween (BR)** | 26000 | 41 |
| **Torrington (TT)** | 35000 | 43 |
| **Total** | **123000** | **500** |

### 2.3.3 Minimum outcrop size and the proportional allocation of quadrats within a virtual 'archipelago' (virtual 'islands'; virtual 'seas')

*A priori* one hectare of exposed rock was the minimum size of outcrop ('island') surveyed as this size of exposed rock is identifiable from aerial photographs and enabled the placement of a 0.1 ha square quadrat (32 x 32 m) without undesirable edge effects. The approximate size in metres squared was determined for each outcrop ('island'), prior to being surveyed, via the simple measure of length x width determined with 'Metric Quadrangle Scales' on aerial photographs and topographic maps. The estimated size was often verified in the field by the use of a 'Hip Chain' distance measuring instrument'. The smallest outcrop was one hectare, the largest was 'Bald Rock' with *c.* 35 ha of exposed adamellite. A simple linear distribution of quadrats would not allow for sufficient sampling of outcrops ('islands') per 'archipelago'. As in Section 2.3.2, a log scale was used to allow equitable distribution of quadrats on outcrops ('islands'). The approximate size of each outcrop was plotted on a log graph and the number of quadrats was assigned (Figure 2.6). This ensured that any outcrop ('island') of a given size class was surveyed at the same intensity. This graph was taken into the field in order that last minute changes in size measurements, based on field observations could be accounted for by increasing or decreasing the number of quadrats assigned to each outcrop (Figure 2.6).

Where possible several *a priori* criteria were used in the selection of outcrop ('island') from each 'archipelago', these were:

1. A cross section of outcrop sizes should be sampled;
2. Duplicate outcrops of the same size should be sampled;
3. Enough smaller outcrops should be sampled so that their cumulative areas approximate the largest outcrop;
4. The degree of isolation should be varied (distance to nearest outcrop);

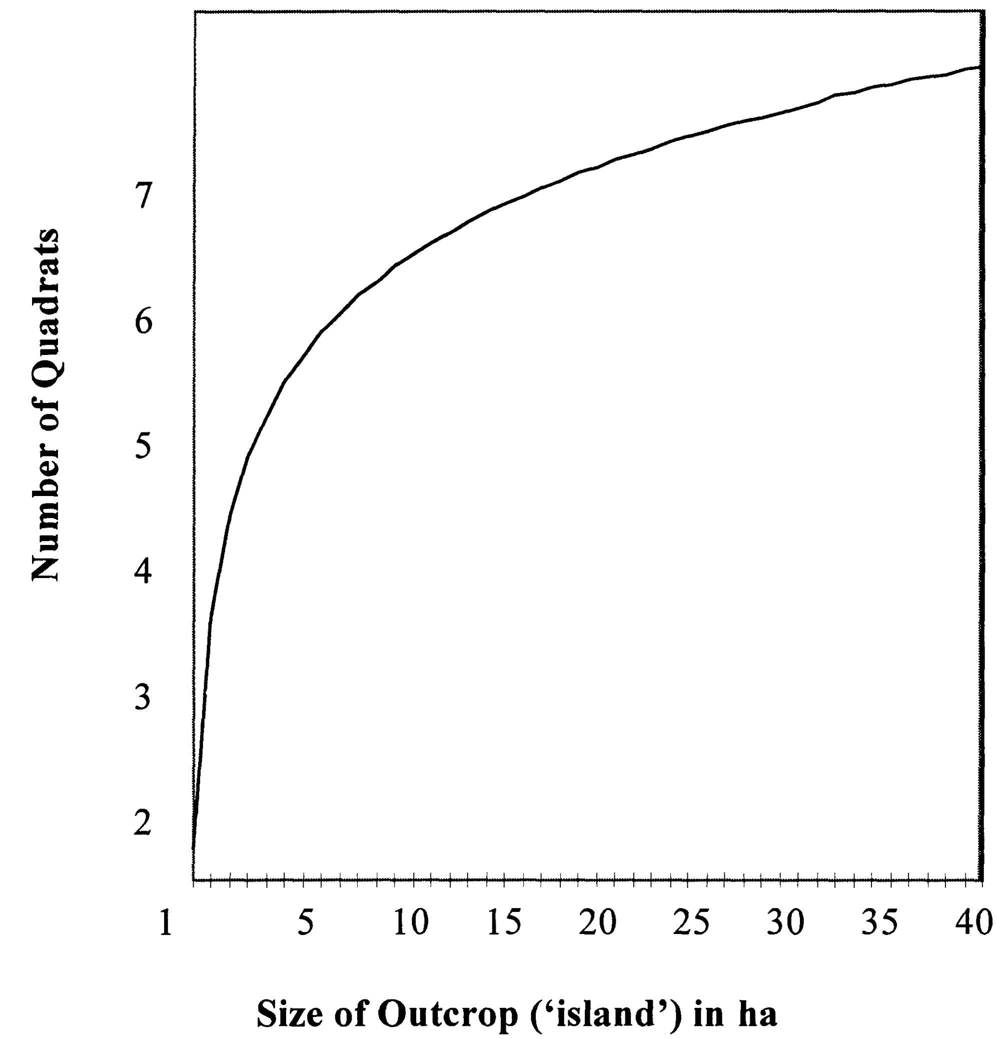



**Figure 2.6:** Log scale graph used for the determination of the number of samples within each outcrop ('island') (Section 2.3.3).

### *2.3.4 Placement of quadrats on outcrops (virtual 'islands')*

After the allocation of quadrats to 'archipelagos' and the selection of outcrops ('island'), plot placement needed to be considered. Strict random allocation was not appropriate as the area of exposed rock pediment (i.e. without vegetation) varied. For instance, on some of the larger outcrops such as 'Bald Rock', a large number of quadrats could be randomly allocated but all may have any vegetation (Figure 2.8). Not all places on outcrops were safe for sampling, either slopes were too steep or crevices too deep (Figure 2.6). Using aerial photographs as a guide and after ground inspection, vegetated patches (in moderately safe terrain) were given a number and numbers chosen at random from all those available on the outcrop ('island').

### *2.3.5 Sampling of the surrounding vegetation (virtual 'sea' )*

In addition to sampling outcrops ('islands') in each 'archipelagos', a number of quadrats were set aside for sampling the flora surrounding the outcrops (i.e. the virtual 'sea'). A numbered grid pattern was placed over remnant vegetation within 500 m of a sampled outcrop and plots placed based on random number selection. A representative sample of the 'sea' was taken from 21 of the 24 'archipelagos'. The 21 'archipelagos' were representative of the environmental variables encountered. Not enough sites were available for distribution to all 'seas'. The only 'archipelagos' not to have their 'sea' (surrounding flora) sampled were Attunga (AT), Bolivia Hill (BH), Butterleaf (BL) and Mount Balala (ML). This strategy enabled comparative analysis to be made between the surrounding flora ('sea'), and the outcrop ('islands') and 'archipelagos' and judgments to be made about the affective insularity of each 'archipelago' and outcrop ('island').

### *2.3.6 Survey pro-formas and collection of quadrat based data*

The position of each quadrat was determined by reference to aerial photographs and topographic maps. 'Australian Map Grid' (AMG) co-ordinates were taken from the topographic maps with the aid of 'Metric Quadrangle Scales'. In some instances a 'Global Positioning System' (GPS) was used in conjunction with topographic maps. AMG co-ordinates were converted to latitude and longitude by using 'GEOGRID Utility for Windows' (Earth Resources Australia 1995).

A unique identification number was assigned to each quadrat and determined as follows. The first five or six characters refer to the site. The first two characters of these refer to the 'archipelago'. Codes for these are given in Table 2.1. Distinction is then made between surrounding virtual 'sea' and outcrop ('island') plots with a consecutive number in the third and sometimes fourth, and sometimes fifth characters. The latter being an 'F' for the 'sea' plots or a 'O' for the 'island' plots. The final character (letter of the alphabet) identifies the quadrat on an outcrop. For example, the code GR5OC refers to a quadrat was placed within Gibraltar Range and was the third quadrat on the fifth outcrop ('island') sampled in that 'archipelago', while the code BR1FD would indicate the fourth 'sea' quadrat placed within the Bald Rock 'archipelago'.

Physical and environmental attributes were recorded. In general, the type of data collected was in concordance with other major surveys being conducted by organisations such as the Royal Botanic Gardens Sydney, State Forests of New South Wales and New South Wales National Parks and Wildlife Service. An example of the pro-formas developed for this survey is given in Appendix A.

Topological information was also collected along with measurements of altitude, slope, aspect and horizontal elevation. Altitude was taken from topographic maps. Slope and horizontal elevation were measured using a 'SUUNTO' optical reading clinometer, the horizontal elevation being measured at eight compass bearings (equally spaced for magnetic north), along the tape measures of the quadrat and at 45° to them (Section 2.3.1). Aspect was measured using a compass with reference to magnetic North (Magnetic Angle 10.3° east).

Details of habitat heterogeneity were taken along with overall vegetation cover in the quadrat (Figure 2.5 & 2.7). Some major habitat factors such as presence of boulders and crevices may strongly influence the number of micro-environments available within any individual plot thereby affecting the vegetation present (Figure 2.5 & 2.8). Boulders varied in size and the extent. Crevices, where most of the vegetation grew, could vary in depth and frequency. A five point scale was used to categorise the variation in both boulder size and crevice depth within each quadrat. A score of 1 for boulders indicated that only small boulders less than 1 m in diameter were present, a score of 5 indicated that a mixture of small, medium and large boulders (over 5 m diameter) were present. A score of 1 for crevices would indicate that only shallow depressions less than 25 cm were present, a score of 5 would indicate that a mixture of small, medium and larger crevices (over 5 m deep) were present. A similar index of fracturing was used for rock outcrop by Wiser *et al.* (1996). A six-point scale was used to indicate the areal extent covered by either crevices or boulders. This scale was arithmetic (a doubling of area covered) and a pictorial representation of this scale was used in the field (Figure 2.7). This same procedure was followed in scoring of habitat attributes for the whole outcrop ('island').

The degree of disturbance at each site was assessed using a 5 point scale. The individual effects of fire, clearing, pollution, and grazing at each quadrat were ranked at the time of surveying via a 5 point scale, with 1 signifying no disturbance and 5 a severe disturbance.

A soil sample large enough to fill a 15 x 15 cm press-sealed bag was collected at each quadrat for determination of pH. The sampling methodology of Rayment and Higginson (1992) was followed. Soil was collected from the centre of each plot and placed into a plastic bag and labeled using permanent ink. On return from each field trip the soils were immediately air dried and then stored in a cool room. Representative rock samples were also taken for verification from each 'archipelago' or whenever the substrate differed from the known rock type.

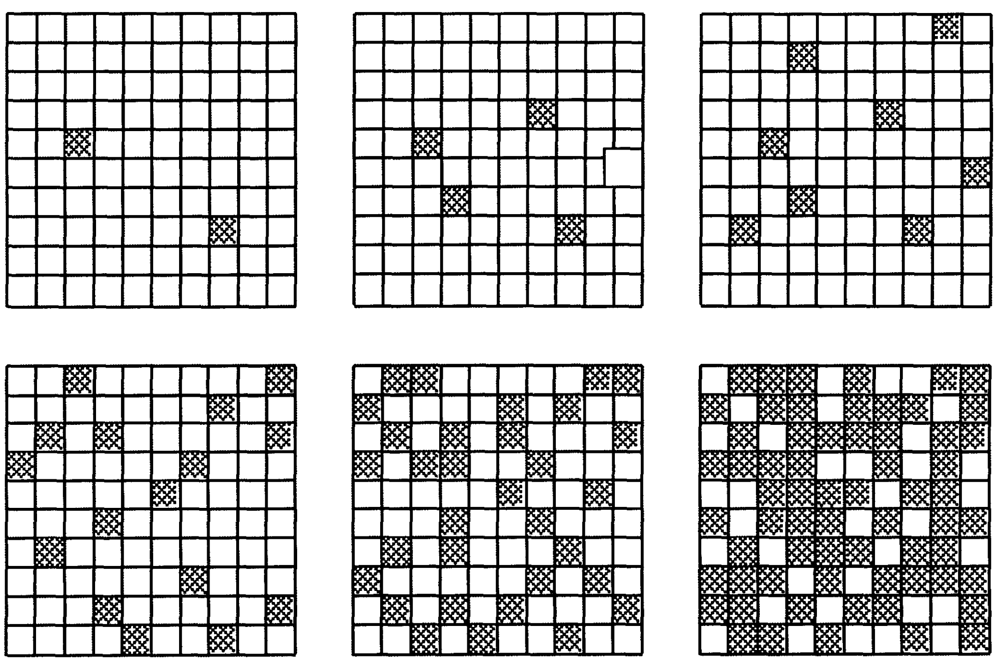


**Figure 2.7:** A pictorial representation of the six-point scale used to assess cover. This chart was taken in the field in order to score the area covered by boulders and vegetation in each quadrat and on each outcrop ('island'). The hatched grids represent 2, 4, 8, 16, 32 and 64% cover.

### 2.3.7 Voucher collections of plant material

One voucher specimen of each taxon was collected from each 'archipelago' when possible. Specimens were placed in the N.C.W. Beadle Herbarium of the University of New England (NE) with duplicates, when available, sent to the National Herbarium of New South Wales (NSW) and Queensland Herbarium (BRI). A small reference set was also set aside and placed in folders for use by the author. Additional material was collected of taxa considered unusual, being different morphologically, rare or out of normal geographic range. Approximately 2000 voucher specimens were collected during this survey. They were re-examined at the end of the survey to check the accuracy of identifications and provide up-to-date nomenclature.

### 2.3.8 Access to sites

Relevant scientific investigation licences were acquired from the New South Wales and Queensland National Parks and Wildlife Service and the State Forests of New South Wales. Since at the time of the survey the Torrington area was held under the control of the 'Torrington Regional Trust', special access permission was gained from that trust. A large proportion of the land investigated was held under private, leasehold and permissive occupancies and permission needed to be gained from all relevant land managers. The 'Shire' and 'Parish' names and 'Portion' numbers of properties were obtained from topographic maps. The names and addresses of land managers were provided by the relevant shire councils. A standard letter with a questionnaire attached (Appendix A) was sent to each land manager. The questionnaire contained boxes to be marked. A stamped return envelope was included. This procedure, requiring little effort on the part of the land manager, resulted in a very high rate of return.

## 2.4 Determination of soil pH

The '1:5 Soil/Water Suspension Method' of Rayment and Higginson (1992) was used for determining soil pH. 20.00 g of air-dry soil and 100 mL of deionised water were placed in a glass jar. 48 jars at a time were placed on a mechanical tumbler that turned the jars end-over-end for one hour. Room temperature was *c.* 25°C. The solutions were allowed to stand for 30 min to allow the soil to settle. The pH meter was standardised using three buffer solutions before and after each session. The solutions were mechanically stirred during measurement. The electrodes were well immersed and the pH value was obtained when the meter appeared to be steady. After each measurement, the electrodes were washed thoroughly with deionised water. Replicate determinations were periodically made on the same solutions to ensure results did not vary within samples by ± 0.1 pH.

## 2.5 Acquisition of environmental data

Site specific climatic data for each quadrat was acquired under licence from the Centre for Resource and Environmental Studies (CRES), the Australian National University. Climate was modelled using 'BIOCLIM – The BIOCLIMatic Prediction System' (McMahon 1995). Twenty-seven bioclimatic attributes were modelled for each plot, these included:

- Annual Mean Temperature
- Mean Diurnal Range (Mean period max-min)
- Isothermality
- Temperature Seasonality
- Maximum Temperature of Warmest Period
- Minimum Temperature of Coldest Period
- Temperature Annual Range
- Mean Temperature of Wettest Quarter
- Mean Temperature of Driest Quarter
- Mean Temperature of Warmest Quarter
- Mean Temperature of the Driest Quarter
- Precipitation Seasonality
- Precipitation of Wettest Quarter
- Precipitation of Driest Quarter
- Precipitation of Warmest Quarter
- Precipitation of the Coldest Quarter

- Annual Mean Radiation
- Highest Period of Radiation
- Lowest Period of Radiation
- Radiation Seasonality
- Radiation of the Wettest Quarter
- Radiation of the Driest Quarter
- Radiation of the Warmest Quarter
- Radiation of the Coldest Quarter

## 2.6 Database development and management

'Paradox 7 for Windows' (Borland 1995) a relational database, was used for data management, validation, storage and retrieval. The 'parent' tables were created with verified information that was used for data entry in 'child' tables allowing consistency in data entry (for example the spelling of species names) (Campbell 1984; McKenzie 1991; McKenzie *et al.* 1991). Three 'parent' tables (SPINFO, QINFO, SINFO) were created to store information with six child tables used for referential integrity, validation and data entry. The three 'parent' tables stored information relating to the taxa, quadrats and the outcrops ('island'). The region number, site number and quadrat number (Section 2.3.6) were the relational fields used to link the three 'parent' tables. The site codes were unique and duplicate values were not accepted by the database. The system was designed to minimise the number of keystrokes, and to allow for subsequent specimen determinations and results of analyses to be incorporated later. Field data collected during a single field trip were added either at night in the field on a 'note book' computer or immediately on returning from the field on the main computer. Thus, discrepancies could be sorted out while the relevant survey sites were fresh in the mind.

### 2.6.1 'SPINFO' the taxon specific database table

The 'SPINFO' table is the primary table for the storage of information on taxon locality. The 18 fields of information specific to individual taxa are held within this table. These fields include:

1. **Name** – The genus and specific epithet.
2. **Caps Code** – These codes are unique four digit numbers for each taxon. These codes are held and maintained by the New South Wales National Parks and Wildlife Service.
3. **Region No.** – The unique two digit code for each 'archipelago' (Section 2.3.6).
4. **Site No.** – The unique two or three digit code for each outcrop in an 'archipelago' (Section 2.3.6).
5. **Quadrat No.** – The alphabetical code for each quadrat placed on an outcrop (Section 2.3.6).
6. **Authority** – The name of the author who validly published the name concerned, Art 46.1 (ICBN 1994).
7. **Family** – The family to which each taxon belongs.
8. **Infrastatus** – The rank of an infraspecific taxon if applied.
9. **Infraspecific** – The infraspecific name given to a taxon if ascribed.
10. **Infra-authority** – The author who validly published the infraspecific name concerned.
11. **Abundance** – The relative abundance score obtained from the nested quadrat design (Section 2.3.1). A maximum value of ten and a minimum of one are set for this field.
12. **Status** – Whether the taxon is introduced or native to the region.
13. **ROTAP** – The conservation code applied to each taxon (Section 2.5.4).
14. **Accuracy** – A three-point scale defining the probability that the name applied to the taxon by the author is correct: 'Accurate', 'Probably' and 'Best Guess'.
15. **Primary Lifeform** – The basic architecture of a taxon, that is whether a tree, shrub, etc. (Section 2.5.4).

16. **Secondary Lifeform** – A further sub-division of the primary architecture (Section 2.5.4).
17. **Tertiary Lifeform** – A subtype of the secondary lifeform category (Section 2.5.4).
18. **Insularity Number** – The Quotient of Insularity subsequently given to each taxon after the survey was conducted and which is derived from work conducted in Chapter 3.

Only fields 3, 4, 5, 11, and 14 are unique to each record. For instance, a taxon will almost inevitably occur in more than one site but for additional sites the locality, abundance and the accuracy of identification will change. The fields 1, 2, 6, 7, 8, 9, 10, 12, 13, 15, 16, 17, and 18 are not unique and are applied each time a species is entered. Therefore, the latter fields were held in a separate table labelled 'species' (section 2.5.4). A form for entering data into the 'SPINFO' table and linking the 'species' table was created. The 'species' table has been designated as a 'lookup' table for the 'SPINFO' table. As each character is typed in spelling a taxon name, the 'Species' table is searched. Usually after the entry of only a few characters, the taxon to be entered is found, by returning the record the fields 1, 2, 6, 7, 8, 9, 10, 12, 13, 15, 16, and 17 (Appendix C) are automatically attached to each taxon. This process increased data entry accuracy.

### *2.6.2 'QINFO' the quadrat specific database table*

The 'QINFO' is the primary table for storage of data unique to each quadrat. Sixty-six fields were included in the table that describes the physical nature and topography of each individual quadrat. These fields include:

1. **Region No.** - The unique two digit code for an 'archipelago' (Section 2.3.6).
2. **Site No.** – The unique two or three digit code for each outcrop in an 'archipelago' (Section 2.3.6).
3. **Quadrat No.** – The alphabetical code for each quadrat placed on an outcrop (Section 2.3.6).

4. **Community No.** – The community identification code derived from the analysis performed in Chapter 4.
5. **Date** – Date that the quadrat was sampled.
6. **Aspect** – Compass slope direction of quadrat, in degrees.
7. **Slope** – The downward inclination of each site, measured in degrees.
8. **Acidity** – The acidity of a soil sample taken at the centre of each quadrat (Section 2.4).
9. **Air Photo** – The name, magnification, place in series and date of the aerial photograph showing the locality of the site.
10. **Habitat** – A brief habitat description taken at the time the site was surveyed.
11. **Map** – The name, magnification and series name of the topographical map showing the locality of the site.
12. **Easting** – The Australian Map Grid (AMG) easting co-ordinate of the surveyed site.
13. **Northing** – The AMG northing co-ordinate of the surveyed site.
14. **Fire** – A five-point scale of disturbance intensity (Section 2.3.6).
15. **Clearing** – A five-point scale of disturbance intensity (Section 2.3.6).
16. **Pollution** – A five-point scale of disturbance intensity (Section 2.3.6).
17. **Grazing** – A five-point scale of disturbance intensity (Section 2.3.6).
18. **Faulting** – A five-point scale of the degree of faulting (crevice depth) within a quadrat (Section 2.3.6; Figure 2.8).
19. **Vegetation Cover** – A six point arithmetic scale of projective vegetation cover within the quadrat (Section 2.3.6; Figure 2.8 & 2.9).
20. **Boulders** – A five-point scale of heterogeneity of boulder size within a quadrat (Section 2.3.6; Figure 2.11).
21. **Boulder Cover** – A five-point scale of boulder numbers and cover within a quadrat (Section 2.3.6; Figure 2.7).
22. **Additional notes** – Any additional notes made about the physical nature of the quadrat.
23. **Elevation N** – The angle of incline to the northern horizon (Section 2.3.6).
24. **Elevation NE** – The angle of incline to the north east horizon (Section 2.3.6).

25. **Elevation E** – The angle of incline to the eastern horizon (Section 2.3.6).
26. **Elevation SE** – The angle of incline to the south east horizon (Section 2.3.6).
27. **Elevation S** – The angle of incline to the southern horizon (Section 2.3.6).
28. **Elevation SW** – The angle of incline to the south west horizon (Section 2.3.6).
29. **Elevation W** – The angle of incline to the western horizon (Section 2.3.6).
30. **Elevation NW** – The angle of incline to the northwest horizon (Section 2.3.6).
31. **Number of taxa** – The richness of each quadrat.
32. **Longitude** – The longitudinal location of each quadrat.
33. **Latitude** – The latitudinal location of each quadrat.
34. **Altitude** – The approximate altitude of the centre of the quadrat.
35. **Decimal Longitude** – The longitudinal location of each quadrat on a decimal scale.
36. **Decimal Latitude** – The latitudinal location of each quadrat on a decimal scale.

37– 63. **Climatic Parameters** – The 27 climatic parameters are those give in Section 2.5 that have been derived from BIOCLIM modelling.

64. **Insularity Number** – The Quotient of Insularity, a number derived subsequently from the survey results and calculated in Chapter 3.
65. **Modified Aspect -** Aspect was coded into four 90° groups for use in analyses thereby avoiding the problem that north is both 0° and 360°. 1 = NNW to NNE; 2 = W to NNW, E to NNE; 3 = W to SSW, E to SSE; 4 = SSE to SSW. This assumes that the greatest differences are between N and S (Söderström 1981).
66. **Modified Geology** – Geology was coded into a five point scale based on the fact that Granite and Granodiorite are at opposing ends of the scale. Granite = 1; Leucoadamellite = 2; Adamellite = 3; Granodiorite = 4. The increase in the scale corresponds to a

decrease in potassium feldspar (75%—0%) and an increase in sodium plagioclase (5%—75%) (Skinner & Porter 1987).

### *2.6.3 'SINFO' the outcrop ('island') specific database table*

The 'SINFO' is the primary table for storage of data unique to each outcrop ('island'). Seventeen fields were included in the table that describe the physical, topographic and tenure of each outcrop ('island'). These fields include:

1. **Site No.** – The unique two or three digit code for each outcrop in an 'archipelago' (Section 2.3.6).
2. **Region No.** – The unique two digit code for an 'archipelago' (Section 2.3.6).
3. **Division** – The botanical division in which the outcrop occurs, as accepted by Hnatiuk (1990).
4. **Region** – The general name for the area in which the VI occurs.
5. **Geology** – The granitic geology of the VI, usually based on geological maps with ground truthing.
6. **Granite Landform** – A brief outline of the type of outcrop, for instance, whaleback, castle koppie, rock pediment, etc.
7. **Outcrop size** – The approximate size in hectares of each outcrop (Section 2.3.3).
8. **Tenure** – The incumbency of the land where the outcrop is located.
9. **Vegetation Cover** – The overall projected vegetation cover on the outcrop on a six-point scale (section 2.3.5; Figure 2.5 & 2.7).
10. **Boulder Cover** – A five-point scale of boulder numbers and cover within the outcrop (Section 2.3.6; Figure 2.8 & 2.9).
11. **Boulders** – A five-point scale of heterogeneity of boulder size within the outcrop (Section 2.3.6; Figure 2.11).
12. **Faulting** – A five-point scale of crevice depth within the outcrop (Section 2.3.6; Figure 2.9).
13. **No. of Taxa** – The richness of the outcrop.

14. **Mean No. of Taxa/Quadrat** – The mean richness of the quadrats placed on the outcrop.
15. **Range of Taxon Richness** – The maximum and minimum richness of quadrats placed on the outcrop.
16. **The No. Quadrats Placed** – The number of quadrats placed on the outcrop.
17. **Average Altitude** – The average altitude of all quadrats placed on the outcrop.

### *2.6.4. 'SPECIES' the validation table of taxon information and associated parent tables*

The 'SPECIES' database table stores information on nomenclature, habit, conservation status and distribution that is applicable to each taxon. This table was used to enter consistent information into the 'SPINFO' table to ensure accuracy (Section 2.5.1). There are 109 fields included within this database table, 12 of which are linked to the 'SPINFO' table - for details on these fields refer to Section 2.5.1. The remaining 97 fields refer to the distribution of each taxon within Australia based on the 97 botanical divisions recognised by Hnatiuk (1990).

The distributions of taxa within the 97 recognised Australian botanical divisions were derived from numerous sources. Initially, presence of a taxon in a division was based on Hnatiuk (1990). These records were matched with information from recently published state floras and articles, in particular; *Flora of New South Wales* (Harden 1990—1993), *Queensland Vascular Plants: Names and Distributions* (Henderson 1994), *Flora of Victoria* (Walsh & Entwisle 1994—1996), *List of Vascular Plants in South Australia* (Jessop 1989), and publications found in *Australian Systematic Botany* and the Australian herbarium journals *Telopea, Austrobaileya*, *Muelleria*, *Journal of the Adelaide Botanic Gardens* and *Nuytsia.*

The data entered into the 'ROTAP' (Rare or Threatened Australian Plants) field are based on the codes derived from Briggs and Leigh (1996) which were applied to the taxon at the time of the survey. The accepted codes were derived from Quinn *et al.*

(1995), Briggs and Leigh (1996), or recent publications. Codes were also given to taxa that are listed under the Threatened Species Conservation Act (New South Wales Government 1995) but not listed under the ROTAP codes. Some undescribed taxa have also been given nominal codes by the author.

Not all fields were unique. These fields included 'Family', 'Authority', 'Infraspecific Authority', 'Primary Lifeform', 'Secondary Lifeform', and 'Tertiary Lifeform'. To allow consistency in data entry for these fields, each was held in a separate table and each defined as 'lookup' tables (Section 2.5.1) for the 'SPECIES' table.

The 'Family' 'lookup' table holds all vascular plant family names currently recognised as occurring in New South Wales by Harden (1990—1993). The spelling of family names were verified with reference to Brummitt (1992).

The separate 'Authority' table was used for data entry in both the fields 'Authority' and 'Infraspecific Authority'. The allocations of authority names were based on those given in the *Australian Plant Name Index* (Chapman 1991) or from recent publications. Author abbreviations conform to those standardized for plants given by Brummitt and Powell (1992).

The three life form categories were represented by separate 'lookup' tables. The life form records themselves are not all encompassing and are meant only as a relative guide to the architecture of each taxon. Some taxa will only be represented by the primary and secondary life form categories, while others are represented by all three. The records held by the life form database tables are given by Table 2.3.

**Table 2.3:** Life form categories used to describe general architecture of each taxon in the three life form tables (based on categories of Clarke 1994).

| Primary Lifeform | Secondary Lifeform | Tertiary Lifeform |
|---|---|---|
| Dwarf Shrubs (< 0.25 m tall) | Annual or Ephemeral | Broom Shrubs |
| Epiphytes | Broad-leaved Deciduous Tree | Deciduous Shrubs |
| Hemi-parasites | Broad-leaved Evergreen Tree | Mesomorphic Evergreen Shrub |
| Herbs | Ferns | Needle or Scale-leaved Tree |
| Lianes & Vines | Forbs | Saltbush Shrubs |
| Low Shrubs (0.25 to 2 m tall) | Geophytes | Sclerophyll Evergreen Shrub |
| Low Tree (7 to 15 m tall) | Halophytes | Succulent Herbs |
| Medium Tree (15 to 25 m tall) | Hummock Grasses | Succulent Shrubs |
| Tall Shrubs (2 to 7 m tall) | Mallee | Thorn Shrubs |
| Tall Tree (> 25 m tall) | Multi-stemmed Shrub | |
| | Needle or Scale-leaved Tree | |
| | Rosette Shrubs | |
| | Sclerophyll Evergreen Tree | |
| | Single Stemmed Shrubs | |
| | Thorn Trees | |
| | Tussock Grasses | |
| | Unbranched | |

## 2.7 Preliminary results based on survey methodology: number and distribution of sample sites

Regression of the six-point scale of vegetation cover (Section 2.6.3) on outcrops with outcrop size indicates that vegetation cover decreases exponentially with increasing outcrop size ($y=1490.437 + \exp(12.89+(-0.84)*X)$; $R = 0.79$, 61.6% of variance accounted for). Thus indicating that overall the sampling design was linear despite the logarithmic allocation of plots based on increasing outcrop size.

In some instances, the basic survey methodology was modified. This was caused by the tradeoff between bias (due to technical problems such as access, time, etc.) and obtaining a representative sample for statistical analysis (Austin 1984). The number of sites and outcrops sampled produced a data set amenable to the type of investigation foreshadowed (Chapter 1).

In total, 522 quadrats were floristically sampled from 24 designated 'archipelagos'. Of the 522 sites, 399 quadrats were placed on (216) outcrops ('islands'), with the remaining 123 plots being placed in the surrounding vegetation ('sea'). Seven of the 24 'archipelagos' was not sampled to the desired intensity required by the methodology (Section 2.3.2; Table 2.4). The 'archipelagos' Attunga (AT), Butterleaf (BL), Chaelundi (CH), Cathedral Rock (CR), Parlour Mountain (PM), Willows (WW) and Yarrowyck (YH) were all under sampled. In most instances, this was due to the aggregated plutons associated with these VAs having very few exposed granitic areas over the minimum required 1 ha size (Figure 2.9). This was particularly so for Attunga (AT), Chaelundi (CH) and Yarrowyck (YH). Most of the outcrops within the CR area were nubbins and castle koppies (Figure 2.10) which were not amenable to the survey methodology. Lack of access to areas within Butterleaf (BL), Parlour Mountain (PM) and Yarrowyck (YH) decreased the number of outcrops available. A large area, including many outcrops within the Butterleaf (BL) 'archipelago', occurred on land for which permission to enter was not given. Land within the Willows (WW) is owned by the Glen Innes Aboriginal Land Council and permission for only a few days work was given. This limited the number of sites that could be surveyed.

Some quadrats were available for redistribution due to the circumstances outlined above. Three 'archipelagos', Backwater (BC), Bald Rock (BR) and Howell (HC) were chosen for increased sampling purposes (Table 2.4). The areas had the greatest range in outcrop sizes, a large number of outcrops, easy access, represented the three most common rock types, and were geographically separated on the New England Batholith.

The methodology set out in Section 2.3.3 was followed where possible in each 'archipelago'. Some 'archipelagos' did not allow the equitable distribution of quadrats on different outcrop sizes. Only a few 'archipelagos' had the larger outcrops and when these where present they were in low numbers. Thus, the sampling of large outcrops was minimal or non-existent for many 'archipelagos' (Table 2.5). Although Gibraltar Range (GR) and Torrington (TT) were areas with a large number of outcrops. However, most outcrops were small or consisted of unsurveyable nubbins and castle koppies.

Regionally only one outcrop of the largest size category was sampled. However, many replicates of all of the other outcrop size categories were sampled across the region, with size category five, the least replicated. It however, is still represented by five outcrops that are geographically spread (Table 2.5).

**Table 2.4:** The number of quadrats assigned to each of the 24 'archipelagos' (aggregated granitic plutons) compared to the actual number of quadrats sampled (see Section 2.3.2). Figure 2.4 shows the locations of the 'archipelagos'.

| *Region ('archipelago')* | *Number Assigned* | *Number Sampled* |
|---|---|---|
| **Mount Lookout (ML)** | 6 | 6 |
| **Demon (DM)** | 6 | 6 |
| **Chaelundi (CH)** | 10 | 6 |
| **Mount Jondol (MJ)** | 10 | 10 |
| **Attunga (AT)** | 12 | 2 |
| **Eagle Creek (EC)** | 15 | 16 |
| **Yarrowyck (YH)** | 15 | 10 |
| **Willows (WW)** | 15 | 11 |
| **Moonbi (MB)** | 16 | 16 |
| **Bolivia Hill (BH)** | 18 | 19 |
| **Parlour Mountains (PM)** | 20 | 14 |
| **Kwiambal (KL)** | 20 | 18 |
| **Kings Plains (KP)** | 20 | 18 |
| **Butterleaf (BL)** | 21 | 15 |
| **Ironbark (IB)** | 22 | 20 |
| **Cathedral Rocks (CR)** | 22 | 7 |
| **Flaggy Range (FR)** | 25 | 30 |
| **Backwater (BC)** | 26 | 45 |
| **Severn River (SR)** | 27 | 29 |
| **Warrabah (WB)** | 28 | 29 |
| **Howell (HC)** | 29 | 45 |
| **Gibraltar Range (GR)** | 32 | 34 |
| **Bald Rock \ Girraween (BR)** | 41 | 69 |
| **Torrington (TT)** | 43 | 47 |
| **Total** | **500** | **522** |

**Table 2.5:** The number of outcrops ('islands') sampled in each size class and within each virtual 'archipelago' (Section 2.3.3).

| Region ('archipelago') | 1 | 2 | 3 | 4 | 5 | 6 | 7 | No. of outcrops |
|---|---|---|---|---|---|---|---|---|
| Attunga (AT) | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| Backwater (BC) | 3 | 2 | 2 | 1 | 2 | 2 | 0 | 12 |
| Bolivia Hill (BH) | 4 | 4 | 1 | 1 | 0 | 0 | 0 | 10 |
| Butterleaf (BL) | 4 | 1 | 0 | 1 | 1 | 0 | 0 | 7 |
| Bald Rock/Girraween (BR) | 4 | 5 | 0 | 3 | 1 | 3 | 1 | 17 |
| Chaelundi (CH) | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| Cathedral Rock (CR) | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 2 |
| Demon (DM) | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| Eagle Creek (EC) | 7 | 0 | 1 | 0 | 0 | 0 | 0 | 8 |
| Flaggy Range (FR) | 16 | 3 | 1 | 0 | 0 | 0 | 0 | 20 |
| Gibraltar Range (GR) | 10 | 4 | 0 | 0 | 0 | 1 | 0 | 15 |
| Howell (HC) | 6 | 0 | 3 | 4 | 0 | 2 | 0 | 15 |
| Ironbark (IB) | 5 | 1 | 1 | 0 | 1 | 0 | 0 | 8 |
| Jondol (JB) | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| Kwiambal (KL) | 7 | 2 | 0 | 0 | 0 | 0 | 0 | 9 |
| Kings Plains (KP) | 6 | 3 | 0 | 0 | 0 | 0 | 0 | 9 |
| Moonbi (MB) | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 3 |
| Mount Lookout (ML) | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 3 |
| Parlour Mountains (PM) | 5 | 0 | 0 | 1 | 0 | 0 | 0 | 6 |
| Severn River (SR) | 7 | 1 | 0 | 2 | 0 | 1 | 0 | 11 |
| Torrington (TT) | 26 | 4 | 1 | 1 | 0 | 0 | 0 | 31 |
| Warrabah (WB) | 8 | 2 | 1 | 2 | 0 | 0 | 0 | 13 |
| Willows (WW) | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 4 |
| Yarrowyck (YH) | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 4 |
| No. VIs | 139 | 32 | 13 | 17 | 5 | 10 | 1 | 216 |

## 2.8 Discussion of survey methods

The nested quadrat was a rapid and accurate means for surveying vegetation communities. After experience was gained, the method could be completed within *c.* one hour or often less depending on the richness and diversity of the vegetation at the site. This is comparable to other survey methods commonly used.

The Braun-Blanquet (1982) cover-abundance approach for example, commonly used to acquire an importance scale for taxa, inevitably introduces observer bias. Some problems include:

1. Conspicuous species (e.g. bright showy flowers) are given a high rating, as they are more noticeable to the observer;
2. Species that are known to the surveyor often are given higher scores due to easy recognition;
3. Inconspicuous herbs will often be given comparatively lower scores although they may cover a large area;
4. The surveyor is not forced to search the entire quadrat evenly;
5. Different observers will often give different estimates of cover-abundance (Inglis & Lincoln Smith 1995).

With the nested quadrat procedure problems of observer bias were reduced because it forces the observer to look for every species 10 times and to search all areas of the quadrat evenly (Section 2.3.1). Inglis and Lincoln Smith (1995) found that abundance measurements were more comparable between different observers than cover. Furthermore, by marking the quadrat with tape measures on the diagonals the margins of the quadrat were more clearly defined.

The return of questionnaires was high. The type of landholder questionnaire used proved very effective with all but one letter being returned. Only two outright refusals were given. Most landholders were keen to know about the land and the plants they managed and welcomed the survey. This is in contrast to difficulties experienced in some of the same areas by Le Brocque and Benson (1995). The assistance of landholders was invaluable. Their local knowledge of plant distributions both past and present and of the disturbance history such as logging and fires was useful.

Many problems associated with data collection, collation, entry, validation, and subsequent retrieval were minimised by using the relational database. Only one person carried out all surveying, collation, data entry, validation and retrieval. The number of steps needed to collect and process information, and the errors associated with this (Choo 1991; NRAC 1995), were minimised.

The most important post survey features of the methodology was the use of specimen voucher (Section 2.3.6) and the relational database (Section 2.5) for information storage. The importance of vouchering is discussed by Hosking *et al.* (1996) who concluded that without vouchers one may as well not publish results. Revisiting vouchered specimens allowed identifications to be cross-checked with others presumably conspecific and accurately identified. This was a particularly important exercise in regard to the earlier work when taxon recognition by the author was less accurate. Lodgment of vouchers at the N.C.W. Beadle Herbarium of the University of New England (hereafter referred to as NE) also gave many taxonomic specialists the chance to check the author's identifications when they visited. This occurred particularly in taxa from the Myrtaceae but also in other families and genera. This process enabled the recognition of new species (Appendix H). As Hosking *et al.* (1996) state, current taxonomic knowledge is continually changing, and what was once one species may be split into ten or *vice versa*. Many name changes have occurred during this project. Vouchers could be checked with up-to-date descriptions and nomenclature changes as they were published. These changes in naming could be traced to specific sites. With the database design, such changes could be made with minimal effort and prior to analyses being conducted. Such basic procedures should be encouraged in future survey methodologies.

An unbiased sampling methodology is the unobtainable goal of any survey design. The stratification outlined within this Chapter is not unbiased, but how decisions are made is clearly defined and represents a compromise between representativeness, bias, practicality and randomness (Austin 1984). As very few 'archipelagos' were not sampled, representativeness was considered adequate at this scale. Representativeness was mainly constrained within 'archipelagos' by the number of quadrats assigned. Thus, an increase in representation could only be acquired by increasing sampling within an archipelago, this was somewhat overcome (with some bias) by allowing extra placement of sites within selected 'archipelagos' (namely Backwater (BC), Bald Rock (BR) and Howell (HC)). Within outcrops, representation was constrained by practicality. For example, some areas such as nubbins and deep crevices could not be surveyed. The choice of outcrops within 'archipelagos' allowed sampling of vegetation communities over the entire 'archipelago'. In some 'archipelagos' this was not possible due to access. Inaccessible areas included, the western areas of Torrington (TT) (which were at the time under the control of the 'Torrington Regional Trust'), the western portion of (Howell) HC, the eastern portion of Demon (DM) and the southern areas of Gibraltar Range (GR). Despite the use of a log scale in distributing sites the overall stratification of sites remained predominantly linear due to a corresponding log decrease in vegetation cover as outcrop size increased.

All 'archipelagos' occurring on the New England Batholith were surveyed with only a few exceptions. These exceptions represented areas with only a few rock outcrops and were close to the larger 'archipelagos' sampled. The largest of these areas was the Basin Nature Reserve north west of Armidale. This reserve is virtually inaccessible, steep sided, has no internal roads and is totally landlocked by private holdings. Sundown National Park in Queensland is difficult to access and only has minor occurrences of small rock outcrops. Other places not sampled included a few minor sites located between Guyra and Inverell and near Woolbrook.

Some significant problems could not be accounted for in the survey design. Of note are those associated with a large survey being conducted by a single researcher. Plots could not be sampled within a single season or in some circumstances within a single calendar year. Therefore, it is likely that annual and ephemeral species may have been sampled more intensively in some 'archipelagos' than in others. Compounding this effect was a severe and extended drought that affected all areas surveyed in the years from 1993 to 1996.

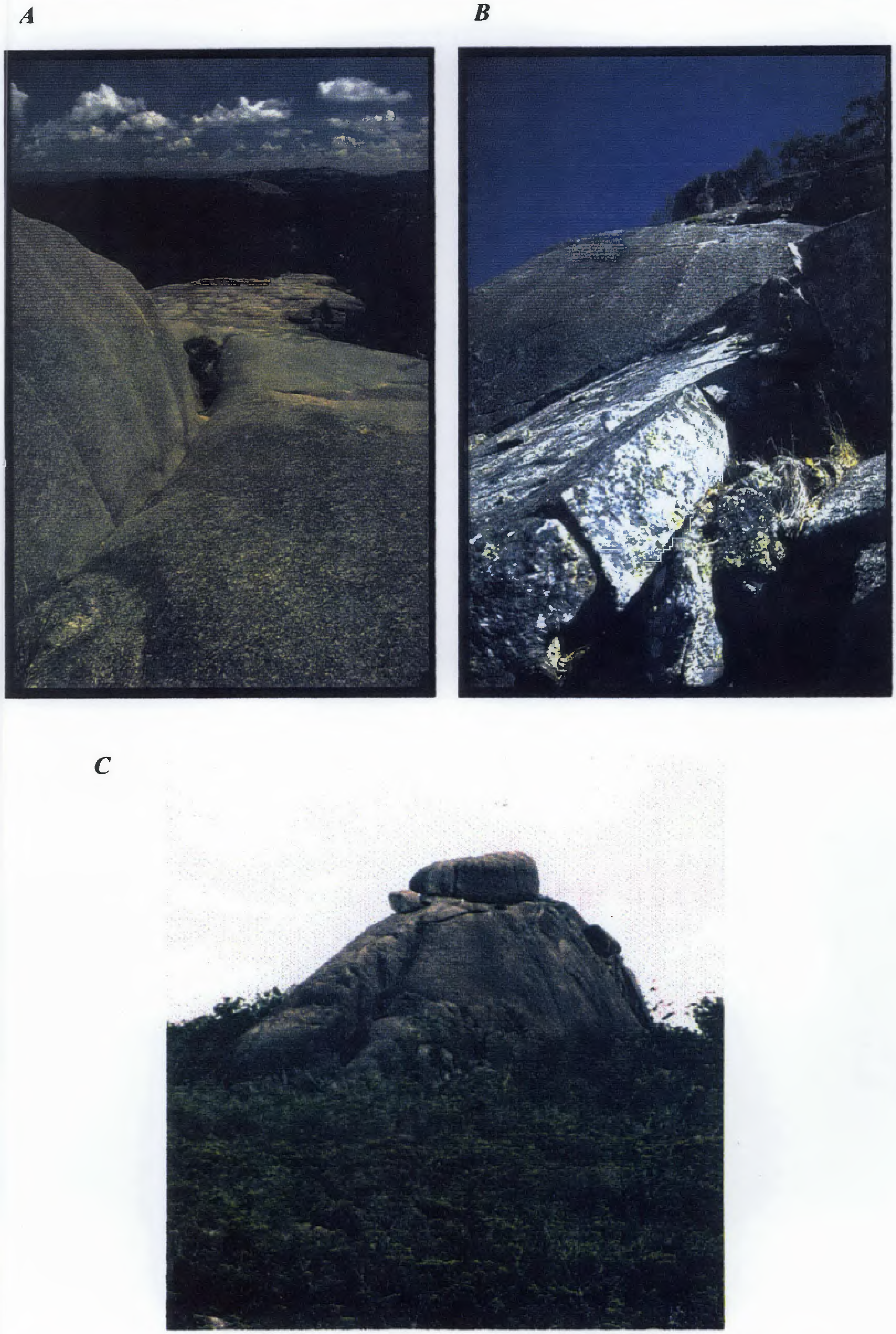


**Figure 2.8:** (A) South Bald Rock (BR) with large expanses of unvegetated surfaces (Section 2.3.4). Some areas could not be surveyed as they were too steep and dangerous such as Back Creek Rock at (B) Moonbi (MB) and (C) Anvil Rock at Gibraltar Range (GR).

*A*

*B* *C*

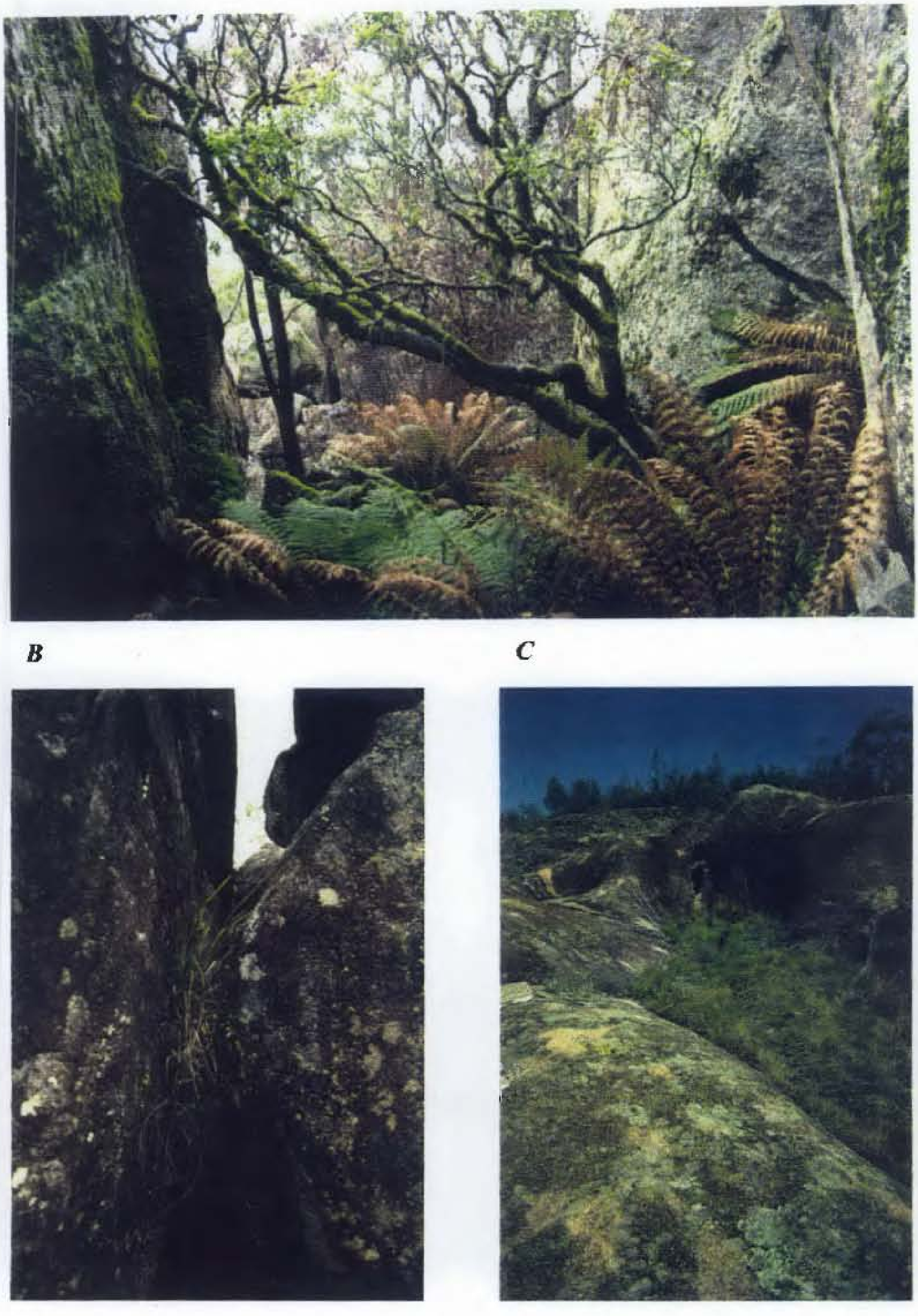
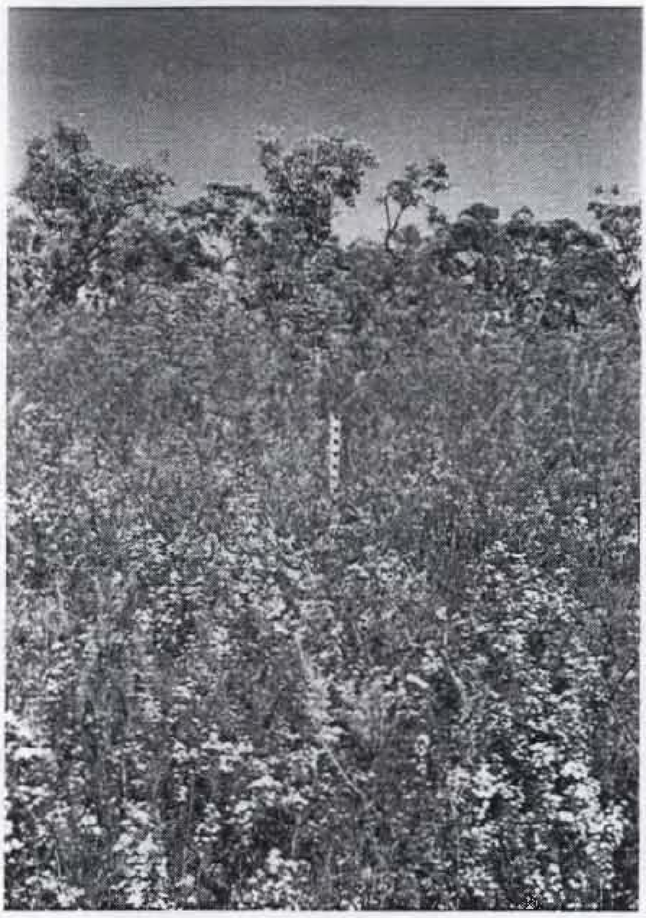


**Figure 2.9:** Crevices form a major component of habitat diversity on outcrops. Some could not be surveyed with the current methodology (A, B) (Section 2.3.4). (C) most crevices however, were easily surveyed.

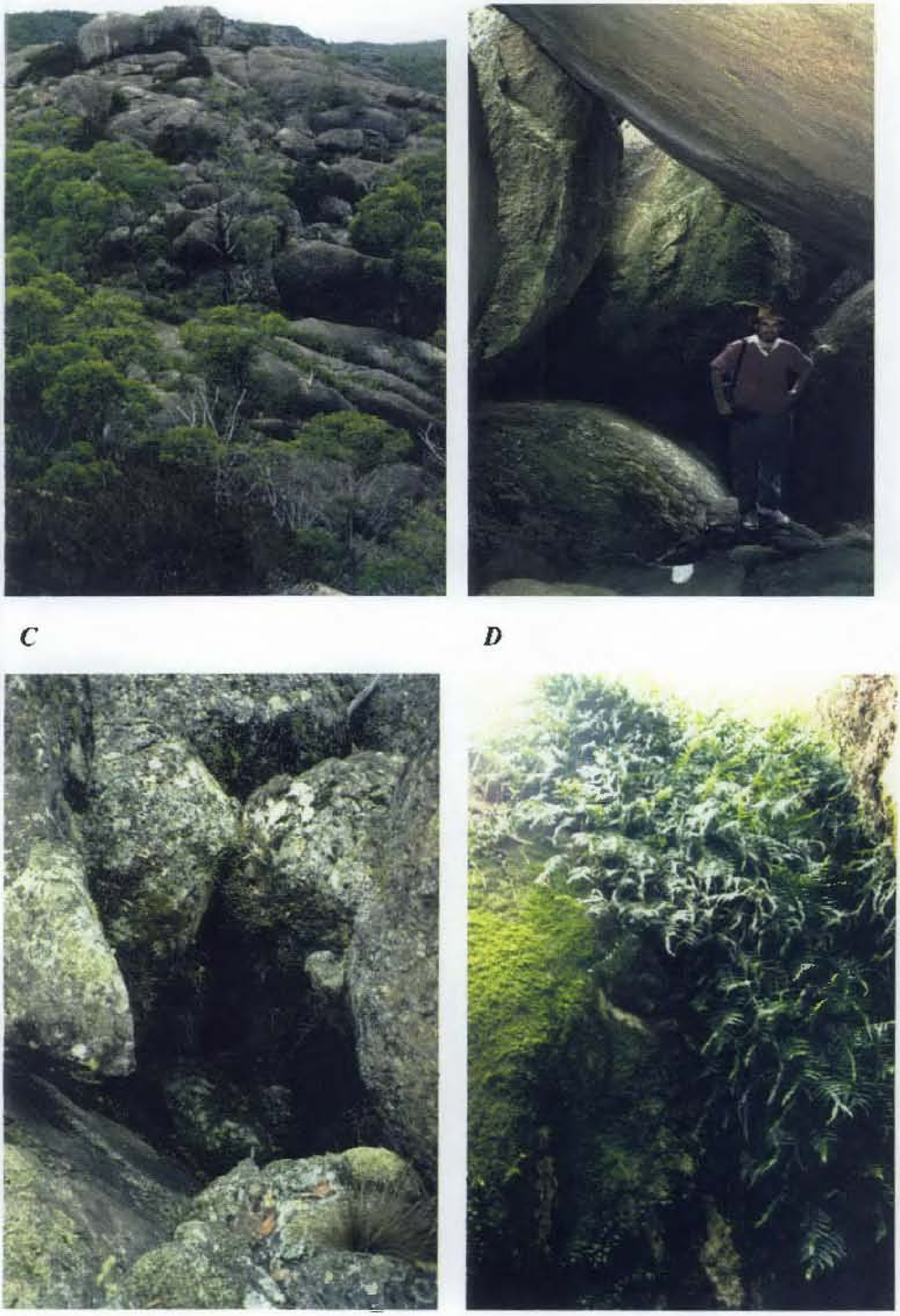
*A*



*B*

**Figure 2.10:** Vegetation cover can vary considerably on outcrops and within plots. In some instances, cover can be almost complete (A) or restricted to small patches (B) (see also Figure 2.8A). This type of habitat heterogeneity was taken into account at the plot and outcrop scale (Section 2.3.4).

*A* *B*



*C* *D*

**Figure 2.11:** Boulders form a major component of habitat diversity on outcrops (A, B). Boulders can form patches of distinct microhabitats to which some species may be restricted (C, D) (Section 2.3.4).

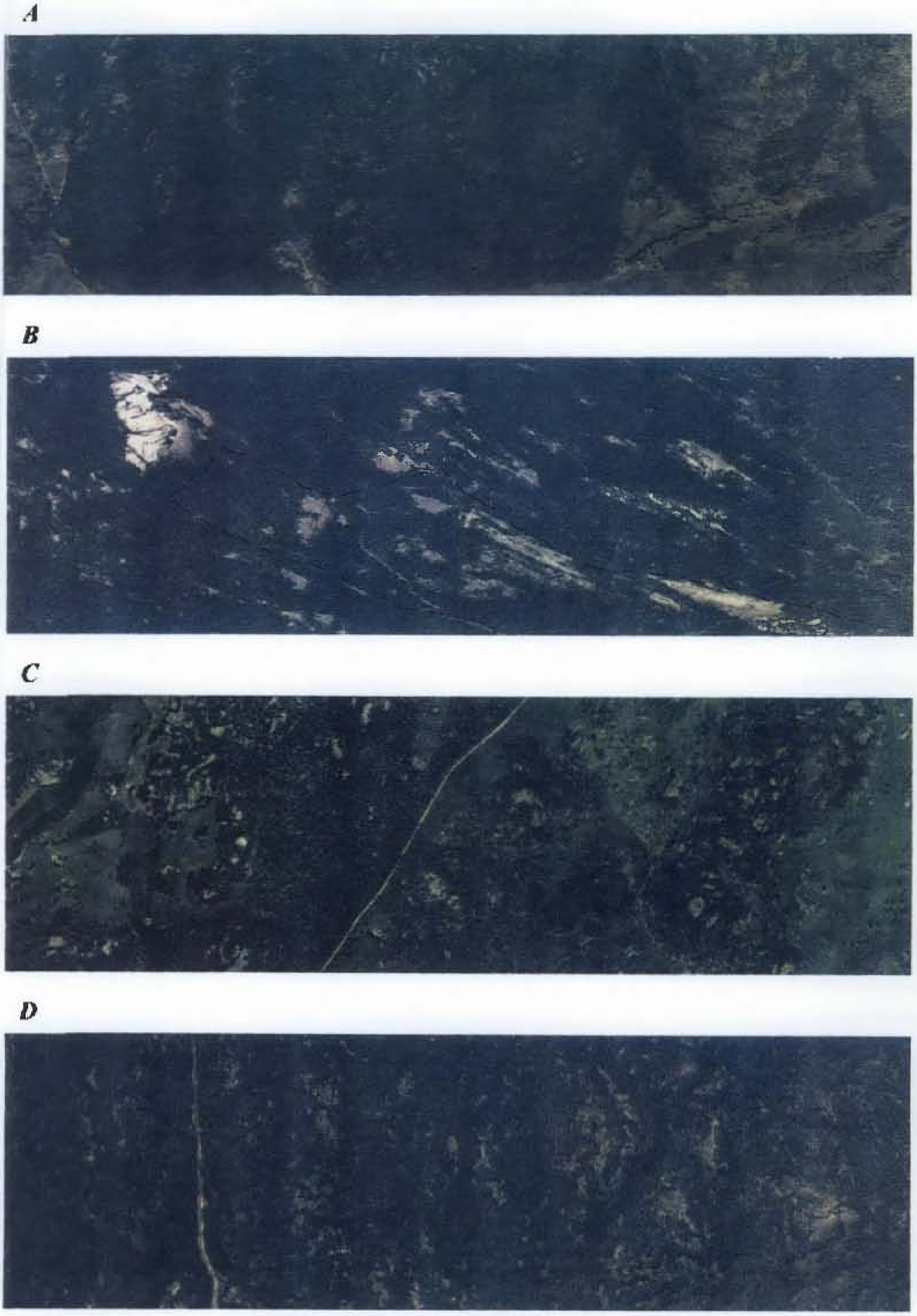



**Figure 2.12:** The number, distribution, density and size of outcrops varies between 'archipelagos'. Four typical examples of the variability within 'archipelagos' are given: (A) Attunga (AT), only a few small outcrops are present (Section 2.6); (B) Bald Rock (BR), with large and well defined outcrops, top left is Bald Rock; (C) Flaggy Range (FR), much clearing has occurred in this section however, the vegetation on outcrops remained largely intact; (D) Howell (HC), large and small outcrops with an uncleared intervening virtual 'sea'. Scale 1:25 000.

*A*

*B*

**Figure 2.13:** Castle Koppies (A) and Nubbins (B) were not able to be surveyed using the methodology set out in this project. Fewer sites than allocated were surveyed at Cathedral Rock (CR) (Section 2.6), as most outcrops within this 'archipelago' were Castle Koppies or Nubbins.