Vegetation patterns and dynamics in the highland peatlands of eastern Victoria, Australia

Submitted by

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A thesis submitted in total fulfilment
of the requirements for the degree of
Doctor of Philosophy

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December 2011

TABLE OF CONTENTS

CHAPTER 5 – THE INFLUENCE OF THE WATER TABLE AND MICROCLIMATE ON VEGETATION PATTERNS IN THE HIGHLAND PEATLANDS OF EASTERN VICTORIA…………………………………………….245

CHAPTER 7 – SYNTHESIS, CONCLUSIONS AND FUTURE RESEARCH……………………………………………………371

(Note: in order to conserve space only a selection of these are provided here. A complete version of the appendices with all tables is provided in the attached CD. See back cover. Tables provided on the CD only are indicated in the text by an asterix*)

EXECUTIVE SUMMARY

Vegetation patterns and ecological processes were studied in *Sphagnum* and restiad-dominated peatlands in three regions across the eastern highlands of Victoria. The community types identified differed due to factors associated with altitude, topographic position, and proximity to woodland or forest. Shrub dominance increases on steeper slopes, drier aspects, and in closer proximity to woodland. Sedges, restiads and *Sphagnum* dominated gentle lower slope positions at all elevations.

Prevailing winds in the Bogong region are from the west or north-west, and there is a west to east decline in precipitation across the area. ‘Cushion bog’ species, ‘hard-leaved’ graminoids, and herbs (*Astelia*, *Oreobolus*, *Celmisia*) were more prominent in alpine and exposed subalpine sites. Sheltered subalpine sites were more shrub-dominated with myrtaceous species (*Baeckea*, *Callistemon*) providing as much cover as ericaceous species (*Epacris* spp., *Richea*). Montane peatlands in the Snowy Range – Dargo High Plains region differed from subalpine peatlands by lacking the shrub *Richea continentis* and containing species associated with lowland wet heaths (e.g. *Baumea*, *Comesperma*). Montane sites in the Baw Baw-Central Highlands region fell into two categories, with the more inundation prone community lacking the restiad *Empodisma minus* and instead being dominated by *Carex* species and *Richea victoriana*.

The three regions studied run south-west to north-east along a gradient of increasing continentality. The Baw Baw-Central Highlands region, at the south-western end, is close to Bass Strait and oceanic influences on climate. Subalpine peatlands in this region are more floristically similar to the alpine sites of the Bogong region than to the subalpine sites of the nearer, but leeward and drier, Snowy Range region. Montane peatlands also differ floristically from those further east. The south-draining Macalister River is a useful bio-geographical dividing line and peatland floristic differences are reflected in the vegetation patterns of the surrounding landscape. Open woodland, open heath and grassland abuts peatlands in the north-east; whereas tall open forest, cool temperate rainforest and open forest predominates in the south-west.

Landscape-scale fires occurred during this research (2006-2007, 2009) and approximately 30% of the transects established prior to the fires were affected, but the extent and severity of burning was variable. On the Snowy Range in December 2006, the level of fire incursion was higher on steeper slopes, drier aspects, and in peatlands occurring closer to forest and non-wetland heath. The February 2009 fires in the Central Highlands area were more severe; there were few if any unburnt patches in peatlands.

Overall vegetation cover 28 months after the Snowy Range fires was higher in *Sphagnum*-dominated bog areas than the shrub-dominated wet heaths, reflecting the lower degree of initial fire incursion. Herbs and graminoids responded rapidly, and after 28 months most exceeded or equalled pre-fire cover values. All peatland shrub species were reduced in cover, especially in wet heaths, but the frequencies of *Epacris paludosa* and *Baeckea gunniana* were approaching pre-fire levels after 28 months. The latter species was recovering mostly vegetatively, and the former mostly from soil-stored seed. Post-fire recovery was more rapid in montane peatlands. The obligate seeding shrub *Richea continentis* only occurs in subalpine areas and was much reduced in frequency after the fires. The response of the dominant hummock-forming *Sphagnum cristatum* was variable. Again, in wet heath areas where pre-fire cover was typically less than 30%, regeneration has been slow. In some moderately burnt montane peatlands, percent cover exceeded pre-fire after 28 months. Some of the more marginal peatland communities, such as the wet heaths, may be in a process of transition. In some cases the seedlings of non-wetland shrubs from adjacent communities appear to be establishing.

The monitoring of water table depth, air temperature, and snow-cover duration was undertaken in several peatland vegetation types. Growing season water tables are high and stable in *Sphagnum* and sedge-dominated Valley bogs, but stable and lower in *Sphagnum* and dwarf shrub dominated Raised bogs. In sheltered subalpine tall wet heath, water table levels were similar to Raised bog, but more variable. Low wet heath occurs in exposed locations on shallow ‘dried peat’ and has highly variable water table levels which include periods of surface flow. Compared to other peatland types, these communities experience higher frost frequency, accumulate less snow during winter (wind-scour), and thus can be exposed to extreme low temperatures and high wind. Differences in microclimate are a strong influence on non-wetland highland vegetation patterns, they also appear to have a greater influence on peatland floristics than previously realised.

Overview and conclusions

Vegetation composition and structure in peatland communities is strongly influenced by the vegetation and processes in the surrounding landscape (e.g. fire regime). These, in turn, are controlled by climate and too a lesser extent geology. Climatic gradients associated with increasing altitude and closer proximity to oceanic influences strongly influence peatland vegetation in eastern Victoria.

STATEMENT OF AUTHORSHIP

Except where reference is made in the text, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis submitted for the award of any other degree or diploma.

No other persons work has been used without due acknowledgement in the main text of the thesis.

This thesis has not been submitted for the award of any degree of diploma in any other tertiary institution.

James Martindale Shannon
12th December 2011

ACKNOWLEDGEMENTS

This has been a challenging time to do research in the Victorian mountains. Much of the last few years has been spent dodging bushfires and floods. The whole project has taken way longer than it should have, but things happen slowly at higher altitudes, so perhaps my progression has been more in keeping with the velocity of high altitude ecological processes. There are many people who have contributed along the way.

Firstly, I would like to thank John Morgan for being game enough to take me on as a ‘mature’ age student in the first place. He has been supportive, encouraging and positive throughout the journey. Warwick Papst is central to many things ‘alpine’ research in Victoria, and he has helped with advice, logistical support and friendship. Arn Tolsma, Andre Messina, Henrik Wahren, Paul Smart helped with field-work, data collection, ideas, discussions and general companionship while in the mountains. My partner Susannah Burgess and my father Ross Shannon also patiently followed me to remote mountain locations in order to assist with data collection on several occasions.

Max Bartley and Sally Kenny helped me with technical matters many times. Shannon Lebel showed me how to generate the BIOCLIM data, and David Cameron was always happy to debate the identity of any number of plant species, that I occasionally dumped in front of him. I would also like to thank Nathan Wong, James Camac, Suzanna Venn, Andrew Walker, Sera Cutler, Jeffrey Garlett, and ‘Bix’ Beiderbecke Burgess.

A generous grant from the Holsworthy Wildlife Research Fund made it possible to purchase the water table monitoring devices; these proved invaluable. Parks Victoria people have always been helpful and generous with their time and information. I would particularly like to thank Elaine Thomas, Charlie Pascoe, Marie Keatley and Peter Lawrence.

The Latrobe University Botany department have always been supportive and encouraging. Thanks must go to Roger Parish, Pete Green and Philip Keane. Bob Parsons kindly and very painstakingly read my chapter ‘drafts’. My partner Susannah ‘Sukey’ Burgess also helped with this. She has very patiently accepted my long absences in the mountains and lack of action on the ‘domestic’ front over recent years. The same is true for my whole ‘clan’, my parents Ross and Helen, and Shirley, Michael, David, Hugh, Francis and Greta have not seen much of me in recent years. Thanks for your support.

Lets hope that we will always have remote, wild and windswept places to explore and be curious about.

CHAPTER 1

INTRODUCTION AND AIMS OF THE RESEARCH

1.1 General background, distribution and significance

In the strict sense, peatland is a term used to describe landscapes dominated by a type of soil that consists mostly of sedentarily accumulated, partially decomposed plant matter. By convention, the organic content of the soil must be a least 20-30% by dry weight to be classified as peat, and the peat layer should be at least 30 cm deep for a defined area to be classified as peatland (Joosten and Clarke 2002). Peats are in wetlands, specifically those in which biomass production is faster than decomposition or removal by herbivory and physical forces (wind, water). Peatlands that are still actively producing and accumulating peat are classified as mires (Rydin and Jeglum 2006).

Peatlands occur in parts of the landscape where seepage occurs, drainage is impeded or water accumulates (Charman 2002). Water tables are constantly at or near the soil surface and this creates anaerobic, often acidic soil conditions which, in turn, reduce microbial activity and thus the breakdown, decomposition and recycling of plant or organic matter. Under stable climatic and hydrological conditions, the excess organic material can accumulate to depths of many metres if undisturbed for hundreds or thousands of years (Clymo 1983).

Nutrient availability in peatlands is low because of the impeded breakdown and recycling. Thus, growing conditions for vascular plants in particular can be quite stressful. There tends to be a specialist wetland or peatland flora with characteristic plant life-forms, growth forms and plant physiognomy. Non-vascular plants are common and often dominate. In higher latitude and altitude regions of the world, the most important of these are the peat or *Sphagnum* mosses. The more familiar plant groups generally associated with wetlands, such as rushes (Juncaceae), sedges (Cyperaceae), and reeds

(Poaceae), are also common (Joosten and Clarke 2002). The presence of woody vascular plants is limited by the shallow zone of aerated soil, which is reduced by constantly high water tables. Graminoids are favoured because of their shallower root networks and ability to produce adventitious roots from the base of the stem, when deeper roots become submerged or smothered by *Sphagnum* growth (Van Breeman 1995, Rydin and Jeglum 2006). The woody plants common in cool climate peat-forming wetlands are those that also have the capacity to do this and thus, the woody plant presence is generally restricted to shrubs (e.g. Ericaceae), although small trees do occur (*Nothofagus, Alnus, Pinus*), especially in the boreal region (Joosten and Clarke 2002). Trees are however often dominant in tropical peatlands (Anderson 1983).

Peat-forming ecosystems are most common in parts of the world where precipitation is high, or evapotranspiration low, or both. It is generally accepted that it is the status of the water balance during the warmer months that limits peatland distribution. There needs to be a moisture surplus during these periods of the year (Ingram 1983) and this is why peatlands are more commonly associated with cool temperate regions or higher latitudes and altitudes (e.g. Scandinavia, Russia, Canada, Scotland). In such climates the processes of decomposition are further impeded by low temperatures and short growing seasons (Silvola et al. 1996). *Sphagnum* mosses are less common or dominant in lowland warm temperate and tropical peatlands where evapotranspiration is higher, and here the peat-forming vegetation tends to consist of sedges, rushes and taller woody vegetation (e.g. coastal wetlands, estuaries, tropical swamp forests, wet heathland).

It has been estimated that a third of all soil carbon is stored in peatlands, yet they cover only 4% of the terrestrial surface of the planet (Joosten and Clarke 2002). The role played by peatlands in regulating atmospheric greenhouse gas concentrations has come under increasing scrutiny in recent decades (Gorham 1991, Bridgham et al. 1995). While sequestration rates are low, the vast extent of the ‘peat resource’ means that the carbon stored in peat is somewhere between 30% and 50% of that stored in the atmosphere as CO_2 (Turunen et al. 2002).

While the peatlands in the temperate regions of the southern hemisphere account for less than 5% of the total global extent, they actually cover relatively large proportions of the available land surface at these latitudes (south of 35-40° S). The most extensive are in southern South America (Chile, Argentina) (Pisano 1983, Joosten and Clarke 2002), followed by New Zealand, the Subantarctic islands (e.g. Falklands, Chatham Island) (Campbell 1983, Rydin and Jeglum 2006), and Tasmania (Whinam and Hope 2005). There are smaller areas of peatland in elevated areas of mainland south-eastern Australia and South Africa (Campbell 1983, Thomson and Hamilton 1983).

The vegetation patterns in mires and peatlands have long fascinated ecologists and they are a much studied ecosystem. The cool temperate peatlands of higher latitudes and altitudes are the focus of this thesis and these are most often associated with *Sphagnum* mosses, although as will be discussed, in parts of the southern hemisphere ‘scale-rushes’ (Family Restionaceae, ‘restiads’), are of at least equal importance (Campbell 1964, 1983, Agnew et al. 1993, Clarkson and Clarkson 2006).

Australian distribution

Peat-forming wetlands are common in the higher rainfall regions of Australia, particularly close to the eastern and south-eastern margins of the continent. In these areas they are associated with estuaries, lowland wet heath, riparian flood-plains and swamps (Campbell 1983, Whinam and Hope 2005). It is sedges, rushes, other graminoids and wet heath shrubs that are the predominant peat-forming plants. A good example is the ‘blanket’ peatlands dominated by button-grass (*Gymnoschoenus sphaerocephalus*) and other graminoids that are common and extensive in western Tasmania (Brown 1999), a region that receives in excess of 2000 mm precipitation per annum.

Peatlands associated with *Sphagnum* mosses are mostly restricted to the highlands of the south-east corner of the continent, and Tasmania. Co-dominant in most of these is the scale-rush *Empodisma minus* (Family Restionaceae) (Campbell 1983, Whinam and Hope 2005). This species is also prominent in New Zealand peat-forming wetlands and is thought to have similar cation exchange capacities to *Sphagnum* and is an important peat-forming species (Agnew 1993, Van Breeman 1995). *Sphagnum* and restiad-dominated peatlands are generally confined to montane, subalpine and alpine regions of Victoria and NSW (above 900 m), and montane to subalpine Tasmania (above 600 m) (Campbell 1983, Whinam et al. 2003b).

1.2 Peatland vegetation dynamics, environmental gradients, typology, and classification schemes

The best known and most widely used system of peatland classification is that developed by Swedish mire ecologists Du Rietz (1954) and Sjors (1948, 1950). It recognises three critical environmental gradients that are the main influence on vegetation patterns, and these can operate at small and large scales. The three gradients are: 1) depth to water table, 2) base cation status and pH, and 3) nutrient availability (N and P).

The depth to water table determines the depth of the aerated peat or moss layer. Ingram (1978) coined the terms ‘acrotelm’ and ‘catotelm’, the former being the aerated peat layer, the extent of which is defined by the lowest point reached by the water table during its annual cycle. Below the acrotelm is the permanently saturated ‘catotelm’ (Ingram 1983). Depth to water table typically varies at small scales between hummocks and hollows (the latter incorporates lawns, carpets, and peat-bottoms or pools) (Sjors 1948, 1983). Surface elevation differences between hummocks and hollows can be anywhere between less than 0.5 m and several metres. The water table can vary across a peatland or mire from 30 to 50 cm (or more) below in hummocks, to being above the surface in the case of pools (Rydin and Jeglum 2006).

In terms of vegetation, woody plants are abundant where depth to water table is greater (e.g. hummocks, peatland margins) with sedges and other graminoids common where it is shallow (lawns, carpets) (Bell and Tallis 1974, Malmer et al. 2003). Pools are often sparsely vegetated with scattered emergent sedges and rushes. In the northern hemisphere, in particular, where there is a greater number of *Sphagnum* species (Joosten and Clarke 2002, Rydin and Jeglum 2006), these too occupy the different ‘depth to water table’ niches and microtopographic positions (Andrus 1986). Some species are adapted to hummocks and some are typically associated with lawns or surface water.

The second key gradient is linked to variation in base saturation and pH. Base saturation is defined as the sum of the main base cations important for plant growth (K, Ca, Mg, Fe, Mn), as a percentage of the total cation exchange capacity. It tends to be correlated with pH and thus, is higher with more neutral to slightly alkaline values. The terms ‘bog’ and ‘fen’ represent either ends of the spectrum, fen being commonly further sub-divided into ‘poor’, ‘intermediate’, and ‘rich’ (Du Reitz 1954, Wheeler and Proctor 2000, Charman 2002). Traditionally the term ‘bog’ was reserved for peatlands that were believed to be sustained purely from direct atmospheric inputs, and isolated from groundwater seepage (Gore 1983a). In the past, classifications based on hydrochemistry have been rigidly linked to determinations of the origin of mire water, or the pathway taken by water to the mire or peatland (Sjors 1948, Du Rietz 1954). Rainwater is very low in mineral and nutrient concentration in comparison to groundwater or run-off, which collects these as it moves through soil and bedrock. When peat deposits are large or deep enough, or in constantly moist regions, the surface layers and vegetation are isolated from the influence of groundwater, and this is usually reflected in the composition and structure of the vegetation. Such peatlands are said to be ‘ombrotrophic’, as opposed to ‘minerotrophic’ or groundwater fed (Gore 1983a, Charman 2002, Joosten and Clarke 2002, Rydin and Jeglum 2006).

Bogs are defined as having pH values of 4 or less, and extremely low concentrations of base cations, particularly Ca^{2+}. All categories of fen are considered minerotrophic or ‘geotrophic’; ‘poor fens’ typically have pH values of 4.0-5.5, ‘intermediate fens’, pH 5.5-7.0, and ‘rich fens’, pH greater than 7.0 and often conspicuously high cation concentrations, particularly Ca^{2+}. Hummock forming *Sphagnum* species tend to dominate at the ‘bog’ and ‘poor fen’ end of the spectrum. Other *Sphagnum* species and graminoids (sedges and rushes) occupy intermediate fens, and graminoids, dicot herbs and ‘brown mosses’ dominate in ‘rich fens’ (Malmer 1986, Wheeler and Proctor 2000).

The third gradient recognised by mire and peatland ecologists is nutrient availability or fertility and this tends to be correlated with pH-base status, but not always (Du Reitz 1954, Sjors 1983, Charman 2002, Joosten and Clarke 2002). The terms ‘oligotrophic’, ‘mesotrophic’ and ‘eutrophic’ are used here in relation to the availability of N and P and thus, productivity. In theory, oligotrophic or nutrient poor peatlands tend to span ‘bog’ and ‘poor fen’; mesotrophic and eutrophic peatlands are broadly equivalent to intermediate and rich fens. However, at very high pH and Ca^{2+} concentrations, phosphorus becomes unavailable, hence productivity can decline (Gore 1983a, Joosten and Clarke 2002, Rydin and Jeglum 2006).

In vegetation descriptions and classifications, the terms ‘bog’ and ‘fen’ tend to be applied to individual discrete peatlands, although sections within individual sites can, in principle, grade from one to another (e.g. bog to poor fen, in response to an increasing groundwater influence). The chemical factors that underpin these classifications can vary at microscale (hummock to hollow) and mesoscale (peatland margin to peatland centre), as well as between different discrete peatlands. For example, mire or peatland margins generally have shallower peats and are often minerotrophic, thus influenced by seepage water from neighbouring non-wetland ecosystems (Charman 2002). Central sections of the same peatland can often be ‘raised bog’, ombrotrophic, and isolated from groundwater influence (Ingram 1983). This can often by expressed in the plant composition by the presence of certain shrub species only at the margin, and others only in the central areas of a peatland. It can also be expressed in vegetation abundance and structure, e.g. higher shrub cover and stature in minerotrophic areas. In the latter context, stunted shrub growth in ombrotrophic central sections of a peatland can be a response to both lower nutrient availability and higher water table (and possibly a more extreme micro-climate as well) (Van Breeman 1995, Charman 2002).

The pattern of water movement or otherwise in minerotrophic peatlands can also influence vegetation patterns. The term ‘soligenous’ is applied to sloping peatlands, where there is groundwater movement through the peat in response to slope (Gore 1983a). The down slope seepage of water can potentially increase the supply of minerals and oxygen to root systems. The same process can operate in hollows during storm or snowmelt flow, even in relatively flat areas. Excess water, often relatively rich in oxygen and minerals, moves through the oxygenated peat and moss layers (acrotelm), and as surface flow between pools or drainage channels. This is sometimes called ‘flushing’ or ‘irrigation’ and can be constant or periodic, and, depending on the nutrient concentration, can be a strong influence on vegetation patterns (e.g. ‘rheophilous’ or ‘flow-loving’ species). Phosphorus (P) is a key nutrient that is probably more available in areas that experience regular flushing such as hollows. In marginally higher microtopographic positions, periods of inundation invariably coincide with cooler periods and the non-growth season, in which case, much of the released phosphorus probably escapes to streams (Gore 1983a, Charman 2002). Under oxidised conditions phosphorus is bound to ferric ions (Fe^{3+}) and is released under anoxic conditions, as ferric ions are reduced to ferrous ions (Fe^{2+}) (Crawford 1983).

‘Topogenous’ mires and peatlands are the opposite end of the spectrum, with minimal water movement; hence, they tend to be found in fairly flat areas. In this situation the flow of oxygen and minerals is less, H^+ ions released during cation exchange can potentially accumulate because of limited dispersal, thus pH can be dramatically lowered unless regular ‘flushing’ occurs (Gore 1983a, Joosten and Clarke 2002). This perhaps occurs most often in topographic positions where there is no or minimal surface outflow from the peatland or occurs seasonally during dry periods, when surface flow declines and pools stagnate. Associated high evapotranspiration during these periods will further enhance peat and pool water acidity.

Australian perspective on classification

Early researchers in Australia classified peatlands based on vegetation structure and composition foremost, rather than the trophic status of the peat or the origin of the water sustaining the system (Costin 1954, Ashton and Hargeaves 1983). For example, Costin (1954) distinguished two sub-formations of ‘bog’ in alpine-subalpine areas, largely based on dominant growth forms (i.e. Raised bog: *Sphagnum* and dwarf shrubs, Valley bog: *Sphagnum* and sedges). In south-eastern Australia, the term ‘fen’ was reserved for peatlands dominated by sedges, rushes and other graminoids, devoid of *Sphagnum*, and typically with shallow surface water for much of the year. Others used the term ‘bog’ in the broad-scale sense to incorporate all *Sphagnum*, sedge and shrub (wet heath) dominated vegetation (McDougall 1982). In these cases, less effort was made to differentiate between sub-formations or wetland sub-community types (McDougall 1982, Millington 1954, Farrell and Ashton 1973, Ashton and Hargreaves 1983). Walsh et al. (1984) adopted the arguably more appropriate and descriptive name in the Victorian context of ‘wet heathland complex’ to incorporate the entire spectrum, from *Sphagnum* and sedge-dominated ‘bog’, to shrub-dominated ‘wet heath’. In this case, vegetation sub-units were determined purely on floristic composition and abundance. A similar approach was adopted in Tasmania by Kirkpatrick (1983). Distinctions were made between different physiognomic vegetation sub-units first and then abiotic factors were analysed to identify influences and gradients. The classification of peatland vegetation was not based on the trophic status or origin of the water as in Europe (Whinam and Hope 2005).

Attempts to incorporate strict interpretations using the ‘Swedish’ method of classification into local peatland typology are likely to confuse. In theory, genuine ombrotrophic peatlands or mires don’t occur in south-eastern Australia, except perhaps in parts of western Tasmania. However, this has not been definitively determined. All Australian mires are at least partly minerotrophic or groundwater fed (Whinam and Hope 2005) and therefore can only be classed as ‘poor fens’ according to the Swedish classification. However, structurally and in a phytosociological sense, the peatland vegetation conforms to ‘Swedish’ criteria for ‘bog’, and furthermore, other indicators such as pH, Ca^{2+} ion concentrations, and base-status also conform to levels acceptable for classification as such (Grover 2006, Whinam and Hope 2005). Clearly, in some regions the bedrock is so mineral and nutrient poor that the emergent groundwater is as impoverished as rainwater (Kirkpatrick 1997, Sylvester 2009). In fact, this is generally the case throughout much of south-eastern Australia, except in areas underlain by basic igneous rocks (e.g. basalt) or calcareous rocks (limestone). Some authors have recently suggested a globally standardised approach that allows minerotrophic peatlands to be also regarded as ‘bog’ rather than ‘poor fens’ if other indicators are aligned or within acceptable levels (Wheeler and Proctor 2000). The majority of environmental gradient studies show the major division to be ‘bog - poor fen’ on one hand, and ‘intermediate - rich fen’ on the other. Furthermore, this is correlated with the sharpest changes in vegetation composition and structure (Malmer 1986, Wheeler and Proctor 2000, Whinam and Hope 2005).

Southern hemisphere peatlands are certainly unique, but share underlying fundamental similarities with those in the north, in terms of the common plant life-forms, growth forms, vegetation dynamics and processes. Australian peatland typology is a phytosociological classification but recognises that the plant species composition, abundance, and vegetation structure, are a reflection of the same influencing factors (Costin 1954, McDougall 1982, Costin et al. 2000, Hope et al. 2009). The more liberal interpretations of ‘bog’ and ‘fen’ are used in this thesis also.

Oceanicity – Continentality Gradient

A fourth gradient is frequently discussed in peatland literature. It relates to the observed geographic variations in peatland composition and structure associated with increasing distances from oceans (Malmer 1986, Glaser 1992). Regions subjected to oceanic climates (high precipitation, low seasonal and inter-annual variability, high humidity and cloud cover, low temperature variation) tend to differ floristically and structurally from those influenced by more continental climate (moderate precipitation, higher seasonal and inter-annual variability, lower humidity and cloud cover, greater temperature variation and extremes). The most studied examples of such gradients in relation to mires and peatlands are from the north Atlantic to Finland and western Russia (e.g. Scotland and Ireland, compared with northern Sweden and Finland) (Malmer 1986), and from west to east across Canada (Vitt and Kuhry 1992). Certain plant species restricted to ‘bogs’ in continental areas can occur in ‘poor’ fens in oceanic areas (Malmer 1986). Trees are a more common feature of hummocks in continental areas and less so in oceanic areas (Vitt and Kuhry 1992). This is thought to be because of greater seasonal variation in depth to water table in continental areas, which permits larger root systems and better ‘anchorage’. Permafrost is also linked to the establishment and life-cycle of trees in peatlands in continental areas at high latitudes (Robinson and Moore 2000). Pools are generally more common and conspicuous in oceanic peatlands (Pisano 1983, Kirkpatrick and Gibson 1984, Vitt and Kuhry 1992). The observed differences in vegetation composition and structure between oceanic and continental areas can also be partly due to differences in the mineral composition of precipitation water (Johnson 1977a, 1977b, Vitt et al. 1990, Malmer 1992). As proximity to oceans increases, so too does the Na^+, Cl^-, and Mg^{2+} ion content in precipitation water (Rydin and Jeglum 2006). ‘Blanket peats’ are more common in regions that have an oceanic climate (e.g. Ireland, Scotland, Wales, Tasmania, southern Chile, western Canada).

In theory, the oceanicity-continentality gradient is also replicated to some extent by changes in altitude. For example, in southern Australia, a 6º shift in latitude to the south corresponds to an approximate fall in mean annual temperature of 3ºC, and a decline in the climatic tree-line of approximately 500 m elevation (Slatyer 1989, Crowden 1999). In Victoria, 500 m elevation approximates a shift from the upper montane zone (1300 m) to the alpine zone (1800 m). It can also correspond to an increase in annual precipitation of up to 1000 mm in some instances, and a change in the structure of the surrounding non-wetland vegetation from tall open forest (40 m), to treeless open heath and grassland.

Disturbance ecology and succession

Succession in peatlands should not be confused with development which generally relates to the longer-term processes of paludification (changes in soil drainage that initiate mires), peat accumulation, and the development of peat deposits and landscapes over thousands of years (Rydin and Jeglum 2006). However, in peatlands, both processes influence and, inturn, are influenced by each other. One deals with geological time-scales (development) and the other biological (succession); the latter generally deals with cycles occurring over hundreds of years or less.

The factors influencing succession, or temporal changes in vegetation composition and structure, are often divided into two groups. Autogenic factors are internal and relate to the interactions between the living organisms that constitute the ecosystem. The small-scale interactions between competing plants, competing plant life-stages, invertebrate herbivores, and decomposing or recycling organisms, change the nature of the environment over time and thus influence the vegetation spatial patterns (Frenzel 1983, Tallis 1983, Charman 2002, Rydin and Jeglum 2006). This is especially the case in peatland environments, where small-scale spatial variability along the environmental gradients outlined earlier (e.g. water table depth, nutrient availability) can trigger changes in vegetation patterns. Autogenic factors are essentially those involved in small-scale ‘pattern and process’ (Watt 1947) and in peatlands are most often associated with differences in microtopography. The idea that pools and lawns replace hummocks given enough time, and *vice versa* (Walker and Walker 1961), was the popular theory in regard to hydroseral succession, but more recent evidence suggests this is unusual (Charman 2002). However, many studies of succession in peatland vegetation identify cycles similar to shrub-grassland cycles in open heathland or grassland, with distinct ‘pioneer’, ‘building’, ‘mature’ and ‘degenerate’ phases (Watt 1947, Costin 1954). In this case, the cycle most often involves *Sphagnum*-dominated and shrub-dominated phases or seres, and these are represented in space as well as time.

Allogenic factors are those influences external to the community or ecosystem (Charman 2002). Climate, geology, and topography are arguably the most fundamental allogenic influences on peatlands, especially in terms of their global and local distribution, size, and general vegetation structure (Tallis 1983). Following behind these in terms of importance is the type, scale, intensity, and frequency of disturbance, or the disturbance ‘regime’. Disturbance can be ‘chronic’ (continuous) and generally of lower intensity, or ‘episodic’ and generally high intensity. Examples of ‘natural’ disturbances in peatlands include herbivory and low intensity trampling by animals, wildfire, and flood damage (Charman 2002). ‘Unnatural’ or introduced disturbances to peatlands can include things like peat mining for fuel, ‘ditching’ and drainage for agriculture and silviculture, domestic livestock grazing, management burning, and *Sphagnum* harvesting for horticulture (Tallis 1983, Whinam and Buxton 1997, McDougall 2001, Joosten and Clarke 2002, Whinam et al. 2003b).

Palaeoecological evidence in the form of charcoal bands and deposits in peat layers reveals that wildfire occurs in most peatlands at varying frequencies. In the northern hemisphere it generally appears to have been more common in peatlands that are associated with boreal forests than in the tundra or higher Arctic regions (Kuhry 1994, Pitkanen et al. 1999, Robinson and Moore 2000). Fire associated with early land clearance and agricultural activities can also be traced in the palaeoecological record (McGlone et al. 1997, McGlone and Wilmshurst 1999, Walker et al. 2001). Natural fire frequencies in peatlands have also varied considerably across the Holocene (last 10,000 yrs). In boreal Canada, fire intervals in the forests adjacent to peatlands are thought to average about 60-100 yrs (Wein 1983). However, estimates of the fire frequency over the last 2500 yrs in peatlands vary from once per 1000 yrs to once in 400 yrs depending on the site. Fire is thought to have been more frequent during the hypsithermal (7500 yrs ago), when it was warmer and drier in western Canada (Kuhry 1994). Similar estimates of fire frequencies have been determined for restiad-dominated peatlands in the southern hemisphere. Fire intervals in some New Zealand peatlands prior to Polynesian arrival are thought to have been 100-240 yrs (Clarkson 1997). The frequency of fire in some highland peatlands in south-east mainland Australia prior to European settlement was probably similar to this (Kershaw and Strickland 1989, Dodson 1994). Fire incidence in these parts of Australia is perhaps likely to mimic frequencies in drier boreal regions (i.e. 60-100 yrs, Alberta, Saskatchewan, mid-western Canada).

Fire effects in peatlands depend on severity of burning, but include the removal of surface vegetation and, in some cases, layers of peat (Tallis 1983). A short term ‘spike’ in nutrients occurs (Vitt and Bayley 1984, Clarkson 1997, Charman 2002, Norton and de Lange 2003) and some of this is lost to streams (Blackford 2000). The initial fertility pulse usually fades by about 5 yrs after fire (Timmins 1992, Clarkson 1997, Norton and de Lange 2003). Changes to hydrology can occur, including alterations to patterns of surface drainage, and a decrease in peatland water retention (Good 1992, Charman 2002, Hope et al. 2005). Chemical and physical changes to the surface layers of peat are possible also, and this can affect pore structure and infiltration capacity (Mallik et al. 1984). There can also be deposition of mineral soil material from burnt neighbouring non-wetland ecosystems and the potential removal of unconsolidated peat by surface water during the early post-fire period (Wimbush and Costin 1979, Wahren and Papst 1999). Volatilisation of nutrients occurs during fires and, in the context of climate change, the prospect of increased carbon losses from warming, drying, and more frequently burnt peatlands, has received much recent attention (Gorham 1991, Bridgham et al. 1995, Moore et al. 1998). Grazing and burning over 10-yr rotations in some northern United Kingdom peatlands has resulted in net carbon losses (Garnett et al. 2000). However, it has been estimated that a 5- to 7-fold fire frequency increase would be required in some Canadian peatlands to reduce net carbon assimilation to zero (Kuhry 1994). Increases of this magnitude have occurred in some Canadian peatlands over the last century (Pellerin and Lavoie 2000).

Post-fire vegetation recovery, regeneration, and succession depend upon fire extent and severity. It also depends on the vital attributes of the species involved (Noble and Slatyer 1980, 1981). *Sphagnum* species can regenerate vegetatively from individual cells or via germinating spores (Clymo and Duckett 1986, Wahren and Papst 1999, Johnson 2001), but can take a decade or longer to reach pre-fire abundance (Wahren and Walsh 2000). Post-fire ephemeral species and opportunistic herbs take advantage of the temporary increase in nutrient availability (Clarkson 1997, Johnson 2001, Norton and de Lange 2003). Rhizomatous species and sprouters recover relatively rapidly. For example sedges and other graminoids are often most abundant in the first few years following fire (e.g.

Carex, *Baumea*, *Eriophorum*, *Juncus*). The response of restiads in the southern hemisphere can be variable, most appear capable of vegetative recovery, but in New Zealand appear to take 15-20 yrs to reach pre-fire cover abundance levels (Clarkson 1997). However, in drier parts of New Zealand, palaeoecological evidence suggests that *Empodisma minus* was eliminated from peatlands by fires after Polynesian arrival 800 years ago (Walker et al. 2001). In south-eastern Australia, restiads like *Empodisma minus* resprouted rapidly within two months of a fire at Wellington Plain (Wahren and Papst 1999), and 14 yrs after a separate fire at Mt Buffalo had doubled pre-fire cover levels (Wahren and Walsh 2000).

Obligate-seeder shrubs are slower to regenerate. In the study by Wahren and Walsh (2000) at Mt Buffalo in Victoria mentioned above, obligate-seeder shrubs had not recovered pre-fire cover abundance after 14 yrs (*Richea continentis*), but resprouter shrub species were more abundant (*Baeckea gunniana*). Similarly slow responses have been noted for key obligate-seeder shrubs in New Zealand peatlands (*Leptospermum scoparium*) (Timmins 1992, Clarkson 1997). Other obligate-seeder ericaceous shrub species were apparently more common in some New Zealand peatlands prior to Polynesian arrival and the associated increase in fire frequency (Walker et al. 2001).

When fire is frequent and coupled with livestock grazing, regeneration is less predictable. Many studies from the northern United Kingdom have demonstrated this, and documented the loss of peat and *Sphagnum* species as a result of combustion and erosion (Mackay and Tallis 1996, Garnett et al. 2000). Graminoids generally become more abundant under such treatment regimes, and the cover of ericaceous shrubs like *Calluna vulgaris* declines. Combined livestock grazing and burning practices have contributed to similar degradation in Australian highland peatlands (Wimbush and Costin 1979, Wahren 1997). However, most ericaceous shrub species appear to have mechanisms to enable recovery following fire, provided time intervals between successive fires are sufficient. In both the northern and southern hemisphere, ericaceous species appear to form large, long-lived seedbanks (Legg et al. 1992, Miller et al. 2003).

1.3 Australian research

The earliest examinations of *Sphagnum* associated peat-forming wetlands in southern and eastern Australia were restricted to more general descriptions, casual observations and documentations of species occurrences. These were often part of broader floristic descriptions of mountain or alpine vegetation (e.g. Helms 1893, Walter 1899, Morris 1929, Willis 1945, Millington 1954). More detailed and systematic studies began during the 1940s and 1950s stimulated by interest in the condition of highland water catchments, and the impacts of overgrazing by domestic livestock (Australian Academy of Science 1957; Carr and Turner 1959; Costin 1954, 1957, 1962a, 1962b; Wimbush and Costin 1979). Some of the more recent work has been focussed on peatland dynamics, processes and succession (Ashton and Hargreaves 1983, Wahren et al. 2001). Other important work documenting, describing and classifying treeless vegetation in the Victorian highlands, including in peatlands, has been performed by Farrell and Ashton (1973), McDougall (1982), and particularly Walsh et al. (1984). These last two formed the basis of the most recent descriptions for the entire mainland south-east Australian subalpine-alpine complex (McDougall and Walsh 2007). In recent decades there has also been continuing work looking at the influence of livestock grazing, and post-grazing recovery (McDougall 1989, Clarke and Martin 1999, Wahren et al. 1999b). The effects of fire on peatlands have also been studied in the aftermath of landscape-scale fires in the last 25 years (Wahren and Papst 1999, Wahren and Walsh 2000, Walsh and McDougall 2004, McDougall 2007).

Alpine and montane peatlands in Tasmania have also been much studied (Kirkpatrick 1983, Gibson and Kirkpatrick 1985a, 1985b, Whinam et al. 1989, Whinam and Kirkpatrick 1995, Whinam et al. 2001). Peatlands have been included in comparisons of subalpine and alpine vegetation in Tasmania with that found on the Australian mainland. The environmental factors influencing both local and regional distributions were part of these examinations (Kirkpatrick 1989, Kirkpatrick and Bridle 1998, 1999).

Peat-forming wetlands in montane areas of the mainland have received less attention with the possible exception of New South Wales where there are more extensive tableland areas at the appropriate altitudes (Millington 1954, Keith and Myerscough 1993, Keith 2004, Hope and Southern 1983, Hunter and Bell 2007). Examples in Victoria include Ladd (1979a) in East Gippsland, Shannon and Morgan (2007) in the Central Highlands, and Whinam et al. (2003a), who included montane wetlands in a Victoria-wide study. Many tableland wet heaths in NSW have been studied, and these contain many species closely related to those in peatlands at higher elevation. *Sphagnum* mosses are generally much less conspicuous in these (Keith and Myerscough 1993, Hope and Southern 1983). The same could be said of lowland wet heaths and those in near coastal areas in southern New South Wales, far eastern Victoria (Forbes et al. 1982), and eastern Tasmania (Kirkpatrick and Wells 1987).

Maintaining undisturbed or ‘intact’ peatlands and mires in mountain water catchment areas has many benefits. These include stabilisation of mountain soils and landscapes, filtration and reduction of turbidity, sediment and nutrient load in the stream water exiting upland areas (Ashton and Williams 1989, Williams and Costin 1994). Reductions in these variables generally enhance freshwater stream ecology; improving macro-invertebrate diversity, species richness and associated food chains in freshwater environments (Chessman 1995). Therefore, high altitude peatlands perform a similar function to lowland swamps and wetlands, providing a water treatment service. These arguments are particularly relevant in the Australian context; our relatively few substantial and reliable river systems are restricted to the eastern and south-eastern fringe of the continent. Indeed, efforts to conserve and protect the limited alpine areas and associated peatlands have been primarily based on their perceived catchment function and water yield benefits (Australian Academy of Science 1957, Carr and Turner 1959, Costin 1957, 1962a, 1962b) .

It is often stated that *Sphagnum* and peat can absorb larger amounts of water than mineral soils and non-wetland mountain ecosystems and thus, can delay stormwater stream discharge and minimise flash-flooding. While these claims are probably partly true, they have perhaps been overstated in the past (Western et al. 2008, 2009). Many studies show that water lost from peatlands via evapotranspiration is higher than from neighbouring non-wetland areas during summer months (Wimbush 1970, Western et al. 2008, 2009). Furthermore, even in the absence of high evapotranspiration, water retention capacity is variable and dependent on peat characteristics such as the degree of decomposition and pore structure (Ingram 1983). More than previously realised, peatland areas perhaps play a more important role in maintaining streamflow during the winter, by encouraging snowmelt, thus ‘smoothing’ the peak late winter/ early spring stream flows from the mountains (Wimbush 1970).

1.4 Aims and main areas of investigation

The purpose of this study is twofold. The first broad aim is to compare the vegetation of peatland communities at a number of different sites across the elevated areas of eastern Victoria and at a range of elevations. Past research in Victoria and New South Wales has focussed mostly on subalpine and alpine peatlands. By including data and observations from montane peatlands a fuller understanding of the differences in vegetation composition and structure along several gradients will be obtained. Variables that change along gradients in altitude, while including the more obvious climatic ones, also include differences in context, e.g. geology, topographic setting, associated neighbouring vegetation, fire and other disturbance regimes.

The second broad aim is to examine peatland vegetation pattern and process, succession, recruitment and regeneration, and some factors that influence these, specifically hydrology and disturbance. Two major landscape-scale fire ‘episodes’ occurred in the high country of south-east Australia during this research (2006-07 and 2009), and another three years earlier (2003). Historically, fire in these elevated regions has been infrequent, as outlined earlier in this chapter. Wetland and peatland communities were affected by the recent fires, and this has created further opportunities to examine aspects of peatland ecology in south-east Australia that may not arise again for several decades. In summary, the aims of the research are:

1. Describe and examine structural and compositional differences in peatland communities *within* and *between* sub-regions across eastern Victoria.
2. Investigate factors, both local and regional, correlated with and responsible for observed differences and patterns.
3. Examine the influence at local scales of water tables and microclimate on peatland vegetation patterns, including depth to water table and its variability, the annual hydrological cycle, temperatures during the growing season, frost frequencies, and snow cover duration.
4. Investigate the effects of recent fires on peatlands, including analysis of burning patterns, and early trends in post-fire recruitment, regeneration and succession. Document the vital attributes of the key species, including their regeneration niche and the nature and role of gaps in this process.

Structure and format of the thesis

Chapter 2 is a broad description of the highland areas of eastern Victoria. It includes a summary of the geology, soils, climate, vegetation, fauna, land-use and fire history. The sites used in this study of peatlands are spread from south-west to north-east across the mountain country of eastern Victoria. The peatland areas themselves cover a small proportion of the landscape above 1000 m elevation (1% or less) and are therefore strongly influenced by the surrounding landscape and ecosystems. The overview and summary in Chapter 2 is provided as context to aid interpretations of peatland vegetation patterns and dynamics.

Chapter 3 is an examination of the peatland vegetation patterns within three discrete regions in eastern Victoria. It documents and analyses the changes in vegetation structure and composition along gradients in altitude and topographic position. Particular focus is on the changes in representation of various indicator species and plant functional or ‘shared attribute’ groups along the various environmental gradients, and the influence of changes in peatland context.

Chapter 4 used the same data and analytical methods as Chapter 3 to make comparisons between the three discrete regions. This was done by comparing peatlands from different sub-regions within the same altitude zone (e.g. montane with montane, subalpine with subalpine). In this fashion, trends along geographical gradients were examined, including gradients in latitude, longitude, continentality and oceanicity. As for Chapter 3, the focus was on trends in plant functional group representation and indicator species.

Chapter 5 examines the influence of depth to water table, hydrological regime, and microclimate on peatland vegetation patterns at small scales. It sought to characterise the hydrological regime in several of the peatland community types identified and described in Chapter 3, and the influence of extreme low temperatures and snow cover.

Chapter 6 examines the influence and role of fire in peatlands, including the patterns of burning within peatlands affected by fire in 2006-07 and 2009. The factors that potentially influence these patterns are examined, both within (‘autogenic’) and external to peatland boundaries (‘allogenic’). The early post-fire regeneration patterns and the regeneration strategies of some of the common species were studied. The questions addressed in relation to peatland vegetation and fire in south-eastern Australia include:

- Which peatland communities are more susceptible to fire?
- Are the more susceptible peatland communities dominated by species that respond rapidly post-fire? Conversely, are fire-sensitive species associated with less frequently fire affected peatland communities?
- What environmental factors are correlated with fire-prone peatland communities? What factors and characteristics are associated with less frequently affected communities?

    - Do recruitment and regeneration continue independently of major disturbance episodes like fire? Which species and community types are likely to be favoured by or unaffected by the long absence of fire?

Some observations on cyclic succession are made, including the important relationships and interactions between *Sphagnum* and other important species, particularly the common shrubs.

Chapter 7 is a summary and synthesis of the observations, analysis and conclusions derived from the work. It includes broad implications, a summary of smaller significant findings and observations that could warrant future research, and recommendations for management.

CHAPTER 2

THE EASTERN HIGHLANDS OF VICTORIA: DESCRIPTION OF THE STUDY AREA AND BACKGROUND ON THE POTENTIAL ALLOGENIC INFLUENCES ON PEATLANDS

2.1 Physical factors

The Australian Alps is a series of plateaus, tablelands and high ridges that extend along the south-eastern perimeter of the Murray-Darling river basin, from central Victoria to southern New South Wales and the Australian Capital Territory (ACT). This is a distance of approximately 500 km, extending from latitudes 35º S to 38º S. By world standards they are gentle and not conspicuously high, the most elevated peaks being around 2200 m in New South Wales and 1900 m in Victoria. Many of Australia’s most important rivers rise from the alpine and mountain regions of the south-east, either flowing inland from the Great Divide to the Murray basin (Murrumbidgee, Mitta Mitta, Ovens, Goulburn, Murray), or east and south from the watershed divide to the ocean directly (e.g. Snowy, Mitchell, La Trobe rivers).

This study of high altitude peatland vegetation spans most of the geographic range of the Eastern Highlands of Victoria. For time and logistical reasons, the eastern most section, between Omeo and the Victoria-New South Wales border, was not included. The peatland sites included in this study can be broadly separated into five sub-regions. These are: the Lake Mountain-Blue Range area (Central Highlands), Baw Baw Plateau and upper Thomson Valley, Snowy Range and upper Moroka Valley, Dargo High Plains, and the Bogong High Plains and western Mitta Mitta River catchment (Figure 2.1). This encompasses an area that extends approximately 150-200 km from near Melbourne in south central Victoria, to north of Omeo in the north-east of the state. The sites chosen vary in altitude from 1000-1730 m and thus span three elevation zones: montane (to 1300 m), subalpine (1300-1650 m), and alpine (above ~1650 m).

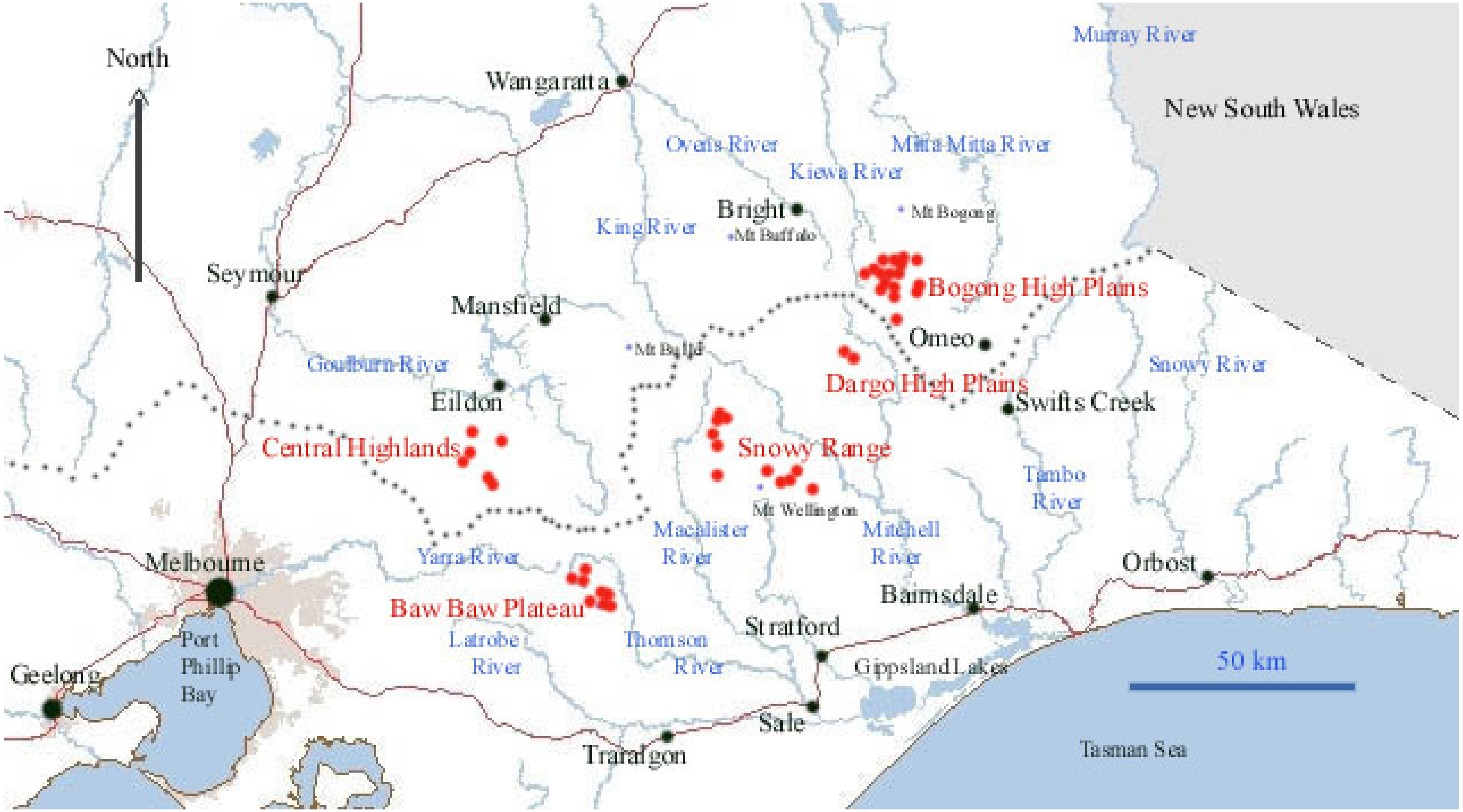


Figure 2.1: Map of eastern Victoria showing the five sub-regions from which data were collected, major towns and rivers. The red dots mark the approximate locations of peatland study sites. The black dotted line marks the approximate position of the Great Dividing Range in Victoria and thus the boundary of the Murray-Darling basin.

In order to understand the current vegetation patterns in the ‘upland’ peat-forming wetlands of the region, it is important to know something about their context. This includes external or allogenic influences such as geology, climate, surrounding vegetation types, fauna, current and past land-use, and disturbance regimes. In this chapter summaries and descriptions of these are provided.

Geology and Geomorphology

The eastern third of the Australian continent consists mostly of rocks that date from the Palaeozoic (550-240 million years ago, Cambrian to Carboniferous), in contrast to the much older and more stable pre-Cambrian rocks of the remaining western two-thirds of the continent (Douglas 1993). These are mostly sediments and metamorphic rocks deposited under marine conditions, folded, faulted and shaped by tectonic movements on several occasions during these periods. Igneous intrusions of granitic rocks, in particular, are thought to have been associated with these periods of instability, together with extrusive igneous deposits. A number of fold-belts comprise the eastern third of the continent. These fold-belts are generally aligned north-south, and most of Victoria (east of about Horsham), and central and southern New South Wales is within the Lachlan Fold Belt (Ollier and Wyborn 1989). The entire geographical extent of the Australian Alps and associated uplands is within the Lachlan Fold Belt zone.

The general trend of the Eastern Highlands of Victoria is east-west and therefore perpendicular to the predominant north-south structural trend. Hence, there is a great diversity of rock ages and types across their range. The sediments of marine origin range from Cambrian to Silurian-Devonian, and consist of sandstones, shales, mudstones and conglomerates. These currently outcrop through most of the country between the Bogong High Plains and the Snowy Range, including much of the Ovens river basin, north of the ‘Great Divide’, and the Mitchell river basin, south-east of the ‘Great Divide’ (Figure 2.1). These are mostly Ordovician or Silurian and therefore, 500-410 million years old (myo) (Douglas 1993).

Non-marine sediments from the Devonian-Carboniferous (~ 360 myo) outcrop in a diagonal band from the Mansfield region in the north-west (Goulburn River catchment), to the Stratford-Briagolong district in the south-east (Gippsland Lakes catchment). These are mostly sandstones, conglomerates and siltstones, and are sometimes called 'the red beds' due to their striking colours, which are revealed in the many spectacular escarpments and jagged ridges associated with scenic features such as 'The Bluff', Bryces Gorge, Moroka Gorge, and the 'Cross-Cut Saw'. Associated with these sediments are igneous extrusive rocks of similar age, mostly rhyolites. Collectively, this group of distinctive sedimentary rocks and acid volcanic deposits are referred to as the Avon group or formation. Many of the peatland sites in this study are underlain by this formation.

Other extrusive igneous rocks from this period (Devonian-Carboniferous) outcrop in the Lake Mountain-Blue Range region (Central Highlands) and include rhyodacite, dacite and ignimbrite (LCC 1973, Rundle 1977). All the Central Highlands peatland sites used in this study are associated with these rocks, which are part of the Cerberean and Acheron caldera (Marysville Igneous Complex).

Granite or granodiorite batholiths or plutons occur in many parts of Victoria and were also formed during the Devonian period (360-410 myo). The most prominent in the Eastern Highlands region are the Baw Baw Plateau and the Buffalo Plateau, but there are also several smaller areas of outcrop, such as on the Bogong High Plains and in the Mt Buller-Mt Stirling area. All the Baw Baw region peatland sites examined in this thesis are underlain by Devonian granodiorite (Cochrane et al. 1991). The most recent volcanic rocks relevant to the study area are the Oligocene basalt lava flows (~ 35 myo) that today are only represented over small areas of the eastern highlands (Douglas 1993), but are more extensive in southern New South Wales (Ollier and Wyborn 1989). In Victoria, these are represented by remnant 'capping', planar and gentle or undulating tablelands, such as the Dargo High Plains, Bryces Plains and Howitt Plains (Snowy Range region), and the Mount Jim area on the western side of the Bogong High Plains. Some of the peatlands examined in this study are associated with these Oligocene basalts.

Metamorphic rocks outcrop over the majority of the Bogong High Plains region. These are mostly schists and gneisses of Ordovician to Silurian age (410-500 myo).

The higher altitude peatlands of mainland south-eastern Australia are mostly ground-water fed, therefore minerotrophic and potentially influenced by the nature of the underlying bedrock (Whinam and Hope 2005, Hope et al. 2009). Arguably the most important geological distinction for peatlands is between those on coarser grained, siliceous sedimentary, metamorphic or igneous rocks on one hand (e.g. granite, sandstone), and those on fine-grained sediments and basic igneous rocks on the other (e.g. basalt). The groundwater from the latter tends to be more mineral rich (e.g. Ca, Mg, K, Fe).

The general consensus is that the uplift that created the Australian Alps and eastern highlands of Victoria was associated with the rifting of Australia from Gondwana, which began in the late Mesozoic (Cretaceous, ~ 80-90 myo). This process continued through the Cainozoic era (Tertiary) to the present day and was accompanied by the dissection that created the major river valleys as we know them today (Ollier and Wyborn 1989).

The Pleistocene glaciation in Australia (last two million years) had its most obvious impact on western and central Tasmania. The only part of mainland Australia that geomorphologists confidently believe supported glaciers during the last glacial maximum (35,000-15,000 yrs before present) is the area around Mt Kosciuszko itself (Petersen 1971, Galloway 1989). However, periglacial landform processes such as solifluction, have left visible reminders of recent colder times across the eastern highlands of Victoria (e.g. scree-slopes, boulder-streams) (Petersen 1971, Rosengren and Petersen 1989, Ashton and Williams 1989). During the last glacial interlude temperatures across south-eastern Australia were at least 5-9º C cooler than the present (McKenzie 1997, Costin et al. 2000).

Soils

In spite of the large geographic, geological, altitudinal and topographical range represented by the sites used in this study, there is a fairly consistent pattern to the distribution of soil types. Parent bedrock, altitude and topography are perhaps the strongest influences on soil type (Costin 1962a, Gibbons and Rowan 1993).

The wetter montane forest areas (tall open forest, cool temperate rainforest) have the best soils for plant growth. The soils are deep friable loams with few plant growth limitations, either chemical or physical (Gibbons and Rowan 1993). They are mildly acidic (pH. 5.0-5.5), uniform in texture and appear to be influenced little by parent bedrock type. Drier montane vegetation tends to occur on shallower organic loams, usually with poor structure and relatively high gravel and stone presence. These are often less than 50 cm deep, more acidic, low in nutrients, and because of their shallow nature, plant-available water supply is also limited (skeletal soils). Tree-root anchorage is also diminished, which further favours reduced forest and woodland canopy stature (10-25 m). The shallower profiles also favour understorey vegetation dominated by shrubs rather than graminoids and herbs. At higher elevations subalpine *Eucalyptus pauciflora* open forests and woodlands with a similarly structured understorey occur on similar soils.

Alpine humus soils predominate in gently sloping treeless areas (Costin 1962a, Ashton and Williams 1989). These are acidic, low in nutrients, high in organic matter, and therefore have high carbon to nitrogen ratios (Gibbons and Rowan, 1993). They are deep on gentle slopes, and support grasslands which grade into open heath on more moderate slopes and shallower soil-profiles (Carr and Turner 1959, McDougall 1982). With increasing slope, the soils are shallow, skeletal, and poorly sorted. At higher elevations (1650-1800 m) the knolls and upper slope positions with skeletal soils support shrub dominated vegetation with scattered low *Eucalyptus pauciflora* ssp. *niphophila* (< 10 m).

The soil gradient is similar in the lower altitude treeless subalpine valleys (1300-1650 m), with subalpine grasslands and open heath on the marginally deeper soils of the gentle lower valley slopes. At this elevation, they grade into low open forest or open forest, on the shallower soils of the steeper upper slopes. The lowest topographic positions and mid-slope seepage areas in all three elevation zones carry wetland vegetation and these soils are fibrous peats, amorphous peats, and oxygenated or ‘dried’ peats, depending on local drainage. The peats are derived mostly from *Sphagnum*, sedge and dwarf shrub biomass in various stages of decomposition (Costin 1954, 1962a). These are acidic, anoxic, low in available nutrients (particularly Ca, K, N and P), and have the highest water holding capacities. In general, extractable P, Zn, and Mg appear to be the soil minerals that have the biggest influence on the distribution of the various treeless vegetation formations in mountain areas of south-eastern Australia (Kirkpatrick and Bridle 1998, 1999).

Climate

By Australian continental standards, the elevated regions of the south-east are amongst the wettest. Annual precipitation totals range between 1000 and 2500 mm throughout most of the area (Ashton and Williams 1989), with the exception of several deep ‘rainshadow’ valleys that are leeward of the higher rain-blocking peaks and plateaus, and these receive less than 800 mm (Aldrick et al. 1988, Bureau of Meteorology 1993).

Much of the precipitation falls as snow between May and September, and is associated with the passage of cold fronts and low pressure cells that sweep from west to east across the south-east of the continent during winter and spring. Thus, predominant winds through much of the area are from within an arc running from north-west to south-west. Wind speeds can be high and are an important abiotic factor, especially along exposed ridgetops and in treeless areas. Strong precipitation gradients operate from north-west to south-east across the high country of Victoria, in the direction of the predominant winds. Perhaps the most dramatic illustration of this is around the Bogong High Plains, where annual precipitation on the north-west slopes is >1500 mm, increasing to over 2000 mm on the windward side of the Bogong High Plains themselves, and then dropping to under 1000 mm on the south-eastern slopes, in the Mitta Mitta River basin (Rowe 1967, Ashton and Williams 1989) (Table 2.1, Figures 2.2, 2.3).

There are also similar gradients that affect the other regions (Table 2.1, Figures 2.2-2.5). The Snowy Range area is somewhat ‘shadowed’ by the peaks and plateaus lying to the north-west and south-west (Rowe and Downes 1960, Farrell and Ashton 1973, LCC 1977, Ashton and Williams 1989). The Baw Baw region, at the south-western end of the highlands, receives precipitation from the south and south-east (in addition to the westerly component), which sub-regions further north and north-east miss, especially during the summer months (Aldrick et al. 1988, Bureau of Meteorology Victoria 1993). ‘East Coast lows’ affect the south coast of New South Wales and far eastern Victoria, and these produce spectacular rainfall episodes, but occur irregularly and are unpredictable. The Snowy Range region, and Baw Baw region to a lesser extent, benefit from the moisture provided by these weather systems (e.g. June 2007, Gippsland floods). The areas on the north-west slopes of the ‘Great Divide’ (Bogong High Plains, Lake Mountain area) do not benefit from these to the same extent. In this situation, the gradient operates in reverse (south-east to north-west). However, the Bogong High Plains does receive summer rainfall from convective storms, and the incidence of these in north-east Victoria is roughly twice the state-wide average (Bureau of Meteorology Victoria 1993). The ‘inland’ slopes of the high country (Murray Basin) also benefit from occasional moist subtropical air-masses that drift south over the interior from northern Australia. These too provide spectacular rainfall in the high country on the north-west slopes (e.g. September 2010), akin to that experienced on the south-east slopes due to ‘East Coast’ or ‘Tasman Sea lows’ (Bureau of Meteorology Victoria 1993).

In general, the south-western regions (Baw Baw in particular) have a more even annual and inter-annual precipitation regime (1500-2000 mm), with lower variability, generally higher humidity and cloud cover, and lower evapotranspiration (Costin 1957, Ashton and Williams 1989). The Snowy Range region receives slightly less precipitation overall (950-1600 mm), which is also relatively evenly distributed across the year, but more variable than the Baw Baw region for example. The Bogong region has a particularly strong winter-spring precipitation maximum (200-350 mm per month, June to

Table 2.1: Precipitation summary statistics for nine sites across the Eastern Highlands of Victoria (data from the Australian Bureau of Meteorology).

	(A) Rocky Valley	**(B) Shannonvale**	**(C) Mount Hotham**	**(D) Mount Buller**	**(E) Rubicon**	**(F) Mount Tamboritha**	**(G) Mount Wellington**	**(H) Reeves Knob**	**(I) Mount Baw Baw**
Latitude	36.88 S	36.93 S	36.98 S	37.15 S	37.33 S	37.47 S	37.50 S	37.53 S	37.84 S
Longitude	147.29 E	147.42 E	147.13 E	146.44 E	145.86 E	146.69 E	146.86 E	147.01 E	146.27 E
Altitude (m)	1661	800	1849	1707	380	1446	1559	1300	1561
Precipitation (mm)									
January	118 ± 10	61 ± 6	95 ± 11	67 ± 8	70 ± 7	66 ± 9	48 ± 10	72 ± 21	87 ± 13
February	86 ± 11	48 ± 5	85 ± 14	65 ± 9	54 ± 7	68 ± 12	83 ± 24	110 ± 38	137 ± 32
March	107 ± 11	55 ± 5	97 ± 20	78 ± 23	74 ± 12	43 ± 7	56 ± 14	55 ± 13	99 ± 17
April	145 ± 15	58 ± 6	102 ± 14	107 ± 17	115 ± 15	93 ± 19	76 ± 15	82 ± 13	126 ± 32
May	217 ± 20	67 ± 6	131 ± 23	145 ± 21	181 ± 15	61 ± 9	68 ± 22	64 ± 21	110 ± 17
June	248 ± 18	72 ± 5	151 ± 19	172 ± 20	188 ± 13	93 ± 15	119 ± 67	108 ± 44	142 ± 35
July	317 ± 25	86 ± 7	134 ± 13	198 ± 29	228 ± 14	79 ± 10	85 ± 16	78 ± 15	152 ± 26
August	328 ± 25	99 ± 7	123 ± 21	163 ± 26	227 ± 11	85 ± 11	70 ± 8	62 ± 10	203 ± 23
September	278 ± 22	99 ± 6	144 ± 22	158 ± 19	164 ± 11	85 ± 8	69 ± 11	69 ± 6	187 ± 37
October	230 ± 19	100 ± 6	133 ± 27	139 ± 25	152 ± 8	79 ± 13	80 ± 23	81 ± 17	130 ± 17
November	171 ± 11	87 ± 6	158 ± 18	118 ± 20	114 ± 8	97 ± 14	116 ± 22	134 ± 21	147 ± 23
December	148 ± 14	70 ± 5	104 ± 20	108 ± 17	90 ±	70 ± 10	90 ± 17	105 ± 14	166 ± 29
Total	**2393 ± 94**	**903 ± 28**	**1457 ± 118**	**1518 ± 95**	**1657 ± 53**	**919 ± 59**	**960 ± 61**	**1021 ± 73**	**1687 ± 80**
Period of obs.	1960-2010	1952-2010	1995-2010	1986-2008	1944-1992	1989-2010	2003-2010	2002-2010	1999-2010
Number of obs.	48 to 50	57 to 59	14 to 16	12 to 13	48	15 to 17	6 to 8	7 to 9	6 to 7

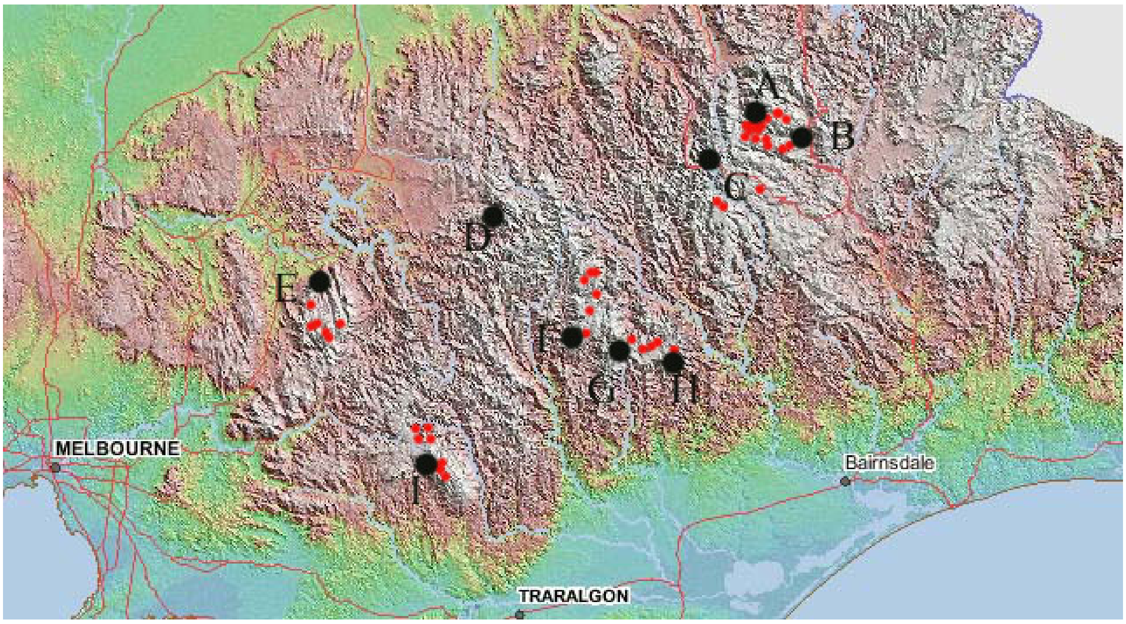


Figure 2.2: Map of eastern Victoria showing the relief, sub-regions studied, and locations of the weather stations for which data are provided. The letters correspond to the sites listed in Table 2.1.

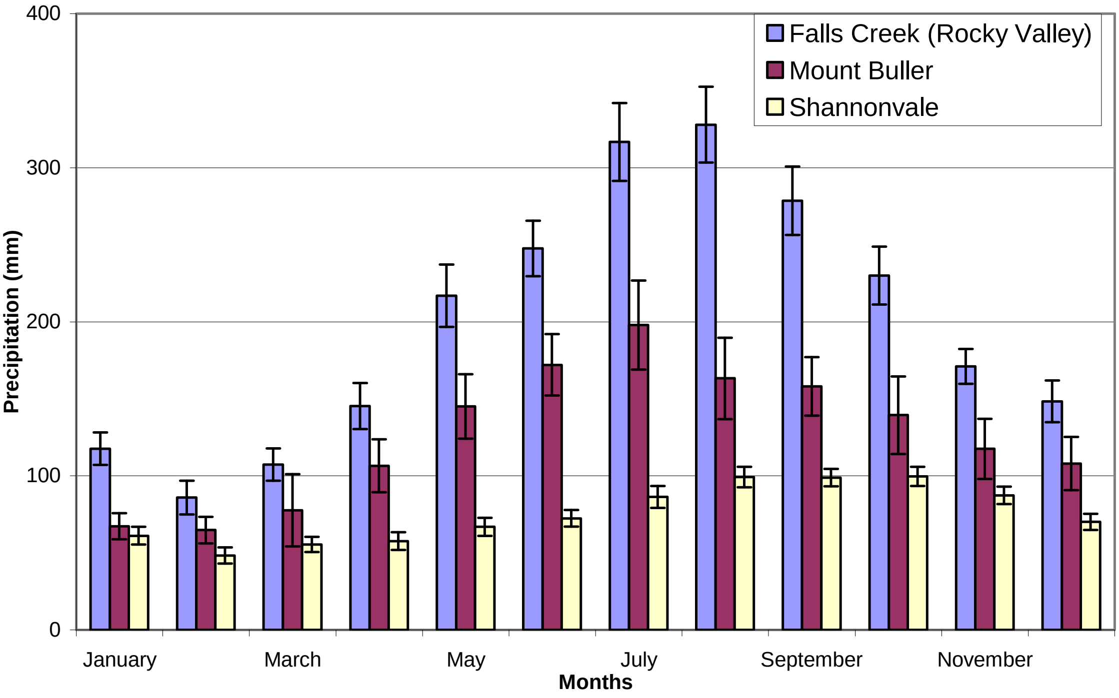


Figure 2.3: Annual precipitation distribution for three locations in the Eastern Highlands area. The location of the stations can be seen in Figure 2.2: Falls Creek (Rocky Valley) = A, Mount Buller = D, Shannonvale = B. (Data derived from Australian Bureau of Meteorology)

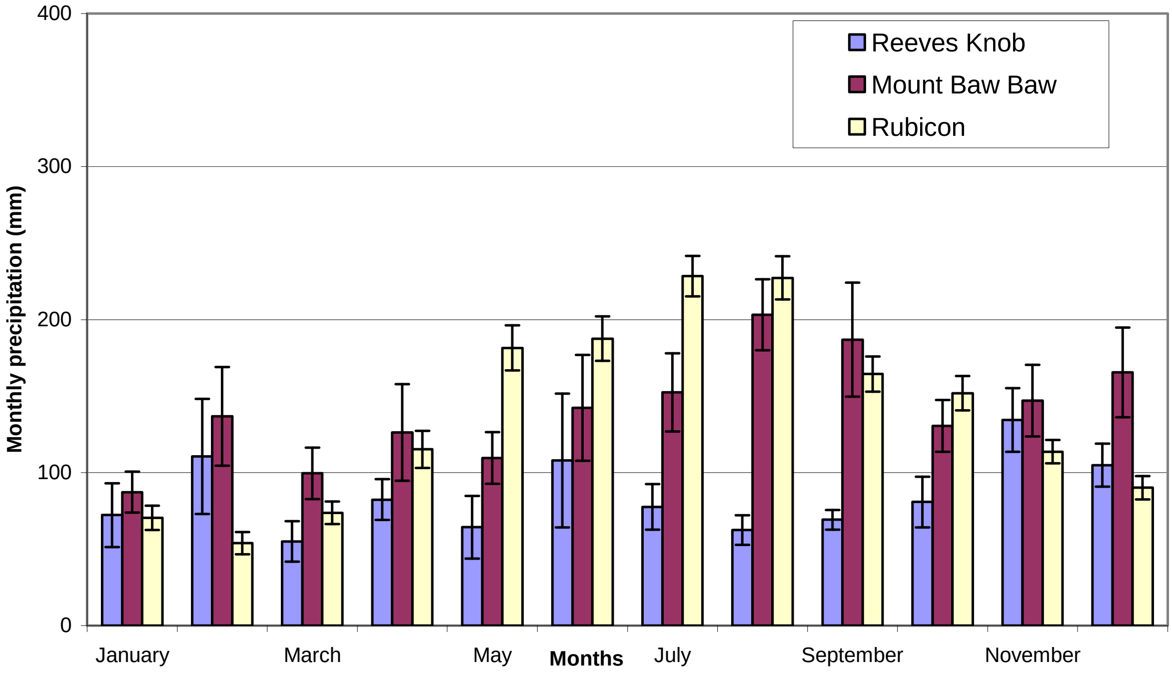


Figure 2.4: Annual precipitation distribution for three locations within the Eastern Highlands area. The location of the stations can be seen in Figure 2.2, Reeves Knob = H, Mount Baw Baw = I, Rubicon = E (derived from Australian Bureau of Meteorology data).

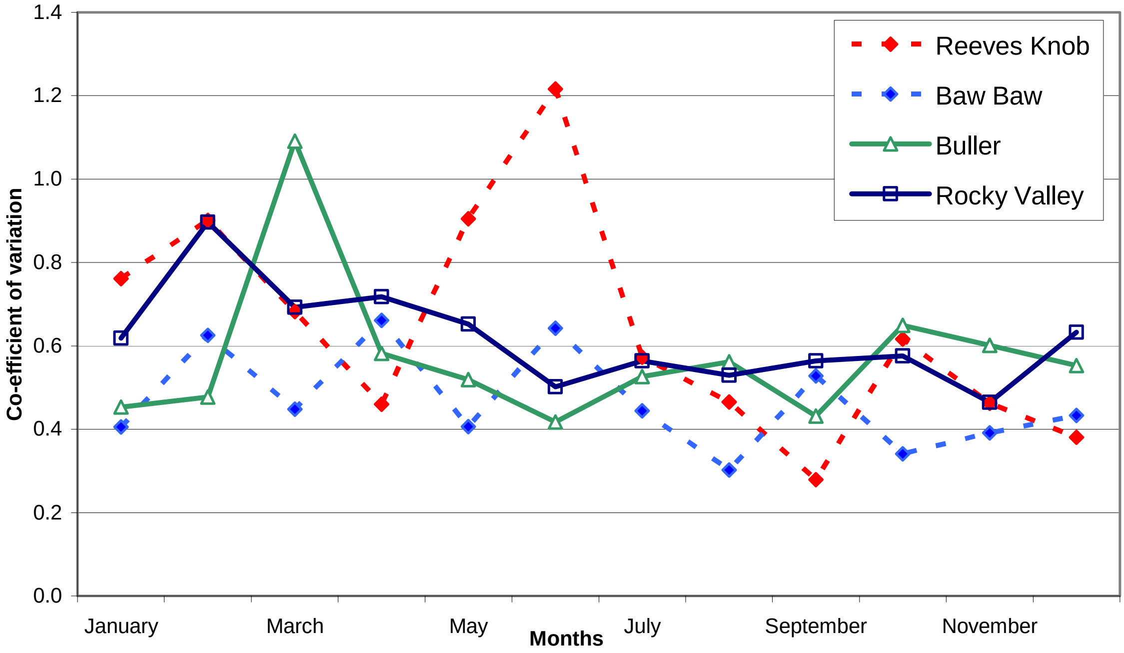


Figure 2.5: Monthly precipitation variability of four sites across the Eastern Highlands of Victoria as measured by the co-efficient of variation. The mean co-efficients of variation for each of the sites: Reeves Knob = 0.64 ±0.08, Baw Baw = 0.47 ±0.03, Buller = 0.57 ±0.0, Rocky Valley = 0.62 ±0.03 (derived from Australian Bureau of Meteorology data).

September), but summer rainfall is highly variable (Rowe 1967, Bureau of Meteorology Victoria 1993, Figures 2.2-2.5, Table 2.1).

Mean annual temperatures above 1000 m are less than 9º C and as low as 4 or 5º C at the highest elevations (Williams and Costin 1994). Mean daily maximum temperatures are generally below 21º C in January and below 6º C in July; minimum temperatures are below 10º C in January and 2º C in July. Frosts are common at any time of year (up to 200 per year), especially at the highest elevations and in treeless valley bottoms (Bureau of Meteorology Victoria 1993). Snow cover can be deep above 1300 m (> 30 cm), and accumulates differentially according to topography, slope and aspect. Because most of the snowfall is associated with north-west, west or south-west winds, it tends to accumulate to greater depths on south and east facing slopes, assisted by the shelter and the snow-drift 'retarding' framework provided by trees and shrubs (Williams 1987). South and east facing slopes also receive less insolation (Kirkpatrick and Nunez 1980) and thus, tend to retain snow cover for longer than other aspects. In general, the duration of snow cover is less than one month below 1200 m, about three months at 1600 m, and above 1800 m elevation increases to five months or more on favourable aspects (Williams and Costin 1994, Costin et al. 2000). At the south-western end of the Victorian high country, snow cover duration is perhaps slightly less at equivalent altitudes, due to the influence of a more oceanic climate (Costin 1957). This is similar to snow accumulation and cover duration patterns in Tasmania, although perhaps less pronounced (Kirkpatrick and Bridle 1999).

2.2 Biotic factors

General broad vegetation patterns

The peatland sites examined in this thesis are spread over a large geographic area, and therefore the vegetation in the surrounding landscape varies considerably in response to the subtle differences in climate and geology already mentioned. The actual area of eastern Victoria above 1000 m is hard to quantify because of the dissected nature of the landscape, but is about 650,000 ha (Conn 1993). Treeless areas account for approximately 70,000 ha (McDougall and Walsh 2007), or about 11%. The extent of peatland in eastern Victoria is also difficult to quantify, partly because of the difficulties defining boundaries and the variation in criteria used for these purposes. Estimates range from 2700 ha (Western et al. 2008) to roughly 4500 ha (Tolsma *pers. comm.* 2009), which suggests that peatlands cover between 0.4% and 0.7% of the land surface above 1000 m, or 3-7% of treeless areas. The proportions vary from region to region, but are greater in the Baw Baw region than anywhere else (Costin 1957, Ashton and Williams 1989, Tolsma and Shannon 2009). The total amount of treeless area is greater in the Snowy Range area than at Baw Baw, but the proportional representation of peatland is lower than elsewhere.

In the south-west of the study area, closer to Bass Strait, montane forests above 1000 m elevation are dominated *Eucalyptus delegatensis* and *E. nitens* (Ashton and Hargreaves 1983, Gullan et al. 1981). Structurally these are tall open forests (Specht 1970), with an understorey dominated by a mix of shrubs, small trees and ferns (e.g. *Tasmannia lanceolata*, *Olearia phlogopappa* var. *phlogopappa*, *Acacia obliquinervia*, *Daviesia* spp., *Polystichum proliferum*) (Table 2.2). In both the Baw Baw and Central Highlands regions, cool temperate rainforest containing *Nothofagus cunninghamii* and *Atherosperma moschatum* is common, especially along streamlines and on south or east facing slopes (Howard and Ashton 1973). *Leptospermum grandifolium* is generally associated with these also. In montane areas, the peatlands that are the focus of this study tend to occur in slightly broader valley floor locations, and also in more enclosed settings, associated with stands of cool temperate rainforest (Shannon and Morgan 2007).

At higher altitude in the Baw Baw-Central Highlands region, above approximately 1320 m, *Eucalyptus pauciflora* open forest is dominant. The understorey in these forests is variable but generally dominated by shrub species (e.g. *Pultenaea muelleri*, *Tasmannia xerophila*, *Olearia phlogopappa* var. *flavescens, Leionema phylicifolium*, *Acrothamnus* *maccraei*, *Orites lancifolia*)(Gullan et al. 1981). Other noteworthy understorey species include *Wittsteinia vacciniacea*, *Trochocarpa clarkei* and *Poa ensiformis*. *Nothofagus cunninghamii* is also present at this altitude (Costin 1957), and often forms small thickets with *Leptospermum grandifolium*, which abut open forest at the edge of peatlands (Ashton and Hargreaves 1983).

Table 2.2: Summary of the broad vegetation structure and types in the areas surrounding the peatland sites in each region.

Non Wetland Vegetation	Baw Baw/ Central H'lands	Snowy Range/ Dargo	Bogong
Montane vegetation structure	Tall open forest Cool temperate rainforest	mostly open forest	Tall open forest Open forest
Montane understorey	taller shrubs small trees, ferns	even mix of shrubs, graminoids and herbs	even mix of shrubs, graminoids and herbs
Subalpine vegetation structure	Open forest Low open forest	Open forest Low woodland	Open forest Low woodland
Subalpine understorey	shrub dominated	even mix of shrubs, graminoids and herbs	even mix of shrubs, graminoids and herbs
Treeless vegetation structure	Heath	Heath Grassland	Heath Grassland

The treeless vegetation in both of these more south-western subalpine areas is heath dominated and grassland is virtually absent (Costin 1957, Ashton and Williams 1989). Subalpine heathlands contain many of the same species present in the neighbouring open forest understorey (Conn 1993). Other common shrubs include *Grevillea australis*, *Asterolasia trymalioides*, *Ozothamnus* spp. and *Epacris petrophila*. Grasses and herbaceous dicots are represented by species like *Poa hiemata*, *Celmisia* spp., *Podolepis robusta* and *Stylidium* spp. (Walsh et al. 1984, McDougall and Walsh 2007). The subalpine heaths in these sub-regions tend to merge gradually with peatland vegetation. The subalpine peatlands tend to be located on the lower valley slopes of these treeless areas.

Montane vegetation in the Snowy Range and Dargo High Plains regions is generally more open. Structurally, it is best described as open forest, tending to woodland in places (Farrell and Ashton 1973, Ashton and Williams 1989). Tall open forest is not as extensive and more restricted to deeper soils and cooler, wetter aspects. Rather than being dominated by *Eucalyptus delegatensis*, the stands of tall open forest tend to be mixed with *E. dalrympleana*, and this latter species often forms pure stands. Other common montane forest and woodland canopy species include *E. stellulata*, *E. rubida* or, on drier aspects, *E. dives* and *E. mannifera* (Conn 1993). *Eucalyptus stellulata* is perhaps the local tree species with the highest tolerance of poor drainage and frequently occurs near the margins of peatland vegetation in the lower subalpine and montane areas of this region. In these locations it is also frequently exposed to frost (Farrell and Ashton 1973). Snowgum, *E. pauciflora*, also occurs in broad enclosed valleys at montane elevations, unlike the Baw Baw-Central highlands region (Farrell and Ashton 1973). The understorey vegetation in forest and woodland areas is drier in character; a mix of shrub, grass and herb species. These include leguminous shrubs (*Podolobium*, *Daviesia*, *Mirbelia*), dry heath shrubs (*Hibbertia*, *Euryomyrtus*, *Persoonia*) and graminoids such as *Poa sieberiana*, *Joycea pallida* and *Lomandra longifolia*.

The transition from the montane zone to the subalpine zone in this region is not as clearly defined as in the other two regions. *Eucalyptus pauciflora* open forest and woodland is dominant above about 1400 m elevation, although even at these elevations *E. dalrympleana*, *E. stellulata* and *E. perriniana* are not uncommon (e.g. near Bryces Plains 1450 m) (Farrell and Ashton 1973, Ashton and Williams 1989). The treeless areas in this region are mostly gentle enclosed valleys and maintained by cold-air drainage. The highest peaks are between 1640 and 1750 m elevation and barely qualify as genuinely ‘alpine’. The highest ridges and plains are sparsely wooded, and tree stature often less than 10 m. The non-wetland vegetation in subalpine treeless areas consists of a high proportion of open heath and grassland (Walsh et al. 1984, Wahren et al. 2001b, McDougall and Walsh 2007). Common species include *Poa fawcettiae, Carex breviculmis, Craspedia* spp., *Celmisia* spp., *Leptorhyncos squamatus*, *Hovea montana*, *Leucopogon hookeri*, and *Grevillea australis*. The areas of cool temperate rainforest associated with forests in the Baw Baw-Lake Mountain region, are absent (Costin 1957, Ashton and Howard 1973). Peatland communities occur adjacent to streams, along the lower slopes of treeless valleys, and occasionally on steeper slopes as a result of seepage or groundwater discharge.

The Bogong region also has montane tall open forest areas dominated by *Eucalyptus delegatensis*, but these are best developed on the wetter, steeper, north-west and western approaches to the area (Ovens and Kiewa Valleys). In the drier south-east and eastern approaches (Mitta Mitta Valley), montane vegetation is open forest containing similar canopy species to the Snowy Range area. Subalpine areas above approximately 1400 m are dominated by *Eucalyptus pauciflora* ssp. *pauciflora* open forest, which becomes woodland and open woodland dominated by *E. pauciflora* ssp. *niphophila* at higher altitudes. Treeless enclosed subalpine valleys (inverted treelines) are common, especially on the more gentle southern and eastern approaches to the region. Treeless areas account for an increasing proportion of the landscape as the true climatic treeline is approached (1800 m). The open forest surrounding the treeless subalpine valleys on the sheltered eastern and southern sides has a more mixed canopy composition and includes *E. stellulata*, *E. dalrympleana*, and *E. perriniana*, as well as *E. pauciflora*. The understorey in steeper subalpine areas is shrub dominated, but is more open and herbaceous in moderately sloping areas (Costin 1957). Vegetation in the treeless subalpine valleys is mostly open heath, grassland, and wetland. It is a similar pattern at higher elevations, but the forested upper slopes and knolls at 1550 m become closed heathland with scattered low trees in similar topographic positions at 1750 m.

The distribution of plant communities in the highest treeless areas of the Bogong region (> 1600 m) is influenced by soil depth, exposure to wind and frost, and soil drainage (McDougall 1982, Ashton and Williams 1989). Peatland and other wetland vegetation is on the lower slopes, valley floors and hill-side seepage areas. Grasslands are on better drained gentle lower valley slopes and broad flat ridgetops (*Poa hiemata*, *Leptorhyncos squamatus*, *Celmisia pugioniformis*, *Carex breviculmis*, *Rytidosperma nudiflorum*, *Craspedia* spp.). Open heath vegetation is on moderate slopes and slightly shallower soils (grassland species and *Grevillea australis*, *Asterolasia trymalioides*, *Hovea montana*). Closed heath dominates steeper rockier slopes (*Prostanthera cuneata*, *Bossiaea foliosa*, *Orites lancifolia*). On the eastern and south-eastern sides of the highest ridges, herb and grass dominated ‘snow-patch’ communities occur (*Celmisia pugioniformis*, *Luzula acutifolia*, *Poa fawcettiae*). These can remain snow covered for up to seven months in some years (June to December) and experience the shortest growing seasons. The more exposed basalt ‘capped’ areas near Mt Jim (1805 m), on the western side of the Bogong High Plains, are dominated by *Poa costiniana* grasslands; these appear to be more moisture retentive and fertile than grassland areas on metamorphic bedrock (*P. hiemata*) (McDougall 1982, Williams and Ashton 1987a).

Fauna

The fauna inhabiting the forests, woodlands and treeless areas above 1000 m in south-east Australia are many and varied. Common mammals and marsupials include the wombats, wallabies, bush rats, antechinuses, bats, possums, and gliders. Some of the rare and more interesting species include things like the Mountain pygmy-possum (*Barramys parvus*), which lives in the boulder-fields at high elevation (>1600 m) in the Bogong, Kosciuszko and Mt Buller areas (Heinze et al. 2004). Another notable species endemic to parts of the various regions is the Leadbeaters possum (*Gymnobelideus leadbeateri*), which lives in the tall open forests of the Baw Baw - Central Highlands region, although once more widespread across eastern Victoria (Lindenmayer 1996, Griffiths 2001). Most if not all of these mammals and marsupials are rare in treeless areas, the exceptions being crypic things like the Broad-toothed rat (*Mastacomys fuscus*), which lives in shrub-dominated vegetation, including wet heath. Macropods such as the Eastern grey kangaroo (*Macropus giganteus*) and Red-necked wallabies (*Macropus rufogriseus*) are also rare above the treeline, although more common in montane tableland areas further east (e.g. Monaro region, New South Wales) (Green and Osborne 1994).

Similarly, birds are reasonably well represented in wooded areas, but less conspicuous at high elevations. Birds of prey include Boobook owls, Peregrine falcons and Wedge-tailed eagles. Other birds common in wooded and forested areas include the Superb lyrebird, Cockatoos, Currawongs, Australian ravens, Flame-robins, Rosellas, Grey fan-tails, Scrub-wrens, Richard's pipit, and Pardalotes. Some of these are also active in treeless areas. Emus (*Dromaius novae-hollandiae*) are relatively rare, but occasionally seen in montane and subalpine treeless plains (Frith 1969, Green and Osborne 1994, Pizzey and Knight 1997).

Frogs, snakes and skinks are well represented. The Corroboree frog (*Pseudophryne corroboree*, *P. pengilleyi*) is the most widely known. These are endemic to the *Sphagnum* dominated bogs and wet heaths in the Snowy Mountains in New South Wales. The Baw Baw frog (*Philoria frostii*) is endemic to Victoria, where associated with wetland vegetation in montane and subalpine areas of the Baw Baw Plateau. The Alpine water-skink (*Sphenomorphis koscuiszkoi*), Alpine bog-skink (*Pseudomoia cryodroma*), Spotted tree frog (*Litoria spenceri*), and Alpine tree frog (*Litoria verreauxii alpina*) are threatened and depend on wetland vegetation for habitat. The most common snakes are the Highlands copperhead (*Austrelaps ramsayi*) and the White-lipped snake (*Drysdalia coronoides*) (Green and Osborne 1994).

Peatland pools and streams are rich with aquatic macro-invertebrate life. These include countless small crustaceans (e.g. Amphipods), as well as stoneflies, caddisflies, blackflies, and mayflies. A high degree of diversity amongst the macro-invertebrate assemblages is thought to indicate high water quality and good stream health (Chessman 1995). Stoneflies in particular are restricted to streams above 700 m, and therefore individual species are highly restricted in range (e.g. *Thaumatoperla* spp.) (Campbell 1986). Peat-burrowing crayfish (e.g. *Euastacus*) are found in some montane and subalpine peatlands. The entrances to their burrows are often seen along streams and pool margins (Campbell 1986). Terrestrial invertebrates are also diverse and include many species of grass-hoppers, ants, and spiders (Green and Osborne 1994). The Alpine case-moth (*Lomera caespitose*) and the Alpine grass-grub (*Oncoptera alpina*) have been linked to dieback in alpine grasslands (Carr and Turner 1959, Costin et al. 2000), and are of interest to plant community ecologists.

Aboriginal land use

Aboriginal use of the highland areas is still shrouded in mystery. However, there has been more appreciation and understanding of Indigenous perspectives on the land in recent years. The Australian Alps falls within the territory of five groups and the Victorian section mostly within two of these. The Jaitmathang people were active in the Bogong High Plains region and Omeo-Benambra area. Most of the rest of the Victorian high country belonged to the Brabiralung (Zylstra 2006). They were mostly concentrated in the lower elevation and tableland areas, but visited the higher areas during the warmer months for spiritual and ceremonial reasons and to collect Bogong moths (*Agrotis infusa*, Flood 1980). Contrary to early colonial belief about Aboriginal use of fire, there was careful thought and strict cultural lore associated with its use. In the tableland and lower montane areas they may have used fire for regeneration of food plants and animal management purposes, but in subalpine and alpine areas it was only used to clear ceremonial pathways (Zylstra 2006). This is supported by palaeoecological and dendrochronological evidence suggesting that fire was rare above 1300 m prior to European settlement (once or twice per century) (Banks 1989, Dodson 1994, Zylstra 2006).

2.3 Influences post-European settlement (1850 onwards)

Livestock grazing and early prospecting

European utilisation of the landscapes within the study area began in the 1850s with gold prospecting and the activities of graziers with properties in the neighbouring valleys. Mining activities were scattered through the upper reaches of most of the major river valleys in eastern Victoria, although these activities did not generally penetrate into the areas above 1000 m, with some exceptions. Early prospectors supposedly used fire as a tool to clear vegetation and expose the gold-bearing quartz reefs (Lawrence 1999), and these actions contributed to the documented increased fire frequency post-1850 (Banks 1989, Zylstra 2006).

Summer stock grazing began on the Bogong High Plains in 1852/53 (Carr and Turner 1959). Similar, albeit slightly later, grazing commencement dates are documented for the other highland regions in eastern Victoria. The first licences for the Dargo High Plains date from 1872, the Snowy Range and Baw Baw Plateau from about the same time (Johnson 1974, Strickland and Strickland 1997). Lake Mountain and the surrounding forests were grazed by the Keppel family from the early 1880s until 1964 (Ashton and Hargreaves 1983, Griffiths 2001). Stock numbers in general are believed to have been relatively low until the 1890s, when demand for new summer pasture increased in response to rabbit plagues and drought in lowland areas (Cabena 1980). This usage pattern continued and intensified in the early 20th century, in response to generally drier decades and severe droughts, particularly those of 1901-03, 1908, 1914/15, the late 1930s and early 1940s. These periods were arguably when most of the well-documented damage to subalpine and alpine areas of Victoria occurred, including in peatlands (Johnson 1974, Lawrence 1999). Cattle were by far the most common stock grazed; however, sheep and horse numbers were very large in the previously mentioned drought years (e.g. 40,000 sheep on the Bogong High Plains in 1901-03 seasons, Cabena 1980). These numbers were probably never exceeded and sheep were banned from the Bogong High Plains in 1947 (Carr and Turner 1959).

It has been suggested that initially the more sheltered montane *Eucalyptus delegatensis* forests were preferred by graziers (Carr and Turner 1959). In fact in many areas, grazing leases included both the lower altitude and valley forests, and adjacent high subalpine ridges. This enabled stock to spend the winter below the ‘snow-line’, then move slowly to higher ground in the warmer months (Stephenson 1980). The understorey of the montane tall open forests (*E. delegatensis*) was allegedly grassy and open in the early decades. This changed to the more shrub-dominated structure apparent today, in response to a management regime of grazing by ‘hard-hooved’ animals, and frequent autumn burning to promote palatable ‘green pick’ for the following season (Carr and Turner 1959, Downes 1961). Graziers have argued that the banning of this practice in the early 20th century by the Forests Commission, led to the change in structure, and their lower suitability for grazing purposes. They also blame this ban for the wildfires of 1926, 1932 and 1939 (Griffiths 2001, Soeterboek 2008). Burning of higher altitude areas (subalpine and alpine) was apparently less common; the practice in Victoria was deemed by the cattlemen to be only necessary in montane forests and not treeless areas (Carr and Turner 1959). This is in contrast to the Kosciuszko region in New South Wales where sheep graziers burnt the subalpine areas as well (Costin 1954, Costin et al. 2000).

The intensity of grazing in Victoria varied considerably. It was high on parts of the Bogong High Plains (e.g. Mt Fainter, north-west Bogong High Plains) and probably on the crests of the steeper sided sedimentary ridges elsewhere in the highlands (e.g. Mt Hotham, Mt Feathertop, Mt Howitt) (Australian Academy of Science 1957, Lawrence 1999). It seems likely that stock numbers were high on the coveted ‘basalt’ capped areas (e.g. Mt Jim, Dargo High Plains, Bryces Plains), with implications for associated peatland communities. Introduced pasture species are common in these areas today, which supports this hypothesis (Walsh et al. 1984, Lawrence 1999). The few remaining pockets of freehold land within the Alpine National Park and associated adjoining state forests are on these basalt areas. The soils derived from basalts are generally more fertile and moisture retentive than the alpine humus soils derived from sedimentary, granitic or metamorphic rocks (Wahren 1997, McDougall and Walsh 2007). Elsewhere, grazing intensities were arguably lower and damage more localised. The Baw Baw Plateau, the Lake Mountain area, much of the Snowy Range area, and even some parts of the Bogong High Plains probably fall into this category.

The detrimental effects of livestock grazing on peatlands have been well documented in south-east Australia and vary according to local grazing intensity (Wimbush et al. 1979, Wahren et al. 1999b). Stock apparently retreat to peatlands particularly during warm, dry summers, to remain cool and graze on certain sedge and other graminoid species (Van Rees 1984). Damage from livestock includes trampling of vegetation, ‘pugging’ of *Sphagnum* and bare peat, ‘breaching’ of bog-pools and alteration of surface drainage patterns (McDougall 1989). At the higher end of the scale, damage has included exposure of larger areas of peat, and its consequent drying, aeration, and removal via wind and water, thus exposing bedrock in extreme cases (Wimbush and Costin 1979, Wahren 1997). Declines in the cover of key species (e.g. *Sphagnum*) or complete removal from some sites has also occurred (McDougall 1989, Wahren 1997, Wahren et al. 2001a).

Timber and forestry

Timber extraction activities on a large scale were initially more concentrated in the tall wet forests close to Melbourne. Here, the activities of ‘timber-splitters’ in the late 19th century, gave way to organised commercial forestry, at about the turn of the 20th century. The Forests Commission was established at this time and controlled the industry (Griffiths 2001). The Black Friday bushfires of 1939 killed most of these Mountain Ash forests (*Eucalyptus regnans*), and while these regenerated, the focus of logging shifted further east to the higher altitude Alpine Ash forests (*E. delegatensis*) (Johnson 1974). Few stands of this species have escaped logging in Victoria over the last 70 years. The landscapes surrounding some montane peatlands in the Baw Baw and Central Highlands areas have been directly affected by clear-fell logging activities, especially in the last 40 years (Blue Range, Upper Thomson River). There is clear scientific evidence that regenerating tall open forests (5-40 years old) draw more groundwater than mature forests. This has implications for the hydrology of adjacent peatland areas (Kuczera 1987).

Wildfire

The Bogong High Plains region and surrounding valleys experienced many smaller fires between 1850 and 1939. Most were fairly localised and less than a few hundred or thousand hectares (Lawrence 1999). Some of these affected montane and subalpine vegetation. The 1926 fires burnt larger areas of the northern and western approaches to the Bogong High Plains, mostly within the Kiewa River catchment (Lawrence 1999). The 1939 fires affected virtually the entire region (Carr and Turner 1959), particularly the forested neighbouring valleys (Figure 2.6). Approximately 80% of the subalpine open forests and woodlands were crown burnt and thus forced to regenerate from lignotubers. It is likely that all major treeless plant communities, including peatlands, would have been affected to some degree, and forests in montane areas also (Carr and Turner 1959). There were no large ‘landscape’ scale fires (> 10,000 ha) in this region until the widespread fires of 2003 (Figure 2.7). Again, as in 1939, these affected probably similar proportions of the region as a whole (> 75%), including montane and subalpine forests, and treeless vegetation (Williams et al. 2006). The largest unburnt areas were the broad treeless grassland and open heath dominated sections of Pretty Valley, Cope Creek, Basalt Hill and Mount Jim (J. Shannon *pers. obs.* 2003, Williams et al. 2006). Parts of the north-west, west and south flanks of the Bogong High Plains were burnt in December 2006 by a fire that originated near Bright. Some areas were affected for the second time in four years (Tolsma and Shannon 2007).

Figure 2.6: Map of Victoria showing the extent of the January 1939 fires (courtesy of Department of Sustainability and Environment, Victoria).

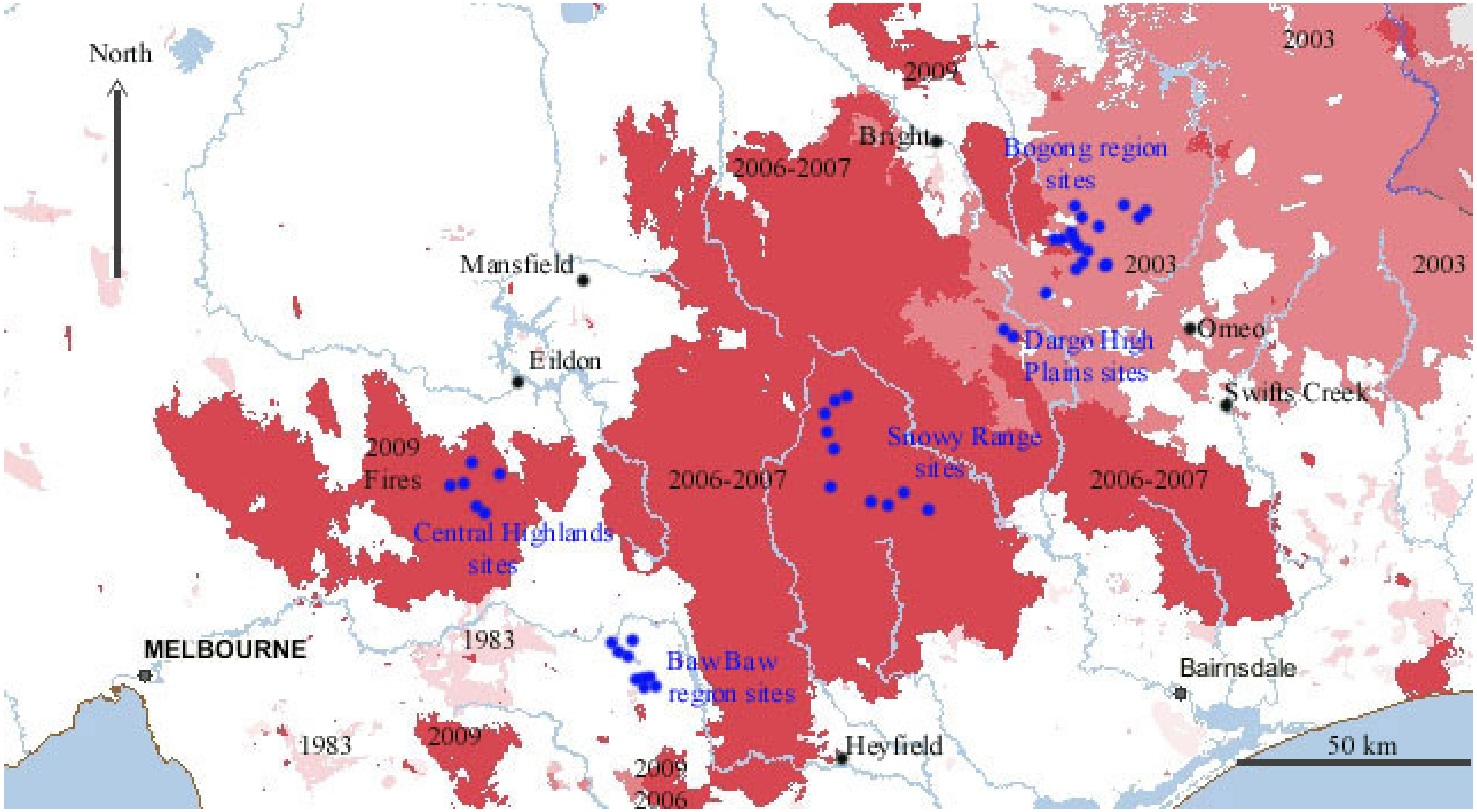


Figure 2.7: Map of eastern Victoria showing the areas affected by fire in 2003, 2006, 2007 and 2009. The approximate positions of the peatland sites studied in this thesis are also indicated (modified map from Department of Sustainability and Environment, Victoria).

The Dargo High Plains were also burnt in 1939, but then did not experience major fire until 2003. The 2003 fires were mostly north and east of the Dargo High Plains, although montane forest on the slopes of the steeper surrounding valleys and ridges were affected. Burning was patchy and less severe on the gently sloping ‘basalt’ capped areas of the tableland (e.g. Lankeys Plain was affected, nearby Omeo Plain was not). Parts of this region again experienced fire in December 2006, although this time it was the deep forested valleys west and south of the tablelands that were most affected. The Dargo High Plains was on the north-eastern edge of the areas affected by the ‘Great Divide fires’ which burnt approximately 1,100,000 ha (Figure 2.7). Smaller areas of treeless and wooded subalpine vegetation on the Dargo High Plains were burnt during these fires, including peatlands. They were generally the areas that escaped fire in 2003. The lower elevation southern sections of these tablelands escaped both earlier fires, but were ultimately burnt in February 2009 (Dargo-White Timber Spur fire).

Details about the fire-history of the Snowy Range region are harder to obtain. Even today this region is remote from towns and settled areas and little if any anecdotal evidence of the passage of the 1939 fires exists. Fires burning north and north-west of this region (Mansfield, Mt Buffalo) in December 1938, eventually spread south-east in January 1939, merging with a large fire burning north of Maffra in Gippsland (Zylstra 2006). Post-World War II forestry activities focussed on the *Eucalyptus delegatensis* forests of this area (Johnson 1974, Aldrick et al. 1984), which suggests that areas of montane tall open forest in this region escaped the 1939 fires. At worst, fires may have been mostly confined to the understorey of these forests (e.g. Mt Stirling, upper Macalister Valley). Large fires were started by lightning north of Maffra in Gippsland in February-March 1965. These burnt 300,000 ha of mostly lower elevation forested country (Collins 2006), but the southern edge of the Snowy Range area was partially affected.

In 1998, approximately 35,000 ha of forested and treeless vegetation in the Snowy Range region, including peatlands, were burnt in the ‘Caledonia’ fires (Wahren et al. 2001, Zylstra 2006). These were ‘dwarfed’ by the ‘Great Divide’ fires of 2006-07, which affected the entire Snowy Range region, burnt for 10 weeks, and ultimately affected approximately 1,100,000 ha of forested and treeless mountain country (Figure 2.7). The area affected stretched from Swifts Creek and Bairnsdale, in the east, to Mansfield and the Thomson Valley in the west.

The Baw Baw plateau region was extensively and severely burnt in 1939. Some parts were also burnt in 1926. The montane *Eucalyptus regnans* and *E. delegatensis* forests on the flanks of the plateau were fire-killed, and most of these forests are even aged regrowth dating from 1939. There were many bad fire years in the Gippsland area in the period from 1895 to 1915, most notably 1898. Details of earlier fires in the Baw Baw region are sketchy, but there were undoubtedly numerous small to medium sized fires on the plateau and surrounds between 1895 and 1926. This can only be inferred from casual comments and descriptions (e.g. Waters 1982) and photos from the time (e.g. pre-WWI photo of Rawsons Hut, Stephenson 1980). The upper montane and subalpine areas of the Baw Baw region have not experienced large fires since 1939.

The Lake Mountain-Blue Range area was affected by fire in 1926, and extensively in 1939, when the entire Central Highlands region was affected (similar to February 2009). The ‘Ash Wednesday’ fires of 1983 did not affect the Lake Mountain area (Griffiths 2001, Collins 2006). However, virtually all of the subalpine and montane areas in the vicinity of Lake Mountain were burnt in February 2009, including peatlands (Tolsma and Shannon 2009, Figure 2.7). Other parts of the eastern highlands to experience fire in the last few decades include areas east of Omeo (2003), and the Buffalo Plateau (1972, 1985, 2003, 2006) (Wahren and Walsh 2000, Williams et al. 2006, 2008).

Science and land management

Scientific exploration in the second half of the nineteenth century was the domain of government surveyors and geologists (e.g. Alfred Howitt). One notable exception was Ferdinand von Mueller (Government Botanist for Victoria). Many of his early collecting expeditions took him to sections of the Eastern Highlands (Carr 1962a, Willis and Cohn 1993). The Field Naturalist Club of Victoria, founded in 1880, also made an enormous contribution to the botanical exploration of Victoria including the eastern highlands, and particularly during the critical early settlement period before substantial clearing and modification had occurred (Willis and Cohn 1993).

By the 1920s, damage due to rabbit plagues, overgrazing by livestock, and other ill-suited farming practices, was evident in the highland areas (Johnson 1974). Observations by people like Helms as early as 1893, who was the New South Wales Chief Botanist, raised concerns about the damage being caused by over grazing in the alpine areas of New South Wales (Helms 1893). It took several more decades before governments began to act. The Soil Conservation Service was established in New South Wales in 1938, and the Soil Conservation Authority in Victoria in 1950 (Johnson 1974, Costin et al. 2000). Dr Alec Costin was amongst the first in the Snowy Mountains to undertake research on the state of the high alpine water catchments. At about the same time in Victoria, Maisie Fawcett, under the supervision of Dr John Turner at Melbourne University, was doing similar work on the Bogong High Plains. Alec Costin and The Australian Academy of Science were involved in assessments of the other subalpine and alpine areas in Victoria in 1957. Since the 1970s, in particular, there has been a steady increase in the amount of research being conducted in the Australian Alps and adjacent forested regions. The range of scientific disciplines pursued includes botany, zoology, geology, geomorphology, soil science, ecology, hydrology, palaeoecology, and the others. All have made contributions to our understanding of the alpine, subalpine and montane areas. This has influenced land management and current land tenure.

In the early 20th century, concerns about soil erosion and the poor condition of highland water catchment areas were fuelled by broader emerging and competing economic considerations. The region’s potential for hydro-electricity generation was recognised, along with the importance of these high rainfall areas to the expanding and developing irrigation schemes in the Murray Basin. Armed with the scientific evidence supplied by the work of Alec Costin, Maisie Fawcett and others, governments in both New South Wales and Victoria began regulation and control of grazing on crown land in the highland areas. This mostly occurred in the decade immediately following World War II, and coincided with the big hydro-electricity generation schemes in New South Wales and Victoria (Snowy Mountains Scheme and The Kiewa Scheme respectively) (Johnson 1974, Lawrence 1999). The growth of recreational pursuits after World War II and an increasing awareness of conservation and resource management issues, due to the contributions of scientific research, ultimately lead to the creation of the Kosciuszko National Park in New South Wales (1969), The Alpine National Park (1989), and the Baw Baw National Park (1979) in Victoria. In 1995, Lake Mountain was included in the Yarra Ranges National Park, which consists mostly of the restricted access water catchment areas in the upper Yarra basin (domestic water-supply).

Grazing ceased within the Kosciuszko National Park in New South Wales in 1969, and the practice was progressively phased out of areas of Victoria’s highlands. Licences covering Mount Feathertop, Mount Hotham, and Mount Bogong were amongst the first to be removed (late 1950s). Grazing ceased on the Baw Baw plateau in 1978, largely because it was within the water catchment of the proposed Thomson dam (completed 1985). Mount Bullfight and Mount Torbreck in the Central Highlands were apparently grazed until the early 1950s, and Lake Mountain until 1964 (Stephenson 1980, Ashton and Hargreaves 1983). Much of the Snowy Range region was released from grazing in the late 1980s, as well as the Mount Nelse - Spion Kopje area of the northern Bogong High Plains in 1992. The remaining licences within the boundaries of the Alpine National Park were withdrawn between 2000 and 2005. However, summer cattle grazing still continues within subalpine and montane sections of state forest adjoining the Alpine National Park in Victoria (e.g. Omeo and Swifts Creek region).

Hydro-electricity generation

Construction of The Snowy Mountains Hydro Scheme in New South Wales and the smaller Kiewa Hydro Scheme in Victoria both began immediately following World War II. The large amount of earth movement, road building, and construction associated with these infrastructure projects has left its mark on the mountain landscapes of both states (Johnson 1974, Lawrence 1999). On the Bogong High Plains in Victoria, as well as submerging large areas of peatland (e.g. Rocky Valley dam), an extensive aqueduct system was constructed which cuts across other areas of peatland. The hydrology of these has been modified, undoubtedly contributing to drying and contraction of affected peatlands. In many ways, the impact of these projects on peatland communities is more dramatic than 150 years of livestock grazing, albeit more localised.

Recreation pursuits

Recreational interest in highland areas probably began to develop in the 1880s with the activities of groups such as the Field Naturalists Club of Victoria and The Bright Alpine Club (Johnson 1974, Griffiths 2001). The expansion of the railways at this time certainly assisted this (Mount Buffalo Chalet). Bushwalking became popular at the same time, but especially in the later period between the ‘wars’. Some local graziers were also involved in horse-trail ride tourism ventures in the mountains, such as the ‘Skyline tours’, run in conjunction with the railways in the 1930s (Johnson 1974).

Skiing, although first practised using crude equipment by miners at Kiandra in the Snowy Mountains during the late 19th century, became popular from the 1920s onwards, again assisted by the railways. The Ski Club of Victoria (SCV) was formed in 1924 and was instrumental in the establishment of purpose-built tourist huts in several areas. The Rover Scouts were also very active at this time and involved in skiing, particularly on the Baw Baw Plateau. Since the 1940s, all these recreational pursuits have grown in proportions commensurate with the population increases in Victoria and the inevitable improved accessibility of the mountain regions. Over recent decades, downhill or ‘alpine’ ski resorts at Mt Buller, Mt Hotham, Falls Creek and Mt Baw Baw have developed into highly commercialised luxury tourism facilities. Each year the Eastern Highlands and alpine areas are the playground of skiers, bushwalkers, horse-riders, four-wheel drive enthusiasts, deer-hunters, recreational fishermen, campers, amateur naturalists, photographers, mountain-bike riders, and others. The competing and often conflicting demands, place enormous pressures on native vegetation, animals and ecosystems. These pressures are magnified when coupled with the demands of agriculture (grazing), resource extraction (timber, mining), and the provision of water (hydro-electricity, irrigation, urban areas domestic supply).

Introduced flora and fauna

Introduced mammals are an increasing management problem in parts of the Victorian Highlands. These include Foxes (*Vulpes vulpes*), Feral dogs (*Canis familiaris*), Feral cats (*Felis cattus*), Hares (*Lepus capensis*) and the European rabbit (*Oryctolagus cuniculus*) (Green and Osborne 1994). Feral horses or ‘brumbies’ (*Equus caballus*) are present in large numbers in parts of the Australian Alps, and they cause damage to peatlands and other plant communities (Figure 2.8) (Thiele and Prober 1999). In Victoria, brumbies are numerous in highland areas east of Omeo, near the border with New South Wales (‘Cobberas’ region) (Walter 2002). They are less common within the study area, but there are localised populations on the southern Bogong High Plains. Elsewhere in the study area, there are only isolated records of smaller ‘mobs’ in the Snowy Range region. Sambar deer (*Cervus unicolour*) are also causing problems in highland areas (Figure 2.9). They cause localised damage to peatlands when they enter to graze on sedges (e.g. *Carex gaudichaudiana*) and to access pools which they use as ‘wallows’.

There are many introduced plant species in the montane, subalpine and alpine areas of the eastern highlands. Many of these can be traced to the different phases of settlement and land-use over the last 170 years. In spite of this, the alpine and subalpine areas of Victoria, in particular, have been less invaded by exotic species than lower elevation areas (Carr 1993, McDougall et al. 2005). Ironically, the grazing ‘era’ was probably responsible for relatively few of the naturalised species currently found in highland areas (e.g. *Acetosella vulgaris*, *Cerastium* spp., *Taraxacum officionale*) (Costin et al. 2000). Many owe their introduction to road building and the infrastructure associated with the hydro-electricity schemes (e.g. *Salix* spp.). Many more are relatively recent and associated with increased recreation, and recreation infrastructure (roads, huts, ski-resorts, off-road vehicles). Introduced animals are also thought to be involved in dispersal and further expansion in some cases (horses, deer).

Figure 2.8: Subalpine peatland near the Victoria-New South Wales border damaged by ‘wild’ horses.

Figure 2.9: Deer ‘wallow’ in peatland vegetation on the Snowy Range.

Some introductions were deliberate and the result of rehabilitation efforts or attempts to stabilise areas after earthworks associated the hydro-electricity schemes (McDougall et al. 2005). These include exotic grass species that are now difficult to eradicate such as *Agrostis capillaris*. The more recent exotic species to undergone rapid expansion include English broom (*Cytisus scoparius*), Orange and King Devil hawkweed (*Hieracium* spp.), Ox-eye daisy (*Leucanthemum vulgare*), Soft rush (*Juncus effusus*), and Grey-sallow willow (*Salix cinerea*). The last two species are currently posing problems in peatlands in the Bogong area. *Salix cinerea* was present in the upper forested reaches of the neighbouring river valleys (Ovens, Kiewa, Mitta Mitta) prior to the 2003 fires (Cremer 1995), but was rare at higher altitude. The seed of this species can be dispersed several kilometres in certain weather conditions. Since 2003 many seedlings of *Salix cinerea* have become established in burnt peatland areas, where previously gaps suitable for colonisation were rare (Tolsma and Shannon 2007). This species has also invaded parts of the Baw Baw Plateau, although efforts to eradicate it from peatlands on the plateau have been fairly successful (Poulton 2001, Tolsma and Shannon 2009, A. Gilham *pers. comm.* 2009).

2.4 Conclusions

Agricultural and other commercial interest in peat has been considerable in other parts of the world, leading to localised depletion (Joosten and Clarke 2002), or draining and conversion to agriculture or silviculture (Charman 2002, Page et al. 2002). Peatlands cover a very small proportion of the landscape in the eastern highlands of Victoria, somewhere between 2700 ha and 4500 ha, or less than 1% (Western et al. 2008, Tolsma *pers. comm* 2009). Hence, commercial interest in the region’s peatlands has been minimal (Whinam and Buxton 1997, McDougall 2001,Whinam and Hope 2005). The marginal, restricted, and fragmented nature of highland peatlands in Victoria means that they are strongly influenced by the surrounding landscape, ecosystems, ecological processes, and land-use, sometimes referred to as *allogenic* influences (Charman 2002).

The impact of post-European settlement on peatland extent and vegetation patterns has been variable and difficult to accurately quantify. In some localised examples, damage has been considerable and irreversible (e.g. livestock, hydro-power generation and ski-resort infrastructure, McDougall 1982, Walsh et al. 1984, Wahren et al. 1997, Lawrence 1999). In more remote and less intensively utilised areas, direct anthropogenic influence has arguably been less. However these areas have at least partly been affected by altered fire-regimes and introduced species, both plants and animals. The varied geological, climatic, edaphic, and biotic influences outlined in this chapter are important to consider when interpreting current peatland vegetation patterns.

The insights provided by palaeoecological research have not been discussed here, but are referred to from time to time in the subsequent chapters of this thesis. Evidence from these studies gives us an idea of the changes possible in peatlands, and the adjacent landscape, over much longer time-spans (100 to 10,000 yrs or more). These are an additional invaluable tool for interpreting and understanding vegetation patterns and changes or trends.

CHAPTER 3

VEGETATION PATTERNS IN HIGHLAND PEATLANDS WITHIN THREE REGIONS OF EASTERN VICTORIA: GRADIENTS IN ALTITUDE AND TOPOGRAPHY

SUMMARY

Floristic and environmental data were collected from highland peatlands in three separate areas of central and eastern Victoria. A total of 89 transects were completed in montane (1000-1300 m), subalpine (1300-1650 m), and alpine areas. The peatland communities studied sorted along altitudinal and topographic gradients.

At the formation level, ‘fens’ occupy valley floor and inundation-prone areas at all altitudes. These are sedge-dominated at high elevation, and sedge and tall shrub dominated in montane areas. Lower valley slopes are associated with valley bogs (*Sphagnum*, restiads and sedges). Raised bogs are in more sloping locations and are dominated by *Sphagnum*, restiads, and dwarf-shrubs. Drier topographic positions are associated with restiad and shrub-dominated wet heaths.

In alpine and more exposed subalpine peatlands, both bogs and wet heaths become more floristically and structurally diverse, with ‘mat’ or ‘cushion-form’ species, ‘hard-leaved’ graminoids, and rosetted herbs prominent (e.g. *Astelia*, *Oreobolus*, *Celmisia*). Myrtaceous shrub species and restiads, although widespread, are most prevalent in sheltered montane and lower subalpine communities (*Baeckea*, *Empodisma*). Ericaceous shrubs (*Epacris* spp., *Richea*) are also ubiquitous, but dominate the shrub component at higher elevations.

The hard-leaved graminoid species *Astelia alpina* was common in alpine and exposed subalpine peatlands, but absent or rare in lower subalpine and montane sites. The restiad

Baloskion australe was prominent in montane and lower subalpine peatlands, uncommon at higher altitudes, but absent from peatlands in the Baw Baw-Central Highlands region. One of the two species of *Richea* is restricted to subalpine peatlands; the other species is mostly montane and restricted to the Baw Baw-Central Highland region. The many species of *Epacris* also have significant distributions; including *Epacris glacialis* (alpine only), *Epacris breviflora* (montane-lower subalpine), and *Epacris paludosa* (montane-subalpine, but not most exposed alpine peatlands). *Sphagnum novozelandicum* was more common and abundant in the Baw Baw - Central Highlands peatland communities than elsewhere.

Environmental factors most associated with altitudinal gradients included temperature and rainfall related indices such as precipitation of the driest quarter, moisture index of driest quarter, and minimum temperature of coldest period. The former three variables were all higher at higher altitude, the latter was higher at lower elevation. Peat depth and shrub height also tended to be less at higher elevations.

3.1 INTRODUCTION

Peatlands of the subalpine and alpine regions of eastern Victoria are generally well described (Farrell and Ashton 1973, McDougall 1982, Ashton and Hargreaves 1983, Walsh et al. 1984, Wahren 1997, Wahren et al. 1999b, 2001a). In the past, most of the research focus has been on the impact of livestock grazing on peatlands above 1600 m elevation on the Bogong High Plains and adjacent areas (McDougall 1989, Wahren 1997). In recent years studies of fire impacts and post-fire regeneration have been undertaken on the Buffalo Plateau (Wahren and Walsh 2000), Snowy Range (Wahren and Papst 1999, Wahren et al. 1999a), and on the Bogong High Plains (McDougall 2007). Most recently, peatland and other wetland vegetation descriptions were included in a study documenting treeless vegetation types and distribution across the entire Australian Alps region (McDougall and Walsh 2007).

By contrast, peat-forming wetlands in the more extensive montane areas (800-1300 m) of Australia have received less attention, with the possible exception of New South Wales where there are more tableland areas at these altitudes (Millington 1954, Keith and Myerscough 1993, Keith 2005, Hope and Southern 1983, Hunter and Bell 2007). In Victoria, montane peatlands have been described in East Gippsland (Ladd 1979a), the Central Highlands (Shannon and Morgan 2007), and some were included in a recent broad study of eastern Victorian peatlands that included lowland areas also (Whinam et al. 2003a). However, in the Snowy Range region of eastern Victoria there are extensive areas of montane peatland that have received little attention. Furthermore, montane peatlands in the Baw Baw Plateau and Central Highlands region have also attracted little interest in the past. Some subalpine areas have also escaped close scrutiny; for example, past focus in the Bogong region has been on the higher altitude peatlands (McDougall 1982, 1989, Wahren 1997, Wahren et al. 1999b, 2001a). Peat-forming wetlands in the lower subalpine areas on the more remote eastern and southern approaches to the Bogong High Plains have been somewhat overlooked, except in specific localised cases associated with protection from livestock grazing impacts (Wahren 1992a). A thorough knowledge of local variation in peatland vegetation composition and structure along altitudinal gradients is useful for predicting the potential effects of climate change.

As in other parts of the world, the research conducted by palaeoecologists and palynologists has revealed the dramatic changes that have occurred in vegetation patterns in south-eastern Australia during the Holocene in particular (Ladd 1979b, Martin 1986, 1999; Kershaw and Strickland, 1989; McKenzie 1997, 2002; Hope et al. 2009), but also over larger time-scales (e.g. Kershaw et al. 2007). These include fluctuations in the elevation of the climatic tree-line, changes in the distribution of alpine species (McKenzie 1997), and variations in the distribution and abundance of cool-temperate rainforest with *Nothofagus cunninghamii* (Kershaw and Strickland 1989). Interpretation of charcoal deposits in peat profiles has provided information about fire regimes and fire history during the Holocene. Changes in the frequency of fires can often be linked to the various advances and retreats of eucalypts and other sclerophyllous vegetation elements in the surrounding landscape (Ashton and Hargreaves 1983, McKenzie 1997, 2002). In palaeoecological studies, documented changes in the surrounding landscape are often correlated with changes in peatland vegetation; the pollen of peatland species no longer present in the standing vegetation is often common in deeper and older peat layers. These species may be locally absent, but instead now restricted to higher elevations.

Geomorphological appraisal of alpine areas has revealed how periglacial processes, during recent and other glacial interludes over the last two million years, have shaped the landscape (Petersen 1971, Rosengren and Petersen 1989, Costin et al. 2000). These have also contributed to the distribution of the various alpine plant communities, including peatlands (Ashton and Williams 1989, Wahren 1997). Many of these processes still operate, to a lesser extent, at the highest elevations (above approximately 1650 m) and include things like frost-heave, needle-ice, and snow-pack abrasion. In peatlands and high-altitude wetlands, several plant communities are closely connected and appear to be different hydroseral stages, partially controlled by 'remnant' periglacial processes (Costin et al. 2000,Wahren 1997, 2001a). Elsewhere, the lower subalpine communites show evidence of cyclic succession, or pattern and process involving *Sphagnum*-shrub alternating phases (Ashton and Hargeaves 1983), or post-fire succession (Wahren and Walsh 2000).

A recent study in eastern Victoria, which compared peatland vegetation from lowland to alpine sites, concluded that there were strong regional floristic differences, due partly to edaphic (geological) factors and partly climatic variation, but also influenced by exogenous disturbance and introduced species, particularly in proximity to more intensive past and present land use (Whinam 2003a). However, the regional differences were more apparent at lower elevation (< 1000 m). Peatland vegetation composition in the elevated treeless areas of eastern Victoria appears to be broadly similar (above 1000 m), regardless of altitude and edaphic factors (Ashton and Williams 1989, McDougall and Walsh 2007). There is a suite of widely co-occurring species; however, the abundance of these, the identity of other associated species and communities, the vegetation structure, and the landscape context all vary with altitude (Walsh et al. 1984, Ashton and Williams 1989, Shannon and Morgan 2007).

Comparisons of peatlands at different altitudes within the same region are hard to find, although the differences in climate and landscape context can parallel differences between oceanic and continental areas at similar latitude (Malmer 1986, Brown 1999, Kleinebecker et al. 2007), or differences between peatlands at different latitudes (e.g. boreal compared with arctic or tundra, Ruuhijärvi 1983, Sjors 1983, Charman 2002). There are many more research papers that deal with climatic gradients of these kinds. Instead, changes in peatland vegetation patterns associated with altitude have to be determined from broader regional vegetation descriptions and studies (e.g. Costin 1954, Brown 1993a, 1993b).

In southern New South Wales and the Australian Capital Territory (ACT), comparisons of alpine, subalpine and montane peatland and wetland vegetation generally occur along a west to east gradient correlated with declining annual rainfall (Costin 1954, Clarke and Martin 1999, Hope et al. 2009). *Sphagnum* and restiad-dominated ‘bogs’ are generally restricted to the wetter alpine and subalpine areas. The lower montane areas in this region experience a more continental climate, thus peatlands are mostly topographically restricted ‘fens’, groundwater fed, and consequently dominated by graminoids and species with lowland floristic affinities (Costin 1954, Hope et al. 2009). Peatlands in the alpine, subalpine and wetter upper montane areas of southern New South Wales are, like those in Victoria, broadly floristically similar. Variation in the montane areas (800-1400 m) may be more associated with edaphic factors (Costin 1954, Hope et al. 2009). However, floristic differences between alpine and subalpine peatlands have been identified (Clarke and Martin 1999), and these differences seem to be related to the presence or otherwise of ‘snow-loving’ or chionophilous genera that are common at high latitudes and altitudes elsewhere in the southern hemisphere (Gibson and Kirkpatrick 1985a, 1985b, Gibson and Hope 1986).

Button-grass moorland (*Gymnoschoenus sphaerocephalus*) or ‘blanket-peatland’ in Tasmania covers vast areas down to low elevations, especially in the western half of the island (Brown 1999). It also occurs in the east, but is more topographically restricted and floristically different. There are distinct floristic variants of these peatland communities at higher elevations in both the east and west of Tasmania (above approximately 600-800 m elevation). The differences are strongly influenced by edaphic factors; those in the west are predominantly on nutrient poor quartzites, those further east are situated on richer dolerite bedrock (Kirkpatrick 1997, Brown 1999, Crowden 1999).

In New Zealand, peatlands dominated by *Empodisma minus* are common down to sea level on the west coast of both islands (Campbell 1983, Clarkson 1997, Clarkson and Clarkson 2006). ‘Cushion bogs’ and patterned mires associated with more ‘alpine’ species occur at higher elevation in the centre and east of the south island (Mark et al. 1995, Rapson et al. 2006). These descend to sea level at the southern tip of the South Island (Johnson 2001).

In this thesis, floristic and environmental data were collected from some previously over-looked peatlands and some previously examined areas, to look at trends along altitudinal gradients in three separate regions across eastern Victoria. The elevation difference between the lowest and highest peatlands examined in each of the three regions is 350-600 m, which is large enough to create significant differences in climate and other largely climate dependent influences on vegetation patterns. The depth and duration of winter snow cover is one obvious example. At more local scales within each elevation zone, there was the opportunity to examine the influence of topographic factors, aspect, slope, and the interaction of these with hydrology, peat depth, microclimate and fire.

The broad aims of this chapter are to:

- describe the peatland vegetation patterns and communities in several discrete regions across eastern Victoria, through their local altitudinal range.
- examine the environmental factors and gradients correlated with community distribution patterns, and the indicator species or plant functional groups associated with these.

The data and community descriptions presented in this chapter will form the basis for much of what follows in the subsequent chapters. Chapter 4 examines differences and similarities between the three regions and compares sites at similar elevations across the entire geographical range of the study. Chapters 5 and 6 use the descriptions and analyses from this chapter as a basis for more detailed examination of the influence of hydrology, microclimate and fire on vegetation patterns in peatlands.

3.2 METHODS

3.2.1 Study sites

Representative peatland vegetation was sampled at 45 sites across the eastern highland areas of Victoria. These sites were initially separated into five sub-regions, which are, running from south-west to north-east across eastern Victoria: the Lake Mountain-Blue Range area (Central Highlands); Baw Baw Plateau and upper Thomson Valley; Snowy Range and upper Moroka Valley; Dargo High Plains; and the Bogong High Plains and western Mitta Mitta River catchment (Figure 3.1).

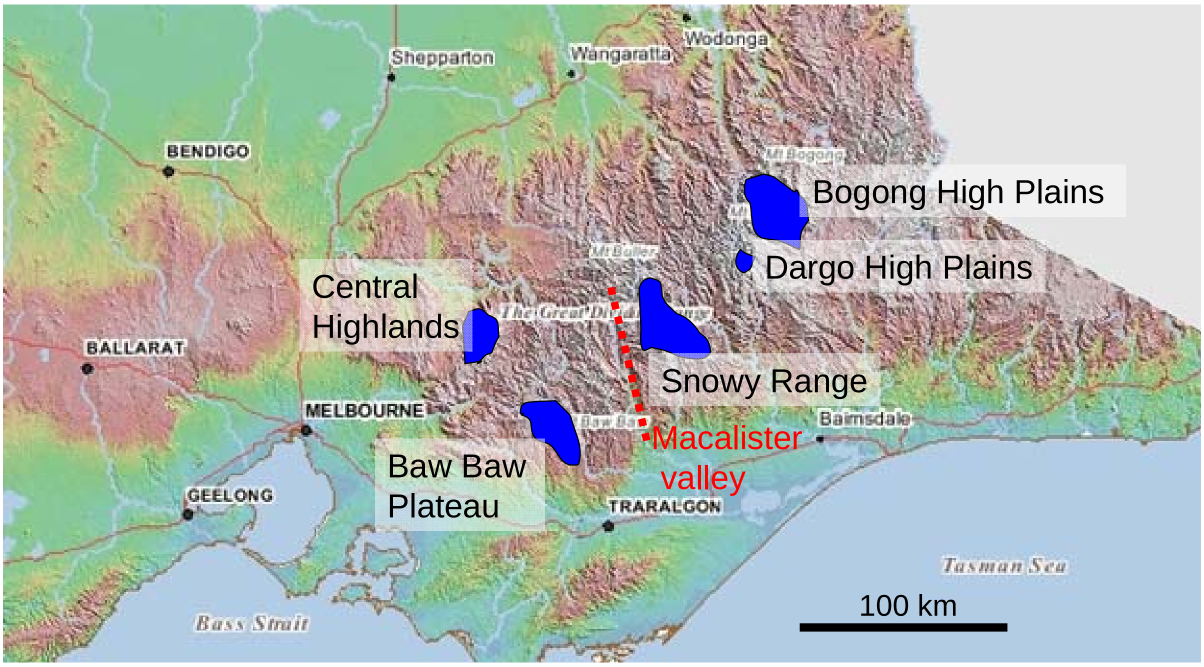


Figure 3.1: Map of Eastern Victoria showing the 5 regions used in the course of this study.

The peatland vegetation sampled can also be separated into three altitude zones: montane (1000-1300 m), subalpine (1300 to 1650 m), alpine (above ~1650 m). In Victoria, 1300 m elevation is the approximate altitude above which winter snow cover is longer than 30 days in most years, and this is generally considered a useful proxy for the lower limit of the subalpine zone (Ashton and Williams 1989). Peatland areas that were sampled at elevations between 1600 m and 1700 m were classified or categorised as either alpine or subalpine, depending on landscape position and the proportion of tree cover in the surrounding landscape.

3.2.2 Floristic and environmental data collection

A total of 89 thirty-metre long transects were established between 2005 and 2008. Each consisted of 60 contiguous quadrats (0.25 m^2) in a line perpendicular to the slope and direction of drainage within that peatland patch. In general, at least two transects were completed at each of the 45 sites, one in sections of higher *Sphagnum* cover, and one in areas of peatland shrub dominance.

When choosing peatland vegetation to sample, the aim was to survey representative patches within each of the five sub-regions and three altitude zones. Appropriate peatland vegetation does not occur within some altitude zones in some sub-regions. For example, peatlands considered alpine in this study only occur in the Bogong High Plains region, which does not have significant areas of montane peatland. Only subalpine peatland vegetation was sampled on the Dargo High Plains, but both subalpine and montane peatland vegetation were sampled in the remaining three sub-regions.

In each quadrat, all vascular plant species present were identified and their cover estimated using the Braun-Blanquet scale. Species nomenclature follows the most recent edition of the Victorian vascular plant census (Walsh and Stajsic 2007). Species of *Sphagnum* were also identified and cover estimated. Other bryophytes and club mosses were generally pooled and given a combined cover, except in a few cases where an individual species was particularly prominent or common (e.g. *Blindia robusta*, *Lycopodium* spp., *Polytrichum* spp.). The amount of exposed bare ground, plant litter, surface water and rock were also estimated, as was the combined cover provided by all shrub species. The height above the surface (soil or *Sphagnum* moss) of the tallest shrub stems was measured (nearest 5 cm) in every quadrat.

The peat profile and mean depth along each transect were determined by probing with a 2 m stainless steel probe (~ 7 mm diameter) at intervals of 3 m. A total of ten measurements were taken per transect. This method generated a mean peat depth for each transect and proportions for each of four depth categories: less than 0.5 m, 0.5-1.0 m, 1.0-2.0 m, and greater than 2 m. Soil or peat type was broadly classified for each transect into three categories: (i) ‘fibric’ or ‘hemic’, plant remains still readily or partially recognisable, (ii) ‘sapric’, highly organic but amorphous and highly decomposed (Isbell 1996), (iii) ‘dried peat’, high degree of decomposition and mineralisation (Costin 1954). The third category refers to peat in which drying and ‘shrinkage’ has occurred, oxygen has penetrated, and an advanced stage of transition to mineral soil has been reached (Grover et al. 2005, Grover 2006). As there were only three peat categories this variable was not used in formal statistical analyses. Instead, general observations of peat type were incorporated into site observations and community type summaries.

Slope perpendicular to the transect was determined with a hand-held clinometer. Three measurements were taken at evenly spaced intervals along the transect (5 m, 15 m and 25 m) and a mean percent slope determined. Each transect sampled was allocated to one of three topographic or landscape position classes: (1) valley bottom, (2) lower slope, or (3) mid-slope. The progression from class 1 to class 3 represents a gradient in topographic wetness and drainage, from poorly drained wet positions to relatively better drained, drier ones. None of the transects completed or peatland patches surveyed occurred in drier topographic positions than these (e.g. upper slope, and ridge crest). Aspect was determined for each transect with a hand-held bushwalking compass (Suunto brand), and each transect was allocated to an aspect category: (1) south-east; (2) south or east; (3) north-east or south-west; (4) north or west; (5) north-west. The progression from classes 1 to 5 in this case represents a gradient of increasing potential evapo-transpiration in southern Australia (Kirkpatrick and Nunez 1980, Kirkpatrick and Bridle 1999). Transects within predominantly flat areas (slopes of 3% or less) were placed in aspect class 3.

Peatland vegetation community classification

Transects were allocated to one of eleven categories depending on a subjective initial appraisal of vegetation structural characteristics, elevation zone, and region. The eleven categories encompass three broad vegetation formations within the ‘upland wetland’ or ‘peatland vegetation complex’. These are fen, bog, and wet heath. The eleven categories or groups are loosely based on the classifications of McDougall and Walsh (2007), McDougall (1982), Walsh et al. (1984), and Wahren et al. (1999a), with modifications and sub-divisions to represent some observed variations in structure. These are generally variations in the prominence of *Sphagnum*, sedges and shrubs.

1. <u>Low wet heath</u>: dominated by a mixture of ‘cushion’ or ‘mat-forming’ species, dwarf shrubs, rosette herbs, graminoids, and restiads, with little or no *Sphagnum* present. Shrub height generally less than 20 cm. (‘relict bog’, McDougall 1982, and/ or ‘low open heath’, Wahren 1997, and/ or ‘*Epacris* moist heathland’, McDougall and Walsh 2007).
2. <u>Alpine raised bog</u>: *Sphagnum*-dominated with a mix of cushion species, dwarf shrubs and sedges. Generally above 1650 m elevation. (‘*Richea continentis* - *Carpha nivicola* - *Sphagnum cristatum* wet heathland’, McDougall and Walsh 2007).
3. <u>Alpine valley bog</u>: *Sphagnum* and sedge-dominated with dwarf shrubs providing less than 15% cover. (‘*Richea continentis* - *Carpha nivicola* - *Sphagnum cristatum* wet heathland’, McDougall and Walsh 2007, and/ or ‘Valley bog’, Costin 1954, Costin et al. 2000).
4. <u>Subalpine raised bog</u>: *Sphagnum*-dominated but with a mix of sedges and taller shrubs. Shrubs generally less than 60 cm tall. Mostly observed between elevations of 1300 m and 1650 m. (‘*Richea continentis* - *Carpha nivicola* - *Sphagnum cristatum* wet heathland’, McDougall and Walsh 2007).
5. <u>Tall wet heath</u>: dominated by taller wet heath shrubs with a lower *Sphagnum* presence (< 30% cover). A mix of shrub species, but generally dominated by ericaceous species. Shrub height up to 1 m. (‘*Richea continentis* - *Carpha nivicola*

- *Sphagnum cristatum* wet heathland', and/ or '*Baeckea gunniana – Callistemon pityoides – Sphagnum cristatum* wet heathland', McDougall and Walsh 2007).

6. Western subalpine raised bog: mixture of *Sphagnum*, dwarf shrubs, sedges and cushion or mat-forming species. Observed on the Baw Baw Plateau and in the Central Highlands area. ('Baw Baw – Lake Mountain wet heathland', McDougall and Walsh 2007).
7. Western subalpine wet heath: similar to group no. 6 above, but with a lower *Sphagnum* cover (< 30%) and higher shrub and restiad presence. ('Baw Baw – Lake Mountain wet heathland', McDougall and Walsh 2007).
8. Myrtaceous wet heath: dominated by taller wet heath shrubs with a lower *Sphagnum* presence (< 30% cover). Usually with a higher myrtaceous shrub presence than group no. 5 (above). Shrub height up to 1 m or more. ('*Baeckea gunniana – Callistemon pityoides – Sphagnum cristatum* wet heathland', McDougall and Walsh 2007).
9. Montane valley bog: dominated by *Sphagnum*, restiads and sedges. Shrub contribution variable, but mostly from ericaceous species. Mostly observed in the upper Moroka Valley at elevations between 1000 m and 1300 m (Snowy Range).
10. Western montane wet heath: mixture of shrubs, sedges and *Sphagnum*. Shrub height up to 1.5 m. Observed between 1000 m and 1200 m elevation in the upper Thomson area and on the Blue Range (Baw Baw – Central Highlands).
11. Western montane fen: dominated by *Sphagnum* and sedges with some taller wet heath shrubs. A formation only observed in the upper Thomson and Blue Range areas. Adjacent to tall open forest and cool temperate rainforest (referrable to 'Rainforest peatlands' Shannon and Morgan 2007).

Long unburnt vegetation was preferred and selected for sampling. However, in the case of Myrtaceous wet heath in the Bogong sub-region, this was not possible due to the extensive 2003 alpine fires. Long unburnt Myrtaceous wet heath could not be found in spite of considerable field reconnaissance. It appears that this vegetation type is more fire-prone than other peatland vegetation and this relationship will be examined in Chapter 6. It was thought to be important to include these plots in analyses regardless of their ‘recently burnt’ status because they appear to represent an important part of the peatland vegetation spectrum in this region. The plots in question were still 4 to 5 years post-fire at the time of sampling. Long unburnt Myrtaceous wet heath vegetation was identified and sampled in the Snowy Range sub-region in April 2006. These plots were subsequently affected by fire in December 2006, and the post-fire examinations of these and other peatland vegetation plots is the subject of Chapter 6.

Bioclimatic data and other climate indices

The BIOCLIM bioclimatic prediction system provided in the ANUCLIM software (Houlder et al. 2000) was used to generate data for 35 climate indices for each of the 45 sites. The variables or indices available relate to four broad environmental factors: temperature, rainfall, radiation (cloud cover, latitude), moisture index (humidity, potential evapo-transpiration, moisture balance). BIOCLIM uses data from existing meteorological stations to extrapolate and estimate the likely climate data for a given point in the landscape (latitude, longitude, elevation). It is useful for generating climate data for remote areas where there is often a lack of long-term meteorological records. It has been mostly used to model climate profiles for rare or threatened species or communities (e.g. Lindenmayer et al. 1991, Fischer et al. 2001). This information can then be used to identify other areas with potentially suitable climate for a species. Spatial changes in climate can also be modelled to help predict possible future expansions or contractions of the climate ‘envelope’ of a particular species.

The estimated mean annual precipitation determined by BIOCLIM for each location was also used to determine hygric continentality (Gams 1931, Barry 2008). This is a useful index for comparing the climate of two or more mountain regions, especially those in maritime or oceanic areas with those in more continental regions. It will be more important in Chapter 4 when sub-regions are compared across eastern Victoria, but has been included in these analyses also. It may help to highlight within sub-region ‘rainshadows’. Hygric continentality is equal to: $\mathrm{Tan}^{-1}(Z/P)$, where Z is the altitude of the location (m), and P is the annual precipitation (mm). The index is expressed in degrees and can vary from figures as high as 75° or more in ‘continental’ mountain areas, such as those in Colorado (U.S.A.), to as low as 18° in ‘oceanic’ regions, like parts of western Scotland (U.K.) (Barry 2008).

3.2.3 Data Analysis

For ease of analysis, the transects from the Dargo High Plains sub-region were pooled with those of the Snowy Range sub-region. The transects from the Baw Baw sub-region were pooled with those from the Central Highlands sub-region. This created three broader regions for the purpose of analysis.

- Bogong High Plains region
- Snowy Range – Dargo High Plains region
- Baw Baw – Central Highlands region.

The three regions are examined individually and the subsequent analyses of the data are presented in this format. The discussion contains separate sections for each of the three regions, then an overall discussion section with final conclusions.

The final division of the samples into three regions for analysis and interpretation can be justified on a catchment basis. Transects in peatlands in the Bogong High Plains area are entirely within the catchments of two major rivers; the Kiewa and the Mitta Mitta. These flow northwards from the Great Dividing Range to the Murray River. Those on the Dargo High Plains and in the Snowy Range-Moroka region are entirely within the catchments of the Mitchell and Macalister rivers, which flow generally south and south-east to the Gippsland Lakes and the Tasman Sea. Transects sampled in the Baw Baw Plateau area and the Lake Mountain-Blue Range area fall within the catchments of the Latrobe, Thomson and Goulburn rivers (Figure 3.1, see also Chapter 2, Figure 2.1); together, they encompass the south-western end of the Eastern Highlands of Victoria.

Braun-Blanquet cover abundance scores were converted to mid-point values: + = 0.5% cover; 1 = 2.5% cover; 2 = 15% cover; 3 = 37.5% cover; 4 = 62.5% cover; and 5 = 87.5% cover. A value of 6 was included for 100% cover, which was generally only used for *Sphagnum cristatum*, which often blankets entire quadrats. For each transect an estimated cover was determined for each species, which is essentially the average percent cover per quadrat for that species (n=60). These figures were also calculated for each life-form group (shrubs, herbs, monocots, ferns, bryophytes), bare-ground, litter, rock and water.

By structuring the sampling in this manner (60 contiguous quadrats along a 30 m transect), frequency counts could also be determined for each transect, which were converted to percent frequency.

Transect means were used for comparison within the three regions individually, and between regions (Chapter 4). Comparisons were made using percent cover and percent frequency. Percent cover, or cover abundance data, is strongly influenced by dominant species and thus a better reflection of vegetation structure. Frequency data are a good compromise between structure and overall composition. They give better representation to common species that rarely have high cover values (e.g. graminoids).

Master data sets incorporating all 89 transects were created for both species and environmental attributes. Species not occurring in a particular region or altitude category, or observed less than twice, were removed from that particular analysis. Some monocots were not fertile at the time of sampling and thus were only identified to genus level (e.g. *Carpha* spp., some *Poa* spp.). Some herb species also fell into this category (e.g. *Craspedia* spp., *Hydrocotyle* spp.). In general these were species that provided minimal cover (<5%), or occurred infrequently. Identification to genus level in these cases gave sufficient diagnostic value for distinguishing vegetation patterns.

Variation in floristic composition and structure was examined using non-metric multidimensional scaling (NMDS). The Bray-Curtis dissimilarity measure was used for constructing the pair-wise resemblance matrices (Bray and Curtis 1957). Non-metric multidimensional scaling procedures in the PRIMER 6 software package were used to produce the ordination graphs (Plymouth Routines in Multivariate Ecological Research 6.1.13., 2009). This procedure positions plots or samples (in this case transects) in multidimensional graph space so that their relative positions reflect the rank similarities as much as possible (Minchin 1987, Quinn and Keough 2002, Quinn et al. 2003). The Kruskal stress index (Kruskal 1964) is the measure of the degree to which each resultant graph configuration satisfies this objective. Fifty iterations or trials were run with each data set. The graph configurations with the lowest stress values in two and three dimensional graph space were then examined. Final stress values of 0.2 or greater indicate that the graph configuration is unreliable and not representative of the relationships between samples (Clarke 1993). In general, three dimensional solutions were preferred because they produce lower stress configurations, unless the best two dimensional solution recorded a stress value of 0.1 or less (Quinn and Keogh 2002). Generally two aspects of the three dimensional solution graphs have been displayed in this thesis, as it was felt that this would more accurately illustrate the relationships between samples and the various correlated variables. The ordination aspect capturing the most variability is displayed with the text, and others are included in the appendices section.

Testing for differences between groups or community types and identification of species associated with groups

Floristic differences between the eleven initially identified peatland community types were tested using the non-parametric ANOSIM procedure in the PRIMER software package (Plymouth Routines in Multivariate Ecological Research 6.1.13., 2009). R-statistic values of approximately 0.25 in pair-wise comparisons of types or groups, generally signify that two groups are barely separable. Values of 0.5 indicate that groups are different but there is some overlap, 0.75 or greater signifies that groups are clearly different (Clarke and Gorley 2001). Significance levels for each pair-wise comparison provided by the ANOSIM procedure were further tested using sequential Bonferroni adjustment (Holm 1979). This is a method of further guarding against the high likelihood of Type 1 error that is inherent in multiple group comparisons.

The SIMPER procedure, also provided in the PRIMER software package (Plymouth Routines in Multivariate Ecological Research 6.1.13., 2009) was used to identify the species that contribute most to the similarity within groups and those that are useful when distinguishing between groups (Quinn et al. 2003). Useful indicator species are those that contribute a high proportion of the overall similarity and are consistently present in transects or samples within that group (indicated by higher mean to standard deviation ratios).

Environmental, structural and floristic variable correlations with ordinations

The relationships between the final chosen ordination graph configuration and the various environmental, structural, and BIOCLIM variables were tested using Spearman Rank correlation. This is a non-parametric procedure that is in keeping with non-metric scaling techniques because it is based on ranking variable scores rather than their actual quantitative relationship (Quinn and Keogh 2002). The PRIMER software examines the correlations between the axes of the graph and variables (e.g. three in a three dimensional solution). The significance of the resultant correlation coefficients was tested using the Student’s t-test (Ho = correlation not significantly different from zero). The trend directions of the environmental and structural variables with the strongest correlations were then displayed with the ordination graph. The individual species were also tested for correlation with the final ordination solutions in each case, as another means of identifying the important indicator species, or those most responsible for differences between groups. Separate ordinations graphs displaying the trend directions of the strongly correlated species were also included.

Plant functional group analyses

Finally, a separate analysis was run looking at species life-form or ‘functional’ groups. The allocation of species to various groups has been done subjectively based on field observations and experience, but is loosely based on similar schemes from cool temperate and arctic environments elsewhere (Chapin et al. 1996, Kleinebecker et al. 2007, 2010). Groups were determined by life-form and shared functional attributes, especially those advantageous in peatland environments. In some cases this meant grouping species from the same family (e.g. ericaceous shrubs), in other cases groups consisted of single widespread or dominant species or genera (e.g. *Astelia*, *Carex* spp.). Other groups consisted of ‘left-overs’ or occasional species from each of the major life-form groups (e.g. ‘other shrubs’, ‘other monocots’). Ease of comparability with other peatland research from elsewhere in the southern and northern hemisphere was also a consideration. Some of the group categories have been identified in previous research as being indicators of certain abiotic conditions in peatlands. For example, high abundance of *Carex* species generally indicate higher nutrient availability. Conversely, high abundance of hard-leaved graminoids and restiads generally indicate more stressful growing conditions and lower nutrient availability (see Chapter 1). The species pool was partitioned into eleven plant functional groups: three shrub or woody dicot groups, five monocot or graminoid groups, two bryophyte groups, and a single group for all herbaceous dicots (Table 3.1). The list of species recorded in quadrats and their functional group allocations can be seen in the Appendices (Table A3.1).

The cover abundances for all the species in a particular group were added to give a mean functional group cover for each transect. Thus, cover totals were generated for each of the eleven plant functional groups for every transect. These were summarised for each community type and the correlations of these plant functional groups with the ordination configurations tested for significance. Again, separate ordination graphs were included for displaying the trend directions of strongly correlated plant functional groups.

Table 3.1: Details of the composition of the eleven plant functional groups used in analyses.

Life-form or functional group	**Notes and details**
Ericaceous shrubs	The most common and widespread shrub family. Genera include *Epacris* and *Richea*.
Myrtaceous shrubs	Next most common shrub family. Genera include *Baeckea*, *Callistemon* and *Leptospermum*.
Other shrubs	All other woody dicots. Includes species from the Asteraceae, Proteaceae, Fabaceae, Winteraceae and others. Generally less common species with sporadic or localised occurrence.
Astelia	Single species group. Important indicator in some peatlands. Genus associated with 'cushion bogs' in the southern hemisphere.
Carex spp.	Most common and widespread genus from the sedge family (Cyperaceae) in both southern and northern hemisphere peatlands.
Other sedges	Includes many southern hemisphere genera that are often associated with 'cushion bogs' (eg. *Oreobolus, Carpha*, *Schoenus*, *Isolepis*). Also species associated with lowland heath (e.g. *Baumea*, *Lepidosperma*).
Restiads	The scale-rushes. Family Restionaceae. Southern hemisphere distribution. Genera include *Empodisma* and *Baloskion*.
Other monocots	All grasses (Poaceae), rushes (Juncaceae), orchids (Orchidaceae) and any other monocots.
Herbs	All dicot herbs. Families include Asteraceae, Apiaceae, Rubiaceae, Scophulariaceae, Droseraceae.
Sphagnum spp.	*Sphagnum cristatum*, *Sphagnum novozelandicum*.
Other bryophytes, ferns, and allies	Includes what are referred to as 'brown mosses', lichens, liverworts, ferns, and 'club mosses'.

3.3 RESULTS

3.3.1 Bogong region transects

There were 38 transects (= plots) completed in peatland vegetation in this region, ranging in altitude from 1380 m, at Malcolm Plain in the upper catchment of the Victoria River (Mitta Mitta catchment), to 1730 m at Heathy Spur and Rocky Knobs, in the upper Kiewa River catchment (Figure 3.2, Appendices Table A3.2). The overall data set containing 93 taxa was reduced for analysis purposes to the 55 species or taxa that occurred in two or more plots in the Bogong region. These included 13 shrub species, 19 graminoids or monocots, 20 herbaceous dicots, one club moss group and two bryophyte groups.

Six of the 11 previously determined peatland vegetation types or groups were sampled in the Bogong region: Alpine valley bog (5 transects), Low wet heath (5), Tall wet heath (4), Alpine raised bog (7), Subalpine raised bog (11), and Myrtaceous wet heath (7).

Non-metric multidimensional scaling ordinations of cover and frequency data

A three dimensional ordination solution was adopted for the frequency data (Kruskal minimum stress = 0.09), but a two dimensional solution was acceptable for the cover data (Kruskal minimum stress = 0.10). The six groups formed discrete but relatively diffuse clusters in the frequency ordination graph, with little if any overlap between groups (Figure 3.3). The three ‘wet heath’ groups were positioned in the lower half of the graph space, and partitioned along axis 1. The three ‘bog’ communities were generally positioned towards the centre and upper right sector of the graph space.

The groups generally formed closer clusters in the cover ordination, but the relative positions of the groups were similar to the frequency graph (Figure 3.4). The bog communities were particularly tightly clustered, with the possible exception of the Alpine

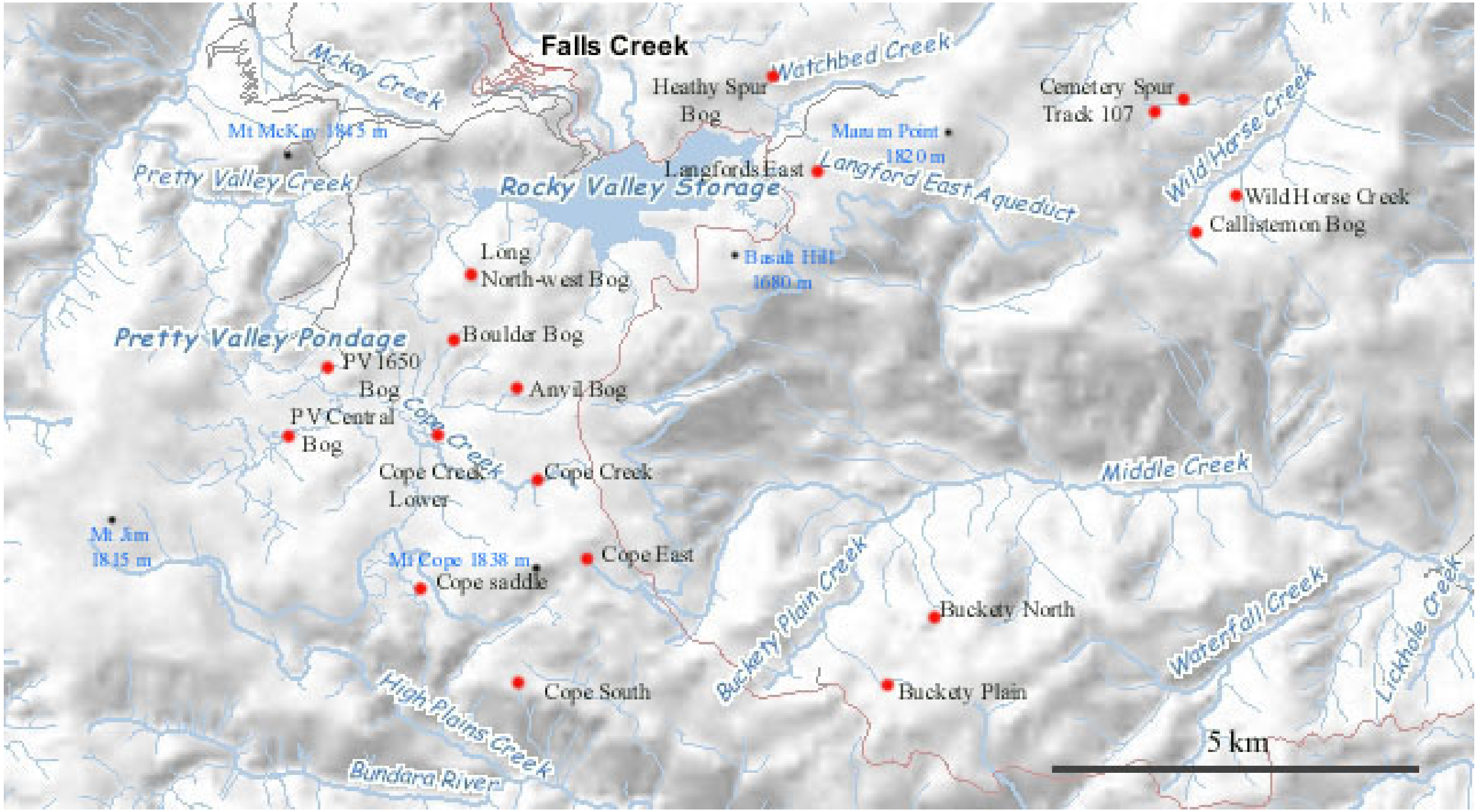


Figure 3.2: Map of the Bogong High Plains area showing the locations of the peatland sites used in the study.

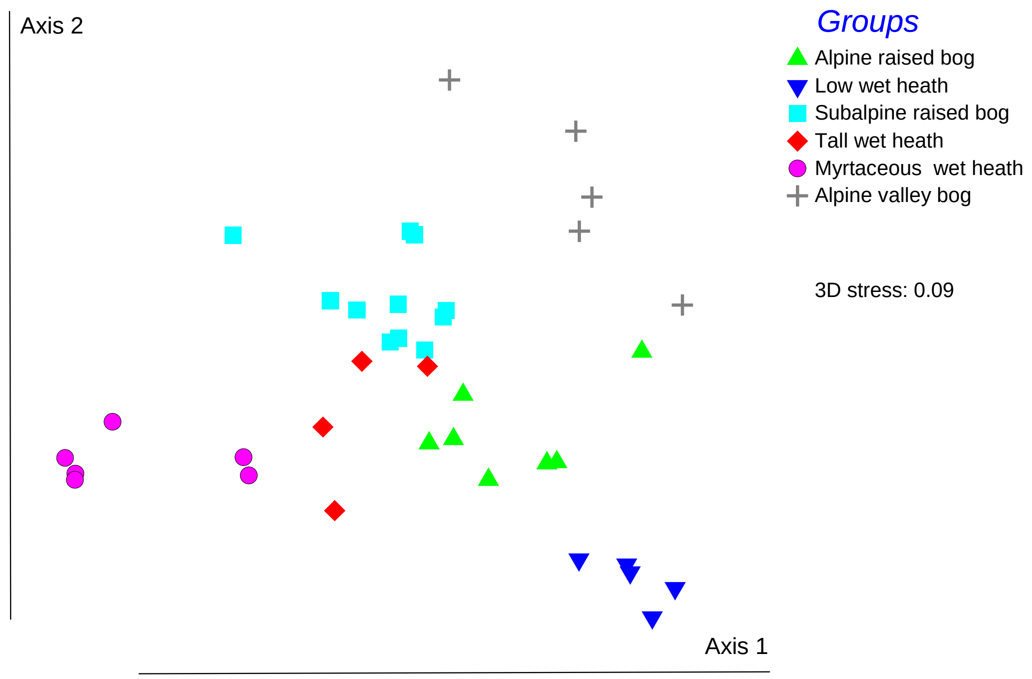


Figure 3.3: Three dimensional ordination graph derived from **Bogong region frequency data** (Axis 1 v Axis 2).

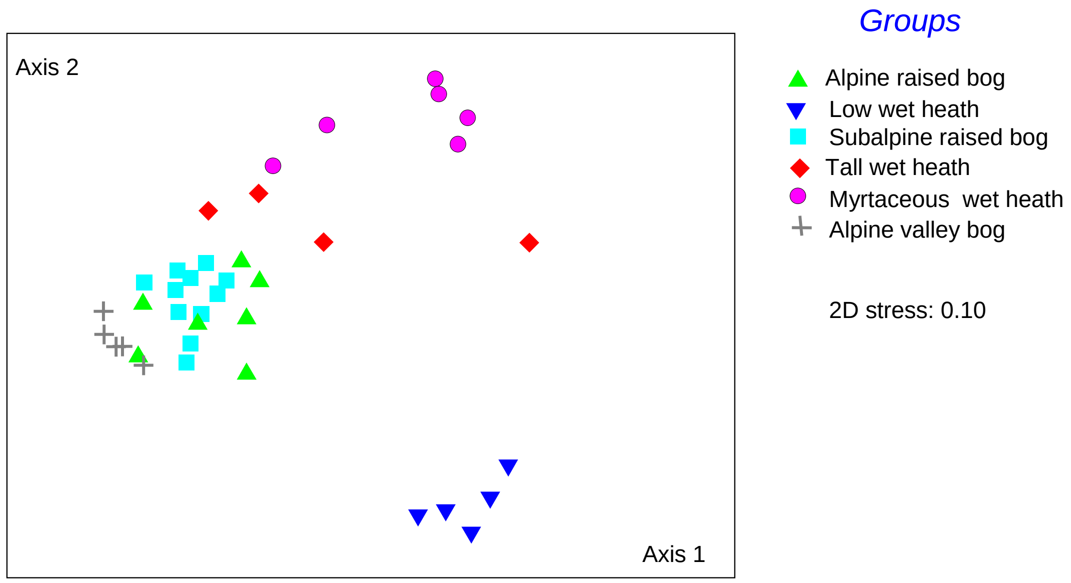


Figure 3.4: Two dimensional ordination graph derived from the **Bogong region cover data**.

valley bog plots, which were slightly separated from the main cluster of bog plots. In spite of the clustering of the three bog communities, overlap was relatively minimal. There was considerable variability in the Tall wet heath and Myrtaceous wet heath groups, but the Low wet heath plots were again tightly clustered and well separated from all other groups.

Group similarities and ANOSIM comparisons of groups or communities

The Bray-Curtis within group similarity levels derived from the frequency data varied from 59% in Tall wet heath, to 73% in Low wet heath. The range for the cover data was similar, varying from 58% in Tall wet heath, to 86% in Alpine valley bog (Table 3.2). The three bog communities had higher levels of similarity based on the cover data than the frequency data, which was probably due to high cover of *Sphagnum* in these communities. The reverse was the case for the three wet heath community types, indicating a generally more even floristic representation in these groups.

Table 3.2: Percentage similarities for the plots within each group or community type.

Community Type	**Abb. code**	**Similarity Percentages**	
		Frequency data	**Cover data**
Alpine raised bog	ARB	67.5	72.8
Low wet heath	LWH	73.4	69.6
Subalpine raised bog	SRB	71.8	79.8
Tall wet heath	TWH	59.1	58.9
Myrtaceous wet heath	MWH	70.5	64.5
Alpine valley bog	AVB	66.7	86.0

ANOSIM overall global test sample values (R-statistics) were highly significant ($p = 0.001$), confirming the strong differences between the groups apparent in both the frequency and cover ordinations (frequency data, $R = 0.789$; cover data, $R = 0.752$; Table 3.3). All individual pair-wise comparisons were significant at the 0.05 level or higher. R-statistic values were generally greater than 0.5, indicating confident differences, and little if any overlap between groups. The possible exceptions (R-statistic < 0.5) were the pair-wise comparisons based on frequency data of Subalpine raised bog with Tall wet heath ($R = 0.378$), and Alpine raised bog with Tall wet heath ($R = 0.437$). These values indicate greater similarity in composition between the groups concerned than in other pair-wise comparisons.

The cover data comparisons of Alpine raised bog with Subalpine raised bog, and Alpine raised bog with Alpine valley bog, also suggested perhaps only marginal differences (R = 0.337 and 0.488 respectively). Cover data comparisons measure similarities in vegetation structure and individual species dominance (see Appendices Table A3.3* for complete ANOSIM table).

Table 3.3: Pair-wise comparisons of the peatland community types based on the **Bogong region transects frequency and cover data**. The statistical significance values of the pair-wise comparisons have been checked with the Bonferroni adjustment and all are significant at 0.05 unless otherwise indicated. Values for R of less than 0.25 indicate that groups are barely separable, values between 0.25 and 0.5 indicate that groups are overlapping but marginally different. Values greater than 0.5 indicate that there are clear differences between groups and these are indicated by bold text.

Analysis of similarity	**Frequency data**		**Cover data**	
Pair-wise Tests Groups	**R Statistic**	**Significance P-value**	**R Statistic**	**Significance P-value**
Alpine raised bog, Low wet heath	**0.655**	0.003	**1**	0.001
Alpine raised bog, Myrtaceous wet heath	**0.964**	0.001	**0.931**	0.003
Alpine raised bog, Subalpine raised bog	**0.585**	0.001	0.337	0.004
Alpine raised bog, Tall wet heath	0.437	0.003	**0.606**	0.003
Alpine raised bog, Alpine valley bog	**0.88**	0.001	0.488	0.015
Low wet heath, Myrtaceous wet heath	**1**	0.002	**1**	0.002
Low wet heath, Subalpine raised bog	**0.988**	0.002	**1**	0.001
Low wet heath, Tall wet heath	**0.888**	0.008	**1**	0.008
Low wet heath, Alpine valley bog	**0.988**	0.008	**1**	0.008
Myrtaceous wet heath, Alpine valley bog	**1**	0.002	**0.997**	0.002
Subalpine raised bog, Myrtaceous wet heath	**0.907**	0.001	**0.973**	0.001
Subalpine raised bog, Tall wet heath	0.378	0.031	**0.864**	0.001
Subalpine raised bog, Alpine valley bog	**0.776**	0.002	**0.82**	0.003
Tall wet heath, Myrtaceous wet heath	**0.758**	0.005	**0.655**	0.010
Tall wet heath, Alpine valley bog	**0.763**	0.008	**0.819**	0.008
Overall global test sample statistic	**0.789**	0.001	**0.752**	0.001

Species defining groups and discriminating between them

The species contributing most to similarity levels within the Alpine raised bog plots were *Sphagnum cristatum, Empodisma minus, Richea continentis, Baeckea gunniana* and *Epacris paludosa* (Table 3.4). The latter three shrub species had cover values of 5-11%.

Common species that provided less overall cover included *Astelia alpina*, *Epacris glacialis*, *Poa costiniana*, *Celmisia* spp., and *Carpha* spp. The dominant species in Low wet heath were *Astelia alpina*, *Epacris glacialis*, *Empodisma minus* and *Richea continentis*, with cover values of 10-27%. Other common species in this community included *Poa costiniana*, *Celmisia* spp., *Oreobolus distichus*, *Baeckea gunniana* and *Gentianella* sp. (frequencies of 28-85%).

Subalpine raised bog had high cover and frequency values for *Sphagnum cristatum* and *Empodisma minus*. The three common shrub species (*Baeckea gunniana*, *Epacris paludosa* and *Richea continentis*) had mean cover values of 8-15%. Common species providing less projective foliage cover (< 5%) included *Carex gaudichaudiana*, *Baloskion australe* and *Poa costiniana*. The dominant species in Myrtaceous wet heath were *Baeckea gunniana*, *Epacris paludosa*, *Empodisma minus* and *Sphagnum cristatum*. These had mean cover values of 10-15%. *Poa costiniana*, *Oreobolus oxycarpus*, *Asperula gunnii*, *Baloskion australe*, *Callistemon pityoides* and *Epacris celata* were common, but typically provided less than 5% cover each.

Sphagnum cristatum was common in Tall wet heath but provided much less cover than in any of the bog communities (34%). Tall wet heath was dominated by the key shrub species, *Richea continentis*, *Baeckea gunniana* and *Epacris paludosa* (15-23% cover). Common species with low overall cover included *Empodisma minus*, *Poa costiniana*, *Epacris celata* and *Asperula gunnii* (frequencies 31-96%). Alpine valley bog had high frequency and cover values for *Sphagnum cristatum* and the sedge *Carex gaudichaudiana*. The shrub species had moderate frequency values (45-60%), but low cover values (< 7%). The most common were *Richea continentis*, *Epacris glacialis* and *Epacris celata*. The restiad *Empodisma minus* was common, but mean cover was comparatively low (complete SIMPER analysis is in Appendices Table A3.4).

Due to the large number of pair-wise comparisons (15 each for frequency and cover data), the comparison tables have been placed in the Appendices to Chapter 3 (Tables

A3.5 to A3.19). Frequency and cover tables are displayed together according to pair-wise combinations.

The immediate and obvious dichotomy was at the formation level, between the three ‘bog’ communities and the three ‘wet heath’ communities (Table 3.4, Appendices Tables A3.5 to A 3.19). This was apparent in the percent cover for *Sphagnum cristatum* which had mean cover abundance of 70-90% in bog communities, compared with 3-35% in wet heath groups. *Empodisma minus* is the other defining species in these peatlands; it was common in all the community types, but provided less overall cover in Alpine valley bog and Tall wet heath, with 8-9% cover, compared with 15-20% elsewhere. In the former of these two groups, Alpine valley bog, *Empodisma* was replaced in prominence by *Carex gaudichaudiana*, which was more abundant here than in any other community.

In addition to the dominance of *Carex gaudichaudiana*, Alpine valley bog also had high frequencies of other sedges, such as *Carex echinata* and *Carpha* spp. The high cover of sedges, and comparatively low shrub presence, distinguished Alpine valley bog from the other two bog community types. The most common three shrub species in Alpine valley bog transects were *Richea continentis*, *Epacris celata* and *Epacris glacialis*. The presence of this last species distinguished Alpine valley bog from Subalpine raised bog, together with the absence of *Epacris paludosa*, and rareness of *Baeckea gunniana* (Appendices Table A3.5).

Subalpine raised bog was also distinguished from Alpine raised bog by the absence of *Epacris glacialis*, virtual absence of *Astelia alpina*, and the greater prominence of *Baloskion australe*, *Richea continentis*, *Baeckea gunniana* and *Epacris paludosa* (Appendices Table A3.6). These latter three shrub species dominated Tall wet heath, which was similar to Subalpine raised bog in floristic composition and was mostly distinguished from this vegetation type by low *Sphagnum* cover (Appendices Table A3.7). *Richea* was present and prominent in five of the six community types, particularly Tall wet heath (> 20% mean cover), but was entirely absent from Myrtaceous wet heath (Appendices Table A3.8). Apart from the absence of *Richea*, the other floristic features of

Table 3.4: Occurrence frequencies and percentage cover abundance values for species identified by SIMPER analysis as contributing most to within group similarities based on the **Bogong region transects (a) frequency data and (b) cover data**. LWH = Low wet heath, ARB = Alpine raised bog, AVB = Alpine valley bog, SRB = Subalpine raised bog, TWH = Tall wet heath, MWH = Myrtaceous wet heath. Species have been grouped according to patterns of co-occurrence.

(a) Frequency data (values greater than 25% indicated in bold)

Species	**LWH**	**ARB**	**AVB**	**SRB**	**TWH**	**MWH**
Empodisma minus	**100.0**	**100.0**	**95.2**	**99.4**	**96.3**	**100.0**
Poa costiniana	**85.7**	**48.6**	**33.3**	**37.2**	**65.0**	**65.0**
Epacris glacialis	**99.3**	**43.1**	**56.3**	0.0	0.0	0.0
Astelia alpina	**76.0**	**41.0**	0.0	1.1	7.1	0.0
Celmisia spp.	**66.0**	**34.1**	0.0	22.1	**33.3**	13.9
Oreobolus distichus	**45.0**	21.4	4.5	5.8	22.9	0.0
Gentianella sp.	**28.0**	6.4	0.0	0.0	0.0	0.0
Sphagnum cristatum	14.3	**89.3**	**98.6**	**96.0**	**66.3**	**29.7**
Richea continentis	**69.7**	**92.6**	**47.4**	**80.6**	**58.8**	0.0
Carex gaudichaudiana	13.0	23.3	**95.3**	**68.8**	**45.0**	6.1
Carpha spp.	8.3	**32.4**	**30.3**	10.2	13.3	0.0
Epacris celata	0.0	20.7	**45.5**	**40.6**	**48.8**	**35.6**
Baloskion australe	0.0	0.0	10.0	**54.8**	**30.8**	**63.1**
Baeckea gunniana	**33.3**	**65.2**	7.6	**60.9**	**83.8**	**90.3**
Epacris paludosa	0.0	**54.1**	2.7	**57.3**	**64.6**	**86.4**
Asperula gunnii	6.0	2.9	0.0	14.6	**31.3**	**72.5**
Luzula modesta	0.0	1.2	3.0	6.4	4.2	**40.8**
Oreobolus oxycarpus	0.0	0.0	0.0	1.5	0.0	**32.2**
Pultenaea fasiculata	0.0	0.0	0.0	0.0	0.0	**32.2**
Callistemon pityoides	0.0	0.0	0.0	0.0	0.0	**30.3**

(b) Cover data (values greater than 1% indicated in bold)

Species	LWH	ARB	AVB	SRB	TWH	MWH
Empodisma minus	**19.6**	**19.4**	**8.9**	**19.9**	**8.6**	**14.6**
Poa costiniana	**2.1**	**1.1**	0.4	0.6	0.8	**4.7**
Astelia alpina	**26.8**	**3.6**	0.0	< 0.1	0.3	0.0
Epacris glacialis	**23.4**	**2.5**	**3.5**	0.0	0.0	0.0
Oreobolus distichus	**3.2**	**1.3**	0.0	0.1	**1.1**	0.0
Celmisia spp.	**2.6**	0.5	0.0	0.2	0.4	0.2
Sphagnum cristatum	3.3	**70.1**	**90.0**	**78.1**	**34.7**	**10.4**
Carex gaudichaudiana	0.2	0.8	**8.7**	**1.1**	0.8	0.1
Richea continentis	**10.6**	**9.8**	**6.8**	**15.0**	**23.2**	0.0
Carpha spp.	0.1	**1.8**	**1.8**	0.6	0.7	0.0
Epacris paludosa	0.0	**11.0**	< 0.1	**12.1**	**15.7**	**12.2**
Baeckea gunniana	**1.5**	**5.9**	0.1	**7.8**	**23.1**	**15.1**
Epacris celata	0.0	**1.9**	**3.2**	**2.9**	**2.1**	**1.5**
Baloskion australe	0.0	0.1	0.0	**2.4**	0.8	**1.6**
Oreobolus oxycarpus	0.0	0.0	0.0	< 0.1	0.0	**6.0**
Callistemon pityoides	0.0	0.0	0.0	0.0	0.0	**3.1**
Pultenaea fasiculata	0.0	0.0	0.0	0.0	0.0	**1.5**
Asperula gunnii	0.1	< 0.1	0.0	0.1	0.3	0.8

Myrtaceous wet heath were a lower and more variable *Sphagnum* cover, an increasing prominence of the restiad species *Baloskion australe*, and the presence of shrub species such as *Callistemon pityoides*, *Comesperma retusum* and *Pultenaea* spp. The hard-leaved sedge *Oreobolus oxycarpus* was also common in this community, but rarely seen elsewhere in the region.

Low wet heath was separated from Alpine raised bog by the low percent cover of *Sphagnum cristatum*, *Epacris paludosa* and *Baeckea gunniana*, and the higher prominence of *Epacris glacialis, Astelia alpina*, *Oreobolus distichus*, *Celmisia* spp. (particularly *C. pugioniformis*), *Poa costiniana* and *Gentianella* sp. (Appendices Table A3.9). *Astelia alpina* was important in Low wet heath and common in Alpine raised bog, but absent or rare in all other communities, including Alpine valley bog (Appendices Table A3.10). *Baloskion australe* never provides high mean cover values (< 3%), and was uncommon in Alpine raised bog, Alpine valley bog and Low wet heath, but more common in Tall wet heath, and most common in Myrtaceous wet heath and Subalpine raised bog. Other useful discriminating species based on frequency alone were the dicot herbs *Celmisia* spp, *Gentianella* sp., *Diplaspis nivis* and *Drosera arcturi*, which tended to be most common in Low wet heath and/or Alpine raised bog. Herbs such as *Asperula gunnii* were most common in the lower altitude wet heaths.

Species and factor correlations with the frequency data ordination

In general, the species identified as having strong correlations with the various ordination graphs were those identified by SIMPER analysis as useful for distinguishing between the various peatland communities. The trend directions of these species in the graph space, and in relation to the positions of the peatland community types in the graph space, are described below. This is useful because trend directions of species can then be compared with the trend directions of environmental and structural variables that are strongly correlated with the same ordination graph.

Forty-seven of the 55 species tested for correlation with the three dimensional ordination graph based on the frequency data showed significant correlation at the 0.05 level with at least one of the three axes. Only the 17 species with Spearman rank correlation co-efficients stronger than 0.6 (positive or negative) are displayed in Table 3.5 (see Appendices Table A3.20* for full list). Those strongly correlated with axis 1 included *Baeckea gunniana*, *Epacris paludosa*, *Epacris glacialis, Oreobolus oxycarpus* and *Asperula gunnii*. There were fewer species showing strong correlations with axis 2, but included in this suite were *Sphagnum cristatum*, *Carex gaudichaudiana*, *Astelia alpina*, *Poa costiniana* and *Celmisia* spp. The only species strongly correlated with axis 3 was *Richea continentis*.

Figure 3.5 is the ordination graph showing the trend directions of some of these correlated species. *Sphagnum cristatum, Carex gaudichaudiana* and *Carex echinata* increased in frequency towards the bog plots in general, and the Alpine valley bog plots in particular. *Baloskion australe*, *Epacris paludosa, Baeckea gunniana* and *Callistemon pityoides* showed negative correlations with axis 1, and thus values for these species increased towards Subalpine raised bog, Tall wet heath, and Myrtaceous wet heath. *Epacris glacialis, Astelia alpina, Oreobolus distichus* and *Celmisia* spp. all trended diagonally from the top left to the bottom right of the graph space, and thus positively with axis 1, and negatively with axis 2. The frequency values for these species increased towards the Alpine raised bog and the Low wet heath plots in particular.

Fifty-five factors were tested for correlation with the three dimensional ordination solution based on the frequency data. These included environmental variables, vegetation structure variables, and thirty-five climate variables determined for each transect location by the BIOCLIM software. Forty-five of these were significantly correlated with at least one of the three axes at the 0.05 level or higher. A subset of variables showing the strongest correlations (positive and negative) is displayed in Table 3.6 (see Appendices Table A3.21* for full table); these included altitude, peat depth, slope, mean height of tallest shrubs, aspect, topographic position and distance from woodland. The most useful explanatory BIOCLIM variables were mean temperature of the coldest quarter, precipitation of the driest quarter, radiation of the driest quarter, and lowest period moisture index. Longitude was also strongly correlated with the configuration, indicating a west to east trend in the plot configuration.

The trend direction arrows of several of these factors were plotted against the frequency ordination solution (Figure 3.6). Lowest period moisture index, annual precipitation, and distance to woodland, all increased along axis 1, in the direction of Low wet heath, Alpine raised bog, and to a lesser extent, Alpine valley bog. This is a reflection of the location of these plots at higher altitudes at or near the tree-line (1650-1750 m), hence the correlation with increasing altitude. Slope, mean height of tallest shrubs, and temperature variables were negatively correlated with axis 1; hence, these increased towards the 'subalpine' plots (Myrtaceous wet heath, Tall wet heath, Subalpine raised bog). The lower altitude subalpine plots were located towards the east and south-east of the Bogong area, which explains the correlation with increasing longitude. Topographic position was negatively correlated with axis 2, indicating less favourable landscape positions for peat-forming wetlands in this direction (mid-slope positions, increased drainage potential). As would be expected, this variable increased towards the wet heath communities. Peat depth was orientated in the opposite direction and positively correlated with axis 2, indicating greater depths towards bog communities, particularly Subalpine raised bog and Alpine valley bog.

The axis 3 perspective of the three dimensional ordination solution (Appendices Figure A3.1) revealed the gradient in altitude to maximum effect. The 'alpine' plots were located towards the far right of the graph space, the 'subalpine' plots in the centre and on the left. There was a slight trend in aspect value (drier aspects, north and west facing) towards the wet heath communities, especially the subalpine groups (Myrtaceous wet heath and Tall wet heath). Slope had a diagonal trend in the graph space, from the top right to the bottom left, towards the subalpine community types.

Table 3.5: Species with the strongest significant correlations with the axes of the ordination graph based on the **Bogong region transects frequency data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Species	MDS1	sig. level	MDS2	sig. level	MDS3	sig. level
Asperula gunnii	**-0.75**	***	-0.21	ns	0.23	ns
Oreobolus oxycarpus	**-0.69**	***	-0.15	ns	0.26	ns
Epacris paludosa	**-0.69**	***	-0.12	ns	-0.25	ns
Baeckea gunniana	**-0.69**	***	-0.31	ns	-0.18	ns
Baloskion australe	**-0.68**	***	0.14	ns	**0.44**	**
Luzula modesta	**-0.64**	***	0.25	ns	0.17	ns
Pultenaea fasiculata	**-0.63**	***	-0.29	ns	0.15	ns
Callistemon pityoides	**-0.63**	***	-0.24	ns	0.06	ns
Rytidosperma nivicola	**0.65**	***	**-0.39**	*	-0.21	ns
Epacris glacialis	**0.83**	***	**-0.35**	*	0.20	ns
Astelia alpina	**0.61**	***	**-0.68**	***	-0.12	ns
Poa costiniana	0.02	ns	**-0.64**	***	**0.44**	**
Celmisia spp.	0.27	ns	**-0.62**	***	-0.25	ns
Gentianella sp.	**0.56**	***	**-0.60**	***	0.14	ns
Sphagnum cristatum	0.11	ns	**0.69**	***	-0.13	ns
Carex gaudichaudiana	0.30	ns	**0.78**	***	-0.02	ns
Richea continentis	**0.47**	**	0.07	ns	**-0.61**	***

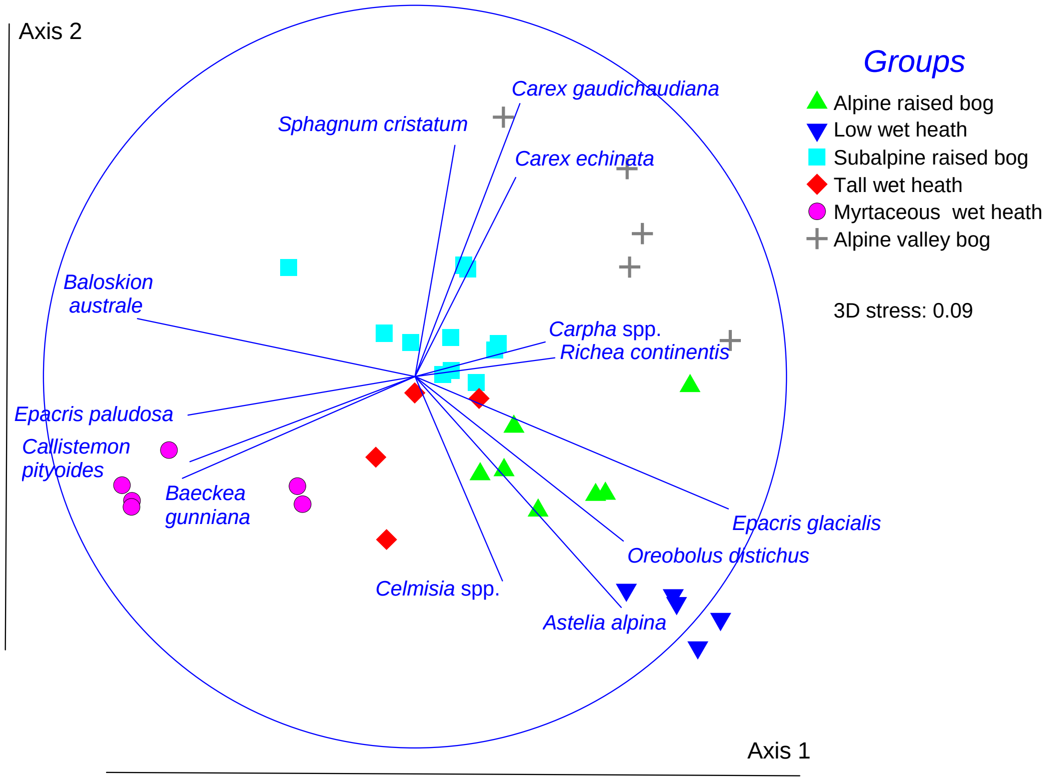


Figure 3.5: Three dimensional ordination graph derived from the **Bogong region transects frequency data** (Axis 1 v Axis 2). The trend directions of strongly correlated species are indicated.

Table 3.6: Factors with the strongest significant correlations with the axes of the ordination graph based on the **Bogong region transects frequency data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Factor	**MDS1**	sig.level	**MDS2**	sig.level	**MDS3**	sig.level
Distance to woodland	**0.87**	***	-0.19	ns	-0.07	ns
Lowest period moisture index	**0.77**	***	**-0.41**	**	-0.29	ns
Altitude	**0.71**	***	**-0.41**	**	**-0.37**	*
Annual precipitation	**0.71**	***	-0.27	ns	**-0.42**	**
Precipitation of driest quarter	**0.71**	***	**-0.40**	*	**-0.38**	*
Peat depth	0.00	ns	**0.78**	***	-0.15	ns
% peat points deep than 1 metre	-0.03	ns	**0.72**	***	-0.10	ns
Radiation seasonality	0.21	ns	**0.52**	***	0.07	ns
Aspect	-0.22	ns	**-0.39**	*	**0.52**	***
Topographic position (dryness)	**-0.40**	*	**-0.53**	***	-0.24	ns
% peat points shallower than 0.5 metres	-0.10	ns	**-0.81**	***	0.13	ns
% slope	**-0.62**	***	-0.10	ns	**-0.50**	**
Radiation of driest quarter	**-0.74**	***	**0.39**	*	**0.35**	*
Annual mean temperature	**-0.74**	***	**0.40**	*	**0.35**	*
Mean temperature of coldest quarter	**-0.74**	***	**0.39**	*	**0.34**	*
Longitude	**-0.74**	***	-0.03	ns	-0.04	ns
Mean diurnal temperature range	**-0.75**	***	**0.35**	*	**0.34**	*
Mean height of tallest shrubs	**-0.83**	***	-0.15	ns	0.02	ns

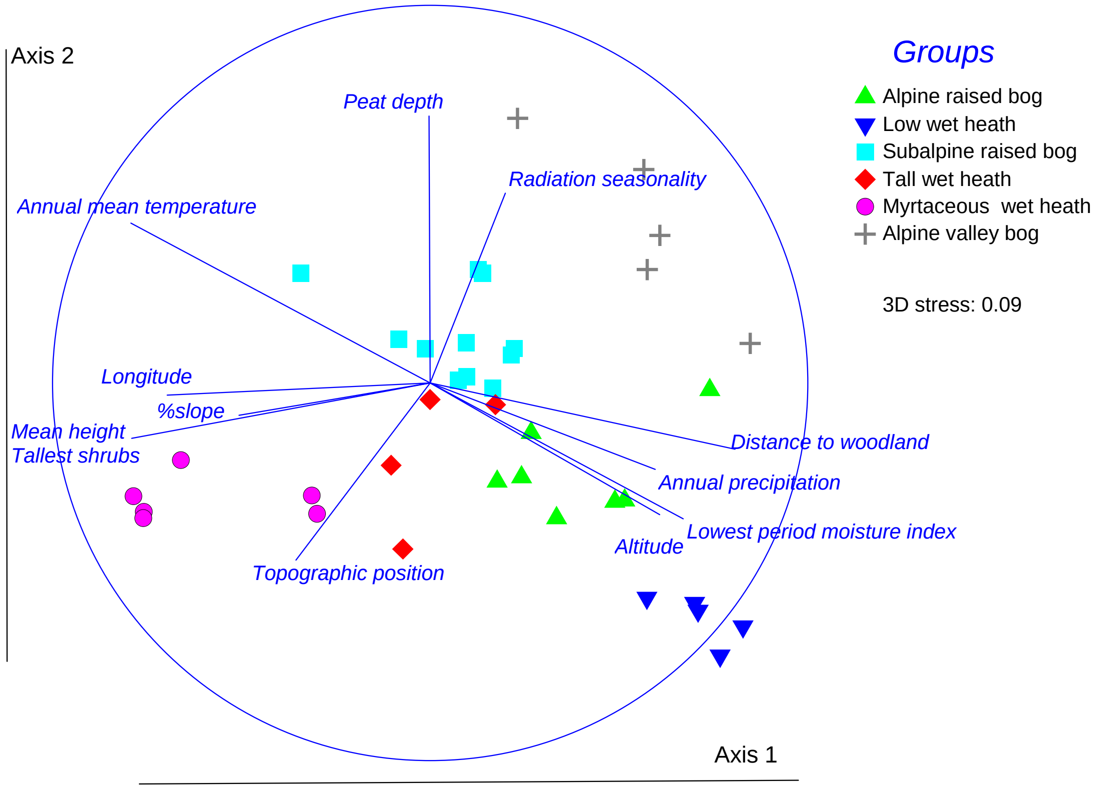


Figure 3.6: Three dimensional ordination graph derived from the **Bogong region transects frequency data** (Axis 1 v Axis 2). The trend directions of significantly correlated factors are indicated.

Species and factor correlations with the cover data ordination

There were fewer species showing significant correlations with the two dimensional ordination solution based on the cover data. Thirty-six of the 55 species showed significant correlations (0.05 sig. level) with at least one of the two axes. The 17 species that recorded correlation co-efficients stronger than 0.5 (positive or negative) are listed in Table 3.7 (Appendices Table A3.22* for the full version). In general, the same species featured as in the frequency ordination solution.

Only two species showed strong negative correlations with axis 1, *Sphagnum cristatum* and *Carex gaudichaudiana* (Figure 3.7). As in the frequency solution, these were orientated towards the Alpine valley bog plots. There is a suite of species that increased in cover value diagonally from the lower left to the upper right of the graph space, including *Baeckea gunniana*, *Oreobolus oxycarpus, Callistemon pityoides, Asperula gunnii* and *Poa costiniana*. Together with *Epacris paludosa,* which appeared to be correlated purely with axis two, these species displayed an increasing cover trend towards Tall wet heath and particularly Myrtaceous wet heath.

Species with correlation trends in the opposite direction were not as strong (0.5-0.6), with the exception of *Epacris glacialis*. This suite of species showed increasing cover values towards Low wet heath plots and included *Astelia alpina*, *Gentianella* sp. and *Rytidosperma nivicola*.

Forty of the 55 environmental, structural and climatic variables were significantly correlated with at least one of the axes of the cover data ordination. In general it was the same factors showing strong correlations as observed in the frequency data ordination (Table 3.8, see Appendices Table A3.23* for the full version). Correlation values of the BIOCLIM variables with the cover ordination were not as strong, these were mostly aligned with axis 2, which is broadly linked with increasing altitude and decreasing longitude. The most informative of the BIOCLIM variables were those associated with humidity (moisture index), and seasonality of cloud cover (radiation).

Table 3.7: Species with the strongest significant correlations with the ordination graph based on the **Bogong region cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Species	MDS1	sig.level	MDS2	sig.level
Poa costiniana	**0.64**	***	0.29	ns
Asperula gunnii	**0.56**	***	**0.51**	**
Baeckea gunniana	**0.40**	*	**0.84**	***
Epacris paludosa	0.08	ns	**0.71**	***
Oreobolus oxycarpus	**0.33**	*	**0.64**	***
Pultenaea fasiculata	**0.43**	**	**0.63**	***
Stylidium sp.	0.31	ns	**0.60**	***
Comesperma retusum	**0.41**	**	**0.59**	***
Callistemon pityoides	**0.37**	*	**0.56**	***
Luzula modesta	0.09	ns	**0.54**	***
Nertera granadensis	0.06	ns	**0.50**	**
Astelia alpina	**0.35**	*	**-0.50**	**
Rytidosperma nivicola	0.02	ns	**-0.51**	**
Gentianella sp.	**0.43**	**	**-0.57**	***
Epacris glacialis	0.12	ns	**-0.77**	***
Carex gaudichaudiana	**-0.73**	***	-0.32	ns
Sphagnum cristatum	**-0.94**	***	-0.28	ns

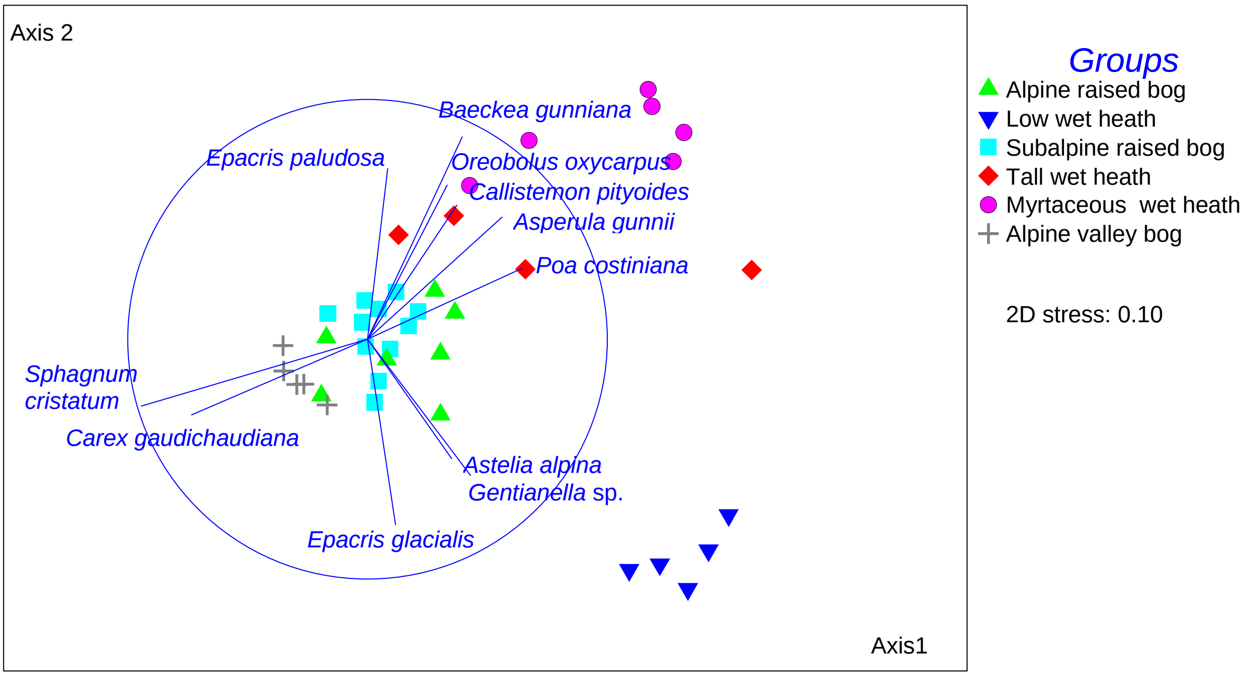


Figure 3.7: Two dimensional ordination graph based on the **Bogong region transects cover data**. The trend directions of significantly correlated species are indicated.

Table 3.8: Factors with the strongest significant correlations with the axes of the ordination graph based on the **Bogong region transects cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Factor	MDS1	sig. level	MDS2	sig. level
% peat points < 0.5 m deep	**0.78**	***	0.16	ns
Litter	**0.55**	***	**0.34**	*
Shrub cover	**0.49**	**	0.31	ns
Aspect	**0.36**	*	0.18	ns
Radiation seasonality (Cof V)	**-0.43**	**	-0.05	ns
% peat points > 1.0 m deep	**-0.58**	***	-0.06	ns
Peat depth	**-0.72**	***	-0.07	ns
Mean height of tallest shrubs	**0.44**	**	**0.77**	***
% slope	0.20	ns	**0.68**	***
Topographic position	**0.50**	**	**0.60**	***
Longitude	0.28	ns	**0.55**	***
Moisture index seasonality (C of V)	-0.14	ns	**0.47**	**
Radiation of warmest quarter	-0.15	ns	**0.46**	**
Annual mean temperature	-0.11	ns	**0.45**	**
Altitude	0.13	ns	**-0.43**	**
Lowest period moisture index	0.13	ns	**-0.49**	**
Distance to woodland	-0.01	ns	**-0.77**	***

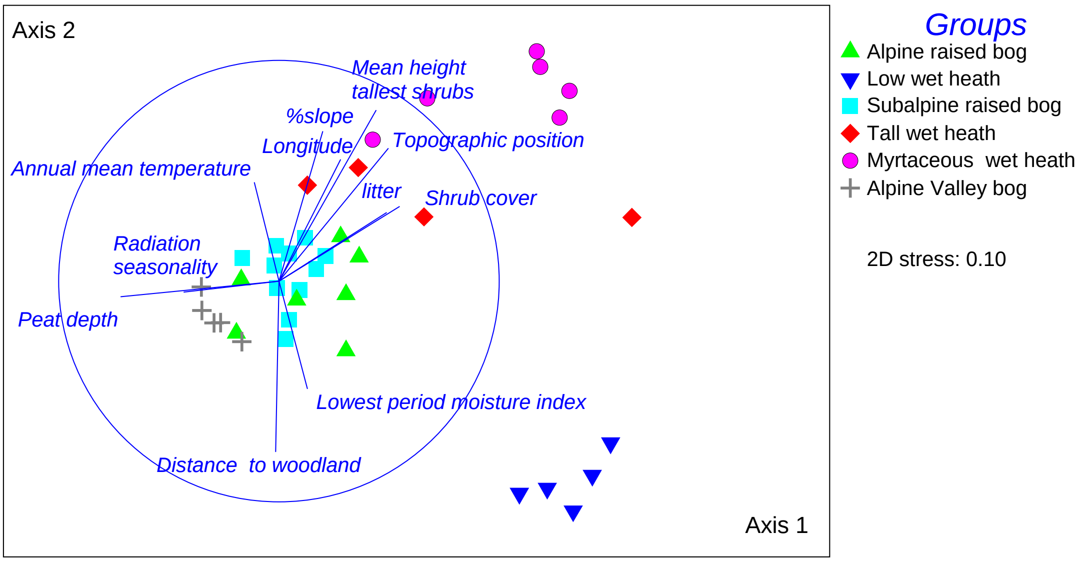


Figure 3.8: Two dimensional ordination graph based on the **Bogong region transects cover data**. The trend directions of significantly correlated factors are indicated.

Peat depth and radiation seasonality decreased from left to right along axis 1, and thus favoured the bog communities, particularly Alpine valley bog (Figure 3.8). Mean height of the tallest shrubs, slope, longitude, and topographic position (dryness) were positively aligned with axis 2, although there was a slight diagonal component, which indicated a general increasing trend from the bottom to the top of the graph space, but slightly to the right (Figure 3.8). Shrub cover had a similar trend direction but more diagonal, and increased from the bottom left to top right of the graph space. The general trend of these five variables was parallel with a progression in community type from Alpine valley bog, to Subalpine raised bog and Alpine raised bog, to Tall wet heath, and finally Myrtaceous wet heath. Distance to woodland, and moisture index of the lowest period, had strong negative correlations with axis 2, thus displaying an increasing trend towards the higher altitude plots (Low wet heath, Alpine raised bog and Alpine valley bog).

Plant functional group patterns

Eight of the 11 plant functional groups were significantly correlated with at least one of the two axes of the cover data ordination (Table 3.9). Groups with strong positive correlations with axis 1 included ‘other monocots’ (grasses, rushes mainly) and ‘other shrubs’. The ‘other shrubs’ category included species such as *Ozothamnus* sp.1, *Olearia algida*, *Comesperma retusum* and *Pultenaea* spp., which tended to be associated with transitional heathland or ecotones at the peatland margins, neither ‘wet’ nor ‘dry’. These showed an increasing trend towards the wet heath communities, particularly Tall wet heath and Myrtaceous wet heath (Figure 3.9). Herbs also had a strong correlation with axis 1 and favoured the wet heath communities in general. *Sphagnum* and *Carex* species showed strong trends in the opposite direction towards the ‘bog’ communities, particularly Alpine valley bog.

Myrtaceous shrubs (*Baeckea*, *Callistemon*) had a strong positive correlation with axis 2 and trended towards the subalpine wet heaths, particularly Myrtaceous wet heath. Ericaceous shrubs and *Astelia alpina* had a strong negative correlation with axis 2; their cover values tended to increase towards the Low wet heath plots.

Table 3.9: Plant functional groups significantly correlated with the ordination graph based on the **Bogong region transects cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Life-form	MDS1	sig.level	MDS2	sig.level
Other shrubs	**0.68**	***	0.19	ns
Herbs	**0.61**	***	-0.01	ns
Other monocots	**0.59**	***	**0.38**	*
Myrtaceous shrubs	**0.40**	*	**0.85**	***
Ericaceous shrubs	**0.36**	*	-0.24	ns
Astelia	**0.35**	*	**-0.50**	**
Carex spp.	**-0.71**	***	-0.14	ns
Sphagnum spp.	**-0.94**	***	-0.28	ns

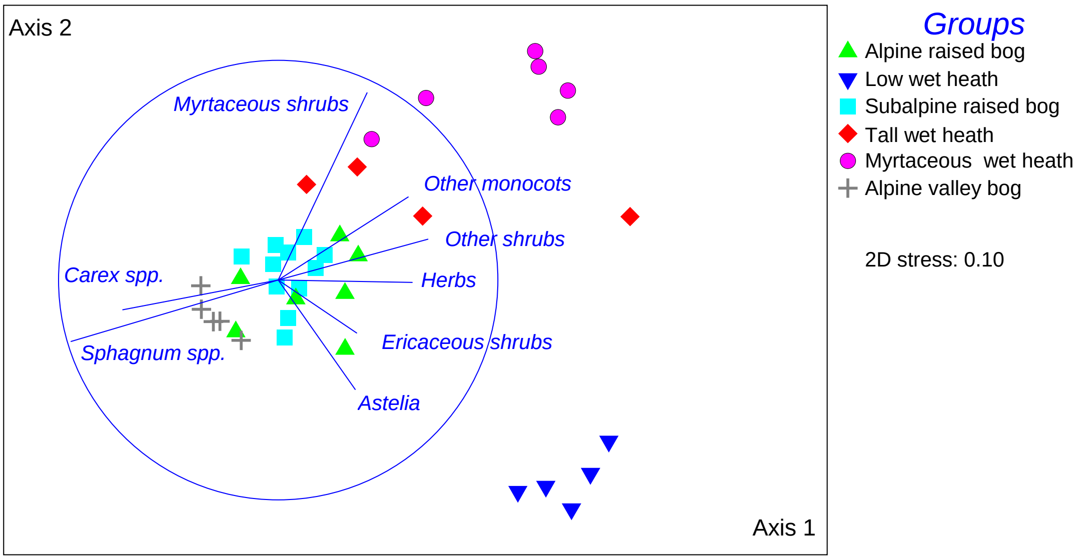


Figure 3.9: Two dimensional ordination graph derived from the **Bogong region transects cover data**. The trend directions of significantly correlated plant functional groups are indicated.

Community type summaries: floristics and environmental characteristics

Alpine raised bog: These were at the highest elevations and thus in predominantly treeless areas, and generally associated with grassland and open heath (Table 3.10). Slopes were moderate and peat depth typically less than 1 m. They generally occupied mid to lower slope positions. In terms of general plant functional groups, they were dominated by *Sphagnum*, restiads (mostly *Empodisma*), and ericaceous shrubs (Table 3.11). However, there was a greater diversity of functional groups represented in Alpine raised bog than in other bog communities, with an even representation of hard-leaved graminoids like *Astelia*, the common sedge genus *Carex*, 'other sedges' (*Oreobolus*, *Carpha*), 'other monocots' (*Poa*, *Rytidosperma*), and herbs (*Celmisia*, *Erigeron*, *Gentianella*, *Diplaspis*). Myrtaceous shrubs were less conspicuous than at lower elevations (Figure 3.10).

<u>Low wet heath</u>: This community type was on the shallowest and most humified peats (< 50 cm deep) and arguably in the most exposed landscape positions. These plots were located on the lower slopes of treeless expanses such as Pretty Valley and Cope Creek (distance to woodland 150-300+ m). Slope gradients were low, and shrub cover generally

Table 3.10: Descriptive statistics for the transects completed in the **Bogong region** according to peatland community type. Mean, standard error of the mean, maximum value and minimum value are listed for each structural or environmental factor. Aspect and topographic position are categorical variables. Higher values for each of these indicate drier aspects and topographic positions. Abbreviations: ARB = Alpine raised bog, LWH = Low wet heath, MWH = Myrtaceous wet heath, SRB = Subalpine raised bog, TWH = Tall wet heath, AVB = Alpine valley bog.

			Community type			
Factors	**ARB**	**LWH**	**MWH**	**SRB**	**TWH**	**AVB**
Altitude (m)	**1710 ± 4**	**1692 ± 9**	**1528 ± 20**	**1521 ± 32**	**1618 ± 28**	**1640 ± 8**
	1690 - 1720	1660 -1720	1470 - 1580	1380 - 1690	1540 - 1700	1610 - 1650
Peat depth (cm)	**57.9 ± 4**	**40.4 ± 5**	**43.8 ± 6**	**111.7 ± 8**	**71.9 ± 12**	**122.1 ± 18**
	43 - 71	28 - 60	33 - 70	79 - 163	54 - 113	82 - 175
% slope	**8.6 ± 1.8**	**3.1 ± 0.2**	**19.2 ± 1.7**	**8.3 ± 1.2**	**5.8 ± 0.9**	**2.2 ± 0.6**
	2.0 - 15.0	2.5 - 4.0	12.0 - 23.0	4.0 - 15.0	4.0 - 7.8	1.0 - 4.0
Shrub cover (%)	**27.6 ± 5.0**	**37.0 ± 5**	**31.0 ± 4**	**36.9 ± 3**	**58.2 ± 6**	**12.9 ± 3**
	14 - 41	29 - 58	20 - 43	16 - 50	41 - 72	6 - 21
Mean height of tallest shrubs (cm)	**22.9 ± 3.0**	**21 ± 1**	**39.8 ± 2**	**33.0 ± 3**	**41.7 ± 3**	**14.0 ± 2**
	14 - 34	17 - 24	33 - 45	23 - 54	35 - 51	8 - 18
Aspect	**2.6 ± 0.3**	**3 ± 0**	**4.2 ± 0.4**	**2.1 ± 0.2**	**3 ± 0.6**	**2.8 ± 0.2**
	1.0 - 3.0	3.0 - 3.0	3.0 - 5.0	1.0 - 3.0	2.0 - 5.0	2.0 - 3.0
Topographic position	**2.6 ± 0.2**	**1.8 ± 0.2**	**3 ± 0.0**	**1.6 ± 0.2**	**2 ± 0**	**1.2 ± 0.2**
	2.0 - 3.0	1.0 - 2.0	3.0 - 3.0	1.0 - 2.0	2.0 - 2.0	1.0 - 2.0
Distance to woodland (m)	**147 ± 32**	**230 ± 27**	**28.3 ± 3**	**55.4 ± 6**	**75 ± 14**	**158 ± 41**
	60 - 300	150 - 300	20 - 40	40 - 100	30 - 100	40 - 300

Table 3.11: Descriptive statistics for the plant functional groups by community type. Mean cover, standard error, and the range of cover values for the eleven plant functional group categories (Abbreviations as for table 3.10).

Lifeform Type	**Community Type**					
	ARB	**LWH**	**MWH**	**SRB**	**TWH**	**AVB**
Ericaceous shrubs	**25.2 ± 2.6**	**35.5 ± 4.2**	**13.7 ± 2.3**	**30.0 ± 2.8**	**41.0 ± 8.4**	**13.6 ± 2.6**
	17.4 - 36.9	28.1 - 53.6	7.2 - 22.0	10.7 - 43.0	23.6 - 59.4	6.3 - 21.3
Myrtaceous shrubs	**5.9 ± 1.7**	**1.5 ± 0.4**	**18.1 ± 1**	**8.2 ± 1.5**	**23.1 ± 2.4**	**0.05 ± 0.05**
	1.5 - 13.8	0 - 3.0	14.6 - 22.4	3.5 - 20.8	17.8 - 29.2	0 - 0.2
Other shrubs	**< 0.1**	**< 0.1**	**2.7 ± 1**	**0.00**	**0.00**	**0.00**
	0 - < 0.1	0 - 0.2	0.6 - 5.9	0.00	0.00	0.00
Astelia	**3.6 ± 1**	**26.8 ± 5.9**	**0.00**	**< 0.1**	**0.3 ± 0.2**	**0.00**
	1.0 - 8.0	6.2 - 41.5	0.00	0 - 0.1	0 - 1.0	0.00
***Carex* spp.**	**0.8 ± 0.5**	**0.1 ± 0.05**	**0.1 ± 0.05**	**1.2 ± 0.2**	**0.8 ± 0.5**	**11.0 ± 2**
	0 - 3.5	0 - 0.6	0 - 0.4	0.2 - 2.6	0.1 - 2.1	5.7 - 17.2
Other sedges	**3.2 ± 0.7**	**3.2 ± 1.3**	**6.3 ± 2.9**	**0.7 ± 0.4**	**1.8 ± 1.3**	**2.1 ± 0.5**
	0.1 - 5.1	0.4 - 7.1	0.3 - 16.5	0 - 3.8	0 - 5.5	0.1 - 3.4
Restiads	**19.5 ± 3.5**	**19.8 ± 1.9**	**16.1 ± 1.9**	**22.3 ± 2.5**	**9.5 ± 1.8**	**9.2 ± 0.7**
	7.5 - 33.6	15.9 - 27.6	9.8 - 21.7	7.2 - 35.0	4.3 - 12.3	7.5 - 11.4
Other monocots	**1.3 ± 0.4**	**2.2 ± 0.5**	**5.7 ± 0.6**	**0.7 ± 0.1**	**0.9 ± 0.2**	**0.6 ± 0.2**
	0.2 - 3.0	0.8 - 3.8	4.2 - 8.4	0.1 - 1.4	0.4 - 1.2	0.1 - 1.2
Herbs	**1.3 ± 0.5**	**3.3 ± 0.5**	**1.6 ± 0.2**	**0.7 ± 0.2**	**1.2 ± 0.4**	**0.3 ± 0.1**
	0.4 - 4.2	1.4 - 4.6	1.2 - 2.5	0.1 - 2.2	0.7 - 2.4	0 - 0.6
***Sphagnum* spp.**	**70.1 ± 7.1**	**3.2 ± 1.5**	**10.4 ± 6.3**	**78.1 ± 2.8**	**34.7 ± 11**	**90.0 ± 3.4**
	53.2 - 95.4	0 - 9.2	0.3 - 36.8	65.6 - 97 9	4.8 - 57.4	78.8 - 99.6
Other bryophytes	**< 0.1**	**< 0.1**	**0.00**	**0.1 ± 0.1**	**0.1 ± 0.05**	**0.1 ± 0.05**
	0 - 0.2	0 - 0.2	0.00	0 - 0.6	0 - 0.2	0 - 0.3

high (30-60%), but shrub stature low (< 25 cm). The dominant functional groups were ericaceous shrubs (*Epacris glacialis*, *Richea*), *Astelia*, restiads (*Empodisma*) and ‘other monocots’ (*Poa costiniana*). Similar to Alpine raised bog, there was a relatively diverse presence of functional groups, with good representation from ‘other monocots’, ‘other sedges’, and ‘herbs’ (*Poa*, *Rytidosperma*, *Oreobolus*, *Celmisia*, *Diplaspis*, *Gentianella*). *Sphagnum* species and myrtaceous shrubs (*Baeckea*) were uncommon (Figure 3.11).

Alpine valley bog: Generally occupied the valley floor positions in exposed locations at high altitude (Figure 3.12). Therefore, slopes were gentle and peats often in excess of 1 m deep. The vegetation was dominated by *Sphagnum* and sedges (*Carex*, *Carpha*, *Isolepis*). Shrub cover and stature were relatively low (< 20%, < 20 cm). The shrub species present were exclusively from the family Ericaceae (*Richea*, *Epacris glacialis*, *E. celata*). Other shrub species were rare. This peatland type was arguably the least diverse and species-rich.

Subalpine raised bog: The lower altitude raised bog communities were on more moderate slopes and in more sheltered landscape positions (distance to woodland 40-100 m). Peat depths were often greater than 1 m. Shrub cover and stature were generally greater than at higher altitude (15-50% cover, mean height of tallest shrubs 20-54 cm). The most prominent plant functional groups were *Sphagnum* (60-100% cover), restiads (7-35% cover, *Empodisma*, *Baloskion*), ericaceous shrubs (10-43% cover, *Richea*, *E. paludosa*, *E. celata*), and myrtaceous shrubs (3-21% cover, *Baeckea*). Dicot herbs were less conspicuous than in alpine bogs. Sedges were common, but cover was variable and relatively low (Figure 3.13).

Tall wet heath: These were usually on gentle to moderate slopes and often at the margins of Subalpine raised bog and thus relatively close to woodland and non-wetland heath (Figure 3.14). Peat depths were generally less than 1 m, and shrub cover and stature were high (40-70% cover, mean height of tallest shrubs 30-51 cm). Both major shrub families were prominent, Ericaceae 23-59% cover (*E.paludosa*, *E.celata*, *Richea*), and Myrtaceae 17-29% cover (*Baeckea*). *Sphagnum* was common, but provided less cover than in neighbouring ‘bog’ sections (Subalpine raised bog). Restiad cover was relatively low compared to other peatland communites (4-12% cover).

Myrtaceous wet heath: This community type occurred on the steepest slopes (12-23%), in closest proximity to open forest (20-40 m), and tended to be on drier aspects. As a consequence, peats tended to be shallow and ‘humified’ or decomposed (30-70 cm deep).

Figure 3.10: Alpine raised bog near Cope Creek. At higher more exposed locations above 1650 m shrubs generally don't emerge far above the *Sphagnum* carpet (< 15 cm).

Figure 3.11: Close-up of Low wet heath vegetation in the Rocky Knobs area. The plant species visible include *Astelia alpina*, *Empodisma minus*, *Celmisia pugioniformis*, *Carpha nivicola*, *Poa costiniana* and the shrubs *Richea continentis* and *Epacris glacialis*. The quadrat frame side length is 50 cm.

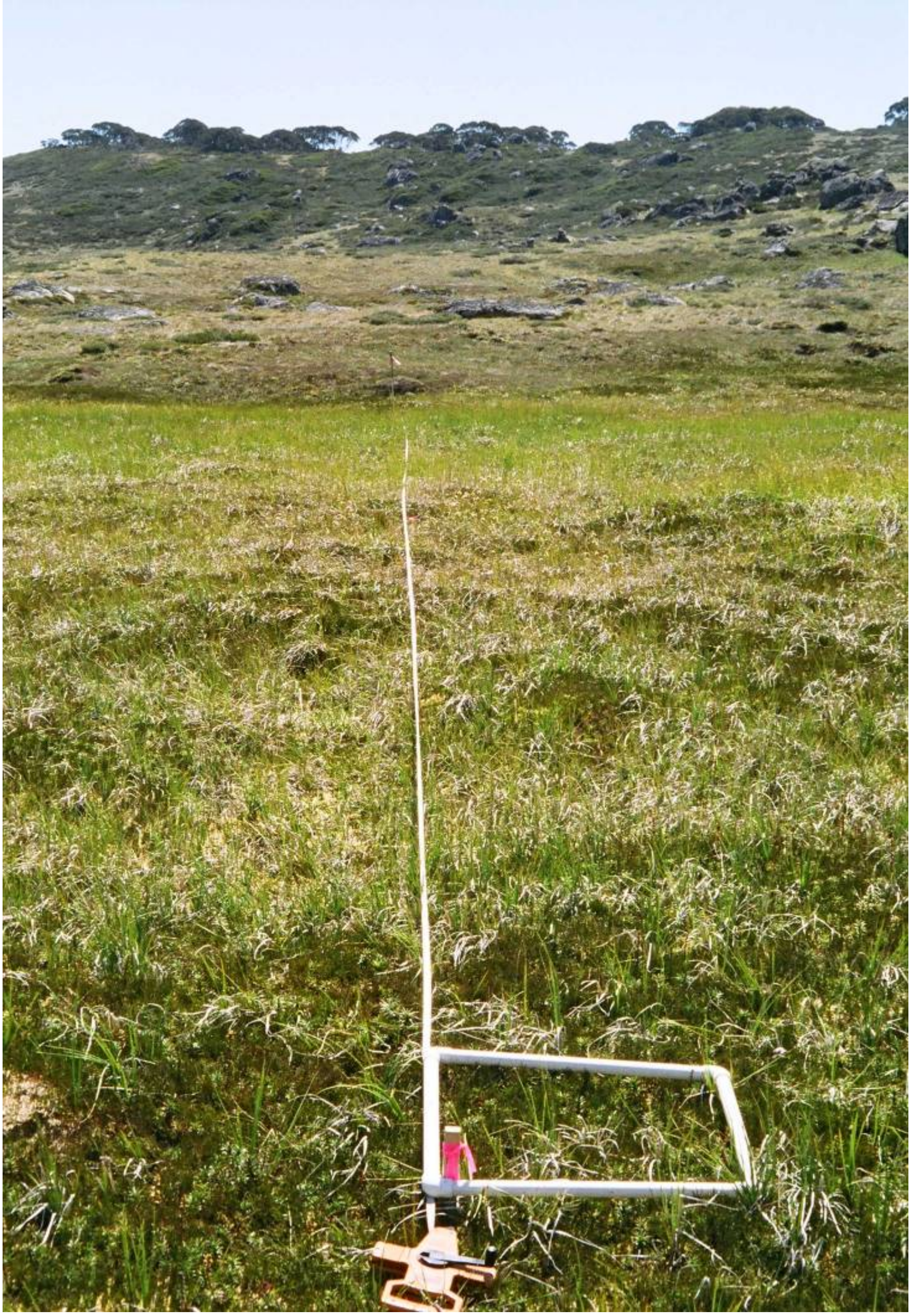


Figure 3.12: Alpine valley bog vegetation in Pretty Valley. This community type is dominated by *Sphagnum cristatum* and sedges such as *Carex gaudichaudiana*. *Empodisma minus* and shrub species are common but provide less overall cover compared to other community types.

Figure 3.13: Subalpine raised bog vegetation at Cope South. *Sphagnum* cover is typically high (> 60%). The shrub species *Epacris paludosa*, *Baeckea gunniana*, and *Richea continentis* are also prominent.

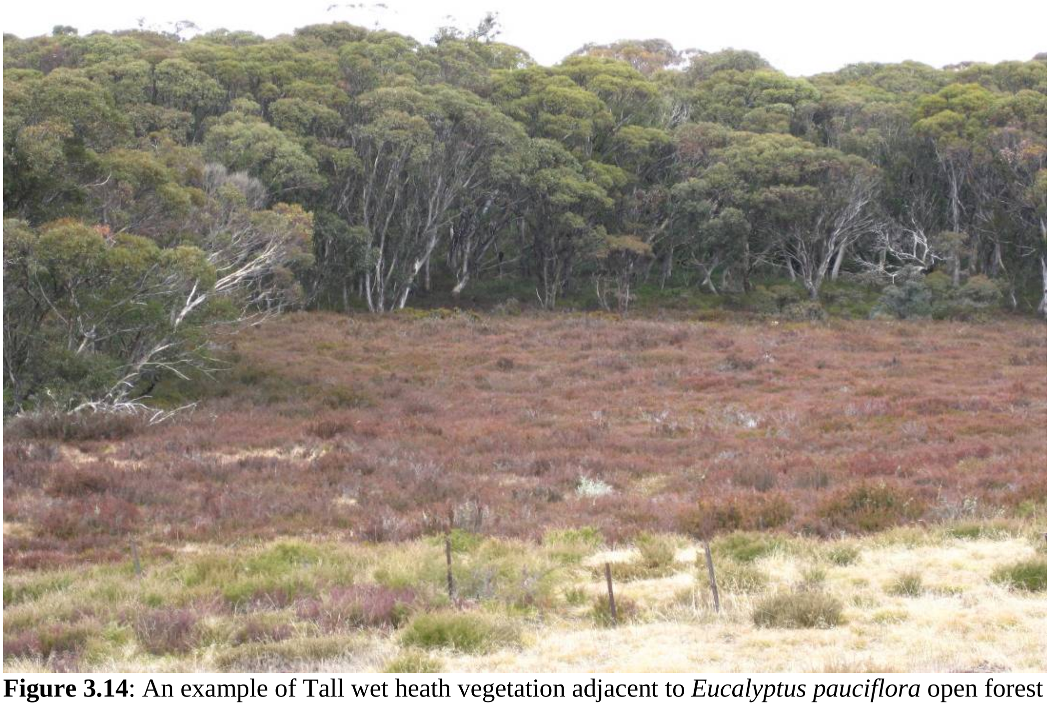


Figure 3.14: An example of Tall wet heath vegetation adjacent to *Eucalyptus pauciflora* open forest at Buckety Plain. This peatland community is typically dominated by *Baeckea gunniana*, *Richea continentis* and *Epacris paludosa*. *Sphagnum cristatum* is less abundant and generally provides less than 30% overall vegetation cover.

Shrub cover and stature were generally high in the six transects sampled (20-43% cover, mean height of tallest shrubs 33-45 cm). The plant functional groups that provided the most vegetative cover were myrtaceous shrubs (14-22% cover, *Baeckea, Callistemon*), ericaceous shrubs (7-22% cover, *E. paludosa, E. celata*), and restiads (10-22% cover, *Empodisma, Baloskion*). Grasses were also more abundant in comparison to the other five communities in the region (3-8% cover, *Poa* spp.). *Sphagnum* cover was low (Figure 3.15).

Site observations and descriptions

In general the peatlands above 1600 m elevation on the Bogong High Plains were a mix of Alpine raised bog, Low wet heath and Alpine valley bog, with small areas of 'Short alpine herbfield' (see McDougall and Walsh 2007). The 'alpine' peatlands tended to differ in peat depth, slope and topographic position, all factors that influence hydrology and microclimate. All these sites were at or near the regional climatic limit of tree-growth, and hence are abutted by grassland, open heathland, or low open woodland. This was reflected by the values for the 'distance to woodland' variable which were higher in the three groups that dominate the higher altitude sites. All nominally alpine sites sampled in this study are from the Rocky Knobs, Heathy Spur, Pretty Valley and Cope Creek areas of the Bogong High Plains region. Furthermore, most are within the north flowing Kiewa River catchment. Ordovician metamorphic rocks underlie all the peatland sites sampled, although Quaternary gravel and alluvial deposits are also involved in some sections carrying Alpine valley bog and Low wet heath (Pretty Valley, Cope Creek).

The subalpine sites, as suggested by the correlations with longitude, were on the eastern and south-eastern flanks of the Bogong High Plains (e.g. Buckety Plain, Cope South, Wild Horse Creek, Malcolm Plain). The three peatland communities that dominated were Subalpine raised bog, Tall wet heath, and Myrtaceous wet heath. Some of these peatlands were in treeless 'cold-air drainage' valleys, on gentle slopes, and abutted by subalpine grassland and open heath (e.g. Buckety Plain). Others were associated with areas of ground-water seepage or discharge on steeper slopes, without the surrounding treeless non-wetland communities. Instead, these peatlands abutted *Eucalyptus pauciflora* open forest with a tall shrub-dominated understorey, and were mostly Myrtaceous wet heath (Figure 3.15). The mix of canopy species adjacent to the lower elevation peatlands was more variable and also included *Eucalyptus stellulata*, *E. dalrympleana* and *E. perriniana*. All of the subalpine peatland sites surveyed in the Bogong region were within the Mitta Mitta River catchment and underlain by the same Ordovician metamorphic rocks as the alpine sites (gneiss, schist).

Figure 3.15: Myrtaceous wet heath vegetation abutting *E. pauciflora* open forest at Strawberry Saddle near Buckety Plain. Grassland and open heath can be seen in the right and left foreground separated by a strip of *Carex* dominated wetland vegetation along the drainage line in the centre.

3.3.2 Snowy Range-Dargo High Plains region transects

A total of 23 transects were completed in the Snowy Range - Dargo High Plains area. These ranged in altitude from 1000 m at Morgans Gully on the Moroka River, to 1580 m on the Snowy Range (Figures 3.16, 3.17, Appendices Table A3.24, Appendices Figure A3.2). The original species pool of 93 species was trimmed to the 61 species recorded in two or more plots in the region. The suite of 61 species included 11 shrubs, 20 graminoids, 25 dicot herbs, one fern, one club moss, and three bryophytes. Four of the 11 peatland community types were identified and sampled in this region: Subalpine raised bog (6 transects), Tall wet heath (6), Montane valley bog (8) and Myrtaceous wet heath (3).

Non-metric multidimensional scaling ordinations of frequency and cover data

Three dimensional ordination solutions were adopted for the final analyses of both the frequency and cover data. The Kruskal stress indices for the best solutions were 0.11 and 0.09 for the frequency and cover data respectively. There was clear separation between the groups in the frequency ordination graph, but there was some overlap between the Subalpine raised bog and Tall wet heath plots (Figure 3.18). The Subalpine raised bog plots were more closely clustered in the graph space than the other groups, suggesting higher similarity and less variability within this group. The Montane valley bog plots were spread along axis 1, as were the two ‘wet heath’ community types. The pattern was similar in the ordination solution derived from the cover data; Subalpine raised bog plots were closely bunched and the other communities more spread, but overlap between all groups was minimal (Figure 3.19).

Group similarities and ANOSIM comparisons of the four groups

The within-groups percentage similarities for the four community types varied between 57% and 78% based on cover data, and from 59% to 72% based on frequency data (Table 3.12). In general, the plots in Tall wet heath showed slightly lower similarity levels (57-

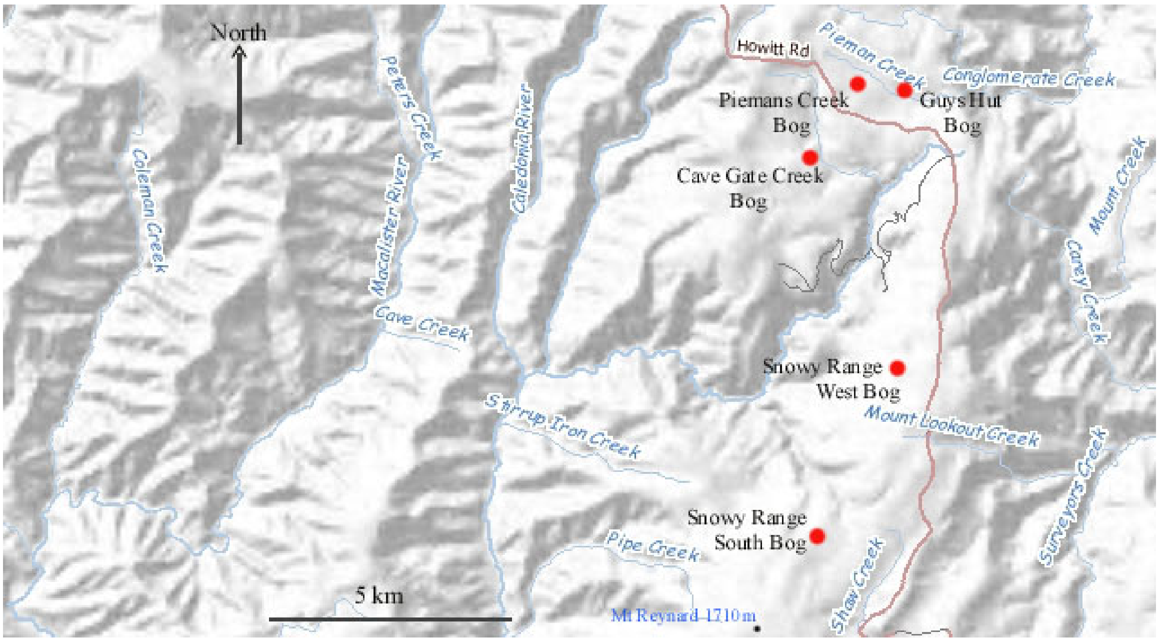


Figure 3.16: Map showing the locations of peatland sites from the northern areas of the Snowy Range. All sites in this area are within the Gippsland Lakes catchment. Mt Reynard (bottom edge of map) is the highest point in the region (1710 m).

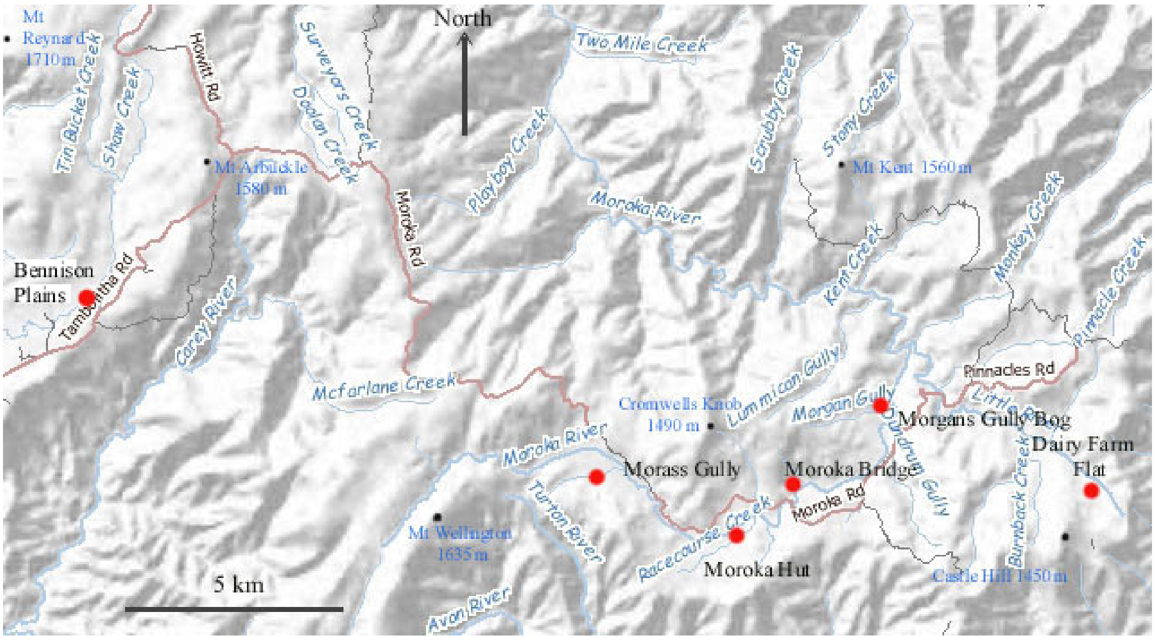


Figure 3.17: Map showing the location of the peatland sites in the southern areas of the Snowy Range region. The area featured lies to the south-east of the previous map. Mt Reynard (1710 m) is in the north-west corner of the map and Mt Wellington is near the bottom margin of the map (1635 m). All peatland sites indicated on this map are below 1300 m.

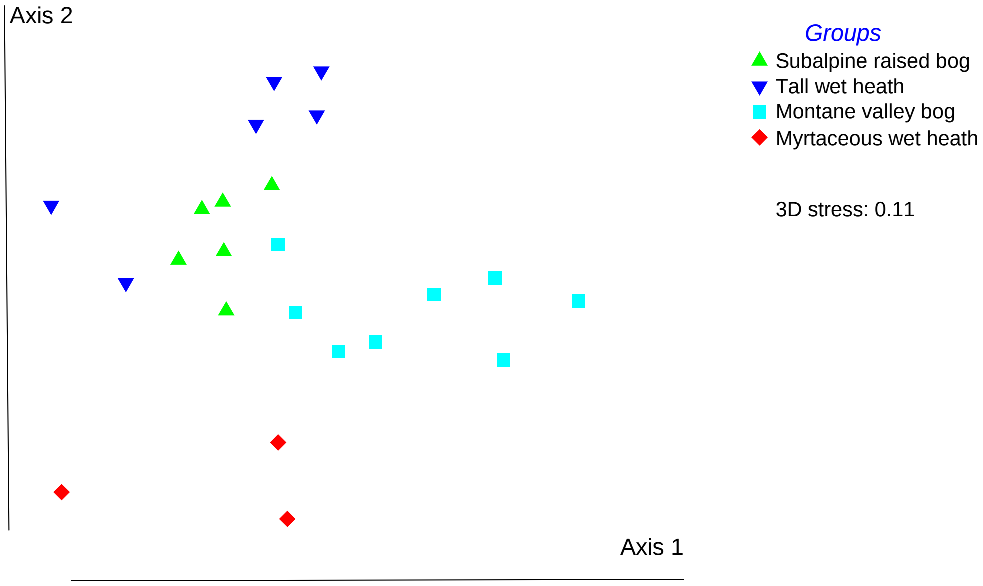


Figure 3.18: Three dimensional ordination graph based on **the Snowy Range-Dargo High Plains transects frequency data** (Axis 1 v Axis 2).

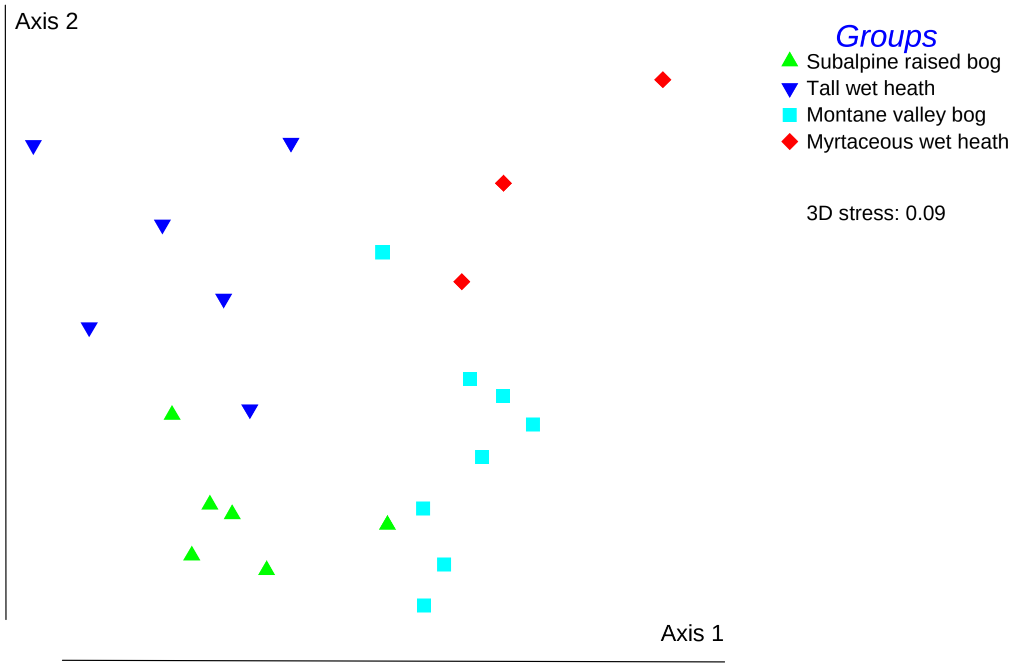


Figure 3.19: Three dimensional ordination graph based on the **Snowy Range-Dargo High Plains transects cover data** (Axis 1 v Axis 2).

59%) indicating more variability. The Subalpine raised bog plots had the highest similarity levels (72-78%).

The ANOSIM overall global test sample statistics were highly significant for both the frequency and cover data analyses, with R-statistic values of 0.615 and 0.694 respectively (Table 3.13, see Appendices Table A3.25* for full version), indicating strong differences between the four groups. All the individual pair-wise group comparisons showed significant differences, R-statistic values were generally between 0.56 and 0.98, with one exception. The frequency data comparison between Subalpine raised bog and Tall wet heath was less conclusive (R-statistic = 0.335), a result reflected in the overlap between these groups in the frequency ordination graph. The R-statistic value for the same comparison based on the cover data was 0.617, indicating that there were similarities in composition, but strong differences in structure and dominance between the two groups.

Table 3.12: Percentage similarities for the plots within each group or community type. **Snowy Range - Dargo High Plains region transects**.

Community Type	**abb. code**	**Similarity Percentages**	
		Frequency data	**Cover data**
Subalpine raised bog	SRB	72.66	78.09
Tall wet heath	TWH	59.55	57.87
Montane valley bog	MVB	66.30	69.80
Myrtaceous wet heath	MWH	66.07	71.35

Table 3.13: Pair-wise comparisons of the peatland community types from the **Snowy Range - Dargo High Plains region** based on both **frequency and cover data**. The P-values of pair-wise comparisons have been checked with the Bonferroni adjustment and are significant at 0.05. R-statistic values of less than 0.25 indicate that groups are barely separable, values between 0.25 and 0.5 indicate that groups are marginally different. Values greater than 0.5 indicate clear differences between groups (indicated by bold text).

Analysis of similarity Pair-wise Tests Groups	**Actual Perm'tns max = 999**	**Frequency data**		**Cover data**	
		R Statistic	**Significance P-value**	**R Statistic**	**Significance P-value**
Montane valley bog, Myrtaceous wet heath	165	**0.747**	0.006	**0.565**	0.012
Subalpine raised bog, Montane valley bog	999	**0.585**	0.003	**0.601**	0.004
Subalpine raised bog, Myrtaceous wet heath	84	**0.951**	0.012	**0.981**	0.012
Subalpine raised bog, Tall wet heath	462	0.335	0.002	**0.617**	0.002
Tall wet heath, Montane valley bog	999	**0.689**	0.003	**0.861**	0.002
Tall wet heath, Myrtaceous wet heath	84	**0.79**	0.012	**0.66**	0.012
Overall global test sample statistic	**999**	**0.615**	**0.001**	**0.694**	**0.001**

Species defining groups and discriminating between them

The important species that defined Subalpine raised bog were *Sphagnum cristatum*, *Empodisma minus*, *Carex gaudichaudiana* and the three shrub species, *Richea continentis*, *Epacris paludosa* and *Baeckea gunniana* (Table 3.14). *Sphagnum cristatum* had a mean cover of 75% in these plots. Mean percentage cover values for *Richea, Epacris, Empodisma* and *Baeckea* varied from 8-18%. The frequency values for *Sphagnum* and *Empodisma* were greater than 90%, and the other four species, including *Carex gaudichaudiana*, were in the 68-80% range. Tall wet heath had similar composition but was less dominated by *Sphagnum* and *Empodisma*. The same shrub species were prominent, with the addition of *Callistemon pityoides* and *Epacris celata*. *Carex gaudichaudiana*, *Poa costiniana* and *Asperula gunnii* were also common (see Appendices Table A3.26* for complete SIMPER analysis tables).

In Montane valley bog the most common species were *Sphagnum cristatum, Empodisma minus* and *Carex gaudichaudiana* (> 86% frequency). Other frequently occurring species were *Epacris paludosa*, *Asperula gunnii*, *Baeckea gunniana* and *Baloskion australe,* with values of 40-55%. In terms of cover, *Sphagnum* was the most dominant species (52%), followed by *Empodisma minus* (28%). The next most important species, with percent cover values of 4-10%, were *Epacris paludosa, Baeckea gunniana* and *Carex* spp.

The species that contributed most to similarity between plots in Myrtaceous wet heath were *Empodisma minus*, *Epacris paludosa* and *Baeckea gunniana* with frequencies of 90-100%. *Callistemon pityoides* was a consistent presence (39% frequency), as were *Baloskion australe, Baumea gunnii* and *Asperula gunnii*, but the latter three were more variable. *Empodisma*, *Baeckea* and *Epacris paludosa* were important species in terms of cover percentages, together with *Callistemon* and *Sphagnum* to a lesser extent.

There are six possible pair-wise group comparisons. The SIMPER group comparison tables listing useful distinguishing species have been placed in the Appendices (Tables

Table 3.14: Occurrence frequencies and percentage cover abundance values for species identified by SIMPER analysis as contributing most to within group similarities based on the **Snowy Range-Dargo High Plains region transects**. SRB = Subalpine raised bog, TWH = Tall wet heath, MVB = Montane valley bog, MWH = Myrtaceous wet heath. Species are grouped according to patterns of co-occurrence.

(a) Frequency data (values greater than 25% indicated in bold)

Species	SRB	TWH	MVB	MWH
Empodisma minus	**97.2**	**80.0**	**96.7**	**100.0**
Sphagnum cristatum	**94.2**	**46.1**	**86.0**	**45.0**
Carex gaudichaudiana	**73.6**	**77.5**	**94.8**	5.0
Richea continentis	**80.3**	**61.9**	0.0	0.0
Epacris celata	10.0	**31.7**	7.9	0.0
Poa costiniana	8.1	**30.0**	17.7	8.9
Baeckea gunniana	**68.6**	**66.1**	**40.6**	**90.0**
Epacris paludosa	**73.1**	**58.9**	**55.0**	**93.3**
Asperula gunnii	10.8	**38.6**	**52.9**	**35.6**
Baloskion australe	**25.8**	5.8	**40.6**	**51.7**
Luzula modesta	1.4	5.6	**25.0**	7.8
Baumea gunnii	0.0	0.0	11.0	**31.1**
Callistemon pityoides	0.0	20.6	0.0	**39.4**

(b) Cover data (values greater than 1% indicated in bold)

Species	SRB	TWH	MVB	MWH
Sphagnum cristatum	**75.8**	**26.1**	**51.8**	**15.4**
Richea continentis	**18.1**	**19.7**	0.0	0.0
Epacris paludosa	**18.0**	**13.9**	**9.8**	**13.8**
Baeckea gunniana	**8.8**	**11.4**	**5.3**	**12.5**
Carex spp.	**1.3**	**3.2**	**4.6**	0.1
Empodisma minus	**9.8**	**4.3**	**28.5**	**27.5**
Callistemon pityoides	0.0	**4.9**	0.0	**6.8**

A3.27 to A3.32). Subalpine raised bog can be separated from Tall wet heath primarily on the cover of *Sphagnum*, which was greater in the former (Appendices Table A3.27). The cover of *Sphagnum* also differentiates Montane valley bog from Myrtaceous wet heath (52% compared with 15%, Appendices Table A3.28). *Empodisma minus*, although common in all four peatland types, was dominant in Montane valley bog and Myrtaceous wet heath.

The most useful species for separating the montane plots from the subalpine plots was *Richea continentis*, which was abundant in both Subalpine raised bog and Tall wet heath, but absent from Montane valley bog and Myrtaceous wet heath (Appendices Tables A3.29-A3.32). *Richea* was also absent from higher elevation examples of Myrtaceous wet heath vegetation (e.g. Cave Gate Creek). *Carex gaudichaudiana* was common in Subalpine raised bog and Tall wet heath, but most conspicuous in Montane valley bog

(95% frequency). Both restiad species were common in subalpine plots, but *Empodisma minus* in particular was highly abundant, reaching mean percent cover of > 25%. *Baloskion australe*, while never achieving mean cover values greater than 1-2%, was more common at montane elevations.

There was a suite of species that never achieved high cover values (< 5%), but are useful indicators purely on frequency of occurrence. These included *Epacris breviflora*, *Luzula modesta* and *Ranunculus collinus*, which were common in Montane valley bog, but rare elsewhere. *Baumea gunnii* was common in Myrtaceous wet heath and an occasional presence in Montane valley bog, but absent from other peatland types. The herb *Asperula gunnii* was widespread in peatlands and present in all communities, but uncommon in Subalpine raised bog. *Epacris celata* also rarely exceeded mean cover percentages of 3%, but was common in Tall wet heath, and elsewhere rare or absent.

Species and factor correlations with the frequency data ordination

Thirty-eight of the 61 species were significantly correlated with at least one of the three axes of the frequency ordination graph. The 21 with the strongest correlations are displayed in Table 3.15 (complete list in Appendices Table A3.33*). *Epacris breviflora*, *Asperula gunnii*, *Ranunculus collinus* and *Luzula modesta* were strongly aligned with axis 1, and increased in value towards the Montane valley bog plots (Figure 3.20). The species negatively correlated with axis 1 included *Baeckea gunniana*, *Celmisia* spp., and *Carex* spp. These were slightly aligned with Tall wet heath and Subalpine raised bog.

Positive correlations with axis 2 included *Ranunculus pimpinellifolius* and *Epacris celata*, which were orientated towards Tall wet heath. *Richea continentis* also had a strong positive correlation with axis 2, but a negative association with axis 1, thus a diagonal trend direction from the bottom right to the top left corner of the graph space, towards the subalpine plots. Species negatively correlated with axis 2 were those generally associated with montane peatlands and Myrtaceous wet heath in particular. These included *Empodisma minus*, *Baumea gunnii* and *Sphagnum novo-zelandicum*.

Table 3.15: Species with strong significant correlations with the axes of the ordination graph derived from the **Snowy Range-Dargo High Plains region transects frequency data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001)..

Species	**MDS1**	**sig.level**	**MDS2**	**sig.level**	**MDS3**	**sig.level**
Epacris breviflora	**0.72**	***	-0.40	ns	-0.09	ns
Veronica sp.2	**0.70**	***	-0.09	ns	-0.02	ns
Asperula gunnii	**0.66**	***	-0.08	ns	**-0.53**	**
Ranunculus collinus	**0.59**	**	-0.27	ns	-0.10	ns
Luzula modesta	**0.55**	**	-0.36	ns	-0.23	ns
Juncus sandwithii	**0.51**	*	-0.39	ns	-0.03	ns
Baloskion australis	**0.43**	*	**-0.42**	*	**-0.42**	*
Carex spp.	**-0.51**	*	0.16	ns	-0.23	ns
Celmisia spp.	**-0.68**	***	0.22	ns	-0.10	ns
Baeckea gunniana	**-0.72**	***	-0.05	ns	-0.26	ns
Richea continentis	**-0.55**	**	**0.75**	***	-0.31	ns
Epacris celata	-0.30	ns	**0.70**	***	0.03	ns
Ranunculus pimpinellifolius	-0.01	ns	**0.69**	***	-0.03	ns
Craspedia spp.	0.16	ns	**0.58**	**	0.10	ns
Myriophyllum pedunculatum	0.02	ns	**0.57**	**	0.12	ns
Hypericum japonicum	0.03	ns	**0.56**	**	0.13	ns
Epacris paludosa	**-0.47**	*	**-0.49**	*	0.12	ns
Empodisma minus	0.06	ns	**-0.54**	**	0.25	ns
Sphagnum novo-zelandicum	-0.32	ns	**-0.61**	**	0.24	ns
Baumea gunnii	**0.49**	*	**-0.69**	***	-0.24	ns
Carpha spp.	-0.38	ns	-0.13	ns	**0.61**	**
Nertera granadensis	-0.07	ns	-0.21	ns	**0.61**	**
Agrostis spp.	0.27	ns	-0.04	ns	**0.54**	**

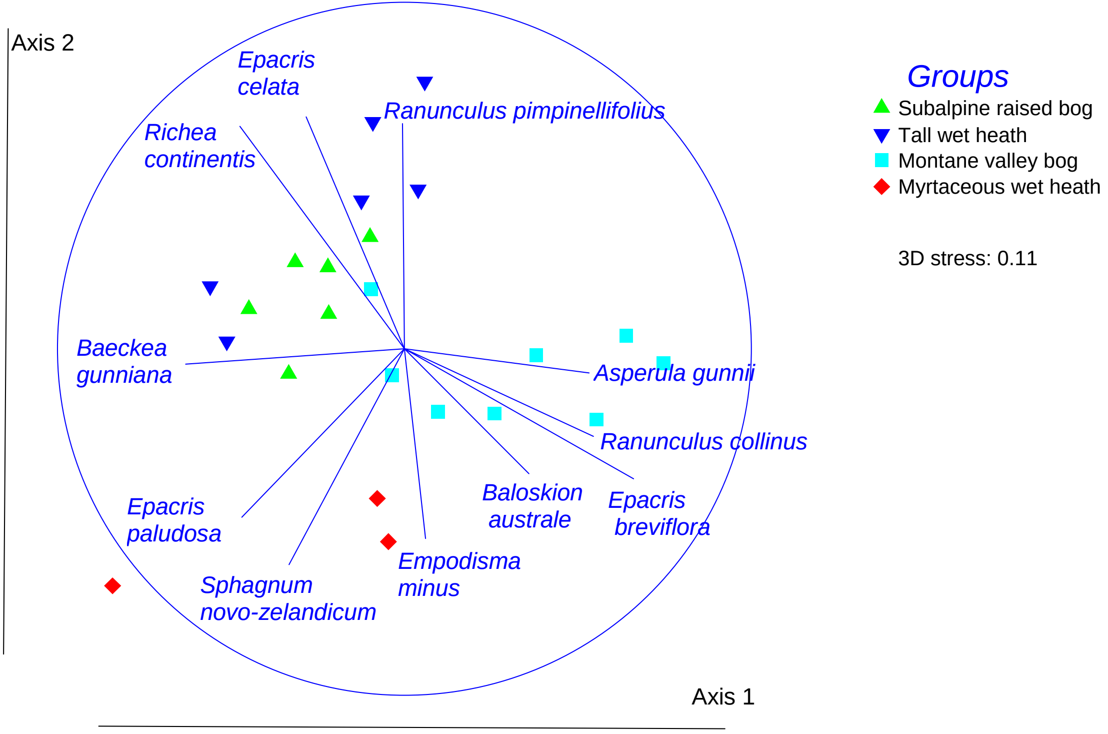


Figure 3.20: Three dimensional ordination graph derived from **Snowy Range-Dargo High Plains region transects frequency data** (Axis 1 v Axis 2). The trend directions of significantly correlated species are indicated.

Epacris paludosa had a diagonal trend direction, decreasing along both axes, a direction that indicates equal associations with all four groups, although slightly stronger with Myrtaceous wet heath.

Carpha spp. and *Nertera granadensis* were positively correlated with axis 3 and generally associated with Subalpine raised bog and Montane valley bog, the communities that have higher *Sphagnum* cover (Appendices Figure A3.3). *Asperula gunnii* increased in the opposite direction along axis 3, towards the wet heath plots in general.

Fifty-five factors were tested for correlation with the frequency ordination solution. Thirty-seven of these showed a significant association with at least one of the three axes. Amongst the strongest environmental and structural variables were altitude, shrub cover, latitude, and peat depth (Table 3.16, see Appendices Table A3.34* for full version). The vast majority of the BIOCLIM variables tested were significant, which is a reflection of the large variation in site altitudes (1000-1580 m).

Amongst the strongest BIOCLIM variables were precipitation of the driest quarter, mean moisture index of the warmest quarter, and annual mean temperature. Shrub cover and precipitation of the driest quarter were negatively correlated with axis 1, and associated with increasing altitude, hence trended towards both subalpine groups (Figure 3.20). There was some separation of Subalpine raised bog and Tall wet heath associated with these factors, although at a local level it is likely to be shrub cover alone. Peat depth, annual mean temperature, and minimum temperature of the coldest period all increased in the opposite direction, towards the lower altitude communities such as Montane valley bog. The increase in latitude along axis 1 can be explained by the more southerly position of the montane plots in this region (Figures 3.16, 3.17).

There was a slight diagonal component to the trend directions of these environmental and structural variables; hence, most also showed correlation with axis 2, albeit not as strong (0.4-0.7 compared with 0.6-0.8). Temperature seasonality and precipitation of the driest quarter, were the two strongest variables and both were associated with peatland plots in

Table 3.16: Factors with strong significant correlations with the axes of the ordination graph derived from the **Snowy Range-Dargo High Plains region frequency data (**Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001). The full version of this table is in the Appendices.

Factor	MDS1	sig.level	MDS2	sig.level	MDS3	sig.level
Annual mean temperature	**0.82**	***	**-0.55**	**	0.15	ns
Percentage of peat points > 1 m deep	**0.78**	***	-0.35	ns	0.16	ns
Minimum temperature of coldest period	**0.78**	***	**-0.61**	**	0.26	ns
Peat depth	**0.74**	***	-0.31	ns	0.10	ns
Latitude	**0.62**	**	**-0.68**	***	0.18	ns
Litter	0.11	ns	0.06	ns	**-0.49**	*
Longitude	0.09	ns	0.12	ns	**-0.56**	**
Other moss	-0.34	ns	-0.22	ns	**-0.44**	*
Shrub cover %	**-0.62**	**	**0.60**	**	-0.28	ns
Temperature seasonality (C of V)	**-0.65**	***	**0.69**	***	-0.23	ns
Annual precipitation	**-0.75**	***	**0.62**	**	-0.28	ns
Precipitation of driest quarter	**-0.76**	***	**0.63**	**	-0.26	ns
Mean moisture index of warm quarter	**-0.83**	***	**0.56**	**	-0.14	ns
Altitude	**-0.84**	***	**0.54**	**	-0.19	ns

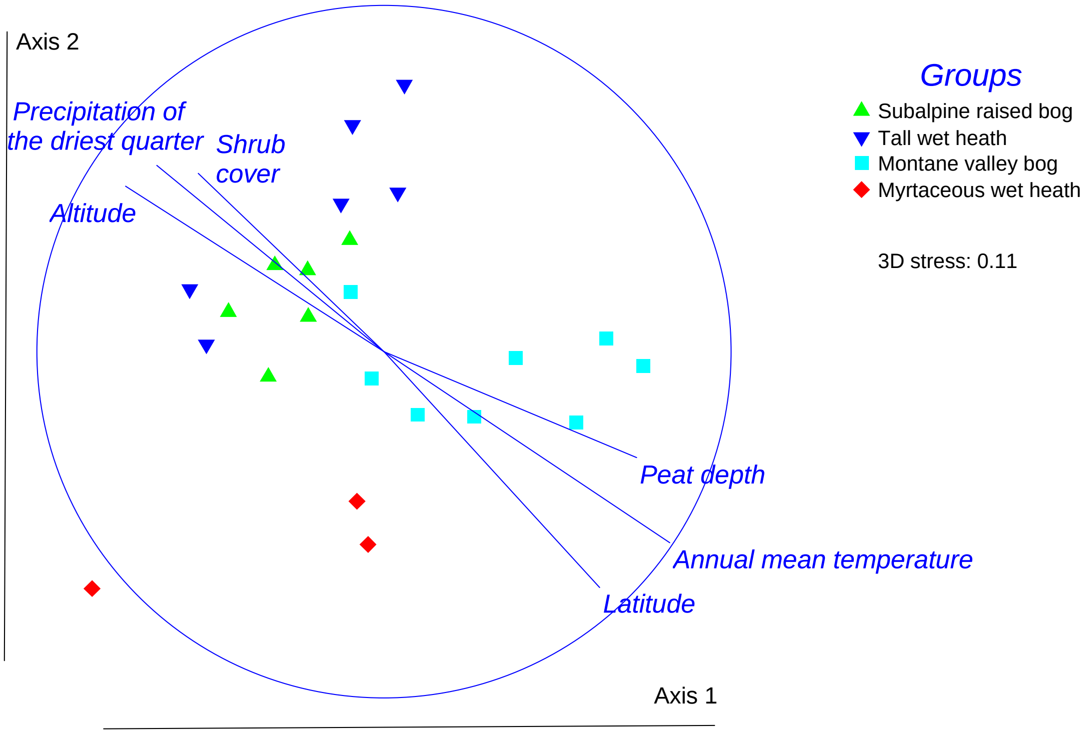


Figure 3.21: Three dimensional ordination graph derived from **Snowy Range-Dargo High Plains region frequency data** (Axis 1 v Axis 2). The trend directions of significantly correlated factors are indicated. The unit circle indicates the strength of the relationship for each factor.

subalpine areas. There were few variables associated with axis 3. Longitude can be explained by the five plots from the Dargo High Plains, which are slightly further east than the Snowy Range plots (Appendices Figure A3.4). Within all four groups, there was variability in the cover of litter, and mosses other than *Sphagnum*.

Species and factor correlations with the cover data ordination

Only thirty species of the original 61 were significantly correlated with the cover ordination. Fourteen of these had co-efficients stronger than 0.5 (positive or negative, Table 3.17, Appendices Table A3.35*). There was general separation of the subalpine and montane plots along axis 1 of the ordination (Figure 3.22). The 'bog' communities separated from the 'wet heath' communities along axis 2. Therefore, *Empodisma minus*, *Baumea gunnii*, and *Epacris breviflora,* were positively correlated with axis 1, and increased in cover value towards Myrtaceous wet heath and Montane valley bog. *Richea continentis* and *Epacris celata* increased in cover value in the opposite direction along axis 1, towards Subalpine raised bog and Tall wet heath.

There were fewer species with strong correlations along axis 2. *Baeckea gunniana* was the species with the strongest positive correlation with axis 2, indicating higher cover values in the two wet heath communities. *Sphagnum cristatum* cover values increased in the opposite direction, towards Subalpine raised bog and Montane valley bog.

Axis 3 captured the variability within the groups, with the Tall wet heath plots being particularly spread along this axis (Appendices Table A3.35* and Figure A3.5). *Celmisia* spp., *Epacris paludosa* and *Carex gaudichaudiana* were negatively aligned with axis 3, slightly favouring Subalpine raised bog and some of the Tall wet heath plots. *Epilobium gunnianum* and *Asperula gunnii* trended in the opposite direction, increasing towards Montane valley bog. *Craspedia* spp. also had a positive association with axis 3, and favoured some of the Tall wet heath plots in particular.

Table 3.17: Species with the strongest significant correlations with the axes of the ordination graph based on the **Snowy Range-Dargo High Plains region transects cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Species	MDS1	sig. level	MDS2	sig. level	MDS3	sig. level
Empodisma minus	**0.89**	***	-0.05	ns	0.02	ns
Baumea gunnii	**0.66**	***	0.20	ns	-0.12	ns
Epacris breviflora	**0.50**	*	-0.01	ns	-0.20	ns
Isolepis spp.	**-0.51**	*	0.23	ns	0.19	ns
Ranunculus pimpinellifolius	**-0.53**	**	0.14	ns	**-0.44**	*
Epacris celata	**-0.59**	**	-0.06	ns	-0.10	ns
Richea continentis	**-0.92**	***	-0.03	ns	0.03	ns
Baeckea gunniana	-0.22	ns	**0.77**	***	0.18	ns
Sphagnum cristatum	-0.04	ns	**-0.93**	***	0.12	ns
Sphagnum novozelandicum	0.40	ns	-0.08	ns	**0.61**	**
Celmisia spp.	**-0.44**	*	-0.23	ns	**0.58**	**
Epacris paludosa	-0.25	ns	0.00	ns	**0.57**	**
Epilobium gunnianum	-0.20	ns	0.10	ns	**-0.51**	*
Asperula gunnii	0.15	ns	0.22	ns	**-0.52**	*

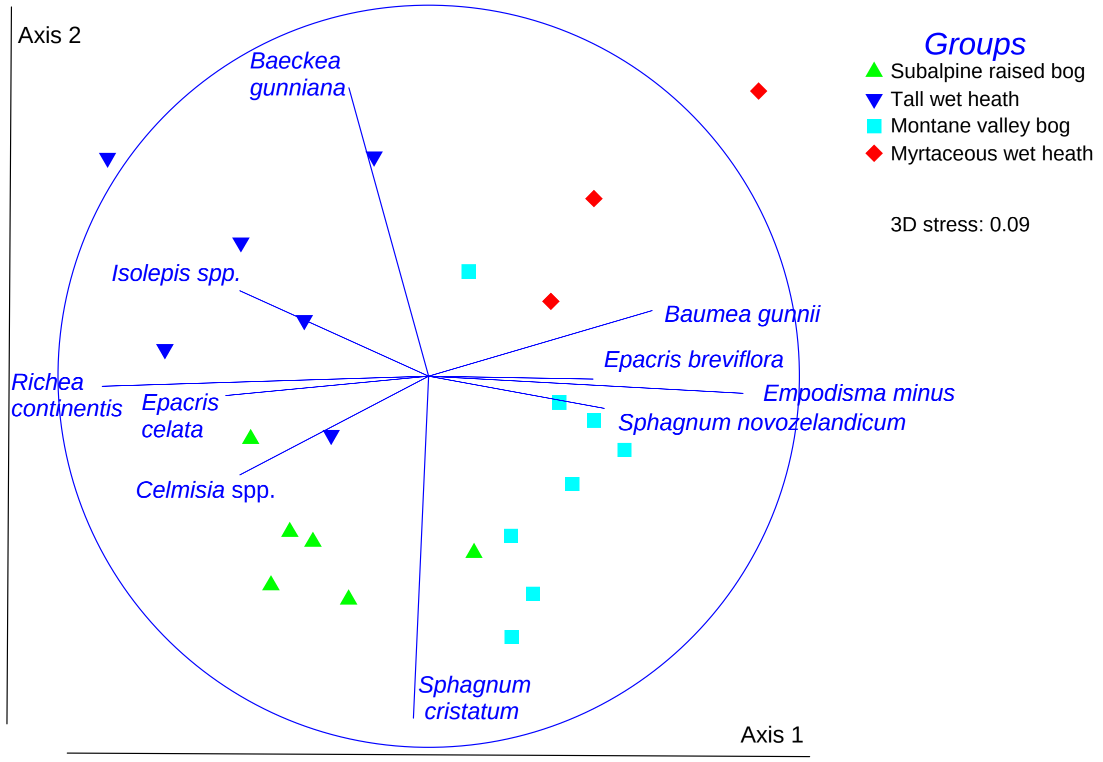


Figure 3.22: Three dimensional ordination graph derived from **Snowy Range-Dargo High Plains region transects cover data** (Axis 1 v Axis 2). The trend directions of strongly correlated species are indicated. The unit circle indicates the strength of the relationship for each vector.

Forty of the 55 factors tested for correlation with the cover data ordination graph were significant. The strongest correlations with axis 1 were for shrub cover, temperature seasonality, latitude, and precipitation of the driest quarter (Table 3.18, see Appendices Table A3.36* for full version). The positively correlated factors trended towards Montane valley bog and Myrtaceous wet heath; the negatively correlated factors trended towards Subalpine raised bog and Tall wet heath (Figure 3.23).

Axis 2 separates the bog communities from the wet heath groups, hence none of the BIOCLIM variables are associated with this axis. However, several of the environmental and structural variables were, including shallowness of the peat, as indicated by the proportion of the transect with peat shallower than 0.5 m deep. This variable increased along axis 2, indicating shallower peat profiles in the ‘wet heath’ communities. Other factors positively correlated with axis 2 included aspect, litter cover, cover of dead *Empodisma*, and shrub height. The amount of litter cover tended to increase towards Tall wet heath. Aspect values (dryness) and shrub height increased towards Myrtaceous wet heath and away from Subalpine raised bog (Figure 3.23).

Plant functional group correlations with the cover data ordination

Seven of the 11 plant functional groups showed significant correlation with the cover data ordination (Table 3.19). Amongst the strongest groups were *Sphagnum* species, restiads, myrtaceous shrubs, ericaceous shrubs, *Astelia*, ‘other sedges’, and ‘other shrubs’.

In the ordination configuration derived from the cover data (Figure 3.24), the separation of subalpine and montane groups along axis 1 was best indicated by trends in the cover of the restiads (*Empodisma*, *Baloskion*) and ericaceous shrubs (*Richea*, *Epacris* spp.). The latter group was more prominent in the two subalpine community types; the former group, the restiads, was most conspicuous in the montane groups. Axis 2 separates the two major formations, bog and wet heath. The cover of myrtaceous shrubs (*Baeckea*, *Callistemon*), and other shrubs (*Hakea*, *Comesperma*, *Pultenaea* spp.), was positively

Table 3.18: Factors with the strongest significant correlations with the axes of the ordination graph derived from the **Snowy Range-Dargo High Plains region cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001). See appendices for full version of this table.

Factor	**MDS1**	**sig. level**	**MDS2**	**sig. level**	**MDS3**	**sig. level**
Latitude	**0.78**	***	0.03	ns	-0.14	ns
Minimum temperature of coldest period	**0.74**	***	-0.04	ns	-0.27	ns
Radiation of driest quarter	**0.72**	***	-0.03	ns	-0.30	ns
Moisture index seasonality (C of V)	**0.66**	***	-0.03	ns	-0.34	ns
Percentage of peat points > 1 m deep	**0.45**	*	-0.34	ns	-0.34	ns
Litter	-0.16	ns	**0.72**	***	-0.28	ns
Dead *Empodisma*	0.32	ns	**0.67**	***	-0.16	ns
Mean shrub height	0.16	ns	**0.58**	**	**-0.43**	*
Percentage of peat points < 0.5 m deep	-0.35	ns	**0.57**	**	0.23	ns
Aspect	**0.42**	*	**0.56**	**	0.11	ns
Mean height of tallest shrubs	0.22	ns	**0.54**	**	-0.35	ns
Altitude	**-0.65**	***	0.05	ns	0.38	ns
Lowest period moisture index	**-0.66**	***	0.04	ns	0.35	ns
Precipitation of driest quarter	**-0.75**	***	0.05	ns	0.24	ns
Temperature seasonality (C of V)	**-0.77**	***	0.04	ns	0.12	ns
Shrub cover	**-0.82**	***	0.32	ns	0.17	ns

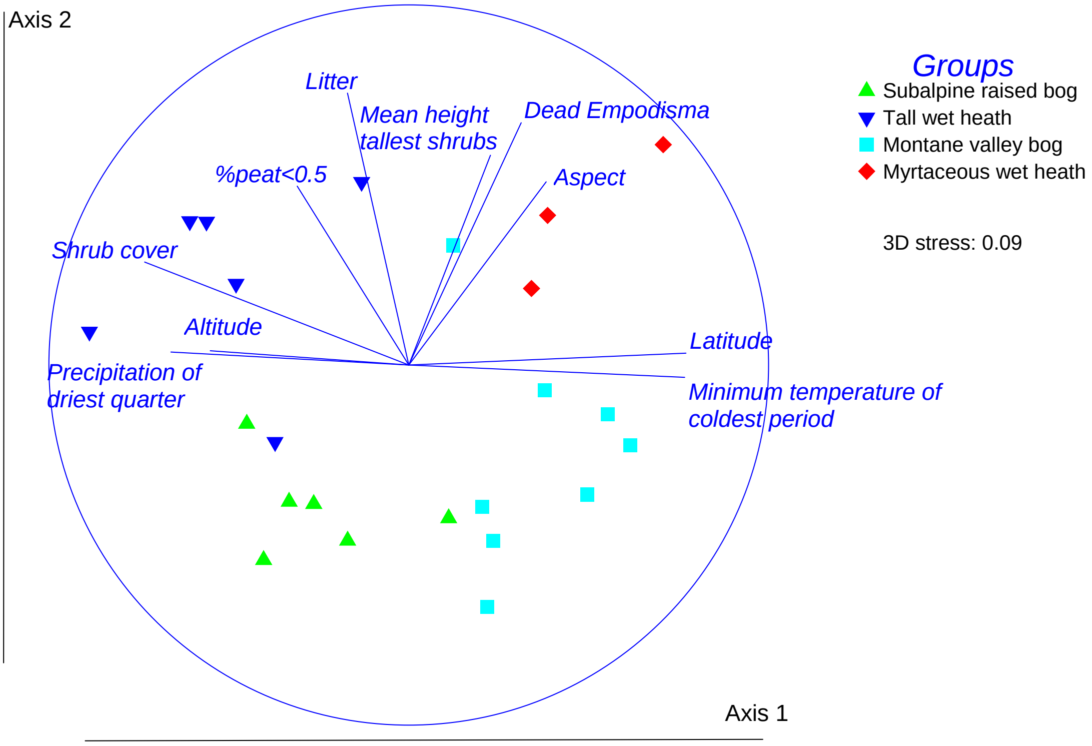


Figure 3.23: Three dimensional ordination graph derived from **Snowy Range-Dargo High Plains region cover data** (Axis 1 v Axis 2). The trend directions of significantly correlated factors are indicated. The unit circle indicates the strength of the relationship for each vector.

Table 3.19: The seven plant functional groups with significant correlations with the axes of the ordination graph derived from the **Snowy Range-Dargo High Plains region cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Functional group	MDS1	sig. level	MDS2	sig. level	MDS3	sig. level
Ericaceous shrubs	**-0.89**	***	0.05	ns	0.17	ns
Myrtaceous shrubs	-0.17	ns	**0.73**	***	-0.02	ns
Other shrubs	-0.17	ns	**0.44**	*	0.10	ns
Astelia	-0.28	ns	-0.14	ns	**0.54**	**
Other sedges	0.26	ns	0.17	ns	**0.52**	*
Restiads	**0.87**	***	-0.07	ns	0.01	ns
Sphagnum spp.	0.00	ns	**-0.94**	***	0.15	ns

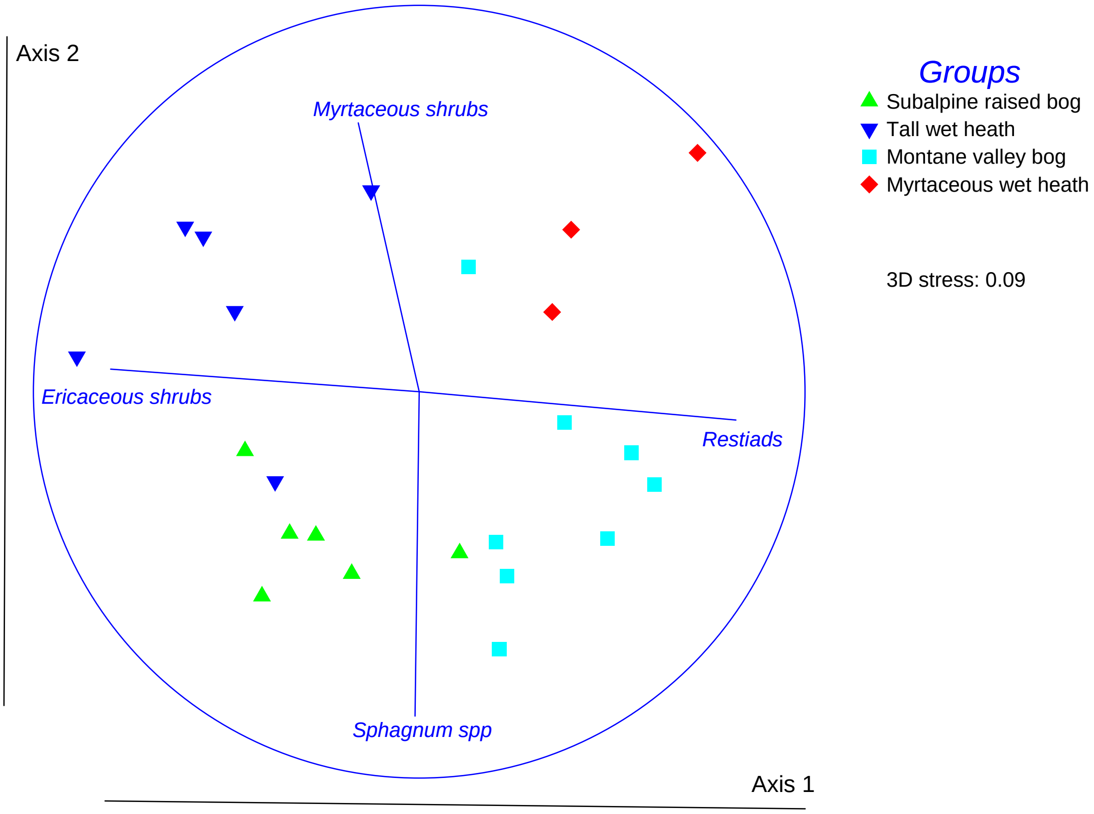


Figure 3.24: Three dimensional ordination graph derived from **Snowy Range-Dargo High Plains region cover data** (Axis 1 v Axis 2). The trend directions of significantly correlated plant functional groups are indicated.

correlated with axis 2, and increased towards the two wet heath community types. The cover of *Sphagnum* species was negatively correlated with axis 2, and increased towards the bog communities, independently of altitude.

The remaining two groups had some affinity with axis 3 (Appendices Figure A3.6). ‘Other sedges’ includes taxa like *Baumea gunnii* and *Isolepis* spp. This group trended towards the montane communities, whereas *Astelia* favoured the subalpine plots or more specifically Subalpine raised bog.

Community type summaries: floristics and environmental characteristics

Subalpine raised bog, Tall wet heath and Myrtaceous wet heath communities in the Snowy range and Dargo High Plains regions were floristically the same as in the Bogong region (Tables 3.20, 3.21, compare with Tables 3.10, 3.11). Therefore the description and summary of environmental attributes for these three communities need only be brief here. Montane valley bog does not occur in the Bogong region and thus requires more focus in these descriptions.

<u>Montane valley bog:</u> This peatland community type was found on gentle broad montane valley floors at elevations of 1000 m to 1290 m (Figure 3.25). Peats were deep, generally well in excess of 1 m, sometimes greater than 2 m, although they often graded into alluvial gravels and clays at greater depth (Table 3.20). Shrub cover was low (5-29%), stature moderate (mean height of shrub layer 30-70 cm), and mostly consisted of ericaceous species (*E. paludosa*, *E. breviflora*; 5-20% cover). The vegetation was dominated by restiads (*Empodisma*, *Baloskion*; 12-55% cover), *Carex* spp. (1-12% cover), and *Sphagnum* species (30-87% cover) (Table 3.21). Distances to neighbouring woodland or open forest were moderate (30-100 m), but generally greater than the other montane peatland community, Myrtaceous wet heath.

<u>Subalpine raised bog:</u> These were found on gentle slopes, moister aspects, and lower slope positions above 1400 m (Figures 3.26, 3.27). Distance to neighbouring wooded

Table 3.20: Summary of the means, maximum and minimum values for several key factors by community type in the **Snowy Range-Dargo High Plains region**. The factors included are altitude, peat depth, slope, shrub cover, shrub height, aspect, topographic position and distance to woodland. The values for aspect and topographic position are categorical variables. In these cases higher values indicate drier aspects or topographic positions. MVB = Montane valley bog, MWH = Myrtaceous wet heath, SRB = Subalpine raised bog, TWH = Tall wet heath.

Environmental and structural factors	**Community type**			
	MVB	**MWH**	**SRB**	**TWH**
Altitude (m)	**1116 ± 41**	**1237 ± 92**	**1540 ± 29**	**1498 ± 32**
	1000 - 1290	1140 - 1420	1400 - 1580	1400 - 1580
Peat depth (cm)	**139 ± 15**	**66 ± 24**	**76 ± 10**	**67 ± 18**
	88 - 193	26 - 110	42 - 114	38 - 153
% Slope	**3 ± 1**	**10 ± 5**	**6 ± 1**	**7 ± 2**
	1 - 6	3 - 20	3 - 10	1 - 16
Shrub cover (%)	**17 ± 3**	**32 ± 4**	**45 ± 4**	**51 ± 6**
	5 - 29	26 - 39	25 - 57	26 - 64
Shrub height (cm)	**51 ± 5**	**72 ± 13**	**38 ± 5**	**52 ± 7**
	30 -70	46 -89	28 - 59	37 - 84
Aspect	**2.8 ± 0.2**	**3.7 ± 0.3**	**2.2 ± 0.3**	**2.5 ± 0.4**
	2.0 - 3.0	3.0 - 4.0	1.0 - 3.0	1.0 -4.0
Topographic position	**1.3 ± 0.2**	**2.3 ± 0.3**	**1.8 ± 0.2**	**1.7 ± 0.3**
	1.0 -2.0	2.0 - 3.0	1.0 - 2.0	1.0 - 3.0
Distance to woodland (m)	**56 ± 10**	**27 ± 7**	**53 ± 14**	**55 ± 12**
	30 -100	20 - 40	20 - 120	10 - 100

vegetation was variable but typically less than 100 m. Shrub cover and height were similar to Subalpine raised bog in the Bogong region (25-57%, 28-57 cm). The most important plant functional groups were *Sphagnum* species (55-94% cover), ericaceous shrubs (*Richea*, *E.paludosa*; 19-45% cover), restiads (*Empodisma*, *Baloskion*; 5-24% cover), and myrtaceous shrubs (*Baeckea*; 5-18% cover). Peat depths were perhaps shallower than in Subalpine raised bog in the Bogong region (42-114 cm).

<u>Tall wet heath:</u> Similar in many respects to Subalpine raised bog in terms of environmental attributes, but shrub cover and height were greater (26-64%, 37-84 cm), and slope more variable (1-16% slope) (Fig 3.28). *Sphagnum* species were less abundant (7-40% cover), as were restiads (1-8%), and the greater overall shrub cover was largely

Table 3.21: Summary of the mean % cover, standard errors, and range of cover values for the eleven plant functional groups by community type in the **Snowy Range-Dargo High Plains region**. Community type abbreviations as for table 3.20.

	Community Type			
Lifeform Type	**MVB**	**MWH**	**SRB**	**TWH**
Ericaceous shrubs	**12.0 ± 1.8**	**14.7 ± 3.9**	**36.4 ± 3.7**	**37.1 ± 6.3**
	5.1 - 20.3	7.3 - 20.5	19.5 - 45.3	20.5 - 56.1
Myrtaceous shrubs	**5.5 ± 1.6**	**19.2 ± 1.1**	**9.2 ± 2.0**	**16.3 ± 2.9**
	0 - 11.1	17.1 - 20.4	5.7 - 18.1	5.4 - 26.4
Other shrubs	**< 0.1**	**0.8 ± 0.8**	**< 0.1**	**0.9 ± 0.7**
	0 - 0.3	0 - 2.4	0 - < 0.1	0 - 4.7
Astelia	**0.0**	**0.0**	**0.2 ± 0.2**	**< 0.1**
	0.0	0.0	0 - 1.0	0 - < 0.1
Carex spp.	**5.1 ± 1.5**	**0.1 ± 0.1**	**1.3 ± 0.4**	**3.3 ± 1.9**
	1.1 - 12.2	0 - 0.3	0.5 - 3.1	0.3 - 12.5
Other sedges	**0.3 ± 0.2**	**0.4 ± 0.2**	**0.6 ± 0.4**	**0.7 ± 0.5**
	0 - 1.7	0.2 - 0.7	0 - 2.4	0 - 3.3
Restiads	**29.2 ± 4.6**	**28.8 ± 0.8**	**10.8 ± 2.9**	**4.3 ± 1.1**
	12.6 - 55.6	27.6 - 30.3	5.4 - 24.1	0.1 - 7.9
Other monocots	**1.6 ± 0.5**	**0.9 ± 0.8**	**0.2 ± 0.1**	**1.7 ± 0.6**
	0 - 3.6	0 - 2.5	0 - 0.5	0.1 - 4.6
Herbs	**< 0.1**	**< 0.1**	**0.1 ± 0.05**	**0.1 ± 0.05**
	0 - 0.1	0 - < 0.1	0 - 0.3	0 - 0.3
Sphagnum spp.	**53.9 ± 7.1**	**16.0 ± 8.6**	**77.3 ± 5.2**	**26.8 ± 4.5**
	30.2 - 86.8	0.7 - 30.7	55.7 - 93.9	7.2 - 40.3
Other bryophytes	**< 0.1**	**0.7 ± 0.7**	**< 0.1**	**0.3 ± 0.3**
	0 - 0.1	0 - 2.1	0 - 0.1	0 - 1.6

due to higher myrtaceous shrub contribution (*Baeckea*, *Callistemon*; 5-26% cover). Grasses, other herbs, and *Carex* species were also more conspicuous than in Subalpine raised bog.

Myrtaceous wet heath: As was the case in the Bogong region this community type occurred on steeper slopes (3-20% slope), drier aspects and topographic positions, and was closer to woodland or open forest (20-40 m) (Fig 3.29).

Figure 3.25: An example of Montane valley bog vegetation at Morgans Gully near the Moroka River. Abundant species include *Sphagnum cristatum*, *Empodisma minus*, *Carex gaudichaudiana*, and *Poa* spp. Shrub cover is generally less than 10% and in this case was provided by *Epacris paludosa* and *Epacris breviflora*.

Figure 3.26: Close up detail of vegetation in Subalpine raised bog. The small pool is approximately 0.5 m² in area and contains *Sphagnum novozelandicum* and emergent *Carex gaudichaudiana*. Around the pool margin is the sedge *Carpha alpina*. The *Sphagnum cristatum* hummocks contain emergent *Richea continentis* and *Epacris paludosa*.

Figure 3.27: Subalpine raised bog transect at Cave Gate Creek site. Dominant species included *Empodisma minus*, *Sphagnum cristatum*, *Epacris paludosa*, *Carpha nivicola*, and *Baeckea gunniana*. The raised bog vegetation merges with tall wet heath in the background (right), before giving way to grassland, open heath and subalpine woodland on higher ground.

Figure 3.28: Tall wet heath vegetation adjacent to subalpine woodland at Omeo Plain on the Dargo High Plains. Common shrub species at this site include *Richea continentis*, *Baeckea gunniana*, *Callistemon pityoides* and *Epacris paludosa*.

Figure 3.29: Two contrasting peatland communities at Cave Gate Creek. The gentle slopes in the foreground and middle-ground are dominated by subalpine raised bog. The steep slope on the opposite side of the creek is an area of strong groundwater seepage and is dominated by Myrtaceous wet heath, except at the very base of the slope, where the transition to subalpine raised bog occurs.

Peats were shallow (26-110 cm mean depth), shrub cover and height moderate to high (26-39%, 46-89 cm). Unlike the Bogong region, Myrtaceous wet heath extended down to montane elevations. Important plant functional groups included myrtaceous shrubs (*Baeckea*, *Callistemon*; 17-20% cover), restiads (*Empodisma*, *Baloskion*; 27-30% cover), ericaceous shrubs (*E. paludosa*; 7-20% cover), and *Sphagnum* species (1-31% cover).

Observations and descriptions of the subalpine peatlands

The peatland studied at Cave Gate Creek on the Snowy Range is situated in an open treeless valley bottom at approximately 1400 m and demonstrates the importance of slope, aspect and proximity to neighbouring forest areas. The peatland straddles an easterly flowing stream and the vegetation to the north of the stream is dominated by Subalpine raised bog (Figure 3.27), with some Tall wet heath towards the margins. The adjacent slopes to the north of this section are gentle to moderate and carry subalpine grassland and open heath vegetation. The edge of the *Eucalyptus pauciflora* open forest on the northern side is 100-400 m from the peatland boundary. The steep north facing slope on the southern side of the main stream is an area of groundwater discharge dominated by Myrtaceous wet heath (Figure 3.29). The upslope boundary of the peatland abuts mixed *Eucalyptus pauciflora-E. dalrympleana* open forest, which has an understorey of dry open heath (*Lomandra* spp., *Podolobium alpestre*, *Hovea montana*). Only a small section (20 m x 50 m) at the very bottom of the slope, on more gentle grades, carries Subalpine raised bog vegetation. The Cave Gate Creek area is underlain by the upper Devonian Snowy Plains sedimentary formation.

The influence of slope and aspect was also apparent at the Snowy Range West peatland, which consisted mostly of Subalpine raised bog on the gentle lower valley slopes, with a high and continuous cover of *Sphagnum cristatum*. Further upslope to the south, on moderate slopes with northerly aspect, there was a greater proportion of Tall wet heath with less *Sphagnum* cover and species such as *Callistemon* and *Baeckea* in prominence.

Some of the peatlands at the nearby Bryces Plains (Piemans Creek) are on areas of Oligocene basalt bedrock and this appears to have a subtle influence on the vegetation composition and structure. There tends to be more herbaceous species present in these peatlands (e.g. *Craspedia* spp., *Hydrocotyle* spp., *Oreomyrrhis ciliata*, *Ranunculus pimpinellifolius*) especially in hollows, and the shrub *Hakea microcarpa* seems to be associated with these sections.

There are strong affinities between these peatlands on the basalt capped areas of the Snowy Range and the peatlands on the Dargo High Plains, another area capped by basalts of Oligocene origin. The Subalpine raised bog and Tall wet heath dominated sections of the peatlands tend to be at the margins of treeless plains, often immediately adjacent to *Eucalyptus pauciflora* open forest on higher ground (Figure 3.28). *Callistemon pityoides* is often present in these peatlands and particularly prominent at the boundary with neighbouring open forest. The microtopography and hummock-hollow oscillations in the peatlands on the basalts are often particularly pronounced, with differences between hummock crest and hollow floor of more than 1 m on occasions.

The highest elevation peatlands in the Snowy Range region are those in the vicinity of Mt Reynard and Racecourse Plain. These are generally on gentle slopes, in an open woodland context and surrounded by open heath and grassland, similar to parts of the Bogong High Plains. In these more exposed areas some sections of Subalpine raised bog are floristically close to ‘Alpine raised bog’ (e.g. the Snowy Range South site), as seen at higher elevation in the Bogong region (species like *Astelia alpina*, *Diplaspis nivis*, *Celmisia* spp., *Oschatzia cuneifolia*). Wellington Plain at 1490 m and situated towards the southern edge of the subalpine areas, has probably the largest expanses of treeless vegetation in this region. There are also large sections of peatland vegetation reminiscent of Low wet heath vegetation on the Bogong High Plains. Species such as *Astelia alpina*, *Oreobolus distichus*, *Celmisia* spp. and *Diplaspis nivis* are more prominent and abundant here than anywhere else in this region. In broad character and landscape setting Wellington Plain is similar to the Cope Creek-Pretty Valley area of the Bogong High Plains. The higher knolls and surrounding ridges (up to 1640 m) carry low open forest and woodland of *Eucalyptus pauciflora*; the lower slopes and broad expanses of Wellington Plain are a treeless mosaic of grassland, open heath and peatland vegetation. Peatland areas cover the majority of the valley floor, and range from Subalpine raised bog and Tall wet heath, to 'wet grasslands' dominated by *Poa costiniana*, *Carex gaudichaudiana*, *Lobelia surrepens* and *Empodisma minus*. Transect data were to be collected from here, but the December 2006 fires intervened. Acidic igneous rocks (rhyolite) from the upper Devonian period outcrop in several areas within this region including Wellington Plain.

Observations and descriptions of the montane peatlands

The montane wetlands occurred in two separate areas. Those on the Bennison Plains are on upper Devonian rhyolite and vary in elevation between 1240 and 1300 m. Of particular interest, further east in the Mitchell River catchment, are the montane peatlands of the Moroka Valley and associated tributary streams. These range in altitude from 1000 m to 1250 m and have received little attention in the past.

The Moroka Valley montane peatlands are underlain by a variety of bedrock types, including acidic igneous extrusive rocks such as the upper Devonian rhyolites and sedimentary formations from the same period. Peats in many of these sites were in excess of 2 m deep in places, although they appear to merge with quaternary alluvial deposits at greater depths. The Montane valley bogs predominate on the gentle slopes and flats adjacent to the Moroka River (Figure 3.25). Near the margins of these peatlands, and in seepage areas on more moderate slopes elsewhere, the floristics are more akin to Myrtaceous wet heath, with shrub species providing more overall cover. The cover of *Sphagnum cristatum* and *Empodisma minus* in these peatlands is generally high, the latter being particularly prominent in Myrtaceous wet heath and the former less so. The Montane valley bog communities have less overall shrub cover and relatively high cover abundance of *Carex gaudichaudiana* and *Baloskion australis*. The dominant shrubs are *Epacris paludosa* and the myrtaceous species *Baeckea gunniana* and *Callistemon pityoides*, particularly in Myrtaceous wet heath. Other shrub species commonly associated with these communities include *Epacris breviflora*, *Hakea microcarpa*, *Leptospermum myrtifolium* and *Comesperma retusum*.

The vegetation surrounding peatlands was an interesting mix of woodland and open forest with a generally shrub-dominated understorey. The most common tree canopy species were *Eucalyptus stellulata*, *E. rubida*, *E. pauciflora* and *E. dalrympleana*. The understorey habitats in adjoining open forests is quite dry and xeromorphic species relatively common (see Chapter 2 'Broad Vegetation Descriptions'). Unlike subalpine areas, the treeless character here is primarily due to impeded drainage, although some secondary reinforcement from cold-air drainage must also occur. Therefore, there is rarely treeless non-wetland vegetation abutting peatlands; open forest is continuous up to peatland boundaries. There are implications for the frequency of fire disturbance, as will be discussed in later chapters.

The montane wetland communities on the Bennison Plains differ from those in the Moroka Valley largely in landscape context. The surrounding non-wetland vegetation, while sharing many of the same canopy eucalypt species, is more woodland in structure than open forest, and therefore has an understorey that is more open in character (grassland and scattered shrubs), and includes some treeless sections.

3.3.3 Baw Baw and Central Highlands region transects

Twenty-eight transects were completed in peatland vegetation in the Baw Baw Plateau and Central Highlands regions. These varied in altitude from 1040 m at Thomson Fen, to 1510 m at Freemans Flat on the Baw Baw Plateau. The geographical range was from Gwinear Flat in the south-east, to Tom Burns Creek (near Eildon) in the north-west (Figures 3.30, 3.31). Sixty-three of the original 93 species in the master data set occurred in two or more transects. The sixty-three species consisted of 13 shrubs, 21 graminoids, 24 herbaceous dicots, one fern, one club-moss and three bryophytes. Four of the 11 peatland community types were identified and sampled in this region: Western subalpine raised bog (7 transects), Western subalpine wet heath (9), Western montane fen (6) and Western montane wet heath (6) (Appendices Table A3.37).

Ordination configurations based on frequency and cover data

Three dimensional ordination solutions were adopted for both the cover and frequency data analyses (Figures 3.32 and 3.33). The best solutions for both data types achieved Kruskal minimum stress values of 0.07. In both solutions there was a clear separation of the Western montane fen plots from the other three groups along axis 1. There was also variability within this group as indicated by the spread along axis 2 in both ordinations. Western montane wet heath plots were tightly clustered in the frequency solution and clearly separated from other groups. There was more variability apparent within this group in the cover data ordination, which was reflected in the slightly lower similarity score (65% vs 70%, Table 3.22). There are also closer affinities between this group and the subalpine plots in the cover data ordination.

Differences between Western subalpine raised bog and Western subalpine wet heath are less clear in both solutions. Variability is greater within the Western subalpine wet heath group as indicated by the greater spread of the plots in the graph space, particularly along axis 2 in the frequency data solution, and axis 1 in the solution based on the cover data.

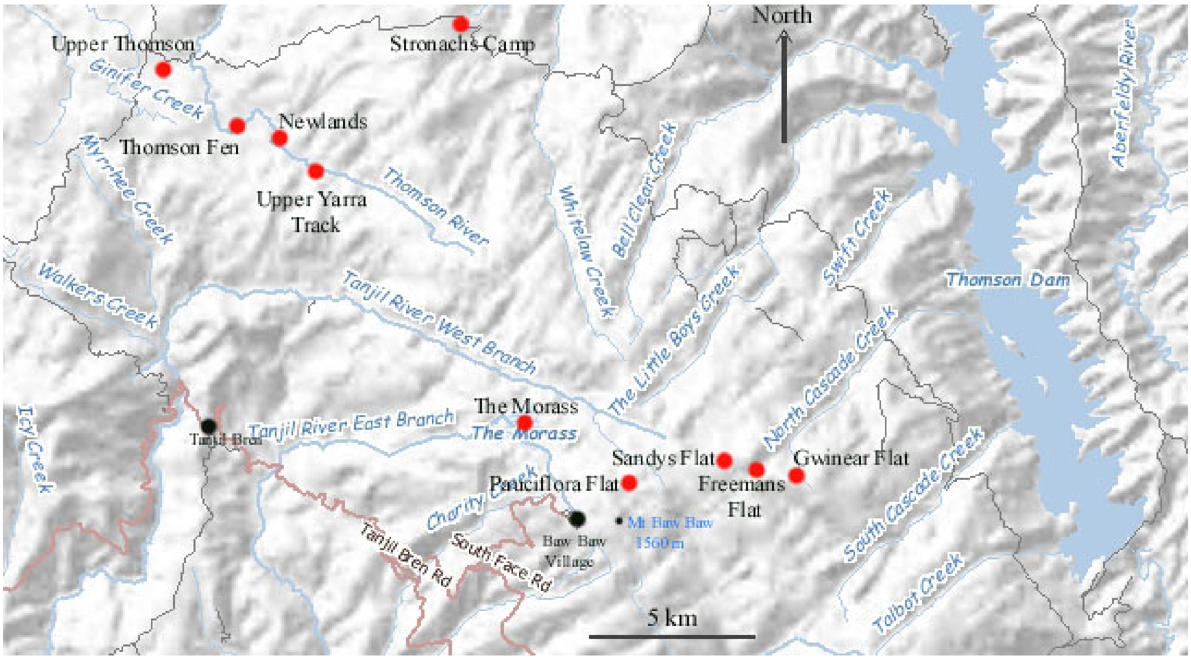


Figure 3.30: Map of the Baw Baw plateau and upper Thomson region showing the location of the peatland sites surveyed. The sites range in altitude from 1040 m (Upper Thomson) to 1510 m (Freemans Flat).

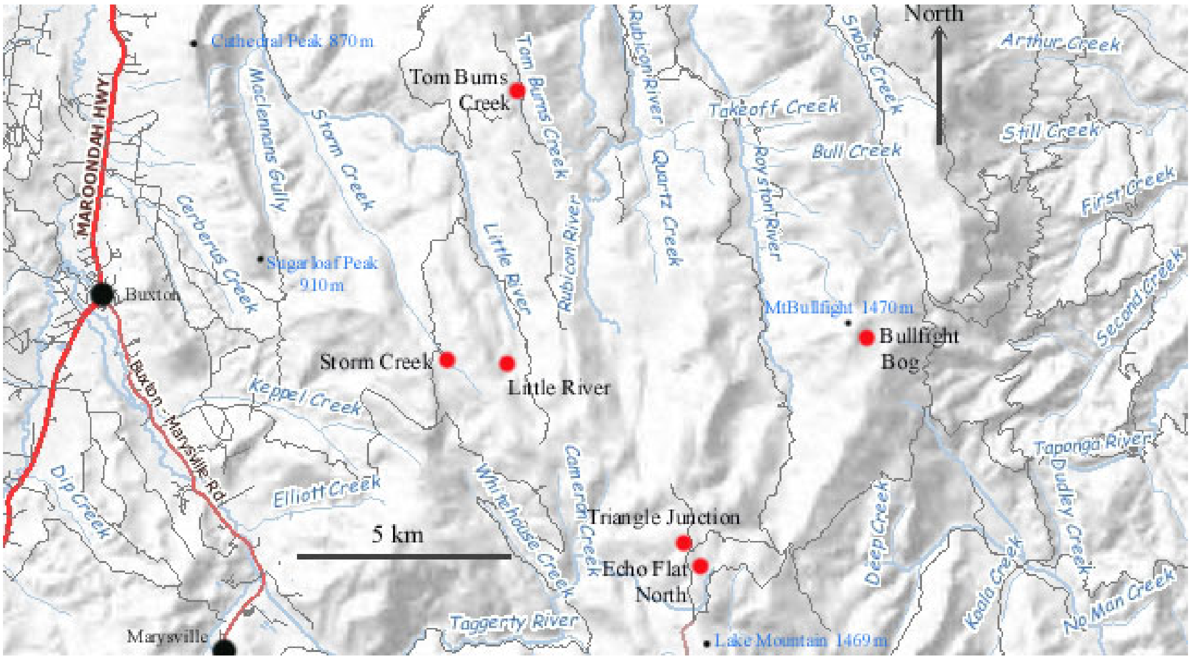


Figure 3.31: Map of the Central Highlands area showing the location of the peatland sites surveyed for this study. All sites are within the Goulburn river catchment and range in altitude from 1080 m (Tom Burns Creek) to 1430 m (Triangle Junction).

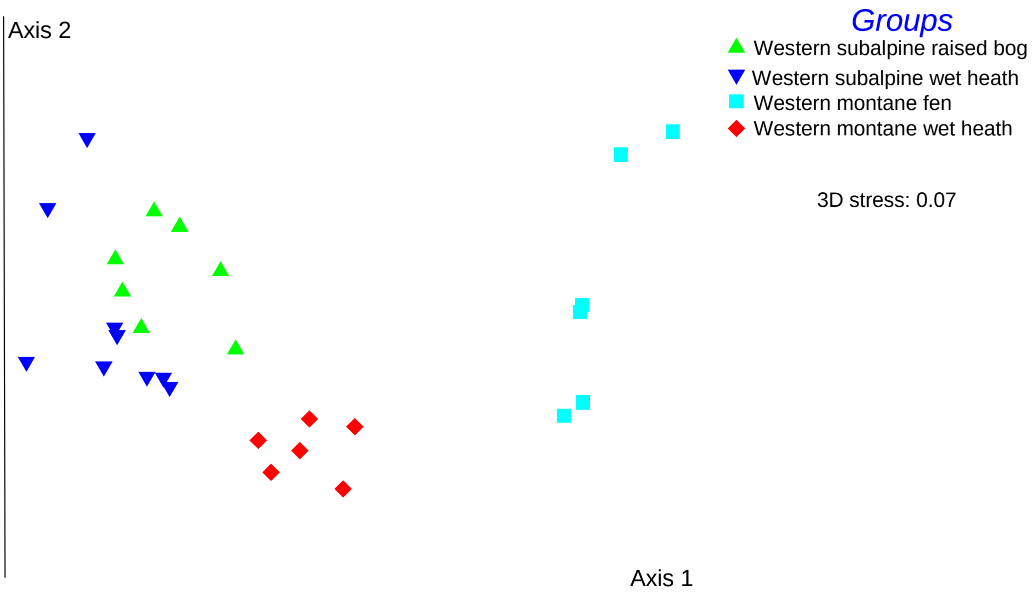


Figure 3.32: Three dimensional ordination graph derived from the **Baw Baw-Central Highlands region frequency data** (Axis 1 v Axis 2).

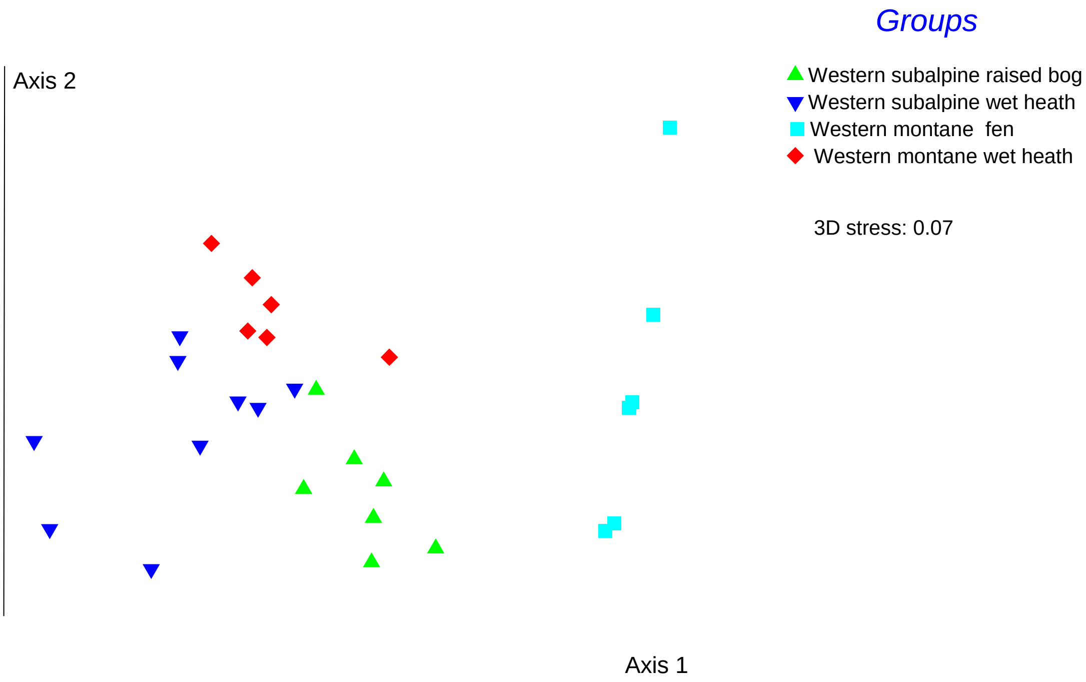


Figure 3.33: Three dimensional ordination graph based on **Baw Baw-Central Highlands region cover data** (Axis 1 v Axis 2).

Group similarities and ANOSIM comparisons of the four groups

The similarity percentages for the respective groups varied between 51% and 65% based on the cover data (Table 3.22). They were slightly higher for the frequency data, varying between 54% and 70%. In both cases, Western montane fen recorded the lowest similarity levels and Western montane wet heath the highest.

The ANOSIM analysis of both the frequency and cover data showed that there were significant floristic differences between the four groups, with global test statistics of 0.741 and 0.599 for frequency and cover data respectively (Table 3.23). Most pair-wise comparisons also produced significant results. R-statistic values were mostly between 0.6 and 1.0, with three exceptions. The pair-wise comparison between Western subalpine raised bog and Western subalpine wet heath based on the frequency data was non-significant (R = 0.163, p = 0.056), although the same comparison based on the percent cover data was significant, indicating more conclusive differences (R = 0.401, p = 0.002). This suggests that groups shared compositional similarities, but perhaps differed more in terms of dominance and vegetation structure. The second non-significant result was the comparison between Western subalpine wet heath and Western montane wet heath based on the cover data (R = 0.172, p = 0.068). The same comparison based on the frequency data separated the groups clearly (R = 0.69, p = 0.002). In this case, the groups differed in composition but have structural similarities (Appendices Table A3.38* for full version).

Table 3.22: Simper analysis group similarity percentages for the four community types. **Baw Baw-Central Highlands region.**

Community Type	**abb. code**	**Similarity Percentages**	
		Frequency data	**Cover data**
Western subalpine raised bog	WSR	61.01	64.38
Western subalpine wet heath	WSW	56.63	52.72
Western montane fen	WMF	54.30	51.96
Western montane wet heath	WMW	70.20	65.28

Table 3.23: Pair-wise comparisons of the peatland community types based on the **Baw Baw-Central Highlands region transects frequency and cover data**. The statistical significance values of the pair-wise comparisons have been checked with the Bonferroni adjustment. Comparisons that are not significantly different are indicated (*). Values for R of less than 0.25 indicate that groups are barely separable, values between 0.25 and 0.5 indicate that groups are overlapping but marginally different. Values greater than 0.5 indicate that there are clear differences between groups and these are indicated by bold text.

Analysis of similarity	**Actual**	**Frequency data**		**Cover data**	
Pair-wise Tests	**Perm'tns**	**R**	**Signif.**	**R**	**Signif.**
Groups	**max = 999**	**Statistic**	**P-value**	**Statistic**	**P-value**
W'tn montane fen, W'tn montane Wet heath	462	**0.931**	0.002	**0.944**	0.002
W'tn subalpine raised bog, W'tn montane fen	999	**1**	0.001	**0.796**	0.002
W'tn subalpine raised bog, W'tn montane wet heath	999	**0.967**	0.001	**0.743**	0.001
W'tn subalpine raised bog, W'tn subalpine wet heath	999	0.163	0.056*	0.401	0.002
W'tn subalpine wet heath, W'tn montane fen	999	**1**	0.001	**0.991**	0.001
W'tn subalpine wet heath, W'tn montane wet heath	999	**0.69**	0.002	0.172	0.068*
Overall global test sample statistic	999	**0.741**	0.001	**0.599**	0.001

Species defining groups and discriminating between them

Important species in Western subalpine raised bog (WSR) in terms of cover percentages and dominance were *Sphagnum cristatum*, *Empodisma minus*, *Epacris paludosa*, *Astelia alpina*, and *Richea continentis*, in that order (Table 3.24). The species that provided less mean cover (< 5%), but were frequently present included *Poa costiniana*, *Nertera granadensis*, *Gentianella* sp. and *Baeckea gunniana*. *Erigeron paludicola* and *Carpha* spp. were common, but their abundance varied between plots within this group. The latter species in particular do not occur in the Central Highlands region.

The same species provided most of the cover in Western subalpine wet heath (WSW) but the emphasis was different. *Sphagnum cristatum* cover was less, with the majority of the cover being provided instead by *Empodisma minus* and the shrub species. The mean cover of *Baeckea gunniana* appeared to be greater in ‘wet heath’ than ‘raised bog’. The same suite of common but less dominant species was also present with the inclusion of *Asperula gunnii* and the shrub *Olearia algida*.

The dominant species that provided most of the cover in Western montane fen (WMF) were *Sphagnum cristatum*, *Richea victoriana*, *Carex appressa*, and ‘brown’ mosses,

Table 3.24: Occurrence frequencies and percentage cover abundance values for species identified by SIMPER analysis as contributing most to within group similarities. These data are derived from the **Baw Baw-Central Highlands region transects**. WSR = Western subalpine raised bog, WSW = Western subalpine wet heath, WMW = Western montane wet heath, WMF = Western montane fen. Species have been grouped according to patterns of co-occurrence.

(a) Frequency data (values greater than 25% indicated in bold)

Species	WSR	WSW	WMW	WMF
Sphagnum cristatum	**79.8**	**31.2**	**38.3**	**76.7**
Empodisma minus	**98.3**	**98.9**	**94.7**	0.0
Astelia alpina	**54.4**	**49.6**	1.7	0.0
Richea continentis	**46.9**	**60.3**	0.0	0.0
Poa costiniana	**45.4**	**36.4**	0.0	0.0
Carpha spp.	**38.3**	18.3	0.0	0.0
Erigeron paludicola	**34.6**	12.9	0.0	0.0
Gentianella sp.	**24.3**	**28.9**	0.0	0.0
Nertera granadensis	**33.5**	18.7	16.1	0.0
Epacris paludosa	**58.3**	**66.1**	**83.3**	0.0
Baeckea gunniana	**25.9**	**46.7**	**44.4**	0.0
Isolepis spp.	20.4	2.6	0.0	1.7
Asperula gunnii	20.4	22.1	6.7	0.0
Olearia algida	11.8	18.1	14.7	22.2
Richea victoriana	0.0	4.4	**43.6**	**90.3**
Carex gaudichaudiana	22.1	6.3	**79.4**	**63.1**
Carex appressa	0.0	0.0	0.0	**57.8**
Polytrichum spp.	1.7	0.0	10.6	**43.6**
Blechnum penna-marina	0.0	0.0	0.0	**38.1**
Poa spp.	6.9	0.6	0.0	**37.8**

(b) Cover data (values greater than 1% indicated in bold)

Species	WSR	WSW	WMW	WMF
Sphagnum cristatum	**47.2**	**10.6**	**15.5**	**48.9**
Empodisma minus	**20.6**	**24.2**	**22.0**	0.0
Epacris paludosa	**12.9**	**13.7**	**25.0**	0.0
Richea continentis	**5.4**	**13.0**	0.0	0.0
Astelia alpina	**6.1**	**8.2**	0.3	0.0
Baeckea gunniana	**1.9**	**7.7**	**5.3**	0.0
Richea victoriana	0.0	0.3	**2.6**	**20.7**
Polytrichum spp.	0.0	0.0	**1.1**	**8.0**
Carex appressa	0.0	0.0	0.0	**6.3**

particularly species of *Polytrichum*. Other important common species included the fern *Blechnum penna-marina* and grasses *Poa labillardierei* and *P. ensiformis*. The sedge *Carex gaudichaudiana* was also common but generally had a more variable presence within this group. Western montane wet heath (WMW) was defined by high cover and frequency values for *Empodisma minus*, *Epacris paludosa*, *Carex gaudichaudiana*, *Baeckea gunniana* and *Richea victoriana*. *Sphagnum cristatum* provided less overall cover in this community, but was still common (see Appendices Table A3.39* for full SIMPER table).

The most useful species for the initial split between groups was *Empodisma minus*, which was common and dominant in three of the community types, but absent from Western montane fen. *Baeckea gunniana* and *Epacris paludosa* were other species that shared this distribution (Appendices Table A3.40). The next most obvious split was between the peatland communities in subalpine and montane areas based on the distribution of the two species of the shrub *Richea* (Appendices Table A3.41). *Richea continentis* was common and sometimes dominant in the two subalpine communities but absent from montane peatlands. In these sites it was replaced by *Richea victoriana*.

The two subalpine peatland types differed in *Sphagnum* frequency and cover; both were lower in Western subalpine wet heath (Appendices Table A3.42). The cover and presence of shrubs, particularly *Richea continentis* and *Baeckea gunniana* were greater in Western subalpine wet heath. Other shrub species such as *Callistemon pityoides*, *Olearia algida*, *Epacris petrophila* and *Ozothamnus* sp.1 were also encountered in this peatland community. These species were either absent or rare in Western subalpine raised bog (WSR). Dicot herbs such as *Nertera granadensis*, *Brachyscome obovata*, *Erigeron paludicola* and *Drosera arcturi* were generally less prominent in Western subalpine wet heath, as were graminoids like *Juncus sandwithii* and *Carex gaudichaudiana*. Exceptions to this rule were *Asperula gunnii* and *Celmisia* spp, which appeared to be more prominent in ‘wet heath’ than ‘raised bog’ (see Appendices for the other pair-wise comparison tables, A3.43 to A3.45).

Species and factor correlations with the frequency data ordination

Forty-three of the 63 species in the data set showed significant correlations with at least one of the three axes of the ordination solution based on frequency. The 29 with the strongest correlations (> 0.5 or < -0.5) are shown in Table 3.25 (see Appendices for the full table, A3.46*).

Table 3.25: Species with strong significant correlations with the axes of the ordination graph derived from the **Baw Baw-Central Highlands region frequency data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

species	MDS1	sig.level	MDS2	sig.level	MDS3	sig.level
Richea victoriana	**0.88**	***	-0.25	ns	-0.21	ns
Carex appressa	**0.76**	***	0.16	ns	0.06	ns
Blechnum penna-marina	**0.74**	***	0.05	ns	0.08	ns
Polytrichum spp.	**0.71**	***	-0.03	ns	-0.01	ns
Poa spp.	**0.61**	***	0.19	ns	0.27	ns
Leptospermum grandifolium	**0.60**	***	**0.41**	*	0.05	ns
Carex gaudichaudiana	**0.58**	**	**-0.55**	**	0.15	ns
Hypericum japonicum	**0.56**	**	0.18	ns	0.13	ns
Tasmannia xerophila	**0.54**	**	**0.43**	*	-0.05	ns
Oreobolus distichus	**-0.55**	**	0.16	ns	0.32	ns
Erigeron paludicola	**-0.56**	**	**0.48**	*	0.18	ns
Empodisma minus	**-0.67**	***	-0.11	ns	0.02	ns
Asperula gunnii	**-0.67**	***	0.29	ns	**-0.40**	*
Gentianella sp.	**-0.68**	***	0.30	ns	**0.41**	*
Celmisia spp.	**-0.81**	***	**0.42**	*	0.27	ns
Poa costiniana	**-0.82**	***	**0.56**	**	0.00	ns
Astelia alpina	**-0.83**	***	0.34	ns	0.30	ns
Richea continentis	**-0.87**	***	**0.43**	*	0.06	ns
Isolepis spp.	-0.27	ns	**0.59**	***	0.27	ns
Baeckea gunniana	**-0.46**	*	**-0.51**	**	-0.02	ns
Epacris microphylla var. *rhombifolia*	**0.40**	*	**-0.62**	***	-0.19	ns
Drosera arcturi	**-0.39**	*	0.16	ns	**0.74**	***
Euphrasia gibbsiae	-0.37	ns	0.09	ns	**0.71**	***
Sphagnum cristatum	0.37	ns	0.18	ns	**0.67**	***
Carpha spp.	-0.37	ns	0.20	ns	**0.66**	***
Coprosma perpusilla	-0.22	ns	0.21	ns	**0.65**	***
Rytidosperma nivicola	**-0.43**	*	0.19	ns	**0.63**	***
Thelymitra cyanea	**-0.44**	*	0.25	ns	**0.57**	**
Psychrophila introloba	-0.24	ns	0.15	ns	**0.50**	**

The species with the strongest positive correlations with axis 1 in the ordination were *Richea victoriana*, *Carex appressa* and *Blechnum penna-marina* (Figure 3.34). These were important species in Western montane fen. Strongly correlated species in the opposite direction along axis 1 included *Richea continentis*, *Astelia alpina* and *Celmisia* spp., all of which were important species in both of the subalpine peatland communities. There were fewer species associated with axis 2, but they included *Poa costiniana*, *Isolepis* spp. and *Erigeron paludicola*, and these increased diagonally from the bottom right to the top left of the graph space, towards the subalpine plots. *Baeckea gunniana* and *Epacris microphylla* var. *rhombifolia* had negative correlations with axis 2. The

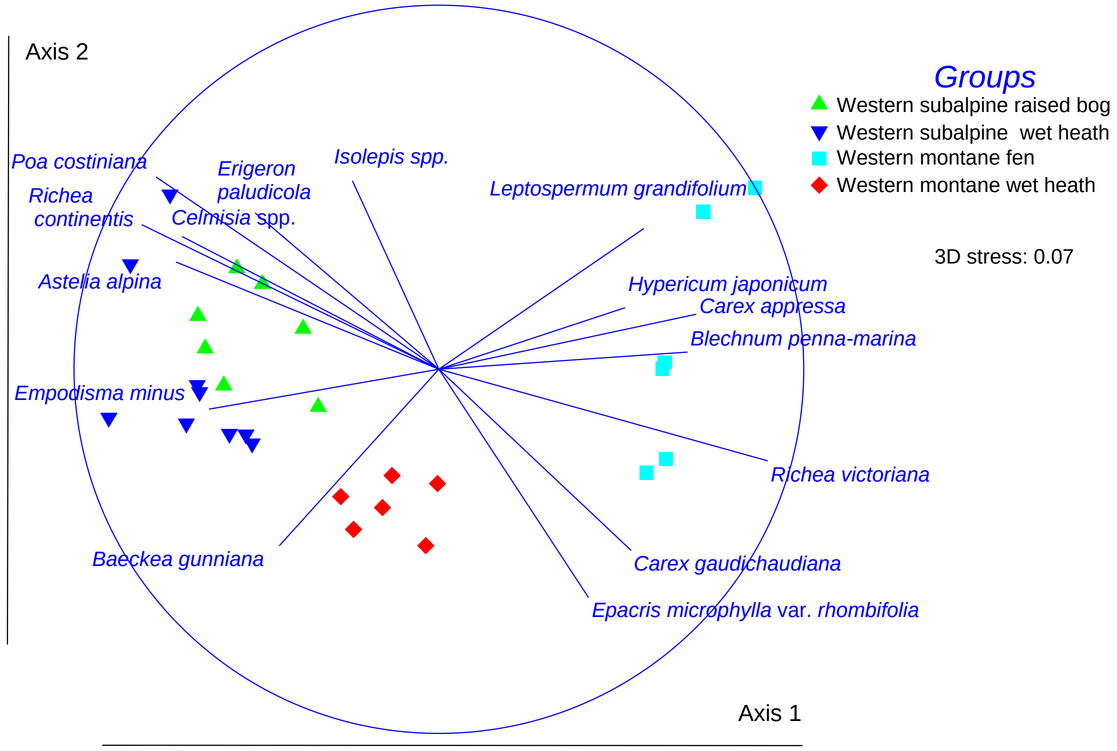


Figure 3.34: Three dimensional ordination graph derived from the **Baw Baw-Central Highlands region frequency data** (Axis 1 v Axis 2). The trend directions of significantly correlated species are indicated.

former was aligned with Western montane wet heath, and the latter with montane peatlands in general.

A suite of species had strong positive correlations with axis 3 (Table 3.25, Appendices Figure A3.7). Included in this group was *Sphagnum cristatum*, which increased in a plane towards both Western subalpine raised bog and Western montane fen. The other species in this suite favoured the raised bog plots and in particular the Baw Baw transects. These included *Drosera arcturi*, *Carpha* spp., *Coprosma perpusilla*, *Rytidosperma nivicola*, *Psychrophila introloba* and *Euphrasia gibbsiae*. All were species either absent or very rare in Western subalpine raised bog transects in the Central Highlands.

Table 3.26: Factors with strong significant correlations with axes of the ordination graph derived from the **Baw Baw-Central Highland region frequency data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001). See appendices for the full table.

Factor	MDS1	sig.level	MDS2	sig.level	MDS3	sig.level
Highest period radiation	**0.76**	***	-0.15	ns	**-0.44**	*
Mean temperature of driest quarter	**0.76**	***	-0.16	ns	**-0.42**	*
Moisture index seasonality (C of V)	**0.75**	***	-0.15	ns	**-0.45**	*
Percentage of peat points > 2 m	**0.74**	***	**-0.44**	*	-0.22	ns
Peat depth	**0.65**	***	**-0.51**	**	-0.34	ns
Percentage of peat points > 1 m	**0.61**	***	**-0.48**	*	**-0.38**	*
Mean height of tallest shrubs	**0.61**	***	**-0.46**	*	**-0.46**	*
Litter	**0.45**	*	**-0.45**	*	-0.35	ns
Topographic position	**-0.46**	*	0.07	ns	0.13	ns
Dead *Empodisma* cover	**-0.50**	**	-0.37	ns	-0.26	ns
Precipitation of driest period	**-0.55**	**	0.00	ns	**0.55**	**
Precipitation of wettest quarter	**-0.61**	***	**0.39**	*	-0.03	ns
Annual precipitation	**-0.69**	***	0.37	ns	**0.43**	*
Altitude	**-0.70**	***	0.29	ns	**0.39**	*
Lowest period moisture index	**-0.75**	***	0.16	ns	**0.46**	*
Precipitation of driest quarter	**-0.75**	***	0.16	ns	**0.45**	*
Mean moisture index of warm quarter	**-0.75**	***	0.15	ns	**0.45**	*
Radiation of wettest quarter	-0.03	ns	**-0.60**	***	0.24	ns
Latitude	-0.37	ns	-0.18	ns	**0.64**	***
Longitude	-0.37	ns	-0.08	ns	**0.56**	**
Shrub cover	-0.10	ns	-0.26	ns	**-0.51**	**
Precipitation seasonality (C of V)	**0.40**	*	0.18	ns	**-0.61**	***
Lowest period radiation	0.34	ns	-0.08	ns	**-0.70**	***

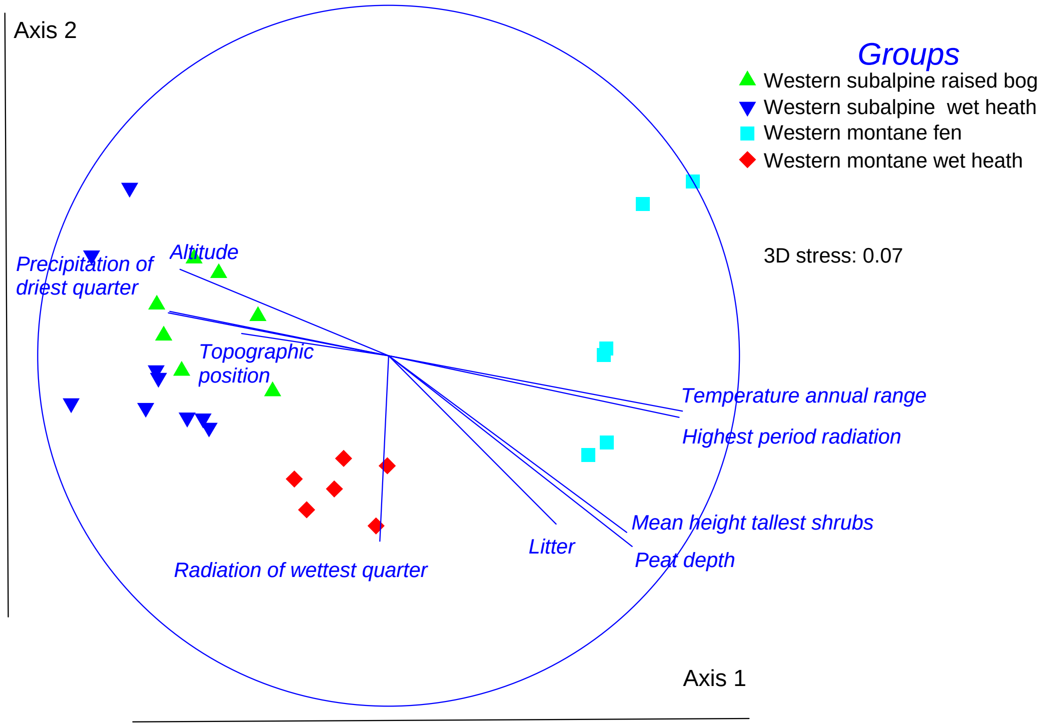


Figure 3.35: Three dimensional ordination graph derived from the **Baw Baw-Central Highlands region frequency data** (Axis 1 v Axis 2). The trend directions of significantly correlated factors are indicated.

Forty-six of the 55 factors tested for correlation with the frequency ordination were significant at the 0.05 level. Amongst the strongest correlations were with altitude, peat depth, shrub cover, mean height of tallest shrubs, and many of the BIOCLIM variables. Latitude and longitude also appeared to be useful, a reflection of some floristic and structural differences between the Baw Baw and Central Highlands regions, the former area being further to the south-east. A brief selection of important variables is provided in Table 3.26 (see Appendices Table A3.47* for full list).

Factors with strong positive correlations with axis 1 included temperature annual range, highest period radiation, peat depth, litter cover, and mean height of the tallest shrubs. These variables all increased in value towards the montane sites, particularly Western montane fen (Figure 3.35). Factors that had strong negative correlations with axis 1 included precipitation of the driest quarter, lowest period moisture index, and altitude. All were orientated towards the subalpine plots (WSR and WSW). There were few factors strongly correlated with axis 2. Radiation of the wettest quarter, litter cover, peat depth, and mean height of tallest shrubs, had some negative correlation with axis 2, and all favoured the montane communities. The important factors correlated with axis 3 were latitude, longitude, and precipitation of the driest period (Appendices Figure A3.8). These all increased along axis 3 and towards the subalpine Baw Baw plots in particular. Factors with strong negative correlations with axis 3 included lowest period radiation, precipitation seasonality, and shrub cover. These favoured the montane communities, but also the subalpine Central Highlands plots to a lesser extent.

Species and factor correlations with the cover data ordination

Thirty-three of the 63 species were significantly correlated with one or more axes of the ordination configuration based on the cover data. The twenty with the strongest correlations have been included in Table 3.27 (Full list in Appendices Table A3.48*).

Species with strong positive correlations with axis 1 included *Carex appressa*, *Blechnum penna-marina* and *Leptospermum grandifolium*. All were associated with Western

Table 3.27: Species with strong significant correlations with axes of the ordination graph based on the **Baw Baw-Central Highlands region cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Species	MDS1	sig.level	MDS2	sig.level	MDS3	sig.level
Carex appressa	**0.74**	***	0.11	ns	0.10	ns
Blechnum penna-marina	**0.73**	***	0.09	ns	0.15	ns
Sphagnum cristatum	**0.73**	***	**-0.55**	**	-0.25	ns
Poa spp.	**0.65**	***	0.08	ns	0.28	ns
Polytrichum spp.	**0.63**	***	0.26	ns	0.37	ns
Leptospermum grandifolium	**0.61**	***	0.02	ns	-0.05	ns
Hypericum japonicum	**0.56**	**	-0.07	ns	0.07	ns
Richea victoriana	**0.54**	**	**0.51**	**	0.17	ns
Tasmannia xerophila	**0.54**	**	0.21	ns	0.08	ns
Cardamine sp.	**0.51**	**	-0.14	ns	-0.19	ns
Hierochloe redolens	**0.50**	**	-0.19	ns	-0.20	ns
Asperula gunnii	**-0.52**	**	-0.25	ns	0.09	ns
Celmisia spp.	**-0.52**	**	**-0.44**	*	-0.15	ns
Astelia alpina	**-0.54**	**	**-0.41**	*	-0.36	ns
Baeckea gunniana	**-0.67**	***	0.36	ns	-0.22	ns
Empodisma minus	**-0.68**	***	-0.07	ns	**0.38**	*
Epacris petrophila	-0.17	ns	**-0.49**	**	0.34	ns
Poa costiniana	-0.37	ns	**-0.59**	**	-0.03	ns
Richea continentis	**-0.51**	**	**-0.60**	***	0.19	ns
Epacris paludosa	**-0.40**	*	**0.42**	*	**-0.50**	**

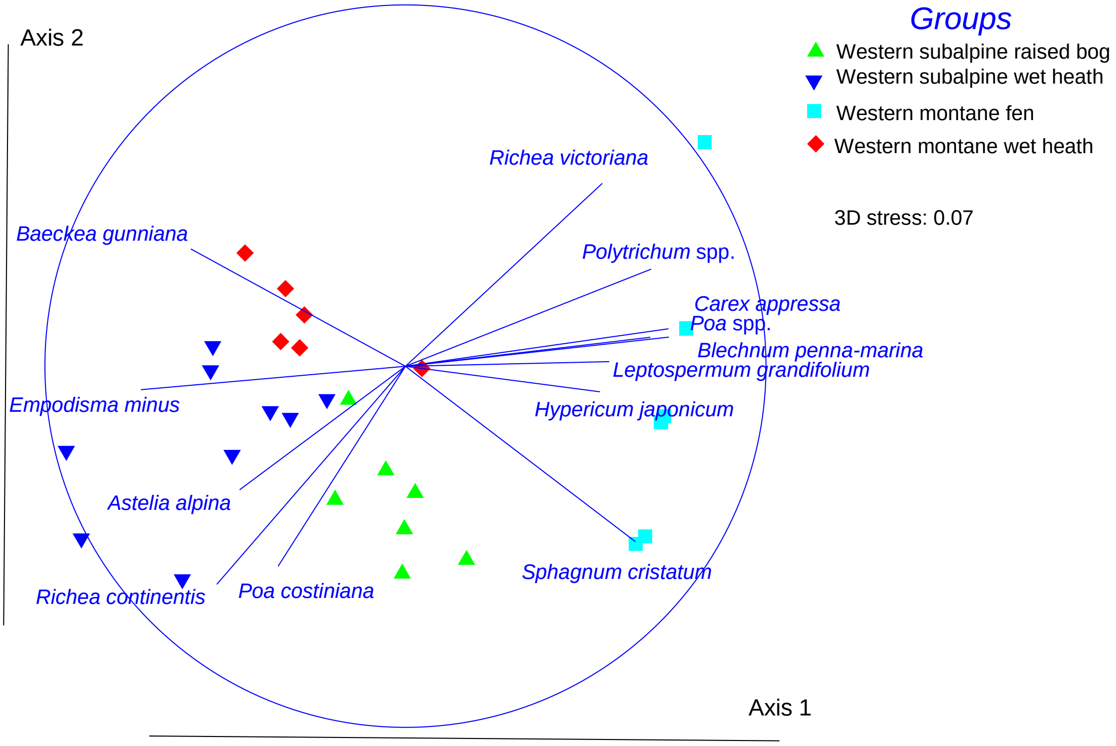


Figure 3.36: Three dimensional ordination graph derived from the **Baw Baw-Central Highlands region cover data** (Axis 1 vs Axis 2). The trend directions of significantly correlated species are indicated.

montane fen plots (Figure 3.36). *Sphagnum cristatum* had a positive correlation with axis 1, but also had some negative association with axis 2. Its cover values displayed an increasing trend towards both Western montane fen and Western subalpine raised bog. The trend in the cover of *Richea victoriana* also had a diagonal component, increasing from the bottom left to the top right of the graph space, away from the subalpine plots. *Empodisma minus* and *Baeckea gunniana* were both negatively correlated with axis 1 of the cover ordination and increased in value towards both wet heath communities, independently of altitude. *Astelia alpina* and *Richea continentis* were also negatively correlated with axis 1, but had a negative association with axis 2, and therefore increased towards the subalpine plots.

Epacris paludosa was one of the few species with a strong positive correlation with axis 3 in the configuration (Appendices Figure A3.9). It is not exclusively associated with any single community, but did increase in cover away from Western montane fen. It was an important structural shrub species in both of the subalpine peatland communities, and also Western montane wet heath. This was consistent with the SIMPER analysis which identified *Epacris paludosa* as a common species in all three communities, but not generally a useful species for distinguishing between them.

Thirty-seven of the 55 tested factors were significantly correlated with the cover data ordination at the 0.05 level. Correlations with the cover ordination were weaker in general than with the frequency ordination (Table 3.28, Appendices Table A3.49*). The strongest positive correlations with axis 1 included some of the temperature variables, but these trended diagonally and therefore have a positive association with axis 2 also (Figure 3.37). Factors in this group included mean temperature of the wettest quarter, and temperature diurnal range, all favoured the Western montane fen plots. The cover of dead *Empodisma minus* (fixed litter) had a strong negative correlation with axis 1, as did shrub cover to a lesser extent. Collectively they favoured the wet heath communities, both montane and subalpine.

Table 3.28: Factors with strong significant correlations with axes of the ordination graph derived from the **Baw Baw-Central Highlands region cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001). See appendices for the full version.

Factor	MDS1	sig.level	MDS2	sig.level	MDS3	sig.level
Litter	0.08	ns	**0.79**	***	0.01	ns
Mean height of tallest shrubs	0.24	ns	**0.70**	***	0.14	ns
Mean shrub height	0.18	ns	**0.64**	***	0.21	ns
Shrub cover	-0.29	ns	**0.56**	**	0.10	ns
Percentage of peat points > 1 m	0.32	ns	**0.54**	**	0.13	ns
Mean temperature of wettest quarter	0.36	ns	**0.51**	**	0.22	ns
Mean diurnal temperature range	**0.40**	*	**0.50**	**	0.22	ns
Highest period radiation	**0.45**	*	**0.43**	*	0.27	ns
Mean moisture index of lowest quarter	**-0.41**	*	**-0.45**	*	-0.14	ns
Altitude	-0.37	ns	**-0.46**	*	-0.20	ns
Precipitation of driest quarter	**-0.41**	*	**-0.46**	*	-0.16	ns
Precipitation of warmest quarter	**-0.41**	*	**-0.46**	*	-0.16	ns
Lowest period moisture index	**-0.40**	*	**-0.47**	*	-0.15	ns
Annual precipitation	-0.34	ns	**-0.47**	*	-0.28	ns
Annual mean moisture index	**-0.40**	*	**-0.48**	*	-0.14	ns
Percentage of peat points < 0.5 m	**-0.43**	*	-0.12	ns	-0.13	ns
Dead *Empodisma* cover	**-0.67**	***	0.27	ns	-0.20	ns

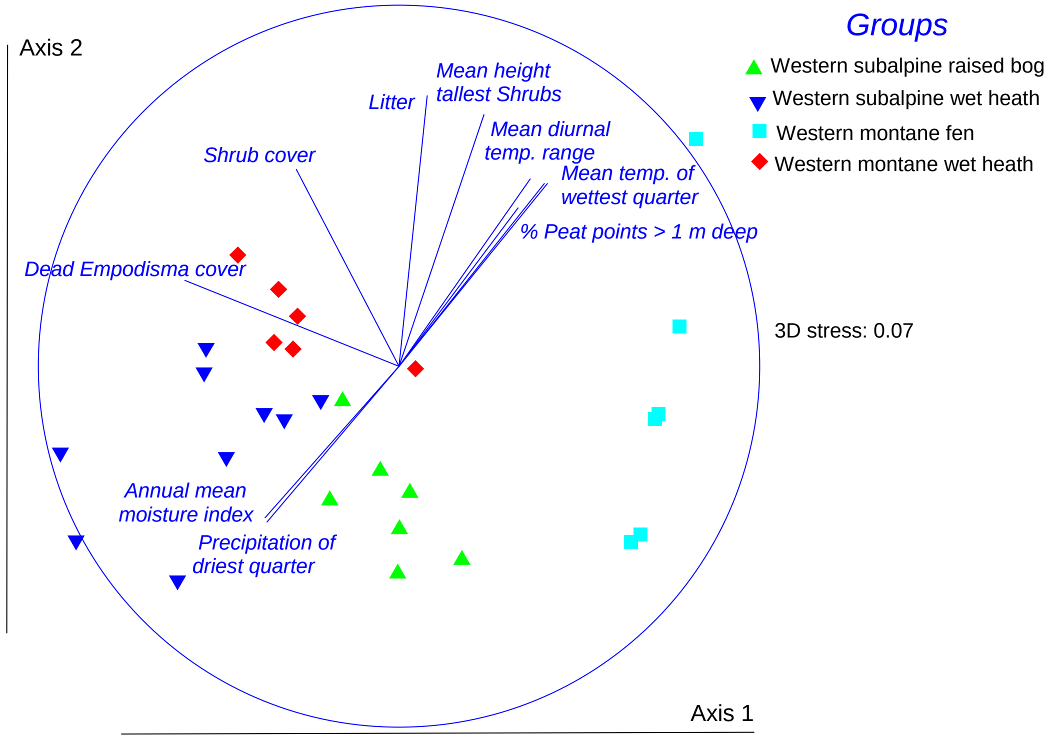


Figure 3.37: Three dimensional ordination graph based on the **Baw Baw-Central Highlands region cover data** (Axis 1 v Axis 2). The trend directions of significantly correlated factors are indicated.

Litter, shrub height, and peat depth (> 1 m deep) had strong positive correlations with axis 2 and had higher values in montane peatland communities. There were fewer factors with strong correlations in the opposite direction. They included annual mean moisture index (humidity) and precipitation of the driest quarter. Both of these increased towards subalpine plots. There were no factors significantly correlated with axis 3.

Plant functional group distribution patterns

Ten of the 11 plant functional groups were significantly correlated with the cover ordination (Table 3.29). The groups with the strongest correlations were *Sphagnum* spp., restiads, *Carex* spp., *Astelia*, herbs, and ericaceous shrubs, in that order.

Two groups were positively correlated with axis 1 and trended towards the Western montane fen plots (Figure 3.38). These were *Carex* spp. and ‘other bryophytes’ (‘brown mosses’). Restiads and *Astelia* had strongly negative correlations with the same axis and increased towards the Western subalpine wet heath plots. Herbaceous species were correlated with Western subalpine raised bog transects, and these included species of *Celmisia*, *Erigeron*, *Brachyscome*, *Coprosma*, *Euphrasia* and *Psychrophila*. The gradient in the cover of *Sphagnum* species was from the top left to the bottom right of the graph space and helped to separate the wet heath plots (left) from the bog-fen plots (right). The gradient in the cover of the major shrub groups (Myrtaceae, Ericaceae), was diametrically opposed to this, and ran from bog-fen plots to wet heath plots, independent of altitude.

Table 3.29: Plant functional group correlations with axes of the ordination graph derived from the **Baw Baw-Central Highlands region cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Lifeform	**MDS1**	**sig.level**	**MDS2**	**sig.level**	**MDS3**	**sig.level**
Sphagnum spp.	**0.72**	***	**-0.58**	**	-0.22	ns
Carex spp.	**0.64**	***	0.26	ns	0.10	ns
Other Bryophytes	**0.43**	*	0.31	ns	0.17	ns
Ericaceous shrubs	-0.22	ns	**0.51**	**	0.23	ns
Myrtaceous shrubs	-0.29	ns	**0.47**	*	-0.35	ns
Other shrubs	0.06	ns	0.21	ns	**0.41**	*
Other monocots	0.10	ns	**-0.44**	*	0.03	ns
Herbs	-0.09	ns	**-0.54**	**	-0.11	ns
Astelia	**-0.56**	**	**-0.39**	*	-0.35	ns
Restiads	**-0.68**	***	-0.07	ns	**0.38**	*

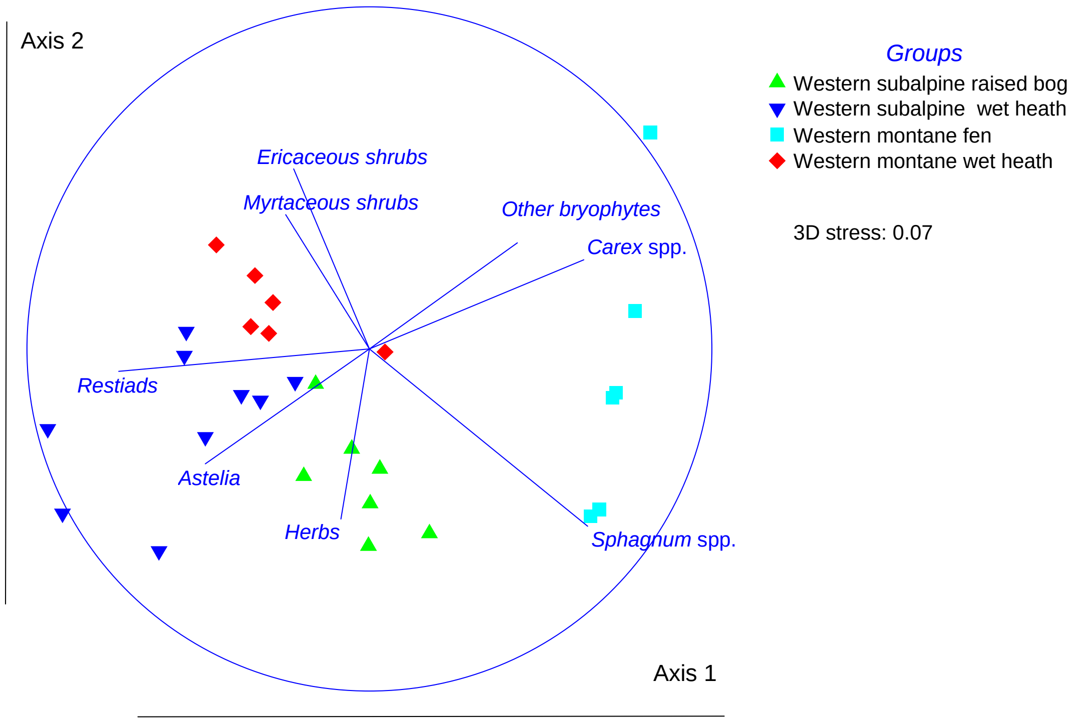


Figure 3.38: Three dimensional ordination graph derived from the **Baw Baw-Central Highlands region cover data** (Axis 1 v Axis 2). The trend directions of significantly correlated plant functional groups are indicated.

Floristic differences between the Baw Baw and Central Highlands peatland vegetation

Figure 3.39 shows the frequency data ordination solution with the 28 transects for this region categorised according to ‘sub-region’ and elevation zone, regardless of nominal community type classification. The montane plots from both regions clustered together into two discrete groups according to community type and independently of ‘sub-region’ (Western montane fen, Western montane wet heath). This result was supported by the ANOSIM pair-wise group comparisons (Table 3.30), which indicated that differences between the Baw Baw montane plots and the Central Highlands montane plots are non-significant (R-statistic =0.228, p = 0.084). However, there was some separation between the subalpine plots according to ‘sub-region’ in the ordination graph. Again, ANOSIM analysis also provided support by indicating that there were marginally significant

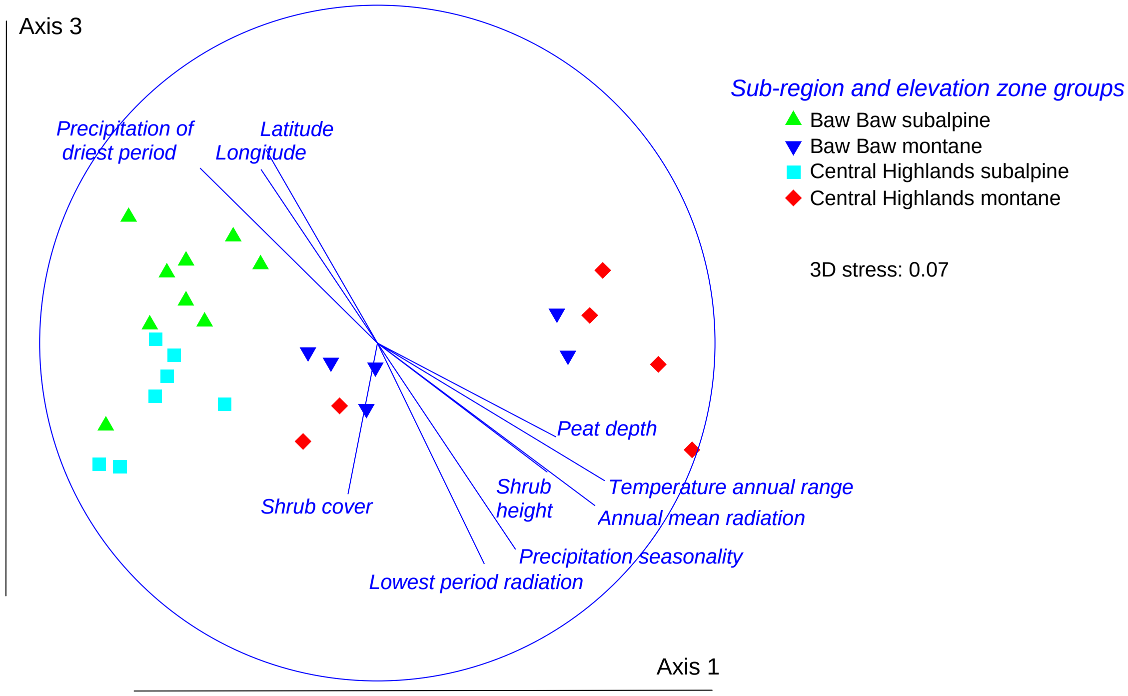


Figure 3.39: Three dimensional ordination graph based on **Baw Baw-Central Highlands frequency data**. Transects have been grouped according to sub-region and altitude zone (Axis 1 v Axis 3). The trend directions of significantly correlated factors are indicated.

differences between the two groups (R-statistic = 0.356, p = 0.003). As would be expected, all other pair-wise group comparisons between elevation zones (montane vs subalpine) indicated significant differences.

The species contributing most to differences between the subalpine plots of both 'sub-regions' were those absent from the Central Highlands (Table 3.31). These include: *Carpha* spp., *Euphrasia gibbsiae*, *Psychrophila introloba*, and *Rytidosperma nivicola*. These species were not recorded in transects, nor were they observed outside of the plots in the Central Highlands. The correlation vectors for environmental and structural attributes (Figure 3.39) illustrate the more southerly and easterly position of the Baw Baw plots (latitude, longitude) and the subtle differences in climate (e.g. precipitation of the driest period).

Table 3.30: Pair-wise comparisons of four ‘sub-region by elevation’ groups from the **Baw Baw-Central Highlands region** based on the **frequency data.**

Pair-wise Tests Groups	R Stat.	Signif. P-value	Signif. bonferr.	Possible Perm'tns	Actual Perm'tns	Num.>= Obs.
Baw Baw subalpine, Baw Baw montane	0.778	0.001	*	5005	999	0
Baw Baw subalpine, Central Highlands montane	0.839	0.001	*	5005	999	0
Baw Baw montane, Central Highlands subalpine	0.775	0.002	*	1716	999	1
Baw Baw subalpine, Central Highlands subalpine	0.356	0.003	*	11440	999	2
Central Highlands subalpine, Central Highlands montane	0.787	0.003	*	1716	999	2
Baw Baw montane, Central Highlands montane	0.228	0.084	ns	462	462	39
Overall global test sample statistic	**0.604**	**0.001**	*	**NA**	**999**	**0**

Table 3.31: Species contributing to differences between the **subalpine transects** at **Baw Baw** and those in the **Central Highlands**, based on the **frequency data**. The species listed contribute most to dissimilarity between the groups up to a cumulative contribution of 90%. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss.) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

Species	Frequency in Baw Baw Subalpine	Frequency in Central Highlands Subalpine	Av.Diss	Diss/SD	Contrib%
Epacris paludosa	63.9	61.2	2.9	1.2	6.4
Sphagnum cristatum	56.3	47.5	2.7	1.3	5.8
Richea continentis	55.2	53.5	2.2	1.4	4.9
Astelia alpina	55.0	47.5	2.4	1.5	5.1
Carpha spp.	48.2	0.0	3.5	2.1	7.6
Baeckea gunniana	38.7	36.2	2.4	1.3	5.2
Gentianella sp.	34.4	17.2	1.6	1.3	3.5
Poa costiniana	32.6	50.4	2.3	1.4	5.0
Euphrasia gibbsiae	23.5	0.0	1.7	2.0	3.7
Carex gaudichaudiana	23.3	0.2	1.8	0.7	3.9
Rytidosperma nivicola	17.8	0.0	1.3	1.0	2.8
Nertera granadensis	17.6	34.8	2.0	1.4	4.3
Celmisia spp.	16.9	10.6	1.0	0.9	2.1
Olearia algida	13.2	18.1	1.4	1.1	3.0
Erigeron paludicola	12.8	34.7	2.2	1.4	4.9
Drosera arcturi	12.4	0.5	0.9	1.0	1.9
Psychrophila introloba	12.2	0.0	0.8	0.5	1.8
Isolepis spp.	11.5	9.0	1.0	1.1	2.1
Epacris petrophila	10.0	7.0	1.2	0.5	2.7
Oreobolus distichus	8.7	0.8	0.6	1.0	1.3
Sphagnum novozelandicum	8.3	7.9	0.9	1.0	1.9
Thelymitra cyanea	7.6	4.1	0.5	1.1	1.2
Asperula gunnii	7.4	39.2	2.4	1.8	5.2
Lycopodium spp.	7.2	0.0	0.5	0.8	1.1
Callistemon pityoides	3.2	5.7	0.6	0.5	1.3
Brachyscome obovata	0.0	12.1	0.9	0.7	1.9

Community type descriptions and environmental characteristics

Western montane fen: This occurred on gentle slopes (2-5%) at elevations ranging from 1000 m to 1150 m, and was always situated on shallow valley floors and in close proximity to open forest, tall open forest or cool temperate rainforest (Table 3.32). Peats and associated organic soils were deep (mean depths 113-189 cm). Mean shrub cover was moderate (14-46%) and stature quite tall (mean shrub canopy height 62-111 cm). *Sphagnum* species cover was high but variable (6-92%, Table 3.33), *Carex* species were the dominant sedges (*C. appressa*, *C. gaudichaudiana*; 3-20% cover), and ericaceous shrubs were important (*Richea victoriana*, *Epacris microphylla* var. *rhombifolia*; 12-36% cover) (Figure 3.40). The cover of myrtaceous shrubs was variable but generally low (0-10%), 'other mosses' were a significant presence (e.g. *Polytrichum* spp.; 0-22% cover) and small ferns like *Blechnum penna-marina* were common but provided little overall cover.

Western montane wet heath: Occurred at similar elevations and was situated on similarly gentle slopes (as WMF), but tended to be greater in area, hence more isolated from the influence of neighbouring forests (20-100 m mean distance to forest). This peatland community type tended to occupy slightly drier aspects and topographic positions than Western montane fen, and as a consequence appears to be less prone to periodic surface water inundation (Figures 3.41 and 3.42). Peats were deep (174-200+ cm mean depths), shrub cover and stature were moderate to high (25-54% mean cover, 66-100 cm mean canopy height). The most important plant functional groups were the restiads (*Empodisma*; 13-36% mean cover), ericaceous shrubs (*E. paludosa*, *R. victoriana*; 16-40% cover), *Sphagnum* spp. (0.5-34% cover), and myrtaceous shrubs (*Baeckea*; 2-12% cover).

Western subalpine raised bog: Situated on gentle to moderate slopes (2-9%), at 1400-1510 m elevation, and in relatively close proximity to wooded vegetation (20-60 m) (Figure 3.43 and 3.44). Peats were moderate to deep (70-150 cm), shrub cover and stature were generally lower than in montane peatlands (10-38% cover, 22-39 cm mean canopy height). The important plant functional groups were *Sphagnum* species (33-72% cover), restiads (9-45% cover), ericaceous shrubs (*R. continentis*, *E. paludosa*; 8-36% cover), and *Astelia* (1-24% cover). *Carex* species, ‘other sedges’ (*Oreobolus*, *Carpha*), ‘other herbs’, and myrtaceous shrubs (*Baeckea*) were also common.

Western subalpine wet heath: This was generally associated with, and adjacent to Western subalpine raised bog, thus found at similar elevations and on similar slopes. Mean peat depths were slightly lower (40-120 cm), shrub cover and stature were higher (20-60%, 30-70 cm mean canopy height), and aspects and topographic positions slightly drier than in Western subalpine raised bog (Figure 3.45 and 3.46). Important structural groups were ericaceous shrubs (*R. continentis*, *E. paludosa*, *E. petrophila*; 19-50% cover), restiads (13-42% cover), *Astelia* (1-22% cover), myrtaceous shrubs (*Baeckea*; 0-17% cover), and *Sphagnum* species (0-30% cover). Other groups were less conspicuous, with the exception of the dicot herb groups (e.g. *Celmisia*, *Euphrasia*, *Coprosma*).

Site descriptions and observations: montane sites

There were two strongly contrasting peatland community types found in montane areas. The patterns at Thomson Fen, north-west of the Baw Baw plateau, perhaps best illustrate the differences. At the margins of this site, the peatland vegetation was dominated by Western montane wet heath, including *Empodisma minus*, tall *Richea victoriana*, *Epacris paludosa*, *Baeckea gunniana*, and some *Sphagnum cristatum*. Further down slope towards the centre of treeless areas and along the main drainage streams, these species disappeared and were replaced by wet tussock grassland dominated by *Poa labillardieri* and *Carex* species (Figure 3.42).

In other sections of this peatland complex, such as the ‘Newlands’ site, vegetation was made up entirely of Western montane fen, the difference being that *Empodisma minus*, *Epacris paludosa* and *Baeckea gunniana* were absent. In their absence *Sphagnum* and *Carex* cover was greater. Other common species include *Richea victoriana*, *Ozothamnus* sp.1, and *Epacris microphylla* var. *rhombifolia* (Figure 3.40). The smaller Stronachs

Table 3.32: The mean, standard error, and range of values of several factors for the **Baw Baw-Central Highlands region peatland communities**. WMF = Western montane fen, WMW = Western montane wet heath, WSR = Western subalpine raised bog, WSW = Western subalpine wet heath.

Environmental and structural factors	**Community type** **WMF**	 **WMW**	 **WSR**	 **WSW**
Altitude (m)	**1085 ± 10** 1050 - 1120	**1123 ± 27** 1035 - 1175	**1450 ± 17** 1400 - 1510	**1432 ± 20** 1330 - 1520
Peat depth (cm)	**151 ± 12** 113 - 189	**193 ± 4** 174 - 200	**109 ± 11** 73 - 148	**88 ± 9** 48 - 120
% slope	**3.8 ± 0.4** 2.0 - 5.0	**3.3 ± 0.2** 3.0 - 4.0	**4.4 ± 0.9** 2.0 - 9.0	**5.5 ± 0.7** 2.0 - 8.0
Shrub cover (%)	**33 ± 5** 14 - 46	**36 ± 4** 25 - 54	**21 ± 4** 10 - 38	**39 ± 4** 21 - 61
Shrub height (cm)	**86 ± 8** 62 - 111	**81 ± 6** 66 - 100	**30 ± 3** 22 - 39	**51 ± 5** 30 - 73
Aspect	**2.7 ± 0.3** 1.0 - 3.0	**3.2 ± 0.2** 3.0 - 4.0	**2.7 ± 0.4** 1.0 - 4.0	**2.9 ± 0.4** 1.0 - 4.0
Topographic position	**1 ± 0.0** 1.0 - 1.0	**1.2 ± 0.2** 1.0 - 2.0	**1.3 ± 0.2** 1.0 - 2.0	**1.7 ± 0.2** 1.0 - 2.0
Distance to woodland (m)	**33 ± 3** 20 -40	**72 ± 13** 20 - 120	**44 ± 5** 20 - 60	**37 ± 8** 20 - 100

Camp site (approx. 5 ha) is mostly Western montane wet heath, with approximately 20% of the peatland being an area of periodic inundation dominated by *Poa* tussocks and *Carex* species.

At Storm Creek in the Central Highlands, the predominant peatland community was Western montane wet heath (Figure 3.41), similar to Stronachs Camp. Once again, there were smaller sections within the peatland that experience periodic inundation and ‘flushing’, these are favoured by species typical of Western montane fen, such as *Epacris microphylla* var. *rhombifolia*, *Carex appressa*, *Tasmannia xerophila*, *Blechnum penna-marina* and *Poa* species (tussocks). At the Tom Burns Creek and Little River peatlands the vegetation is entirely Western montane fen. The former site was dominated by *Richea*

Table 3.33: Mean percent cover, standard error, and range of cover values for each plant functional group in the **Baw Baw-Central Highlands region peatland communities**. Abbreviations as for table 3.32.

Plant functional group	**Community Type**			
	WMW	**WMF**	**WSW**	**WSR**
Ericaceous shrubs	**28.1 ± 3.8**	**27.2 ± 4.8**	**28.4 ± 3.6**	**18.3 ± 3.8**
	16.0 - 39.8	12.1 - 36.6	19.3 - 49.9	8.6 - 35.6
Myrtaceous shrubs	**6.6 ± 1.6**	**3.3 ± 1.7**	**9.1 ± 2.4**	**1.9 ± 0.8**
	1.8 - 12.4	0 - 10.0	0 - 17.0	0.1 - 6.4
Other shrubs	**0.8 ± 0.3**	**2.7 ± 1.3**	**1.8 ± 1.3**	**0.8 ± 0.6**
	0 - 2.0	0 - 7.9	0 - 11.7	0 - 4.7
Astelia	**0.3 ± 0.3**	**0.0**	**8.2 ± 2.6**	**6.1 ± 2.7**
	0 - 1.9	0.0	1.4 - 22.7	1.2 - 24.6
***Carex* spp.**	**4.4 ± 1.7**	**9.8 ± 2.3**	**0.1 ± 0.1**	**1.9 ± 1.5**
	0.3 - 10.5	3.2 - 20.0	0 - 1.1	0 - 11.8
Other sedges	**< 0.1**	**< 0.1**	**1.0 ± 0.4**	**3.9 ± 1.4**
	0 - < 0.1	0 - 0.1	0 - 2.6	0.1 - 11.3
Restiads	**22.0 ± 3.1**	**0.0**	**24.2 ± 3.3**	**20.6 ± 4.2**
	13.6 - 36.1	0.0	13.7 - 42.5	8.7 - 45.4
Other monocots	**0.2 ± 0.2**	**1.0 ± 0.7**	**1.4 ± 0.9**	**1.0 ± 0.1**
	0 - 1.3	0.1 - 4.3	0.1 - 8.2	0.5 - 1.4
Herbs	**0.2 ± 0.1**	**1.0 ± 0.4**	**2.1 ± 0.9**	**2.0 ± 0.4**
	0 - 0.8	0.2 - 2.9	0.4 - 8.6	0.5 - 4.0
***Sphagnum* spp.**	**15.8 ± 4.7**	**48.9 ± 13.7**	**11.5 ± 3.1**	**50.4 ± 4.6**
	0.4 - 34.5	6.4 - 92.5	0 - 29.6	33.6 - 71.7
Other bryophytes	**1.1 ± 0.8**	**8.0 ± 3.9**	**0.1 ± 0.1**	**0.4 ± 0.3**
	0 - 4.7	0 - 22.6	0 - 0.8	0 - 2.6

victoriana, *Carex appressa*, *Epacris breviflora* and *Leptospermum grandifolium*. Composition was similar at Little River, but *Epacris breviflora* was absent and *Sphagnum* cover high. The surrounding vegetation at Little River is unusual for this region, being dominated by *Eucalyptus perriniana* open forest with an understorey of more subalpine species, such as *Leionema phylicifolium* and *Trochocarpa clarkei*. All other montane sites visited in this region were surrounded by tall open forest (*E. delegatensis, E. nitens*) or cool temperate rainforest (*Nothofagus cunninghamii*).

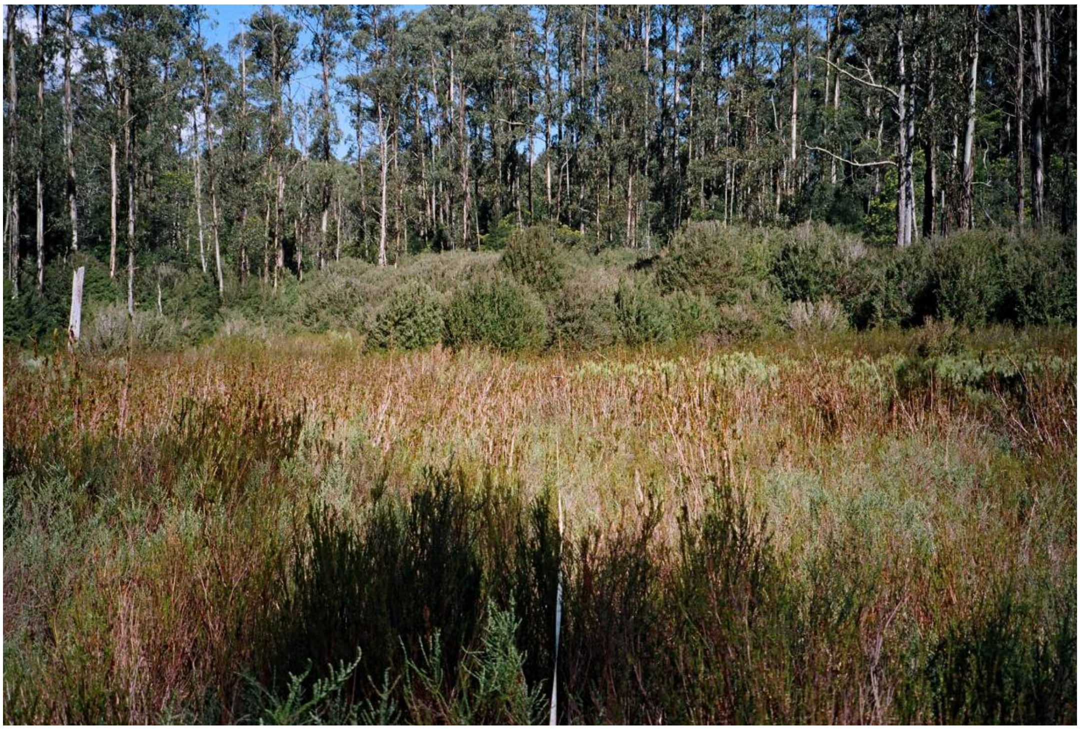


Figure 3.40: An example of Western montane fen vegetation. This is the site of the transect at ‘Newlands’ in the upper Thomson area. Dominant species at this site included *Sphagnum cristatum*, *Richea victoriana*, *Epacris microphylla* var. *rhombifolia*, *Olearia algida* and *Ozothamnus cupressoides*. Spreading rope-rush, *Empodisma minus*, was absent from this peatland community type.

Figure 3.41: Western montane wet heath at Storm Creek in the Central Highlands. Flowering species are *Richea victoriana* in the foreground and *Epacris microphylla* var. *rhombifolia* behind. Other species visible include *Baeckea gunniana* and *Empodisma minus*.

Figure 3.42: Western montane wet heath in the upper Thomson area. The central area dominated by *Poa labillardierei* tussocks is subject to periodic inundation. The margins on higher ground carry wet heath dominated by *Empodisma minus*, *Epacris paludosa*, *Baeckea gunniana*, *Richea victoriana* and *Sphagnum cristatum*. The surrounding tall wet forests are dominated by *Eucalyptus nitens* and E. *delegatensis*.

Figure 3.43: Subalpine peatland at Freemans Flat on the Baw Baw plateau. The Western subalpine raised bog vegetation surrounding the pool complex merges with Western subalpine wet heath adjacent to woodland areas on the upper slopes.

Figure 3.44: Western subalpine raised bog vegetation at Gwinear Flat on the Baw Baw plateau. Species visible include *Sphagnum cristatum*, *Empodisma minus*, *Astelia alpina*, *Epacris paludosa*, and *Richea continentis*.

Figure 3.45: Western subalpine wet heath vegetation at Pauciflora Flat on the Baw Baw plateau.

Figure 3.46: Western subalpine wet heath at Gwinear Flat on the Baw Baw plateau. Dominant species in this wetland vegetation type include *Epacris paludosa*, *Baeckea gunniana*, *Richea continentis*, *Empodisma minus*, *Olearia algida* and *Astelia alpina*.

Site descriptions and observations: subalpine sites

The subalpine sites were surrounded by open forest, low open forest or woodland of *Eucalyptus pauciflora*, with a shrub-dominated understorey. The peatlands in the Central Highlands area were generally smaller and less extensive than those at Baw Baw. They also tended to occur in closer proximity to wooded areas, a reflection of the slightly lower mean elevation (c. 1400 m compared with 1470 m).

The Mt Bullfight wetland was only about 3 ha in area and situated on the gentle south-east and east slopes of the range, where abutted by *Eucalyptus pauciflora* open forest. In smaller pockets along the upslope margins (west) of the treeless areas there were small patches of cool temperate rainforest with *Nothofagus cunninghamii*, *Leptospermum grandifolium* and *Baeckea latifolia*. The Mt Bullfight wetland is significant because it contains some unusual species co-occurrences. Both *Richea continentis* and *Richea victoriana* were common at this peatland, the latter is usually restricted to montane areas. There were three species of *Epacris* at this site. These were *Epacris paludosa*, *Epacris petrophila* and *Epacris microphylla* var. *rhombifolia*; the latter of the three is also more often encountered in montane peatlands.

The Lake Mountain sites were similar in landscape setting and associated with similar patches of cool temperate rainforest along sections of their western margins. Some of these rainforest patches also contained the native conifer *Podocarpus lawrencei*. One of the most common species in the peatlands at these sites is *Astelia alpina*. The second of the Lake Mountain sites (Triangle Junction) did not have the abutting band of cool temperate rainforest, but had some small adjacent areas of grassland and open heath, otherwise rare at Lake Mountain. *Sphagnum novozelandicum* was particularly abundant in the pools and channels of this peatland. This second species of *Sphagnum* was particularly prominent in peatlands on the Baw Baw plateau.

Separation between the peatland boundaries and woodland margins is generally greater at Baw Baw, although the surrounding damp heath generally merges with wet heath at the peatland margins (Figures 3.43-3.46). There were many herbaceous species at these sites that do not occur in subalpine peatlands in the Central Highlands, such as *Psychrophila introloba*, *Euphrasia gibbsiae*, *Coprosma perpusilla*, and *Erigeron tasmanicus*, to name but a few. There were also sedge species not present in the Central Highlands, such as *Carpha* spp. and *Oreobolus pumilio*. The large treeless area 4 km north-west of the Baw Baw ski village known as ‘the Morass’, is at the lower end of the subalpine altitude bracket but contains one of the largest continuous peatland areas on the plateau. There is approximately 70 to 80 ha of treeless vegetation at this location and roughly 50% of this is peatland. The vegetation was mostly Western subalpine wet heath, with smaller patches of Western subalpine raised bog. Common species at this peatland included *Richea continentis*, *Empodisma minus*, *Epacris petrophila*, *Astelia alpina*, *Carex gaudichaudiana*, *Poa costiniana* and *Sphagnum novozelandicum*.

3.4 DISCUSSION

3.4.1 Bogong region patterns and environmental determinants

The peatland communities in the Bogong High Plains region sort predominantly along gradients in altitude and topography. The factors correlated with altitude are the obvious climatic variables such as temperature, precipitation, cloud cover, humidity, wind exposure, snow cover duration and length of growing season. The climatic differences due to altitude in this region appear to be further enhanced by the predominant direction of wind and air mass flow, which also produces a strong west to east rainfall gradient. The alpine sites are all positioned to the west or north-west and windward (e.g. Rocky Knobs, Pretty Valley); the subalpine sites are east or south-east and consequently leeward (e.g. Buckety Plain, Wild Horse Creek). The subalpine areas examined appear to receive less precipitation than those at similar elevations on the steeper north-western approaches to the region (Ashton and Williams 1989, see also Chapter 2 ‘Climate’), but they benefit from the shelter provided by their leeward location.

The climatic variables interact at local scales with factors associated with topography. Depth to water table or hydrology is one of these factors, and ultimately influences the capacity for *Sphagnum* growth and dominance, thus peat depth or accumulation. These topographic differences are also reflected in the distribution of the other major plant life-forms, functional groups and individual vascular plant species. This is apparent at the vegetation formation level, with fens occupying valley floors, bogs generally on the lower slopes (valley bog and raised bog), wet heathland on the mid-slopes and marginally better drained areas. Associated with ‘Fen pools’ dominated by *Carex gaudichaudiana*, which are scattered across the higher valley floors (McDougall and Walsh 2007), are areas of Low wet heath and Alpine valley bog described in this chapter. The Alpine valley bogs are dominated by *Sphagnum cristatum* and sedges, but shrub cover is typically less than 15% and shrub stems barely protrude above the undulating *Sphagnum* ‘carpet’. The low shrub cover and stature is partly due to high water tables and competition from *Sphagnum* and sedges, it is also partly influenced by exposure and cold-air accumulation (Williams 1987), which must further limit the competitiveness of the shrub species.

The microclimate differs between mid-slope positions (closer proximity to wooded areas in this context) and lower slope positions or valley bottoms, where cold air accumulates (Leigh et al. 1987, Williams 1987). Hence, the plant species in peatland communities not only sort along hydrological gradients, but also according to tolerance of frost and wind exposure. Topography, aspect and slope also determine snow accumulation and persistence patterns, which also influence vegetation patterns in this region (McDougall 1982, Ashton and Williams 1989, Wahren 1997), as they do in alpine areas generally (Billings and Mooney 1968, Billings 1973, Bliss 1979). The exposed nature of the 'alpine' peatlands means that wind contributes to evapo-transpiration and influences the moisture balance in peatlands, but also contributes less directly through its influence on snow-drift and accumulation patterns. Wind has been identified as an important influence on peatland vegetation patterns elsewhere in southern Australia (Morgan et al. 2010). Its influence on peatland vegetation in this region may have been under estimated in the past.

The Low wet heath communities described in this chapter are akin to '*Epacris glacialis* moist heathland' (Walsh and McDougall 2007), 'Relict Bog' (McDougall 1982) and 'Low open heath' (Wahren 1997, Wahren et al. 2001a), and are situated on shallow 'dried peats' and in better drained positions than Alpine raised bog or Alpine valley bog. They are common in the broad, gently sloping expanses of the Pretty Valley and Cope Creek area on the Bogong High Plains, where frost frequencies and wind speeds are high (Williams 1987).

The greater 'stress' associated with the higher altitude peatland communities can be seen in the higher prominence of species which are arguably less competitive (Grime 1979), such as the hard-leaved graminoids *Oreobolus distichus* and *Astelia alpina*. These species sometimes exhibit 'cushion' or 'matted' growth form and they, or similar species from the same genera, are associated with 'cushion bogs' in Tasmania and elsewhere in the southern hemisphere (Gibson and Kirkpatrick 1985b, Mark et al. 1995, Kleinebecker 2007). Rosetted dicot herbs such as *Celmisia*, *Diplaspis* and *Gentianella* are also more common under conditions less conducive to shrub and *Sphagnum* dominance. The stress associated with 'alpine' bogs and low wet heath is also reflected by the close association of these communities with the 'Short alpine herbfield' or 'Gravel pavement' communities associated with late-lying snow (McDougall 1982, Costin et al. 2000, McDougall and Walsh 2007). These are not peatlands, but small wetland communities irrigated by melt-water from late-lying snow-patches and permanent springs, usually on the steep south-eastern slopes of the highest ridges. Hard-leaved graminoids and rosetted herbs colonise these areas, including *Oreobolus pumilio, Psychrophila introloba* and *Juncus antarcticus* (Wahren 1997, Wahren et al. 2001a).

In sheltered subalpine bogs, *Sphagnum* cover is generally higher, shrubs such as *Epacris paludosa* and *Baeckea gunniana* are increasingly dominant, and dicot herb presence is considerably lower. The floristic and structural differences between the three subalpine peatland communities were also partially correlated with differences in topographic position, degree of slope, aspect, and particularly distance from woodland. Hence, the shrub-dominated wet heaths tend to be in steeper mid-slope 'seepage' positions and on aspects exposed to higher insolation and the prevailing north-west wind (see Figure 3.15), while *Sphagnum*-dominated communities are on deeper peats, gentle slopes, lower topographic positions and more favourable aspects. Myrtaceous shrubs are associated most with wet heath on steeper slopes, topographically drier positions and shallow decomposed peats. They are also closest in proximity to wooded or forested areas, with associated milder microclimate.

The Tall wet heath and Myrtaceous wet heath plots in this study are closest to the '*Baeckea gunniana-Callistemon pityoides-Sphagnum cristatum*' wet heathland described by McDougall and Walsh (2007). The important difference between the two in this analysis is the apparent absence of the key shrub *Richea continentis* in Myrtaceous wet heath. This would appear to have something to do with fire-sensitivity (Walsh and Wahren 2000, Wahren et al. 2001b).

McDougall and Walsh (2007) did not differentiate between Alpine valley bog, Alpine raised bog and Subalpine raised bog in their broad-scale study of subalpine and alpine vegetation across the entire south-eastern highlands of Australia. In that study, '*Richea continentis-Carpha nivicola-Sphagnum cristatum*' wet heathland encompasses the three 'bog' communities described here for the Bogong region. Analyses in this study do suggest that there is overlap between these three groups and differences are perhaps marginal. In descriptions and classifications of alpine and subalpine vegetation at Kosciuszko in New South Wales, the *Sphagnum* and sedge-rich 'Valley bog' communities were separated in analyses from more shrub and *Sphagnum*-dominated 'Raised bogs' (Costin 1954, 1957, Costin et al. 2000). 'Valley bog' communities appear to be more restricted on the Bogong High Plains compared with the Kosciuszko area, and would appear to be confined to Pretty Valley and a few other smaller areas within peatlands elsewhere in the region.

Epacris glacialis and *Astelia alpina* were the best indicator species for separating alpine and subalpine peatlands. Both were prominent in Low wet heath and common in Alpine raised bog, but the latter species was rare, and the former absent, from subalpine peatlands in the region. The myrtaceous shrubs became more prominent with declining altitude and strengthening associations with more wooded neighbouring ecosystems and non-wetland communities. McVean (1969) draws attention to the presence of *Astelia alpina* and *Astelia psychrocharis* in 'alpine bogs' at Kosciuszko as a good means of differentiating between this community and the nearby 'subalpine bogs' where species of *Astelia* are absent. This distribution of *Astelia alpina* in the Kosciuszko region is also supported by the findings of Clarke and Martin (1999). In their study, there was a clear separation of alpine sites from subalpine sites (above and below 1820 m). The same study also reports a decline in the cover of *Baloskion australe* with increasing altitude. A similar trend was identified here.

Whether or not the distinctions between all the different peatland communities identified here are valid or 'real' is perhaps inconsequential. They are useful in the context of this study for the purposes of gradient analysis, and there are certainly indicator species that are meaningful in relation to each transition in the Bogong region, if not the broader Australian Alps context (*Astelia*, *Baloskion*). The common ericaceous shrubs *Epacris glacialis* and *Epacris paludosa* separate according to altitude. At higher altitude sites (> 1620 m) they also separate according to topography and microclimate, with *E. paludosa* occurring in peatlands closer to wooded vegetation, and *E. glacialis* downslope in large treeless valley bottoms (J. Shannon *pers. obs.*). The attributes of these and other species obviously reflect the changing influence of the environmental and biotic factors discussed above.

3.4.2 Snowy Range and Dargo High Plains region patterns and environmental determinants

There were similarites between the subalpine peatlands of the Snowy Range-Dargo High Plains region and the Bogong region. However, the patterns are more complex, due to lower altitudes, less clear-cut climate gradients, and less uniform geology (Farrell and Ashton 1973, Ashton and Williams 1989). In general, the same relationships between vegetation patterns, slope, aspect, topographic position, peat depth, and proximity to wooded areas apply. The three ‘subalpine’ wetland community types described for the Bogong region occur in this region, and one of these, Myrtaceous wet heath, is also common in montane areas. The subalpine and montane communities were separated by temperature and rainfall indices in the analyses. The plant functional groups most associated with this split were ericaceous shrubs and restiads, the latter being most prominent at lower elevation. The bog communities were separated from the wet heath communities by topographic position, slope, aspect and distance to woodland, although not all of these variables were statistically significant in correlations. The plant functional groups strongly correlated with this dichotomy were *Sphagnum* species and myrtaceous shrubs. The depth to water table gradient, although not measured, is likely to be largely responsible for separating Subalpine raised bog from Tall wet heath in subalpine areas, and Montane valley bog from Myrtaceous wet heath in montane areas. The mean cover of *Sphagnum cristatum* in this case can perhaps be used as a surrogate for depth to water table; this varied from 76% in Subalpine raised bog, to only 26% in Tall wet heath. In montane peatlands, the gradient in *Sphagnum* cover and 'inferred' depth to water table was from 15% in Myrtaceous wet heath (deep), to 52% in Montane valley bog (shallow).

Walsh et al. (1984) noted that two sub-communities of the 'Wet alpine heathland' complex differed in proximity to woodland (sub-communities 9.5 and 9.6). The data in these analyses tend to support these observations. The sub-community '9.6' in that classification was dominated by wet heath shrubs such as *Callistemon pityoides*, *Baeckea gunniana*, *Epacris paludosa* and *Hakea microcarpa*, similar to Myrtaceous wet heath transects in this study. Again, as in the Bogong region, *Richea continentis* was conspicuously absent, and is also absent from Montane valley bog transects. The floristics in these peatland communities gradually assume a more lowland wet heath character, with increasing representation from genera like *Hakea*, *Baloskion*, *Leptospermum*, *Juncus*, *Baumea*, *Comesperma* and *Pultenaea* (Forbes et al. 1982). However, these species also appeared in peatlands on drier and warmer aspects at higher elevation (e.g. Cave Gate Creek).

There were subtle structural and floristic differences in subalpine peatland communities on the basalt-capped areas such as those at Omeo Plain and Piemans Creek, although these were not always apparent in the analyses. Hummocks appeared more pronounced and the presence of herbaceous taxa was greater (e.g. *Craspedia, Ranunculus*). Hummock height in peatlands can be enhanced by emergent upright shrubs, which provide a 'scaffold' structure for the associated *Sphagnum* species (Clymo 1973, Van Breeman 1995, Whinam and Buxton 1997, McDougall 2001). In these peatlands, it was shrubs like *Baeckea gunniana*, *Epacris paludosa* and *Callistemon pityoides* providing the scaffolding, and they sometimes reached heights of a metre or more above the *Sphagnum* or peat surface. The proportion of Tall wet heath in the peatlands on the Dargo High Plains was particularly high and there were also sections dominated by *Richea continentis*, a species normally associated with *Sphagnum cristatum*. In these patches the *Richea* growth form is rounded and hummock shaped (see Figure 3.47), and could signify changes to hydrology, long-term drying, and *Sphagnum* retreat, possibly enhanced by high levels of local disturbance (Wahren 1992a, 1992b).

Figure 3.47: Hummock shaped growth-form of wet heath shrubs on the Dargo High Plains. *Richea continentis* is the most common species, but *Baeckea gunniana* and *Epacris paludosa* are also present. Other peatland species are now absent, including *Sphagnum*, possibly indicating a long-term trend towards lower water table at this location.

The basalt capped regions of both the Snowy Range and the Dargo High Plains have a strong association with domestic livestock grazing (Walsh et al. 1984, Ashton and Williams 1989, Wahren 1992b). Therefore the differences in structure, higher species richness, increased dicot herb representation, and prominence of exotics, are likely to be partly a result of the recent exogenous disturbance history (last 130 yrs).

Montane peatland communities were examined in two areas of the Snowy Range region. Those at Bennison Plains are at slightly higher elevation (c. 1260 m) and more associated with woodland and treeless non-wetland communities than those in the Moroka Valley (c.

1100 m). The local influence of cold-air drainage appears to be particularly strong there (Farrell and Ashton 1973), and likely to be responsible for the larger areas of treeless vegetation. Floristically, the montane peatland communities examined were closest to the ‘*Callistemon-Baeckea-Sphagnum* wet heaths’ described by Walsh and McDougall (2007), and similar montane-subalpine wet heaths in the Australian Capital Territory (ACT) (Hope et al. 2009). The key difference is the absence of *Richea continentis* which is the principal reason for separating Mytaceous wet heath and Tall wet heath in the stratified sampling regime. This classification was also observed for shrub-dominated bogs in the ACT (Hope et al. 2009). Montane valley bog was structurally somewhat similar to the higher altitude Alpine valley bogs in their shared dominance of *Sphagnum* and sedges, but floristically most similar to ‘*Empodisma minus* restiad fen’ from ACT (Hope et al. 2009). Montane peatland communities in far eastern Victoria and southern New South Wales also appear to be floristically similar (Costin 1954, Ladd 1979a, Keith 2004).

3.4.3 Baw Baw and Central Highlands region patterns and environmental determinants

In the Baw Baw - Central Highlands region, there seems to be more variability in the non-*Sphagnum* dominated wet heaths. The plots at the *Sphagnum*-dominated end of the gradient (WSR) are closely allied with, and conform to, the descriptions of the ‘Baw Baw - Lake Mountain wet heath’ (McDougall and Walsh 2007) and ‘Wet alpine heathland community 9.2’ in earlier work (Walsh et al. 1984). The plots at the drier end of the gradient, classified in this study as Western subalpine wet heath (WSW), probably span ‘Baw Baw - Lake Mountain wet heath’ and ‘*Epacris petrophila* open heathland’ (McDougall and Walsh 2007); and the earlier classification ‘Wet alpine heathland community 9.1’ (Walsh et al. 1984). The overlap between floristic groups is perhaps a further reflection of the general vegetation patterns in this region. Distinctions between communities are less clear, transitions from dry heath to wetter heaths, and then to bogs, are often gradual (Ashton and Williams 1989). These regions lack the extensive grasslands and more open heaths of the areas further north and east, and this is widely thought to be due to the influence of the more oceanic climate (Costin 1957, McVean 1969, Bridle and Kirkparick 1999). Comparisons of the proportional representation of peatland in treeless areas also reflect differences in climate. Peatland vegetation covers approximately 36% of the treeless area on the Baw Baw Plateau, and 9% of the total area above 1300 m. This compares with a combined peatland-wetland vegetation cover of approximately 15% in treeless areas on the Bogong High Plains. However, the Bogong region has the largest total area of peatland vegetation in Victoria (Tolsma and Shannon 2009, Western et al. 2009).

In terms of gradients in altitude, apart from the obvious climatic differences (rainfall, temperature), other environmental variables separating the montane and subalpine peatlands in this study included peat depth and slope; the latter was greater in subalpine peatlands, and the former in montane sites. The deeper peats in montane sites imply that these have been functioning as peatlands for longer (McKenzie 1997). Plant functional groups most associated with altitudinal differences were the ‘cushion bog’ or ground-layer species common in subalpine plots (*Astelia*, ‘other sedges’, herbs). *Carex* species were more prominent in montane peatlands and mean shrub canopy height taller. Topography, slope, and ‘inferred’ hydrology separated wet heath from bog-fen in both elevation zones. The strongest plant functional group indicators for this dichotomy were *Sphagnum* and myrtaceous shrubs. However, differences due to topographic position were greater in montane plots, despite slope and general relief being low. The differences were partly driven by the larger size of the peatlands or catchment areas. Western montane fen is prone to inundation and had higher cover of *Carex*, ‘brown mosses’, other monocots (*Poa labillardierei*, *Juncus* spp.), and ‘other shrubs’ (*Tasmannia xerophila*, *Olearia algida*). More enclosed examples also contain *Leptospermum grandifolium* and the small fern *Blechnum penna-marina*.

The clearest floristic distinction was between Western montane fen (WMF) and all other community types because of the absence of restiads (Family Restionaceae). This was the strongest unifying characteristic of this floristic group, otherwise composition was variable and included some species more associated with adjacent tall open forest understorey strata. *Empodisma minus* appears to be ‘keystone’ species in the peatland ecosystems of south-east Australia, New Zealand and the Subantarctic Islands, being universally dominant or co-dominant in nutrient poor, acidic wetlands (Whinam and Hope 2005, Clarkson and Clarkson 2006). *Empodisma minus* is also thought to possess similar cation exchange capacities to *Sphagnum* (Agnew 1993) and thus, similar ability to influence the pH, base status and nutrient availability (Van Breeman 1995). In southern hemisphere peatlands, the dominance or prominence of restiads like *Empodisma minus* may be a more reliable indicator of oligotrophic, mineral poor peatland conditions than *Sphagnum*. Its absence from Western montane fen suggests a strong allogenic influence from the surrounding lanscape (and possibly parent bedrock). This could be through soil fertility, via runoff and seepage water from the surrounding highly productive tall open forests (wet-sclerophyll) (Gibbons and Rowan 1993). These generally have higher phosphorus availability than open forest (dry-sclerophyll), which in turn have higher phosphorus levels than heathland or scrub (Beadle 1954, 1962). The more mesophytic understorey composition in tall open forest, compared to open forest, is also thought to be an indicator of improved phosphorus availability (Beadle 1954, 1962). The common sedge, *Carex appressa*, is a species that seems to be associated with streams and ‘flushing’ (Shannon 2003), or water movement and thus higher nutrient and oxygen availability. It is more commonly associated with lower elevation wetland areas in Victoria (Conn 1993), and graminoid-dominated fens in montane areas of southern New South Wales (Costin 1954, Keith 2004, Hope et al. 2009).

3.4.4 General discussion

Plant functional groups

In general, peatland ecosystems above 1000 m elevation in south east Australia are dominated by *Sphagnum* and scale-rushes from the family Restionaceae (restiads), particularly *Empodisma minus*. These are associated with dwarf shrub species and grade into taller shrub dominated wet heath vegetation at margins. Dwarf shrubs are characteristic of peatlands the world over and the Ericaceae family is prominent in both hemispheres. Its success in peatlands is attributed to sclerophylly and the unique ecto-mycorrhizal associations that it forms, which enable greater nutrient uptake (Read 1996).

Most vascular plants form mycorrhizal associations of some description, particularly those in non-wetland plant communities on nutrient poor soils. They greatly enhance the host plants uptake of phosphorus and nitrogen in particular; however, these symbiotic relationships between host plant and fungal partner are less common in peatlands (Rydin and Jeglum 2006), probably because of the lack of oxygen in the rhizosphere. In the appropriate micro-topographical positions (e.g. hummocks), mycorrhizal associations have been identified in some peatland plant species (Read 1996). Shrubs from the family Ericaceae have their own unique ectomycorrhizae; these release enzymes into the surrounding soil, which enhance mineralisation in the vicinity of the root network (Read 1996). They are called ‘ericoid’ mycorrhizae to distinguish them from other more common forms of ectomycorrhizae, and are obviously advantageous where organic matter is particularly decay resistant, as is the case in *Sphagnum*-dominated peatlands (Van Breeman 1995). This symbiotic relationship is possibly the main reason that ericaceous shrubs are prominent in peatlands all over the world. Ericoid mycorrhizae have also been identified in highland Australian ericaceous shrubs, including the species commonly found in peatlands (Davies et al. 2003).

The ‘cushion’ growth form is seen in many peatland plants in alpine and oceanic regions of the temperate southern hemisphere (Chile, New Zealand, Tasmania), and also at high altitude in New Guinea (Hope and Gibson 1986), but less so in similar parts of the north (Bliss 1979). There are also examples from arid or semi-arid regions (Parsons and Gibson 2009). Cushion plants are chamaephytes or hemicryptophytes that form tight, closely branched compact hemispherical structures. The resultant small cushions or hummock growth forms can be quite hard. Cushion plants were first classified by Rauh (1939) and strict definitions allow for plants in which the cushion growth habit is both obligate and facultative. Cushion-form species appear to thrive under hyper-oceanic climate conditions (constant mist, moisture, wind, and little variation in temperature). Most explanations of the adaptive significance of the growth form relate to stresses of various kinds, including high wind, temperature extremes, moisture stress, and low soil fertility (Gibson and Kirkpatrick 1985b). Any or all of these could explain their presence in the oceanic peatlands of the southern hemisphere, with the probable exception of moisture stress (Moore 1979, Pisano 1983, Gibson and Kirkpatrick 1985b, Gibson and Hope 1986). Species capable of this growth habit in peatlands include hard-leaved sedges (*Oreobolus*, *Carpha*), other hard-leaved monocots such as *Astelia*, some herbs (*Abrotanella*, *Donatia*, *Phyllacne*) and some ericaceous shrubs (e.g. *Dracophyllum* spp., *Pentachondra pumila*).

Cushion plants are a useful functional group, indicative of certain abiotic conditions. Pisano (1983) notes when describing cushion bog dominated by *Astelia pumila* and *Donatia fascicularis* in southern Patagonia, that the former species is favoured by mineralised water and therefore unlikely to be in ombrotrophic sections of peatland. Therefore it colonises areas of excess groundwater discharge in between ombrotrophic patches dominated by raised *Sphagnum magellanicum* bog. In more oceanic western parts of Patagonia cushion-bog is dominant (Kleinebecker et al. 2007, 2010), but associated peats are generally shallow and more decomposed. A similar association with shallow, ‘irrigated’, decomposed peats was observed for *Astelia alpina* and *Oreobolus* species in this study. However, the former species occasionally dominated the crests of *Sphagnum* hummocks, where seemingly more isolated from seepage and surface-flow (see Chapter 4, Figure 4.31).

Other useful functional groups include mosses other than *Sphagnum*, and other dwarf shrubs (e.g. Myrtaceae). The abundance of dicot herbs in peatlands is variable, and when high, often indicates less competition from shrubs and or *Sphagnum*, and thus higher levels of stress or disturbance. High grass representation or abundance in peatlands (Poaceae) can indicate improved drainage and higher soil fertility. The ‘other shrubs’ functional group included the occasional leguminous species (e.g. *Pultenaea tenella*). Nitrogen-fixing vascular plants are uncommon in peatlands and their presence probably indicates better drainage and more marginal peatland conditions (Rydin and Jeglum 2006). The presence of legumes in dry heathland is supposedly limited by low phosphorus availability (Beadle 1954, 1962), which is also a characteristic of peatland environments.

Trends associated with altitude

The landscape context of mountain peatlands in Victoria changes dramatically with increasing altitude, from enclosed valleys with forested upland slopes (Figure 3.48), to open treeless or low sparsely wooded high plains (Figure 3.49). In the more sheltered montane and lower subalpine context, there is vigorous competition between *Sphagnum*, dominant shrubs and the more rapidly growing graminoid species (e.g. *Carex*). The vegetation structure and relative abundance of these competing life-forms are largely dependent on microtopography and hydrology. Therefore, at the lower end of the altitude gradient, peatland vegetation tends to be less diverse and species rich. In the more exposed, high altitude context, growth rates are low, thus competition for light and space is reduced, and peatland vegetation is a more diverse mix of life-forms, functional groups and species. These include the ‘cushion’ or ‘mat-form’ species mentioned above, and other robust, chionophilous graminoids and dicot herbs common in similar environments elsewhere in the southern hemisphere (Gibson and Kirkpatrick 1985b, Gibson and Hope 1986, Mark et al. 1995, Kleinebecker et al. 2007).

This general trend in peatland vegetation structure and composition occurred in all three regions studied here, although it was more pronounced in the Bogong region, where subalpine and alpine peatlands were compared, and to a lesser extent in the Baw Baw-Central Highlands region, where montane and subalpine peatlands were compared. ‘Cushion-bog’ species, hard-leaved graminoids, and rosetted herbs were most prominent in the alpine and more exposed subalpine peatland communities. As a group, ericaceous species, although ubiquitous, also tended to be more prominent at higher elevation. In contrast, restiads and myrtaceous shrubs were more important in montane and the more sheltered subalpine peatlands.

Figure 3.48: Subalpine vegetation at Buckety Plain on the south-eastern side of the Bogong High Plains. The ‘subalpine’ peatland communities visible on the valley floor and lower slopes are more sheltered than their ‘alpine’ associates.

Figure 3.49: Treeless vegetation in Pretty Valley on the Bogong High Plains, illustrating the landscape context of the ‘alpine’ peatland communities. These occur on the valley floor and lower slopes. Non-wetland heath and woodland can be seen on the upper slopes and ridge opposite. Grassland and open heath vegetation can be seen on the better drained areas of the valley floor, and in the foreground.

In the Kosciuszko region of New South Wales many of the same species separate alpine and subalpine peatlands. The former are associated with species of *Astelia, Oreobolus*, *Drosera*, *Celmisia*, *Carpha* and *Gentianella*. In the latter, *Callistemon*, *Baloskion* were more prominent (McVean 1969, Clarke and Martin 1999). In the same study by Clarke and Martin (1999), less common species in subalpine peatlands like *Hakea microcarpa, Leptospermum lanigerum, Isolepis subtilissima* and *Ranunculus pimpinellifolius* were linked with more disturbed sites. Increased *Sphagnum* cover was associated with long undisturbed sites, further illustrating the dominance of superior competitors like *Sphagnum* in sheltered infrequently disturbed peatlands.

Astelia alpina appears to be a useful indicator species for ‘alpine’ or ‘oceanic’ climate peatlands. Palynological work on peat cores from a subalpine peatland at Kosciuszko revealed *Astelia* was locally common when peat began forming at the site in question 10,000 years ago. It persisted during the Holocene until 6,500 years ago, but today this species is restricted locally to sites above 1800 m (Martin 1999). This changing altitudinal distribution pattern is repeated in other paleoecological research in south-east Australia (Kershaw and Strickland 1989, McKenzie 1997).

Further north in montane and subalpine peatlands in the Australian Capital Territory, many of the same species feature, but *Astelia alpina* is absent. Hard-leaved graminoids and herb species associated with alpine peatlands appear to be less conspicuous also (Hope et al. 2009). The key peatland shrub *Richea continentis* was absent from lower subalpine and montane peatlands in that study, as was observed here.

In New Zealand, restiads, particularly *Empodisma minus,* are ubiquitous in lowland peatlands, especially on the west coast of the South Island. They appear to be less common in the higher altitude peatlands of the more central and eastern areas of the south island (Mark et al. 1995, Johnson 2001, Dickinson et al. 2002, Rapson et al. 2006). It is thought that increased burning in the last 600-800 years is partly responsible for its absence (Walker et al. 2001, McGlone et al. 1997, McGlone and Wilmshurst 1999). In eastern Victoria *Empodisma minus* is most abundant in montane and sheltered subalpine peatlands, but still common in alpine areas. It is however curiously absent from some previously heavily grazed alpine peatlands on the Bogong High Plains (Wahren 1997, Wahren et al. 1999b). Peatlands in elevated areas of New Zealand are dominated by many of the same ‘cushion bog’ and chionophilous plant genera common in western Tasmania and alpine areas of mainland Australia, including species of *Oreobolus*, *Carpha*, *Gentianella*, *Euphrasia*, *Coprosma* and *Celmisia* (Mark et al. 1995, Dickinson et al. 2002, Rapson et al. 2006). Ericaceous shrubs are represented by genera such as *Dracophyllum*, *Cyathodes*, and *Pentachondra*.

In Scotland, *Sphagnum*-dominated peatlands are associated with the widespread ericaceous shrub *Calluna vulgaris* and the sedge *Eriophorum vaginatum*. However, *Calluna vulgaris* is limited to areas below 1000 m elevation in the east and 700 m in the more oceanic and wind-swept north-west. *Calluna* is replaced in *Sphagnum* dominated bogs above this elevation by the ericaceous shrub *Empetrum*. Other dwarf shrubs are apparently more common at higher elevation in peatlands including *Vaccinium myrtillus* (also ericaceous) and *Rubus chamaemorus* (Ratcliffe 1964, Brown 1993a).

Influence of parent bedrock type

The influence of parent bedrock type is hard to determine but in theory is an important influence on groundwater fed peatlands and less so for ombrotrophic peatlands. The biggest floristic differences are generally observed with calcareous rock types such as limestone, which produce rich fen vegetation dominated by *Carex* species, ‘brown mosses’, and certain *Sphagnum* species (Joosten and Clarke 2002, Johnson and Steingraeber 2003). The next most important distinction based on parent rock type is between peatlands on basic igneous rocks (e.g. basalt); compared with those on either siliceous igneous rocks (e.g. granite), sedimentary rocks (e.g. sandstone) or metamorphic rocks (e.g. schist, gneiss). The majority of subalpine plots in this study are on these nutrient poor siliceous rock types. A handful of the subalpine plots occurred on basalt, these were all in the Snowy Range - Dargo High Plains region and were classified as Tall wet heath and Subalpine raised bog in these analyses. The influence of basalt may explain some of the variability within these two floristic groups. The basalt bedrock probably has a stronger influence on the extent of peatlands rather than their composition (Ashton and Williams 1989). The basalt capped areas of the subalpine region generally have more extensive wet grassland and herbfield in the topographic positions (valley bottoms, lower slopes) where raised bogs dominate on siliceous rocks in other areas (Walsh et al. 1984). This vegetation pattern on basalt may also be at least partly an artefact of disturbance associated with livestock grazing (Ashton and Williams 1989, Wahren 1992b).

CHAPTER 4

A COMPARISON OF HIGHLAND PEATLAND VEGETATION AND SITES BETWEEN REGIONS ACROSS EASTERN VICTORIA: GRADIENTS IN LATITUDE, LONGITUDE AND OCEANICITY

SUMMARY

In this chapter peatland vegetation composition, structure and environmental influences in three separate mountain regions of eastern Victoria are compared. The three examined regions occur along a climatic gradient that runs from south-west to north-east across highland areas of Eastern Victoria. The gradient is best expressed in BIOCLIM variables such as minimum temperature of the coldest period, precipitation of the driest quarter, and moisture index during the driest periods. These are all higher in the Baw Baw-Central Highlands region. Diurnal and annual temperature range and radiation indices were higher for the areas north-east and east of the Macalister Valley, which forms a useful approximate 'biogeographical' line. Estimated values for hygric continentality (Barry 2008) varied from 32-42°.

The climatic differences were reflected in the landscape context of the peatland areas studied, and this has implications for the nature and strength of allogenic influences on peatlands. Tall open forests and cool temperate rainforest were common adjacent to some peatlands south-west and west of the Macalister Valley. Open forest, woodland and grassland were common adjacent to peatlands north-east and east of the Macalister Valley.

Cushion or 'mat-forming' species, hard-leaved graminoids, rosetted and creeping herbs, were more prominent in the more 'oceanic' subalpine peatland communities 'west' of the 'Macalister line'. These plant groups were less common in subalpine peatlands in the 'east', but were common in exposed 'alpine' peatlands above 1650 m elevation. West of

the Macalister Valley, montane and subalpine peatlands appear to have stronger floristic affinities with montane and subalpine Tasmania. Those in highland areas east of the ‘Macalister line’ have affinities with tableland areas of southern New South Wales (e.g. Monaro, Southern Highlands).

Similar, albeit stronger climatic and floristic gradients occur at higher latitudes in the southern hemisphere (Tasmania, New Zealand, southern South America). In peatlands, similar plant growth forms, species, and genera, are associated with this gradient in these regions (e.g. *Astelia*, *Oreobolus*, *Carpha*, restiads, ericaceous dwarf-shrubs).

4.1 INTRODUCTION

In the broad literature on peatlands and mires several environmental gradients are universally acknowledged as being the principal determinants of vegetation patterns. These are depth to water table, pH - base cation status, and fertility (N, P) (Gore 1983a, Charman 2002, Joosten and Clarke 2002, Rydin and Jeglum 2006). A fourth geographical gradient is recognised, and this is related to the changes in climate that occur with movement from regions adjacent to oceans, to inland and central continental regions: the oceanicity – continentality gradient (Malmer 1986, Charman 2002).

The climatic differences between oceanic areas and continental areas are most apparent in factors such as the amount and annual distribution of precipitation, temperature annual and diurnal variability, cloud cover, humidity, frost frequency and snow cover duration. Relative to continental regions, oceanic areas tend to have higher precipitation and a more even annual distribution, more ‘raindays’ per annum, lower annual and diurnal temperature variability, greater cloud cover and humidity, higher mean wind speeds, lower frost incidence, and shorter snow cover duration (Barry 2008).

Changing vegetation patterns along gradients in oceanicity-continentality have featured in ecological studies of several regions of the world (Moore 1979, Pisano 1983, Brown 1993a, 1993b, Kirkpatick and Bridle 1998, 1999). There are numerous examinations of the influence of this gradient on peatlands, but in the past these have been predominantly those of the northern hemisphere (Malmer 1986, Johnson 1977, Vitt et al. 1990, 1994). More recently the focus has turned to peatlands in the southern hemisphere, and specifically southern Patagonia (Kleinebecker et al. 2007, 2010).

In southern Patagonia there are dramatic changes in peatland vegetation structure and composition from west to east over distances of less than 100 km (Kleinebecker et al. 2007, 2010). On the western side of Patagonia at latitude roughly 50º S, under hyper-oceanic conditions enhanced by the orographic effect of the southern Andes (precipitation up to 10,000 mm per annum), cushion growth form species such as *Astelia* *pumila* and *Donatia fascicularis* dominate the peat bogs. At similar latitudes further east, the peatlands are mixed cushion-plant and raised *Sphagnum magellanicum* bogs. Finally, on the eastern side of the Andes mountain chain, under a continental climate (precipitation < 1000 mm per annum), *Sphagnum magellanicum* peat bogs prevail. These changes in peatland vegetation are correlated with a progression in the surrounding non-wetland vegetation from wind-swept scrub and heath, to evergreen *Nothofagus* rainforest, to deciduous *Nothofagus* forest, and finally the more open grasslands and woodlands of the Patagonian steppe (Moore 1979, Pisano 1983, Kleinebecker et al. 2007).

Similar west to east gradients enhanced by orographic factors exist across both New Zealand and Tasmania. In mountain areas this is most often manifested in a change from low shrub, wet scrub, and hard-leaved graminoid dominated vegetation, to more open grassland and herbfield. Shrub-dominated vegetation in the more oceanic western areas is attributed to the high number of ‘raindays’ annually, milder temperatures and shorter duration of snow cover. All these factors favour the establishment of woody vegetation. The mountainous western regions of Tasmania, New Zealand, and southern South America are generally also those that carried glaciers and ice-sheets only 15,000 years ago (Jackson 1999a, Gibson and Kirkpatrick 1985b, Kleinebecker et al. 2007). They are therefore frequently devoid of any substantial soil mantle (shallow and skeletal), and this is thought to further enhance the prominence of these plant life-forms. The general exception to skeletal soils in these areas is where blanket bogs have created shallow peatlands (< 50 cm deep). The extremes of wind, rain, and cloud cover in the western areas of the southern temperate land-masses are universally expressed in peatlands by the dominance of ‘cushion’ form species, ‘hard’ or sclerophyllous sedges and other graminoids, and scale-rushes (Restionaceae). These are life-forms or growth forms that are absent from peatlands in the northern hemisphere although the cushion growth form is occasionally seen in some high alpine plant species (Billings 1973).

In the montane and alpine areas of south-east mainland Australia and Tasmania, there is a similar trend in treeless areas from shrub and hard-leaved graminoid dominated vegetation, to grasslands and herbfields, in the more continental north-eastern regions

(Costin 1957, McVean 1969, Kirkpatrick 1983). This pattern has been attributed to climatic influences by some authors (Kirkpatrick and Bridle 1998, 1999). However, these climatic influences are not as strong or immediately apparent, and more seasonal (Jackson 1999a), compared with Tasmania, New Zealand and southern Patagonia (41-56°S), due largely to the more northern position of the mainland Australian alpine and subalpine areas (35-38ºS). While the high elevation treeless vegetation of mainland south-eastern Australia is well documented and described, there are few studies that have looked closely at the influence of gradients in climate, and only one, to my knowledge, that focussed specifically on peatlands. In that case the study was not restricted to highland communities and focussed on other factors as well, particularly anthropogenic impacts (Whinam et al. 2003a).

The 89 peatland plots (= transects) examined in Chapter 3 are spread across three broad regions and three elevation zones. Their distribution enables a comparison to be made along a transect running from south-west to north-east across the mountains of eastern Victoria, from anecdotally described oceanic areas closer to the coast and Bass Strait, to more inland and continental, albeit slightly higher regions in the north-east of Victoria.

The aims of this chapter are:

- to examine trends in peatland vegetation structure, composition and context along a geographical transect running from south-west to north-east across the eastern highlands of Victoria
- to identify climatic and other environmental variables associated with trends in peatland vegetation patterns
- to make comparisons with similar gradients elsewhere in the peatlands of the southern hemisphere and to a lesser extent the northern hemisphere as well.
- to examine the distribution patterns of species and plant functional or attribute groups that have been identified elsewhere as indicators of increasing oceanicity or continentality

4.2 METHODS

In the previous chapter the 89 plots from 45 sites across eastern Victoria were separated into three broad regions for the purposes of analysis. The divisions were based on river catchment boundaries and position relative to the Great Dividing Range. Trends and patterns were essentially examined along gradients in altitude within each region; from montane to subalpine in two regions, and subalpine to alpine in the Bogong region. In this chapter the data ‘pool’ was separated not by region, but by elevation zone. Therefore the methods in this chapter are essentially the same as in the previous chapter. A brief summary is provided here. These should be read in conjunction with the methods descriptions from Chapter 3.

The geographical trends in floristics and vegetation patterns from south-west to north-east across the mountainous regions of eastern Victoria are complicated and confounded to a certain extent by the highest and genuine ‘alpine’ areas being only in the north-east. Hence in this study attempts were made to circumvent these confounding factors by comparing peatland vegetation and context along this gradient at similar altitudes. Three elevation zones are recognised: Montane, 1000 to 1300 metres above sea level; Subalpine, 1300 to approximately 1650 m; Alpine, greater than approximately 1650 m. The initial classification of plots (= transects) as nominally ‘alpine’ or ‘subalpine’ was largely in response to perceived differences in the vegetation structure that occur in the landscape adjacent to peatlands at about 1650 m, although sometimes lower or higher depending on aspect and exposure. In Victoria the tree-line is at approximately 1750 metres, but arguably closer to 1600 m at the southern edge of the high country. Peatland areas that were sampled at elevations between 1600 m and 1700 m were classified or categorised as either ‘alpine’ or ‘subalpine’, depending on landscape position and the proportion of tree cover in the surrounding landscape.

In the first set of analyses, all plots within the montane zone are examined together. In the initial survey, montane plots were only sampled in two of the three broad regions. Hence, the montane study is in essence a comparison of plots from the Baw Baw and Central

Highlands region with those from the Snowy Range area. This encompasses four of the 11 *a priori* determined peatland community types from Chapter 3. Subalpine transects from all three broad regions were examined in the second set of analyses. Five of the 11 initial community types were compared in this study (Table 4.1, and Chapter 3 methods). Truly ‘alpine’ plots were only sampled in the Bogong region. In the third section, comparisons were made between these and all the subalpine plots. Eight of the 11 community types were represented in this study.

In each of the elevation zone studies, the emphasis was on comparisons between community types not previously compared in the separate regional examinations from Chapter 3. For example, Subalpine raised bog plots only occur east of the Macalister Valley (Snowy Range-Dargo High Plains region, Bogong region); these were compared with Western subalpine raised bog plots, which only occur west of the Macalister Valley (Baw Baw-Central Highlands region) (Table 4.1).

Table 4.1: Distribution of the eleven peatland community types sampled.

Community Type	Altitude Zone	Region Sampled
Low wet heath	Alpine	Bogong
Alpine raised bog	Alpine	Bogong
Alpine valley bog	Alpine	Bogong
Subalpine raised bog	Subalpine	Bogong, Snowy Range-Dargo High Plains
Tall wet heath	Subalpine	Bogong, Snowy Range-Dargo High Plains
Myrtaceous wet heath	Subalpine-Montane	Bogong, Snowy Range-Dargo High Plains
Western subalpine raised bog	Subalpine	Baw Baw-Central Highlands
Western subalpine wet heath	Subalpine	Baw Baw-Central Highlands
Montane valley bog	Montane	Snowy Range-Dargo High Plains
Western montane wet heath	Montane	Baw Baw-Central Highlands
Western montane fen	Montane	Baw Baw-Central Highlands

In all other respects the methods are the same as in Chapter 3. Transects are 30 m long, perpendicular to slope direction, and consist of 60 contiguous quadrats (0.25 m^2). Braun-Blanquet mid-point values were used to generate cover percentages. Analyses examined both cover and frequency of occurrence data. The original species data pool of 93 taxa was reduced accordingly for each set of analyses, to those species occurring in two or more plots.

Pair-wise plot resemblance matrices were again derived from the Bray/ Curtis measure (Bray and Curtis 1957). Ordination graphs examining the patterns in floristic composition and structure were created using non-metric multi dimensional scaling (NMDS) procedures in the PRIMER 6 software package (Plymouth Routines in Multivariate Ecological Research 6.1.13., 2009). Fifty iterations or trials were run per analysis to determine the lowest stress configuration of plots, which was decided based upon Kruskal stress indices (Kruskal 1964).

Floristic differences between the initially identified community types were tested using the non-parametric ANOSIM procedure in the PRIMER software package (Plymouth Routines in Multivariate Ecological Research 6.1.13., 2009). Significance levels for each pair-wise comparison provided by the ANOSIM procedure were further tested using sequential Bonferroni adjustment (Holm 1979). The SIMPER procedure was used to identify species contributing to similarities within groups, and differences between them (Quinn et al. 2003). The same environmental, structural, and BIOCLIM climatic variables were examined as in Chapter 3. The eleven plant functional group categories are also identical. Full details of all variables examined are in the Chapter 3 methods section.

As in Chapter 3, the relationships of the structural, environmental, climatic, individual species, and species functional group variables with the final ordination solutions were tested using Spearman rank correlation. Separate ordination graphs displaying strongly correlated variables are again provided.

4.3 RESULTS

4.3.1 Montane transects all regions

A total of 22 transects out of the initial 89 were eligible for inclusion in this study. These varied in altitude from 1000 m above sea level at Morgans Gully on the Moroka River, to 1290 m, at Bennison Plains, and from Storm Creek south of Eildon, in the west, to Dairy Farm Flat north of Stratford, in the east. The northern most site was at Tom Burns Creek near Eildon, and the southern most site was Newlands, on the north-western edge of the Baw Baw Plateau (refer to Chapter 3, Figures 3.1, 3.17, 3.30, 3.31; Appendices Tables A3.24, A3.37).

Four of the 11 community types were represented in the montane altitude zone (1000-1300 m), eight transects in Montane valley bog (MVB), two in Myrtaceous wet heath (MWH), six in Western montane wet heath (WMW), and six in Western montane fen (WMF). Myrtaceous wet heath also occurs in subalpine areas, but only two of the nine transects sampled in this peatland vegetation type fall within the montane zone. Two of the community types are restricted to the Baw Baw-Central Highlands region, west of the Macalister Valley, and the remaining two are restricted to montane wetlands east of the Macalister Valley.

The original data set containing 93 was trimmed to 61, by removing species that were only recorded at higher altitude and species recorded in less than two transects. In terms of life-forms, 14 of the species were shrubs, 22 were graminoids, 21 were herbaceous dicots, there was one fern species, one club-moss group, and two *Sphagnum* species.

Ordinations based on the cover and frequency data

Two dimensional solutions were adopted for both the cover and frequency ordinations. In both cases the minimum stress of the best ordination configuration was less than 0.1.

In the graph space of both cover and frequency ordinations the Western montane fen plots are clearly separated from the other three communities along axis 1 (Figures 4.1, 4.2). The difference is not quite as defined based on cover data, with some sites sharing similarity with several of the Montane valley bog plots from east of the Macalister Valley. Separation between the other three communities is clear based on the frequency data, Western montane wet heath and Montane valley bog are separated along axis 2. To a limited extent, Montane valley bog and Myrtaceous wet heath separate along axis 1. There is some overlap between these same groups based on the cover data. Myrtaceous wet heath and Western montane wet heath are inseparable, but collectively are relatively distinct from Montane valley bog along axis 2.

ANOSIM comparisons of the montane communities

Myrtaceous wet heath with only two transects sampled, had insufficient replicates for significance testing. The pair-wise comparisons involving this group have been included nonetheless. In cases such as this, the R-statistic values are a useful approximate indicator from which to draw tentative conclusions (Clarke and Gorley 2001). Hence, pair-wise comparisons between Myrtaceous wet heath and the other three community types are listed as non-significant, but in the case of the comparisons based on frequency data, R-statistic values are greater than 0.6, indicating clear differences (Table 4.2, Appendices Tables A4.1*, A4.2* for full list). The frequency data is generally a good measure of overall similarity in composition.

Pair-wise comparisons between groups from within the same region have already been discussed in Chapter 3 and will not be discussed in detail here. When comparing montane communities from east and west of the Macalister Valley, the most noteworthy pairing is between Myrtaceous wet heath and Western montane wet heath. The ANOSIM analysis of the cover data suggests that these communities are barely separable (R-statistic = 0.01). Cover data are generally a better indicator of overall vegetation structure because they emphasise the dominant species. Other comparisons across the ‘Macalister line’

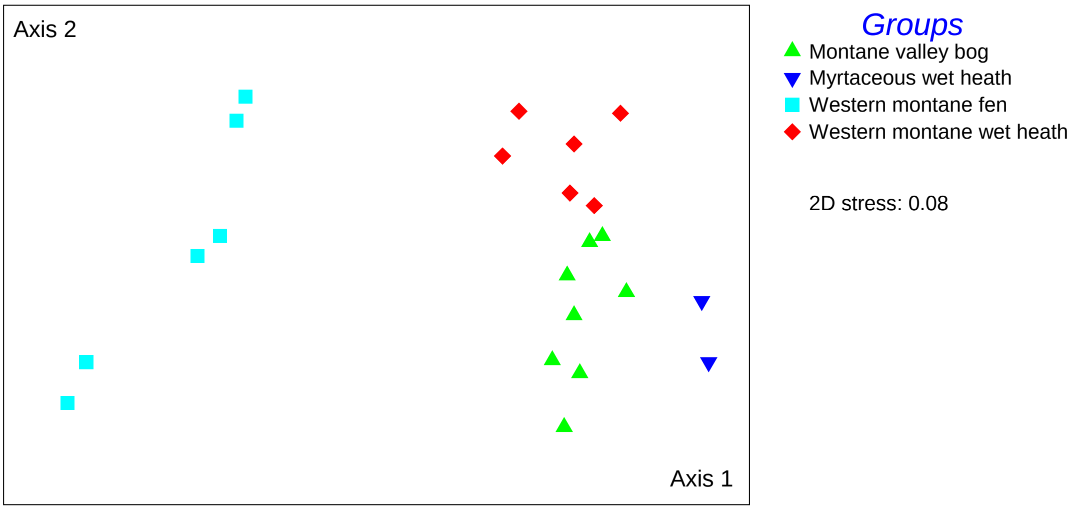


Figure 4.1: Two dimensional ordination graph based on the **Montane transects frequency data.**

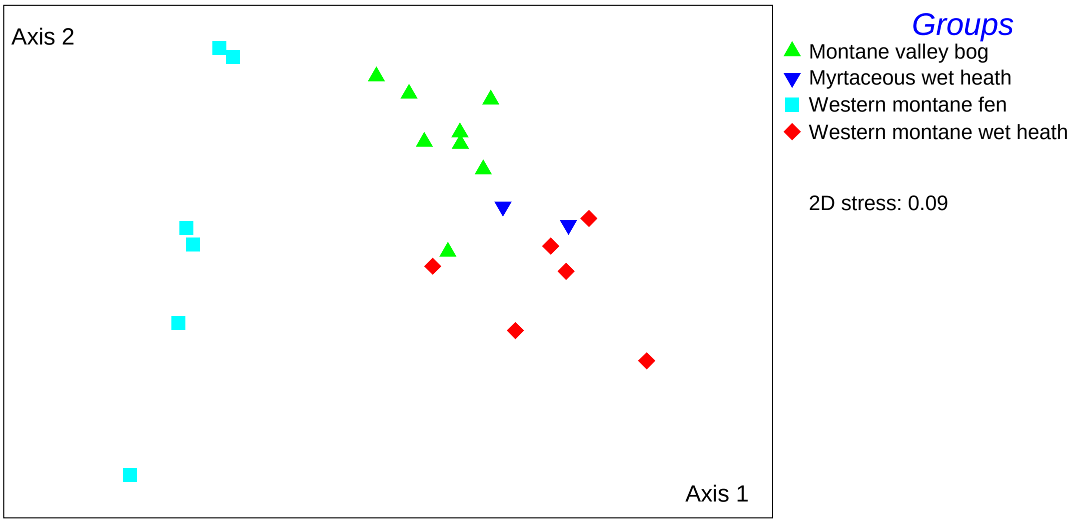


Figure 4.2: Two dimensional ordination graph based on the **Montane transects cover data**.

Table 4.2: Pair-wise comparisons of the **montane peatland communities** based on both **frequency and cover data.**

Analysis of similarity Pair-wise tests Groups	**Actual Perm'tns** max = 999	**Frequency data R Statistic**	**Frequency data Significance P-value**	**Cover data R Statistic**	**Cover data Significance P-value**
Montane valley bog, Myrtaceous wet heath	45	**0.634**	0.022*	0.362	0.089*
Montane valley bog, Western montane fen	999	**0.973**	0.002	**0.815**	0.001
Montane valley bog, Western montane wet heath	999	**0.693**	0.001	**0.729**	0.001
Myrtaceous wet heath, Western montane fen	28	**1**	0.036*	**0.906**	0.036*
Myrtaceous wet heath, Western montane wet heath	28	**0.99**	0.036*	0.01	0.5*
Western montane fen, Western montane wet heath	462	**0.933**	0.002	**0.944**	0.002
Overall global test sample statistic	999	**0.786**	0.001	**0.654**	0.001

showed clear differences based on the cover data (R-statistic values of between 0.7 and 0.95).

SIMPER analysis of the montane communities: species distinguishing between groups

The tables and lists of species defining the four groups were examined and described in detail in Chapter 3 and need not be discussed further here. Species that help to distinguish between community types within the same region have also been discussed previously. In this section the focus is on comparisons between groups or community types across the ‘geographic’ divide, those east and west of the Macalister Valley.

The main point of division is between Western montane fen and all other montane communities, and is primarily based on the complete absence of *Empodisma minus*, *Baeckea gunniana* and *Epacris paludosa* from the former (Table 4.3, Appendices Table A4.6). Instead this peatland type has a high cover of *Sphagnum cristatum*, *Carex appressa*, *Carex gaudichaudiana* and *Richea victoriana*. Other common species include *Blechnum penna-marina*, *Epacris microphylla* var. *rhombifolia*, *Polytrichum* spp., *Olearia algida*, *Leptospermum grandifolium* and grasses like *Poa labillardierei*.

At the regional level of comparison, both montane peatland communites east of the Macalister contain *Baloskion australe*, *Epacris celata* and *Baumea gunnii*, all of which are entirely absent from peatlands ‘west’ of the Macalister (Tables 4.3, 4.4, Appendices Tables A4.4- A4.6). The two communities in the east differ mainly in shrub presence; species like *Baeckea gunniana*, *Callistemon pityoides* and *Epacris paludosa* were dominant in Myrtaceous wet heath and less common in Montane valley bog. *Epacris breviflora* seems to be more associated with Montane valley bog than the other more prominent peatland shrubs in the east.

There are strong similarities between Western montane wet heath and the two communities in the east, particularly Myrtaceous wet heath, as already mentioned. The species in common between these two include *Epacris paludosa*, *Baeckea gunniana*,

Table 4.3: Species contributing to differences between **Montane valley bog (MVB)** and **Western montane fen (WMF)** based on the **montane transects, (a) Frequency data, (b) cover data**. The species listed contribute more than 80% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they were most prominent.

(a): Frequency data. **(MVB)** and **(WMF).** Mean dissimilarity = 73.9%.

Common in MVB and rare or absent in WMF	**Av.freq(MVB)**	**Av.freq(WMF)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Empodisma minus	**96.7**	0.0	8.2	9.0	11.2
Epacris paludosa	**55.0**	0.0	4.7	1.9	6.4
Asperula gunnii	**52.9**	0.0	4.4	1.9	5.9
Baloskion australe	**40.6**	0.0	3.3	1.2	4.5
Baeckea gunniana	**40.6**	0.0	3.5	1.5	4.8
Luzula modesta	**25.0**	3.1	1.9	1.4	2.6
Poa costiniana	**17.7**	0.0	1.5	0.7	2.1
Veronica sp.2	**17.1**	0.0	1.4	0.8	1.8
Ranunculus spp.	**12.3**	0.0	1.0	0.8	1.3
Baumea gunnii	**11.0**	0.0	0.9	0.9	1.2
Common in WMF and rare or absent in MVB					
Richea victoriana	0.0	**90.3**	7.7	5.5	10.5
Carex appressa	1.9	**57.8**	4.8	1.6	6.5
Polytrichum sp.	1.9	**43.6**	3.6	1.0	4.9
Blechnum penna-marina	1.5	**38.1**	3.1	1.3	4.2
Poa spp.	12.7	**37.8**	3.0	1.4	4.0
Epacris microphylla var. *rhombifolia*	0.0	**22.2**	1.9	0.7	2.5
Olearia algida	0.0	**22.2**	1.8	0.7	2.5
Leptospermum grandifolium	0.0	**13.6**	1.2	0.8	1.6
Tasmannia xerophila	0.0	**10.8**	0.9	0.6	1.2
Shared species					
Carex gaudichaudiana	94.8	63.1	3.1	0.9	4.2
Sphagnum cristatum	86.0	76.7	2.1	0.9	2.9
Epacris breviflora	21.0	21.4	2.5	1.1	3.4

(b): Cover data. (**MVB)** and **(WMF).** Mean dissimilarity = 63.7%

Higher % cover in MVB	**Av.cov(MVB)**	**Av.cov(WMF)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Empodisma minus	**28.5**	0.0	13.5	2.5	21.2
Epacris paludosa	**9.8**	0.0	4.6	1.5	7.2
Baeckea gunniana	**5.3**	0.0	2.6	1.2	4.1
Higher % cover in WMF					
Richea victoriana	0.0	**20.7**	10.2	2.3	16.0
Polytrichum sp.	0.0	**8.0**	4.1	0.9	6.4
Carex appressa	0.5	**6.3**	2.9	1.1	4.6
Epacris microphylla var. *rhombifolia*	0.0	**4.1**	2.0	0.7	3.2
Leptospermum grandifolium	0.0	**3.3**	1.5	0.9	2.4
Similar % cover in both					
Sphagnum cristatum	51.8	48.9	13.6	1.4	21.4
Carex gaudichaudiana	4.6	3.5	2.0	1.4	3.2
Epacris breviflora	2.0	2.4	1.6	1.0	2.5

Table 4.4: Species contributing to differences between **Myrtaceous wet heath (MWH)** and **Western montane wet heath (WMW)** based on the **montane transects, (a) Frequency data, (b) cover data**. The species listed contribute more than 80% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they were most prominent.

(a): Frequency data. (MWH) and **(WMW).** Mean dissimilarity = 51.2%

Common in MWH and rare or absent in WMW	**Av.freq(MWH)**	**Av.freq(WMW**	**Av.Diss**	**Diss/SD**	**Contrib%**
Baloskion australe	**77.5**	0.0	6.6	4.3	13.0
Asperula gunnii	**53.3**	6.7	4.1	3.7	8.0
Baumea gunnii	**44.2**	0.0	3.9	26.8	7.5
Callistemon pityoides	**42.5**	7.8	3.4	2.0	6.6
Poa spp.	**17.5**	0.3	1.4	1.0	2.8
Poa costiniana	**13.3**	0.3	1.1	3.0	2.2
Luzula modesta	**11.7**	1.1	0.9	2.2	1.7
Hakea microcarpa	**10.0**	0.0	0.8	1.2	1.6
Oreobolus distichus	**9.2**	0.0	0.8	1.2	1.5
Epacris breviflora	**8.3**	0.0	0.7	1.0	1.3
Common in WMW and rare or absent in MWH					
Carex gaudichaudiana	3.3	**79.4**	6.6	3.5	13.0
Richea victoriana	0.0	**43.6**	3.8	1.8	7.5
Nertera granadensis	3.3	**16.1**	1.4	0.8	2.7
Olearia algida	0.0	**14.7**	1.3	0.8	2.5
Polytrichum sp.	3.3	**10.6**	0.9	0.9	1.8
Shared species					
Epacris paludosa	**90.8**	83.3	1.2	1.0	2.4
Baeckea gunniana	**87.5**	44.4	3.7	2.2	7.2
Sphagnum cristatum	**67.5**	38.3	3.0	1.3	5.9
Sphagnum novozelandicum	**9.2**	3.3	0.7	1.3	1.4

(b): Cover data. (MWH) and **(WMW).** Mean dissimilarity = 35.4%

Higher % cover in MWH	**Av.cov(MWH)**	**Av.cov(WMW)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Baeckea gunniana	**11.4**	5.3	3.8	1.8	10.8
Callistemon pityoides	**7.4**	1.3	3.9	2.0	10.9
Baloskion australe	**1.9**	0.0	1.1	4.2	3.1
Epacris breviflora	**1.3**	0.0	0.8	1.0	2.2
Hakea microcarpa	**1.1**	0.0	0.6	1.0	1.8
Higher % cover in WMW					
Carex gaudichaudiana	0.2	**4.1**	2.2	1.0	6.3
Richea victoriana	0.0	**2.6**	1.6	1.2	4.4
Polytrichum sp.	0.0	**1.1**	0.7	0.6	1.8
Similar % cover in both					
Empodisma minus	27.5	22.0	4.8	2.6	13.6
Sphagnum cristatum	23.1	15.5	7.2	1.3	20.3
Epacris paludosa	17.1	25.0	5.5	1.4	15.6

Empodisma minus, and *Sphagnum* spp. These taxa provide most of the cover in both groups, hence the non-significant comparison in the ANOSIM analysis (Table 4.2, Appendices Tables A4.1*, A4.2*). The key differences are the absence of *Richea victoriana* 'east' of the Macalister, and to a lesser extent *Olearia algida*, which is uncommon except in subalpine areas. *Epacris microphylla* var. *rhombifolia* is also common in Western montane wet heath, and was not recorded in transects east of the Macalister, despite isolated individuals of this species occasionally being observed elsewhere in the Moroka Valley. *Callistemon pityoides* and *Hakea microcarpa* are also common in peatlands in the east, the former is less common in the west, and the latter absent altogether.

The two montane peatland community types within each region, 'east' and 'west', separate according to topography and hydrology as discussed in the previous chapter. The wet heath communities are in better drained positions than the bog-fen communities.

Species and factor correlations with the montane frequency data ordination

Twenty-seven of the 61 species tested were significantly correlated with at least one of the two frequency ordination axes (Table 4.5, see Appendices Table A4.7* for full list). Western montane fen is separated from the other three groups along axis 1 of the frequency ordination (Figure 4.3). The species that have strong positive correlations with the latter three groups and axis 1, are those absent from Western montane fen, such as *Empodisma minus*, *Epacris paludosa* and *Baeckea gunniana*. Species with strong negative correlations along axis 1, thus towards Western montane fen, include *Carex appressa* and *Blechnum penna-marina*. An imaginary diagonal line running from the bottom left corner to top right corner of the graph space separates the 'western' and 'eastern' communities. *Richea victoriana*, *Olearia algida* and *Epacris microphylla* var. *rhombifolia* have strong correlations perpendicular to this imaginary line, towards the western groups. A group of species with strong frequency trends towards the opposite corner and the 'eastern' groups includes *Baumea gunnii*, *Baloskion australe* and *Asperula* *gunnii*. *Epacris breviflora* has a strong negative correlation with axis 2, and trends towards the bog-fen communities, independently of region.

In general it is the BIOCLIM variables that are the most useful when separating groups in the frequency ordination (Table 4.6, Appendices Table A4.8*). Hygric continentality has a diagonal trend towards the eastern peatland community types, hence there is an associated correlation with increasing longitude as well (Figure 4.4). The climatic variables associated with continentality also have similar trends. In the east, for example, radiation of the warmest quarter and mean diurnal temperature range are higher. Precipitation of the driest quarter, mean moisture index of the lowest quarter, and minimum temperature of the coldest quarter, all increase in value towards the western peatland community types. These variables are all associated with more oceanic climates. Peat depths in montane peatlands are generally greater than in subalpine areas, but in this examination depths were greater in western montane peatlands, as indicated by the higher frequency of peat depth measurements in excess of 2 m.

Table 4.5: Selection of species with the strongest significant correlations with the axes of the **montane frequency data** ordination (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001). See appendices for full table.

Species	MDS1	sig.level	MDS2	sig.level
Baeckea gunniana	**0.83**	***	-0.05	ns
Epacris paludosa	**0.78**	***	0.16	ns
Empodisma minus	**0.78**	***	-0.16	ns
Asperula gunnii	**0.64**	**	**-0.56**	**
Hypericum japonicum	**-0.60**	**	0.02	ns
Richea victoriana	**-0.71**	***	0.41	ns
Blechnum penna-marina	**-0.78**	***	0.18	ns
Carex appressa	**-0.78**	***	-0.02	ns
Epacris microphylla var. *rhombifolia*	-0.09	ns	**0.75**	***
Olearia algida	-0.27	ns	**0.68**	***
Baloskion australe	**0.51**	*	**-0.63**	**
Baumea gunnii	**0.51**	*	**-0.64**	**
Epacris breviflora	-0.22	ns	**-0.80**	***

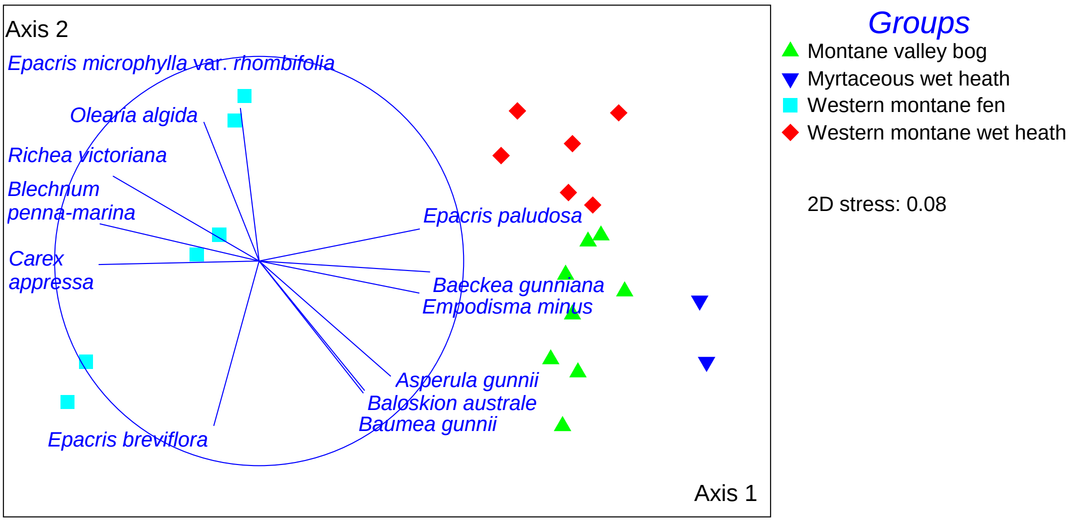


Figure 4.3: Two dimensional ordination graph based on the **montane transects frequency data**. The trend directions of strongly correlated species are indicated.

Table 4.6: Selection of factors with the strongest significant correlations with the axes of the **montane transects frequency data** ordination (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Factor	**MDS1**	**sig.level**	**MDS2**	**sig.level**
Dead *Empodisma*	**0.56**	**	0.06	ns
Hygric continentality	**0.54**	**	**-0.53**	**
Longitude	**0.46**	*	**-0.45**	*
Minimum temperature of coldest period	**-0.66**	***	0.37	ns
Mean moisture index of lowest quarter	-0.11	ns	**0.86**	***
Precipitation of driest quarter	-0.24	ns	**0.85**	***
% peat points > 2m deep	-0.39	ns	**0.52**	*
Maximum temperature of warmest period	-0.40	ns	**-0.52**	*
Mean diurnal temperature range	0.11	ns	**-0.73**	***
Radiation of warmest quarter	0.29	ns	**-0.83**	***
Temperature annual range	0.04	ns	**-0.84**	***

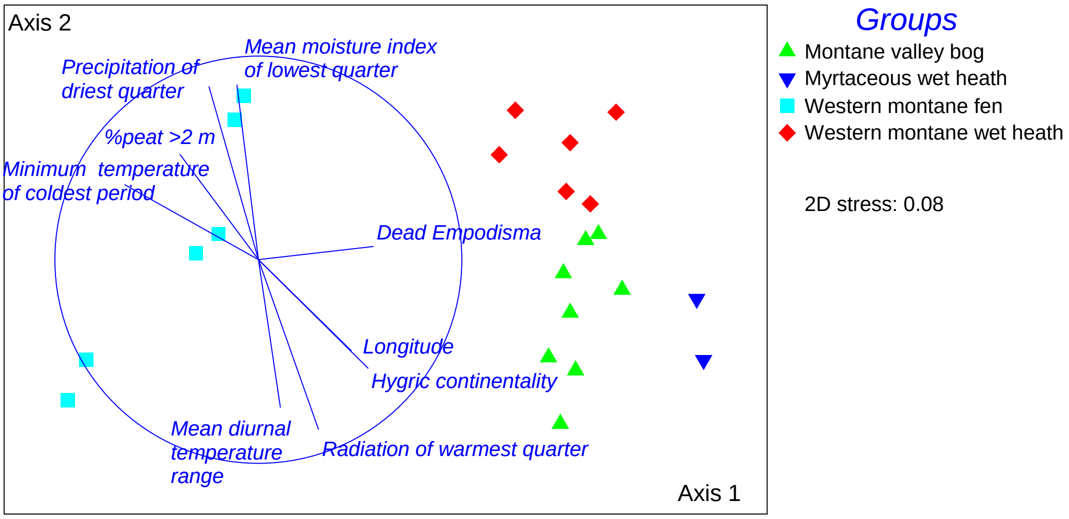


Figure 4.4: Two dimensional ordination graph based on the **montane transects frequency data**. The trend directions of strongly correlated factors are indicated.

Species and factor correlations with the montane cover data ordination

In the ordination based on cover data there were fewer species showing significant correlation (19), but the suite of species with strong correlations are essentially the same, with the notable inclusion of *Sphagnum cristatum* (Table 4.7). It has a strong positive correlation with axis 2, and the bog-fen communities, which on average have higher *Sphagnum* cover than the ‘wet heaths’ (Figure 4.5). The common shrubs *Baeckea gunniana* and *Epacris paludosa* had strong correlations with the two ‘wet heath’ communities; *Richea victoriana*, *Carex appressa* and *Blechnum penna-marina* had strong associations with Western montane fen.

Aspect and dead *Empodisma minus* fixed litter, both factors indicating drier microsites, were positively correlated with axis 1 of the ordination based on the cover data (Table 4.8). These increased towards the ‘wet heath’ communities, independently of region (Figure 4.6). Annual mean radiation is positively correlated with axis 2 and the ‘eastern’ communities in general. Shrub height, shrub cover, and litter increase in the opposite direction, separating Western montane wet heath and Myrtaceous wet heath, from

Montane valley bog and some of the Western montane fen transects. There was considerable variability apparent within the Western montane fen group along axis 2. The positions of the six transects in the graph space span the entire length of the axis, and the differences within the group would appear to be correlated with variation in shrub cover, shrub height and peat depth.

Table 4.7: Species significantly correlated with one or both of the axes of the ordination based on the **montane transects cover data** (nineteen of 61). The species have been sorted according to axis and strength of correlation (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Species	MDS1	sig.level	MDS2	sig.level
Epacris paludosa	**0.79**	***	-0.26	ns
Baeckea gunniana	**0.78**	***	-0.15	ns
Empodisma minus	**0.65**	***	0.32	ns
Herpolirion novae-zelandiae	**0.50**	*	-0.21	ns
Stylidium sp.	**0.45**	*	0.00	ns
Leptospermum grandifolium	**-0.45**	*	0.03	ns
Poa spp.	**-0.46**	*	-0.13	ns
Tasmannia xerophila	**-0.56**	**	-0.19	ns
Hypericum japonicum	**-0.56**	**	0.13	ns
Carex appressa	**-0.73**	***	-0.19	ns
Blechnum penna-marina	**-0.79**	***	-0.04	ns
Richea victoriana	**-0.43**	*	**-0.44**	*
Olearia algida	-0.05	ns	**-0.43**	*
Lagenophora montanus	-0.05	ns	**0.43**	*
Hydrocotyle spp.	-0.03	ns	**0.44**	*
Juncus sandwithii	-0.10	ns	**0.45**	*
Oreomyrrhis ciliata	-0.05	ns	**0.46**	*
Luzula modesta	0.02	ns	**0.50**	*
Sphagnum cristatum	**-0.49**	*	**0.88**	***

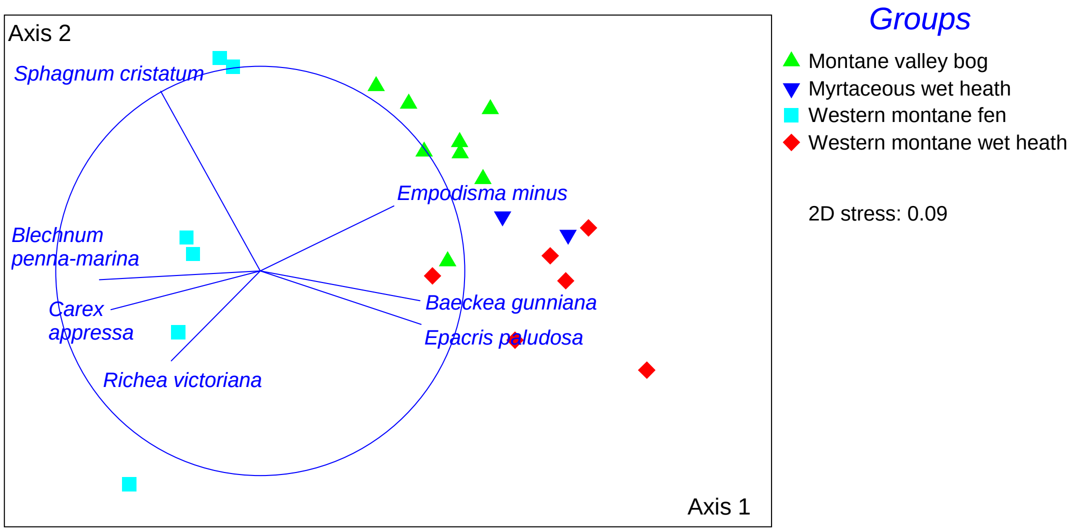


Figure 4.5: Two dimensional ordination graph based on the **montane transects cover data**. The trend directions of strongly correlated species are indicated.

Table 4.8: Factors significantly correlated with one or both of the axes of the ordination based on the **montane transects cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Factor	**MDS1**	**sig.level**	**MDS2**	**sig.level**
Dead *Empodisma*	**0.65**	***	-0.12	ns
Aspect	**0.43**	*	-0.28	ns
Shrub cover	0.08	ns	**-0.80**	***
Mean shrub height	-0.06	ns	**-0.74**	***
Litter	0.05	ns	**-0.73**	***
Mean height of tallest shrubs	-0.05	ns	**-0.72**	***
% peat points > 2 m deep	0.04	ns	**-0.52**	*
Highest period radiation	-0.22	ns	**0.44**	*
Lowest period radiation	0.12	ns	**0.44**	*
Radiation of coldest quarter	0.09	ns	**0.44**	*
Radiation of warmest quarter	-0.07	ns	**0.45**	*
Annual mean radiation	-0.06	ns	**0.48**	*

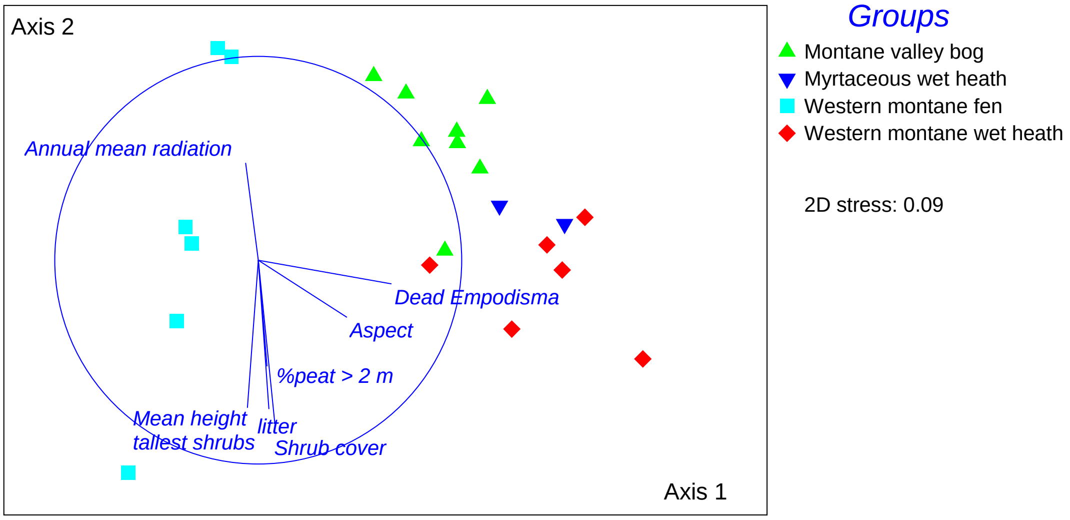


Figure 4.6: Two dimensional ordination graph based on the **montane transects cover data**. The trend directions of strongly correlated factors are indicated.

Plant functional group correlations with the montane cover data ordination

The strongest correlations at the plant functional group level were for *Sphagnum* species, ericaceous shrubs, restiads, and *Carex* spp. (Table 4.9). As would be expected, the *Sphagnum* species group displays an association with the fen-bog groups, independently of region (Figure 4.7). Restiads (*Empodisma*, *Baloskion*) increase in cover towards Western montane wet heath, Myrtaceous wet heath and Montane valley bog. *Carex* species trend in the opposite direction, towards Western montane fen. Ericaceous shrubs have a strong negative correlation with axis 2, and favour the 'western groups' marginally, independently of vegetation formation. Myrtaceous shrubs (*Baeckea*, *Callistemon*, *Leptospermum*) have a weaker correlation with axis 1, and are associated with the 'wet heath' groups, independently of region. 'Other shrubs' (*Olearia*, *Tasmannia*, *Ozothamnus*) are associated with the 'western' plots, particularly some of the Western montane fen sites.

Table 4.9: Plant functional groups strongly correlated with the axes of the **montane transects cover data** ordination (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Lifeform groups	MDS1	sig.level	MDS2	sig.level
Restiads	**0.65**	***	0.31	ns
Astelia	**0.50**	*	-0.24	ns
Myrtaceous shrubs	**0.47**	*	-0.24	ns
Other monocots	**-0.42**	*	0.15	ns
Carex spp.	**-0.69**	***	-0.02	ns
Sphagnum spp.	**-0.48**	*	**0.87**	***
Other shrubs	-0.26	ns	**-0.46**	*
Ericaceous shrubs	0.05	ns	**-0.78**	***

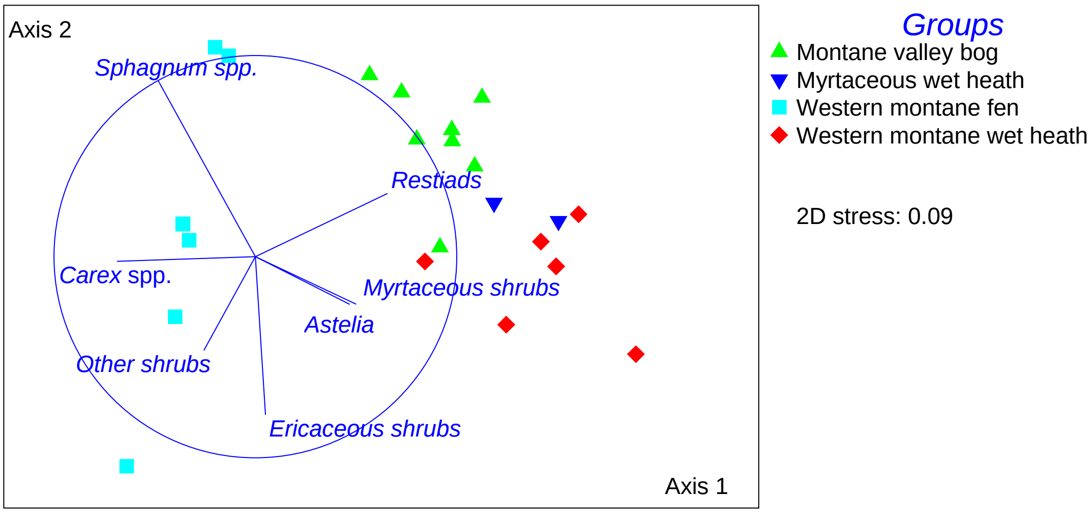


Figure 4.7: Two dimensional ordination graph based on the **montane transects cover data**. The trend directions of strongly correlated plant functional groups are indicated.

4.3.2 Subalpine transects all regions

Fifty of the 89 transects completed were classified as subalpine for the purposes of this study. These varied in altitude from 1330 m at The Morass, on the western side of the Baw Baw Plateau, to 1700 m at Cope East, on the south-eastern side of the Bogong High Plains. They also covered a broad geographical range, from Long Flat at Lake Mountain in the far west of the study area, to Wild Horse Creek, north of Omeo, in the far east. Transects used in these analyses are from all three of the defined regions used in the earlier analysis: the Bogong region; Snowy Range-Dargo High Plains region; and the Baw Baw plateau-Central Highlands region (Figures 3.1, 3.2, 3.16, 3.30, 3.31, Appendices Figure A3.2, Appendices Tables A3.1, A3.24, A3.37)

In addition five of the 11 peatland community types identified previously are represented in these analyses. These are Subalpine raised bog, Tall wet heath, Myrtaceous wet heath, Western subalpine raised bog, and Western subalpine wet heath. As the community names suggest, the latter two community types only occur west of the Macalister Valley, in the Baw Baw-Central Highlands region. The remaining three community types were sampled in the Bogong region and the Snowy Range-Dargo High Plains region.

In total 17 transects were from Subalpine raised bog, 10 were in Tall wet heath, 7 in Myrtaceous wet heath, 7 in Western subalpine raised bog, and 9 were in Western subalpine wet heath. The original data set for the full 89 transects contains 93 species; this was trimmed to the 79 species that occurred in two or more transects. In terms of life-forms, 15 of the species are shrubs, 26 are graminoids, 34 are herbaceous dicots, there was one club-moss group and three bryophyte species or groups.

Ordinations based on the subalpine frequency and cover data

Three dimensional ordination solutions were adopted for both the cover and frequency data, with Kruskal minimum stress values of 0.11 and 0.13 respectively. In the ordination solution derived from the frequency data, there appear to be three clusters (Figure 4.8).

One cluster contains the Subalpine raised bog and Tall wet heath plots, although the latter group is more spread, indicating greater variability. This cluster is located in the top right sector of the ordination space. The Myrtaceous wet heath plots form a more diffuse cluster in the bottom right sector.

The Western subalpine raised bog and Western subalpine wet heath plots form an even more diffuse group along the left side of the ordination space, mostly towards the bottom. There appears to be more overlap between these groups and variability within them. There is a clear diagonal partition from top left to bottom right in the ordination space, between the plots of the Baw Baw-Central Highlands region (west of the Macalister Valley) and the rest of the subalpine plots (east of the Macalister Valley).

There is little overlap between the five groups in the cover data ordination solution (Figure 4.9). A trend exists along axis 1, from the two raised bog community types to the wet heath groups. Group separation associated with axis 3, is along regional lines, with western groups towards the bottom and more eastern plots towards the top and right. Subalpine raised bog is the most tightly clustered group. There is more variability within the Western subalpine wet heath and Myrtaceous wet heath groups.

ANOSIM comparisons of subalpine communities

The pair-wise comparisons based on both the frequency and cover data show that there are highly significant differences between the five groups (Table 4.10, Appendices Tables A4.9*, A4.10*). The overall R-statistic values were 0.658 and 0.729 for the frequency and cover data respectively. All individual pair-wise group comparisons were significant except for one. Western subalpine raised bog and Western subalpine wet heath could not be separated using the frequency data (R= 0.152; p = 0.066). Several other comparisons showed only marginal differences (R-statistic values between 0.25 and 0.5), these were comparisons of Western subalpine raised bog and Western subalpine wet heath based on the cover data, Subalpine raised bog and Tall wet heath based on frequency data, Myrtaceous wet heath and Western subalpine wet heath based on cover,

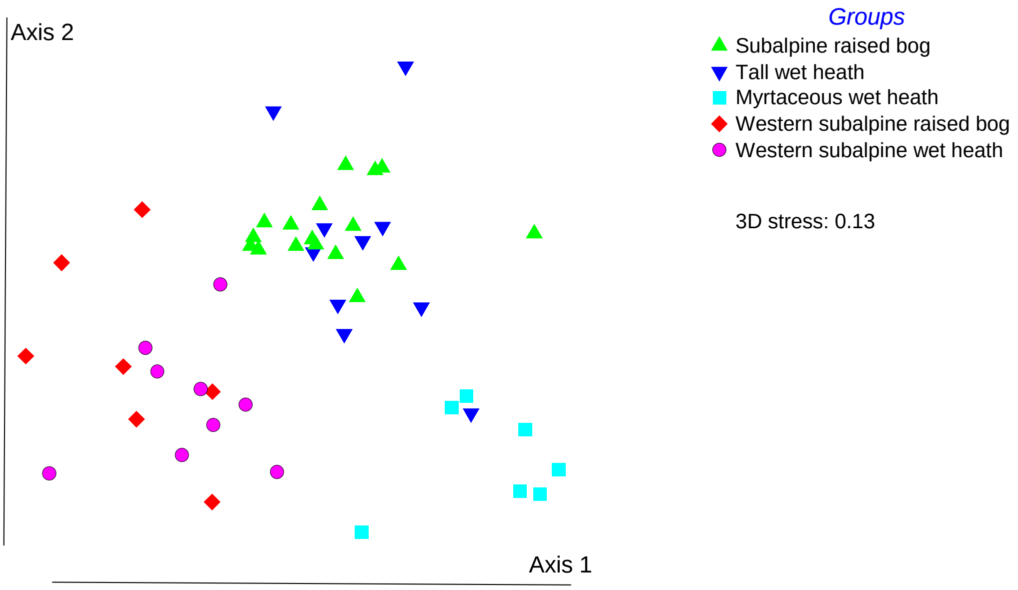


Figure 4.8: Three dimensional ordination graph based on the **subalpine transects frequency data** (Axis 1 v Axis 2).

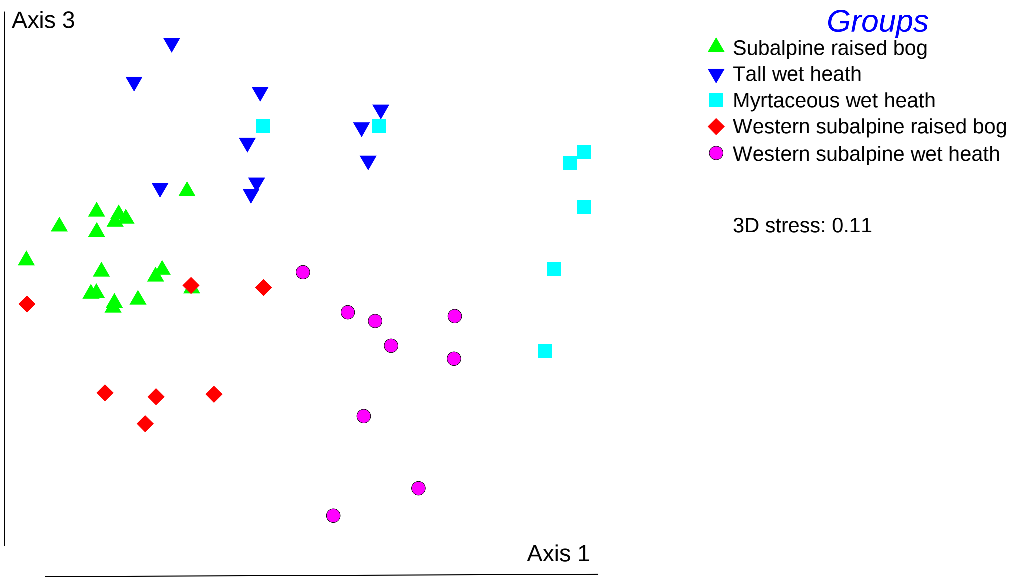


Figure 4.9: Three dimensional ordination graph based on the **subalpine transects cover data** (Axis 1 v Axis 3).

and Tall wet heath and Western subalpine wet heath based on cover. All other pair-wise group comparisons achieved R-statistic values of greater than 0.5, indicating clear differences.

Table 4.10: Pair-wise comparisons of the peatland communities based on the **subalpine transects frequency and cover data** (* = not significant).

Analysis of similarity	**Actual**	**Frequency data**		**Cover data**	
Pair-wise Tests	**Perm'tns**	**R**	**Signif.**	**R**	**Signif.**
Groups	max = 999	**Statistic**	**P-value**	**Statistic**	**P-value**
Myrtaceous wet heath, W'tn subalpine raised bog	999	**0.968**	0.003	**0.878**	0.001
Myrtaceous wet heath, W'tn subalpine wet heath	999	**0.762**	0.001	0.421	0.001
Subalpine raised bog, W'tn subalpine raised bog	999	**0.853**	0.001	**0.822**	0.001
Subalpine raised bog, W'tn subalpine wet heath	999	**0.788**	0.001	**0.875**	0.001
Tall wet heath, W'tn subalpine raised bog	999	**0.689**	0.001	**0.521**	0.001
Tall wet heath, W'tn subalpine wet heath	999	**0.5**	0.001	0.486	0.001
Subalpine raised bog, Myrtaceous wet heath	999	**0.889**	0.001	**0.983**	0.001
Tall wet heath, Myrtaceous wet heath	999	**0.605**	0.001	**0.668**	0.001
Subalpine raised bog, Tall wet heath	999	0.41	0.001	**0.768**	0.001
W'tn subalpine raised bog, W'tn subalpine wet heath	999	0.152	0.066*	0.402	0.002
Overall global test sample statistic	999	0.658	0.001	0.729	0.001

SIMPER analysis of the subalpine communities: species defining groups

These peatland community types were defined in the relevant regional studies (Chapter 3). In those community types that are shared between the Bogong region and the Snowy Range-Dargo High Plains region the species defining them varies little. Subalpine raised bog is one such group, and the important species that contribute to the similarity within transects in this group are *Sphagnum cristatum*, *Empodisma minus*, *Epacris paludosa* and *Richea continentis*. Common species that provide less overall percentage cover include *Carex gaudichaudiana*, *Baeckea gunniana* and *Baloskion australe*.

It is the same species that contribute to the overall similarity of the Tall wet heath plots, except for higher percent cover values for the shrub species concerned and lower *Sphagnum* and *Empodisma* cover. Other common species in Tall wet heath include *Asperula gunnii* and *Epacris celata*.(Appendices Tables A4.14*-A4.16*)

Myrtaceous wet heath also occurs in both regions east of the Macalister Valley and the key feature of this vegetation type is the absence of *Richea continentis*. In many respects it is otherwise similar to Tall wet heath, which it differs from by typically having high abundance and cover of *Baeckea gunniana*, *Epacris paludosa*, *Empodisma minus*, *Callistemon pityoides* and *Baloskion australe*. Graminoids and herbs are represented by *Poa costiniana*, *Oreobolus oxycarpus* and *Asperula gunnii*.

The two peatland community types west of the Macalister Valley share many of the same species with Subalpine raised bog and Tall wet heath in particular, but their relative representations differ and there are many species in these communities not featured elsewhere at subalpine elevations. *Sphagnum* is, in general, less dominant in these communities and *Empodisma minus* more prominent. *Astelia alpina* is an important species which was less common in the subalpine peatlands of the north and east. Other species common here but not common at these elevations further east included herbs such as *Gentianella* sp. (higher elevation in the east), *Euphrasia gibbsiae*, *Brachyscome obovata* and *Psychrophila introloba*. Important species in eastern peatland communities that are missing west of the Macalister Valley include *Epacris celata* and *Baloskion australe* (see Chapter 3, Tables 3.4, 3.14, 3.24, Appendices Tables A3.3*, A3.25*, A3.38*).

Indicator species for discriminating between subalpine peatland communities

Comparisons between community types that occur within the same region were covered in Chapter 3. In this section comparisons were made between community types unique to the areas west of the Macalister Valley and those found in the east (Tables 4.11-4.13, Appendices Tables A4.11-A4.13).

Raised bog communities either side of the ‘Macalister line’ (Subalpine raised bog and Western subalpine raised bog) differ in cover abundance of *Sphagnum cristatum* and *Empodisma minus* (Table 4.11). The former is more abundant in the eastern peatlands, the latter dominates raised bogs in the west. Overall shrub cover appears to be slightly greater in the east, especially for *Richea continentis* and *Baeckea gunniana* (Table 4.12). The species that are more prominent in subalpine raised bogs in the west apart from *Empodisma*, include *Astelia alpina* and *Sphagnum novo-zelandicum*. The scale rush *Baloskion australe* and the ericaceous shrub *Epacris celata* are common in raised bogs east of the Macalister, although typically not providing high cover abundance. These species are absent from raised bogs in the west. *Carex gaudichaudiana* is a common bog species in the east, but is less common in the west, particularly in the central highlands region. On the Baw Baw plateau it is more restricted to larger fen pools along valley floors. Common species in the west that typically never provide much overall projective foliage cover include *Carpha* spp., *Nertera granadensis*, *Gentianella* sp. and *Euphrasia gibbsiae*. These species are less common or absent from subalpine raised bogs east of the 'Macalister line'(Appendices Tables A4.11 - A4.13).

It is a similar pattern when comparing the wet heath communities from south-west and north-east of the Macalister line (Tables 4.12, 4.13). Wet heath communities are by definition less dominated by *Sphagnum* than raised bogs. Wet heath communities in the south-west have less *Sphagnum* than those in the north-east. They also appear to have a more even representation of shrub species, herbs and hard-leaved Graminoids. The north-eastern wet heaths are perhaps more shrub dominated, hence in Tall wet heath *Richea, Baeckea* and *Epacris paludosa* provide most of the projective foliage cover. *Empodisma minus* is much less prominent. Western subalpine wet heath is dominated by *Empodisma*, *Epacris paludosa*, *Richea* and *Astelia alpina*. Other shrub species like *Olearia algida* and *Epacris petrophila* also feature in these south-western subalpine wet heaths.

The key differences between Myrtaceous wet heath and Western subalpine wet heath are the absence of *Richea*, *Astelia*, *Gentianella* sp., *Olearia algida* and *Epacris petrophila* from the former. Species absent from the latter include *Baloskion*, *Epacris celata*, *Pultenaea* spp. and *Comesperma retusum*. Sedges and herbs such as *Carpha*, *Coprosma* and *Erigeron* are uncommon in Myrtaceous wet heath; *Baeckea*, *Asperula*, *Luzula* and

Isolepis spp. are less common in Western subalpine wet heath (Appendices Tables A4.11-A4.13).

Table 4.11: Species contributing to differences between **Subalpine raised bog (SRB)** and **Western subalpine raised bog (WSR)** based on the **subalpine transects, (a) Frequency data, (b) cover data**. The species listed contribute more than 80% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they were most prominent.

(a): Frequency data. **(SRB)** and **(WSR).** Mean dissimilarity = 48.8%

Species more common in SRB	**Av.freq.(SRB)**	**Av.freq.(WSR)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Carex gaudichaudiana	**70.5**	22.1	3.9	1.9	8.1
Baeckea gunniana	**63.7**	25.9	2.8	1.7	5.7
Baloskion australe	**44.6**	0.0	3.1	1.2	6.2
Epacris celata	**29.8**	0.0	2.0	1.1	4.1
Species more common in WSR					
Astelia alpina	2.2	**54.4**	3.7	2.6	7.5
Carpha spp.	11.6	**38.3**	2.6	1.2	5.3
Erigeron paludicola	5.5	**34.6**	2.2	1.2	4.5
Nertera granadensis	11.8	**33.5**	2.3	1.4	4.6
Gentianella sp.	0.0	**24.3**	1.7	1.9	3.4
Sphagnum novozelandicum	1.5	**15.0**	1.1	1.1	2.2
Euphrasia gibbsiae	0.0	**14.5**	1.0	1.0	2.0
Rytidosperma sp.	0.1	**13.3**	0.9	0.7	1.9
Isolepis spp.	5.4	**12.8**	0.9	1.0	1.9
Olearia algida	0.0	**11.8**	0.8	0.8	1.6
Brachyscome obovata	0.0	**11.2**	0.8	0.6	1.7
Drosera arcturi	0.0	**11.0**	0.8	1.0	1.6
Similar frequencies in both					
Richea continentis	80.5	46.9	3.0	1.8	6.1
Epacris paludosa	62.8	58.3	2.6	1.5	5.3
Poa costiniana	26.9	45.4	1.9	1.4	3.9
Asperula gunnii	13.3	20.4	1.3	1.1	2.7
Celmisia spp.	17.8	11.5	1.2	1.0	2.4
Sphagnum cristatum	95.4	79.8	1.2	1.6	2.4

(b): Cover data. (SRB) and **(WSR).** Mean dissimilarity = 38.9%

Higher % cover in SRB	**Av.cover.(SRB)**	**Av.cover.(WSR)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Richea continentis	**16.1**	5.4	4.9	1.3	12.6
Baeckea gunniana	**8.2**	1.9	2.6	1.3	6.7
Higher % cover in WSR					
Astelia alpina	0.1	**6.1**	2.4	0.8	6.2
Carpha spp.	0.5	**3.4**	1.4	0.9	3.6
Sphagnum novozelandicum	0.5	**3.3**	1.4	0.9	3.5
Similar cover % in both					
Sphagnum cristatum	77.3	47.2	12.2	2.1	31.5
Empodisma minus	16.3	20.6	4.7	1.2	12.0
Epacris paludosa	14.2	12.9	4.6	1.5	11.8
Carex gaudichaudiana	1.2	1.9	1.0	0.7	2.7

Table 4.12: Species contributing to differences between **Tall wet heath (TWH)** and **Western subalpine wet heath (WSW)** based on the **subalpine transects, (a) Frequency data, (b) cover data**. The species listed contribute more than 80% to the dissimilarities between groups. Useful distinguishing species are those that have a high dissimilarity score (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species listed according to the community type in which they were most prominent.

(a): Frequency data. **(TWH)** and **(WSW).** Mean dissimilarity = 52.0%

Species more common in TWH	**Av.freq.(TWH)**	**Av.freq.(WSW)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Carex gaudichaudiana	**64.5**	6.3	4.7	1.8	9.0
Epacris celata	**38.5**	0.0	2.8	1.6	5.4
Baloskion australe	**15.8**	0.0	1.0	0.6	1.9
Species more common in WSW					
Astelia alpina	2.8	**49.6**	3.4	1.6	6.6
Gentianella sp.	0.5	**28.9**	2.1	1.6	4.1
Nertera granadensis	7.8	**18.7**	1.4	1.1	2.6
Carpha spp.	5.5	**18.3**	1.3	1.0	2.6
Olearia algida	1.2	**18.1**	1.4	1.0	2.7
Epacris petrophila	0.0	**15.1**	1.2	0.5	2.3
Similar frequencies in both					
Epacris paludosa	61.2	66.1	2.8	1.5	5.5
Baeckea gunniana	73.2	46.7	2.7	1.4	5.2
Sphagnum cristatum	54.2	31.2	2.6	1.5	5.0
Richea continentis	60.7	60.3	2.5	1.3	4.8
Poa costiniana	44.0	36.4	2.3	1.4	4.4
Asperula gunnii	35.7	22.1	2.2	1.2	4.2
Erigeron paludicola	15.7	12.9	1.5	1.0	2.9
Celmisia spp.	15.3	16.1	1.5	1.1	2.8
Callistemon pityoides	12.3	7.6	1.3	0.7	2.5
Empodisma minus	86.5	98.9	1.2	0.5	2.2

(b): Cover data. (TWH) and **(WSW).** Mean dissimilarity = 57.1%

Higher % cover in TWH	**Av.cover.(TWH)**	**Av.cover.(WSW)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**29.5**	10.6	11.2	1.6	19.6
Baeckea gunniana	**16.1**	7.7	5.5	1.5	9.6
Callistemon pityoides	**3.0**	1.4	1.9	0.6	3.4
Epacris celata	**2.9**	0.0	1.5	0.8	2.6
Carex gaudichaudiana	**2.3**	0.1	1.2	0.6	2.1
Higher % cover in WSW					
Empodisma minus	6.0	**24.2**	9.8	1.7	17.2
Astelia alpina	0.1	**8.2**	4.5	1.1	7.8
Epacris petrophila	0.0	**1.4**	0.8	0.4	1.3
Similar cover % in both					
Richea continentis	21.1	13.0	9.9	1.2	17.3
Epacris paludosa	14.6	13.7	5.0	1.5	8.8
Poa costiniana	1.2	1.2	0.9	0.8	1.5

Table 4.13: Species contributing to differences between **Myrtaceous wet heath (MWH)** and **Western subalpine wet heath (WSW)** based on the **subalpine transects, (a) Frequency data, (b) cover data**. The species listed contribute more than 80% to the dissimilarities between groups. Useful distinguishing species are those that have a high dissimilarity score (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species listed according to the community type in which they were most prominent.

(a): Frequency data. **(MWH)** and **(WSW).** Mean dissimilarity = 58.2%

Species more common in MWH	**Av.freq.(MWH)**	**Av.freq.(WSW)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Baeckea gunniana	**91.0**	46.7	3.3	1.4	5.7
Asperula gunnii	**62.1**	22.1	3.4	1.7	5.9
Baloskion australe	**54.1**	0.0	3.8	1.7	6.5
Luzula modesta	**35.0**	1.0	2.3	1.1	4.0
Callistemon pityoides	**30.7**	7.6	2.0	1.7	3.4
Epacris celata	**30.5**	0.0	2.1	1.9	3.6
Pultenaea fasciculata	**27.6**	0.0	1.9	1.1	3.2
Oreobolus oxycarpus	**27.6**	0.6	1.8	1.2	3.1
Agrostis spp.	**20.2**	3.0	1.4	1.0	2.4
Comesperma retusum	**14.3**	0.0	0.9	1.1	1.6
Species more common in WSW					
Richea continentis	0.0	**60.3**	4.4	2.1	7.6
Astelia alpina	0.0	**49.6**	3.4	1.8	5.9
Gentianella sp.	0.0	**28.9**	2.0	1.6	3.5
Olearia algida	0.0	**18.1**	1.4	1.0	2.4
Epacris petrophila	0.0	**15.1**	1.1	0.5	2.0
Similar frequencies in both					
Poa costiniana	55.7	36.4	2.7	1.5	4.6
Epacris paludosa	88.1	66.1	2.4	0.9	4.1
Sphagnum cristatum	25.5	31.2	2.1	1.3	3.6
Celmisia spp.	12.4	16.1	1.4	1.2	2.4

(b): Cover data. **(MWH)** and **(WSW).** mean dissimilarity = 55.2%

Higher % cover in MWH	**Av.cover.(MWH)**	**Av.cover.(WSW)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Baeckea gunniana	**15.0**	7.7	5.1	1.5	9.3
Oreobolus oxycarpus	**5.1**	0.0	3.1	0.8	5.6
Poa costiniana	**4.0**	1.2	2.3	1.7	4.2
Callistemon pityoides	**3.4**	1.4	2.2	1.8	4.0
Baloskion australe	**1.3**	0.0	0.8	0.6	1.4
Pultenaea fasciculata	**1.3**	0.0	0.8	1.0	1.5
Epacris celata	**1.3**	0.0	0.8	1.4	1.4
Higher % cover in WSW					
Richea continentis	0.0	**13.0**	8.0	0.9	14.4
Astelia alpina	0.0	**8.2**	5.3	1.1	9.7
Epacris petrophila	0.0	**1.4**	0.9	0.4	1.6
Olearia algida	0.0	**1.3**	0.8	0.6	1.4
Similar cover % in both					
Sphagnum cristatum	8.9	10.6	7.9	1.4	14.3
Empodisma minus	16.5	24.2	6.5	1.2	11.8
Epacris paludosa	11.5	13.7	5.4	1.8	9.8

Species and factor correlations with the subalpine frequency data ordination

Many of the species that are useful discriminators between the various peatland groups also show strong correlations with the ordination solutions (Tables 4.14, 4.16, Appendices Tables A4.17*, A4.19*). The shrubs *Epacris celata*, *Baeckea gunniana* and the scale-rush *Baloskion australis* have strong positive correlations with axis 1 of the frequency ordination, and the wet heath communities east of the Macalister (Tall wet heath and Mytaceous wet heath) (Fig 4.10). Strongly correlated species in the opposite direction include *Astelia alpina*, *Gentianella* sp., *Rytidosperma nivicola* and *Drosera arcturi*. These are orientated towards the western peatland communities, Western subalpine raised bog and Western subalpine wet heath. Species strongly correlated with axis 2 included the important 'bog' species, *Sphagnum cristatum*, *Carex gaudichaudiana* and *Richea continentis*. These species displayed a trend towards raised bog, the 'eastern' variety in particular. *Epacris paludosa* increases in the opposite direction, and favours 'wet heath' over 'bog', regardless of region. *Asperula* and *Carpha* are aligned with axis 3 of the frequency ordination, but in opposite directions; *Asperula* favours wet heath communities, and *Carpha* species are associated with bogs (Appendices Figure A4.1).

Thirty-seven of the 55 factors tested with the frequency ordination graph showed significant correlation with at least one of the three axes (Table 4.15, Appendices Table A4.18*). Amongst the strongest correlations with axis 1 are those factors associated with continental climates, such as mean diurnal temperature range, mean annual temperature range, and radiation of the lowest period (less cloud cover). These factors increase in value towards the peatland plots and community types of the Bogong, Snowy Range and Dargo High Plains regions (Subalpine raised bog, Tall wet heath, Myrtaceous wet heath) (Figure 4.11). These regions are east of the Macalister Valley, hence there is also an association with increasing longitude. Latitude trends in the opposite direction towards the Baw Baw and Central Highlands plots, further illustrating the general trend from south-west to north-east. Moisture index during the warmest quarter, and minimum temperature of the coldest period are also strongly correlated with the western sites, indicating conditions are generally milder and wetter in this region. Thus, variables

Table 4.14: Species with the strongest significant correlations with the axes of the ordination graph derived from the **subalpine transects frequency data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Species	MDS1	sig.level	MDS2	sig.level	MDS3	sig.level
Epacris celata	**0.80**	***	**0.30**	*	0.19	ns
Baloskion australe	**0.73**	***	0.12	ns	-0.01	ns
Baeckea gunniana	**0.67**	***	-0.26	ns	-0.25	ns
Luzula modesta	**0.63**	***	-0.01	ns	**0.38**	**
Gonocarpus micranthus	**0.59**	***	-0.13	ns	0.07	ns
Stylidium sp.	**0.56**	***	**-0.37**	**	-0.02	ns
Pultenaea spp.	**0.55**	***	**-0.45**	**	0.13	ns
Comesperma retusum	**0.50**	***	**-0.44**	**	0.18	ns
Coprosma perpusilla	**-0.50**	***	-0.08	ns	**-0.30**	*
Olearia algida	**-0.56**	***	**-0.43**	**	0.03	ns
Euphrasia gibbsiae	**-0.59**	***	-0.19	ns	**-0.42**	**
Drosera arcturi	**-0.61**	***	-0.24	ns	**-0.40**	**
Rytidosperma sp.	**-0.64**	***	-0.19	ns	**-0.33**	*
Gentianella sp.	**-0.71**	***	**-0.41**	**	-0.18	ns
Astelia alpina	**-0.80**	***	**-0.39**	**	-0.10	ns
Carex gaudichaudiana	0.15	ns	**0.78**	***	-0.16	ns
Richea continentis	-0.27	ns	**0.61**	***	**0.31**	*
Sphagnum cristatum	0.00	ns	**0.52**	***	-0.28	ns
Epacris paludosa	0.14	ns	**-0.56**	***	**-0.50**	***
Asperula gunnii	**0.36**	**	-0.27	ns	**0.69**	***
Carpha spp.	**-0.43**	**	-0.05	ns	**-0.60**	***

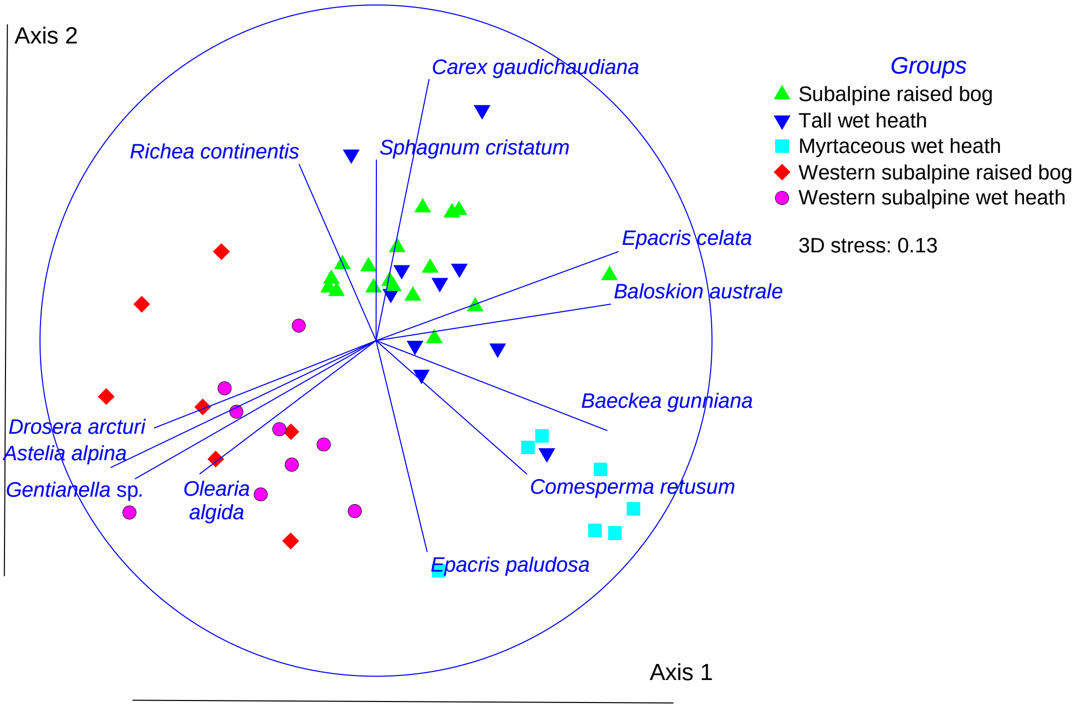


Figure 4.10: Three dimensional ordination graph derived from the **subalpine transects frequency data** (Axis 1 v Axis 2). The trend directions of strongly correlated species are indicated.

Table 4.15: Factors with the strongest significant correlations with the three axes of the ordination graph derived from the **subalpine transects frequency data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Factors	MDS1	sig.level	MDS2	sig.level	MDS3	sig.level
Lowest period radiation	**0.86**	***	**0.31**	*	0.18	ns
Temperature annual range	**0.82**	***	0.18	ns	0.23	ns
Mean diurnal temperature range	**0.80**	***	0.15	ns	0.17	ns
Longitude	**0.76**	***	0.23	ns	0.04	ns
Radiation of wettest quarter	**0.63**	***	**0.36**	*	-0.04	ns
Maximum temperature of warmest period	**0.56**	***	-0.06	ns	**0.31**	*
Precipitation seasonality	**0.51**	***	-0.05	ns	**0.29**	*
Topography	**0.41**	**	**-0.30**	*	-0.11	ns
% slope	**0.38**	**	-0.12	ns	-0.07	ns
Peat depth	**-0.40**	**	**0.28**	*	0.10	ns
Minimum temperature of coldest period	**-0.59**	***	-0.27	ns	0.00	ns
Mean moisture index of warmest quarter	**-0.60**	***	-0.09	ns	-0.27	ns
Latitude	**-0.76**	***	-0.24	ns	-0.20	ns
Radiation seasonality (Cof V)	**-0.81**	***	-0.26	ns	-0.12	ns
Distance to woodland	-0.09	ns	**0.47**	***	0.08	ns
Mean height of tallest shrubs	0.25	ns	**-0.28**	*	0.16	ns
Aspect	0.22	ns	**-0.47**	***	-0.12	ns
Other mosses	0.00	ns	**-0.55**	***	-0.14	ns

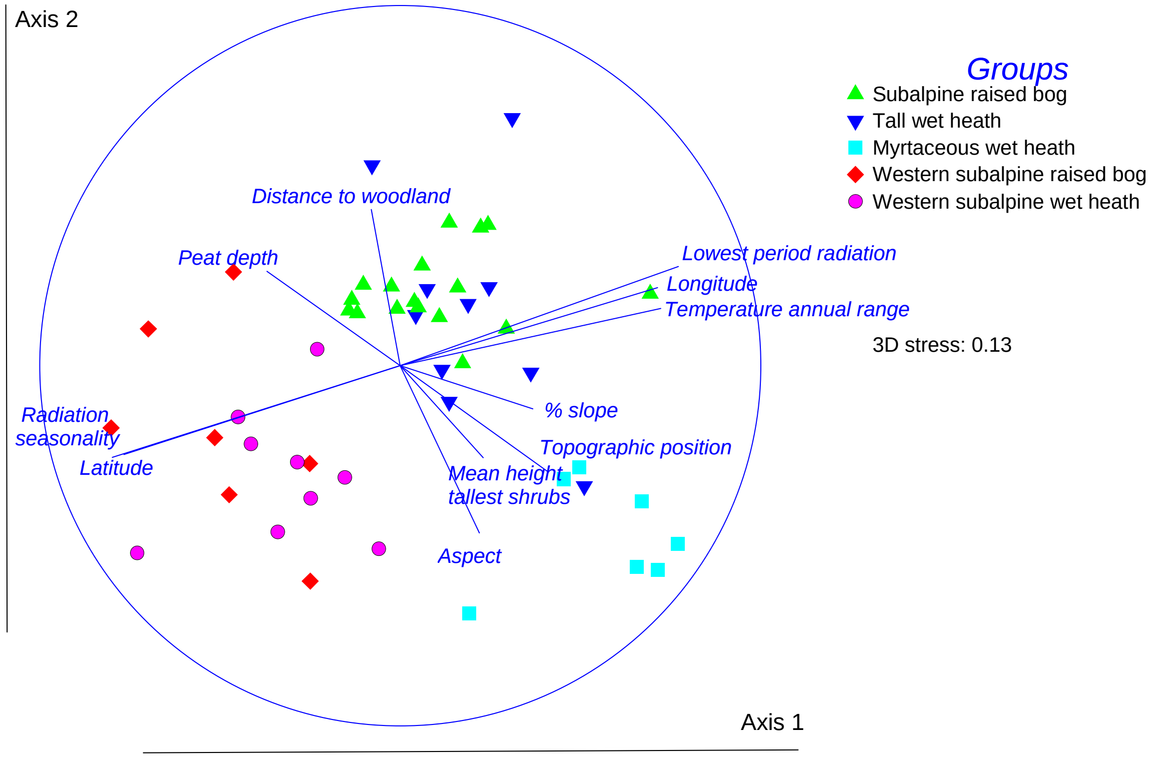


Figure 4.11: Three-dimensional ordination graph derived from the **subalpine transects frequency data** (Axis 1 v Axis 2). The trend directions of the factors with strong correlations are indicated.

correlated with the clear floristic separation between eastern and western peatland plots appear to provide strong evidence of the influence of the gradient in oceanicity-continentality.

The diagonal spread of the plots from top left to bottom right would appear to be along gradients in local factors such as peat depth, aspect, dryness of topographic position. Gradients in these factors appear to be separating Myrtaceous wet heath from all other subalpine wetland types, hence they all have strong negative correlations with axis 2, and trend towards this community type in particular, which is restricted to the regions east of the Macalister.

The third plane or direction of separation is directly aligned with axis 2, and is perhaps related to the differences in altitude within the subalpine zone (1300-1650 m). Plots positioned near the bottom of the ordination space have a higher ‘other mosses’ representation and are at slightly lower altitudes (Western subalpine raised bog, Western subalpine wet heath, and Myrtaceous wet heath), whereas the plots near the top of the graph space are associated with greater distances from the surrounding woodland or forest, and tend to be at slightly higher elevations (Subalpine raised bog and Tall wet heath). Peat depth shows an association with ‘raised bog’ in general regardless of region.

Species and factors correlations with the subalpine cover data ordination

The pattern is similar in the cover ordination configuration (Table 4.16, Figure 4.12, Appendices Figure A4.2). The shrub species *Comesperma*, *Pultenaea* and *Baeckea* have strong positive correlations with axis 1, and Myrtaceous wet heath and Tall wet heath. *Sphagnum* and *Carex gaudichaudiana* have strong negative correlations with this axis and favour both of the ‘bog’ communities, although the latter shows increasing cover values towards the ‘eastern’ raised bogs.

Empodisma minus and *Astelia alpina* have very strong negative correlations with axis 3 of the cover ordination and trend towards the western communities, particularly wet

Table 4.16: Species with the strongest significant correlations with the axes of the ordination graph derived from the **subalpine transects cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Species	MDS1	sig.level	MDS2	sig.level	MDS3	sig.level
Comesperma retusum	**0.48**	***	0.13	ns	0.27	ns
Pultenaea fasciculata	**0.47**	***	0.19	ns	**0.32**	*
Baeckea gunniana	**0.46**	***	-0.03	ns	**0.57**	***
Asperula gunnii	**0.42**	**	-0.22	ns	**0.36**	*
Carex gaudichaudiana	**-0.54**	***	-0.11	ns	**0.30**	*
Sphagnum cristatum	**-0.93**	***	-0.04	ns	0.00	ns
Epacris paludosa	0.09	ns	**0.52**	***	0.22	ns
Richea continentis	**-0.33**	*	**-0.71**	***	0.05	ns
Epacris celata	-0.18	ns	-0.27	ns	**0.57**	***
Gonocarpus micranthus	0.25	ns	0.10	ns	**0.49**	***
Euphrasia gibbsiae	0.09	ns	**0.46**	***	**-0.41**	**
Drosera arcturi	0.07	ns	**0.52**	***	**-0.41**	**
Olearia algida	**0.28**	*	0.16	ns	**-0.44**	**
Rytidosperma sp.	0.05	ns	**0.37**	**	**-0.44**	**
Gentianella sp.	0.20	ns	**0.44**	**	**-0.60**	***
Astelia alpina	0.13	ns	**0.29**	*	**-0.65**	***
Empodisma minus	0.14	ns	-0.15	ns	**-0.80**	***

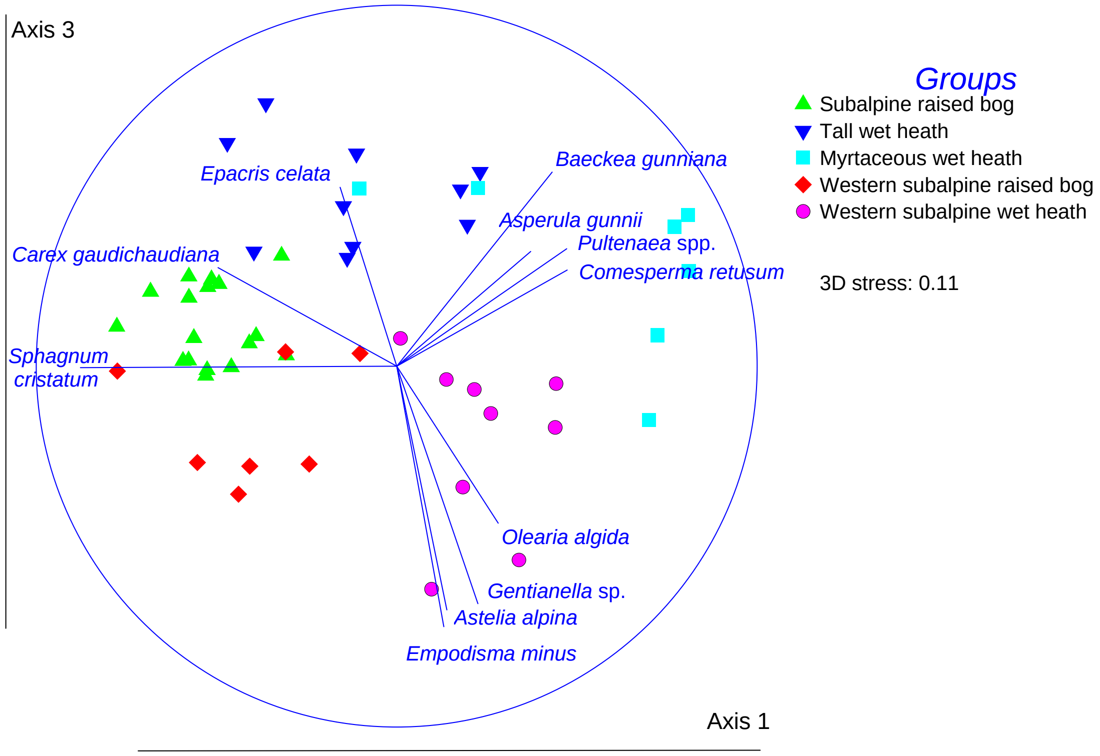


Figure 4.12: Three-dimensional ordination graph derived from the **subalpine transects cover data** (Axis 1 v Axis 3). The trend directions of the species with the strongest correlations are indicated.

heath. *Epacris celata* shows increasing values along axis 3, trending towards Tall wet heath in particular. *Richea continentis* shows a less clear trend based on cover, it favours a mix of wet heath and bog communities, although as expected it trends away from Myrtaceous wet heath from which it is absent.

Twenty-nine of the 55 environmental and structural factors showed significant correlation with the axes of the cover ordination (Table 4.17, Appendices Table A4.20*). In general the same relationships observed in the frequency ordination are apparent. Factors associated with continentality increase in value towards eastern communities (Subalpine raised bog, Tall wet heath, Mytaceous wet heath), those associated with oceanicity (e.g. minimum temperature of the coldest period, latitude in this context) increase towards Western subalpine raised bog and Western subalpine wet heath (Figure 4.13). Peat depth decreases, but shrub height and litter cover increase, towards the three ‘wet heath’ communities in general, and away from the two ‘bog’ communities, independently of geographic region (east or west). Therefore, in the cover ordination the subalpine plots separate along axis 1 according to structure, with ‘bog’ to the left, and ‘wet heath’ to the right. Separation along axis 3 is according to region; plots east of the Macalister Valley are near the top of the ordination space, plots to the west of the Macalister are towards the bottom. There is a slight increasing trend in altitude associated with axis 3 also. The plots in Tall wet heath and Subalpine raised bog were located at marginally higher elevations within the subalpine zone, than those in Myrtaceous wet heath and the ‘western’ peatland communities (see Appendices Table A4.21).

Table 4.17: Factors with the strongest significant correlations with axes of the ordination derived from the **subalpine transects cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Factor	MDS1	sig.level	MDS2	sig.level	MDS3	sig.level
Mean height of tallest shrubs	**0.56**	***	-0.06	ns	0.28	ns
% peat points < 0.5 m deep	**0.54**	***	0.03	ns	**0.49**	***
Litter	**0.51**	***	0.04	ns	**0.34**	*
Mean shrub height	**0.49**	***	-0.11	ns	0.16	ns
Aspect	**0.49**	***	0.19	ns	0.02	ns
Other mosses	**0.46**	***	**0.37**	**	-0.05	ns
Topographic position	**0.35**	*	0.18	ns	**0.34**	*
Dead *Empodisma*	**0.33**	*	0.00	ns	-0.24	ns
% peat points > 1 m deep	**-0.41**	**	-0.15	ns	**-0.31**	*
Peat depth	**-0.50**	***	-0.09	ns	**-0.38**	**
Temperature seasonality	-0.12	ns	-0.27	ns	**0.57**	***
Lowest period radiation	-0.20	ns	**-0.33**	*	**0.55**	***
Longitude	-0.12	ns	-0.17	ns	**0.53**	***
Altitude	-0.07	ns	-0.09	ns	**0.50**	***
Shrub cover	0.11	ns	**-0.38**	**	**0.46**	***
Temperature annual range	-0.11	ns	-0.28	ns	**0.43**	**
Precipitation of driest period	-0.03	ns	-0.04	ns	**0.40**	**
Mean temperature of coldest quarter	0.10	ns	0.04	ns	**-0.46**	***
Latitude	0.11	ns	**0.31**	*	**-0.52**	***
Radiation seasonality	0.14	ns	0.24	ns	**-0.61**	***
Minimum temperature of coldest period	0.14	ns	0.23	ns	**-0.62**	***

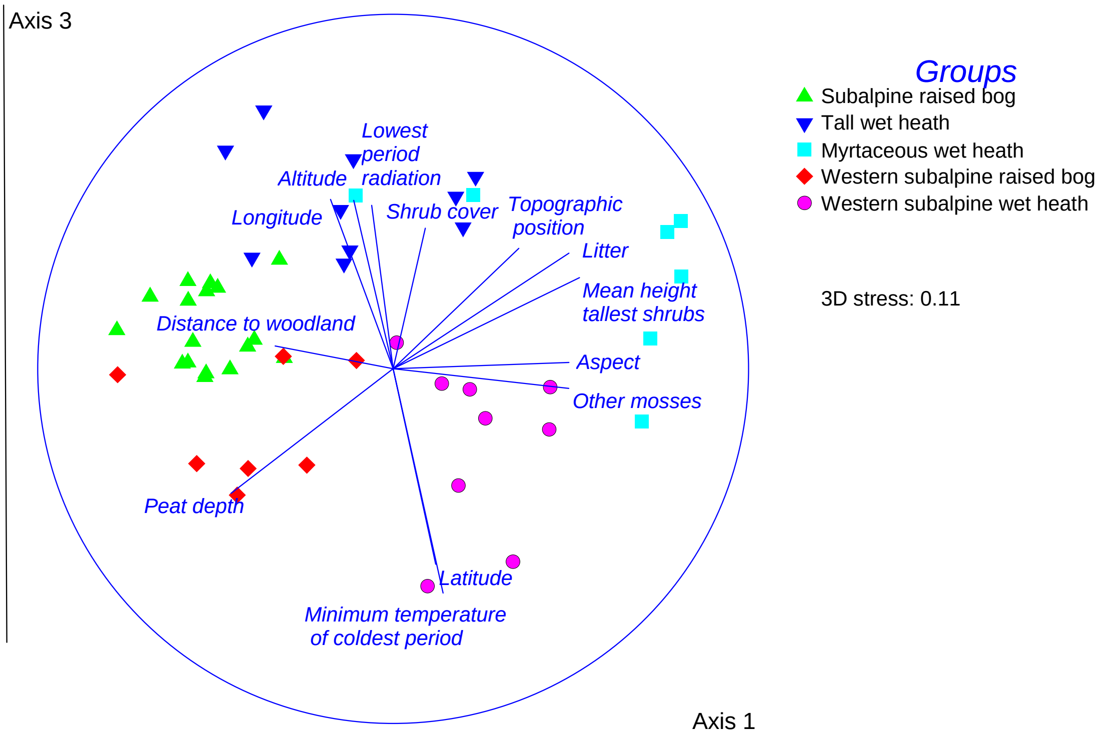


Figure 4.13: Three dimensional ordination graph derived from the **subalpine transects cover data** (Axis 1 v Axis 3). The trend directions of factors with strong correlations are indicated.

Plant functional group correlations with the subalpine cover data ordination

Ten of the 11 life-form groups showed significant correlations with the subalpine transect cover ordination (Table 4.18). The categories with the strongest correlations were the restiads, *Astelia*, myrtaceous shrubs, and *Sphagnum* spp. All these groups achieved Spearman correlation coefficients of stronger than 0.6 (positive or negative).

Sphagnum species are negatively correlated with axis 1 and trend towards the ‘bog’ communities in general (Figure 4.14). The *Carex* species group also has a negative correlation with axis 1, but trends diagonally towards Subalpine raised bog and Tall wet heath. Myrtaceous shrubs are positively correlated with axis 3, and show a trend towards increasing cover values in the two eastern wet heath communities. The ‘Other shrubs’ group is associated with the wet heath communities in general, independently of region. Restiads and *Astelia* have strong negative correlations with axis 3, and trend towards the two western communities in general.

There are really only two groups with strong associations with axis 2, ericaceous shrubs and ‘other sedges’ (Table 4.18). These appear to be linked to variation within the wet heath categories, particularly Western subalpine wet heath, and Tall wet heath to a lesser extent (Appendices Figure A4.3). There is a considerable spread of the plots from the Western subalpine wet heath group along axis 2. Some of these wet heath plots are associated with a higher cover of sedges other than *Carex* spp. (*Carpha* spp., *Oreobolus*) and a relatively lower ericaceous shrub presence. These plots also have a slight association with herbs also (e.g. *Coprosma* spp., *Psychrophila introloba*, *Euphrasia gibbsiae*). Those at the opposite end of the spectrum have a high cover of ericaceous shrubs and are low in ‘other sedges’ and herbs.

Table 4.18: Plant functional groups significantly correlated with axes of the ordination derived from the **subalpine transects cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001)**.**

Functional groups	**MDS1**	**sig.level**	**MDS2**	**sig.level**	**MDS3**	**sig.level**
Other shrubs	**0.59**	***	0.27	ns	-0.01	ns
Other monocots	**0.36**	*	0.07	ns	**0.29**	*
Carex spp.	**-0.50**	***	-0.07	ns	**0.38**	**
Sphagnum spp.	**-0.94**	***	-0.04	ns	-0.04	ns
Other sedges	0.22	ns	**0.51**	***	-0.13	ns
Herbs	0.27	ns	**0.30**	*	0.06	ns
Ericaceous shrubs	-0.15	ns	**-0.51**	***	0.27	ns
Myrtaceous shrubs	**0.46**	***	0.04	ns	**0.62**	***
Astelia	0.15	ns	0.27	ns	**-0.62**	***
Restiads	0.07	ns	-0.19	ns	**-0.76**	***

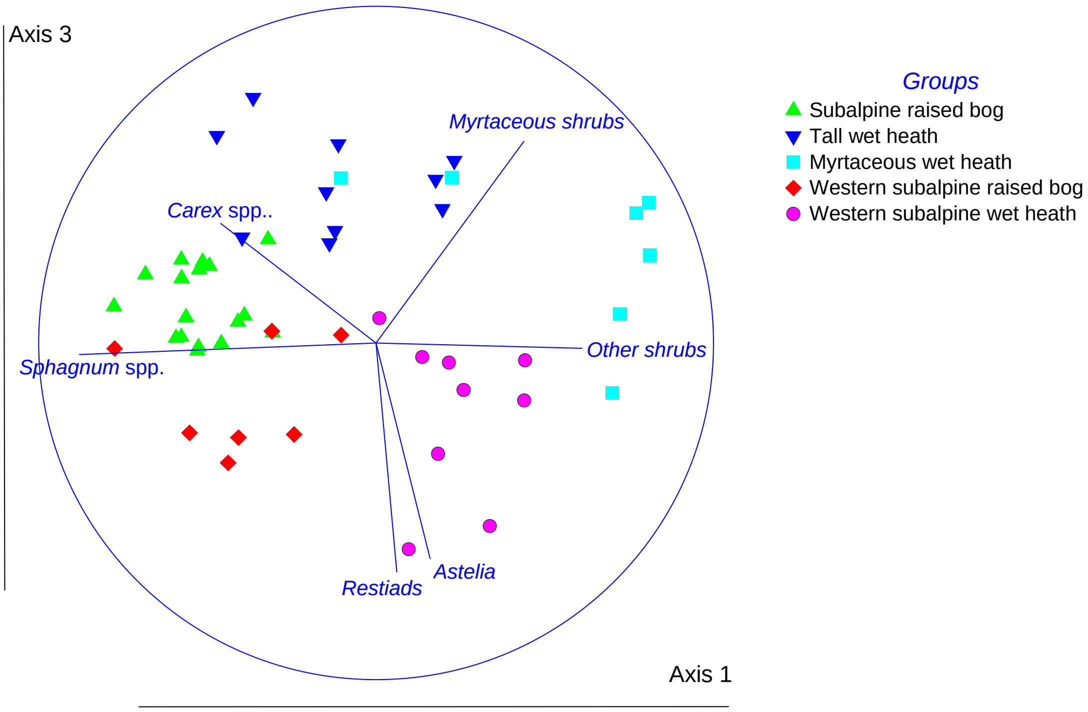


Figure 4.14: Three dimensional ordination graph derived from the **subalpine transects cover data** (Axis 1 v Axis 3). The trend directions of plant functional groups with strong correlations are indicated.

4.3.2 Comparisons between the alpine and subalpine plots from all regions

This section includes the alpine plots thus swelling the transect pool to 67. The addition of the 17 alpine plots allows us to compare these with the subalpine plots from the Snowy Range-Dargo High Plains region and the Baw Baw-Central Highlands region. Differences between the ‘alpine’ and ‘subalpine’ Bogong region plots were established and discussed in Chapter 3. In this section 8 of the 11 community types are represented. These are Alpine raised bog (7 plots), Low wet heath (5), Alpine valley bog (5), Subalpine raised bog (17), Tall wet heath (10), Myrtaceous wet heath (7), Western subalpine raised bog (7), and Western subalpine wet heath (9). The main focus of this section is to compare the alpine plots from east of the Macalister Valley (Bogong region) with the subalpine plots from west of this north-south line (see Figure 3.1). The original species pool of 93 species was reduced accordingly to the 82 species recorded in two or more transects. The life-form breakdown of the species pool is as follows: 17 shrubs, 27 monocots, 34 herbs, one club moss group, and three bryophyte taxa.

Ordinations based on the alpine and subalpine frequency and cover data

Three dimensional ordination graph solutions were adopted for both the cover and frequency data. The Kruskal stress index values for the frequency and cover ordination graphs were 0.14 and 0.10 respectively (Figures 4.15, 4.16). There is little if any overlap between the cluster of ‘eastern’ subalpine plots and the ‘western’ subalpine plots, as observed in the previous section (subalpine analysis).

In the ordination configuration derived from the frequency data, two of the three ‘alpine’ community types appear to have more in common with the two ‘western’ subalpine groups than with their subalpine ‘near-neighbours’ (Figure 4.15). The Alpine raised bog plots sit amongst the Western subalpine raised bog plots in the graph space and in close proximity to the Western subalpine wet heath plots. The Low wet heath plots form a tight cluster on the far right of the graph space, but have more in common with Western subalpine wet heath than with the ‘eastern’ wet heath community plots (MWH, TWH).

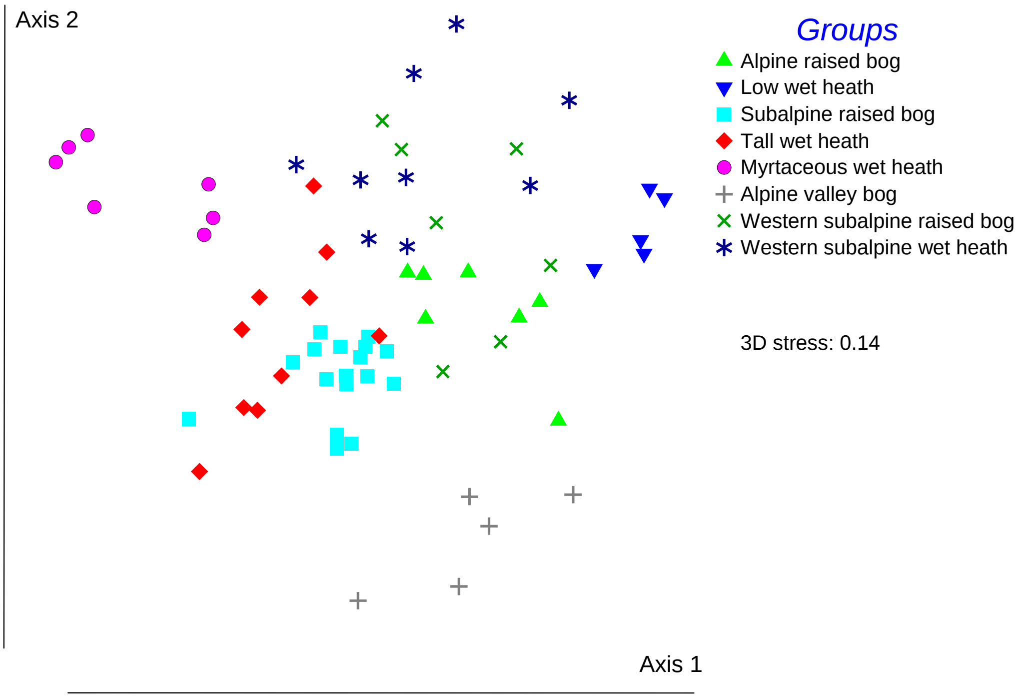


Figure 4.15: Three dimensional ordination graph derived from the **alpine and subalpine frequency data** (Axis 1 v Axis 2).

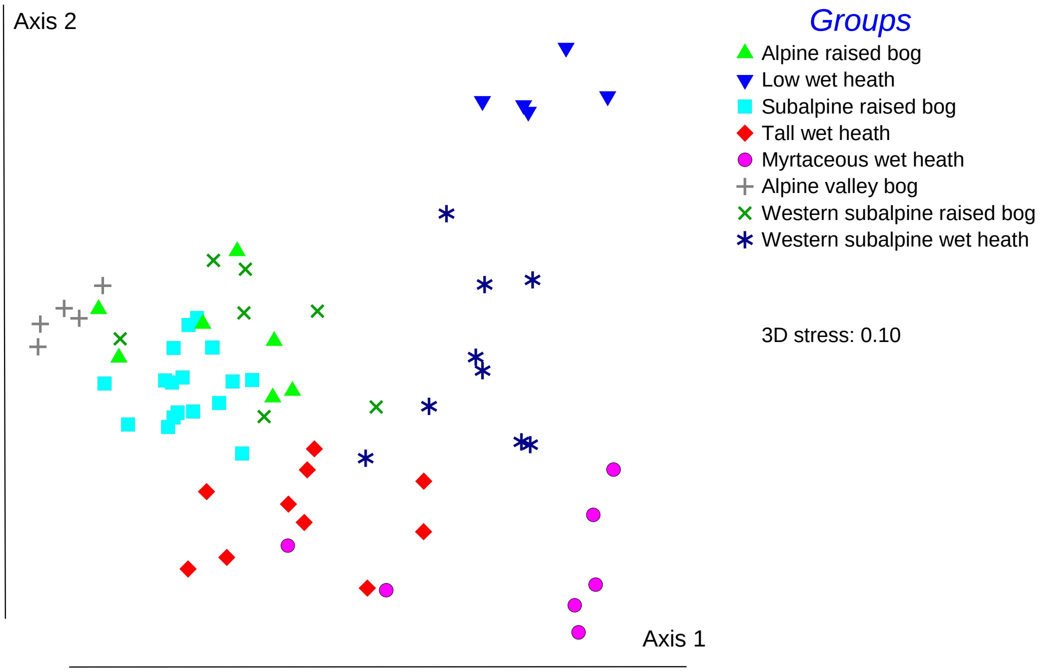


Figure 4.16: Three dimensional ordination graph derived from the **alpine and subalpine cover data** (Axis 1 v Axis 2).

Alpine valley bog forms a separate, but diffuse group in the lower right corner of the graph space.

In the ordination derived from the cover data there is some clustering according to formation type rather than region (Figure 4.16). The four ‘bog’ communities cluster on the left of the graph space, although there is separation according to community type. For example, Western subalpine raised bog would appear to have more in common with Alpine raised bog than with the other two ‘bog’ communities (Alpine valley bog, Subalpine raised bog). The four wet heath community types sit in the right half of the ordination graph, but are clearly separated along axis 2. Low wet heath is at the top, Western subalpine wet heath in the middle, and the two ‘eastern’ subalpine wet heath groups are at the bottom. The latter two groups (MWH, TWH) are separated along axis 1. Again, Low wet heath plots would appear to be closer in structure and composition to Western subalpine wet heath, than to Tall wet heath or Myrtaceous wet heath.

ANOSIM comparisons of the alpine and subalpine peatland communities

The evidence from the ordination graphs was supported by the pair-wise group comparisons which showed Alpine raised bog and Western subalpine raised bog to be marginally different based on the frequency data ($R = 0.545$, $p = 0.004$) and barely separable based on the cover data ($R = 0.165$, $p = 0.05$) (Tables 4.19-4.21). Based on the frequency data, the Alpine raised bog plots were more similar to the Western subalpine wet heath plots, than to the Western subalpine raised bog group ($R = 0.389$, $p = 0.002$). This was perhaps understandable given that the same analysis of the frequency data failed to separate the two ‘western’ subalpine groups ($R = 0.152$, $p = 0.077$, ns; Table 4.20). The clear differences between the ‘wet heath’ groups apparent in the ordination graphs were also supported by ANOSIM comparisons.

Based on the frequency data, Western subalpine raised bog and Western subalpine wet heath are the most similar, followed by Alpine raised bog and Western subalpine wet heath (Table 4.20, see Appendices Table A4.22* for full version). In the equivalent table

Table 4.19: Pair-wise comparisons of a selection of **subalpine and alpine peatland communities** based on both **frequency and cover data**. R-statistic values of greater than 0.5 are highlighted in bold type.

Analysis of similarity	Actual	Frequency data		Cover data	
Pair-wise Tests	**Perm'tns**	**R**	**Signif.**	**R**	**Signif.**
Groups	max = 999	**Statistic**	**P-value**	**Statistic**	**P-value**
Low wet heath, W'tn subalpine raised bog	792	**0.972**	0.001	**0.998**	0.001
Alpine valley bog, W'tn subalpine wet heath	999	**0.97**	0.002	**0.957**	0.003
Alpine valley bog, W'tn subalpine raised bog	792	**0.948**	0.001	**0.637**	0.004
Low wet heath, W'tn subalpine wet heath	999	**0.614**	0.001	**0.605**	0.002
Alpine raised bog, W'tn subalpine raised bog	999	**0.545**	0.004	0.165	0.050
Alpine raised bog, W'tn subalpine wet heath	999	0.389	0.002	**0.53**	0.001
Overall global test sample statistic	**999**	**0.701**	**0.001**	**0.702**	**0.001**

Table 4.20: The five most similar group pairings based on the ANOSIM analysis of the **alpine and subalpine transects frequency data**.

Pair-wise Tests	R	Signif.	Possible	Actual	Num. >=
Groups	**Stat.**	**P-value**	**Perm'tns**	**Perm'tns**	**Obs.**
W'tn subalpine raised bog, W'tn subalpine wet heath	0.152	0.077	11440	999	76
Alpine raised bog, W'tn subalpine wet heath	0.389	0.002	11440	999	1
Subalpine raised bog, Tall wet heath	0.410	0.001	8436285	999	0
Alpine raised bog, Tall wet heath	0.472	0.001	19448	999	0
Tall wet heath, W'tn subalpine wet heath	0.500	0.001	92378	999	0

Table 4.21: The five most similar group pairings based on the ANOSIM analysis of the **alpine and subalpine transects cover data**.

Pair-wise Tests	R	Signif.	Possible	Actual	Num. >=
Groups	**Stat.**	**P-value**	**Perm'tns**	**Perm'tns**	**Obs.**
Alpine raised bog, W'tn subalpine raised bog	0.165	0.05	1716	999	49
W'tn subalpine raised bog, W'tn subalpine wet heath	0.402	0.4	11440	999	3
Alpine raised bog, Subalpine raised bog	0.403	0.1	346104	999	0
Myrtaceous wet heath, W'tn subalpine wet heath	0.421	0.2	11440	999	1
Tall wet heath, W'tn subalpine wet heath	0.486	0.1	92378	999	0

based on the cover data, Alpine raised bog and Western subalpine raised bog were the most similar, followed by Western subalpine raised bog and Western subalpine wet heath (Table 4.21, Appendices Table A4.23*). Both frequency and cover data suggested higher similarity between Low wet heath and Western subalpine wet heath plots, than between Low wet heath and the two ‘eastern’ subalpine wet heath groups.

SIMPER analysis of the alpine and subalpine communities: distinguishing species

The Alpine raised bog and Western subalpine raised bog plots have similar cover abundances of species like *Epacris paludosa*, *Empodisma minus,* and *Astelia alpina* (Table 4.22). The inundation tolerant bryophyte *Sphagnum novozelandicum* and the two species of the hard-leaved sedge *Carpha* were more common in Western subalpine raised bog. In contrast, Alpine raised bog had higher cover of *Sphagnum cristatum*, *Richea continentis* and *Baeckea gunniana*. It also had *Epacris celata*, *Epacris glacialis,* and some *Baloskion australe*, all of which are totally absent from the western subalpine region. Alpine raised bog also had more *Celmisia*, *Drosera arcturi* and *Oreobolus distichus* than Western subalpine raised bog, whereas *Gentianella*, *Nertera* and *Erigeron paludicola* were more common in the latter (Tables 4.22-4.24, Appendices Tables A4.24-A4.26).

Comparing the Western subalpine wet heath with Low wet heath is useful given their relative proximity in the ordination space (Table 4.23). The species they have in common are *Astelia alpina*, *Baeckea gunniana*, *Richea continentis*, *Gentianella* and *Empodisma minus*. In Low wet heath, *Poa costiniana, Celmisia* spp., and *Oreobolus distichus* are more common; *Epacris paludosa*, *Sphagnum cristatum*, *Carpha* spp., and *Asperula gunnii* were more common in Western subalpine wet heath. The shrub species *Olearia algida* and *Epacris petrophila* occurred in Western subalpine wet heath, but were absent from Low wet heath. However, *Epacris glacialis* does not occur in Victoria outside the Bogong High Plains, thus was not recorded in the ‘western’ groups.

Alpine valley bog is characteristically dominated by *Sphagnum cristatum* and has a high cover of sedges relative to other community types (Table 4.24, Appendices Table A4.26). These included *Carex gaudichaudiana*, *Carpha* spp. *Carex echinata,* and *Isolepis* spp. *Empodisma minus* and shrubs such as *Richea continentis*, *Epacris celata* and *Epacris glacialis* were common but provided relatively little cover. Some of the hallmark species that typify Alpine raised bog and Western subalpine raised bog, such as *Astelia alpina*, *Epacris paludosa*, *Baeckea gunniana*, *Oreobolus distichus* and *Celmisia* spp., were rare or absent.

Table 4.22: Species contributing to differences between **Alpine raised bog (ARB)** and **Western subalpine raised bog (WSR)** based on the **alpine and subalpine, (a) Frequency data, (b) cover data**. The species listed contribute more than 80% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they were most prominent.

(a): Frequency data. **(ARB)** and **(WSR).** Mean dissimilarity = 42.3

More common in ARB	**Av.freq (ARB)**	**Av.freq (WSR)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Richea continentis	92.6	46.9	3.0	2.1	6.8
Baeckea gunniana	65.2	25.9	2.7	1.6	6.0
Epacris glacialis	43.1	0.0	2.8	1.1	6.3
Celmisia spp.	34.1	11.5	1.7	1.9	3.7
Drosera arcturi	21.7	11.0	1.4	0.9	3.2
Oreobolus distichus	21.4	3.1	1.3	1.2	2.9
Epacris celata	20.7	0.0	1.4	0.6	3.1
Diplaspis nivis	16.7	0.0	1.0	0.6	2.3
More common in WSR					
Erigeron paludicola	17.6	34.6	2.0	1.3	4.5
Nertera granadensis	0.0	33.5	2.2	1.4	4.9
Gentianella sp.	6.4	24.3	1.3	1.5	2.8
Asperula gunnii	2.9	20.4	1.2	0.9	2.7
Sphagnum novozelandicum	0.7	15.0	1.0	1.1	2.3
Similar frequency in both					
Epacris paludosa	54.1	58.3	2.7	1.5	6.1
Carpha spp.	32.4	38.3	2.3	1.5	5.1
Carex gaudichaudiana	23.3	22.1	2.1	1.0	4.8
Poa costiniana	48.6	45.4	2.0	1.3	4.4
Rytidosperma sp.	20.0	13.3	1.4	1.2	3.1
Astelia alpina	41.0	54.4	1.3	1.3	3.0

(b): Cover data. (ARB) and **(WSR).** Mean dissimilarity = 34.9%

Higher % cover in ARB	**Av.cover (ARB)**	**Av.cover (WSR)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**70.1**	47.2	10.7	1.4	30.6
Richea continentis	**9.8**	5.4	2.1	1.6	6.1
Baeckea gunniana	**5.9**	1.9	2.0	1.2	5.7
Epacris glacialis	**2.5**	0.0	1.1	0.9	3.0
Epacris celata	**1.9**	0.0	0.8	0.6	2.4
Higher % cover in WSR					
Carpha spp.	1.8	**3.4**	1.5	1.0	4.2
Sphagnum novozelandicum	0.0	**3.3**	1.4	0.8	3.9
Carex gaudichaudiana	0.8	**1.9**	1.0	0.6	2.9
Similar % cover in both					
Epacris paludosa	11.0	12.9	4.7	1.4	13.5
Empodisma minus	19.4	20.6	4.6	1.3	13.2
Astelia alpina	3.6	6.1	2.1	0.7	6.0

Table 4.23: Species contributing to differences between **Low wet heath (LWH)** and **Western subalpine wet heath (WSW)** based on the **alpine and subalpine transects, (a) Frequency data, (b) cover data**. The species listed contribute more than 80% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they were most prominent.

(a): Frequency data. **(LWH)** and **(WSW).** Mean dissimilarity = 52.9%

More common in LWH	**Av.freq (LWH)**	**Av.freq (WSW)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Epacris glacialis	**99.3**	0.0	7.3	6.5	13.9
Poa costiniana	**85.7**	36.4	3.8	1.7	7.2
Celmisia spp.	**66.0**	16.1	3.8	2.4	7.1
Oreobolus distichus	**45.0**	6.9	2.8	1.8	5.4
Diplaspis nivis	**25.3**	0.0	1.7	0.8	3.2
Baloskion australe	**15.3**	0.0	1.1	0.5	2.1
Epacris celata	**14.7**	0.0	1.0	0.5	2.0
More common in WSW					
Epacris paludosa	1.0	**66.1**	4.7	1.8	8.9
Sphagnum cristatum	14.3	**31.2**	1.7	1.2	3.2
Asperula gunnii	6.0	**22.1**	1.5	1.1	2.9
Nertera granadensis	0.0	**18.7**	1.4	1.1	2.6
Carpha spp.	8.3	**18.3**	1.3	1.1	2.5
Olearia algida	0.0	**18.1**	1.4	1.0	2.6
Epacris petrophila	0.0	**15.1**	1.2	0.5	2.2
Similar frequency in both					
Astelia alpina	76.0	49.6	2.8	1.4	5.3
Baeckea gunniana	33.3	46.7	2.4	1.4	4.5
Richea continentis	69.7	60.3	2.1	1.2	3.9
Gentianella sp.	28.0	28.9	1.3	1.4	2.5

(b): Cover data. (LWH) and **(WSW).** Mean dissimilarity = 60.4%

Higher % cover in LWH	**Av.cover (LWH)**	**Av.cover (WSW)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Astelia alpina	**26.8**	8.2	10.9	1.7	18.0
Epacris glacialis	**23.4**	0.0	13.0	2.4	21.5
Oreobolus distichus	**3.2**	0.2	1.7	1.0	2.8
Celmisia spp.	**2.6**	0.4	1.2	2.0	2.0
Poa costiniana	**2.1**	1.2	1.2	1.3	2.1
Higher % cover in WSW					
Epacris paludosa	0.3	**13.7**	7.4	1.6	12.3
Sphagnum cristatum	3.3	**10.6**	4.8	1.1	7.9
Baeckea gunniana	1.5	**7.7**	3.8	1.2	6.2
Similar % cover in both					
Richea continentis	10.6	13.0	6.3	1.2	10.4
Empodisma minus	19.6	24.2	4.7	1.1	7.7

Table 4.24: Species contributing to differences between **Alpine valley bog (AVB)** and **Western subalpine raised bog (WSR)** based on the **alpine and subalpine, (a) Frequency data, (b) cover data**. The species listed contribute more than 80% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they were most prominent.

(a): Frequency data. **(AVB)** and **(WSR).** Mean dissimilarity = 57.9%

More common in AVB	**Av.freq (AVB)**	**Av.freq (WSR)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Carex gaudichaudiana	**95.3**	22.1	5.3	2.1	9.2
Epacris glacialis	**56.3**	0.0	4.1	1.6	7.0
Epacris celata	**45.5**	0.0	3.3	1.7	5.6
Carex echinata	**39.4**	0.0	2.9	1.2	4.9
More common in WSR					
Epacris paludosa	2.7	**58.3**	3.9	1.7	6.8
Astelia alpina	0.0	**54.4**	3.9	2.8	6.8
Erigeron paludicola	10.3	**34.6**	2.2	1.3	3.9
Nertera granadensis	0.3	**33.5**	2.4	1.3	4.1
Baeckea gunniana	7.6	**25.9**	1.7	1.4	2.9
Gentianella sp.	0.0	**24.3**	1.7	1.9	3.0
Asperula gunnii	0.0	**20.4**	1.4	1.0	2.5
Sphagnum novozelandicum	0.0	**15.0**	1.1	1.1	2.0
Euphrasia gibbsiae	0.0	**14.5**	1.0	1.0	1.8
Similar frequency in both					
Poa costiniana	33.3	45.4	2.5	1.5	4.2
Carpha spp.	30.3	38.3	2.4	1.7	4.2
Richea continentis	47.4	46.9	2.2	1.5	3.8
Isolepis spp.	23.0	12.8	1.8	1.0	3.1
Sphagnum cristatum	98.6	79.8	1.4	1.8	2.4

(b): Cover data. (AVB) and **(WSR).** Mean dissimilarity = 46.1%

Higher % cover in AVB	**Av.cover (AVB)**	**Av.cover (WSR)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**90.0**	47.2	18.2	3.0	39.5
Carex gaudichaudiana	**8.7**	1.9	3.3	2.7	7.1
Epacris glacialis	**3.5**	0.0	1.5	1.0	3.2
Epacris celata	**3.2**	0.0	1.4	1.5	3.0
Higher % cover in WSR					
Empodisma minus	8.9	**20.6**	5.0	1.1	10.7
Epacris paludosa	0.2	**12.9**	5.3	1.2	11.6
Astelia alpina	0.0	**6.1**	2.6	0.8	5.6
Carpha spp.	1.8	**3.4**	1.4	1.0	3.0
Sphagnum novozelandicum	0.0	**3.3**	1.4	0.8	3.0
Similar % cover in both					
Richea continentis	6.8	5.4	2.0	1.6	4.2

Species and factor correlations with the alpine and subalpine data ordinations

Sixty-seven of the 82 species showed significant correlation with at least one of the three axes of the alpine and subalpine frequency data ordination graph (Table 4.25). The species with strong trends towards the ‘alpine’ and ‘western subalpine’ plots, and away from the ‘eastern subalpine’ plots included *Astelia alpina, Gentianella, Drosera arcturi, Rytidosperma nivicola, Oreobolus distichus* and *Poa costiniana* (Figure 4.17). The strongest trends towards the ‘eastern’ subalpine plots, in the opposite direction, were for species like *Baeckea gunniana, Callistemon pityoides, Baloskion australe, Epacris celata* and *Asperula gunnii*.

A total of 50 out of the 55 environmental and structural variables were significantly correlated with the frequency data ordination (Table 4.26). The strongest factors linked to differences between the ‘alpine’ and ‘western subalpine’ plots on one hand, and the ‘eastern subalpine’ plots on the other, were those associated with the climatic gradient (Figure 4.18). Hence, values for moisture index and precipitation of the driest quarter were higher for the ‘alpine’ and ‘western subalpine’ plots; values for radiation and temperature range were higher for ‘eastern subalpine’ plots. Peat depth favours the ‘bog’ plots, particularly Alpine valley bog and Subalpine raised bog. Distance to woodland favours ‘alpine’ plots in general, independently of formation type. Shrub height, litter, and slope all increase towards Western subalpine wet heath, Tall wet heath and Myrtaceous wet heath, particularly the latter two, the ‘eastern’ subalpine wet heath groups (Appendices Tables A4.27*, A4.28*).

Fifty-two of the 82 species had significant correlations with at least one of the three axes of the cover data ordination graph (Table 4.27, Appendices Table A4.29*). *Sphagnum cristatum* and *Carex gaudichaudiana* help to distinguish Alpine valley bog and Subalpine raised bog, from Alpine raised bog and Western subalpine raised bog (Figure 4.19). In similar fashion to the frequency ordination, *Astelia alpina*, *Gentianella* spp., and *Empodisma minus* favoured Low wet heath, Alpine raised bog, Western subalpine raised bog, and Western subalpine wet heath, over the remaining four groups. Compared with

Table 4.25: Species significantly correlated with the **alpine and subalpine frequency data** ordination axes (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Species	MDS1	sig.level	MDS2	sig.level	MDS3	sig.level
Astelia alpina	**0.72**	***	**0.53**	***	-0.17	ns
Rytidosperma sp.	**0.69**	***	0.12	ns	-0.24	ns
Epacris glacialis	**0.63**	***	-0.14	ns	**0.35**	**
Gentianella sp.	**0.58**	***	**0.49**	***	-0.22	ns
Oreobolus distichus	**0.50**	***	0.03	ns	0.17	ns
Drosera arcturi	**0.50**	***	0.11	ns	**-0.49**	***
Gonocarpus micranthus	**-0.50**	***	0.06	ns	**0.31**	*
Luzula modesta	**-0.51**	***	-0.09	ns	**0.37**	**
Oreobolus oxycarpus	**-0.51**	***	**0.26**	*	0.21	ns
Asperula gunnii	**-0.54**	***	**0.36**	**	**0.26**	*
Callistemon pityoides	**-0.57**	***	0.16	ns	-0.04	ns
Baeckea gunniana	**-0.65**	***	0.17	ns	-0.05	ns
Epacris paludosa	**-0.49**	***	**0.36**	**	**-0.42**	***
Olearia algida	0.14	ns	**0.50**	***	**-0.36**	**
Sphagnum cristatum	0.09	ns	**-0.67**	***	-0.12	ns
Carex gaudichaudiana	-0.08	ns	**-0.85**	***	-0.09	ns
Poa costiniana	0.21	ns	**0.41**	***	**0.62**	***
Epacris celata	**-0.42**	***	**-0.44**	***	**0.55**	***
Baloskion australe	**-0.50**	***	-0.20	ns	**0.52**	***
Euphrasia gibbsiae	**0.31**	*	0.19	ns	**-0.52**	***

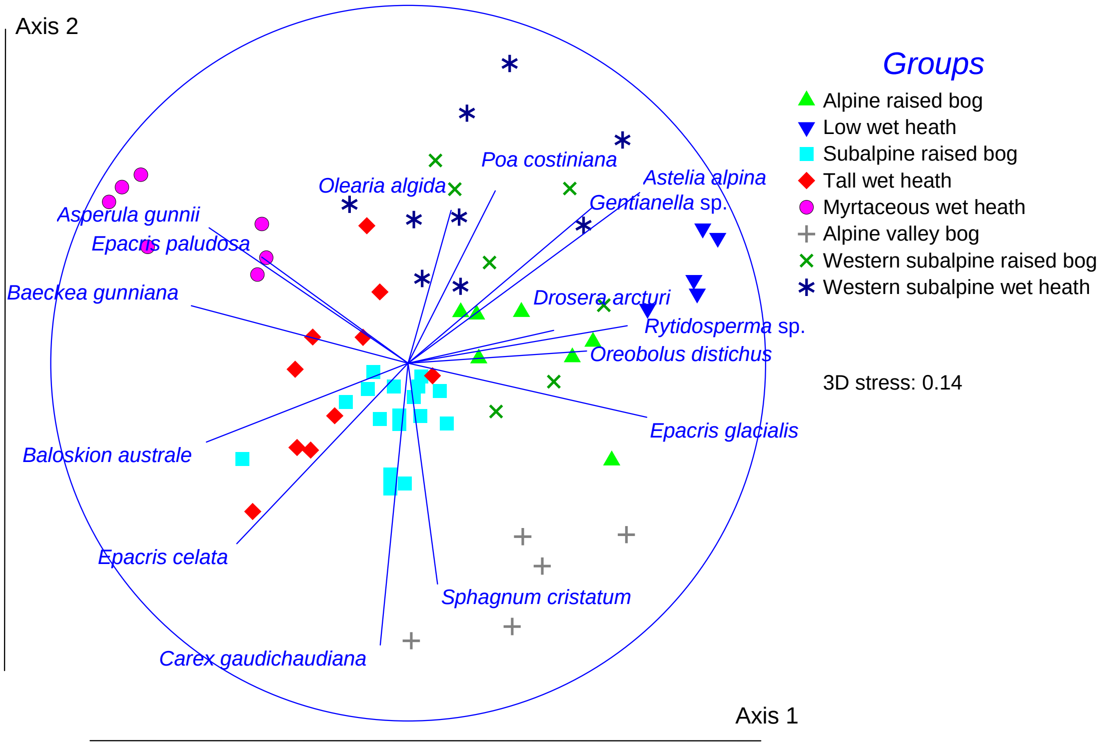


Figure 4.17: Three dimensional ordination graph based on the **subalpine and alpine transects frequency data** (Axis 1 v Axis 2). The trend directions of significantly correlated species are indicated.

Table 4.26: Factors significantly correlated with the axes of the ordination based on the **subalpine and alpine transects frequency data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Factor	MDS1	sig.level	MDS2	sig.level	MDS3	sig.level
Mean moisture index of warmest quarter	**0.73**	***	0.08	ns	-0.21	ns
Distance to woodland	**0.54**	***	**-0.36**	**	0.23	ns
Other mosses	-0.17	ns	**0.41**	***	-0.03	ns
Litter	**-0.31**	*	**0.33**	**	-0.16	ns
Temperature annual range	**-0.34**	**	**-0.31**	*	**0.65**	***
Longitude	**-0.29**	*	**-0.26**	*	**0.54**	***
Topography	**-0.28**	*	0.23	ns	0.03	ns
Peat depth	0.09	ns	**-0.30**	*	-0.21	ns
Hygric continentality	-0.24	ns	0.01	ns	**-0.42**	***
Latitude	0.04	ns	**0.28**	*	**-0.53**	***
Radiation seasonality	0.19	ns	0.21	ns	**-0.54**	***
Radiation of coldest quarter	**-0.35**	**	**-0.47**	***	**0.49**	***
% slope	**-0.45**	***	0.13	ns	-0.21	ns
Annual mean temperature	**-0.62**	***	0.07	ns	0.06	ns
Lowest period radiation	**-0.62**	***	**-0.42**	***	**0.52**	***
Mean height of tallest shrubs	**-0.65**	***	**0.39**	**	-0.11	ns
Mean diurnal temperature range	**-0.69**	***	-0.19	ns	**0.44**	***
Mean temperature of warmest quarter	**-0.70**	***	-0.11	ns	**0.36**	**
Moisture index seasonality	**-0.72**	***	-0.08	ns	0.12	ns
Highest period radiation	**-0.78**	***	**-0.29**	*	**0.26**	*

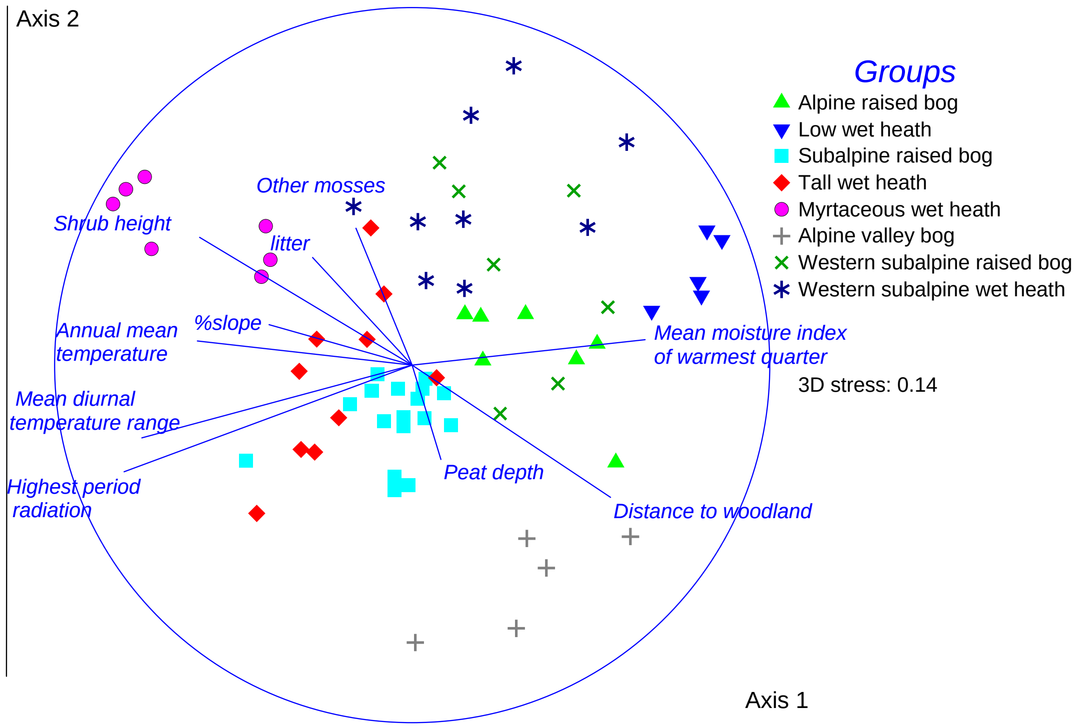


Figure 4.18: Three dimensional ordination graph based on the **subalpine and alpine frequency data** (Axis 1 v Axis 2). The trend directions of significantly correlated factors are indicated.

Table 4.27: Species significantly correlated with the axes of the ordination graph based on the **subalpine and alpine cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Species	**MDS1**	**sig.level**	**MDS2**	**sig.level**	**MDS3**	**sig.level**
Asperula gunnii	**0.43**	***	**-0.44**	***	-0.12	ns
Poa costiniana	**0.41**	***	-0.07	ns	0.05	ns
Gentianella sp.	**0.40**	***	**0.44**	***	**0.41**	***
Carex echinata	**-0.41**	***	0.19	ns	-0.03	ns
Carex gaudichaudiana	**-0.64**	***	0.04	ns	**-0.24**	*
Sphagnum cristatum	**-0.95**	***	0.22	ns	-0.12	ns
Epacris glacialis	-0.02	ns	**0.58**	***	-0.09	ns
Astelia alpina	**0.38**	**	**0.53**	***	**0.29**	*
Rytidosperma sp.	0.04	ns	**0.46**	***	**0.29**	*
Empodisma minus	**0.38**	**	**0.44**	***	0.06	ns
Ranunculus gunnianus	0.15	ns	**0.41**	***	-0.03	ns
Comesperma retusum	**0.39**	**	**-0.42**	***	0.22	ns
Oreobolus oxycarpus	**0.27**	*	**-0.44**	***	**0.35**	**
Stylidium sp.	**0.25**	*	**-0.45**	***	0.19	ns
Gonocarpus micranthus	**0.25**	*	**-0.45**	***	0.12	ns
Pultenaea fasciculata	**0.37**	**	**-0.45**	***	**0.27**	*
Callistemon pityoides	**0.30**	*	**-0.54**	***	0.13	ns
Epacris paludosa	0.08	ns	**-0.59**	***	**0.35**	**
Baeckea gunniana	**0.32**	**	**-0.82**	***	-0.03	ns
Euphrasia gibbsiae	0.11	ns	0.10	ns	**0.49**	***
Thelymitra cyanea	-0.07	ns	-0.08	ns	**0.43**	***
Coprosma perpusilla	-0.02	ns	0.20	ns	**0.41**	***
Richea continentis	-0.18	ns	**0.24**	*	**-0.81**	***

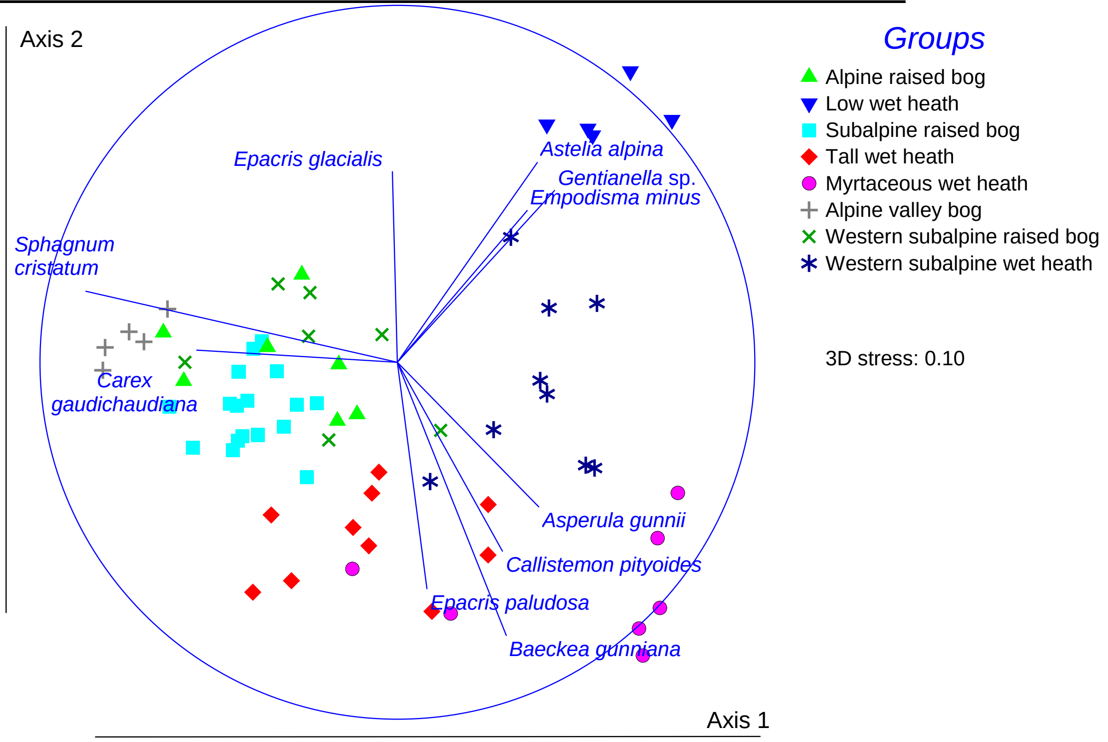


Figure 4.19: Three dimensional ordination graph based on the **subalpine and alpine cover data** (Axis 1 v Axis 2). The trend directions of significantly correlated species are indicated.

Low wet heath, Western subalpine wet heath had more *Baeckea gunniana*, *Epacris paludosa* and *Callistemon pityoides,* but less than the 'eastern' wet heaths, Myrtaceous wet heath and Tall wet heath.

There were fewer factors significantly correlated with the alpine and subalpine cover data ordination (39 out of 55), but as mentioned above, the same variables associated with separation in the frequency data ordination were again important (Table 4.28, Figure 4.20).

Plant functional group correlations with the alpine and subalpine cover data ordination

Ten out of the 11 functional groups showed significant correlation with the cover data ordination (Table 4.29). Not surprisingly, the strongest were *Sphagnum* mosses and *Carex* species, which favoured the 'bog' plots ahead of ' wet heath', Myrtaceous shrubs, which favoured 'eastern' subalpine wet heath plots, *Astelia* and restiads, which favoured Low wet heath, Alpine raised bog, Western subalpine raised bog, and some of the Western subalpine wet heath plots (Figure 4.21). Herbs, 'other monocots', and 'other shrubs' favoured the 'wet heath' groups, particularly Low wet heath, Western subalpine wet heath and Myrtaceous wet heath.

Ericaceous shrubs and 'other sedges' were strongly correlated with axis 3 of the ordination, but in opposing directions (Appendices Figure A4.4). They appear to explain the variability within some groups, particularly the Western subalpine wet heath and Tall wet heath. The axis 3 perspective of the ordination graph highlights a progression along axis 2, from 'eastern' subalpine wet heaths, to 'bog' communities, and finally to Low wet heath. It runs parallel to a trend towards decreasing Myrtaceous shrub cover, and increasing *Astelia* and restiad prominence.

Table 4.28: Factors significantly correlated with the axes of the ordination graph based on the **subalpine and alpine transects cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Species	MDS1	sig.level	MDS2	sig.level	MDS3	sig.level
% peat points < 0.5 m deep	**0.55**	***	**-0.28**	*	0.02	ns
Aspect	**0.42**	***	-0.16	ns	**0.29**	*
Other mosses	**0.38**	**	**-0.25**	*	**0.35**	**
% peat points > 1 m deep	**-0.40**	***	0.12	ns	-0.10	ns
Peat depth	**-0.52**	***	0.21	ns	-0.05	ns
Distance to woodland	-0.23	ns	**0.50**	***	**-0.28**	*
Mean moisture index of warmest quarter	-0.02	ns	**0.41**	***	0.19	ns
Topographic position	**0.28**	*	**-0.36**	**	0.17	ns
Lowest period radiation	-0.19	ns	**-0.38**	**	**-0.31**	*
Moisture index seasonality	0.01	ns	**-0.42**	***	-0.14	ns
Shrub cover %	**0.29**	*	**-0.44**	***	**-0.38**	**
Highest period radiation	-0.10	ns	**-0.49**	***	**-0.29**	*
Litter	**0.48**	***	**-0.49**	***	-0.07	ns
% slope	0.12	ns	**-0.51**	***	0.10	ns
Mean shrub height	**0.45**	***	**-0.55**	***	-0.08	ns
Mean height of tallest shrubs	**0.44**	***	**-0.67**	***	-0.04	ns

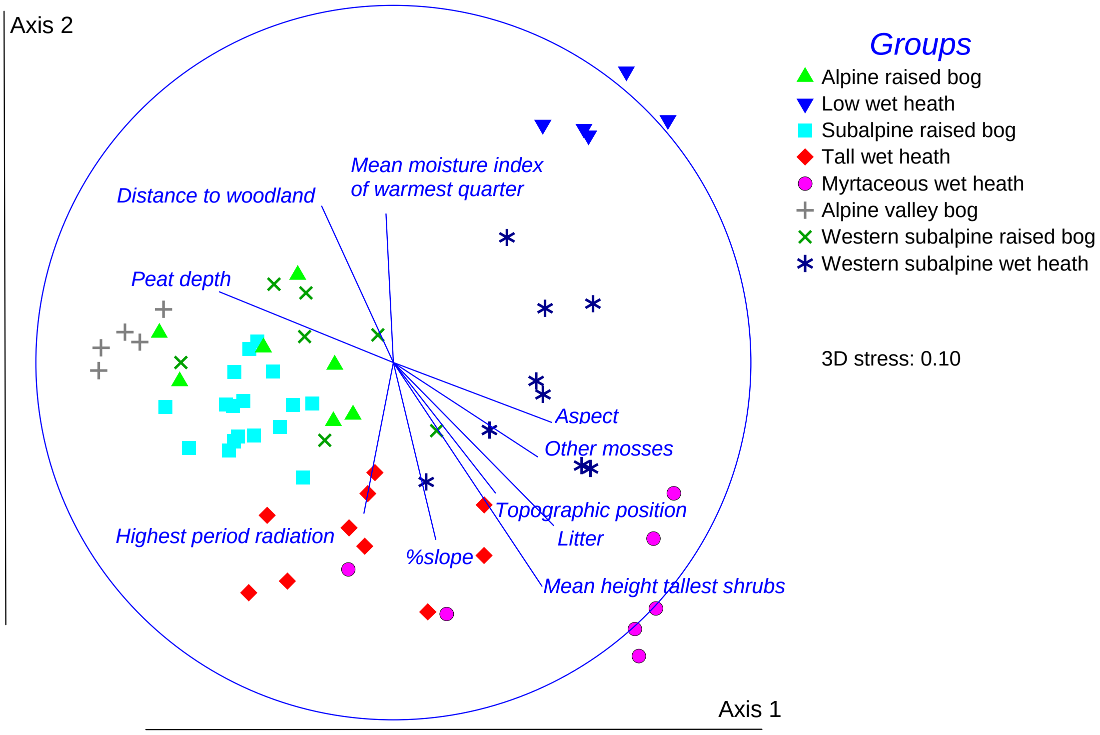


Figure 4.20: Three dimensional ordination graph based on the **subalpine and alpine transects cover data** (Axis 1 v Axis 2). The trend directions of significantly correlated factors are indicated.

Table 4.29: Plant functional groups significantly correlated with the axes of the ordination graph based on the **subalpine and alpine transects cover data** (Significance levels: ns = not significant, * = 0.05, ** = 0.01, *** = 0.001).

Lifeform group	MDS1	sig.level	MDS2	sig.level	MDS3	sig.level
Other shrubs	**0.61**	***	-0.22	ns	**0.33**	**
Herbs	**0.42**	***	0.06	ns	**0.30**	*
Other monocots	**0.40**	***	-0.08	ns	0.11	ns
Astelia	**0.39**	**	**0.52**	***	**0.27**	*
Restiads	**0.32**	**	**0.41**	***	0.05	ns
Myrtaceous shrubs	**0.32**	**	**-0.85**	***	-0.01	ns
Ericaceous shrubs	0.13	ns	-0.05	ns	**-0.53**	***
Other sedges	0.08	ns	0.17	ns	**0.55**	***
Carex spp.	**-0.61**	***	-0.05	ns	-0.20	ns
Sphagnum spp.	**-0.95**	***	0.23	ns	-0.11	ns

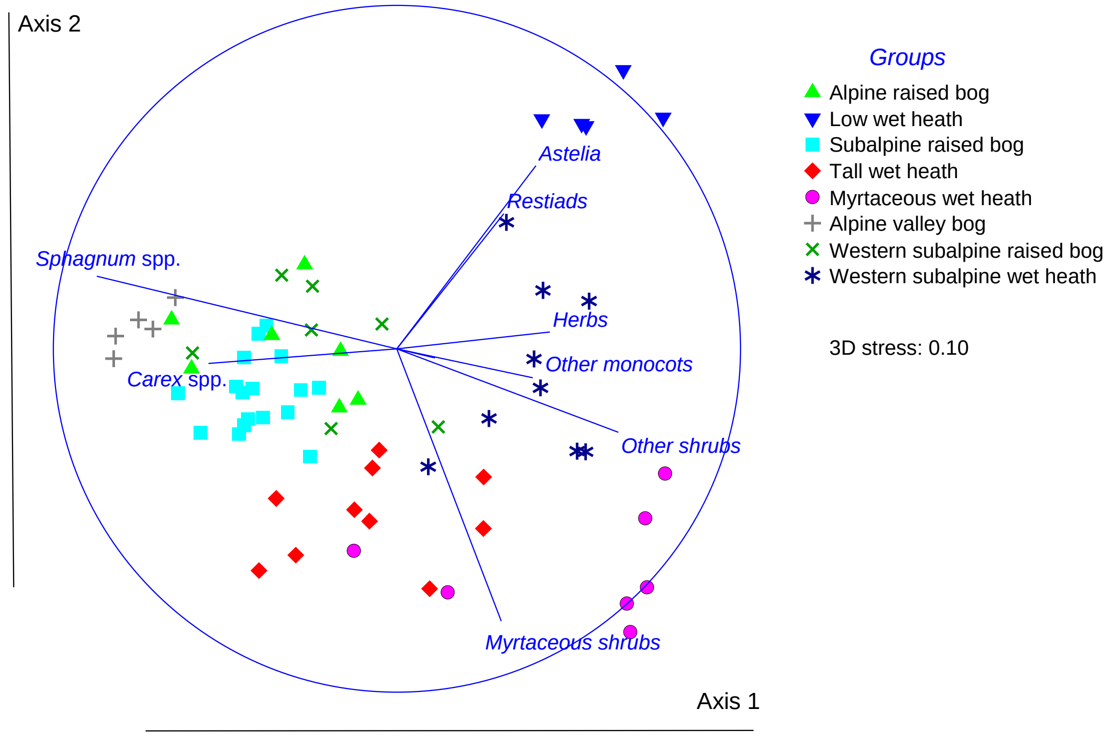


Figure 4.21: Three dimensional ordination graph based on the **subalpine and alpine transects cover data** (Axis 1 v Axis 2). The trend directions of significantly correlated plant functional groups are indicated.

4.4 DISCUSSION

4.4.1 Montane peatlands

The subtle changes in peatland vegetation and structure across eastern Victoria can in part be attributed to a gradient in climate. A convenient dividing line is provided by the valley of the Macalister River, which flows south from Mount Howitt, on the crest of the Great Dividing Range in the centre of the eastern highlands, before meeting the east flowing La Trobe River on the lowland plains of Gippsland (see Figures 2.1, 3.1). West of the ‘Macalister Line’, at the south-western end of the study area, climate is more oceanic and maritime in character, with a more even annual distribution of precipitation, smaller seasonal and diurnal temperature variation, and greater cloud cover and humidity levels. The north-eastern regions in this study, east of the ‘Macalister Line’, experience greater extremes in temperature, higher radiation and lower humidity. Values for hygric continentality, which are a useful index for continentalty, are significantly higher in the east, a product of the lower annual rainfall. Annual precipitation totals in the ‘western’ montane plots are about 1700 mm, compared with approximately 1200-1300 mm at sites east of the Macalister Valley (Appendices Tables A3.50*, A3.51*). In montane sites, hygric continentality varied from 32° at sites in the west, to 42° in the east. The ‘western’ sites were correlated in the analyses with BIOCLIM variables such as precipitation of the driest quarter, and mean moisture index of the lowest quarter. High radiation in the warmest quarter of the year, was also more associated with eastern montane plots, further indication of the reduced summer cloud cover in this region compared to the west.

Surrounding vegetation and context of montane peatlands

In the broadest terms, these climatic differences and associated floristic patterns are best characterised by the present day distribution of the key cool temperate rainforest tree *Nothofagus cunninghamii*, which is common in mountain forests south and west of this line, but does not occur to its east. The montane peatland plots compared in this chapter fall either side of the ‘Macalister Line’, and many of those in the ‘west’ were abutted by pockets of cool temperate rainforest containing *Nothofagus cunninghamii*. In this region, the landscape surrounding these peatlands was dominated by tall open forest (30-40 m) containing such wet forest canopy species as *Eucalyptus delegatensis* and *E. nitens* (Figures 4.22, 4.23). The montane peatland and wetland areas in the 'east' were associated with lower and more open forest types of species such as *Eucalyptus rubida*, *E. dalrympleana*, *E. pauciflora* and *E. stellulata* (4.24, 4.25). All of these species coppice from basal lignotubers or epicormic buds after fire or other canopy damage. This contrasts with the tall open forest species mentioned, which are fire-sensitive obligate-seed regenerators. There were also differences in the understorey structure of the adjacent forests in the two regions; in the east for example, understorey vegetation in forests abutting peatlands was more open in structure and contained species associated with drier heathlands and grasslands. The understorey of forests abutting peatlands in areas west of the 'Macalister Line' were more 'closed' and damp in comparison (see Chapter 2 ' Broad Vegetation Descriptions'). These associations highlight important differences in allogenic factors influencing peatlands in the two regions, which are partly linked to the differences in climate.

Regional differences in montane peatlands

In terms of composition, montane peatlands east and west of the Macalister Valley share many of the same species. One of the key differences between montane peatlands in the two regions is the absence of *Richea victoriana* in the east, which is a prominent and important species in peatlands throughout the Baw Baw-Central Highlands region. The genus *Richea* from the family Ericaceae is endemic to the cool wet mountainous regions of south-east Australia. There are nine species endemic to Tasmania, occurring in bogs, heathland, and cool temperate rainforest (Kirkpatrick 1983, 1997, Busby and Brown 1994, Crowden 1999). Both mainland species of *Richea* are confined to peatlands and wet heath or scrub. *Richea victoriana* is also sometimes associated with *Nothofagus cunninghamii* and riparian cool temperate rainforest (Shannon and Morgan 2007). Another important species in the west is *Epacris microphylla* var. *rhombifolia*, especially in peatland communities more prone to seasonal inundation.

Figure 4.22: Western montane wet heath at Storm Creek surrounded by tall open forest with *E. delegatensis*. Peatland species include *Empodisma minus*, *Epacris paludosa*, *Epacris microphylla* var. *rhombifolia* (flowering), *Richea victoriana* (flowering), and *Baeckea gunniana*.

Figure 4.23: Western montane fen in the upper Thomson Valley surrounded by tall open forest with *E. nitens*. Wetland species include *Poa labillardieri*, *Olearia algida*, *Richea victoriana* and *Epacris microphylla* var. *rhombifolia*.

Figure 4.24: Montane valley bog at Bennison Plains surrounded by open forest containing *E. rubida*, *E. pauciflora* and *E. dalrympleana*. Species in the bog include *Empodisma*, *Epacris* spp., *Carex gaudichaudiana*, and *Sphagnum cristatum*.

Figure 4.25: Myrtaceous wet heath at Morass Gully in the Moroka Valley. Surrounding forest contains *E. dalrympleana*, *E. pauciflora* and *E. rubida*. Wet heath contains *Baeckea*, *Callistemon*, *Epacris paludosa*, *Hakea microcarpa*, *Empodisma minus* and *Baloskion australe*.

In eastern peatland sites restiads are prominent, particularly *Empodisma minus* but also *Baloskion australe*, a species entirely absent from ‘western’ peatlands. In the montane zone of both regions the same patterns in relation to topography apply. The ‘Valley bog’ and ‘Fen’ areas are dominated by *Sphagnum* and sedges. However in the west *Empodisma minus* is absent from the more inundation prone peatland community; in its absence *Carex appressa*, in particular, is highly prominent. The ‘wet heath’ communities, or marginally better drained areas of both regions, contain species like *Epacris paludosa* and *Baeckea gunniana*, hence there is a high degree of structural similarity. In the east however, these are associated with shrub species like *Callistemon pityoides, Hakea microcarpa*, and *Leptospermum myrtifolium*, all of which resprout after fire. In western montane wet heath, *Epacris paludosa* and *Baeckea gunniana* are instead associated with *Richea victoriana* and *Leptospermum grandifolium*, both of which are fire sensitive obligate-seed regenerators.

Floristically there are strong similarities between the montane peatlands ‘east’ of the Macalister Valley described here, and those on the Delegate River in far eastern Victoria (Ladd 1979a), and on the southern tablelands in New South Wales (Costin 1954, Keith 2004). It could also be argued that those ‘west’ of the Macalister Valley have affinities with montane Tasmania through the obvious association with *Nothofagus cunninghamii* and cool temperate rainforest. *Richea gunnii* is a key shrub species in Tasmanian montane and subalpine peatlands, a closely related and morphologically similar species to *Richea victoriana* (Menadue et al. 1995). *Nothofagus cunninghamii* is common in adjacent vegetation in both southern Victoria and Tasmania. *Astelia alpina* is currently absent from eastern montane peatlands in Victoria, and very rare in western sites (Figure 4.26), although is occasionally common in the understorey of montane cool temperate rainforest in this latter region (Shannon and Morgan 2007). Previous analysis of peat cores taken from the Storm Creek site in the Central Highlands has determined an age of 17,000 yrs for the lowest sections. The pollen of *Astelia* is particularly abundant in these lower levels, and maintains a continued albeit diminishing presence through most of the Holocene (McKenzie 1997).

Figure 4.26: *Astelia alpina* in Western montane wet heath vegetation at Storm Creek in the Central Highlands. Other species include *Empodisma minus*, *Epacris paludosa* and *Richea victoriana*. *Astelia alpina* is rare in montane areas, but pollen analysis suggests it was common in the area during the last glacial maximum (McKenzie 1997) when this site would have been above the local tree-line.

There were differences between the two regions in relation to the species contributing to the ‘others’ functional group categories. For example, in the east it was species like *Comesperma retusum*, *Pultenaea tenella*, and *Baumea gunnii*, all of which suggest a closer association with nutrient poor wet heaths of lowland eastern Australia (Specht 1979, Keith et al. 2002). In contrast the ‘other’ species associated with montane peatland vegetation in the ‘west’ included *Olearia algida*, *Ozothamnus* sp.1, *Tasmannia xerophila*, and the fern *Blechnum penna-marina*, which are from families and genera commonly associated with alpine or oceanic climate vegetation in Tasmania and mainland Australia (Kirkpatrick 1983, 1989,1997, Crowden 1999).

The peat depths in montane areas are greater in the ‘west’ and perhaps suggest longer periods when the conditions for peat accumulation have been favourable, and limited opportunities for peat drying or removal by erosion. This is supported to a certain extent by palaeoecological research. Peat cores from the Storm Creek and Tom Burns Creek sites on the Blue Range have produced ages of 17,000 and 32,000 yrs respectively at their lowest depths (McKenzie 1997). There are no data available from montane peatland vegetation in the Snowy Range region, with the exception of Caledonia Fen. The age dates of 140,000 yrs associated with this site are not indicative of the peatland ages for the region because this particular site is a shallow lake associated with an unusual and localised set of geological and geomorphological conditions (Kershaw et al. 2007). The only ages available from subalpine sites in this region suggest they are younger than sites ‘west’ of the Macalister by two or three thousand years (Ashton and Hargreaves 1983, McKenzie 1997, Grover 2006).

4.4.2 Subalpine peatlands

The same climatic differences between montane areas east and west of the Macalister Valley obviously apply to subalpine areas also. However, the sampled subalpine sites span a greater distance; montane sites east of the Macalister Valley were only sampled in the Snowy Range area. The subalpine peatland plots included the Dargo High Plains and Bogong region also, therefore introducing greater variation within the climate and other environmental data. The same climatic differences in relation to the oceanicity-continentality gradient are apparent, although they are best expressed in temperature and radiation variables rather than precipitation. Annual precipitation totals derived from BIOCLIM were similar in all three subalpine regions (1500-2000 mm), but highest in the Bogong region because it is nearer the windward side of the Eastern Highlands (~ 2000 mm). Its more northern position contributes to a more seasonal precipitation pattern, with strong winter-spring maximum. The Snowy Range area is in a slight ‘rainshadow’ compared with the other two regions (see Chapter 2, ‘Climate’). Precipitation totals during the well documented dry period of the last 10-15 years (National Climate Centre 2006a, 2006b) in the Snowy Range region have been below 1000 mm in many years. In comparison, those in more windward locations (Baw Baw, Central Highlands, Bogong High Plains) have been mostly above 1500 mm, even in the driest years (see Chapter 2, ‘Climate’, Figures 2.2-2.5, Table 2.1).

Comparisons of the context of subalpine peatlands

In similar fashion to the landscape context of the montane peatlands, the surrounding vegetation of the peatlands in subalpine areas differed between east and west. Open forests and low open forests dominated by the various taxa of the *Eucalyptus pauciflora* complex are dominant in all subalpine areas. *Eucalyptus pauciflora* ssp. *acerina* is dominant on the Baw Baw plateau, but is restricted to this area. In these ‘western’ regions the forest habitats are moister and contain more mesomorphic species.

Open forest is common east of the Macalister Valley also, but the structure tends towards open woodland in places. The canopy species in the east are *E. pauciflora* ssp. *pauciflora* and *E. pauciflora* ssp. *niphophila* at higher elevations; in some sites at moderate elevations *E. dalrympleana* and *E. stellulata* may be present. The understorey vegetation abutting peatlands in these areas is relatively open in structure and contains more herbs and graminoids in places (Figures 4.27, 4.28). There is no such separation between non-wetland heath and peatland vegetation in subalpine peatlands west of the Macalister Valley. There is structural continuity between abutting non-wetland heath and wet heath across peatland boundaries (Fig 4.29). This is the predominant pattern in western regions but much less common in the east. Even in larger treeless areas at Baw Baw and Lake Mountain, the predominant vegetation is heath (wet and dry) with a high degree of shrub cover (40-90%), compared with open heath and grassland dominated treeless vegetation in the east with less shrub cover (10-40%).

Regional differences in subalpine peatlands

The climatic differences are best expressed in peatland vegetation composition and structure by plant functional groups like the restiads, hard-leaved graminoids, shrubs from the family Myrtaceae, and the presence of ‘other’ non-ericaceous shrubs. The cooler, moister summers of ‘western’ subalpine regions appear to favour restiads like *Empodisma minus*, hard-leaved graminoids such as *Astelia alpina*, and herbs such as *Gentianella*, *Drosera arcturi* and *Psychrophila introloba*. Under more continental conditions east of the Macalister Valley, the subalpine ‘bogs’ generally contain more *Sphagnum* and *Carex*, and the ‘wet heaths’ higher *Baeckea gunniana* and *Callistemon pityoides* cover. Other shrubs such as *Epacris celata*, *Hakea microcarpa*, *Comesperma retusum* and *Pultenaea tenella* only occur in eastern peatlands.

Like the differences between ‘eastern’ and ‘western’ subalpine ‘bog’ communities, those between the Tall wet heath and Western subalpine wet heath communities were correlated with factors associated with regional climatic differences. On an individual community basis, the differences between the Myrtaceous wet heath plots from east of

Figure 4.27: The Cemetery Spur peatland site at 1500 m on the eastern side of the Bogong High Plains is mostly Subalpine raised bog vegetation and is adjacent to grassland, woodland and open forest.

Figure 4.28: Subalpine raised bog vegetation at Buckety Plain (1550 m). Common species here included *Baeckea gunniana*, *Epacris paludosa*, *Baloskion australe*, *Carpha nivicola*, *Carex gaudichaudiana*, *Sphagnum cristatum*, *Empodisma minus* and *Richea continentis*. Adjacent plant communities include open forest and subalpine grassland.

Figure 4.29: Western subalpine raised bog transect at Gwinear Flat on the Baw Baw Plateau. Boundaries between ‘bog’, ‘wet heath’ and non-wetland heath vegetation are often not strongly defined in the area. The dominance of heath vegetation of all persuasions in treeless areas of the region can be seen from this photograph.

the Macalister Valley and the other two wet heath community types (Tall wet heath, Western subalpine wet heath) are also influenced by factors such as slope, topographic position, peat depth and aspect to a lesser extent. As described in the previous chapter, Myrtaceous wet heath seems to be associated with seepage zones in wooded areas on quite steep slopes and appears to have no obvious analogue in ‘western’ regions. These are generally areas that would not otherwise be treeless, the exclusion of trees being primarily due to poor drainage and constantly wet ground, with subsequent reinforcement by cold-air drainage (Fig 4.30). This is perhaps related to bedrock type; Myrtaceous wet heath occurs mostly on metamorphic and sedimentary rocks. The wet heath communities in the areas west of the Macalister Valley all occur on gentle slopes and acid igneous rocks.

Figure 4.30: Myrtaceous wet heath vegetation at Buckety Plain North. This community type is generally found on steeper slopes and there is little if any adjacent treeless non-wetland vegetation.

Tall wet heath differs from the other two subalpine wet heath communities by being more remote from wooded areas, therefore immediately adjacent to more open non-wetland vegetation. The same generalisations apply to Subalpine raised bog and Western subalpine raised bog, the former being more distant from woodland.

4.4.3 Alpine peatlands and subalpine peatlands from all regions

These analyses showed that the alpine plots (Alpine raised bog and Low wet heath) were more similar to the ‘western subalpine plots’ than their eastern subalpine neighbours. Alpine valley bogs in the Pretty Valley area remained separate from all else, and this is probably confirmation that they are a separate sub-formation (i.e. ‘valley’ bogs not sampled in the subalpine zone). The species groups linking the ‘alpine’ and ‘western’ subalpine peatland plots were the ‘hard-leaved’ graminoids, herbs, restiads, together with the higher ericaceous shrub presence relative to myrtaceous species (e.g. *Astelia*, *Gentianella*, *Oreobolus*, *Celmisia*, *Carpha*) (Figures 4.31, 4.32). The same climate variables were correlated with the separation of the ‘eastern’ subalpine plots from the rest, including higher annual and diurnal temperature range, higher radiation, and lower dry season moisture index values. The strong west to east climatic and floristic gradient in the peatland vegetation of the Bogong region over a distance of less than 20 km is enhanced by the decline in elevation of 400 m. A similar west to east gradient occurs across the Kosciuszko region of southern New South Wales (Costin 1954, Clarke and Martin 1999, Costin et al. 2000). However, both are similar to the climatic and floristic gradient which occurs within the subalpine zone from south-west to north-east across eastern Victoria, a distance of 150 km.

There are parallels with Tasmania, New Zealand, and Patagonia, particularly the latter, where the climatic gradient is linked to changes from pure ‘cushion’ bog, to mixed ‘cushion-raised’ bog, to pure *Sphagnum* ‘raised’ bog. Similar, but less obvious gradients exist across eastern Victoria, albeit only the last two stages of this progression: mixed ‘cushion-raised’ bog (*Astelia*, *Sphagnum*, *Oreobolus*, *Carpha*), and ‘raised’ bog (*Sphagnum*, *Richea*, *Carex*, *Baeckea*). The Low wet heath community found at high altitude in Victoria and southern New South Wales is akin to a ‘relict’ cushion bog or moorland vegetation, and in some sections still very close to moorland when dominated by *Astelia* , hard-leaved sedges, and rosetted herbs (McDougall 1982, Whinam and Hope 2005). There are also small pockets at Baw Baw that are reminiscent of this community and moorland or alpine sedgeland from Tasmania (Kirkpatrick 1983) with *Empodisma*

Figure 4.31: Western subalpine wet heath vegetation at The Morass on the Baw Baw Plateau. Hummocks dominated by *Empodisma minus* and *Richea continentis* can be seen in the fore and middle ground. Inundation prone 'fen' areas dominated by *Carex* are in the background.

Figure 4.32: Hummocks dominated by *Astelia alpina* surrounded by surface water and *Carex gaudichaudiana*. The Morass, Baw Baw Plateau.

minus, *Astelia alpina*, *Oreobolus pumilio, Psychrophila introloba*, *Coprosma perpusilla*, *Euphrasia gibbsiae* ssp. *subglabrifolia*, *Brachyscome obovata*, *Erigeron tasmanicus*, *Celmisia pugioniformis*, and *Carpha alpina*. In Tasmania, Alpine sedgeland on the central plateau and eastern alpine areas (Ben Lomond) is associated with many of these species, but on the poorer parent rock materials further west some of these are replaced by species like *Isophysis tasmanica* and *Carpha curvata* (Kirkpatrick 1997).

The peat type (dried or ‘humified’) and depth (< 50 cm) in Low wet heath on the Bogong High Plains is suggestive of blanket peat origin, similar to sedgeland on blanket peat in western Tasmania (Brown 1999). Perhaps during the wetter periods of the middle Holocene (c. 7000-5000 yrs ago) a sedge dominated blanket-bog community existed in these landscape positions on the Bogong High Plains, where today under seasonally drier conditions, Low wet heaths exist. Palaeoclimate reconstructions for the region suggest cooler or wetter conditions between 3000 and 500 yrs ago that were more conducive to peatland formation (Kershaw and Strickland 1989, McKenzie 1997, Whinam and Hope 2005). Thus, drying and change to more shrub, grass and restiad dominated low wet heathland may be relatively recent, as suggested in the original name for this plant community, ‘Relict Bog’ (McDougall 1982), and partly accelerated or expanded by livestock grazing over the last 150 years (Australian Academy of Science 1957, Wahren 1997, Lawrence 1999).

The vastly different growth form and behaviour of *Richea continentis* in south-western areas is interesting to note. The species has a more upright growth habit, often growing to heights of 1.5 m on Baw Baw and at Lake Mountain. The layering, adventitious root-forming growth habit seen in *Sphagnum* hummocks and lawns in the north-east is rare in bogs at Baw Baw. This is supported by the lower frequency values for the species in Western subalpine raised bog, where it tends to occur as isolated clumps. In more ‘continental’ areas it typically layers under *Sphagnum* ‘carpets’, appearing as many scattered stems protruding through the carpet. The growth form at Baw Baw is reminiscent of *Richea scoparia* in Tasmania (Figure 4.33), which also can occur with

Figure 4.33: Subalpine peatland vegetation on the Baw Baw plateau dominated by *Empodisma minus*. Pronounced hummocks dominated by *Richea continentis* can be seen in the middle ground. Taller wet heath shrubs dominate the better drained areas further back. The pools in the foreground are filled with *Sphagnum novozelandicum*.

Sphagnum cristatum, and would appear to be a further reflection of the milder and more humid growing conditions compared with north-east Victoria.

4.4.4 General Discussion

The trend in vegetation patterns along a gradient in oceanicity-continentalty is complicated in Victoria and confounded to a certain extent by the highest and 'genuine' alpine areas being towards the north-east. In this study, attempts were made to circumvent these confounding factors by comparing peatland vegetation and peatland context along a geographical transect *within* the same altitude zones. The differences in context (surrounding landscape) are consistent with differences in position along this gradient and these are correlated with differences in climatic indices determined by BIOCLIM. The peatland sites in this study are in the 32-42º hygric continentality range, the lowest values are for montane peatlands in the south-west, and the highest are for some of the montane and subalpine sites on the Snowy Range. Values for hygric continentality in the Rocky Mountains in Colorado of 76º are indicative of strongly continental influences; Ben Nevis in Scotland experiences more than 250 rain days per annum and has a hygric continentality index of 18º (Barry 2008). The range in Tasmania is from approximately 21º in the west to 36-37º in the east central and north-east.

The patterns associated with this gradient in eastern Victoria although less dramatic than other regions in the southern hemisphere, are significant and can be detected in peatlands as well as in the broader landscape. Costin (1957), in the relatively early days of ecological research in the Australian Alps, remarked upon the higher proportion of bog and wet heath in the Baw Baw region relative to more north-eastern alpine and subalpine areas in Victoria and New South Wales. He also recognised the significance of the presence of *Nothofagus cunninghamii* in subalpine and montane vegetation of the south-western regions. These patterns he also attributed to higher humidity and cloudiness during the summer in these more southern regions.

The differences in peatland composition and structure are more subtle, especially given that many of the same species are prominent at either end of the geographical spectrum. They are most evident in the prominence of species like *Astelia alpina*, the restiad *Empodisma minus*, hard-leaved sedges, and rosetted herbs, in 'western' subalpine peatlands. Most of these are less common or absent in more eastern subalpine sites, probably due to increased competition from *Sphagnum* and the common shrub species under more continental conditions. However, they reappear in the 'alpine' zone where mean annual rainfall is above 2200 mm. Furthermore, these are species or closely related to species that are prominent in 'cushion bog' and 'alpine sedgeland' communities in central and western Tasmania (Kirkpatrick 1983, Gibson and Kirkpatrick 1985b). The 2000 mm per annum precipitation barrier is perhaps significant. In Patagonia the oceanic 'cushion bogs' dominate in areas receiving more than this amount (Moore 1979); continental 'raised bogs' are generally in the areas that receive 600-1500 mm per annum (Pisano 1983, Kleinebecker et al. 2007). Presumably, mixed 'cushion-raised bogs' are in the 1500-2000 mm range. In eastern Victoria we arguably have mixed 'cushion-raised bogs' in regions receiving in excess of 2000 mm per annum, and 'raised bogs' in areas receiving 1200-2000 mm per annum. The higher precipitation required for each level is possibly due to the warmer mean temperatures associated with the lower latitudes.

Species of *Astelia* appear to be important indicator species for oceanic climate vegetation in general. In this study, *Astelia alpina* var. *novae-hollandiae* is common in Alpine raised bog and Low wet heath in the highest parts of the Bogong region, but virtually absent from lower subalpine areas (< 1600 m) in that region. It then reappears and is prominent in Western subalpine raised bog and wet heath in the far south-west of the Victorian highlands at elevations of 1300-1500 m. *Astelia pumila* dominates oceanic cushion bogs in western Patagonia, but is absent from *Sphagnum magellanicum* raised bogs in eastern Patagonia (Moore 1979, Pisano 1983, Kleinebecker et al. 2007). *Astelia alpina* var. *alpina* is present in Tasmania in several montane to alpine plant communities, including Deciduous heath, Coniferous heath, and several other types of heath, grassland and herbfield. It is however most abundant in Alpine sedgeland and Bolster heath (Kirkpatrick 1997). On the west coast of the south island of New Zealand 'Alpine herbmoor' contains *Astelia linearis*. Species of *Oreobolus*, *Carpha*, and *Coprosma* are also present in this and other cushion plant communities in the oceanic regions of western and southern New Zealand (Campbell 1983, Mark et al. 1995, Johnson 2001, Rapson et al. 2006) and western Tasmania (Gibson and Kirkpatrick 1985). Species of *Astelia*, *Oreobolus*, and *Carpha* also dominate cushion bogs at high altitude in New Guinea (> 3500 m) (Gibson and Hope 1986).

The raised bogs in more eastern subalpine areas of Victoria are arguably closer in structure and composition to genuine raised bogs, with high *Sphagnum cristatum* and *Carex* spp. cover and lower diversity or species richness. A decline in species richness and diversity indices was also observed along the oceanicity-continentality gradient in Patagonia (Kleinebecker et al. 2010), and is likely to be due to increased competition with *Sphagnum*.

In Tasmania the annual rainfall declines from more than 3000 mm in places in the western mountains, to under 700 mm in the midlands and east. In montane and alpine areas of the east-central and east (e.g. Mt Wellington, Ben Lomond) it drops to approximately 1000-1500 mm (Kirkpatrick 1997, Jackson 1999a). This is correlated with a change in treeless vegetation structure from heath shrubs, sedges, cushion-form species, and dwarf conifers, to more mixed grass, shrub and herb dominated vegetation at Ben Lomond in the north-east (Kirkpatrick 1997, Kirkpatrick and Bridle 1998, 1999). The dividing line in Tasmania is the Tamar valley, although the changes are already apparent along this transect on the eastern Central Plateau (Kirkpatrick 1983, Kirkpatrick and Bridle 1998, 1999). Fire-sensitive conifers and deciduous beech (*Nothofagus gunnii*) decline in prominence along this gradient, evidence of increasing fire frequency and influence. Native conifers are rare in the Victorian highlands, but west of the Macalister Valley *Podocarpus lawrencei* is an occasional presence in subalpine tall heath and woodland abutting peatland areas. This species is restricted to infrequently burnt boulder-screes at the highest elevations in the north-east; elsewhere in the eastern highlands it is uncommon (McDougall 1982, Walsh et al. 1984).

Kirkpatrick and Bridle (1998, 1999) examined subalpine and alpine vegetation patterns and influences across Tasmania and the mainland highland areas. They identified climatic variables associated with the oceanicity-continentality gradient as an important influence, particularly when looking more broadly at the distribution of vegetation formations. The influence of edaphic and topographic factors was deemed to be more important in determining the distribution of floristic communities. Those studies were an examination of all treeless vegetation formations and communities, whereas this study only focussed on wet heath and bog-fen formations. It did however span the geographic extent of the Victorian treeless montane, subalpine and alpine peatlands, and a range of parent bedrock types. In eastern Victoria topographic factors appear to have the greatest influence on formation type (Fen, Bog, Wet heath) through their control of hydrology and nutrient availability. The influence of the regional climatic gradient is more evident in community floristic composition and functional group proportional representation.

Proximity to the ocean has been shown to increase the base-cation content in precipitation water, therefore this factor must also have some influence on peatland vegetation patterns. Several authors have demonstrated a gradient in peatland water chemistry associated with movement from oceanic to continental regions (Vitt et al. 1990, Malmer 1992, Proctor 1994). *Sphagnum* mosses absorb mineral cations deposited in precipitation water directly across leaf and stem surfaces, therefore obtaining an advantage over rival vascular plants. This competitive advantage is reduced under higher deposition conditions such as those in more oceanic areas, and may break down completely in the hyper-oceanic conditions of the south. A similar process has led to declines in *Sphagnum* cover in European peatlands due to industrial atmospheric pollution (Gunnarson and Rydin 2000, Bragazza et al. 2003). *Sphagnum* species do appear to be less prominent in southern hemisphere oceanic mires and peatlands, where they are replaced by cushion-form species, and scale-rushes from the family Restionaceae (Kirkpatrick 1983, 1997; Gibson and Kirkpatrick 1985b, Pisano 1983, Kleinebecker 2007). However this is not the case in northern hemisphere oceanic peatlands, where there are generally more *Sphagnum* species and they are as collectively abundant as in continental raised bogs (Vitt et al.1990, Asada et al. 2003b).

While the influence of proximity to the ocean on soils in lowland south-western and south-central Victoria is recognised and understood (Gibbons and Rowan 1993), its influence on the soil chemistry of higher and wetter mountain areas of southern Victoria is less clear, including the Baw Baw-Central Highlands region. The relatively reduced dominance of *Sphagnum* mosses in the peatlands of the region may be in part attributable to atmospheric input of cations derived more directly from ocean sources. It is perhaps mostly due to milder temperatures, greater cloud cover, diminished snow cover periods, and consequently greater competition from shrub species. *Sphagnum* growth rates are reduced by lower radiation and temperature during the growing season (Clymo 1973, Gerdol 1995), and these are the usual conditions in regions that experience an oceanic climate.

CHAPTER 5

THE INFLUENCE OF THE WATER TABLE AND MICROCLIMATE ON VEGETATION PATTERNS IN THE HIGHLAND PEATLANDS OF EASTERN VICTORIA

SUMMARY

The water table depth below surface was monitored in several different peatland vegetation communities in the highlands of eastern Victoria over a three-year period. A large proportion of the annual precipitation occurs as snow during the June to September period thus, the water table levels were at their highest in September and October of each year in response to the annual ‘snow-thaw’. Thereafter water table levels slowly decline to their lowest point in the February-April period of the following year.

Growing season (November to March) water tables were high and stable in *Sphagnum* and sedge-dominated Valley bogs. Levels were relatively stable, but lower in *Sphagnum* and dwarf shrub- dominated Raised bogs. In the taller wet heath areas in relatively sheltered locations, water tables were more variable, but mean levels relative to the surface were similar to those recorded in Raised bog.

Low wet heath communities occur in exposed locations on shallow ‘dried’ peat, these had highly variable water table levels which included periods of surface flow, and periods when levels descended below the underlying bedrock. Compared to the other peatland types monitored, these experienced the highest frost frequencies. Less snow accumulated at the Low wet heath monitoring wells (wind-scour), and thus the duration of exposure to extreme low temperatures and high wind speeds is longer than in other peatland communities. This was especially the case in the lightest snow-cover year of the three monitored (2009).

Astelia, other hard-leaved graminoids, and herbs are more prominent in Low wet heath and the more exposed Raised bog communities, than in the more sheltered Raised bog and Tall wet heath communities. There are also subtle differences in shrub species composition and prominence correlated with these differences in hydrology and exposure. For example, *Epacris paludosa*, is associated with 'sheltered' bogs and wet heaths, whereas *Epacris glacialis* occurs exclusively in 'exposed' bogs and low wet heaths.

Therefore, the differences in vegetation structure and composition between the various peatland community types can, in large part, be attributed to differences in hydrological regime. However, the temperature and snow-cover duration data gathered in this monitoring project suggest that differences in microclimate are also an important influence upon the competitive interactions between *Sphagnum* and vascular plants in these communities.

5.1 INTRODUCTION

The vegetation patterns in peatlands are largely determined by gradients in depth to water table. Different plant life-forms, plant functional groups, and individual species vary in their tolerance of high water tables and respond in numerous ways. Thus, hydrological characteristics (water table height, variability, temporal cycles) mediate plant community composition and structure (Gore 1983a, Charman 2002, Joosten and Clarke 2002, Rydin and Jeglum 2006). Peatlands in the mid to high latitude regions of the southern and northern hemispheres are structurally similar and there are also floristic similarities at higher taxonomic levels (e.g. family, genus). *Sphagnum* mosses are cosmopolitan, as are sedges such as *Carex* (family Cyperaceae), and shrubs from the family Ericaceae (Gore 1983b, Rydin and Jeglum 2006). Each of these plant groups, and others, have recognisable and consistent micro-topographical distribution patterns related to the water table level and hydrological regime.

Sphagnum species lack roots and thus, require water tables close to the surface, especially during the growing season. *Sphagnum* mosses require constant moisture and high light levels and thus favour cool, wet, treeless and nutrient-poor environments (Clymo 1973). In warmer, drier and more nutrient-rich environments, they are unable to compete as they are without the morphological and anatomical advantages of higher plant life-forms (roots, woody stems, vascular tissue). Dessication tolerance and resistance is low in *Sphagnum* mosses, although there is some variability between the many species in this regard, hummock species are more resistant, but less tolerant, than hollow species (Hayward and Clymo 1982, 1983, Wagner and Titus 1984, Rydin and Jeglum 2006). The close colonial growth habit and consequent tight packing of shoots and leaves allow capillary water movement to growth points at shoot tips (Clymo and Hayward 1982), but some *Sphagnum* species (e.g. hollow species) lack this capacity and its effectiveness diminishes when water tables fall below a certain level (approx. 30 cm, Rydin 1985).

In contrast to *Sphagnum,* high water tables are limiting for most vascular plants, and this is especially the case for woody species, which require greater depths of aerated surface soil horizon to accommodate woody root networks. Herbaceous species, and graminoids in particular, have the ability to form adventitious roots at the surface and can better adapt to high water tables and waterlogged soil conditions (Crawford 1983). Many successful peatland shrubs also have this ability. Sedges like *Carex* have aerenchyma tissue which allows oxygen diffusion to submerged roots (Rydin and Jeglum 2006). Thus, water table level and variability have an important influence on the competitive interactions between *Sphagnum* mosses and peatland vascular plants.

A diplotelmic model has been adopted in the study of peatland hydrology, and this recognises the existence of two major distinct layers or zones in the peat profile (Ingram 1978, 1983, Clymo 1984). The uppermost, or aerated layer, is called the ‘acrotelm’ and is the region in which the water table fluctuates through diurnal, annual and longer-term cycles (hydro-periods). It consists typically of raw *Sphagnum*, fibric peat, plant roots and other recognisable plant litter. It has high porosity and the passage of water through this material is relatively rapid (high hydraulic conductivity). This is the biologically active zone due to the cycles of wetting, drying, and the presence of oxygen-requiring agents of decomposition. The lowest point below the surface reached in the annual water table cycle generally corresponds to the upper layers of the more decomposed (sapric) peat, where plant remains are no longer recognisable. The lower zone is called the ‘catotelm’ and is permanently saturated, anoxic, contains few plant roots, has low hydraulic conductivity, and is less biologically active. The depth to the top of the catotelm, or the width of the ‘acrotelm’, is an important determinant of vascular plant presence and bog surface vegetation structure.

The surface topography of peatlands is typically variable. The acrotelm is deeper in *Sphagnum* and shrub-dominated hummocks than in *Sphagnum* and graminoid-dominated lawns (fewer emergent shrubs). It is shallowest in hollows containing sedges and inundation tolerant *Sphagnum* species, often adjacent to open water pools (Sjors 1948, 1983). The depth to water table in hummocks is generally 20-50 cm, and in lawns 5-20 cm (Figure 5.1).

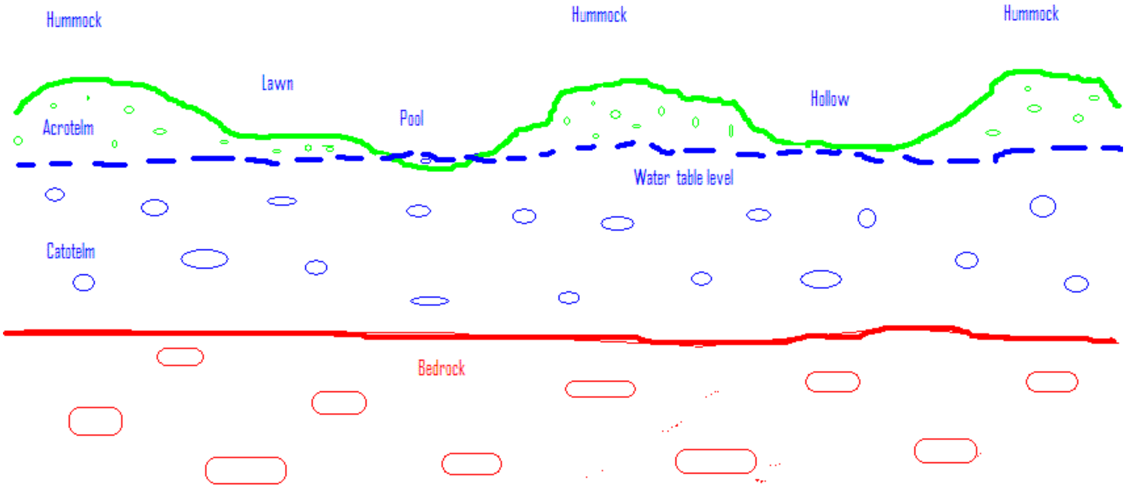


Figure 5.1: The relationship between hummocks, hollows, lawns, pools and the depth to the water table in peatlands.

While peatland research in southern Australia has acknowledged the influence of hydrology on the vegetation patterns, there have been few studies that have directly monitored water table behaviour. Numerous studies have described floristic patterns, vegetation structure and ecological processes (Costin 1954, McDougall 1982, Ashton and Hargreaves 1983, Wahren et al. 2001a). Others have studied and described the long-term impacts of livestock grazing and prescribed fire. Accepted in much of this work is the damage caused to hydrological function by these introduced disturbances and the consequent effect on peat properties, vegetation composition and structure (Wimbush et al. 1979, McDougall 1989, Wahren 1992a, 1992b, Wahren et al. 1999b, Grover et al. 2005).

Grover (2006) monitored water table behaviour at Wellington Plain in Victoria as part of examinations of the properties of different types of peat. Water table levels in *Sphagnum*-dominated bog areas were higher and more stable than those in mineralised peat sections devoid of *Sphagnum*. Further analysis in that project was focussed on the other chemical and physical attributes of the peat and more detailed examinations of the vegetation patterns associated with the different peat types were not undertaken.

Two other studies in Victoria have compared water table behaviour in different plant assemblages within individual peatlands. These were limited to ‘spot’ water table depth measurements at intervals of a week or more. One of these in alpine-subalpine areas on the Bogong High Plains demonstrated an association between *Sphagnum* covered areas and high, stable water tables on one hand; and shallow, mineralised peat, with unstable water table and vascular plant dominance, particularly ericaceous shrubs, on the other hand (Wahren 1997, Wahren et al. 2001a). The second, brief study occurred in montane peatlands and found that the seasonal fluctuation had a strong influence on vegetation patterns. In that case, flooding associated with ‘snowmelt’ and high winter-spring precipitation, restricted the presence of *Sphagnum* and restiads in some sections (Shannon 2003). That study also found a strong association of high stable water tables with higher *Sphagnum* presence, and reduced shrub abundance and stature.

Eleven community types were identified in the previous two chapters of this thesis. In this chapter, the relationships between some of these communities and hydrological regime are examined. Some areas that burnt in recent fires were also included in monitoring. This was done to better understand post-fire regeneration patterns and trends in different microhabitats. Water table levels were monitored within several community types:

- Firstly, to characterise the hydrological regime for the communities and microhabitats in terms of mean water table depth, variability and seasonality.
- Secondly, to relate this back to typical vegetation composition and community structure, particularly at the plant functional group level. Correlations were examined between water table behaviour and the comparative abundance of graminoids, *Sphagnum*, ericaceous shrubs, other shrubs, restiads, and other locally common groups.

The simple working hypothesis was that there are differences in the mean depth and variability of the water table between peatland community types and that these largely explain differences in vegetation composition and structure. It was expected that mean water table levels would be higher in *Sphagnum*-dominated areas and that the various vascular plant functional groups would sort along the depth to water table gradient according to their attributes and adaptations. The monitoring devices also recorded air temperature at close to ground level; thus, some inferences were drawn about temperatures. From these recordings, it was possible to collect some data on frost frequency and snow cover duration. These are also potentially important influences on the vegetation patterns within the different peatland plant communities and need to be considered when examining the influence of hydrology.

5.2 METHODS

Sites

The majority of the water table monitoring was undertaken in peatlands on the Bogong High Plains and the sites chosen varied in elevation from 1610 m to 1700 m (Table 5.1). Data from two other wells at a subalpine peatland on Wellington Plain (1500 m) were also included. These wells were partially a continuation of earlier work (Grover 2006).

Microsites chosen for water table monitoring were mostly close to the transects used for vegetation pattern analysis (Chapters 3 and 4) and were selected because they were broadly representative of the various community types. The communities sampled were: Low wet heath (3 wells), Tall wet heath (2 wells), Alpine valley bog (2 wells), and Raised bog (5 wells). In the original floristic analysis, the raised bog transects were categorised according to altitude zone, but this distinction was not maintained for the analysis of hydrological patterns. The floristic differences established between Alpine raised bog and Subalpine raised bog in earlier analysis relate more to composition than structure (see Chapter 3 results section), and these are thought to be more related to factors associated with increasing altitude, than with hydrology.

The Alpine valley bog wells were in areas of high *Sphagnum* cover with few shrubs. These are referrable to lawn and hollow microsites. Raised bog wells were placed in sections of high *Sphagnum* cover with relatively high shrub presence also. These are equivalent to hummocks. Low wet heath wells were in exposed landscape positions where peat is shallow and *Sphagnum* uncommon. Tall wet heath wells were placed in vegetation dominated by taller wet heath shrub species, with little or no *Sphagnum*. The peat in these microsites is deeper than in Low wet heath and this vegetation type tends to occur in more sheltered landscape positions, often in closer proximity to woodland or forest.

Table 5.1: Water table monitoring well location details and recent fire history. Latitudes and longitudes are in decimal degrees (WGS 84 datum).

Well site	Vegetation type	Latitude	Longitude	Altitude (m)	Peat depth (cm)	Fire damage
Boulder Bog	Raised bog	36.89 S	147.27 E	1710	79	none
Boulder Bog	Low wet heath				33	none
Cope Creek	Low wet heath	36.92 S	147.28 E	1685	32	none
Cope East	Tall wet heath	36.93 S	147.29 E	1700	65	none
Cope South	Valley bog	36.95 S	147.28 E	1610	160	none
Cope South	Raised bog				200	none
Cope South (Well S1)	Burnt lawn				57	06' moderate
Cope South (Well S2)	Burnt lawn				82	06' moderate
Cope South (Well S3)	Raised bog				120	none
Cope South (Well S4)	Tall wet heath				170	none
Horror Bog (Well no. 7)	Burnt hummock	36.90 S	147.26 E	1700	164	03' high
PV1650	Valley bog	36.90 S	147.25 E	1650	100	none
Wallaces Track (Well no. 3)	Raised bog	36.89 S	147.30 E	1650	87	03' low
Wallaces Track (Well no. 5)	Burnt hummock				124	03' high
Wellington Plain	Low wet heath	37.50 S	146.83 E	1500	35	06' moderate
Wellington Plain	Raised bog				140	06' low

In addition to the four community types mentioned above, two other microsite positions were sampled. These were in peatland vegetation burnt at moderate to high severity by the fires of January 2003 or December 2006. Topographically, they are referrable to hummocks and hollows or lawns. The hummock sections used were burnt in the 2003 fires and have been slow to regenerate (2 wells). In contrast, the chosen hollow or lawns were burnt in 2006 and the vegetation has responded more rapidly (2 wells).

Two of the five Raised bog microsites were lightly burnt in recent fires (2003 and 2006), but at insufficient intensity to change surface drainage patterns. Thus, they were included with unburnt wells in the analyses. One of the three Low wet heath microsites (Wellington Plain) was also affected by fire (2006) at low to moderate severity.

The wells, water table loggers, and sampling regime

The wells consisted of sections of 40 mm diameter PVC pipe (0.5-2.0 m). A peat probe (2.0 m length) was used at each chosen sampling location to determine the peat depth. The sections of PVC pipe were then cut to length accordingly, allowing 25-30 cm pipe extension above the peat or *Sphagnum* surface. Holes of approximately 4 mm diameter were drilled in the sides of each pipe. These were spaced at 5 cm intervals on four faces of the pipe (~ 80 m^{-1}). The pipes were then inserted in the peat so that the bottom or base of the pipe rested on the underlying bedrock or gravel. A PVC cap was placed on each well to exclude rainfall or snowmelt water (Figures 5.2, 5.3). The texture of the peat removed from each well was noted and classified according to the commonly used simplified von Post scale (Clymo 1983, Rydin and Jeglum 2006). This method reduces the original 10 von Post classes, which were based on degree of peat decomposition, to three simple categories. 'Fibric' peat is the least decomposed or humified, and the identity of the contributing plant species is relatively easy to discern. Plant matter is more decomposed in 'hemic' peat and less recognisable. 'Sapric' peat is in an advanced state of decomposition (amorphous). A fourth category was reserved for oxidised, 'dried' or mineralised sapric peat, which is the next stage in the decomposition process and involves rapid shrinkage and loss of bulk density (Gibbons and Rowan 1993). These are highly organic soils in transition to mineralised soil. The depth to bedrock was also noted at each well.

An electronic water depth sensor-logging recorder was placed in each PVC pipe or well. These vary in length from 50-125 cm, and have a water level sensory zone of 25, 50 or 100 cm depending on the model (Trutrack Pty.Ltd. New Zealand; models WT-HR 250, WT-HR 500, WT-HR 1000). The uppermost portion of each unit houses the logging device which stores the measurements (Figure 5.4). These were downloaded with a laptop computer, via a 3-pin plug and cable, at approximately 4-5 month intervals using Omnilog software data management program (OMNI version 1.58.1212. Trutrack Ltd.) The sensor-loggers were programmed to take 12 readings per day at 2-hr intervals. The devices were also programmed to record water and ambient air temperature (~ 10-15 cm above surface). They were suspended in each pipe-well with the aid of a metal pin. On each occasion that loggers were downloaded and reprogrammed, the position of the upper edge of the sensor-zone relative to the surface (*Sphagnum* or peat) was noted. This enabled the water table data to be corrected and expressed relative to the surface. Most wells were installed and operating by November 2007, some earlier, some were later moved or discontinued or suffered technical problems and logger failure.

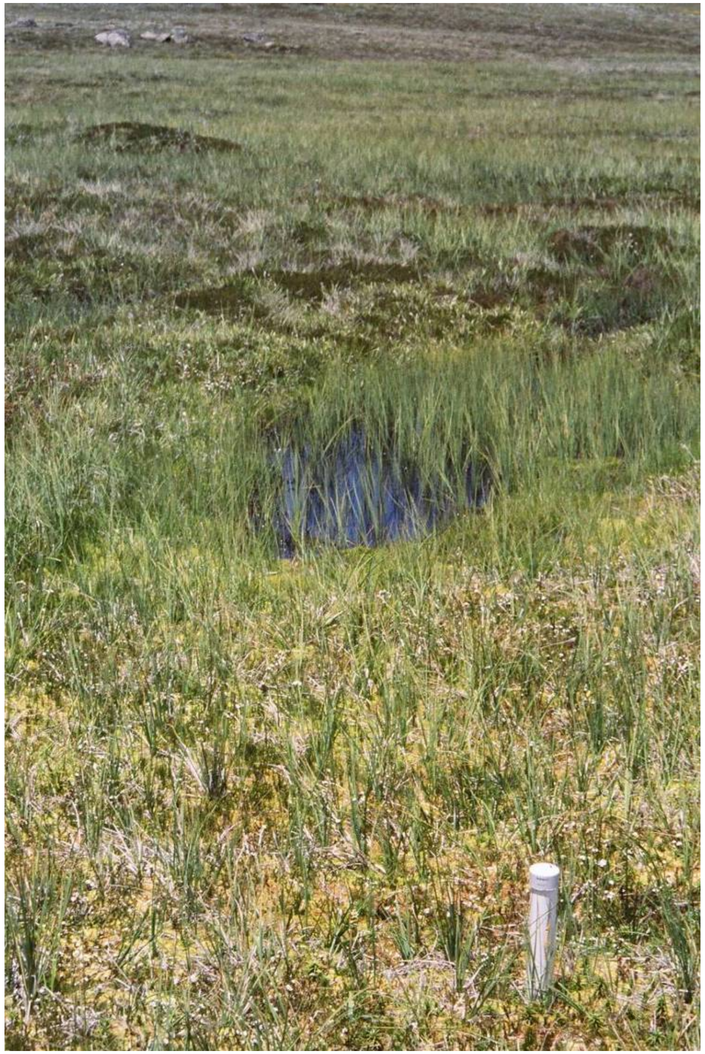


Figure 5.2: Capped water table monitoring well in Valley bog vegetation in Pretty Valley.

Figure 5.3: Close-up photo of capped well in Raised bog vegetation at Wellington Plain.

Figure 5.4: The loggers used in water table monitoring. This particular logger has a 25 cm water level sensing zone.

Temperature data and snow-cover duration

The temperature data also consisted of 12 readings per day at 2-hr intervals. From the air temperature readings during the cooler months it was possible to determine the approximate duration of snow cover. The air temperature sensor is located in the upper section of the logger, and thus, 10-15 cm above the ground surface. When covered by snow, the temperature variability is dramatically reduced, and what is then being measured is the air temperature of the ‘sub-nivian’ space. When diurnal variation once again appears in the data (usually September), it can generally be assumed that the snow cover is ‘breaking-up’ and receding. A snow depth of 25-30 cm will cover the well-cap, therefore limiting air penetration from above the snowpack where winter temperatures typically range from -10°C to 5°C. Maximum temperatures in the data of greater than 3°C indicate warmer periods with incomplete snow cover, which typically occur in early June and late September. Low overnight temperatures are particularly common in valley bottoms where many of these monitoring wells were positioned (Williams 1987). A broken cover of snow allows the penetration of sub-zero night time air from above the snowpack, which is indicated in the data by temperatures of less than -3ºC or -4ºC. Days with a diurnal temperature fluctuation of less than 2°C, between June 1 and September 30, signify a ‘snow cover day’. These were tallied and thus, the number of ‘snow cover’ days was estimated for the period between June 1 and September 30. In this examination a ‘snow cover day’ indicates that the snow depth is confidently greater than or equal to 25 cm at the well point. The derived figures were partially verified and checked against the meteorological data from the Falls Creek, Rocky Valley and other meteorological stations (precipitation and temperature).

The temperature recordings also made it possible to determine maximum, minimum, and mean daily temperature for each well location. It was possible to estimate the number of frosts per month from the temperature data. A conservative approach was adopted with the minimum temperatures and determination of ‘frost’ days to allow for error. Therefore, a ‘frost’ day was defined here as one or more readings of -2°C or less, during a 24-hr period. Most interest was in the frequency of frost during the non-snow cover periods at each well, particularly during the growing season (November-March).

Floristic data at each well

New and separate floristic quadrats were sampled around each well (0.5 m^2). In each quadrat the species were identified and their percent projective foliage cover estimated. The cover of surface water, bare ground, fixed and loose litter was also estimated. Shrub canopy height was measured in each quadrat (nearest 5 cm). The quadrat data were then grouped according to community (= microsite) type to determine mean percent cover values for species, attributes, life-forms and functional groups. The same eleven plant functional groups adopted for analysis in Chapters 3 and 4 were utilised because of their broad applicability to peatlands in other parts of Australia, the southern hemisphere, and the rest of the world (see Chapter 3, Table 3.1). The eleven groups were: *Sphagnum* spp., 'other bryophytes', *Carex* spp., *Astelia* spp., restiads, 'other sedges', 'other monocots', ericaceous shrubs, myrtaceous shrubs, 'other shrubs', and herbs.

Data analysis

The data analyses mostly take the simple form of comparisons of the descriptive statistics generated for each well and community type. These include means, standard deviations, maximum and minimum readings for each month and other designated periods.

The annual cycle was divided into four recognisable phases:

(1) 'Snowmelt' or 'snow-thaw', which was defined for the purposes of this study as from September 1 to October 31
(2) 'Growing season', designated as November 1 to March 31
(3) 'Autumn', April 1 to May 31
(4) 'Winter' or 'snow cover' period, June 1 to August 31.

The data span three growing seasons between 2007 and 2010. Data were collected for two Autumn, Winter, and Spring (snowmelt) periods from most sites, and three ‘seasons’ at several. The statistics generated from the water table data were then compared with vegetation structural and abundance indices to identify relationships and correlations. It is generally the water table levels during the growing season that have the most influence on interactions between *Sphagnum*, graminoids, shrubs and other vascular plants. Accordingly, most of the focus and emphasis in the analysis was on these periods.

The differences in water table depth between wells and between years were not tested for significance because of the very high sample numbers (336-372 per month). It is inevitable that differences between wells will be significant. Differences between years at the same well will also be significant. Instead, growing season mean water table levels and standard deviations for each well were grouped according to microsite or community. A simple mean level and mean standard deviation was determined for each of these, and the pair-wise comparisons were then tested for significant differences, using the non-parametric Mann-Whitney test. The relationship between the cover abundance of some of the key plant functional groups and water table depth was tested using Spearman-rank correlation, as was shrub height correlation with water table depth.

5.3 RESULTS

Overview of precipitation, temperature, and annual hydrological cycle

In the Bogong High Plains region (Rocky Valley), the highest monthly precipitation totals between April 2007 and April 2010 generally occurred during the May to December period, with several monthly totals exceeding 200-300 mm (Figure 5.5, Appendices Table A5.1). Much of this precipitation would have fallen as snow. The highest sustained precipitation totals during the monitored period were between July and October 2009. The lowest monthly precipitation totals were in February 2009 and October 2008. There were many ‘dry’ months in 2006 (El Nino year) during the period immediately prior to monitoring and this is likely to have had some influence on ground water and recorded water table levels. Overall, the annual precipitation totals in 2007 and 2009 were close to average, whereas those in 2008 and particularly 2006 were below average (see Chapter 2, ‘Climate’). Precipitation in 2010, although only partially relevant to the monitored period, was well above average.

Precipitation totals during the monitored period at Wellington Plain (Mt Wellington) were much lower than those recorded on the Bogong High Plains, with the wettest months generally occurring in spring and late summer (e.g. November 2008, October 2009, February 2010, Appendices Table A5.2). Annual precipitation totals in both 2008 and 2009 were less than 1000 mm. However at both locations (Rocky Valley and Mount Wellington), the last 12 months of monitoring (2009-2010) was the wettest period of the study.

Mean monthly temperatures recorded in loggers (< 15 cm above ground surface) peaked in January and February of each year at between 11°C and 14° C, then steadily declined to between approximately -1°C and 2° C in July. The winter figures recorded by these loggers will generally reflect temperatures in the ‘sub-nivian’ space (below the snowpack) although these can vary considerably from year to year depending on the snow cover. Thus, in some cases, when the snow cover is light or intermittent, the winter

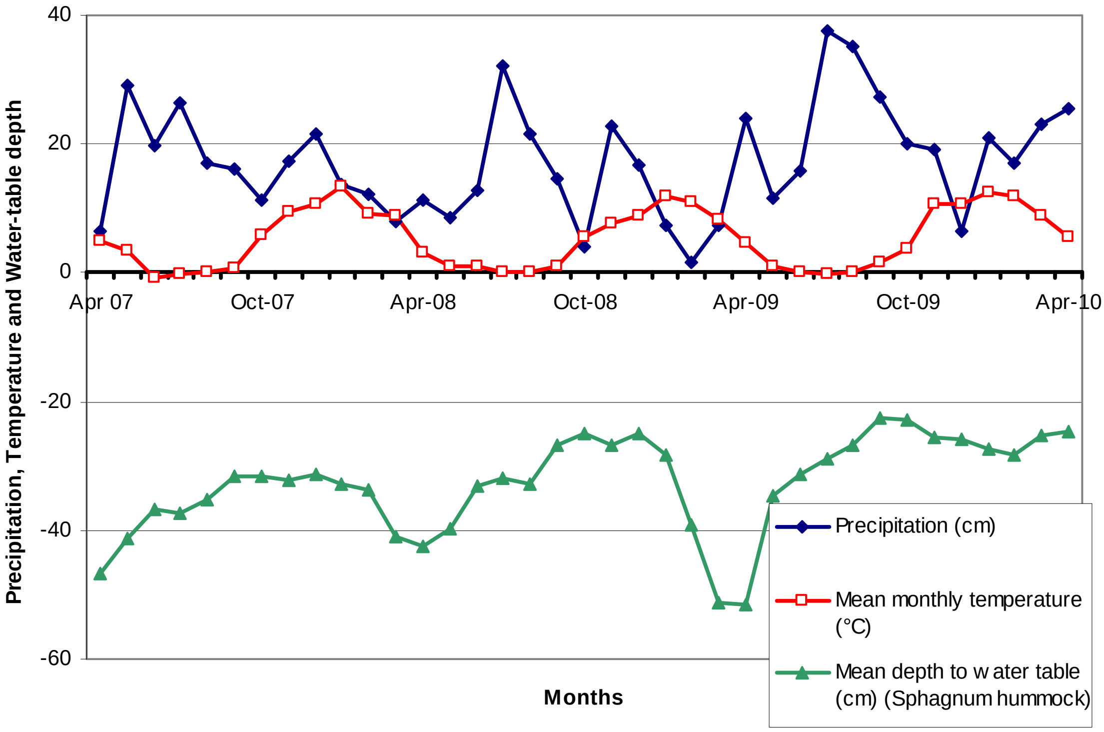


Figure 5.5: Monthly precipitation (cm) at the Rocky Valley (Station no. 83043; 147.29°E, 36.88°S, elevation 1661 m), compared with the mean daily logger temperature (°C) and mean monthly water table depth below surface (cm) in a *Sphagnum* hummock at Boulder Bog (southern Rocky Knobs). The air temperature sensor in the loggers is less than 15 cm above the surface.

mean monthly temperatures are influenced by sub-zero overnight temperatures from above the snowpack (e.g. 2009).

The water table levels generally peaked in September or early October in response to snowmelt. They remained high during the spring, then declined between December and April in response to higher temperatures and evapotranspiration during the 'growing' season. The lowest water table levels generally occurred between February and mid-April. A sharp rise occurred in late April or May, in response to the autumn rainfall 'break' and the lowering of evapotranspiration rates associated with declining temperatures and radiation (see Chapter 2, 'Climate'). Thereafter, water table levels slowly increased until approximately September when a more dramatic increase occurred in response to snowmelt (Figure 5.5).

The most obvious feature of the data for the period between April 2007 and April 2010 is the inter-annual variability, particularly the differences between the three growing seasons. The lowest water table levels recorded were between February and April 2009, in response to well below-average rainfall during the January to March period of that year (‘Heat-wave’ and ‘Black Saturday fires’) (Fig. 5.5, Appendices Table A5.1). In contrast, levels remained high during the corresponding period of the following year, and were somewhere between these two extremes during the same period of 2008.

Water table behaviour in the different microsites during the growing season

The water table was generally within 50 cm of the surface in all microsite types for most of the time, with the exception of Burnt hummock wells (Table 5.2). Mean growing season depths to water table in the Valley bog wells (= lawns) were less than 15 cm and as low as 2 cm in one well. The water table was within 20 cm of the surface for more than 85% of the growing season in the ‘PV1650 well’ during the dry period of early 2009 (Table 5.3). In general, the levels in Valley bog wells were within 20 cm of the surface for 95% of the growing season (Figure 5.6).

In the Raised bog wells, mean growing season water table depths differed considerably between sites, but most were in the 14 to 26 cm below surface range. The exception was the Boulder Bog well where mean growing season depth below surface varied between 26 and 34 cm over the 3-yr period. The amount of time during the growing season that water table levels were within 20 cm of the surface also varied within this group, ranging from 92% at Wellington Plain in 2009-2010, to less than 1% at Boulder Bog well in all three growing seasons. However, in ten of the 12 ‘well x growing season’ data sets, water table levels did not fall below 40 cm. In these ten data sets, levels were within 30 cm of

Table 5.2: Mean depth to water table during the growing seasons from November 2007 to April 2010. The number of readings, standard error of the mean, standard deviation, maximum and mininum levels are also included for each season at each well. For some wells there are only one or two complete growing season data sets available.

Community type, well name and growing season	Number of readings	Mean water table level (cm)	Standard deviation	Maximum level (cm)	Minimum level (cm)
Valley bog					
Cope South Valley bog 2007-2008	1811	-1.7 ± 0.0	1.8	5.8	-7.0
PV1650 Valley bog 2007-2008	1824	-12.3 ± 0.1	3.1	6.1	-21.0
PV1650 Valley bog 2008-2009	1812	-14.2 ± 0.1	5.1	1.2	-26.3
PV1650 Valley bog 2008-2010	1812	-10.8 ± 0.1	4.7	3.9	-25.9
Tall wet heath					
Cope East Tall wet heath 2007-2008	1824	-24.3 ± 0.1	5.3	-8.5	-41.6
Cope East Tall wet heath 2008-2009	1812	-32.7 ± 0.3	13.4	-8.7	-55.7
Cope East Tall wet heath 2009-2010	1812	-22.8 ± 0.2	6.9	-4.3	-45.8
Cope South (Well S4) 2009-2010	1811	-25.4 ± 0.2	7.8	-11.2	-39.6
Raised bog					
Boulder Bog Raised bog 2007-2008	1819	-34.2 ± 0.1	4.0	-23.0	-45.8
Boulder Bog Raised bog 2008-2009	1808	-34.0 ± 0.3	10.8	-17.4	-61.0
Boulder Bog Raised bog 2009-2010	1807	-26.4 ± 0.1	2.6	-12.6	-33.2
Cope South (Well S3) 2009-2010	1811	-14.0 ± 0.1	6.0	-0.4	-29.4
Cope South Raised bog 2007-2008	1824	-15.9 ± 0.1	5.1	-5.0	-28.8
Cope South Raised bog 2008-2009	1812	-13.8 ± 0.2	7.9	1.0	-30.5
Cope South Raised bog 2009-2010	1812	-16.6 ± 0.1	5.0	-3.9	-30.4
Wallaces Track (Well no. 3) 2007-2008	1822	-20.8 ± 0.1	4.3	-5.9	-28.0
Wallaces Track (Well no. 3) 2008-2009	1811	-21.8 ± 0.1	4.8	-3.4	-30.1
Wallaces Track (Well no. 3) 2009-2010	1811	-21.3 ± 0.1	5.6	1.5	-30.9
Wellington Plain Raised bog 2008-2009	1760	-18.1 ± 0.1	3.4	-7.9	-25.3
Wellington Plain Raised bog 2009-2010	1812	-16.5 ± 0.0	1.9	-12.5	-22.0
Low wet heath					
Boulder Bog Low wet heath 2007-2008	1824	-18.0 ± 0.2	7.7	2.1	-30.0
Boulder Bog Low wet heath 2008-2009	1811	-21.0 ± 0.2	9.9	4.0	-30.7
Cope Creek Low wet heath 2007-2008	1824	-0.2 ± 0.2	7.8	8.0	-33.3
Cope Creek Low wet heath 2008-2009	1812	-17.9 ± 0.2	9.7	7.9	-31.6
Cope Creek Low wet heath 2009-2010	1812	-13.8 ± 0.2	6.4	4.5	-30.6
Wellington Plain Low wet heath 2008-2009	1808	-16.9 ± 0.3	13.5	3.6	-30.5
Wellington Plain Low wet heath 2009-2010	1812	-6.3 ± 0.2	10.3	7.2	-26.5
Burnt lawns					
Cope South (Well S1) 2009-2010	1811	-3.7 ± 0.1	2.5	2.6	-13.0
Cope South (Well S2) 2009-2010	1811	-6.4 ± 0.1	5.1	-0.6	-24.1
Burnt hummocks					
Horror Bog (Well no. 7) 2007-2008	1823	-68.6 ± 0.2	7.3	-39.3	-84.2
Horror Bog (Well no. 7) 2008-2009	1811	-65.0 ± 0.3	14.2	-31.9	-93.5
Horror Bog (Well no. 7) 2009-2010	1811	-57.0 ± 0.2	7.2	-24.9	-71.6
Wallaces Track (Well no. 5) 2007-2008	1769	-40.4 ± 0.2	7.7	-27.0	-57.7
Wallaces Track (Well no. 5) 2008-2009	1790	-41.3 ± 0.2	9.9	-21.2	-57.3
Wallaces Track (Well no. 5) 2009-2010	1788	-43.5 ± 0.1	6.0	-19.0	-53.4

Table 5.3: Percentage of the growing season that the water table level is within each depth zone in each well. The growing season is defined as the period between November 1 and the following March 31. The wells have been grouped according to vegetation type. Note*: Peat depth to bedrock in the Low wet heath wells is 30-35 cm in all cases, therefore these wells are effectively dry when the level drops below 30 cm. NA = not applicable.

	% of time water table is in each category						
Community type, well name and growing season	**Above surface**	**Below surface (cm)**					
		0-10	**10-20**	**20-30**	**30-40**	**40-50**	**> 50**
Valley bog							
Cope South Valley bog 2007-2008	13.1	86.9	0.0	0.0	0.0	0.0	0.0
PV1650 Valley bog 2007-2008	0.0	17.2	82.4	0.4	0.0	0.0	0.0
PV1650 Valley bog 2008-2009	0.3	19.5	66.7	13.5	0.0	0.0	0.0
PV1650 Valley bog 2008-2010	1.3	41.0	51.4	6.3	0.0	0.0	0.0
Tall wet heath							
Cope East Tall wet heath 2007-2008	0.0	0.4	14.8	71.3	12.9	0.7	0.0
Cope East Tall wet heath 2008-2009	0.0	0.4	12.3	41.4	13.8	14.5	17.7
Cope East Tall wet heath 2009-2010	0.0	2.0	30.6	54.3	10.8	2.3	0.0
Cope South (Well S4) 2009-2010	0.0	0.0	34.5	36.8	28.8	0.0	0.0
Raised bog							
Boulder Bog Raised bog 2007-2008	0.0	0.0	0.0	5.8	81.6	12.6	0.0
Boulder Bog Raised bog 2008-2009	0.0	0.0	0.4	54.1	17.4	14.2	13.9
Boulder Bog Raised bog 2009-2010	0.0	0.0	1.0	88.9	10.1	0.0	0.0
Cope South (Well S3) 2009-2010	0.0	29.4	53.6	17.0	0.0	0.0	0.0
Cope South Raised bog 2007-2008	0.0	8.6	66.9	24.5	0.0	0.0	0.0
Cope South Raised bog 2008-2009	0.1	45.0	28.0	26.3	0.7	0.0	0.0
Cope South Raised bog 2009-2010	0.0	9.0	68.7	22.0	0.2	0.0	0.0
Wallaces Track (Well no. 3) 2007-2008	0.0	2.4	32.2	65.4	0.0	0.0	0.0
Wallaces Track (Well no. 3) 2008-2009	0.0	2.7	25.8	71.4	0.1	0.0	0.0
Wallaces Track (Well no. 3) 2009-2010	0.1	5.6	24.5	69.1	0.8	0.0	0.0
Wellington Plain Raised bog 2008-2009	0.0	0.5	66.4	33.2	0.0	0.0	0.0
Wellington Plain Raised bog 2009-2010	0.0	0.0	92.1	7.9	0.0	0.0	0.0
Low wet heath							
Boulder Bog Low wet heath 2007-2008	0.8	16.8	36.7	45.4	0.3*	NA	NA
Boulder Bog Low wet heath 2008-2009	0.6	19.1	25.1	11.0	44.2*	NA	NA
Cope Creek Low wet heath 2007-2008	68.1	17.7	10.9	3.3	0*	NA	NA
Cope Creek Low wet heath 2008-2009	1.2	27.0	30.0	20.7	21.2*	NA	NA
Cope Creek Low wet heath 2009-2010	0.8	22.5	64.6	5.7	6.4*	NA	NA
Wellington Plain Low wet h'th 2008-2009	17.0	22.3	10.8	7.1	42.9*	NA	NA
Wellington Plain Low wet h'th 2009-2010	32.8	38.4	12.1	16.7	0*	NA	NA
Burnt lawns							
Cope South (Well S1) 2009-2010	2.8	95.6	1.7	0.0	0.0	0.0	0.0
Cope South (Well S2) 2009-2010	0.0	84.6	12.5	2.9	0.0	0.0	0.0
Burnt hummocks							
Horror Bog (Well no. 7) 2007-2008	0.0	0.0	0.0	0.0	0.1	0.8	99.0
Horror Bog (Well no. 7) 2008-2009	0.0	0.0	0.0	0.0	0.8	10.3	89.0
Horror Bog (Well no. 7) 2009-2010	0.0	0.0	0.0	0.2	1.3	12.6	85.9
Wallaces Track (Well no. 5) 2007-2008	0.0	0.0	0.0	6.1	49.7	28.6	15.6
Wallaces Track (Well no. 5) 2008-2009	0.0	0.0	0.0	20.0	20.2	34.4	25.4
Wallaces Track (Well no. 5) 2009-2010	0.0	0.0	0.1	3.4	20.1	63.9	12.5

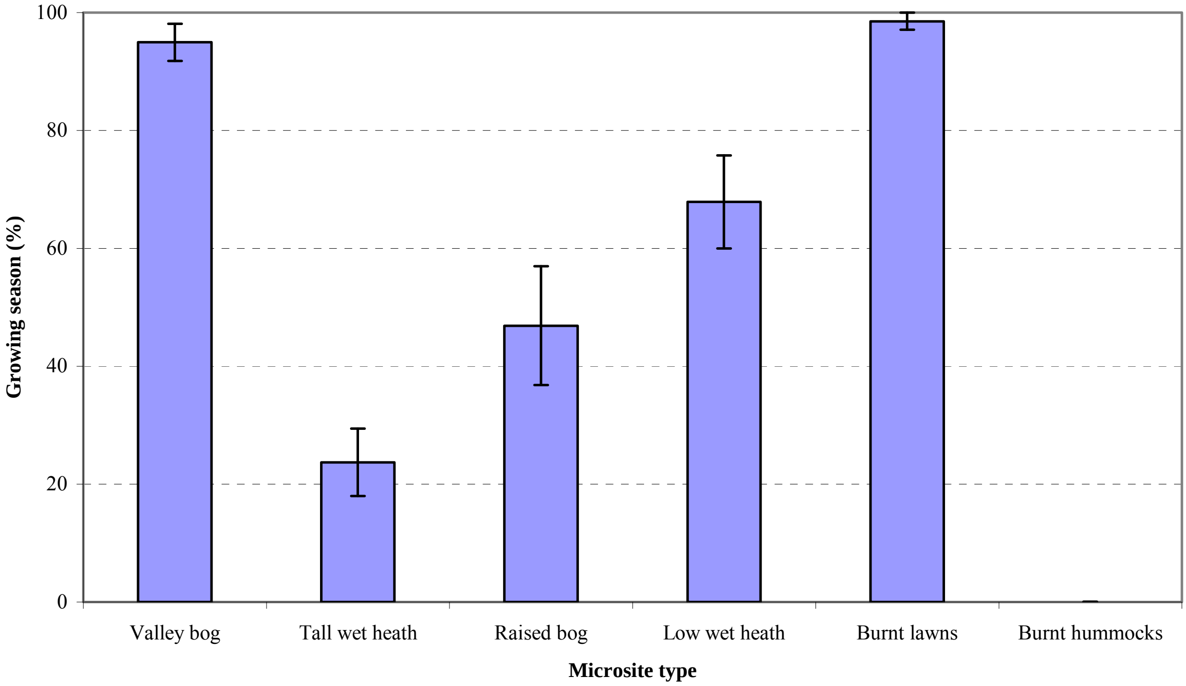


Figure 5.6: Mean percentage of the growing season that the water table was within 20 cm of the surface in each microsite type (includes time above the surface).

the surface for 90% or more of the growing season. Overall, the water table was within 20 cm of the surface in raised bog wells for 47% of the growing season.

Mean growing season depths to water table were similar in Tall wet heath wells (23-33 cm) and were within 20-40 cm of the surface for more than 65% of the growing season. They were within 10-20 cm of the surface for approximately 30% of the growing season, but rarely if ever within 10 cm. Unlike most of the Raised bog wells, there were periods when levels in Tall wet heath dropped below 40 cm. These were usually between February and April. During the extended dry period in early 2009, the mean water table level in the Cope East Tall wet heath well dropped below 50 cm, but remained above 26 cm in Valley bog wells and above 30 cm in most Raised bog wells (Figures 5.7-5.10, Appendices Tables A5.3-A5.8). The mean percentage proportion of the growing season that water table levels were within 20 cm of the surface in Tall wet heath wells was 24%.

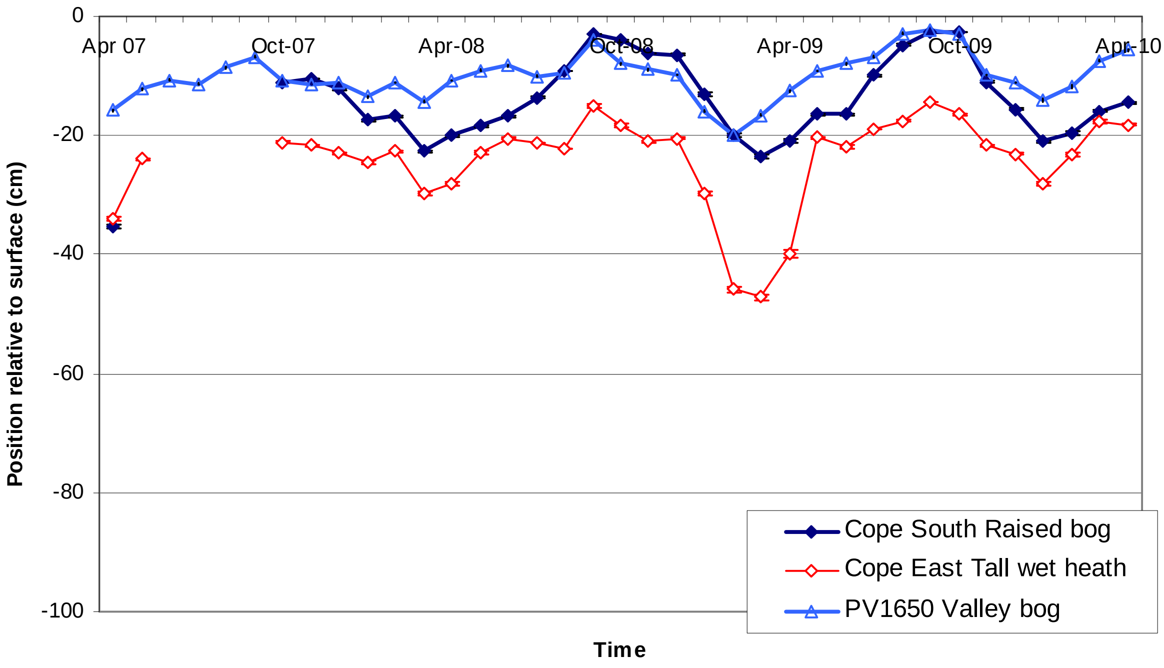


Figure 5.7: Mean monthly water table positions (with standard errors) in three peatland microsite types from April 2007 to April 2010. The monthly means are derived from 336-372 readings per month at 2-hr intervals.

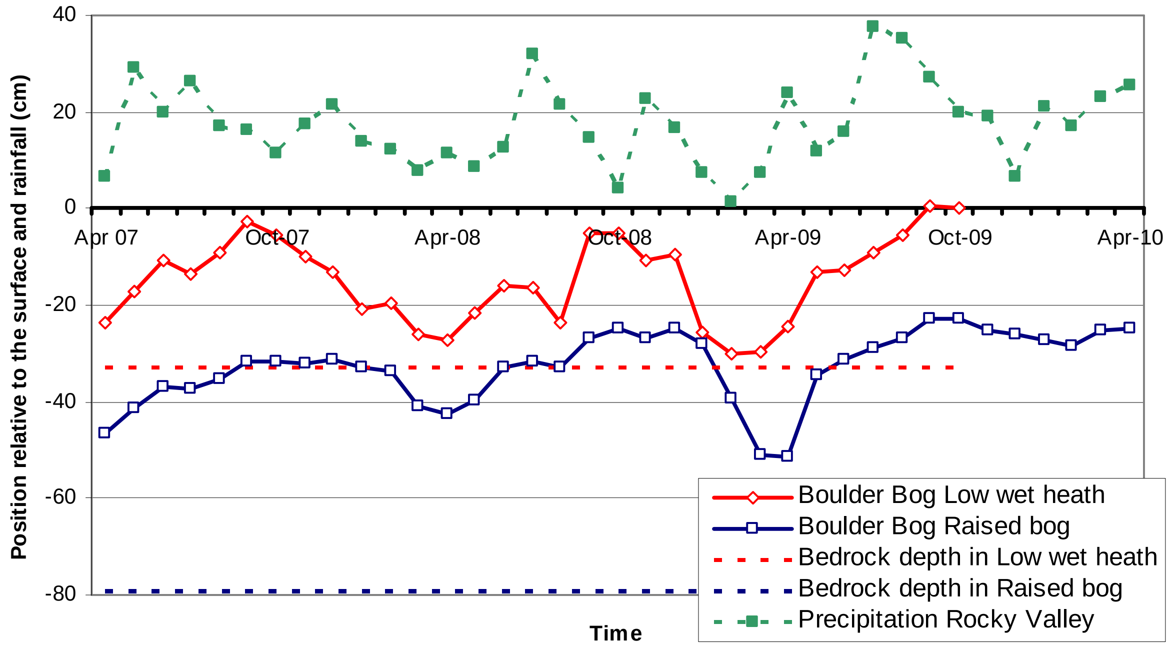


Figure 5.8: Mean monthly water table positions (with standard errors) in two peatland microsite types from April 2007 to April 2010. The monthly means are derived from 12 readings per day at 2-hour intervals (336-372 per month).

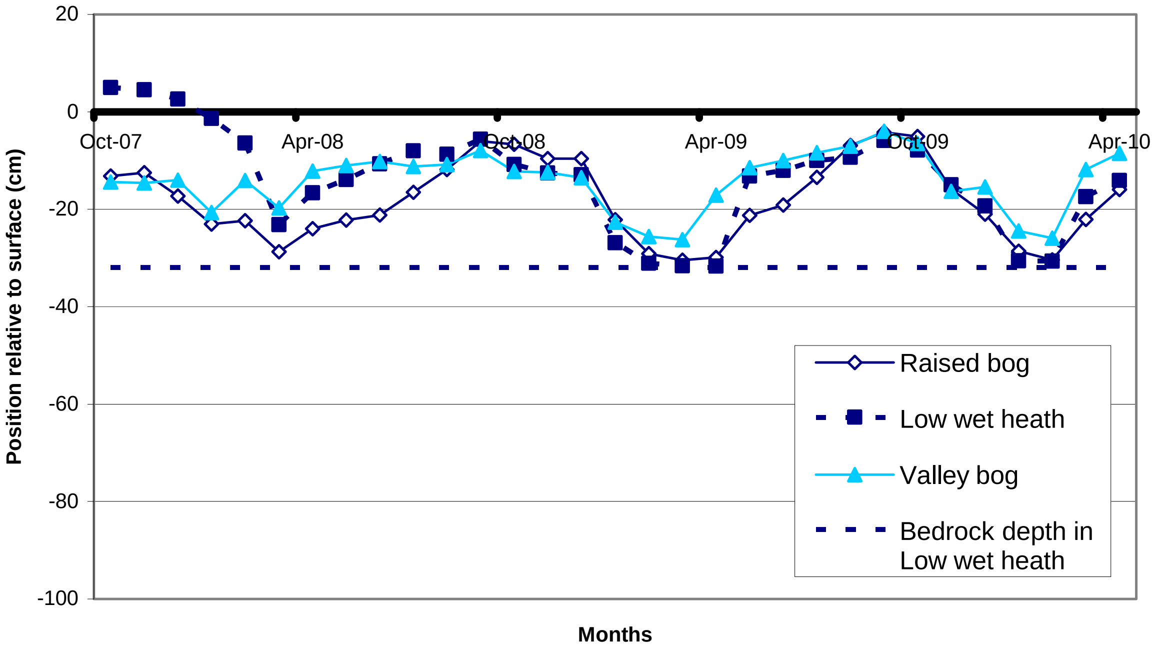


Figure 5.9: The monthly minimum water table levels in three different peatland microsite types. The period of sampling is from October 2007 to April 2010. The straight broken line represents the depth of the underlying bedrock in the Low wet heath well. The depth of the bedrock in the Valley bog well was 100 cm and in the Raised bog well it was 180 cm. Wells are: Raised bog = Cope South, Low wet heath = Cope Creek, Valley bog = Pretty Valley 1650.

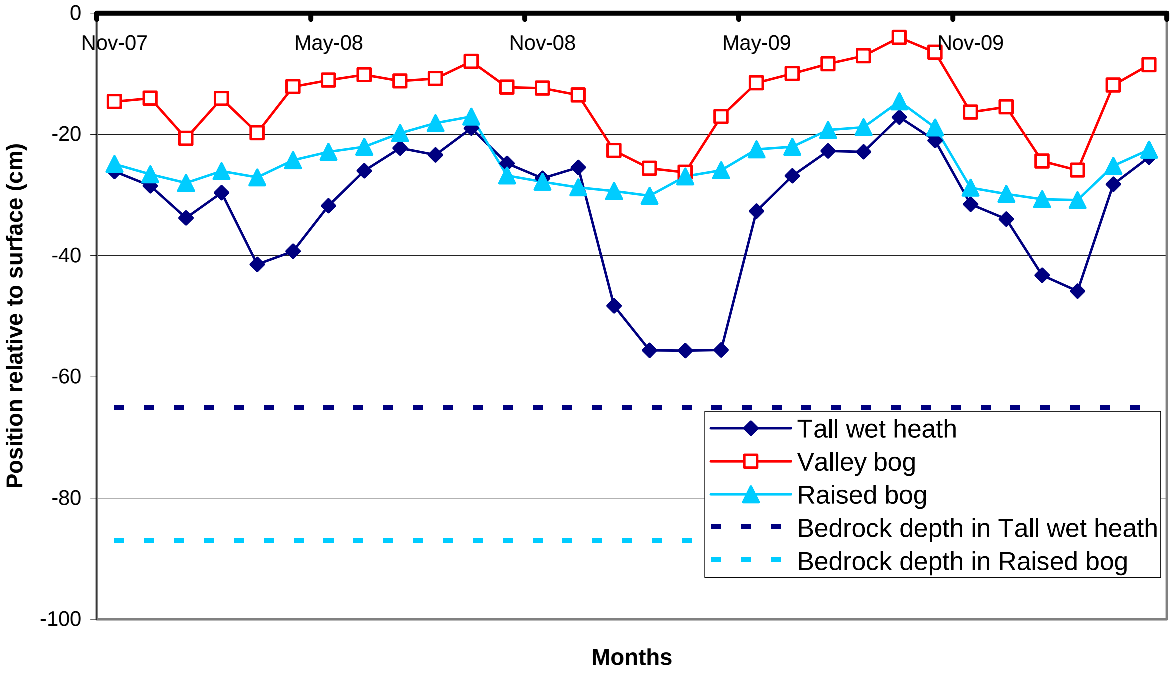


Figure 5.10: Monthly minimum water table levels in three different peatland microsite types. The depth of the bedrock in the Valley bog well is 100 cm. Well locations: Raised bog = Wallaces Track, Valley bog = Pretty valley 1650, Tall wet heath = Cope East. Depth to bedrock in each well: Wallaces Track Raised bog = 87 cm, Wallaces Track Burnt hummock = 124 cm, Horror Bog Burnt hummock = 164 cm.

The Low wet heath communities are typically found on shallow, highly humified or ‘dried’ peats. Depths to bedrock are mostly less than 40 cm. Even during the growing season there are periods of surface water accumulation or ‘sheet’ surface water flow (‘irrigation’) in these peatland communities. This was particularly the case at Wellington Plain where surface water occurred in 2009-2010 for approximately 35% of the growing season. Overall, surface water occurred at the Low wet heath wells for 17% of the growing season (Figure 5.11). There were also substantial periods when wells were dry in this plant community, water table levels having dropped below the underlying bedrock; for example, the water table was below 30 cm at Cope Creek in 2008-2009 for 11% of the growing season and therefore effectively dry.

The Burnt hummock wells were positioned in large hummocks that were severely burnt in January 2003. The peat is deep in these hummocks (120-170 cm), and the mean growing season depth to water table was in the 40-75 cm range across the six ‘well x growing season’ data sets within this group. In contrast, seepage water remained close to the surface for much of the growing season in Burnt lawn wells. The water table at these wells was within 10 cm of the surface for 84-98% of the 2009-2010 growing season. These peatland sections were near the upslope margin of the Cope South peatland and were burnt in December 2006 (adjacent to woodland).

Patterns in water table variability across microsite types in all seasons

The summer and early autumn was the period of greatest water table variability across all microsite types within these peatlands. This is associated with the periods of highest evapotranspiration and lowest monthly rainfall. However, there were considerable differences in water table stability between microsite types. The water table depth varied most in Tall wet heath wells, especially during the growing season. Standard deviations are a good indication of the variability in water table level and in Tall wet heath wells these were in the 5-13 cm range during the growing season (Figures 5.12, 5.13, Appendices Tables A5.3-A5.8). Levels were also variable in Low wet heath, but in this case the variability was not restricted to the growing season; standard deviations were again in the 6-13 cm range. These were the shallowest wells and experienced periods of surface water in most months (Figures 5.14, 5.15).

In contrast, water table levels varied least in the bog community wells, particularly the Valley bog wells. Standard deviations were in the 2-5 cm range in Valley bog wells and mostly in the 2-8 cm range in Raised bog wells. Periods of inundation were rare in Raised bog sections (= hummocks). When they did occur, they were associated with the 'snowmelt' peak-flow in late September. Water levels above the surface were more common in Valley bog areas, but generally restricted to winter and early spring. Maximum water table levels in Burnt hummocks were in the 10-30 cm below surface range and also occurred during the snowmelt period (Figure 5.16).

Mann-Whitney significance testing of mean depth to water table and variability

Mean depth to water table in the Valley bog wells was significantly higher than all other groups, except those in Low wet heath (Table 5.4). Water table variability in Valley bog was similar to Raised bog wells but significantly less than all other groups. Mean water table levels in Low wet heath were similar to both Valley bog and Raised bog, but significantly more variable. Levels in Low wet heath were significantly higher than in Tall wet heath and Burnt Hummock wells.

Although water table levels in Raised bog appeared to be higher and less variable than in Tall wet heath, the differences for both attributes were not significant (Table 5.4). In the Burnt hummock wells, water table levels were significantly lower than all other groups; variability was similar to Low wet heath and Tall wet heath, but less than Valley bog and Raised bog.

The results of the pair-wise significance tests involving the Burnt lawn group are the less reliable because there were only two 'well by season' data sets. However, in terms of mean water table depth and variability they were generally similar to Valley bog.

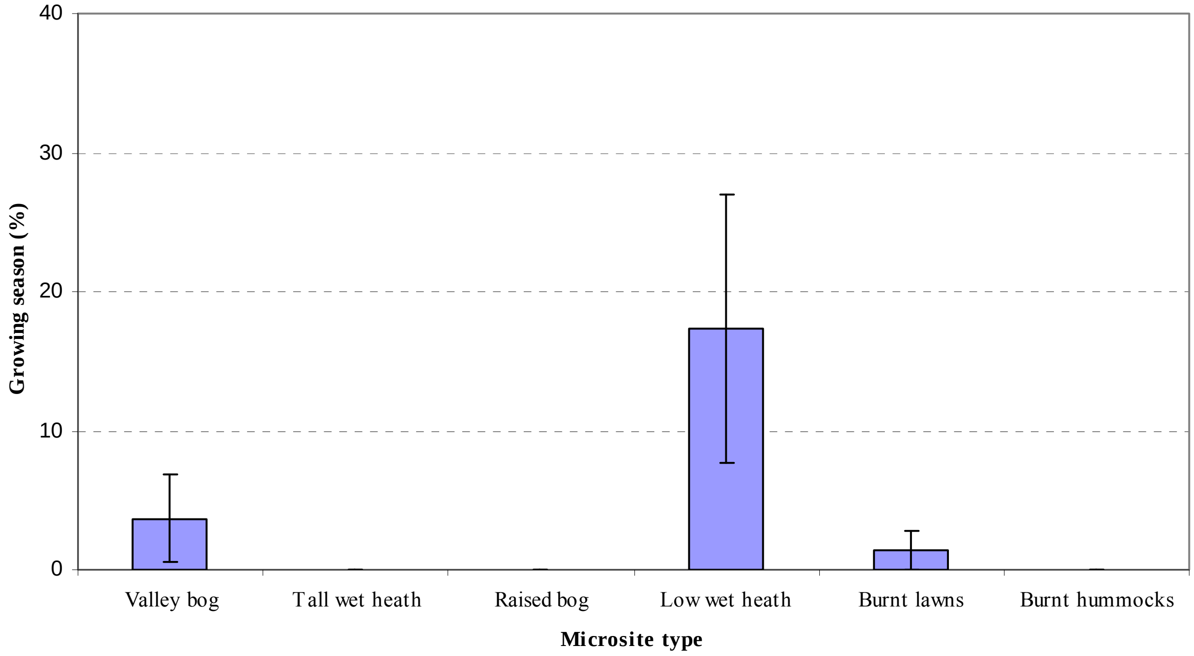


Figure 5.11: Percentage proportion of the growing season that the water table is above the surface in each peatland microsite type.

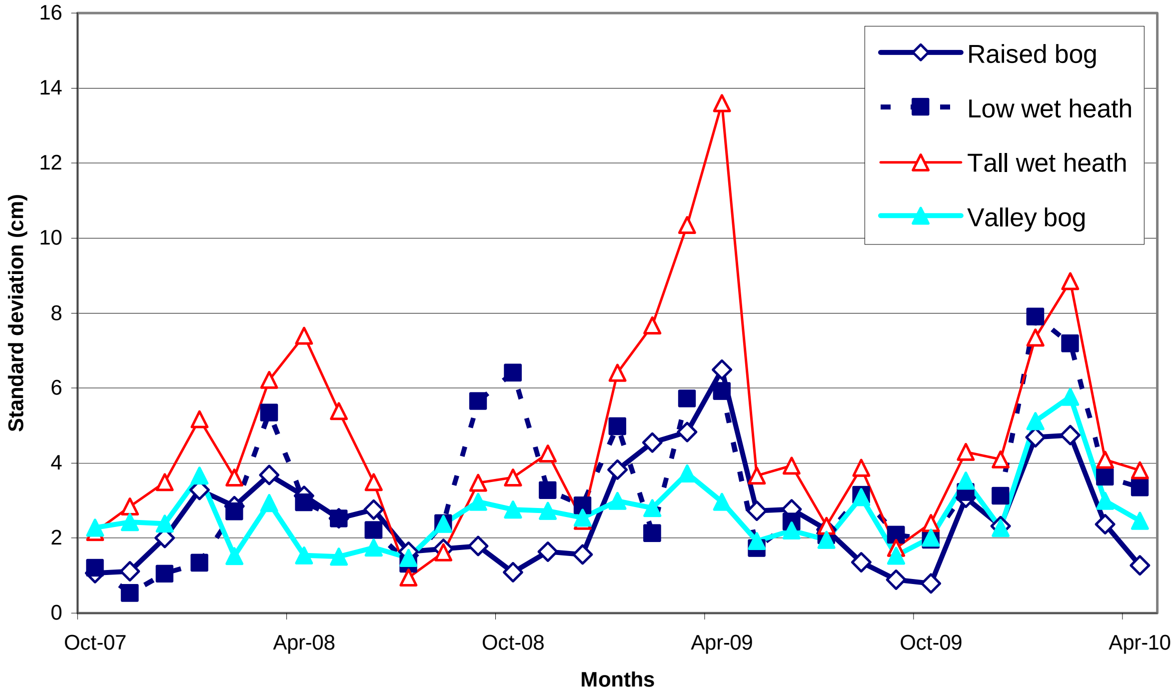


Figure 5.12: Water table variability in four peatland microsite types between October 2007 and April 2010. The figures plotted are the standard deviations from each month's water level data. The data are derived from 12 readings per day at 2-hour intervals (336-372 per month). Well locations: Raised Bog = Cope South, Low wet heath = Cope Creek, Tall wet heath = Cope East, Valley Bog = Pretty Valley 1650.

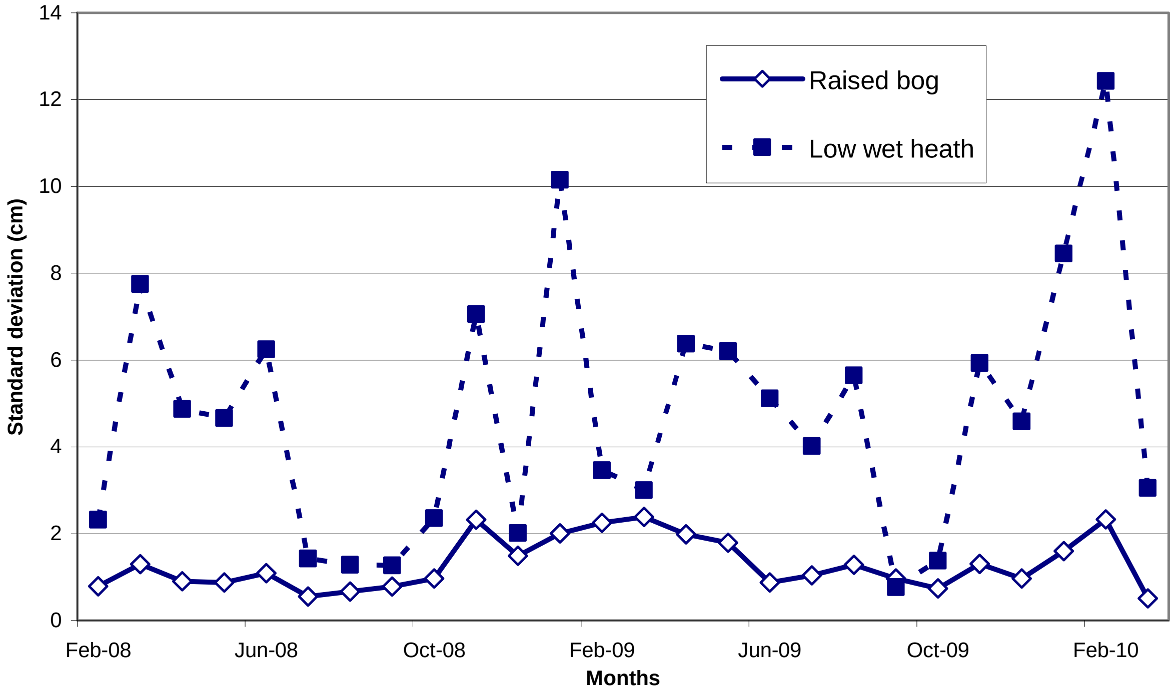


Figure 5.13: Water table variability in two peatland microsite types at Wellington Plain. Data are the standard deviations for each month from February 2008 to March 2010. In each well the loggers recorded water level at 2-hr intervals, therefore between 336 and 372 readings per month.

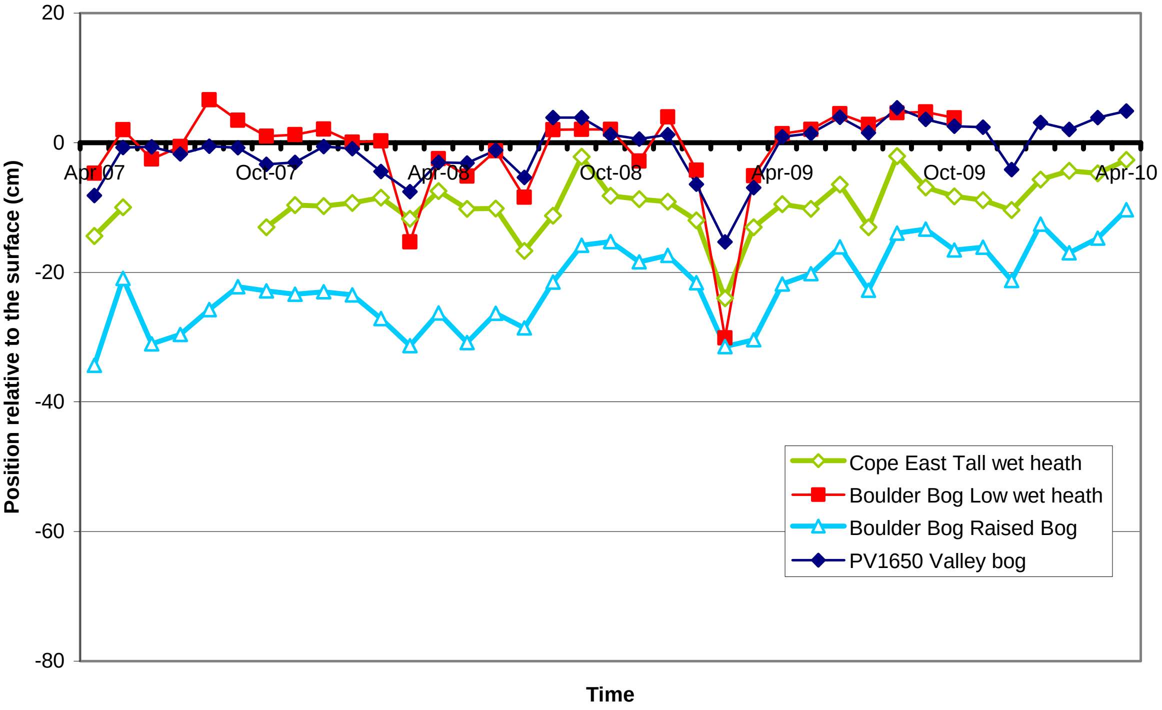


Figure 5.14: Maximum water table levels in each month at four different wells. The period covered is from April 2007 to April 2010. Depths to bedrock in each well: Boulder Bog Low wet heath = 33 cm, Cope East Tall wet heath = 65 cm, Boulder Bog Raised bog = 79 cm, PV1650 Valley bog = 92 cm.

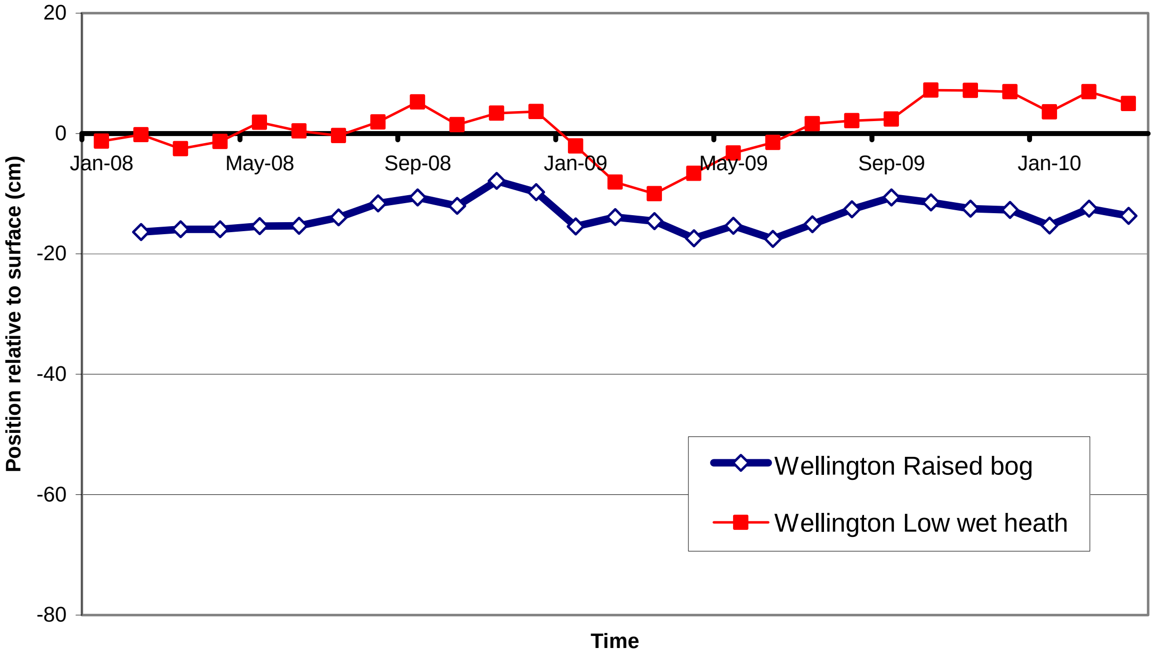


Figure 5.15: Monthly maximum water table levels in two wells at Wellington Plain. Depths to bedrock in each well: Wellington Raised bog = 124 cm, Wellington Low wet heath = 32 cm.

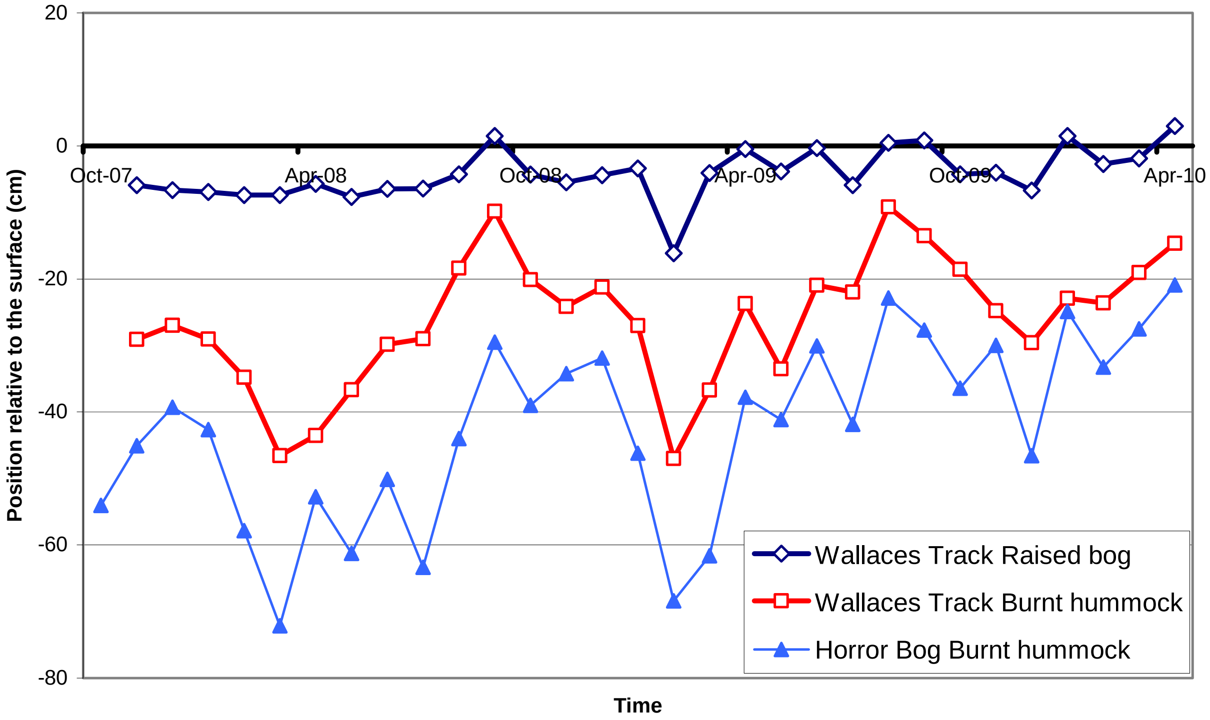


Figure 5.16: Maximum monthly water table levels in three wells between November 2007 and April 2010 (Wallaces Track Raised bog = Well no. 3, Wallaces Track Burnt hummock = Well no. 5, Horror Bog Burnt hummock = Well no. 7, see tables 5.2 and 5.3).

Table 5.4: P-values for the Mann-Whitney test pair-wise comparisons. The factors tested are mean water table depth during the growing season and water table variability during the growing season. Variability was assessed by calculating the mean of the standard deviations for the wells in each group. The reliability of the result of each individual pair-wise test will depend on the number of replicates for each of the groups concerned (Burnt Lawn = 2, Burnt Hummock = 6, Low wet heath = 7, Raised Bog = 11, Tall wet heath = 4, Valley bog = 4).

	Mean water table level				
Microsite type	Burnt lawn	Burnt hummock	Low wet heath	Raised bog	Tall wet heath
Burnt hummock	**0.046***				
Low wet heath	0.242	**0.003***			
Raised bog	**0.028***	**0.001***	0.099		
Tall wet heath	0.064	**0.011***	**0.008***	0.115	
Valley bog	0.355	**0.011***	0.257	**0.008***	**0.021***

	Mean water table variability				
Microsite type	Burnt lawn	Burnt hummock	Low wet heath	Raised bog	Tall wet heath
Burnt hummock	**0.046***				
Low wet heath	**0.040***	0.390			
Raised bog	0.522	**0.013***	**0.005***		
Tall wet heath	0.064	0.670	0.394	0.052	
Valley bog	0.814	**0.011***	**0.008***	0.249	**0.021***

Temperature, frost and snow-cover duration

The highest numbers of frosts per month (< -2°C) occurred in April, May and October. In light snow years (e.g. 2009), and years when snow cover was late arriving or departed early, frost numbers were high in June and September also. Hence, peatland plants were exposed to very low temperatures at some sites during these periods (< -10°C). During the period from October 2007 to May 2008, the number of frosts per month was highest in the Low wet heath sites (Table 5.5). This was also the case in the other two snow-free periods monitored (2008-2009, 2009-2010, see Appendices Table A5.9). There were 60-70 frosts at Low wet heath wells during the October to May period of 2007-2008, including some during February, March and December. Frost numbers were even higher at these sites during the corresponding period of 2008-2009, including several during January. Low wet heath communities occur in the most exposed and open parts of the landscape, with distances to woodland or forest of several hundred metres. Frosts were also common at the PV1650 Valley bog well. This site is also in an open, relatively exposed location, several hundred metres from wooded areas. Frosts were less common

Table 5.5: The number of frosts (< -2°C) at each well in each month between October 2007 and May 2008. The totals for the entire period are also displayed.

2007 - 2008	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
Cope South Valley bog	5	0	0	0	0	0	0	8	**13**
PV1650 Valley bog	10	8	1	0	4	4	17	16	**60**
Cope East Tall wet heath	4	0	0	0	0	0	0	4	**8**
Boulder Bog Raised bog	12	0	1	0	2	2	7	8	**32**
Cope South Raised bog	8	0	1	0	0	0	5	10	**24**
Wallaces Tr'k (Well no. 3) Raised bog	0	0	1	0	0	0	0	9	**10**
Boulder Bog Low wet heath	11	6	2	1	3	3	16	18	**60**
Cope Creek Low wet heath	12	7	2	0	9	10	20	18	**78**
Horror Bog (Well no. 7) Burnt hm'k	9	0	1	0	3	4	11	14	**42**
Wallaces Tr'k (Well no. 5) Burnt hm'k	0	0	1	0	2	3	11	13	**30**

at the other well sites in the warmer months (December to February) and overall frost numbers were generally lower at these wells even during the more frost-prone months.

In terms of overall mean daily temperatures, there is little difference between the microsites. Mean monthly temperatures varied between 12°C and 14°C in January, and approximately -1°C and 2°C in July. Slightly higher January temperatures were recorded in the subalpine sites (e.g. Cope South, close to woodland, sheltered south-eastern slopes) and in Valley bogs (Figure 5.17, Appendices Tables A5.10* - A5.15*). The lower winter mean monthly temperatures at Cope Creek in Low wet heath are further illustration of the influence of cold-air drainage, coupled with reduced snow cover. Temperatures in Tall wet heath are slightly milder at both seasonal extremes. The Cope Creek and Boulder Bog Low wet heath sites consistently recorded the lowest minimum temperatures in all months. These were generally in the range from -5°C to -15°C (Figure 5.18), with the absolute minimum temperature recorded being -16.4°C at Cope Creek in July 2009. The PV1650 well experienced almost as many frosts during the growing season as the Cope Creek site, but minimum monthly temperatures were not as extreme. Monthly minimum temperatures were generally in the 0°C to -5°C range at the more sheltered well sites (e.g. Cope South, Cope East, Appendices Tables A5.11, A5.12).

The length and timing of snow cover varied considerably across the three years. The longest snow cover occurred in 2008, then followed by 2007 (Table 5.6, Figure 5.19).

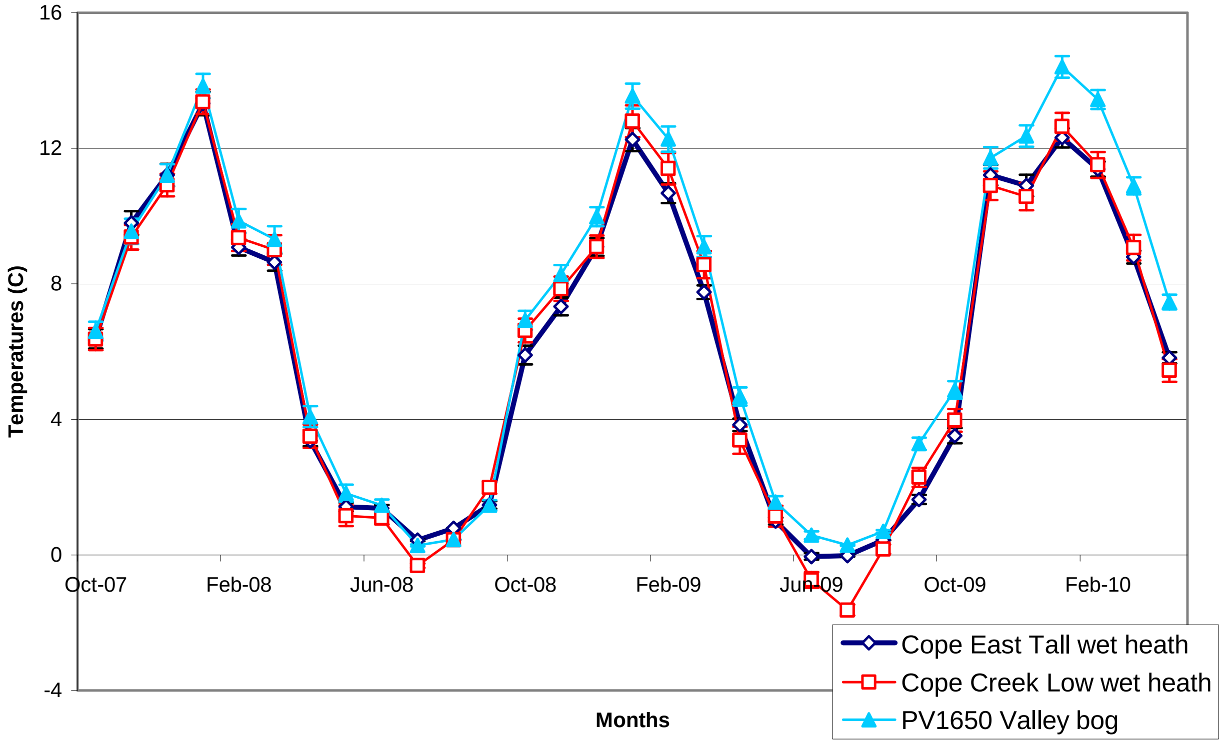


Figure 5.17: Mean monthly temperatures at three different well microsites on the Bogong High Plains between October 2007 and April 2010.

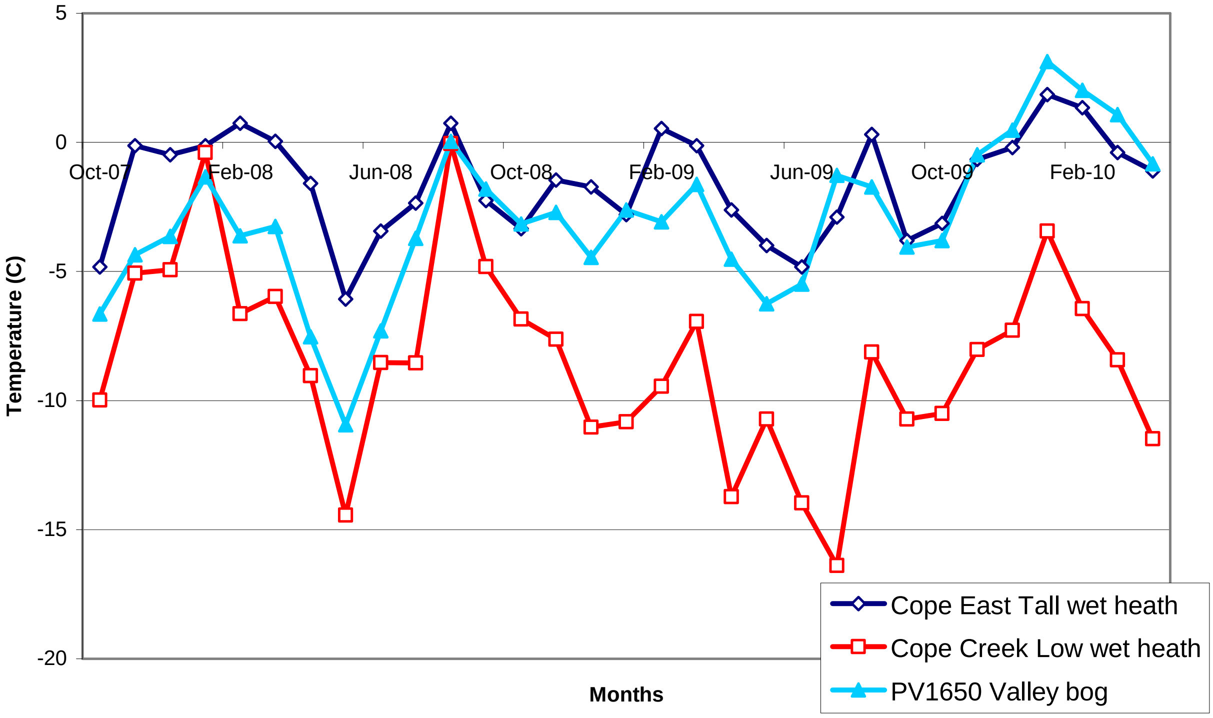


Figure 5.18: Minimum monthly temperatures recorded at three different well microsites on the Bogong High Plains between October 2007 and April 2010.

Table 5.6: Snow-cover duration at the various water table wells between June 2007 and September 2009. The data are the number of days between June 1 and September 30 with cover greater than 25 cm deep. Also displayed are the aspect, slope, altitude and distance to woodland for each well (S = south, SE = south-east, E = east, NE = north-east, W = west, SW = south-west, no data available for some years).

Well site and vegetation type	2007	2008	2009	Aspect	Slope %	Altitude (m)	Distance to woodland (m)
Valley bog							
Cope South Valley bog	-	80	46	S	2	1610	40
PV1650 Valley bog	80	88	68	SW	3	1650	150
Tall wet heath							
Cope East Tall wet heath	-	94	89	SE	10	1700	80
Cope South (Well S4)	-	-	60	S	5	1610	40
Raised bog							
Boulder Bog Raised bog	85	95	82	S	7	1700	150
Cope South (Well S3)	-	-	80	S	5	1610	30
Cope South Raised bog	-	87	79	S	5	1610	30
Wallaces Track (Well no. 3)	-	94	96	SE	12	1660	40
Wellington Plain Raised bog	-	44	6	NE	5	1500	100
Low wet heath							
Boulder Bog Low wet heath	84	89	84	S	4	1700	200
Cope Creek Low wet heath	-	75	17	W	3	1690	300
Wellington Plain Low wet h'th	-	45	16	E	3	1500	250
Burnt lawns							
Cope South (Well S1)	-	-	89	S	7	1610	15
Cope South (Well S2)	-	-	67	SW	8	1610	40
Burnt hummocks							
Horror Bog (Well no. 7)	-	77	37	SW	10	1690	200
Wallaces Track (Well no. 5)	-	70	52	NE	7	1660	30

The cover in 2009 was not continuous at many sites. The exact timing of the snow-cover period also varied from year to year. It was early in 2007, but later in 2008 and 2009. Peak cover at the ‘PV1650’ well was from mid-June to early September in 2007 (80 days), early July to late September in 2008 (88 days), and early July to early September in 2009 (68 days). The shortest snow cover durations occurred at Wellington Plain (6-45 days) which is at lower altitude and at the southern edge of the eastern highlands (Snowy Range region, see Chapter 3).

In both 2007 and 2008, snow cover durations were generally 80-95 days at most sites. The exceptions were the Burnt hummock wells (70-77 days) and one of the Low wet heath well sites (Cope Creek, 75 days). In 2009, when snow cover was generally light, there was greater variation in the snow-cover duration between the well sites (Figure

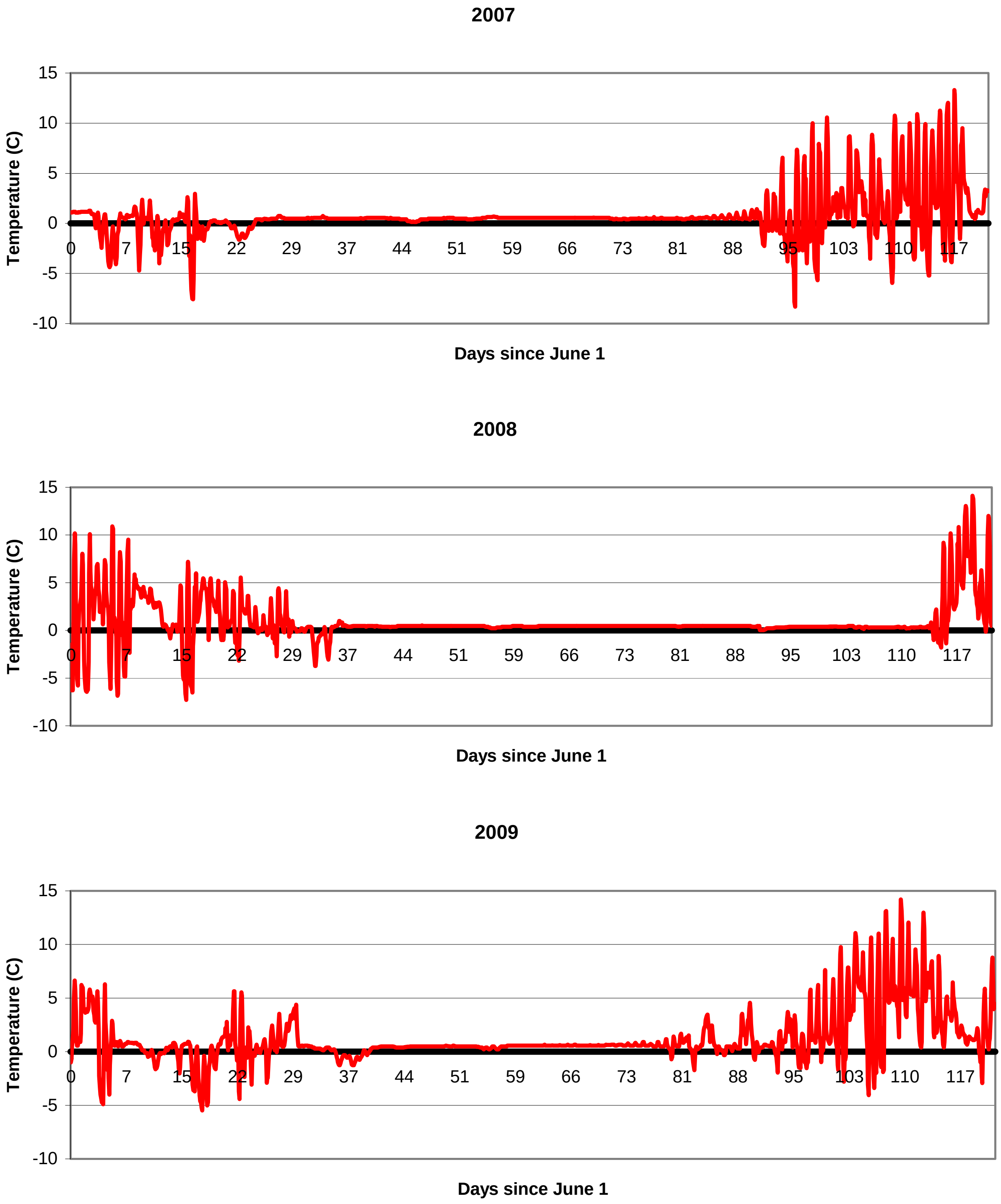
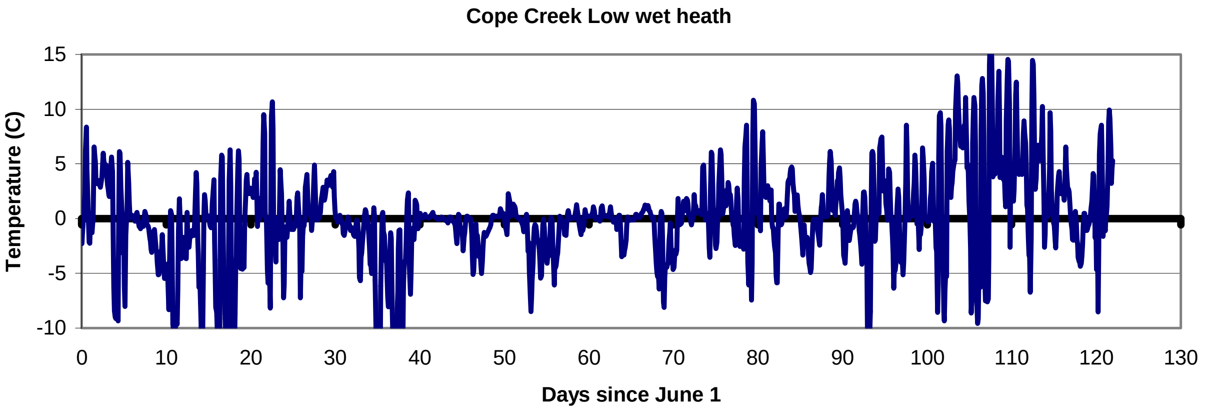
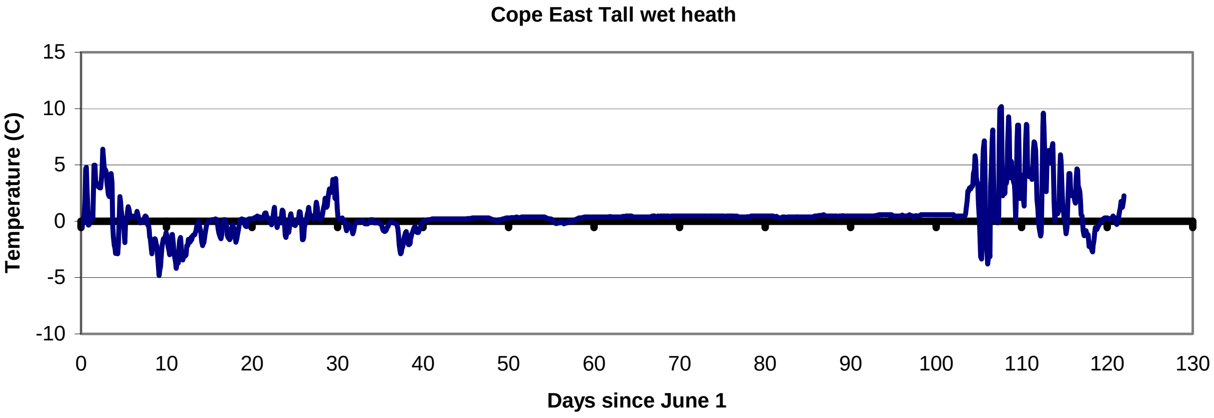


Figure 5.19: Comparison of temperature fluctuations (°C) during three winter periods at PV1650 well (June-September). The period of low fluctuation represents snow cover of depth greater than 25-30 cm.





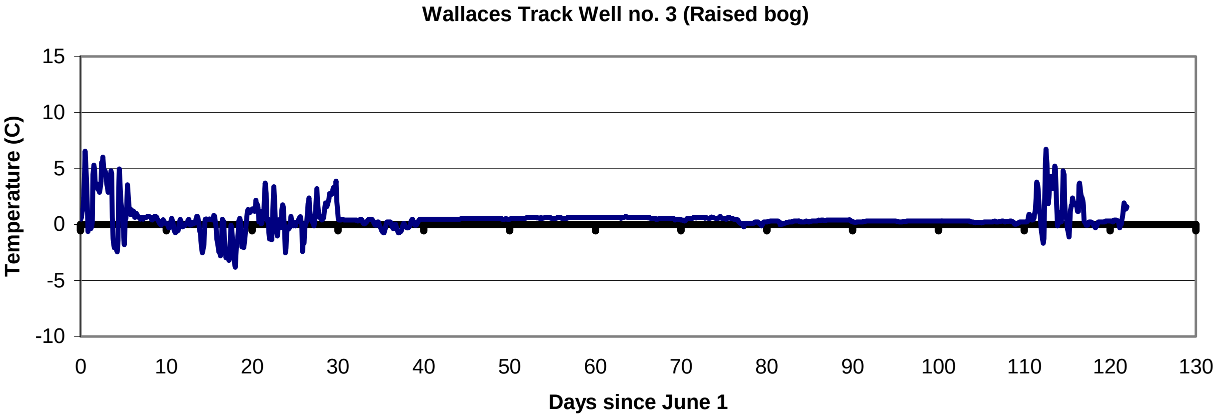


Figure 5.20: Comparison of temperature fluctuations during winter 2009 at three different wells. The period of low fluctuation represents snow cover of depth greater than 25-30 cm.

5.20). For example, the duration of cover deeper than 30 cm at the Cope Creek well was only 17 days, and at several other wells only 37-52 days. Alternatively, several well sites experienced 79-96 days of snow cover deeper than 25-30 cm. These included wells in Low wet heath, Raised bog, Tall wet heath and Burnt lawn areas. The common factor for all these sites appears to be south or south-easterly aspect and moderate slope of 5-15% (Figure 5.21).

Figure 5.21: South draining valleys on the southern slopes of the Rocky Knobs, Bogong High Plains. This photograph is looking north in early October 2007 and illustrates the typical snow accumulation and persistence patterns.

Summary of hydrological regime in each microsite or community type with references to the floristic and structural attributes

Valley bog: Peat was generally greater than 80 cm (92-160 cm) deep and varied from fibric to sapric through the profile. The water table level was high and stable, with mean depth to water table during the growing season being 10 cm, and levels rarely more than 20 cm from the surface (Table 5.7), therefore the catotelm is of considerable depth. There were some periods of surface water flow, generally during winter and the spring ‘thaw’. The snowmelt began earlier than in other wetland communities and frosts occurred at some locations during the warmer months. The *Sphagnum* cover was high in the immediate vicinity of these wells (Tables 5.8, 5.9). Sedges were also abundant, particularly *Carex* and *Carpha* species, but restiads such as *Empodisma minus*, although common, provided less cover than in other peatland communities (< 2%). Shrub cover was less than 6% and shrub height less than 15 cm. The shrub species recorded in quadrats at these wells were exclusively the ericaceous species (*Richea continentis*, *Epacris celata*, *Epacris glacialis*). The microtopography consisted mostly of hollows, lawns and low hummocks. Pools and surface water were common.

Raised bog: Peat depth was similar in these sections (79-180 cm) and varied in texture from fibric to sapric through the profile. The mean depth to water table during the growing season was 21 cm and levels were generally between 20 cm and 40 cm, but still relatively stable. The catotelm was therefore variable in thickness. Surface water flow was rare, brief, and generally restricted to the ‘snowmelt’ peak in late September. The snow cover duration at these locations was relatively long and frosts during the warmer months were uncommon. The mean cover of *Sphagnum* in the vicinity of these wells was greater than 70% and the cover of restiads (mostly *Empodisma minus*) approximately 20%. The shrub cover was approximately 11% and shrub height greater than in Valley bog microsites (15-30 cm). The ericaceous species were again dominant (*Richea continentis*, *Epacris paludosa*), but *Baeckea gunniana* (Myrtaceae) was recorded at some wells. Pools and surface water were less common at these sites and there was greater

Table 5.7: Summary of water table, peat and microtopography characteristics in each microsite or community type. The data are derived from the 35 complete microsite by growing season data sets (refer to Table 5.2).

Attribute	**Valley bog**	**Tall wet h'th**	**Raised bog**	**Low wet h'th**	**Burnt lawns**	**Burnt hm'ks**
Peat type	fibric-hemic	hemic-sapric	fibric-hemic	sapric-dried	hemic-sapric	fibric-sapric
Mean water table level (cm)	-10 ± 3	-26 ± 2	-21 ± 2	-13 ± 3	-5 ± 1	-53 ± 5
Mean water table variability	4 ± 1	8 ± 2	5 ± 1	9 ± 1	4 ± 1	9 ± 1
Peat depth (cm)	115	91	125	35	70	144
Peat depth range (cm)	92 - 160	65 - 170	79 - 200	32 - 40	57- 82	124 - 164
Variability/depth	0.03	0.09	0.04	0.27	0.05	0.06
Catotelm present	yes	yes	yes	no	yes	yes
Number of data sets	4	4	12	7	2	6
Microtopography	lawns		lawns			
	low hm'ks	NA	high hm'ks	NA	NA	NA
Pools	very common	rare	common	rare	NA	NA

relief between hummock crests and hollow bottoms (40-70 cm). The microtopography consisted mostly of hummocks and lawns (Figure 5.22).

Low wet heath: The wells in Low wet heath were in shallow dried peat, mostly less than 40 cm deep. Depth to water table was highly variable and unstable (Table 5.7), with periods of surface flow in most months, but these episodes were less common between January and June. There were also frequent periods between January and April when the water table was below the underlying bedrock and this occasionally occurred in other months also. Therefore, there was no catotelm layer (permanently wet, anoxic peat horizon) in the underlying peat. Snow-cover duration was variable depending on aspect, but relatively short in some more exposed sites. Frosts are common and occurred in the warmer months also. The vegetation cover within 75 cm of these wells was dominated by shrubs (25%), restiads (20%), *Astelia alpina* (12%), grasses (5%), herbs and other sedges (4%). Fixed litter and exposed sapric peat were also quite common (15%). Ericaceous shrub species were dominant (*Epacris glacialis*, *Epacris celata*, *Richea continentis*) but some cover was provided by myrtaceous species (*Baeckea gunniana*) at Wellington Plain. Plant species are probably benefitting from the surface flow 'irrigation' which would deposit nutrient.

Table 5.8: Species abundances in floristic quadrats (0.5 m^2) around each well. The data are mean values for each community type. The data are derived from two wells (quadrats) in Valley bog, 2 in Tall wet heath, 5 in Raised bog, 3 in Low wet heath, 2 in Burnt hummocks, 2 in Burnt hollows.

Species	**Peatland community type**					
shrubs	**Valley Bog**	**Tall wet h'th**	**Raised Bog**	**Low wet h'th**	**Burnt Hm'k**	**Burnt Hollow**
Richea continentis	2.3 ± 1.8	0.0 ± 0.0	2.1 ± 0.8	8.3 ± 6.0	0.0 ± 0.0	1.0 ± 0.0
Epacris paludosa	0.0 ± 0.0	37.5 ± 2.5	9.4 ± 2.5	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3
Baeckea gunniana	0.0 ± 0.0	12.5 ± 2.5	0.8 ± 0.6	1.7 ± 1.7	0.0 ± 0.0	0.5 ± 0.5
Epacris celata	2.8 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	2.3 ± 2.3	0.0 ± 0.0	0.0 ± 0.0
Epacris glacialis	1.0 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	12.7 ± 11.2	0.0 ± 0.0	0.0 ± 0.0
monocots						
Empodisma minus	1.5 ± 1.0	17.5 ± 7.5	18.0 ± 5.8	18.3 ± 1.7	0.3 ± 0.3	10.0 ± 5.0
Poa costiniana	0.0 ± 0.0	0.3 ± 0.3	0.5 ± 0.2	5.3 ± 4.8	1.5 ± 1.5	30.0 ± 5.0
Carex gaudichaudiana	4.8 ± 2.3	1.0 ± 1.0	1.7 ± 0.9	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3
Poa hothamensis	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	7.5 ± 7.5	0.0 ± 0.0
Baloskion australe	1.3 ± 1.3	0.3 ± 0.3	1.4 ± 1.4	1.8 ± 1.6	0.0 ± 0.0	0.0 ± 0.0
Astelia alpina	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	11.7 ± 6.8	0.0 ± 0.0	0.0 ± 0.0
Carpha spp.	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Chiloglottis valida	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3
Isolepis sp.	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	10.0 ± 10.0
Luzula modesta	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.5
Carex echinata	1.3 ± 1.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Oreobolus distichus	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	3.3 ± 3.3	0.0 ± 0.0	0.0 ± 0.0
Thelymitra cyanea	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
herbs						
Asperula gunnii	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	1.0 ± 0.0	2.8 ± 2.3
Celmisia spp.	0.0 ± 0.0	0.3 ± 0.3	1.0 ± 0.4	0.7 ± 0.7	0.0 ± 0.0	1.0 ± 1.0
Acetosella vulgaris	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 1.0	0.0 ± 0.0
bryophytes						
Sphagnum cristatum	100.0 ± 0.0	15.0 ± 15.0	72.0 ± 13.7	0.0 ± 0.0	0.0 ± 0.0	25.0 ± 20.0
Polytrichum sp.	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.8
Lycopodium sp.	0.0 ± 0.0	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
shrub cover	5.3 ± 2.8	47.5 ± 2.5	11.4 ± 2.7	23.3 ± 13.6	0.0 ± 0.0	1.5 ± 0.5
mean shrub height (cm)	7.5 ± 2.5	45.0 ± 15.0	14.0 ± 2.4	16.7 ± 3.3	0.0 ± 0.0	7.5 ± 2.5
shrub height high	12.5 ± 2.5	85.0 ± 25.0	25.0 ± 4.7	21.7 ± 6.0	0.0 ± 0.0	12.5 ± 7.5
litter	0.3 ± 0.3	22.5 ± 17.5	2.2 ± 0.7	3.7 ± 0.9	7.5 ± 2.5	1.3 ± 0.8
fixed litter	0.0 ± 0.0	32.5 ± 17.5	7.3 ± 5.3	5.0 ± 3.3	22.5 ± 12.5	0.0 ± 0.0
bare peat	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.9	8.7 ± 5.7	60.0 ± 5.0	20.0 ± 10.0

Tall wet heath: The depth to bedrock was 65-170 cm and the peat sapric or hemic. Water table levels were more variable than either of the two ‘bog’ communities and generally 20-50 cm below the surface during the growing season. Therefore, at some wells the catotelm was relatively thin. Snow cover duration at these microsites was relatively long and frosts uncommon. The mean shrub cover around these wells was 47% and shrub

Table 5.9: Plant functional group and life-form mean cover abundances for the different peatland microsite - community types. The data are derived from the well floristic quadrats (0.5 m²).

Plant Functional	**Peatland community type**					
or life-form group	**Valley bog**	**Tall wet h'th**	**Raised bog**	**Low wet h'th**	**Burnt lawn**	**Burnt hm'k**
Ericaceous shrubs	6.0 ± 3.0	37.5 ± 2.5	11.5 ± 3.1	23.3 ± 16.4	1.3 ± 0.3	0.0 ± 0.0
Myrtaceous shrubs	0.0 ± 0.0	12.5 ± 2.5	0.8 ± 0.6	1.7 ± 1.7	0.5 ± 0.5	0.0 ± 0.0
Total shrub cover	6.0 ± 3.0	50.0 5.0	12.3 ± 3.0	25.0 ± 15.3	1.8 ± 0.8	0.0 ± 0.0
Astelia	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	11.7 ± 6.8	0.0 ± 0.0	0.0 ± 0.0
Carex spp.	6.0 ± 1.0	1.0 ± 1.0	1.7 ± 0.9	0.0 ± 0.0	0.3 ± 0.3	0.0 ± 0.0
Other monocots	0.3 ± 0.3	0.3 ± 0.3	0.6 ± 0.2	5.3 ± 4.8	30.8 ± 4.8	9.0 ± 6.0
Other sedges	0.3 ± 0.3	0.0 ± 0.0	1.5 ± 1.0	3.3 ± 3.3	10.0 ± 10.0	0.0 ± 0.0
Restiads	2.8 ± 2.3	17.8 ± 7.8	19.4 ± 5.2	20.2 ± 2.9	10.0 ± 5.0	0.3 ± 0.3
Total monocot cover	9.3 ± 1.8	19.0 ± 9.0	23.2 ± 5.6	40.5 ± 7.8	51.0 ± 0.0	9.3 ± 5.8
Total herbs cover	0.0 ± 0.0	0.3 ± 0.3	1.1 ± 0.4	0.7 ± 0.7	3.8 ± 1.3	2.0 ± 1.0
Other bryophytes	0.0 ± 0.0	0.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.8	0.0 ± 0.0
Sphagnum	100.0 ± 0.0	15.0 ± 15.0	72.0 ± 13.7	0.0 ± 0.0	25.0 ± 20.0	0.0 ± 0.0
Total b'phyte cover	100.0 ± 0.0	15.3 ± 14.8	72.0 ± 13.7	0.0 ± 0.0	26.3 ± 19.3	0.0 ± 0.0

heights 30-80 cm. The shrub species providing most cover were *Epacris paludosa* and *Baeckea gunniana*. Cover provided by restiads was variable and *Sphagnum* generally low. There was a substantial amount of fixed litter (dead *Sphagnum cristatum* and *Empodisma minus*) and loose litter (shrub leaves) covering the ground layer around these wells.

Burnt hollow and lawn areas: The peat texture was hemic or sapric at these microsites and depth varied from 57 cm to 82 cm. The mean depth to water table during the growing season was 5 cm and levels did not fall below 20 cm during this period, and thus there was a reasonably substantial catotelm layer. These patches were burnt in December 2006, but had recovered relatively rapidly (> 50% live vegetation cover). The cover provided by *Sphagnum* and shrubs was still low, but shrub seedlings were common. Most of the vegetation cover around these wells was provided by *Empodisma minus*, and other graminoids like *Poa costiniana* and *Isolepis* species.

Burnt hummocks: The peat in these large hummocks spanned the full texture range (sapric to fibric) and the depth of wells varied from 124 cm to 164 cm. The water table was moderately stable, but typically 40-75 cm below the surface during the growing season. Therefore, despite the relatively low water table levels, the catotelm was relatively thick. These hummocks were burnt in January 2003 and the percent cover of bare ground was still high (< 50% live vegetation cover). There were no shrubs recorded in the immediate vicinity of the wells and no shrub seedlings observed within 3-4 m. However, limited vegetative recovery of shrubs was occurring within this distance. No *Sphagnum* recolonisation had occurred in the vicinity of these wells. Instead, grasses (*Poa costiniana*, *P. hothamensis*) were establishing and appear to be expanding.

Figure 5.22: An area of bog vegetation at Cope Saddle on the Bogong High Plains which illustrates the differences between lawns and hummocks. The photo also encapsulates at small scale the differences between the Valley bog and Raised bog communities. In the top left of frame is a broad stream channel dominated by *Carex gaudichaudiana* and contains permanent surface water. *Sphagnum cristatum* and *Carex* spp. dominated areas in centre frame and top right are slightly above channel level and only intermittently inundated ('thaw'). These are floristically referable to Valley bog. The hummocks (olive green) are higher again above the mean water table level and dominated by *Empodisma minus*, ericaceous shrubs and *Sphagnum cristatum*. These are floristically referrable to Raised bog.

Functional group distributions along the depth to water table gradient

Figures 5.23 and 5.24 show the percent cover values of two of the key plant functional groups at nine bog and wet heath wells, plotted against the mean annual lowest water table level at the respective wells between 2008 and 2010. The Low wet heath, Burnt hummock and Burnt lawn wells were not included in these analyses. There was a significant negative correlation between mean annual lowest water table level and the percent cover of ericaceous shrubs (-0.80, $P < 0.01$, df = 5; Figure 5.23). Conversely there was a significant positive correlation between mean annual lowest water table level and the percent cover of *Sphagnum* (0.76, $P < 0.05$, df = 5; Figure 5.24). The correlation for *Carex* was similarly positive but not significant, whereas there was a significant negative correlation for restiad species (mostly *Empodisma minus*)(-0.68, $P < 0.05$, df = 5; Appendices Figures A5.1, A5.2). There was also a strong negative correlation between mean annual lowest water table level and maximum shrub heights at each well (-0.87, $P < 0.01$, df = 5; Figure 5.25). *Baeckea gunniana* (Myrtaceae) was the only non-ericaceous shrub recorded in the vicinity of the wells, and there were insufficient records to make conclusive observations. However, a similar negative relationship between mean annual lowest water table level and *Baeckea gunniana* percent cover was apparent from the limited recordings (four sites only). Hence, to summarise, lower levels favoured shrubs and restiads, higher levels favoured *Sphagnum* and sedges like *Carex*.

The most abundant ericaceous shrub was *Epacris paludosa* which reached highest percent cover values at Tall wet heath wells. Other ericaceous species displayed wider water table level tolerances (*Richea*, *Epacris glacialis*, *E. celata*). All except *E. paludosa* were abundant at Low wet heath wells on the Bogong High Plains, especially *E. glacialis*. The latter species does not occur at the more southern and lower elevation Wellington Plain peatland.

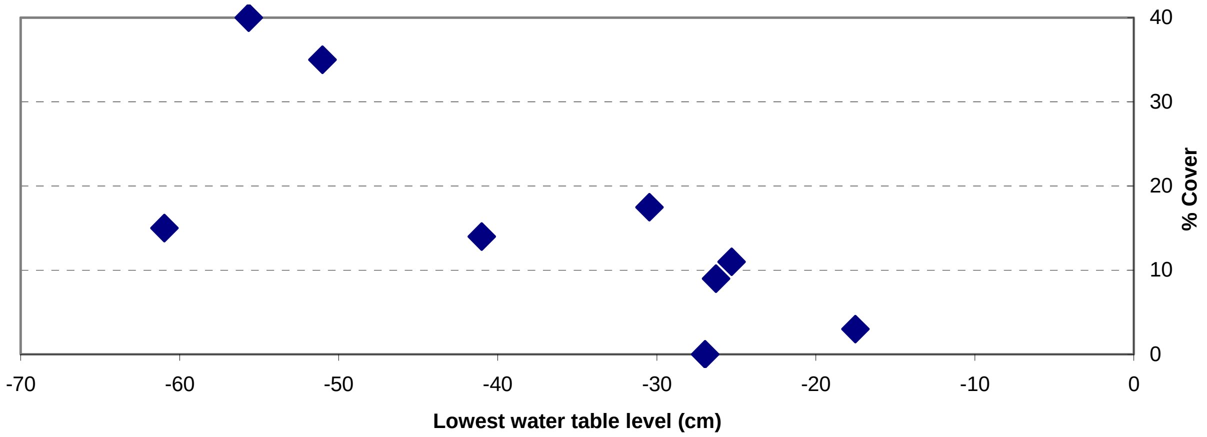


Figure 5.23: Percent cover of ericaceous shrubs vs mean lowest water table level.

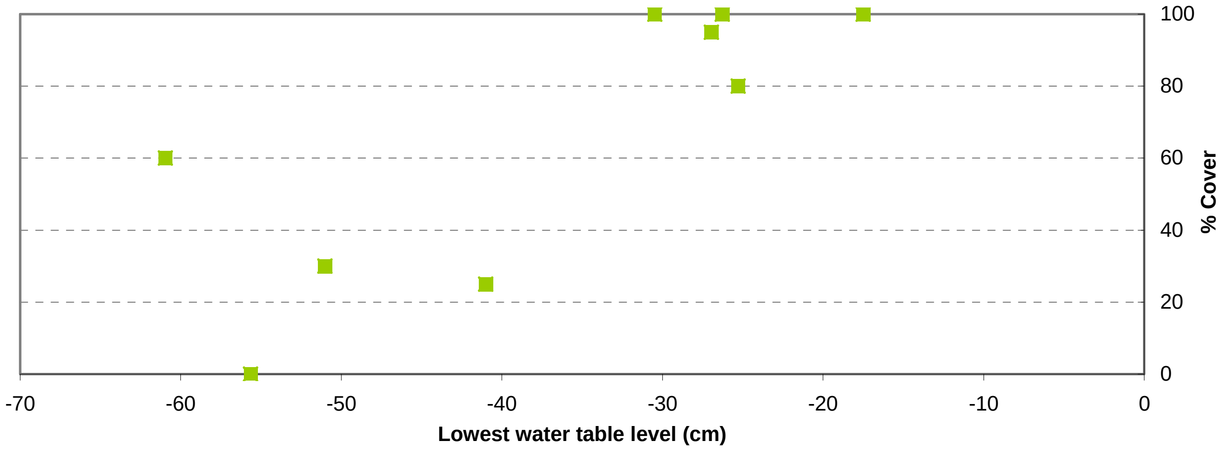


Figure 5.24: Percent cover of *Sphagnum* vs mean lowest water table level.

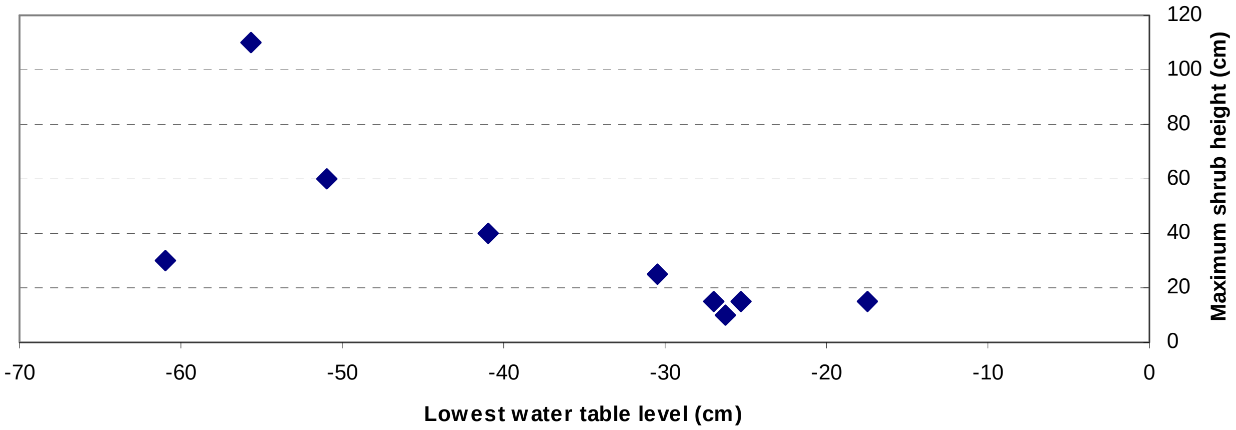


Figure 5.25: Maximum shrub height vs mean lowest water table level.

5.4 DISCUSSION

The annual hydrological cycle in subalpine peatlands in the Eastern Highlands of Victoria is influenced by annual precipitation and temperature regimes. In the Bogong High Plains region monthly precipitation totals are high and generally in the form of snow between June and September. This has the effect of delaying groundwater recharge, runoff and peak stream-flow until September-October (Western et al. 2008, 2009). Monthly precipitation totals are also high in spring and gradually decline with progress into summer and autumn. Precipitation in the summer and autumn months is more variable from year to year (see Chapter 2, ‘Climate’). The seasonal distribution of precipitation between 2006 and 2010 was fairly typical in this respect, but involved at least two years in which annual totals were below average, particularly 2006-2007. Wellington Plain is on the south-eastern edge of the elevated country (Gippsland side) and the annual and inter-annual precipitation patterns are very different. It receives less precipitation overall and its timing is more variable and less predictable (see Chapter 2). The period of water table monitoring at Wellington Plain was one of generally below average precipitation, except perhaps for the last 6-8 months.

Water table behaviour

The *Sphagnum* and sedge dominated lawn areas, like those associated with the two Valley bog sites, experienced the highest and most stable water table levels during the growing season. Futhermore, shrub cover and stature were much reduced in this community type. Much of the past research in peatlands attributes this to the shallow depth of the acrotelm (< 20 cm), providing little oxygenated space for shrub roots to develop (Gorham 1991). The water table levels recorded in Valley bog areas on the Bogong High plains were comparable to those in *Sphagnum* and *Eriophorum vaginatum* (Cyperaceae) dominated blanket mire in northern United Kingdom (Holden and Burt 2003). In that study, the water table levels were within 5 cm of the surface for 82% of the summer period. Maximum summer depth to water table readings were generally about 20 cm in most years, but occasionally dropped to 40 cm in the drought years of that particular study.

Water table levels in Raised bog communities were more variable (20-50 cm below surface). This concurs with figures for hummocks in many studies (Sjors 1948, Ingram 1983, Rydin and Jeglum 2006). The acrotelm or aerated peat layer available to plant roots was deeper than in Valley bog areas and, correspondingly, the surface cover of shrubs was greater.

The cover of shrubs was high in Tall wet heath areas, *Sphagnum* cover was low and the peat more decomposed (sapric). Water table depths were similar to those in hummocks or raised bog sections, but less stable, and it is water table stability as much as proximity to the surface, that influences peat characteristics and therefore, vegetation patterns. Large fluctuations in the depth to the water table, and the consequent wetting and drying cycles, are thought to enhance the rates of decomposition, which in turn favour vascular plant species, particularly ericaceous shrubs (Hogg et al. 1992, Updegraff et al. 2001, Breeuwer et al. 2009).

The higher shrub cover, shrub stature and litter cover in wet heath areas reduces the light reaching the surface and is partly responsible for the lack of *Sphagnum* (Hayward and Clymo 1983, Ohlson et al. 2001, Malmer et al. 2003). Thus, the structure of the vegetation in wet heath areas is the result of a positive feedback. A variable water table leads to enhanced decomposition and nutrient availability, which in turn enables taller shrub stature and shading of *Sphagnum*. More vigorous shrub growth, both above and below ground, can further enhance the feedback by increasing transpiration (Ingram 1983). In this study, diurnal water level fluctuations during warm, dry periods were greater in Tall wet heath wells than in bog wells. This would appear to be evidence supporting this process.

To a certain extent, the Tall wet heath communities represent a seral stage in a shrub-*Sphagnum* cycle, similar to shrub-grassland cycles described in non-wetland communities

(Watt 1947, Costin 1954, Ashton and Hargreaves 1983, Williams and Ashton 1987a, 1987b, Williams 1990, 1992). The eventual shrub senescence improves light and influences microscale hydrology which, inturn, allows seedling recruitment and *Sphagnum* re-invasion or, if water levels remain low, allows the expansion more marginal peatland species (e.g. *Poa costiniana*) and neighbouring non-wetland species.

The water table levels in Low wet heath communities are unstable. Many of these areas that now carry Low wet heath vegetation are likely to have experienced periglacial activitity during the last glacial maximum (15-35 mya), which may explain the drainage characteristics (Tallent 1965, Peterson 1971). The peats are typically shallow, humified, and often underlain by alluvial gravels (Ashton and Williams 1989). These are also amongst the harshest and most exposed areas in the region (high wind speeds and frost frequency). *Sphagnum* is absent and low ericaceous shrubs like *Epacris glacialis* and *Richea continentis* predominate. *Empodisma minus* is also common together with ‘cushion’ or mat-form species such as *Oreobolus distichus* and *Astelia alpina*. The latter two species appear to be favoured by the irrigation and nutrient supplied by frequent surface water flow (Holden and Burt 2003). The preference of *Astelia* species for these hydrological regimes has been noted elsewhere in the southern hemisphere (Pisano 1983, Kirkpatrick and Gibson 1984, Gibson and Kirkpatrick 1985b, Mark et al. 1995).

The areas of Low wet heath are often interspersed with smaller areas of Alpine raised bog and may represent an earlier seral stage in this community (Wahren 1997, Wahren et al. 2001a). Thus, the relationship between the two communities may be similar to that described above between Subalpine raised bog and Tall wet heath. The origin of the Low wet heath communities in exposed treeless areas on the floor of Pretty Valley has been debated, with many researchers considering them to be relictual bog communities that have dried (McDougall 1982), possibly recently as a result of damage caused by livestock grazing (Wahren 1997, Grover et al. 2005, Grover 2006). The water table monitoring in this study has shown that these areas do not possess permanent water tables and thus, the traditional division of peat layers into catotelm and acrotelm is possibly inappropriate. The catotelm is of considerable thickness in some wells (up to 170 cm or more). The water table did not fall below bedrock level at any stage in Valley bog, Raised bog, Tall wet heath, Burnt hummock or Burnt lawn wells. It did, however, descend to within approximately 15-20 cm of this level at some wells during the extended dry period of January to March 2009.

The only other monitoring of water table depths in different peatland communities in this region was limited to 'spot' sampling in early, middle, and late growing season (November, February, April) over two years (Wahren 1997). In that study the depth of the water table was 32-43 cm below the surface in 'closed heath' without *Sphagnum* (wet heath), and 15-27 cm below the surface in 'closed heath' with *Sphagnum* (raised bog). In 'low open heath' (comparable to Low wet heath in this study) the water table was level with or below the bedrock in February and April of both years. All these figures and observations are similar to the results of this study. Monitoring of 'bog flat peat' (*Sphagnum* lawns), 'bog hummock peat' (*Sphagnum* hummocks), and 'dried peat' (low wet heath) at Wellington Plain between 2004 and 2006 produced comparable results to this study, with the water table typically 10-36 cm below the surface in *Sphagnum*-dominated sections (Grover 2006). The water table descended below bedrock level in dried peat areas devoid of *Sphagnum* in that examination also.

Temperatures and duration of snow cover

Aspect appears to be the most critical factor influencing snow-cover duration in this region. Prevailing winter winds are from the west and north-west. The heaviest snow comes from this direction and tends to accumulate to greater depths on south and east aspects (Williams 1987, Williams and Ashton 1994, Wahren 1997, Costin et al. 2000). Hence, the peatland sites in these locations experienced the longest snow cover. Valley bog and Low wet heath communities are on gentle slopes (< 5% slope) and in large open treeless windswept expanses, such as Pretty Valley. Thus, they accumulate less snow and are more likely to lose the snow cover early. Tall wet heath and Raised bog communities were generally on more moderate to steep slopes (5-15% slope), often with aspects ranging from east to south (90-180°). Thus, snow accumulated to greater depth and persisted longer in these locations. The duration of snow cover also varied least across the three years there.

There are parallels with similar examinations of snow cover duration and temperature in the non-wetland vegetation adjacent to these peatland communities. Williams (1987) found that snow accumulated to greater depths and persisted longer on south-eastern slopes dominated by closed heathland, than on exposed gentle valley floor slopes dominated by grasses and herbaceous vegetation. The floristic analysis of peatlands from earlier in this thesis (Chapters 3 and 4) identified two types of raised bog in the Bogong region, one in more exposed locations at higher elevation (Alpine raised bog), and the other in sheltered positions at high elevation or, at lower altitude locations (Subalpine raised bog). Closed heathland dominated by non-wetland heath shrubs like *Bossiaea foliosa*, *Orites lancifolia*, and *Prostanthera cuneata* (McDougall 1982), is commonly adjacent to Subalpine raised bog and Tall wet heath communities. Low wet heath, Valley bog, and Alpine raised bog, are commonly surrounded by grassland and open heath.

In the research performed by Williams (1987), maximum and minimum temperatures were also consistently 3-5°C higher in closed heath than in the valley floor grasslands. The extreme minimum temperatures (e.g. -16.4°C) recorded in Low wet heath during the winter months of 2009, a light snow year, are comparable to temperatures recorded in adjacent grassland during the winter of 1982 (-18°C, Williams 1987). That was an El Nino year and snow cover was exceptionally light. Williams (1987) hypothesised that the absence of closed heath shrub species like *Prostanthera cuneata* and *Phebalium squamulosum* in grassland and open heath on the lower valley floor slopes was related to exposure, extreme low temperatures, and insufficient snow depth to provide adequate protection from these. Elsewhere in the Australian Alps, shrub death in treeless subalpine heathland near Kiandra in 1982 was attributed to the absence of snow cover combined with severe frosts (-21°C, Leigh et al. 1987). One of the ericaceous species found in peatlands, *Epacris glacialis*, appears to only occur in the more exposed communities. The more widespread species in subalpine and montane areas is *Epacris paludosa*, but this is absent or very rare in exposed sites. However, it usually reappears in raised bog areas further upslope, in closer proximity to woodland, with other common subalpine species like *Baeckea gunniana*. Furthermore, shrub height in these exposed peatlands rarely exceeds 30 cm, whereas not only is the species assemblage slightly different in sheltered peatlands, but shrub height often exceeds 1 m.

Woody vegetation in the tundra is dependent upon protection from winter extremes afforded by the deeper snow associated with sheltered leeward aspects (Wardle 1971, Billings 1973). For snow cover to be effective in this regard, a minimum depth of 30-35 cm is thought to be necessary (Bell and Bliss 1979). Recent research in the Arctic has linked climate warming to shrub expansion which, inturn, has been shown to influence snow depth and accumulation patterns. A positive feedback-loop is created whereby taller shrubs trap and hold snow, leading to greater accumulation. The deeper snow and consequent ground insulation raises winter soil temperatures, increasing soil microbial activity, mineralisation, and nutrient availability (Sturm et al. 2001, 2005, Walker et al. 2006). A similar process may partly explain the subtle differences in composition and structure between exposed and sheltered peatlands in eastern Victoria, particularly when hydrological characteristics are otherwise similar. Hence, shrubs dominate in taller subalpine wet heath and raised bog, but alpine low wet heath and raised bog are a more even mix of shrubs, graminoids, herbs and *Sphagnum*.

The minimum temperatures in Alpine valley bog wells were not as low as those recorded at the Low wet heath wells, despite these communities being situated in similarly exposed, treeless topographic hollows. In this situation, the extreme low temperatures are possibly ameliorated by the volume of surface water and closer proximity of water tables (Billings and Mooney 1968). Ground-water temperatures are generally stable and around 5-6°C (Western et al. 2009) although it appears that surface water temperature in the acrotelm generally fluctuates between 2°C and 12°C across the year, in unison with the mean monthly air temperatures (J. Shannon unpublished data 2010).

The dominance of the shrub component by ericaceous species increases in higher and more exposed peatlands, regardless of drainage characteristics, and may be due to the unique mycorrhizal relationships formed by their roots. These enable enhanced nutrient uptake in unfavourable, low nutrient niches such as these (recalcitrant plant litter) (Read 1996, Davies et al. 2003). Ericaceous species are often the only shrubs able to persist at the shallow end of the water table depth spectrum and similar patterns are often observed in the northern hemisphere (Joosten and Clarke 2002, Rydin and Jeglum 2006). In this study, ericaceous species such as *Richea continentis* and *Epacris celata* are adept at layering and producing adventitious roots from stems buried by the *Sphagnum* carpet. These traits enable persistence and expansion even in sections where the thickness of the acrotelm is less than 10 cm. The increasing prominence of myrtaceous species like *Baeckea gunniana* in sheltered and better drained peatlands suggests that the competitive advantages normally enjoyed by ericaceous shrub species are perhaps less influential here. Higher soil temperatures, discussed above, may also be a contributing factor.

There was a general negative correlation between shrub stature and water table level at some of the wells. Other research has also established this general relationship (Verry 1997), although there are often complex interactions involving other factors, such as microclimate (as was the case in this project), and the occurrence of periods of ‘flow’ or ‘flushing’ (Crawford 1983, Ingram 1983). The latter factor can ameliorate the effects of low oxygen and nutrient availability. For example, taller shrub growth is often seen along stream banks in montane peatlands, and is sometimes associated with frequently inundated areas. These structural characteristics are regarded as evidence of the influence of flushing (Shannon 2003). Dominant species like *Sphagnum cristatum* and *Empodisma minus* drop out of ‘flushed’ or frequently inundated areas in these peatlands.

Climate change effect on water tables and therefore vegetation structure

Climate change is predicted to bring warmer and drier conditions to parts of the northern hemisphere and south-eastern Australia and this is likely to reduce mean water table levels. Longer periods of summer drought could lead to greater water table draw-down and this is expected to favour vascular plant species, particularly shrubs, at the expense of *Sphagnum* (Weltzin et al. 2000, Breuwer et al. 2009). The best example of such drought conditions during the 3-yr monitoring period occurred in early 2009 when heat-wave conditions and well below-average rainfall combined to reduce water tables to their lowest recorded levels. In Victoria, areas of wet heath within the broader ‘peatland complex’ may expand if these episodes become more common. Some studies suggest that graminoids are also favoured by such changes in hydrology (Strack et al. 2006); this may apply to the wetter end of the spectrum, such as in valley bogs and fens, where the influence of surface and ground water is greater. Water tables in these communities are generally stable and while this characteristic is perhaps unlikely to change in the short-term, levels will be lower and hence boundaries will contract, thereby reducing spatial extent.

In parts of the sub-Arctic, climate change may mean higher precipitation, much of this falling in the winter as snow. Research in Arctic non-wetland plant communities suggests this will also favour shrub species, partly because of longer and deeper snow cover and protection from the climate extremes (Sturm et al. 2001, Tape et al. 2006). Peatland research in that region suggests that this scenario will increase both vascular plant and *Sphagnum* biomass production, but the present community structure is likely to be maintained (Keuper et al. 2010). In south-east Australia, peatlands are marginal and precipitation is more likely to decline, especially during the winter months (Wheton et al. 1996). Hence, *Sphagnum* is less likely to be favoured. In the higher and more exposed treeless peatlands this may mean an expansion of herbs and graminoids like *Astelia, Oreobolus, Empodisma* and *Celmisia*. Indeed, these species were apparently more common in peatlands during the last glacial maximum, when conditions were considerably drier, but colder, than the present (Kershaw and Strickland 1989, McKenzie 1997). In subalpine peatlands, drier conditions are more likely to favour shrubs like *Epacris paludosa* and *Baeckea gunniana*. Drier conditions and lower water tables also mean more frequent fire (Hennessy et al. 2005); this too is likely to favour graminoids in some sections and fire-adapted shrubs in others. This question will be examined in more detail in Chapter 6.

In the northern hemisphere it is common for several *Sphagnum* species to co-occur and for these to fill most, if not all, micro-topographical niches (Andrus 1986). Warmer and drier conditions are likely to favour some species. For example, one study suggested that hummock forming species are likely to be favoured by more frequent summer drought periods, and those with broader geographical range would be favoured by increased temperatures (Robroek et al. 2007). In the Victorian highlands one species dominates hummocks and lawns (*S. cristatum*). A second, hollow-dwelling species (*S. novozelandicum*) is common in some areas, but never dominant (< 5% site coverage maximum). Observations by Ashton and Hargreaves (1983) at Lake Mountain suggest that *S. novozelandicum* predominated in areas where the mean growing season water table depth was 8 cm. *Sphagnum cristatum* was observed invading sections where the mean growing season water table depth was 12 cm. These readings are similar to those in nearby montane peatlands (1175 m); mean depth to water table was 8 cm in *S. novozelandicum* lawns with emergent *Juncus sandwithii*, and 13 cm in *S. cristatum* and *Empodisma minus* dominated low hummocks (J. Shannon unpublished data 2009).

The small amount of monitoring in this study associated with recently burnt areas suggests that water table behaviour and hydrology play a critical role in post-disturbance vegetation trends and regeneration. *Sphagnum* recolonisation and shrub seedling recruitment appears to only be possible in patches where water table levels are mostly within 10 cm of the surface. Excessive surface water flow has also been shown to be detrimental to *Sphagnum* recolonisation of disturbed or bare peat areas (Wahren 1997, Wahren et al. 2001a).

CHAPTER 6

THE INFLUENCE OF FIRE ON THE MONTANE AND SUBALPINE PEATLANDS OF EASTERN VICTORIA: BURNING PATTERNS AND TRENDS IN EARLY POST-FIRE REGENERATION

SUMMARY

Some transects surveyed as part of the study of regional vegetation patterns in peatlands (Chapters 3 and 4) were affected by fire in December 2006 and February 2009.

In the Snowy Range fires of December 2006, the extent and severity of burning was variable. Most peatlands contained a ‘mosaic’ of burnt and unburnt patches. Fire impacts were greater in the shrub-dominated wet heath communities, and less in the areas dominated by *Sphagnum* before the fires. The more severely burnt communities tended to be on steeper slopes, drier aspects, and closer to wooded vegetation. Myrtaceous shrub species were more associated with these areas than with *Sphagnum*-dominated bog areas.

Shrub species with the capacity to regenerate vegetatively were more common in wet heath transects. Ericaceous species were more fire-sensitive (*Epacris* spp., *Richea*) and equally common in both wet heaths and bogs. The plant functional groups with rapid mostly vegetative response during the post-fire period were restiads (*Empodisma*, *Baloskion*), other graminoids (*Poa*, *Carex*, *Astelia*), herbs and myrtaceous shrubs (*Baeckea*). Those generally slower to respond included *Sphagnum* and most, but not all, ericaceous species. *Epacris paludosa* seedling recruitment was very high in burnt hollows during the first 28 months post-fire. Shrub species when growing in *Sphagnum*-dominated patches benefitted from the protection afforded by this association during the passage of fire. These were often unburnt or less severely affected, thus the incidence of vegetative shrub regeneration was higher here. These appear to act as ‘fire-refugia’ for the more fire-sensitive species like *Richea continentis*.

Burning of the Central Highlands peatlands in February 2009 was generally more extensive and severe; unburnt patches within peatland boundaries were rare. Recovery of pre-fire vegetation structure will be slower in these. The 2003, 2006-2007, and 2009 fires in eastern Victoria probably reflect the subtle differences in fire-regime that exist between the various regions affected. These differences are apparent in the characteristics of the adjacent non-wetland vegetation, but can also be detected in the vegetation patterns and characteristics of the peatland areas.

6.1 INTRODUCTION

The factors influencing peatland ecosystems are often separated into two categories: *allogenic* or external factors, and *autogenic* or within ecosystem factors (Charman 1992). Autogenic factors essentially are related to the biotic processes such as plant growth, decay and nutrient recycling, and the influence of these on small-scale hydrology and microclimate (Van Breeman 1995, Couwenberg 2005, Couwenberg and Joosten 2005). The interactions between competing plant species, plant life-forms, small-scale hydrological patterns and microclimate, influence, and inturn are influenced by, the spatial distribution of features like hummocks, hollows and pools (Ohlson et al. 2001, Malmer 2003, Rydin and Jeglum 2006).

Allogenic factors, by their nature, tend to be macro-scale and include the broad-scale background conditions which allow peat-forming wetlands to develop. These include things like climate, topography, and the influence of the underlying bedrock on soil and groundwater chemistry (Moore and Bellamy 1973, Malmer 1986, Wheeler and Proctor 2000). Other allogenic influences include the type, frequency, and severity of disturbance, and relationships with surrounding non-wetland ecosystems (Mackay and Tallis 1996, Robinson and Moore 2000, Pellerin et al. 2006).

Periodic disturbances such as fire are an important influence in peatland ecosystems. However, because of the obvious association of *Sphagnum*-dominated or associated peatlands with cooler, wetter climates, wetter microhabitats, and lower rates of biomass production, fire is generally less frequent than in grassland, non-wetland heath and some forest ecosystems (Ashton 1981, Specht 1981, Ashton and Hargreaves 1983, Kuhry 1994). Palaeoecological evidence, in the form of charcoal deposits in peat cores, suggests that fire is part of the long-term cycle in many peatlands (Whinam and Kirkpatrick 1995, McKenzie 1997, Rydin and Jeglum 2006), albeit often at frequencies of once per century or less in the absence of anthropogenic interference (Newnham et al. 1995, McGlone et al. 1997, McGlone and Wilmshurst 1999, Pitkanen et al. 1999). This appears to be the case in highland areas of south-eastern Australia also (Kershaw and Strickland 1989, Dodson 1994, Martin 1999).

Fire frequency in the highland areas of south-eastern Australia is thought to have increased during the first 100 years of European settlement (Banks 1989, Zylstra 2006), culminating in the infamous fires of 1939, when 1,600,000 ha of Victoria were affected, and large areas in New South Wales also (Griffiths 2001, Collins 2006). After 1939 there was a long period with relatively few large landscape-scale fires (> 10,000 ha) in the high country until 2003, when approximately 3,000,000 ha were affected in Victoria, New South Wales and The Australian Capital Territory, mostly in mountain areas (Esplin et al. 2003). The 2003 fires affected all the major vegetation formations and communities to varying degrees, including peatlands. In the aftermath of these fires, there has been the opportunity for research into the fire patterns and responses of mountain ecosystems, including peatlands (Walsh and McDougall 2004, Williams et al. 2006, 2008, Jarryd et al. 2008).

A study that examined burning patterns in treeless vegetation on the Bogong High Plains after the 2003 fires showed that the closed heath communities, which have the highest cover of woody shrub species, were the most fire-affected (Williams et al. 2006). Conversely, it was grassland communities, which are the vegetation formations with the lowest cover of shrubs, that were least affected. Wetland communities were not included in this study, but within the highland areas of south-eastern Australia these cover approximately 5-10% of the treeless landscape surface (Costin 1957, McDougall 1998). There is a spectrum of different communities within the ‘upland wetland complex’ (McDougall 1982, Walsh et al. 1984, McDougall and Walsh 2007). The composition of the shrub component, and cover it provides, varies within this spectrum, and appears to be an important factor influencing differences in flammability (Williams et al. 2006). The type and flammability of adjacent non-wetland vegetation is also important, especially given the small and fragmented nature of most mountain peatlands in the region.

Past research in Australia has emphasised the effects of burning on all subalpine and alpine plant communities, and the slow recovery rates (Costin 1954, Australian Academy of Science 1957, Carr and Turner 1959, Wimbush et al. 1979, Wahren 1997). More recent examinations of post-fire regeneration in subalpine vegetation, including peatlands, have occurred at Mount Buffalo (Wahren and Walsh 2000), the Snowy Range (Wahren and Papst 1999, Wahren et al. 1999a, 2001b), and the Bogong High Plains (McDougall 2007) in Victoria, and the Kosciuszko region in New South Wales (Walsh and McDougall 2004). Some of the peatland studies in these cases were in the fortuitous position of having pre-fire floristic data with which to make comparisons and analyses of post-fire regeneration. These studies reveal a high degree of resilience to fire, regardless of severity, but suggest susceptibility to repeated fires. Most perennial species recorded pre-fire are present within two years post-fire (McDougall 2007). Graminoid species recover rapidly and regain, or sometimes exceed, initial cover levels within three or four years (Wahren et al. 1999, Wahren and Walsh 2000). Shrub species take longer but can exceed initial cover abundance by 15 years post-fire (Wahren and Walsh 2000), but more fire sensitive obligate-seeder species generally take more time to recover to pre-fire cover levels. Overall, the vegetation ground cover is typically greater than 90% in long unburnt peatlands and is dramatically reduced to less than 20% in severely burnt areas, but usually approaches pre-fire levels after 15 years (Wahren and Walsh 2000). The recovery of *Sphagnum* appears to depend on fire severity, the stability of the hydrological regime, and rainfall in the immediate post-fire years (Wahren et al. 1999a). Recovery can take decades at higher elevations (Wimbush et al. 1979, McDougall 1989, Wahren and Walsh 2000).

In this thesis, the transects sampled in the Snowy Range and Dargo High Plains regions as part of the study of regional vegetation patterns in peatlands (Chapters 3 and 4), were completed by May 2006, seven months before the extensive ‘Great Divide’ fires. Thus, there was the opportunity to look closely at burning patterns in peatlands, individual species responses to fire, and general post-fire community regeneration. In February 2009, the ‘Black Saturday’ fires burnt the peatland sites used for the Central Highlands section of the regional studies. Although these occurred near the end of the time-frame for this thesis, some post-fire research was undertaken at these sites also. In fire-affected areas the main research questions were:

- Which of the peatland communities and vegetation formations identified in Chapters 3 and 4 appear to burn most severely?
- What are the environmental, compositional and structural factors that influence these burning patterns?
- What are the predominant methods of regeneration of some of the important species in these peatlands? Do these vary according to microsite characteristics (hummock, hollow, sapric peat, fibric peat)?
- Which species and plant life-forms or functional groups respond rapidly and are better adapted to more frequent fire?
- Is there an association between fire-sensitive species and communities that didn’t burn or burnt less? Conversely, is there an association between the more ‘robust’ species that respond rapidly after fire, and more fire-affected or severely burnt communities?

6.2 METHODS

6.2.1 Study sites

All 45 sites used in the floristic and regional studies (Chapters 3 and 4) were used to varying degrees in this chapter. Peatland sites affected by the 2006 and 2009 fires were used for the studies of burning patterns, post-fire regeneration and recruitment niche. Additional data were collected from several new sites burnt in December 2006, for some of the examinations of recruitment niche.

Background on the 2006 fires

Winter-Spring rainfall across eastern and southern Australia was well below average in 2006 (National Climate Centre 2006b), largely due to the influence of the El Nino-Southern Oscillation (Drosdowsky and Williams 1991). The ‘Great Divide’ fires began on December 1st 2006, triggered by electrical storms and ‘dry lightning’. More than 50 individual small fires were started by lightning in remote inaccessible parts of Victoria’s Eastern Highlands. The areas affected were mostly south and west of those burnt in the 2003 fires, within an area bounded by Whitfield in the north-west, Walhalla in the south-west, Bruthen in the south-east, and Mt Hotham in the north-east (see Chapter 2, Figure 2.7). The smaller fires eventually amalgamated over the ensuing 10 weeks and affected approximately 1,100,000 ha of mountainous forest country, including treeless montane, subalpine and alpine areas (Tolsma and Shannon 2007). There were also several other fires during this period as a result of arson. One of these, near Mt Beauty, eventually burnt south and along the western and southern edges of the Bogong High Plains, affecting some areas for the second time in four years.

Eighteen of the 23 transects established in peatlands on the Dargo High Plains, and in the Snowy Range-Moroka region, as part of the examinations of regional peatland vegetation patterns (Chapters 3 and 4) were affected to varying degrees. Fire conditions varied throughout the duration of this period, but generally the fires moved at low to moderate intensity. When conditions deteriorated on ‘blow-up’ days (low humidity, high wind, high air temperature), the fire intensity increased and the area affected greatly expanded. Such is the nature of mosaic burning in large landscape-scale fires, that five of the original 23 transects were in wetlands that were entirely unaffected by fire. Adjoining forest, heathland, and grassland vegetation at these sites were also unburnt.

The peatland transects in fire-affected areas were relocated, remarked and post-fire data collected in April 2007, four months after the fires. Only the 18 transects that were either directly fire-affected, or had neighbouring land and adjoining non-wetland vegetation burnt in the fires, were eligible for inclusion in these analyses. In essence, fire had to have been present in the surrounding landscape and therefore to have had the potential to spread to peatland vegetation.

Background to the 2009 fires in the Central Highlands

Thirteen transects were completed in peatland sites in the Central Highlands region between 2006 and 2008. These were analysed in Chapters 3 and 4 as part of the examinations of regional peatland vegetation patterns. On February 7th 2009, these sites were burnt in the ‘Black Saturday’ bushfires. A fire in the Murrindindi Valley, approximately 25 km north-west of Marysville, moved rapidly south-east under extreme fire conditions and then north-east after a wind change, causing large losses of life and property (see Chapter 2, Figure 2.7). Large areas of foothill, open, and tall open forest were also affected by these fires. Montane and subalpine treeless vegetation was also affected by these fires. All 13 of the transects established in peatlands prior to the fires were affected, including those at Lake Mountain, Mount Bullfight, and on the Blue Range. In relation to the research and ‘time-line’ of this thesis, there was insufficient time to fully incorporate post-fire studies of peatlands. However, some preliminary data and observations are included in this chapter. These are mostly early post-fire recovery trends and relevant observations to supplement the more extensive analyses of the peatland sites burnt in December 2006. Post-fire data from six of the original 13 transects were collected in April 2010, fourteen months after the February 2009 fires.

Earlier fires, in particular 2003

The extensive ‘alpine’ fires of January 2003, were similarly started by ‘dry lightning’ storms after a period of ‘El Nino’ induced drought. Eighty-seven fires were started by lightning strikes on the inland slopes of the Great Divide across the Australian Capital Territory, southern New South Wales, and the most north-eastern parts of Victoria (Esplin et al. 2003). Two of the five regions outlined and examined in Chapters 3 and 4 were affected: the Bogong region, and the Dargo High Plains region (see Chapter 2, Figure 2.7). These fires pre-date this study but were an inescapable and important influence on the vegetation patterns at the time of surveying (2006-2008). Indeed, some of the data collected in the regional studies were collected from sites burnt four years previously. Some observations and informal data from these areas are included in this chapter.

6.2.2 Analysis of burning patterns in wetlands after the December 2006 fires

Data collection

The fresh data collected from 17 of the original eighteen transects were used for the studies of burning patterns. One of the eighteen eligible transects was not resurveyed because of post-fire access difficulties. Fourteen transects were in the Snowy Range-Moroka area and three on the Dargo High Plains. Ten of the 17 transects were in the subalpine elevation zone (1300-1650 m), and seven were from montane areas (1000-1300 m).

The initial pre-fire transects were 30 m long and consisted of 60 contiguous 0.25 m^2 quadrats. Both floristic cover abundance data (Braun/ Blanquet) and frequency of occurrence data were collected for all vascular plant species and common bryophytes (*Sphagnum* spp.). The suite of environmental and structural data measurements made initially in 2006 included peat depth, slope, aspect, topographic position, shrub height, life-form group cover, and the type and proximity of the neighbouring non-wetland plant communities. More detail on the collection and classification of these data is available in the methods section in Chapter 3.

Post-fire data collected in April 2007

The initial transects were relocated and resurveyed in April 2007. The original transects had been marked with wooden stakes (0.40 m); in most cases these were relatively easily relocated and remarked with the aid of original GPS readings and photographs taken at the time of the initial survey. A general classification was made of the fire severity in the surrounding landscape and adjacent non-wetland vegetation at each site (within 100 m of peatland boundary). This was done to aid the interpretation of the fire patterns within peatland boundaries and for comparisons between sites. A four-category scale of fire severity was used for this exercise, ranging from low (class 1) to high (class 4) (Table 6.1). Data collected along each transect on a per quadrat basis, included an estimate of the percentage area fire-affected in each quadrat. A separate five-category fire damage scheme was employed for assessing fire severity within peatlands. This was determined for each individual quadrat from the degree of damage to *Sphagnum* and woody vegetation (Table 6.2). The amount of burnt or scorched *Sphagnum*, and the total cover of live vegetation, was also estimated in each quadrat. Thus, mean figures could be calculated for each of these attributes on a per quadrat and transect basis.

The data generated by resurveying the initial transects were then compared with the initial data to examine the relationships between the patterns of burning and the pre-fire abundance of various plant species, life-form groups and functional groups. The same eleven plant functional groups adopted in Chapters 3 and 4 were used in fire pattern analyses (see Chapter 3 methods). Of particular interest are the *Sphagnum* spp., ericaceous shrubs, and myrtaceous shrubs groups. Relationships between the burning

Table 6.1: Estimations of fire severity in the vegetation surrounding peatland areas. These appraisals apply to the non-wetland vegetation within 100-150 m of peatland boundaries.

Fire severity	**Category definitions and characteristics**
(1) Low	Patchy ground fire, tree canopy intact. Less than 50% of the surrounding ground layer vegetation burnt.
(2) Low to moderate	All ground layer vegetation burnt (80-100%). Tree canopy intact (> 90%).
(3) Moderate	Ground layer burnt. Some of the tree canopy also removed (< 50%).
(4) High	Ground layer burnt. High proportion of the tree canopy also removed (50-100%).

Table 6.2: Estimations of fire severity in individual peatland quadrats.

Fire severity	**Category definitions and characteristics**
(1) Low	Scorching to shrub stems and *Sphagnum* surface if present, some scorched shrub leaves still retained and species identifiable. Some *Sphagnum* recovery at four months post-fire if present in quadrat pre-fire.
(2) Low to moderate	Shrub stems burnt, leaves consumed, burnt shrub stem tips generally less than 5 mm diameter. Some deeper burning to *Sphagnum* hummocks if present in quadrat pre-fire.
(3) Moderate	Shrub stems burnt, many shrub stem tip diameters greater than 5 mm, a greater proportion of deep burning and scorching of *Sphagnum* hummocks if present in quadrat pre-fire.
(4) Moderate to high	Shrub stem tips generally greater than 5 mm, many more than 10 mm diameter. *Sphagnum* severely burnt and 'cooked' if present pre-fire.
(5) High	Deep burning to *Empodisma minus* basal stems. Some sapric peat exposure and burning. Severe burning of shrub stems. Burnt stem tip diameters in excess of 10 mm common.

patterns and other structural attributes, such as total pre-fire shrub cover and pre-fire shrub height, were also examined, as were those between burning patterns and the original environmental factors. The data from the original 17 transects was compared using NMDS ordination, as in earlier chapters. More emphasis was placed on the pre-fire cover data than the pre-fire frequency data, because this was deemed to be most relevant to fire patterns via its closer association with vegetation structure and above-ground biomass. The trend directions of environmental, structural and species variables significantly correlated with the resultant configurations were plotted, together with the post-fire condition assessment variables (% burnt, severity).

The 17 transects encompassed the two formations and four peatland community types examined in the Snowy Range-Dargo High Plains region in Chapter 3. The formations are:

- Bog, which includes Subalpine raised bog, and Montane valley bog transects.
- Wet Heath, which is comprised of Tall wet heath, and Myrtaceous wet heath transects.

Comparisons are made at both the formation and community type level. Differences between the pre-fire mean environmental and structural attributes of the two formation types were tested for significance using the non-parametric Mann-Whitney test, as were mean values for some of the post-fire measurements. Differences were tested at the formation type level only because of the relatively low number of replicates at the community type level. Nevertheless, tables giving mean attribute figures for each of the four community types are also displayed and discussed.

6.2.3 Post-fire regeneration patterns after the December 2006 fires

The quadrats and transects burnt in the 2006 fires also provided the opportunity to look at early post-fire regeneration trends and patterns. When transects were resurveyed at four months post-fire (April 2007), the cover abundance and regeneration mode (seed, resprout, or both) of all vascular species were noted on a quadrat by quadrat basis. Separate cover estimates were made where a species was present in a quadrat as both unburnt pre-existing vegetation and early regeneration. The cover abundance of *Sphagnum*, total live vegetation, life-form types, and functional group types were also estimated in each quadrat, as were structural measurements such as shrub height. Thus, the mean abundance and frequency figures for each attribute for each transect could then be calculated as in the original survey.

Post-fire floristic data were collected again at 28 months post-fire (April 2009). Additional observations made at this stage included the presence of evidence of flowering. Particular emphasis was placed upon the common shrub species. The time taken to reach reproductive maturity, or ‘secondary juvenile period’, is a good indicator of post-fire recovery speed and therefore, the longer-term persistence prospects.

Combined analyses of the three data sets (2006, 2007, and 2009) made it possible to compare the recovery modes and speeds of various species, functional groups, and life-form groups, as well as trends in overall vegetation cover and species richness over time. These were then analysed relative to initial pre-fire structure, cover and environmental factors (2006 pre-fire data) and the degree of fire impact on each transect. The speed of recovery of severely burnt and lightly burnt transects could then be compared, as well as recovery rates on a per formation and community type basis.

Data analyses

Non-metric multidimensional scaling (NMDS) ordination techniques were used as in the earlier chapters. The original transect data were included with the data collected for each transect at 4 and 28 months post-fire. The samples were grouped and compared in two ways, firstly, by time relative to the December 2006 fires (3 groups) and secondly, by formation type and time relative to the fires (6 groups). The PRIMER software package (Plymouth Routines in Multivariate Ecological Research 6.1.13., 2009) was again used. In most cases three dimensional solution graphs were preferred unless the final Kruskal stress index was less than 0.10 for the two dimensional solution. The ANOSIM procedure (PRIMER software package) was used to test the significance of differences between groups.

The ‘recovery rate’ of each individual transect was determined by comparing the data at each sampling (4 and 28 months post-fire) with the initial data using the Bray-Curtis similarity indices generated for the NMDS ordinations. These figures were then grouped to compare mean similarity of each community type at 4 and 28 months post-fire, to its original composition and structure, thus generating a comparative estimate of recovery rate. This is a useful method of examining the post-fire trends. It can provide a comparative measure of the initial change for each transect as a consequence of the fire, and the rate of return to initial composition and structure, or otherwise.

Recovery trends for each vegetation functional group and life-form group were also determined by adding the cover values of all group members along each transect. In the initial floristic analyses (Chapters 3 and 4), the species pool was divided into 11 functional groups based on similarities in life-form and functional attributes. The same eleven groups have been used in these analyses and the descriptions of these can be found in the methods section of Chapter 3.

6.2.4 Regeneration niche: comparison of modes of regeneration in two different microsite types after the December 2006 fires

A separate, smaller study was conducted in burnt peatlands on the Snowy Range in December 2006 to examine the regeneration niche of common peatland species. The aim was to examine differences between species in terms of preferred regeneration niche and modes of regeneration. Also investigated was whether some species recruit via different modes depending on niche or microsite. Two common microsite types were identified in burnt peatland sites. In the broad sense these correspond to *hummocks* and *hollows* in unburnt peatlands. However, in unburnt peatlands it is often difficult to consistently delineate between the two because of high and continuous *Sphagnum* cover. For the purposes of this post-fire examination, hummocks were defined as ‘islands’ of burnt or scorched *Sphagnum*, with variable cover of live moss. Hollows were defined as the spaces between these ‘islands’, now devoid of recognisable *Sphagnum* litter (live *Sphagnum* possibly not present pre-fire). Hence, the surface material in damaged hummocks usually consisted of coarse fibric dead *Sphagnum* moss, compared with soil surfaces of damp sapric or hemic peat in hollows (plant remains more decomposed and less recognisable). There is generally a height difference between the surfaces of the two microsites of approximately 20-50 cm.

Regeneration mode data were collected in subalpine areas from a total of 27 quadrats each in hummocks and hollows. These were randomly placed in three different subalpine sites in the Snowy Range area. Fifteen quadrats were sampled in each microsite type at a montane site in the nearby Moroka Valley. Thus, a total of 84 quadrats (0.25 m^2) were sampled, 42 in each microsite type. In every quadrat, vascular plant species were identified and mode of regeneration recorded. Where a species was both recruiting from seed and regenerating vegetatively in the same quadrat, this was noted. Each quadrat was divided into twenty-five 0.01 m^2 plots (0.1 m x 0.1 m) to assist the seedling counts. These methods generated both raw counts of seedling numbers and frequency of occurrence for each microsite type. The frequency of vegetative regeneration for each species was also determined for each microsite type. The survey was conducted in February and March 2008, approximately 14 months post-fire.

6.2.5 Burning patterns and early trends in post-fire recovery of peatland sites burnt in the February 2009 fires

All 13 transects sampled in the Central Highlands region as part of the regional patterns study (Chapter 3) were burnt in the ‘Black Saturday’ fires of February 2009. Six of these were relocated and data collected in March and April 2010, approximately 14 months after the fires. The methods employed, and the data collected from these quadrats and transects, were essentially the same as for the Snowy Range-Dargo High Plains peatlands burnt in December 2006. Three of the freshly sampled subalpine transects were originally classified as bog (Western subalpine raised bog), the remaining subalpine transect was categorised as wet heath (Western subalpine wet heath). Both montane transects were classified as wet heath based on the 2006 survey (Western montane wet heath). The six resurveyed transects were not analysed by formation type, but were separated and analysed according to altitude. Data from the four subalpine transects were grouped, tabulated and analysed separately from the montane transects data. Detailed statistical analyses of this data were not undertaken. Instead, simple comparisons are made of the pre- and post-fire data. Comparisons are also made with the December 2006 fires in relation to fire patterns within and surrounding peatland areas, and early regeneration trends.

6.3 RESULTS

6.3.1 Fire patterns in peatlands and influencing factors

General

The severity of burning in the adjacent non-wetland plant communities at all sites was uniform, with one or two exceptions. In most cases the fires consumed the ground layer vegetation (grasses, shrubs, small trees), but there was minimal damage to the tree canopy (Table 6.3). The exceptions were the Dairy Farm Flat, Snowy Range West, and Moroka Hut sites. More of the adjacent open forest canopy was burnt at Dairy Farm Flat than any of the other study sites. The forest canopy adjacent to the southern margin of the Snowy Range West site (north facing slope) also sustained more canopy damage (near transect no. 2). The Moroka Hut peatland was at the opposite end of the spectrum and had areas of adjacent non-wetland vegetation that escaped fire. Fire impacts at this site were restricted to the understorey of adjacent open forest on the southern and eastern approaches to the peatland. The transect at this study site was unaffected by fire and less than 10% of the wetland area was burnt.

There were six transects of the 17 that were entirely unaffected by fire, despite extensive ground-layer fire to the margins of the peatlands in question (Table 6.3). The remaining 11 transects were affected over between 32% and 100% of their area. The mean fire severity for each transect, estimated *a posteriori* from the extent of damage to shrub stems and *Sphagnum* carpet, showed a strong correlation with the extent of burning. On the fire damage scale adopted for this study (classes 1 to 5), the means ranged from 0 in unaffected transects, to 2.8 in the more severely affected transects. Most transects had at least some quadrats rated as fire damage class 4 or 5. Most also had at least some unaffected quadrats.

The 17 transects span the entire spectrum of peatland vegetation, from more shrub-dominated wet heath in marginal areas, to more *Sphagnum* and sedge-dominated ‘bog’

Table 6.3: List of the transects eligible for analysis in this study. Included in the information is the peatland community type, surrounding vegetation type, and surrounding landscape fire severity index. The pre-fire *Sphagnum* cover, percent transect area fire affected, and mean fire severity within the transect area are also given. Community type codes are: MVB = Montane valley bog, MWH = Myrtaceous wet heath, SRB = Subalpine raised bog, TWH = Tall wet heath.

Transect	**Peatland community**	**Surrounding vegetation type and its fire severity index**		***Sphagnum* % cover**	**% fire affected**	**Mean severity**
Bennison Plain 1	MVB	woodland, grassland, heath	2	87	0	0.0
Bennison Plain 2	MVB	woodland, grassland, heath	2	46	0	0.0
Dairy Farm Flat 1	MVB	shrubby open forest	2 or 3	41	72	1.6
Morgans Gully 1	MVB	open forest, heath	2	78	0	0.0
Morgans Gully 2	MVB	shrubby open forest	2	64	32	0.6
Moroka Hut	MVB	shrubby open forest	1 or 2	41	0	0.0
Cave Gate Creek 2	MWH	woodland, grassland, heath	2	1	100	2.8
Dairy Farm Flat 2	MWH	shrubby open forest	2 or 3	31	95	2.4
Cave Gate Creek 1	SRB	grassland, heath	2	82	46	0.7
Lankeys Plain Excl. Plot	SRB	woodland, grassland, heath	2	76	0	0.0
Omeo Plain 1	SRB	open forest, grassland, heath	2	56	45	1.7
Snowy Range South	SRB	woodland, grassland, heath	2	94	0	0.0
Snowy Range West 1	SRB	woodland, heath	2	74	40	1.2
Omeo Plain 2	TWH	open forest, grassland, heath	2	28	77	2.9
Piemans Creek 1	TWH	grassland, heath	2	31	95	2.1
Piemans Creek 2	TWH	woodland, grassland, heath	2	30	93	2.3
Snowy Range West 2	TWH	woodland, heath	2	24	76	2.0

areas. Accordingly, the variation in the pre-fire *Sphagnum* cover reflects this spectrum. The Cave Gate Creek transect no. 2 was classified as community type ‘Myrtaceous wet heath’ and had the lowest pre-fire *Sphagnum* cover, less than 1% in total. In contrast, the ‘Subalpine raised bog’ transect at Snowy Range South had a pre-fire *Sphagnum* cover of nearly 94%. These two transects illustrate the apparent relationship between *Sphagnum* cover and degree of fire incursion; the Cave Gate Creek transect no. 2 was 100% affected in the fires, but the Snowy Range South transect was entirely unaffected (Figures 6.1-6.9).

Comparisons by formation type: bog versus wet heath

Eleven of the 17 transects were in bog communities and five of these were directly affected by fire (Table 6.4). All six wet heath transects were directly fire-affected. Eighty-two percent of wet heath quadrats were 100% fire-affected. In contrast, only 5%

Figure 6.1: Cave Gate Creek peatland viewed from the slopes to the north-east in April 2006. The peatland is dissected by the main east flowing creek. The gentle slopes along the valley floor adjacent to the creek are dominated by Subalpine raised bog vegetation (transect 1). Myrtaceous wet heath dominates the steep north facing slope on the southern side of the creek (transect 2).

Figure 6.2: The Cave Gate Creek site viewed from a similar position in April 2007, four months post-fire. Myrtaceous wet heath vegetation on the steeper slopes was entirely burnt (transect 2); the Subalpine raised bog areas near the valley floor were less affected by fire and contained entirely unburnt areas (transect 1).

Figure 6.3: Myrtaceous wet heath at Cave Gate Creek in April 2006.

Figure 6.4: Myrtaceous wet heath at Cave Gate Creek in April 2007. The less burnt areas in the foreground on more gently sloping ground are predominantly Subalpine raised bog.

Figure 6.5: The Snowy Range South peatland in March 2007, three months post-fire. The surrounding ground layer vegetation, comprising grassland and open heath was entirely burnt in the fires. The tree canopy in woodland areas was mostly unburnt or only scorched. The central areas of this peatland including the transcect area were not directly affected. The margins of the peatland carried Tall wet heath prior to the fires. The vegetation in these areas was mostly consumed (photo courtesy of Arn Tolsma).

Figure 6.6: The Snowy Range West peatland in March 2007, three months post-fire. The Subalpine raised bog vegetation in the left fore and middle ground was unburnt (transect 1). Areas of Tall wet heath in the middle and background (adjacent to woodland) were mostly burnt (transect 2).

Figure 6.7: Cave Gate Creek transect no. 1 looking east in April 2007. The transect sections in the foreground were burnt and scorched in December 2006. The far end of the transect was unburnt. The regeneration in neighbouring grassland and woodland is visible in the background.

Figure 6.8: Snowy Range West transect no. 1 looking north in April 2007. Most of this transect was unburnt. The understorey vegetation in the adjacent woodland was removed by the fires.

Figure 6.9: Snowy Range West transect no. 1 looking west along the northern boundary of the peatland in April 2007. The fire stopped at the boundary of this section of the peatland.

Table 6.4: Summary of the transects and quadrats affected by the fires in December 2006. The formation types are compared. The quadrat numbers and percentages in brackets are the figures for Bog if the six totally unburnt transects are removed from the analysis.

	Formation type		
Variable or attribute	**Wet heath**	**Bog**	
Total number of transects	6	11	
Number of transects directly affected	6	5	
Transects affected as % proportion of total	100%	45.4%	
Total number of quadrats	360	660	(300)
Number of quadrats 100% fire-affected	296	108	
% proportion of quadrats 100% fire-affected	82.2%	16.4%	(36%)
Number of quadrats partially fire-affected	46	89	
% proportion of quadrats partially fire-affected	12.8%	13.5%	(29.7%)
Number of quadrats unburnt	18	463	(103)
% proportion of quadrats unburnt	5.0%	70.2%	(34.3%)

were unburnt. Sixteen percent of bog quadrats were 100% fire-affected and 70% were unburnt. If we exclude the unburnt bog transects from analyses, the proportions are still much less than in wet heath transects. Along the five fire-affected bog transects 36% of quadrats were entirely affected and 34% were unaffected.

The mean pre-fire attribute values for both formation types were generally consistent with those outlined for the relevant bog and wet heath community types in earlier analyses (Chapters 3 and 4), despite the smaller and more localised subsample (Table 6.5). In summary of these results from Chapter 3, bog areas tend to have deeper peat, less shrub cover, lower shrub stature, and less loose litter cover than wet heath areas. They also have higher *Sphagnum* cover, lower myrtaceous shrub cover, and occur on gentler slopes and cooler aspects.

In this case, the differences in pre-fire *Sphagnum* percent cover were considerable. The mean cover in bog transects was 67%, compared with 24% in wet heath plots. The fire incursion and severity measurements are also strongly contrasting; mean percent area of transect fire-affected was 21% in bog plots, compared with 89% in wet heath plots. Mean fire severity across the bog transects was estimated to be 0.5, compared with 2.4 in the

Table 6.5: Environmental and structural factors data for the 17 transects affected by fire in December 2006. All the data contributing to these figures were collected in April and May 2006, except for the post-fire attributes (bold type) which were collected in April 2007, four months after the fires. The plots (= transects) have been grouped by formation type; bog (Subalpine raised bog, Montane valley bog), and wet heath (Tall wet heath, Myrtaceous wet heath). The differences between the means were tested for significance using the Mann-Whitney test. Bog: n = 11, Wet heath: n = 6.

	Formation type						
	Bog			**Wet heath**			
Pre-fire transect attributes	**Mean**	**(S.E)**	**Range**	**Mean**	**(S.E)**	**Range**	**P-value**
Altitude (m)	**1310**	± **71.5**	(1000-1580)	**1430**	**± 61.5**	(1150 - 1580)	0.364
% slope	**4.7**	± **0.7**	(3.0 - 10.0)	**7.9**	**± 2.8**	(1.0 - 20.0)	0.411
Peat depth (cm)	**106.0**	± **142.0**	(41.5 - 193.3)	**74.0**	**± 19.6**	(26.4 - 152.9)	0.132
% peat points > 1 m deep	**46.4**	± **12.2**	(0.0 - 100.0)	**25.0**	**± 13.1**	(0.0 - 70.0)	0.202
% peat points < 0.5 m deep	**8.2**	± **5.5**	(0 - 50)	**43.3**	**± 16.1**	(0 - 90)	**0.034***
Shrub cover %	**28.8**	± **5.1**	(5.1 - 57.4)	**40.8**	**± 6.7**	(25.5 - 63.2)	0.070
Mean ht of tallest shrubs (cm)	**42.4**	± **4.1**	(27.8 - 70.2)	**51.9**	**± 7.7**	(36.9 - 88.9)	0.228
Litter cover %	**5.6**	± **1.2**	(0.9 - 12.6)	**11.6**	**± 2.1**	(4.9 - 16.6)	**0.012***
Ericaceous shrubs % cover	**22.6**	± **4.4**	(5.1 - 45.3)	**26.7**	**± 7.1**	(7.3 - 56.1)	0.546
Myrtaceous shrubs % cover	**6.5**	± **1.5**	(0.0 - 18.1)	**16.3**	**± 2.4**	(5.4 - 20.4)	**0.016***
Other shrubs % cover	**0.0**	± **0.0**	(0.0 - 0.3)	**0.9**	**± 0.8**	(0.0 - 4.7)	0.055
Restiads % cover	**22.1**	± **4.4**	(5.4 - 55.6)	**12.7**	**± 5.3**	(0.1 - 30.3)	0.269
Herbs % cover	**0.6**	± **0.1**	(0.1 - 1.8)	**1.2**	**± 0.6**	(0.1 - 4.0)	0.580
Sphagnum spp. % cover	**67.1**	± **5.6**	(40.9 - 93.9)	**24.1**	**± 4.8**	(0.7 - 30.7)	**0.001***
Post-fire measurements							
% area fire affected	**21.2**	± **7.9**	(0.0 - 72.1)	**89.2**	**± 4.2**	(75.8 - 100.0)	**0.001***
Mean fire intensity	**0.5**	± **0.2**	(0.0 - 1.7)	**2.4**	**± 0.1**	(2.0 - 2.9)	**0.001***

wet heath transects (scale 0-5). These differences were all highly significant (p = 0.001, Mann-Whitney test, Table 6.5). The cover of litter and myrtaceous shrubs were significantly higher in the six wet heath plots (p = 0.012, p = 0.016, respectively). Peat was significantly shallower in the wet heath plots as indicated by the higher proportion of transect points with peat depth less than 0.5 m (p = 0.034). The percent cover values of ‘other shrubs’, and total shrub cover, were also higher in wet heath transects, although this was not statistically significant. The non-significant result is possibly an artefact of the relatively small sample size (n=17).

Comparisons by community type

The transects in the two wet heath community types, Myrtaceous wet heath and Tall wet heath, were 98% and 85% burnt or scorched respectively (Table 6.6, Appendices Table A6.1). The two bog community types were less affected (< 25%), particularly Montane valley bog. The pre-fire cover of myrtaceous shrubs was relatively low in both bog community types (< 10%). In contrast, this figure was in the 14-20% range in the two wet heath communities (Table 6.6). The pre-fire cover of ericaceous shrubs although also high in Tall wet heath (34%), was much less in Myrtaceous wet heath (11%), and was also high in Subalpine raised bog (36%), which was one of the two less fire-affected peatland communities.

Mean peat depths were generally similar in three of the community types (~ 70 cm), but much greater in Montane valley bog (Table 6.6). Overall shrub cover and slope gradients were also less in Montane valley bog transects than those of the other three communities. Both are factors that are likely to minimise fire incursion. Distances to woodland were generally similar amongst community types, with the exception of Myrtaceous wet heath, which tended to occur in closer proximity to neighbouring wooded vegetation. This community type was also consistently on drier aspects, steeper slopes, in drier topographic positions, and had a taller shrub canopy. These are all factors likely to predispose the community to burning, and would appear to correlate with the fire impact measurements (e.g. 98% fire-affected).

The cover of restionaceous species was higher in both of the lower altitude community types (Montane valley bog, Myrtaceous wet heath) regardless of formation type. The pre-fire cover abundance of these species appeared to have no relationship with the patterns of burning in peatland vegetation (Table 6.6).

Table 6.6: Summary of environmental factors and pre-fire attributes for the 17 fire-affected transects by community type. The data includes the mean, standard error of the mean, and range of values for each attribute. These data were collected in April-May 2006 (7 months before the fires), except the post-fire measurements which were collected in April 2007 (4 months after).

	Community Type											
	Montane valley bog			**Subalpine raised bog**			**Myrtaceous wet heath**			**Tall wet heath**		
Pre-fire transect attributes	**Mean**	**(S.E.)**	**Range**	**Mean**	**(S.E.)**	**Range**	**Mean**	**(S.E.)**	**Range**	**Mean**	**(S.E.)**	**Range**
Altitude (m)	**1125.0**	**(± 54.0)**	1000 - 1290	**1532.0**	**(± 33.80)**	1400 - 1580	**1285.0**	**(± 135.0)**	1150 - 1420	**1502.5**	**(± 34.2)**	1440 - 1580
Peat depth (cm)	**131.8**	**(± 18.5)**	88.2 - 193.3	**75.1**	**(± 12.2)**	41.5 - 114.2	**68.1**	**(± 41.7)**	26.4 - 109.7	**77.0**	**(± 25.8)**	37.6 - 152.9
% slope	**3.7**	**(± 0.5)**	3.0 - 6.0	**5.9**	**(± 1.1)**	3.0 - 10.0	**11.5**	**(± 8.5)**	3.0 - 20.0	**6.1**	**(± 2.1)**	1.0 - 11.0
Shrub cover %	**16.1**	**(± 2.5)**	5.1 - 22.2	**44.0**	**(± 5.4)**	24.9 - 57.4	**28.2**	**(± 2.3)**	25.9 - 30.5	**47.1**	**(± 8.5)**	25.5 - 63.2
Mean height tallest shrubs (cm)	**46.6**	**(± 5.7)**	30.3 - 70.2	**37.3**	**(± 5.6)**	27.8 - 59.0	**67.6**	**(± 21.3)**	46.3 - 88.9	**44.0**	**(± 3.4)**	36.9 - 53.3
Litter cover %	**7.2**	**(± 1.5)**	3.7 - 12.6	**3.6**	**(± 1.6)**	0.9 - 9.9	**9.4**	**(± 4.1)**	5.3 - 13.5	**12.7**	**(± 2.6)**	4.9 - 16.6
Aspect class	**2.7**	**(± 0.2)**	2.0 - 3.0	**2.2**	**(± 0.4)**	1.0 - 3.0	**3.5**	**(± 0.5)**	3.0 - 4.0	**2.8**	**(± 0.6)**	1.0 - 4.0
Topographic position class	**1.3**	**(± 0.2)**	1.0 - 2.0	**1.8**	**(± 0.2)**	1.0 - 2.0	**2.5**	**(± 0.5)**	2.0 - 3.0	**1.5**	**(± 0.3)**	1.0 - 2.0
Distance to woodland (m)	**53.3**	**(± 10.5)**	30.0 - 100.0	**56.0**	**(± 16.9)**	20.0 - 120.0	**30.0**	**(± 10.0)**	20.0 - 40.0	**65.0**	**(± 13.2)**	40.0 - 100.0
Ericaceous shrubs (% cover)	**11.6**	**(± 2.3)**	5.1 - 20.3	**35.9**	**(± 4.4)**	19.5 - 45.3	**11.8**	**(± 4.5)**	7.3 - 16.3	**34.1**	**(± 8.3)**	20.4 - 56.1
Myrtaceous shrubs (% cover)	**4.7**	**(± 1.9)**	0.0 - 9.9	**8.7**	**(± 2.3)**	5.7 - 8.1	**20.3**	**(± 0.1)**	20.2 - 20.4	**14.3**	**(± 3.3)**	5.4 - 19.9
Restiads (% cover)	**31.1**	**(± 5.3)**	21.9 - 55.6	**11.3**	**(± 3.5)**	5.4 - 24.1	**28.9**	**(± 1.3)**	27.6 - 30.3	**4.6**	**(± 1.7)**	0.1 - 7.9
Sphagnum spp. (% cover)	**59.5**	**(± 8.1)**	40.9 - 86.8	**76.3**	**(± 6.2)**	55.7 - 93.9	**15.7**	**(± 15.0)**	0.7 - 30.7	**28.3**	**(± 1.6)**	23.8 - 30.7
Post-fire measurements												
% fire affected	**17.3**	**(±12.1)**	0.0 - 72.1	**25.9**	**(± 10.6)**	0.0 - 45.7	**97.6**	**(± 2.4)**	95.2 - 100.0	**85.1**	**(± 5.0)**	75.8 - 94.7
Mean burning intensity	**0.4**	**(± 0.3)**	0.0 - 1.6	**0.7**	**(± 0.3)**	0.0 - 1.7	**2.6**	**(± 0.2)**	2.4 - 2.8	**2.3**	**(± 0.2)**	2.0 - 2.9

The three dimensional ordination of the pre-fire cover data and correlated variables

The relationship between the pre-fire floristics, environmental attributes, fire incursion and fire severity were further examined using NMDS ordination and Spearman rank correlation (Table 6.7, Figure 6.10). The lowest stress three dimensional ordination configuration based on pre-fire cover data from the 17 transects (Kruskal stress = 0.07) is similar to that derived from the full 23-transect data set in Chapter 3 (see Figures 3.22, 3.24). Percent area fire-affected and fire severity indices are negatively correlated with axis 2. These increase towards the wet heath transects in the lower half of the ordination space. The pre-fire attributes correlated with these include shrub height and myrtaceous shrub cover. Pre-fire *Sphagnum* cover has a strong correlation in the opposite direction, as does peat depth to a lesser extent.

The cover of ericaceous shrubs and restiads trend in opposite directions along axis 1, and are associated with separation of the montane and subalpine plots, as identified in Chapter 3. It is important to note here that these are not associated with the gradient in degree of fire incursion and fire severity.

Table 6.7: Data derived from the 17 sites affected by fire in 2006-07. Factors, structural attributes and plant functional groups showing significant correlation with the three dimensional **pre-fire cover data ordination** configuration. Significance levels: * = < 0.05, ** = < 0.01, *** = < 0.001.

Factor or functional group	MDS1	sig. level	MDS2	sig. level	MDS3	sig. level
Ericaceous shrubs	**0.80**	***	-0.39	ns	-0.27	ns
Altitude	**0.60**	**	-0.34	ns	-0.45	ns
Dead *Empodisma*	**-0.66**	**	-0.43	ns	0.36	ns
Restiads	**-0.83**	***	0.38	ns	0.13	ns
Sphagnum spp.	0.33	ns	**0.87**	***	-0.13	ns
% peat points > 1 m deep	-0.29	ns	**0.50**	*	0.46	ns
Peat depth	-0.25	ns	**0.50**	*	0.46	ns
Mean shrub height	-0.36	ns	**-0.54**	*	0.33	ns
% peat points < 0.5 m deep	0.17	ns	**-0.62**	**	-0.43	ns
Shrub cover	**0.59**	*	**-0.63**	**	-0.33	ns
Litter	-0.22	ns	**-0.69**	**	0.11	ns
Myrtaceous shrubs	-0.30	ns	**-0.73**	***	-0.18	ns
% transect fire affected	-0.22	ns	**-0.75**	***	-0.08	ns
Severity of burning	-0.05	ns	**-0.80**	***	-0.10	ns
Other mosses	0.01	ns	-0.34	ns	**-0.50**	*

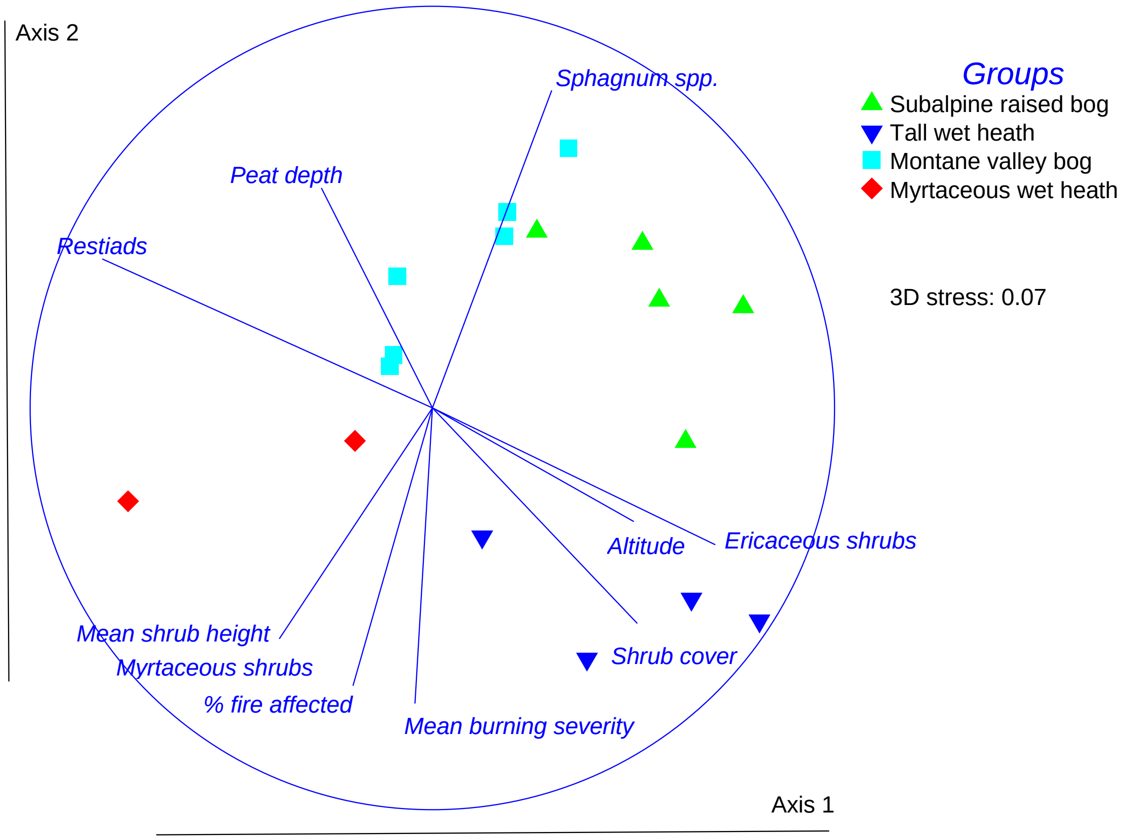


Figure 6.10: Three dimensional ordination graph of the 17 fire-affected transects based on the **pre-fire percent cover data**. The trend directions of correlated environmental and structural variables are indicated.

The relationships of Sphagnum, myrtaceous, and ericaceous shrubs with the extent of burning in peatlands

The relationship between pre-fire *Sphagnum* cover and the degree of fire damage to the transects was examined further and tested using linear regression (Figure 6.11). The influence of the two dominant shrub families on fire patterns was also tested in this manner (Figures 6.12, Appendices figure A6.1).

There was a significant regression of mean area of transect burnt on mean pre-fire *Sphagnum* cover (df = 15, F = 21.8, $R^2 = 0.593$, $p < 0.001$). The regression of mean area of transect burnt on pre-fire myrtaceous shrub cover was also significant (df = 15, F = 14.1, $R^2 = 0.485$, p = 0.002). There was no relationship between the pre-fire ericaceous shrub cover and the area of transects that were fire-affected (df = 15, F = 0.282, R^2 = 0.018, p = 0.603).

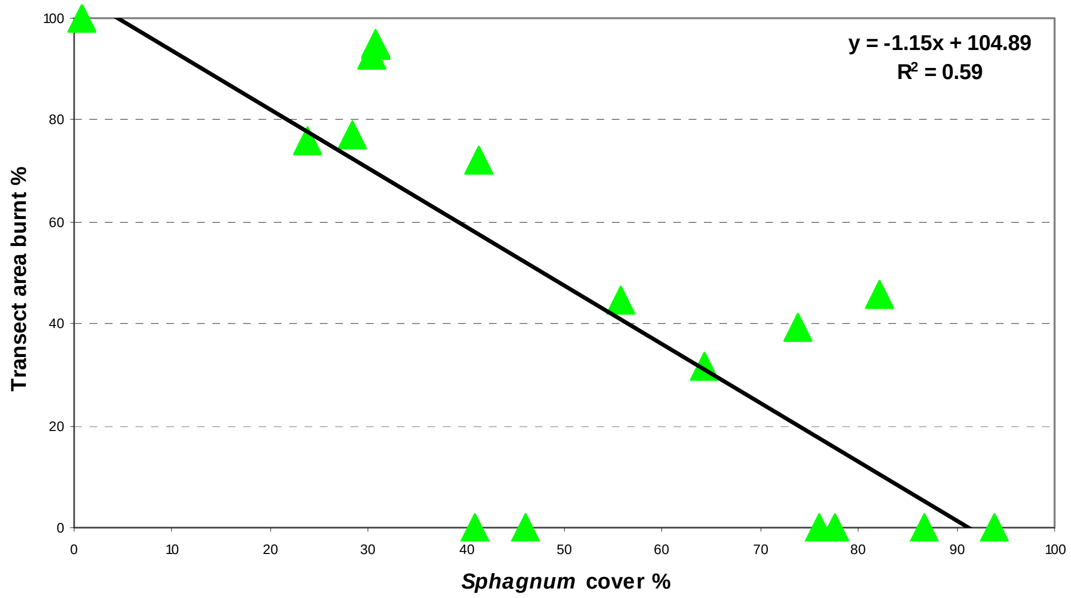


Figure 6.11: The relationship between pre-fire cover of *Sphagnum* and the extent of fire damage to transects in the December 2006 fires. The regression equation and R^2 value are included in the top right corner of the graph.

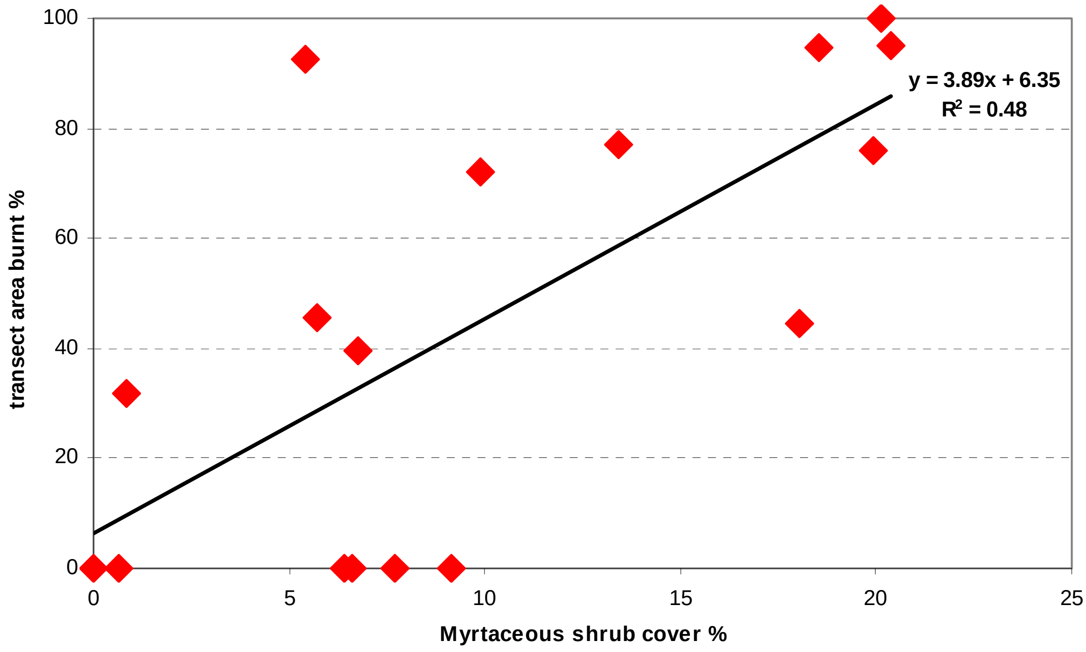


Figure 6.12: The relationship between pre-fire cover of myrtaceous shrub species and the extent of fire damage to transects in the December 2006 fires. The regression equation and R^2 value are included in the top right corner of the graph.

6.3.2 Early trends in post-fire regeneration after the December 2006 fires

Trends in plant life-form and functional groups

Initial vegetation cover in bogs and wet heaths was typically high. In the ten transects directly affected by fire in December 2006, the pre-fire cover was in the vicinity of 90-95%, with the remaining 5-10% mostly comprised of water-bodies (pools, streams), loose litter, and small areas of fixed litter (e.g. dead *Empodisma minus*). Four months post-fire, this figure had been reduced to 30-35% cover of live vegetation, made up mostly of unburnt patches (Figure 6.13). Cover was lower in wet heath transects (~ 20% cover) than in bog transects (~ 55% cover), reflecting differences between the two formations in degree of fire incursion. By 2009, the cover had increased to 70-75%. Again, the mean vegetation cover figures were greater in bog transects (~ 84%) than in wet heath transects (~ 66%).

Shrubs and bryophytes provided the majority of the pre-fire vegetation cover in these peatlands; both life-form groups provided mean cover of approximately 40% each in April 2006. These figures had declined to 9% and 22% respectively when the transects were resampled in April 2007 (Table 6.8). Twenty-eight months after the fire the mean cover for shrubs was approximately 20%, and that provided by bryophytes was 31%. In contrast, the cover of both monocots (graminoids) and herbs increased over the three year period, after an initial decline immediately post-fire. Collectively, the two groups provided approximately 30% cover by 2009, compared with less than 20% cover in April 2006.

Sphagnum species provided almost the entire bryophyte group contribution (Tables 6.8, 6.9). Twenty-eight months post-fire, the mean *Sphagnum* cover in bog transects was 52% compared with 17% in wet heath transects, down from 63% and 24% respectively in 2006. The two dominant shrub families were slower to respond; ericaceous shrubs declined from approximately 28% mean cover in 2006, to about 13% cover in 2009. The change was more dramatic in wet heath, declining from roughly 27% mean cover in

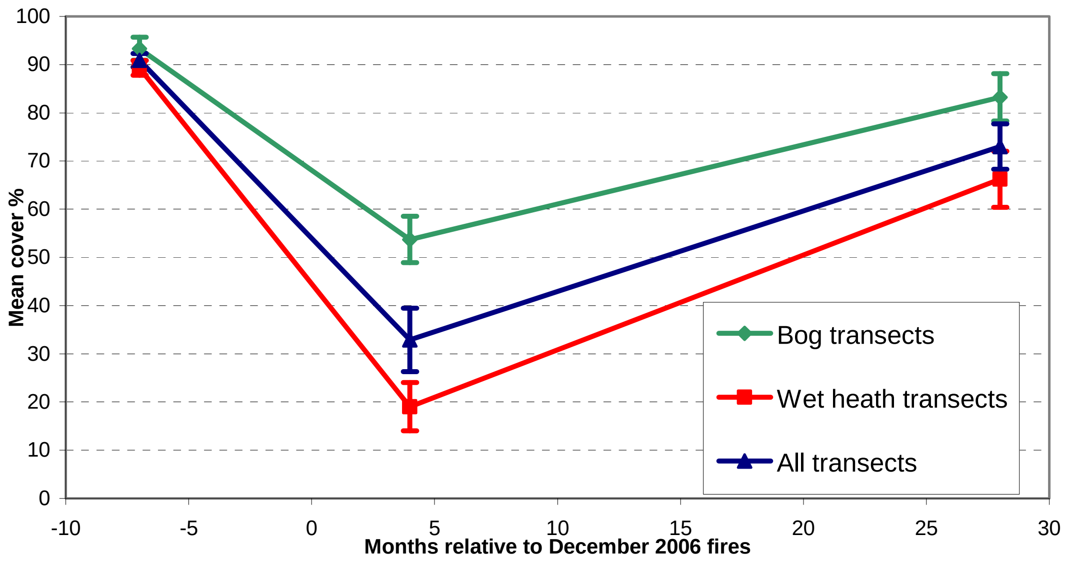


Figure 6.13: Total percent vegetation cover of the directly fire-affected transects at three times relative to the December 2006 fires. Cover in relation to formation type is also indicated (Bog transects, n = 4; Wet heath transects n = 6; All transects, n = 10).

Table 6.8: Changes in total percent cover of the plant functional groups and major life-form groups in the Snowy Range – Dargo High Plains region between April 2006 and April 2009. Data include the mean, standard error, and range for each functional group and life-form. These data are derived from the 10 transects that had some portion of their area affected by fire in December 2006.

	Time of sampling					
	2006		**2007**		**2009**	
Functional group	**Mean (S.E.)**	**Range**	**Mean (S.E.)**	**Range**	**Mean (S.E.)**	**Range**
Ericaceous shrubs	**27.8 (± 5.1)**	7.3 - 56.1	**6.4 (± 2.5)**	0.3 - 23.2	**12.7 (± 3.8)**	3.5 - 41.1
Myrtaceous shrubs	**13.8 (± 2.0)**	5.4 - 20.4	**2.4 (± 0.7)**	0.3 - 8.4	**7.1 (± 1.4)**	3.1 - 16.8
Other shrubs	**0.6 (± 0.5)**	0.0 - 4.7	**<0.1 (±<0.1)**	0.0 - 0.3	**0.3 (± 0.2)**	0.0 - 1.6
Astelia	**0.1 (± 0.1)**	0.0 - 1.0	**0.1 (± 0.1)**	0.0 - 1.2	**0.1 (± 0.1)**	0.0 - 1.5
Carex spp	**2.1 (± 1.2)**	0.04 - 12.52	**2.9 (± 1.1)**	0.1 - 11.1	**5.6 (± 2.1)**	0.1 - 23.1
Restiads	**14.7 (± 4.1)**	0.1 - 35.2	**3.1 (± 1.2)**	0.2 - 12.5	**15.0 (± 4.3)**	4.1 - 44.3
Other sedges	**0.4 (± 0.2)**	0.0 - 2.4	**0.4 (± 0.2)**	0.0 - 2.3	**0.9 (± 0.4)**	0.0 - 4.1
Other monocots	**1.2 (± 0.4)**	0.04 - 4.63	**0.7 (± 0.2)**	0.0 - 2.3	**2.7 (± 0.7)**	0.1 - 7.9
Herbaceous spp.	**1.0 (± 0.4)**	0.1 - 4.0	**1.2 (± 0.3)**	0.03 - 3.8	**5.9 (± 1.7)**	0.1 - 16.1
Sphagnum spp.	**39.7 (± 7.7)**	0.7 - 82.2	**21.9 (± 6.3)**	0.0 - 54.8	**30.7 (± 6.7)**	1.0 - 68.2
Other bryophytes	**0.2 (± 0.2)**	0.0 - 2.1	**<0.1 (±<0.1)**	0.0 - 0.1	**0.4 (± 0.2)**	0.0 - 2.5

	2006		**2007**		**2009**	
Life-form	**Mean (S.E.)**	**Range**	**Mean (S.E.)**	**Range**	**Mean (S.E.)**	**Range**
Total shubs	**42.3 (± 5.5)**	22.7 - 69.5	**8.9 (± 2.9)**	1.7 - 26.8	**20.1 (± 3.7)**	7.9 - 45.3
Total monocots	**18.4 (± 3.9)**	2.6 - 38.1	**7.2 (± 1.6)**	1.1 - 16.9	**24.3 (± 3.7)**	11.7 - 48.1
Total herbs	**1.0 (± 0.4)**	0.1 - 4.0	**1.2 (± 0.4)**	0.04 - 3.8	**5.9 (± 1.7)**	0.1 - 16.1
Total bryophytes	**40.0 (± 7.6)**	2.8 - 82.2	**21.9 (± 6.3)**	0.1 - 54.9	**31.1 (± 6.5)**	3.5 - 68.2

2006, to about 6% cover by 2009. Myrtaceous shrubs were reduced from approximately 14% to about 7% mean cover over the same period. Again, the change was more dramatic in wet heath transects than bog transects. Amongst the ericaceous species, the change in the cover of *Richea continentis* was the most dramatic, declining from 21% to 3% in wet heath transects by 2009, and from 15% to 9% in bog transects (Table 6.9). *Epacris* species cover changed little in bog transects over the three-year period, but declined from 12% to 4% in wet heath transects. The change in the cover of the most common myrtaceous species, *Baeckea gunniana*, was not as dramatic, declining from 10% to 6% in bog transects over the three years, and from 12% to 6% in wet heath transects over the same period. Herbs and graminoids generally respond rapidly after fire. Restionaceous species, such as *Empodima minus* and *Baloskion australe*, which resprout after fire and also recruit from seed, had regained their pre-fire cover by 2009 (Figure 6.14). In the wet heath transects, recovery of restiad cover was slightly slower, but in bog transects it had exceeded pre-fire cover levels by April 2009. *Carex* species also responded rapidly, with a cover increase from 2% pre-fire, to 6% by 2009. ‘Other graminoids’, such as the sedge *Baumea gunnii*, and grasses like *Poa costiniana*, were more abundant than in 2006, with post-fire growth and expansion being particularly vigorous in wet heath transects. Herbaceous species followed a similar pattern, increasing in wet heath transects from about 1% to 8% mean cover over the three-year period, mainly due to opportunistic, creeping, peat colonising and stabilising species like *Gonocarpus micranthus*, *Asperula gunnii*, and *Viola fuscoviolacea*.

Species richness increased dramatically in wet heath transects between 2007 and 2009 (Table 6.10). The increase in bog transects over the same period was only modest in comparison. Many of the new species in the 2009 survey are species from adjacent non-wetland plant communities, and included seedlings of common grassland and open heath species, such as the shrubs *Grevillea australis*, *Hovea montana* and *Pimelea alpina*. The increased occurrence of exotic species was also more pronounced in wet heath transects and included some potentially troublesome taxa, such as *Juncus effusus*, *Salix cinerea* and *Mimulus moschatus* (Table 6.11).

Table 6.9: Changes in the percent cover of functional groups and key species by formation type and year. Data include the mean, standard error, and range of values for each functional group and key species. Only the 10 directly fire-affected transects are included in these analyses.

	Formation type (per cent cover by year)											
	Bog						**Wet heath**					
	2006		**2007**		**2009**		**2006**		**2007**		**2009**	
Functional groups	**Mean (S.E.)**	**Range**	**Mean (S.E.)**	**Range**	**Mean (S.E.)**	**Range**	**Mean (S.E.)**	**Range**	**Mean (S.E.)**	**Range**	**Mean (S.E.)**	**Range**
Sphagnum spp.	**63.2 (± 9.2)**	41.2 - 82.2	**42.3 (± 6.7)**	24.0 - 54.8	**51.9 (± 6.2)**	38.0 - 68.2	**24.1 (± 4.8)**	0.7 - 30.7	**8.3 (± 3.2)**	0.0 - 17.5	**16.5 (± 4.3)**	1.0 - 33.1
Restiad	**17.6 (± 7.4)**	5.4 - 35.3	**6.4 (± 2.3)**	2.5 - 12.5	**23.2 (± 8.8)**	6.4 - 44.3	**12.7 (± 5.3)**	0.1 - 30.3	**0.9 (± 0.3)**	0.2 - 2.1	**9.4 (± 2.9)**	4.1 - 20.5
Other shrubs	**0.2 (± 0.2)**	0.0 - 0.7	**<0.1 (±<0.1)**	0.0 - 0.04	**0.1 (± 0.1)**	0.0 - 0.26	**0.9 (± 0.8)**	0.0 - 4.6	**0.1 (± 0.1)**	0.0 - 0.3	**0.4 (± 0.2)**	0.02 - 1.6
Other sedges	**0.7 (± 0.6)**	0.0 - 2.4	**0.6 (± 0.6)**	0.0 - 2.3	**0.6 (± 0.3)**	0.0 - 1.3	**0.2 (± 0.1)**	0.0 - 0.6	**0.2 (± 0.1)**	0.04 - 0.5	**1.1 (± 0.6)**	0.1 - 4.1
Other monocots	**0.6 (± 0.3)**	0.05 - 1.43	**0.6 (± 0.3)**	0.1 - 1.5	**1.6 (± 0.4)**	0.5 - 2.4	**1.5 (± 0.7)**	0.04 - 4.63	**0.8 (± 0.4)**	0.02 - 2.3	**3.4 (± 1.1)**	0.1 - 7.9
Other bryophytes	**<0.1 (±<0.1)**	0.0 - 0.04	**0.1 (±<0.1)**	0.0 - 0.06	**0.1 (± 0.1)**	0.0 - 0.2	**0.4 (± 0.3)**	0.0 - 2.06	**<0.1 (±<0.1)**	0.0 - 0.1	**0.6 (± 0.4)**	0.0 - 2.5
Myrtaceous shrubs	**10.1 (± 2.8)**	5.7 - 18.1	**3.0 (± 1.8)**	1.0 - 8.4	**5.6 (± 1.5)**	3.5 - 10.2	**16.3 (± 2.4)**	5.4 - 20.4	**2.1 (± 0.6)**	0.3 - 4.0	**8.1 (± 2.1)**	3.1 - 16.8
Herbs	**0.6 (± 0.1)**	0.41 - 0.66	**0.7 (± 0.3)**	0.3 - 1.6	**2.6 (± 0.9)**	0.5 - 5.0	**1.3 (± 0.6)**	0.08 - 4.02	**1.5 (± 0.5)**	0.03 - 3.8	**8.1 (± 2.5)**	0.1 - 16.1
Ericaceous shrubs	**29.6 (± 7.9)**	12.8 - 45.3	**12.4 (± 5.0)**	2.6 - 23.2	**22.2 (± 7.3)**	7.6 - 41.1	**26.7 (± 7.1)**	7.3 - 56.1	**2.4 (± 1.3)**	0.3 - 8.1	**6.3 (± 1.2)**	3.5 - 10.2
Carex spp	**0.9 (± 0.1)**	0.7 - 1.1	**1.4 (± 0.3)**	0.8 - 2.0	**2.7 (± 0.3)**	2.1 - 3.5	**2.9 (± 2.0)**	0.04 - 12.5	**3.9 (± 1.7)**	0.1 - 11.1	**7.5 (± 3.4)**	0.1 - 23.1
Astelia	**0.3 (± 0.3)**	0.0 - 1.0	**0.3 (± 0.3)**	0.0 - 1.2	**0.4 (± 0.4)**	0.0 - 1.5	**0.0**	0.0	**0.0**	0.0	**0.0**	0.0
	Bog						**Wet heath**					
	2006		**2007**		**2009**		**2006**		**2007**		**2009**	
Species	**Mean (S.E.)**	**Range**	**Mean (S.E.)**	**Range**	**Mean (S.E.)**	**Range**	**Mean (S.E.)**	**Range**	**Mean (S.E.)**	**Range**	**Mean (S.E.)**	**Range**
Sphagnum crist'm	**62.8 (± 9.0)**	41.2 - 81.3	**42.1 (± 6.6)**	23.9 - 54.6	**51.4 (± 5.7)**	38.0 - 66.0	**23.3 (± 5.0)**	0.0 - 30.7	**7.9 (± 3.0)**	0.0 - 17.5	**15.5 (± 4.1)**	0.0 - 31.2
Empodisma minus	**17.3 (± 7.1)**	5.4 - 34.2	**6.3 (± 2.3)**	2.5 - 12.5	**22.9 (± 8.7)**	6.4 - 44.3	**12.4 (± 5.1)**	0.1 - 28.7	**0.8 (± 0.2)**	0.1 - 1.9	**9.2 (± 2.8)**	4.0 - 20.5
Carex g'chaudiana	**0.8 (± 0.1)**	0.7 - 1.1	**1.4 (± 0.3)**	0.8 - 2.0	**2.7 (± 0.3)**	2.1 - 3.5	**2.9 (± 1.9)**	0.04 - 12.51	**3.8 (± 1.7)**	0.1 - 11.1	**7.2 (± 3.4)**	0.1 - 23.1
Baeckea gunniana	**9.6 (± 2.8)**	5.7 - 17.8	**2.9 (± 1.8)**	1.0 - 8.3	**5.4 (± 1.7)**	2.5 - 10.1	**12.3 (± 2.0)**	5.4 - 18.6	**1.5 (± 0.3)**	0.3 - 2.9	**5.9 (± 1.7)**	2.7 - 13.4
Epacris spp.	**18.0 (± 3.0)**	12.8 - 26.5	**8.0 (± 3.9)**	2.6 - 19.5	**15.7 (± 6.2)**	7.6 - 33.9	**12.8 (± 2.4)**	6.9 - 21.0	**1.1 (± 0.4)**	0.3 - 2.8	**4.4 (± 0.8)**	1.9 - 7.3
Richea continentis	**15.4 (± 8.5)**	1.4 - 30.6	**5.9 (± 4.2)**	0.02 - 13.92	**8.6 (± 5.2)**	0.5 - 18.2	**20.9 (± 9.7)**	6.1 - 49.2	**2.1 (± 1.6)**	0.02 - 6.77	**2.9 (± 1.9)**	0.03 - 8.25

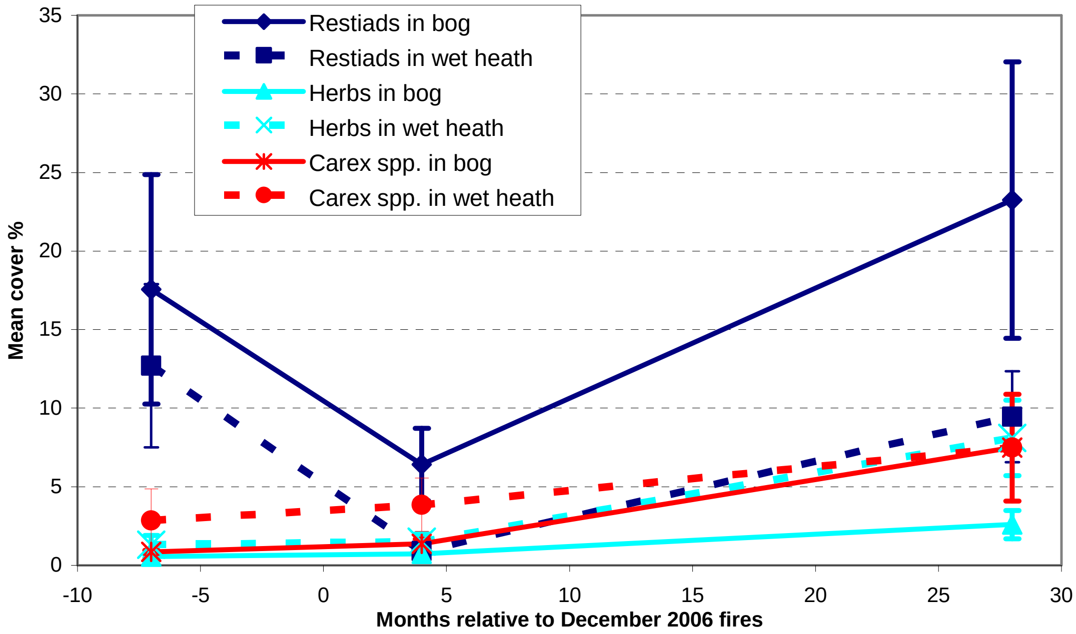


Figure 6.14: Changes in the percent cover of restiads, herbs, and *Carex* spp. in bog and wet heath transects at three time stages relative to the December 2006 fires. The data are derived from the 10 transects that were directly affected by fire in December 2006 (Bog; n = 4, Wet heath; n = 6).

Table 6.10: Mean species richness in the 10 fire-affected transects according to formation type and overall.

	Bog transects			**Wet heath transects**			**All transects**		
Year	Mean	**(S.E.)**	**Range**	Mean	**(S.E.)**	**Range**	Mean	**(S.E.)**	**Range**
2006	20.3	± 2.9	(13 - 27)	22.5	± 3.7	(13 - 34)	21.6	± 2.4	(13 - 34)
2007	20.8	± 2.0	(16 - 25)	23.2	± 3.5	(11 - 33)	22.2	± 2.2	(11 - 33)
2009	24.5	± 3.1	(17 - 32)	32.0	± 4.4	(14 - 42)	29.0	± 3.1	(14 - 42)

Table 6.11: Mean number of introduced species in the 10 fire-affected transects by formation type and overall.

	Bog transects			**Wet heath transects**			**All transects**		
Year	Mean	**(S.E.)**	**Range**	Mean	**(S.E.)**	**Range**	Mean	**(S.E.)**	**Range**
2006	0.5	± 0.3	(0 - 1)	0.8	± 0.7	(0 - 4)	0.7	± 0.4	(0 - 4)
2007	1.0	± 0.4	(0 - 2)	0.8	± 0.5	(0 - 3)	0.9	± 0.3	(0 - 3)
2009	1.3	± 0.8	(0 - 3)	1.8	± 0.9	(0 - 5)	1.6	± 0.6	(0 - 5)

Analysis of similarity, non-metric multidimensional scaling, and SIMPER analysis: cover data

The comparisons of the overall cover data at the three time stages produced only one statistically significant result from the three pair-wise tests (Table 6.12). The transect data collected in April 2006 was significantly different from that collected from the same transects in April 2007 (R = 0.27, p = 0.004). The differences between the 2006 (7 months pre-fire) and 2009 data (28 months post-fire) were not significant, nor were those between the 2007 and 2009 samples (four months and twenty-eight months post-fire).

Table 6.12: ANOSIM table based on the cover data. Pair-wise comparisons of the transect cover data. There were 10 transects sampled at three times relative to the fires (n=30). Transects are grouped according to sampling time (Groups = 3) (ns = not significant, * = significant after sequential Bonferroni adjustment).

Pair-wise tests Groups	R Statistic	Signif. P-value	Signif. Bonferr.	Possible Perm'tns	Actual Perm'tns	Num >= Observed
Pre-fire, Post-fire 4 months	0.27	0.004	*	92378	999	3
Post-fire 4 months, Post-fire 28 months	0.111	0.055	ns	92378	999	54
Pre-fire, Post-fire 28 months	0.103	0.076	ns	92378	999	75
Overall global test sample statistic	**0.154**	**0.004**	**NA**	**NA**	**999**	**3**

Comparisons of the cover data were also made by formation type and time. There were six groups and 15 pair-wise comparisons in these analyses. After modification of the significance thresholds using the sequential Bonferroni adjustment, only one of the 15 pair-wise comparisons showed significant differences (Table 6.13). This was despite the overall global test sample statistic (R) being 0.282 (p = 0.01), indicating significant differences between groups. The relatively small number of replicates for each formation type might be responsible for this result. There were only six wet heath transects and four bog transects in the analyses. In cases such as these, it is considered acceptable to use the 'R' statistic alone as a tentative guide or indicator of differences between groups (see methods section Chapter 3).

The important comparisons are those at the three different times within the same formation type. There were substantial differences between the wet heath plots at the three times, with R-statistic values ranging between 0.2 and 0.6. However, because of the

Table 6.13: ANOSIM table based on the cover data. There were 10 transects sampled at three times relative to the fires (n=30). Transects are grouped according to formation type and sampling time relative to the December 2006 fires (Groups = 6) (ns = not significant, * = significant after sequential Bonferroni adjustment).

Pair-wise tests **Groups**	**R Statistic**	**Signif. P-value**	**Signif. Bonferr.**	**Possible Perm'tns**	**Actual Perm'tns**	**Num >= Obs.**
Wet heath prefire, Wet heath 4 m'ths post-fire	0.596	0.002	*	462	462	1
Wet heath prefire, Wet heath 28 m'ths post-fire	0.237	0.071	ns	462	462	33
Wet heath 4 m'ths post-fire, Wet heath 28 m'ths post-fire	0.272	0.006	ns	462	462	3
Bog pre-fire, Bog 4 m'ths post-fire	0.167	0.2	ns	35	35	7
Bog pre-fire, Bog 28 m'ths post-fire	-0.146	0.686	ns	35	35	24
Bog 4 m'ths post-fire, Bog 28 m'ths post-fire	0.063	0.286	ns	35	35	10
Wet heath 4 m'ths post-fire, Bog pre-fire	0.714	0.005	ns	210	210	1
Wet heath 7 m'ths pre-fire, Bog 28 m'ths post-fire	0.607	0.01	ns	210	210	2
Wet heath 28 m'ths post-fire, Bog pre-fire	0.52	0.01	ns	210	210	2
Wet heath 4 m'ths post-fire, Bog 4 m'ths post-fire	0.421	0.019	ns	210	210	4
Wet heath 28 m'ths post-fire, Bog 28 m'ths post-fire	0.393	0.033	ns	210	210	7
Wet heath 28 m'ths post-fire, Bog 4 m'ths post-fire	0.313	0.043	ns	210	210	9
Wet heath prefire, Bog 4 m'ths post-fire	0.262	0.057	ns	210	210	12
Wet heath prefire, Bog pre-fire	0.21	0.1	ns	210	210	21
Wet heath prefire, Bog 28 m'ths post-fire	0.179	0.148	ns	210	210	31
Overall global test sample statistic	**0.282**	**0.1**	**NA**	**NA**	**999**	**0**

large number of groups, only the comparison between wet heath plots in 2006 (seven months pre-fire) and 2007 (four months post-fire) was statistically significant (R = 0.596, p = 0.002). The comparisons between the bog plots at the various times were not significant, with R-statistic values being less than 0.2, indicating that the groups concerned are barely separable (Wills and Read 2002, 2007, Clarke and Gorley 2001).

The three dimensional ordination graph of the cover data from the 10 transects illustrates the differences between the transects at the three time stages (Figure 6.15). Based on the April 2006 data, the ten transects are relatively closely clustered. The same transects sampled at four months post-fire in April 2007 are considerably spread on both axes, most transects being positioned much further to the left along axis 1 than in the original samples. The transect positions in April 2009 are closer in the graph space to the original 2006 positions, indicating regeneration and a general trend towards the initial pre-fire vegetation patterns.

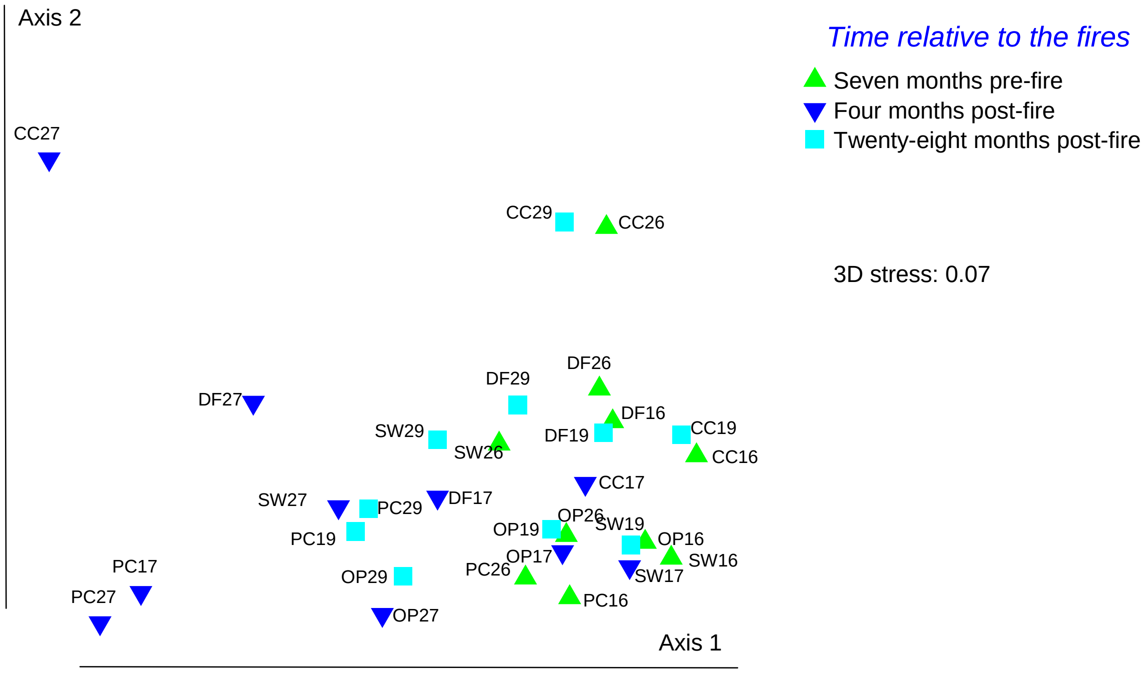


Figure 6.15: Three dimensional ordination graph derived from the cover abundance data of the 10 sites directly affected by fire in December 2006. The letters and first digit refer to the site and transect number. The last digit refers to the year of sampling. The site codes are as follows: CC1 = Cave Gate Creek transect 1, CC2 = Cave Gate Creek transect 2, DF1 = Dairy Farm Flat transect 1, DF2 = Dairy Farm Flat transect 2, OP1 = Omeo Plain transect 1, OP2 = Omeo Plain transect 2, PC1 = Piemans Creek transect 1, PC2 = Piemans Creek transect 2, SW1 = Snowy Range West transect 1, SW2 = Snowy Range West transect 2. The year codes are as follows: 6 = 2006, 7 = 2007, 9 = 2009.

The same ordination viewed from the formation by time perspective illustrates the differences between bog and wet heath identified in the analysis of similarity (Figure 6.16). The bog plots are clustered in the bottom right corner of the graph space, regardless of time, suggesting less floristic change due to the fires. The wet heath plots in contrast, were more variable initially, affected by fire over a greater proportion of their surface area, and at higher fire intensity. Consequently, the wet heath transects when sampled in April 2007 are significantly different. After 28 months regeneration, there is some trend towards the initial composition and structure in most transects.

The SIMPER analysis identified changes in the cover of the previously mentioned species as responsible for group differences. These included declines in the cover of *Sphagnum* and the key shrub species and increases in the cover of graminoids and herbs

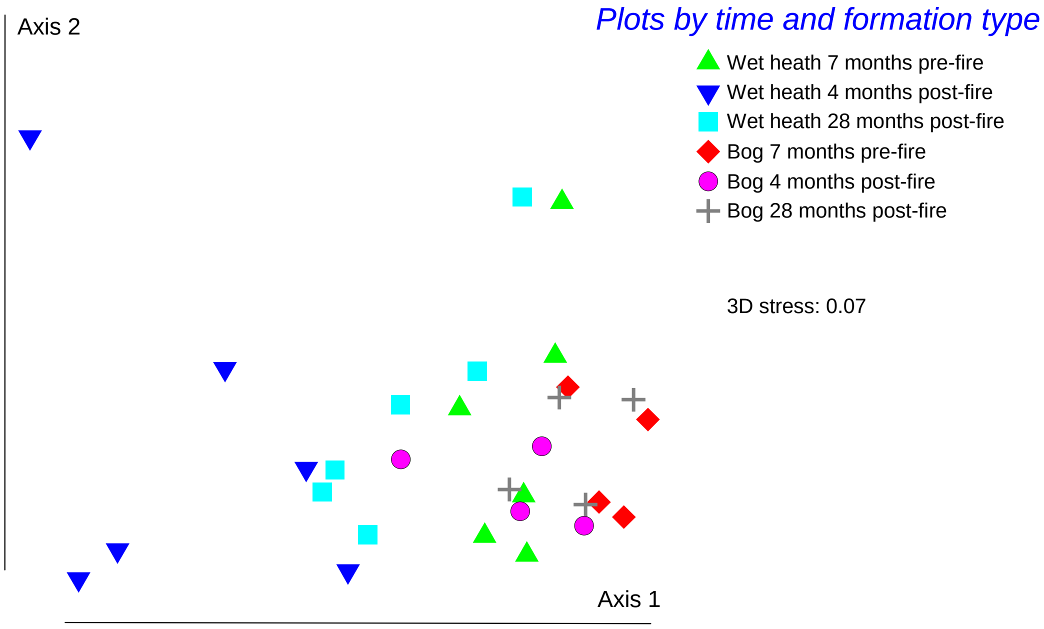


Figure 6.16: Three dimensional ordination graph derived from the cover data of the 10 transects directly affected by fire in December 2006. The transects have been grouped according to formation type and sampling time relative to the fires.

such as *Empodisma*, *Carex*, *Poa*, *Asperula*, *Gonocarpus*, and *Hydrocotyle* (Appendices Tables A6.2-A6.10).

The Bray-Curtis similarity scores for each transect at each sample time were grouped according to community type, and mean similarity with the original data determined for each community (Table 6.14). These figures further demonstrated the high degree of difference between wet heath community plots before and after the fires (similarity values 20-35%). However, the two wet heath community types responded differently after April 2007. Myrtaceous wet heath transects ‘rebounded’ rapidly in comparison to the Tall wet heath transects. Both bog communities showed less change as a result of the fire, and slow but steady recovery of initial vegetation composition and structure. Of the two, the lower altitude peatland community, Montane valley bog, appeared to be recovering more rapidly.

Table 6.14: Comparison of the transect data at two time stages post-fire with the initial 2006 data. The Bray-Curtis similarity index for each transect has been used to generate means for the community type in question at each time stage. This can be used as a measure of regeneration speed in that community type.

Community type	**(n)**	**Mean Bray-Curtis similarity of 2007 transect cover data to the 2006 cover data**	**Mean Bray-Curtis similarity of 2009 transect cover data to the 2006 cover data**
Myrtaceous wet heath	(2)	20.0 (± 9.2)	80.5 (± 7.2)
Montane valley bog	(1)	54.0 (± 0.0)	82.2 (± 0.0)
Tall wet heath	(4)	35.2 (± 10.5)	52.8 (± 6.0)
Subalpine raised bog	(3)	73.2 (± 2.8)	75.8 (± 2.1)

Analysis of similarity and non-metric multidimensional scaling: frequency data

Comparisons of the overall frequency data at the three times using ANOSIM showed no significant differences. There were also no significant differences between the various 'time by formation type' groups. This was reflected in the three dimensional ordination graphs derived from the frequency data. There was generally little apparent separation of the transects according to sampling time, and greater variability between transect sites than within transect sites at the three different sampling times (Appendices Figure A6.2). Most initially recorded species were still present in 2007, and although frequencies were initially reduced, these had generally recovered to near pre-fire levels by April 2009. In the 'time by formation type' frequency ordination, the four bog plots clustered towards the centre (Figure 6.17). The six wet heath plots were more variable and spread along the entire length of axis 1. This separation reflects the subtle differences in composition between the two community types. The wet heath plots situated above and to the right of the Bog plots are Myrtaceous wet heath, whereas those above and left are from the Tall wet heath community.

Fire impacts on the key shrub species in subalpine plots

The three most widespread and abundant shrub species in subalpine peatlands were *Epacris paludosa, Richea continentis,* and *Baeckea gunniana*. All three declined in severely fire-affected quadrats from mean cover of 15-30% pre-fire, to under 2% by April 2007 (Figure 6.18, Appendices Tables A6.11*-A6.13*). By 2009, *Baeckea gunniana* had

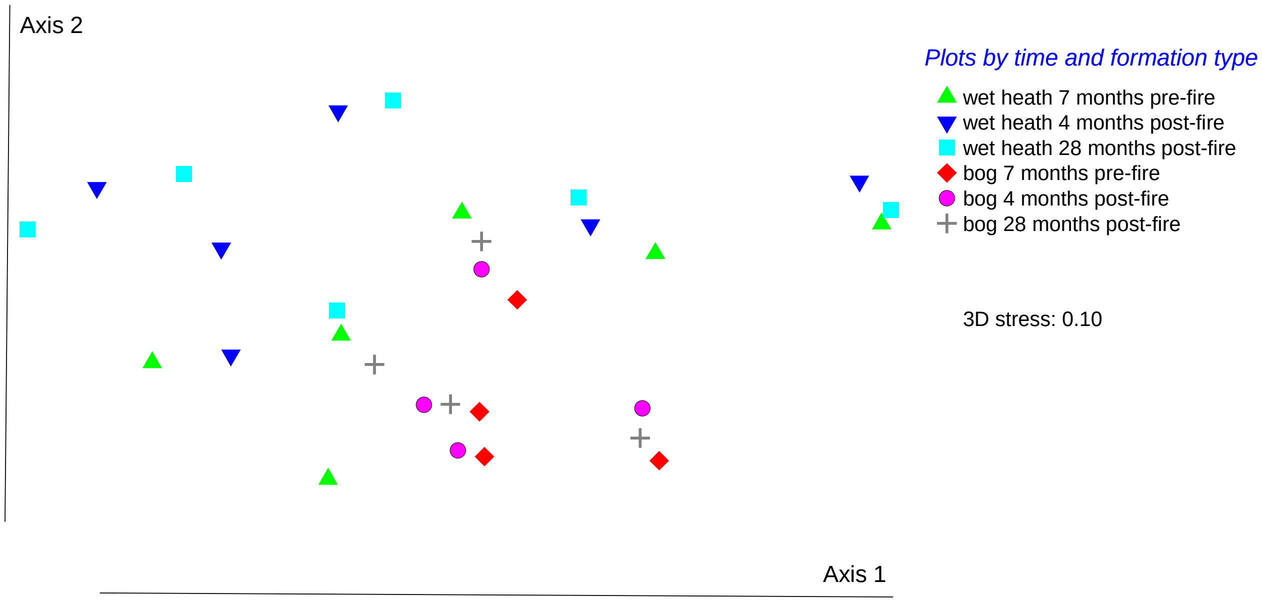


Figure 6.17:Three dimensional ordination graph derived from the frequency data of the 10 transects directly affected by fire in December 2006. The transects have been grouped according to formation type and sampling time relative to the fires.

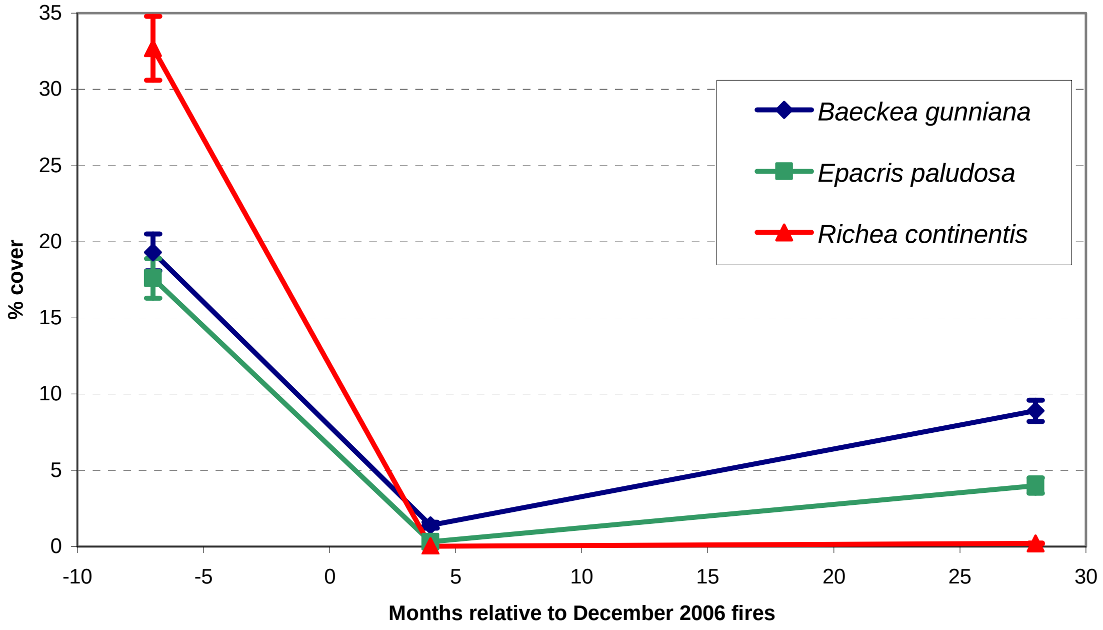


Figure 6.18: Changes in cover of the three key shrub species between 2006 and 2009. These are from quadrats in which the species in question was present in April 2006 that were ultimately 100% affected in the December 2006 fires.

recovered to about 9% cover and *Epacris paludosa* to approximately 4% mean cover. The cover of *Richea continentis* was only 0.2% by April 2009 in areas where it averaged close to 33% cover pre-fire. In the unburnt quadrats the cover of these same three species ranged between 12% and 20% before the fires, but had increased slightly to 13-33% by 2009 (Figure 6.19, Appendices Tables A6.11*-A6.13*). *Epacris paludosa* in particular appeared to have expanded in the unburnt quadrats during the 2006-2009 period.

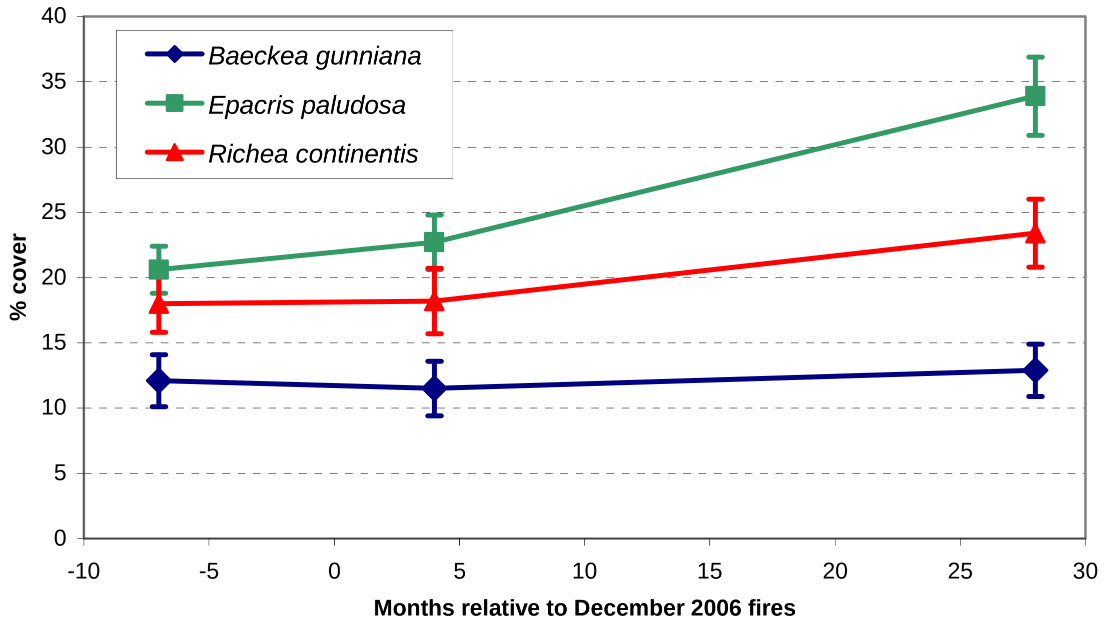


Figure 6.19: Changes in cover of the three key shrub species between 2006 and 2009. These are from quadrats in which the species in question was present in April 2006 that were not directly affected by fire in December 2006.

The figures in relation to formation type were not examined in detail here, but can be inferred from the associated *Sphagnum* cover in 100% fire-affected and unaffected quadrats. The pre-fire *Sphagnum* cover in the unaffected subalpine plots was 80-85% and remained at about this level (Figure 6.20, Appendices Tables A6.11*-A6.13*), although there was a slight decline in cover, which may be attributable to the drier than average summer periods between 2006 and 2009 (see Chapter 5, Appendices Tables A5.1, A5.2). In contrast, the pre-fire *Sphagnum* cover in 100% fire-affected quadrats was approximately 20-25%, and declined to less than 1% in April 2007, then recovered to approximately 6-7% by April 2009. These figures emphasise the relationship between pre-fire *Sphagnum* cover and the extent of burning in peatlands (Figures 6.21 - 6.26).

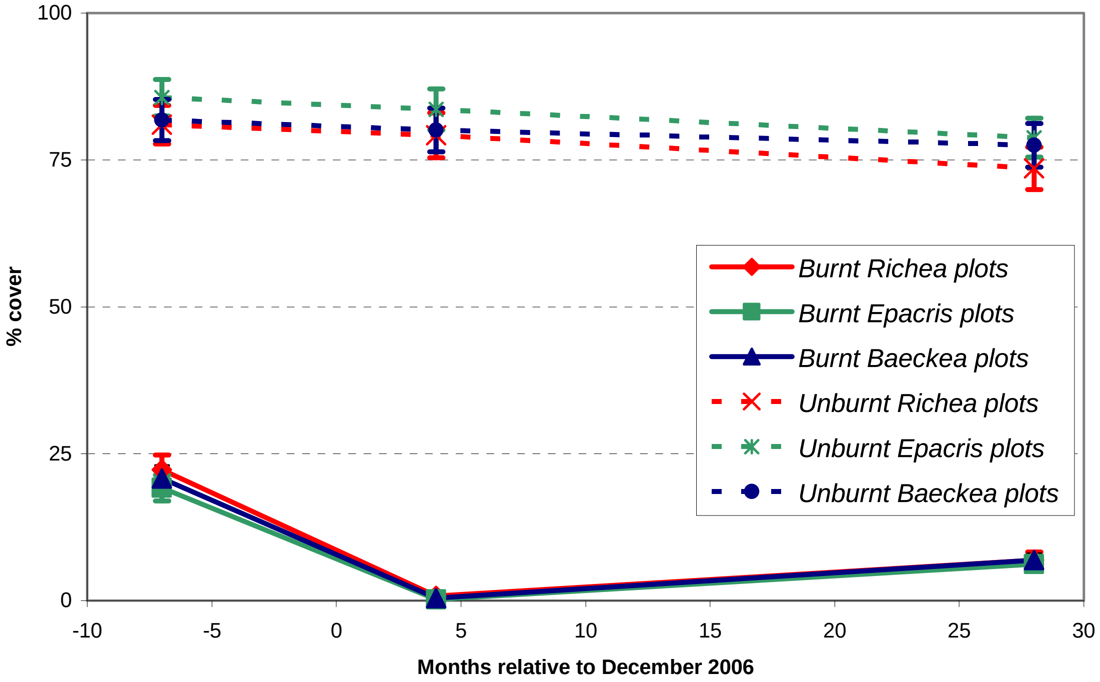


Figure 6.20: The changes in percent cover of *Sphagnum cristatum* in the burnt and unburnt shrub quadrats between 2006 and 2009. The burnt plots data are from quadrats that contained the shrub species in question in April 2006 that were ultimately 100% affected in the December 2006 fires.

Figure 6.21: Snowy Range West transect no. 1 looking south in May 2006. This is Subalpine raised bog vegetation with a high cover of *Sphagnum cristatum*.

Figure 6.22: Snowy Range West transect no. 1 in April 2007. Large sections of this transect were unburnt. Little if any of the ground layer vegetation in the surrounding landscape escaped the fires.

Figure 6.23: Snowy Range West transect no. 1 in April 2009. The vegetation composition and structure along this transect has changed little over the three-year period.

Figure 6.24: Omeo Plain transect no. 2 in April 2006. This is Tall wet heath dominated by *Richea continentis*, *Baeckea gunniana* and *Callistemon pityoides*. The site abuts *Eucalyptus pauciflora* woodland.

Figure 6.25: Omeo Plain transect no. 2 in April 2007, four months post-fire. At this early stage there was strong regeneration from *Carex* species. This section of the transect was dominated by *Richea continentis* before the fires.

Figure 6.26: Omeo Plain transect no. 2 in April 2009. There has been regeneration from *Carex* spp., *Empodisma minus*, and *Poa costiniana*, but the shrub species will take years to regain former cover values, particularly *Richea continentis*. This transect is near the margin of the wetland and is vulnerable to colonisation by non-wetland species in the post-fire period (e.g. *Grevillea australis*).

Regeneration methods of the three common shrub species: subalpine transects

Altogether, *Richea continentis* was present in 293 of the 480 subalpine quadrats in April 2006. One hundred and seventy-three of the 293 were fire-affected over their entire surface area (Table 6.15, Appendices Table A6.11*). By April 2007, *Richea* was present in only 5% of the quadrats in this fire-damage class, as partially burnt or scorched pre-existing individuals only. Twenty-eight months after the fires *Richea* had recovered to be present in 22% of these. Seedlings were recorded in 18% of the severely fire-affected quadrats in April 2009. None of the individual *Richea continentis* shrubs that sustained 100% foliage damage during the fires had resprouted by April 2009.

Three hundred and thirty-nine of the 480 subalpine quadrats contained *Baeckea gunniana* in 2006. Two hundred and twenty-nine of these quadrats were 100% fire-affected (Table 6.15, Appendices Table A6.12*). Four months after the fires, *Baeckea* was present in 68% of these as either partially burnt pre-existing individuals, fire-consumed individuals resprouting at ground level, or as new seedlings. By April 2009, *Baeckea* was present in 82% of the severely fire-affected quadrats, and seedlings were recorded in 4%.

In April 2006, *Epacris paludosa* was present in 333 of the four hundred and eighty subalpine quadrats. Two hundred and three of these were 100% fire-affected in December 2006 (Table 6.15, Appendices Table A6.13*). Four months after the fires, *Epacris paludosa* was recorded in 34% of these, either as partially burnt pre-existing shrubs, totally burnt resprouting individuals, or seedlings. Twenty-eight months after the fires, *Epacris* was present in 74% of severely fire-affected quadrats, and seedlings were recorded in 38%.

In the subalpine transects by 2009, *Epacris paludosa* seedlings were by far the most common in fire-affected quadrats. Thirty-two per cent of all severely fire-affected quadrats contained seedlings of this species (Figure 6.27). The frequency of occurrence for seedlings of *Richea continentis* and *Baeckea gunniana* in the same quadrats were 12% and 4% respectively. In the moderately burnt quadrats class (50-95% fire-affected),

Table 6.15: Analysis of the 480 **subalpine** quadrats. These transects were affected by fire in December 2006, and resampled in 2007 and 2009. The quadrats containing the species in question in April 2006 were categorised according to the degree of fire damage. Only quadrats containing the species in question that were 100% fire-affected are displayed here. The full analyses for each species are in the Appendices. Also included in this table are the number and percentage of quadrats for each species that contained seedlings or evidence of recent flowering.

	Richea continentis		***Baeckea gunniana***		***Epacris paludosa***	
Variable or attribute	**Number**	**%**	**Number**	**%**	**Number**	**%**
Total number of quadrats containing the species pre-fire	293		339		333	
Quadrats containing species pre-fire that were 100% fire affected	173	(59)	229	(67.6)	203	(61)
How many of these contained the species in April 2007?	8	(4.6)	155	(67.6)	68	(33.5)
How many of these contained the species in April 2009?	39	(22.5)	188	(82.1)	150	(73.9)
Quadrats with seedlings (2009)	31	(17.9)	10	(4.4)	78	(38.4)
Quadrats with flowering (2009)	0	(0)	0	(0)	5	(2.4)

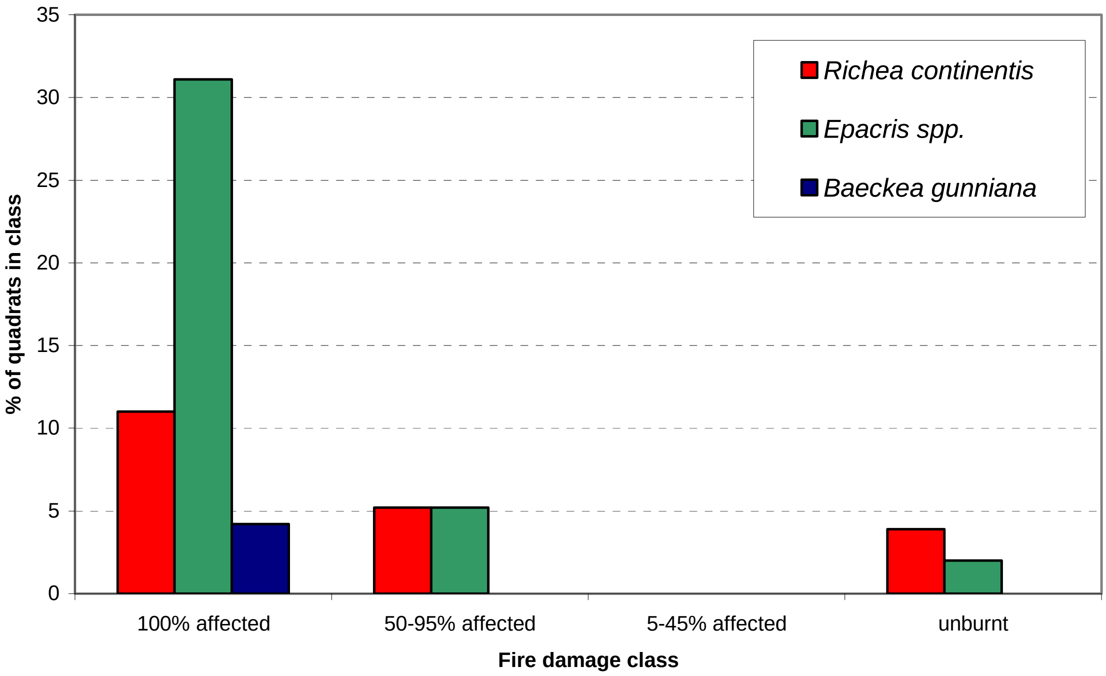


Figure 6.27: The percent of all subalpine quadrats in each fire damage class that contained shrub seedlings in 2009, twenty-eight months post-fire. These are for the eight subalpine transects only (n = 480).

approximately 5% of the quadrats contained seedlings of *Richea* and *Epacris*, but *Baeckea gunniana* seedlings were not found. It is worth noting that seedlings were also detected in some of the unburnt quadrats in 2009. Four percent of unburnt quadrats contained seedlings of *Richea continentis*, whereas *Epacris paludosa* was found in 2%. Again, seedlings of *Baeckea gunniana* were not recorded in these quadrats.

Regeneration methods of the common shrub species: montane transects

Richea continentis was not recorded in any of the montane transects or observed elsewhere in montane peatlands either before or after the fires. *Epacris paludosa* was present in 103 of the 120 quadrats at the time of initial sampling (Table 6.16, Appendices Table A6.14*). Seventy-three of these were 100% fire-affected. In April 2007, it was recorded in 40% of these quadrats, but recovered to be present in 82% by April 2009. Twenty-eight months after the fires seedlings were recorded in 66% of these quadrats. *Baeckea gunniana* in the same transects was recorded in 83 out of 120 quadrats initially, and sixty of these were 100% fire-affected in December 2006 (Table 6.16, Appendices

Table 6.16: Analysis of the 120 **montane** quadrats. These transects were affected by fire in December 2006, and resampled in 2007 and 2009. The quadrats containing the species in question were categorised according to the degree of fire damage. Only quadrats containing the species in question which were 100% fire-affected are analysed and displayed here. The full analyses for each species are in the Appendices. Also included in this table are the number and percentage of quadrats for each species that contained seedlings or evidence of recent flowering.

	Baeckea gunniana		***Epacris paludosa***	
Variable or attribute	**Number**	**%**	**Number**	**%**
Total number of quadrats containing the species pre-fire	83		104	
Quadrats containing species pre-fire that were 100% fire affected	60	(72.3)	73	(70.2)
How many of these contained the species in April 2007?	32	(53.3)	29	(39.7)
How many of these contained the species in April 2009?	42	(70.0)	60	(82.2)
Quadrats with seedlings (2009)	10	(16.7)	48	(65.8)
Quadrats with flowering (2009)	0	(0)	12	(16.7)

Table A6.15*). This species was present in only 53% of these quadrats by April 2007, but then recovered to 70% by April 2009. Recovery was mostly via resprouting of 100% foliage damaged individual shrubs, or the persistence of partially burnt shrubs. By twenty-eight months post-fire, 17% of the severely fire-affected montane *Baeckea* quadrats contained seedlings.

Trends in overall presence of the three shrub species since April 2006

By April 2009, *Epacris paludosa* was rapidly regaining its pre-fire presence, being located in 80% of the subalpine and 85% of the montane quadrats in which it previously occurred. *Baeckea gunniana* was also rapidly recovering overall presence. It occurred in 82% of the subalpine and 70% of the montane quadrats in which it was present in April 2006 (Table 6.17). In contrast, *Richea continentis*, which was not recorded in the original montane transects, occurred in only 47% of the subalpine quadrats in which it was initially recorded (Figure 6.28).

In severely burnt quadrats (100% affected), only *Epacris paludosa* showed signs of having progressed to flowering by April 2009. In subalpine transects, 2% of quadrats had individuals flowering, while the species had flowered in 17% of the severely burnt montane quadrats in which it was initially recorded in 2006 (Tables 6.15, 6.16, Appendices Tables A6.11*- A6.15*).

Table 6.17: Changes in the presence of the three key shrub species since April 2006. The data are the number of quadrats in which the species occurred in 2009 divided by the number that contained the species in question pre-fire, expressed as percentages. Subalpine and montane transects were analysed separately. There were eight subalpine transects (n = 480 quadrats) and two montane transects (n = 120 quadrats) included in these analyses.

	2009 proportional presence relative to 2006	
Shrub species	**subalpine %**	**montane %**
Baeckea gunniana	82	70
Epacris paludosa	80	85
Richea continentis	47	NA

Figure 6.28: The lightly burnt surface of a *Sphagnum cristatum* hummock. There is some *Sphagnum* regeneration visible and *Baeckea gunniana* is resprouting from one of these patches. The burnt shrub stems not resprouting are mostly *Richea continentis*. A small stem of *Richea continentis* that has managed to survive is visible amongst the regenerating, or possibly unburnt *Sphagnum* (above *Baeckea* in the photo).

6.3.3 Regeneration niche: modes of regeneration in two different microsite types after the December 2006 fires

Recruitment from seed in scorched hummocks was limited, regardless of species. In contrast, the seedling counts for inter-hummock spaces (hollows) were sometimes very high (Figures 6.29, 6.30). The only species recruiting from seed in scorched hummocks on a consistent basis was the herb *Asperula gunnii*. However, seedlings of this species were also common in hollows. The vast majority of seedlings in hollows were of *Epacris* species, particularly *Epacris paludosa* (Tables 6.18, 6.19). The mean seedling density per quadrat (0.25 m^2) for *Epacris paludosa* was 97 ±15, but varied considerably. Ninety-three percent of the hollow quadrats contained at least some *Epacris* seedlings. The myrtaceous shrub species *Baeckea gunniana* was also recruiting from seed in hollows, but numbers were lower. Seedlings of *Empodisma minus* also occurred in hollows, especially in damper depressions within more severely burnt patches (Figure 6.31). Several species, although recorded in less than 30% of hollows, were only recruiting from this microsite. These included important bare peat colonising herbs and graminoids, such as *Schoenus calyptratus*, *Gonocarpus micranthus*, *Scaevola hookeri* and *Viola fuscoviolacea*.

Seedlings of *Richea continentis*, *Callistemon pityoides* and *Comesperma retusum* were not common and only recorded in hollow quadrats. The latter two species were less common generally in some wet heaths, especially at higher altitude, and the low seedling numbers for these species are partly a reflection of this. However, *Callistemon pityoides* is of interest because it is one of the few shrubs at this altitude with canopy stored seed. We might therefore have expected to see more seedlings post-fire, but few were seen. It did, however, resprout vigorously regardless of fire severity (Table 6.20). *Richea continentis*, on the otherhand, does not resprout. Instead, it recruits from seed in low numbers and slowly, taking two to three years to appear in appreciable numbers.

Both *Epacris paludosa* and *Baeckea gunniana* were resprouting from hummocks of scorched *Sphagnum*, apparently benefitting from the extra protection afforded by these microsites (Figure 6.32). *Baeckea* and *Empodisma* resprouts were equally common in

Figure 6.29: Severely burnt peatland vegetation at the Dairy Farm Flat site. This photo illustrates the differences between the two recruitment niches. Some shrubs and restiads will resprout from both hummocks and hollows, but seedlings are rare on badly burnt, scorched or 'cooked' *Sphagnum* hummocks.

Figure 6.30: A subalpine peatland site on the Snowy Range in February 2008. The post-fire vegetation mosaic depicted is typical, with a mixture of unburnt patches, burnt hummocks, and more severely burnt hollows. *Poa* and other grasses resprouted vigorously in the adjoining burnt open heath. Pyrogenic flowering occurred in these species and the dried inflorescences create a strong colour contrast with peatland areas.

Table 6.18: Number of seedlings in hummock and hollow quadrats in areas burnt in December 2006. Means and maximums are also included. These data are derived from 84 quadrats at four sites in the Snowy Range area, 42 each in hummocks and hollows.

	Total count		**Mean per 0.25 m^2**		**Max per 0.25 m^2**	
Species	**hollows**	**hummocks**	**hollows**	**hummocks**	**hollows**	**hummocks**
Baeckea gunniana	862	1	20.5 ± 5.3	0.0 ± 0.0	165	1
Callistemon pityoides	11	0	0.3 ± 0.2	0.0 ± 0.0	6	0
Comesperma retusum	51	0	1.2 ± 1.5	0.0 ± 0.0	44	0
Epacris paludosa	4055	23	96.5 ± 15.5	0.5 ± 0.3	463	10
Epacris sp.	62	0	1.5 ± 2.0	0.0 ± 0.0	62	0
Richea continentis	9	0	0.2 ± 0.5	0.0 ± 0.0	8	0
Empodisma minus	1007	22	24.0 ± 9.6	0.5 ± 0.5	338	21
Luzula modesta	102	8	2.4 ± 1.5	0.2 ± 0.2	40	6
Schoenus calyptratus	192	0	4.6 ± 2.6	0.0 ± 0.0	43	0
Asperula gunnii	520	131	12.4 ± 4.1	3.1 ± 1.3	108	30
Chionogentias sp.	4	0	0.1 ± 0.1	0.0 ± 0.0	2	0
Coprosma granadensis	36	1	0.9 ± 0.6	0.0 ± 0.0	15	1
Drosera peltata	22	0	0.5 ± 0.8	0.0 ± 0.0	13	0
Gonocarpus micranthus	68	0	1.6 ± 1.2	0.0 ± 0.0	44	0
Scaevola hookeri	35	0	0.8 ± 0.7	0.0 ± 0.0	21	0
Viola fuscoviolacea	42	0	1.0 ± 0.5	0.0 ± 0.0	10	0

Table 6.19: Frequency of seedlings of certain species in hummock and hollow quadrats.

	Frequency of occurrence	
Species	**hummocks %**	**hollows %**
Only recruiting in hollows		
Gonocarpus micranthus	0	29
Schoenus calyptratus	0	24
Viola fuscoviolacea	0	17
Comesperma retusum	0	14
Scaevola hookeri	0	14
Callistemon pityoides	0	10
Drosera peltata	0	10
Chionogentias sp.	0	7
Richea continentis	0	5
Epacris sp.	0	2
Some hummock recruitment		
Epacris paludosa	10	93
Baeckea gunniana	2	83
Asperula gunnii	29	45
Empodisma minus	5	38
Luzula modesta	7	24
Coprosma granadensis	2	14

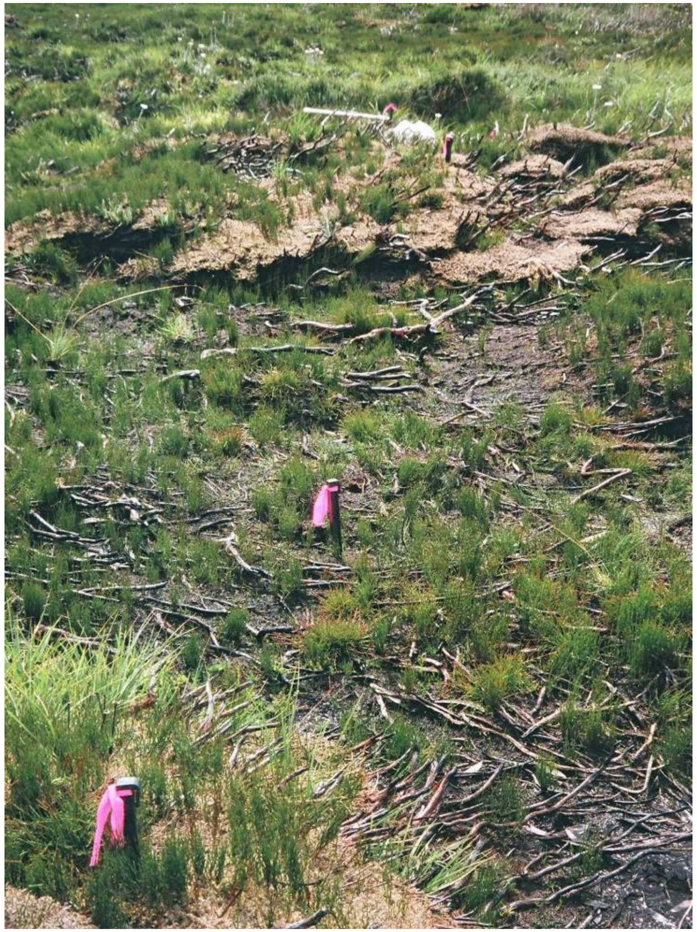


Figure 6.31: An inter-hummock or hollow area between two burnt *Sphagnum* hummocks. The main resprouting species visible are *Empodisma minus* and *Carex gaudichaudiana*. There were also some *Empodisma* seedlings in hollows such as these.

Figure 6.32: Excavated burnt *Sphagnum* hummock at the Dairy Farm Flat site. *Epacris paludosa* shoots are visible emerging from the large shrub stem below the hummock surface (right of picture). The stem appears to have been protected by the *Sphagnum* during the passage of the fire.

Table 6.20: The percentage frequency of vegetative recovery according to microsite. These data were generated from 84 quadrats, 42 each in hummocks and hollows.

	Frequency of quadrats containing vegetative recovery	
Species	**hummocks %**	**hollows %**
Empodisma minus	100	100
Baeckea gunniana	67	79
Epacris paludosa	62	19
Sphagnum cristatum	55	48
Baloskion australe	40	36
Carex gaudichaudiana	33	29
Astelia alpina	12	5
Baumea gunnii	12	14
Callistemon pityoides	12	7
Diplaspis nivis	12	0
Celmisia spp.	7	10
Epacris sp.	7	0
Pultenaea tenella	7	12
Thelymitra venosa	7	7
Asperula gunnii	5	5
Carpha spp.	5	7
Epacris celata	2	0
Polytrichum sp.	0	12
Richea continentis	0	0

both microsite locations, but *Epacris paludosa* resprouts were less common in hollows. Suckering from exposed roots in inter-hummock spaces was also observed in *Baeckea* at some sites. Scorched *Sphagnum* was regenerating in some hummocks from individual cells protected during the passage of fire, where moisture was sufficient. Many of the hummocks showed no visible signs of *Sphagnum* recovery by 14 months post-fire. These are essentially piles of fixed litter and may persist for several years.

Other species occasionally observed recruiting from seed in hummocks included *Luzula modesta* and *Nertera granadensis*, but these were more common as seedlings in hollows. The leguminous shrub *Pultenaea tenella*, a species peripheral to wetlands, was only observed regenerating vegetatively, but with no apparent microsite preference. Common graminoids such as *Baloskion australe, Carex gaudichaudiana, Baumea gunnii,* and *Carpha* spp. were observed resprouting in even proportions in both hummock and hollow quadrats. *Astelia alpina* was not common in the survey area, but appeared more often in hummocks than hollows. The tough, rigid leaves of this species form dense tussocks, often in mats or cushions. The apical meristem of *Astelia* was protected during the passage of fire, but leaf extremities were consumed. In most cases these damaged leaves continued to grow in the months post-fire.

6.3.4 Preliminary analysis of peatland sites burnt in the 2009 fires

General

The fires of February 2009 were very different to those of 2006-07, being relatively shorter in duration and of higher mean severity. There was complete removal of both understorey vegetation and tree canopy in the surrounding tall open forest at the montane Storm Creek site. The smaller pockets of cool temperate rainforest were also severely burnt. The pattern was similar at the two subalpine Lake Mountain sites (Long Flat, Triangle Junction). The pre-fire surrounding vegetation at the Lake Mountain sites consisted of *Eucalyptus pauciflora* open forest with a moist understorey environment dominated by shrubs. Both the understorey vegetation and forest canopy crown were severely burnt at Lake Mountain (Figures 6.33-6.35). Areas of non-wetland heath in the treeless sections abutting peatlands were also severely burnt.

Mount Bullfight is approximately 7 km north-east of the Lake Mountain sites and was near the north-eastern edge of the fire-affected areas. Consequently, the impact of the fires in that area was not as great. More sections of the surrounding subalpine forest canopy were intact. There were also areas of ground layer vegetation that escaped burning. Using the same scale to categorise the fire impact in the vegetation surrounding peatlands used for the 2006-2007 analyses, the levels at both Lake Mountain sites, and at Storm Creek were class 4 (highest). Fire intensity in adjacent subalpine open forest at Mount Bullfight appeared to have been lower and was graded as class 2 or 3 (Table 6.21).

The peatland transects at both the Triangle Junction and Long Flat sites were severely burnt (~ 100%). The Mount Bullfight transects were approximately 65% affected. Hence, the overall mean percent area burnt figure for subalpine transects was close to 90%. In similar fashion to the 2006-2007 fires, the shrub cover declined from 32-33% before the fires to under 3% by 2010. The vegetation cover in subalpine transects was approximately 90% in 2006, but had been reduced to 48% by April 2010. The mean

Figure 6.33: Burnt subalpine peatlands at Echo Flat in April 2009. The species recovering from Hummock crests is *Astelia alpina*.

Figure 6.34: The Mount Bullfight peatland site in May 2010. *Astelia alpina* recovered rapidly post-fire and its projective foliage cover in transects at this time was the same as pre-fire.

Figure 6.35: Pool photo sequence in the Mount Bullfight peatland site: top, April 2006, middle, May 2009, bottom, May 2010. The *Sphagnum*-dominated areas around the pool were less affected by the fires.

Table 6.21: Summary of trends in species cover and frequency in four Central Highlands subalpine transects between 2006 (26 months pre-fire) and 2010 (14 months post-fire). Means for environmental and structural variables are also given.

	Percent cover by year				**Frequency (n = 230)**	
	2006		**2010**		**2006**	**2010**
Species	**Mean**	**(S.E.)**	**Mean**	**(S.E.)**	**Number**	**Number**
Shrubs and trees						
Baeckea gunniana	2.60	± 1.55	0.55	± 0.30	78	71
Callistemon pityoides	2.24	± 2.24	0.45	± 0.41	24	37
Epacris paludosa	19.72	± 6.34	1.47	± 1.26	165	94
Eucalyptus pauciflora	0.00	± 0.00	0.04	± 0.02	0	20
Leptospermum grandifolium	0.00	± 0.00	0.10	± 0.10	0	41
Olearia algida	0.23	± 0.13	0.19	± 0.12	25	44
Ozothamnus sp.1	0.13	± 0.13	0.01	± 0.01	3	7
Richea continentis	6.50	± 1.90	0.07	± 0.03	116	22
Monocots						
Astelia alpina	11.19	± 4.87	10.91	± 4.54	163	150
Carex blakei	0.00	± 0.00	0.02	± 0.02	1	3
Empodisma minus	24.60	± 7.62	3.16	± 0.91	228	226
Isolepis aucklandica	0.20	± 0.08	2.05	± 1.52	37	79
Isolepis habra	0.00	± 0.00	0.19	± 0.19	0	15
Juncus sandwithii	0.10	± 0.06	0.43	± 0.26	24	47
Luzula modesta	0.00	± 0.00	0.11	± 0.11	1	8
Oreobolus oxycarpus	0.09	± 0.09	0.06	± 0.06	14	16
Poa costiniana	0.73	± 0.11	2.53	± 0.80	134	143
Prasophyllum sp.	0.01	± 0.01	0.03	± 0.03	3	11
Thelymitra sp.	0.03	± 0.02	0.06	± 0.03	13	25
Herbs						
Asperula gunnii	0.23	± 0.07	0.50	± 0.17	84	91
Brachyscome obovata	0.17	± 0.10	0.35	± 0.20	51	62
Celmisia sp.	0.09	± 0.06	0.11	± 0.07	23	21
Chionogentias sp.	0.11	± 0.04	0.09	± 0.04	43	30
Nertera granadensis	0.80	± 0.37	0.96	± 0.35	93	103
Drosera arcturi	0.03	± 0.01	0.01	± 0.01	4	2
Erigeron paludicola	0.48	± 0.23	0.28	± 0.11	100	56
Gonocarpus micranthus	0.00	± 0.00	0.02	± 0.01	0	7
Bryophytes						
Marchantia sp.	0.00	± 0.00	0.01	± 0.01	0	6
Sphagnum cristatum	38.03	± 9.34	15.75	± 4.83	166	148
Sphagnum novozelandicum	4.73	± 2.76	1.94	± 1.06	33	45
Other bryophytes % cover	0.98	± 0.14	0.73	± 0.39		
% burnt			89.29	± 7.52		
Fire severity			2.12	± 0.31		
Live vegetation % cover	93.00	± 4.00	47.92	± 5.08		
Dead *Empodisma* % cover	4.87	± 1.66	1.18	± 1.18		
Water % cover	2.46	± 2.02	8.66	± 2.52		
Shrub % cover	32.64	± 6.13	2.76	± 1.45		
Mean shrub height (cm)	26.94	± 6.47	5.13	± 1.10		
Mean height of tallest shrubs (cm)	45.00	± 9.57	7.82	± 2.17		
Litter % cover	5.72	± 3.62	3.10	± 0.62		
Bare peat % cover	0.03	± 0.02	3.04	± 2.41		
Fixed litter % cover	6.00	± 1.70	33.13	± 6.04		

height of the tallest shrubs in quadrats declined from 45 cm in 2006, to less than 10 cm in April 2010.

In most respects the impact of the fires and the regeneration patterns after 14 months are similar to the corresponding period after the 2006 Snowy Range fires. The important difference is that the transects burnt in 2009 had few if any unburnt patches. There were slightly more at the Mount Bullfight peatland.

Early post-fire regeneration trends: subalpine transects

The most striking feature of the early regeneration pattern is probably the response of *Astelia alpina* (Figure 6.34). It had recovered completely and its percent cover was unchanged from April 2006 (~ 12%). As observed on a smaller scale after the Snowy Range fires, the apical meristem of this hard-leaved lily (Family Asteliaceae) appeared to survive even quite severe fire and resumed growth immediately afterwards. The group of species responding rapidly in the post-fire environment were mostly the same as observed after the 2006-07 fires. These included *Poa costiniana*, *Isolepis* spp., *Gonocarpus micranthus*, and *Asperula gunnii*, all of which were more common and abundant than pre-fire. The cover of *Sphagnum cristatum* declined from 38% to 16% over the three-year period. Again, the most fire-affected shrub species was *Richea continentis*. By 2010 it was present in only 22 of its original 116 pre-fire quadrats and its cover had been reduced from 6% to less than 0.1%.

Seedlings were plentiful by 14 months post-fire, particularly those of *Epacris* spp. and *Empodisma minus* (Table 6.22). There were relatively few seedlings of *Richea continentis*, but more than at the same recovery stage following the Snowy Range fires. The seedlings of myrtaceous shrubs were also more numerous than in the 2006 fire study and this may be due to the locally higher fire severity. These included both *Baeckea gunniana* and *Callistemon pityoides*; seedlings of the latter were not common after the 2006 fires. It is also worth noting the ‘blow-in’ species, particularly *Leptospermum grandifolium*. This species was not recorded in transects before the fires, but did occur at

Table 6.22: The percentage frequency of Central Highlands subalpine quadrats (0.25 m²) containing seedlings in April 2010. These data are from the four subalpine transects that were resampled post-fire, a total of 230 quadrats.

Species	Subalpine quadrats frequency (%)
Baeckea gunniana	14
Callistemon pityoides	7
Empodisma minus	33
Epacris paludosa	30
Eucalyptus pauciflora	9
Leptospermum grandifolium	18
Olearia algida	17
Ozothamnus sp.1	3
Richea continentis	7

the margins of some peatlands, and within 20 m of some transects. These individuals were fire-killed and there were numerous seedlings emerging in their vicinity by April 2010, as well as some recruitment occurring in adjacent peatland quadrats.

Early post-fire regeneration trends: montane transects

The Storm Creek transects were, if anything, more severely burnt than those at Lake Mountain (4.3 mean fire-severity, Table 6.23, Figures 6.36-6.39). The vegetation cover for these transects was only 22% in April 2010. Important post-fire species at this peatland included *Empodisma minus*, *Carex gaudichaudiana*, *Scaevola hookeri*, *Gonocarpus micranthus*, *Oreobolus oxycarpus*, *Asperula gunnii*, and *Isolepis* sp. Several of these were either rare or not recorded in 2006. *Richea continentis* was not recorded at this lower elevation site (1175 m) and this niche is instead occupied by the Victorian endemic *Richea victoriana*, which although similarly fire-sensitive (no resprouting), responded rapidly from soil stored seed in the 14 months after the fires (Table 6.24). Seedlings of *Richea victoriana* were recorded in 77% of the quadrats in which it occurred in 2006. Another important ericaceous shrub species recorded at Storm Creek in 2006 was *Epacris microphylla* var. *rhombifolia*. No vegetative regeneration was observed in this taxon, and although there were many *Epacris* seedlings emerging in burnt hollows, these were generally too small to confidently identify to species level. Most appeared to be of *Epacris paludosa*, which was by far the more abundant of the two species pre-fire.

Figure 6.36: Storm Creek transect no. 2 in May 2006. The peatland was dominated by *Empodisma minus*, *Epacris paludosa*, *Richea victoriana*, *Baeckea gunniana* and *Carex gaudichaudiana*. The surrounding vegetation is *Eucalyptus delegatensis* and *Eucalyptus nitens* tall open forest, with some pockets of cool temperate rainforest containing *Nothofagus cunninghamii*.

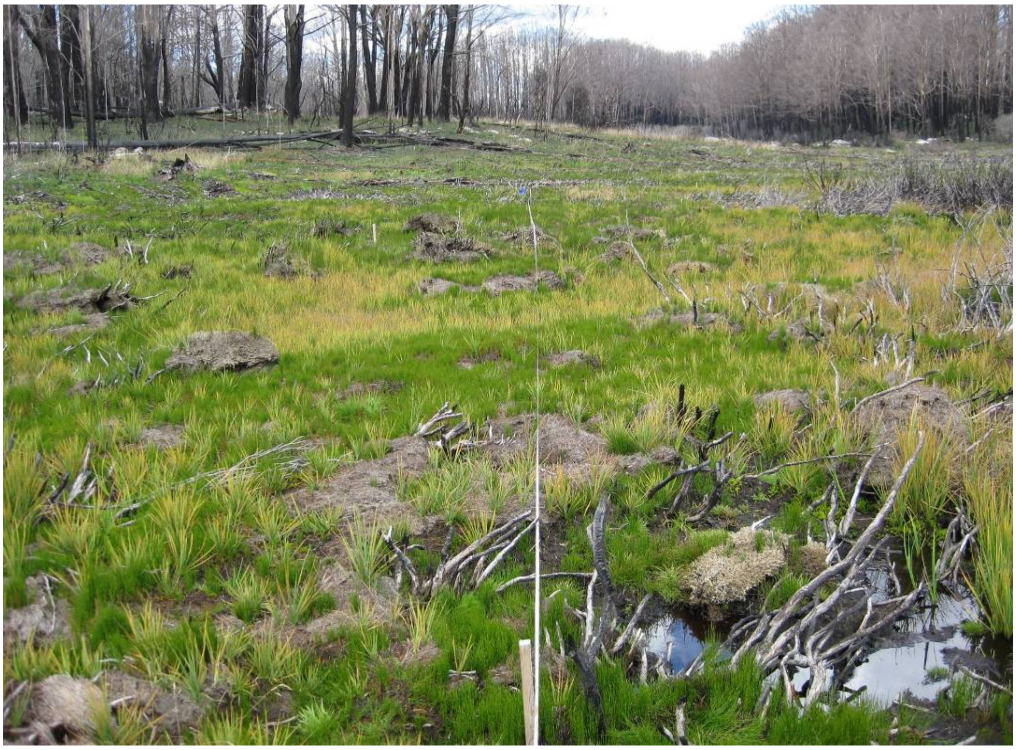


Figure 6.37: Storm Creek transect no. 2 in March 2010, thirteen months after the fires. Both surrounding forest and montane wet heathland were severely burnt. The regenerating species visible are *Empodisma minus* and *Carex gaudichaudiana*.

Figure 6.38: Storm Creek site in November 2009. Burnt *Sphagnum cristatum* hummocks are visible in the foreground and middle-ground.

Figure 6.39: Scorched stem of *Richea victoriana* in a montane peatland site nine months after the fires. The apical meristem appears to have survived the scorching and subsequent growth has occurred.

Table 6.23: Summary of trends in species cover and frequency of occurrence in two Central Highlands montane transects between 2006 (26 months pre-fire) and 2010 (14 months post-fire). Both transects are from the Storm Creek site.

	Percent cover by year				**Frequency (n = 120)**	
	2006		**2010**		**2006**	**2010**
Species	Mean	(S.E.)	Mean	(S.E.)	Number	Number
Shrubs and trees						
Baeckea gunniana	2.21	± 0.43	1.75	± 0.18	40	42
Epacris microphylla var. *rhombifolia*	0.99	± 0.69	0.00	± 0.00	10	0
Epacris paludosa	26.95	± 4.78	1.06	± 0.09	102	95
Eucalyptus delegatensis	0.00	± 0.00	0.00	± 0.00	0	1
Leionema phylicifolium	0.00	± 0.00	0.01	± 0.01	0	3
Olearia algida	0.00	± 0.00	0.02	± 0.02	0	5
Richea victoriana	4.65	± 1.09	0.27	± 0.00	79	61
Monocots						
Astelia alpina	0.92	± 0.92	1.61	± 1.61	6	7
Carex blakei	0.00	± 0.00	0.28	± 0.02	0	14
Carex gaudichaudiana	0.80	± 0.50	3.55	± 0.56	71	75
Deyeuxia inominata	0.00	± 0.00	0.17	± 0.02	0	25
Empodisma minus	26.80	± 9.28	6.35	± 2.28	115	115
Herpolirion novae-zelandiae	0.02	± 0.01	0.03	± 0.03	4	3
Isolepis sp.	0.00	± 0.00	3.42	± 1.48	0	62
Luzula modesta	0.00	± 0.00	0.34	± 0.09	1	21
Oreobolus oxycarpus	0.00	± 0.00	0.10	± 0.03	1	25
Poa costiniana	0.00	± 0.00	0.01	± 0.00	1	2
Herbs						
Acaena novae-zelandiae	0.00	± 0.00	0.03	± 0.02	0	7
Asperula gunnii	0.10	± 0.06	0.27	± 0.12	24	29
Nertera granadensis	0.37	± 0.23	0.81	± 0.51	49	52
Erigeron paludicola	0.05	± 0.05	0.18	± 0.18	3	7
Gonocarpus micranthus	0.00	± 0.00	0.74	± 0.20	1	38
Scaevola hookeri	0.00	± 0.00	2.53	± 0.25	0	50
Bryophytes						
Marchantia sp.	0.00	± 0.00	0.03	± 0.03	0	3
Polytrichum sp.	0.07	± 0.07	0.85	± 0.45	8	38
Sphagnum cristatum	7.18	± 6.91	0.68	± 0.50	26	23
Sphagnum novozelandicum	0.93	± 0.83	0.05	± 0.04	12	9
Other bryophytes % cover	1.07	± 0.35	0.36	± 0.18		
% burnt			100.00	± 0.00		
Fire intensity			4.32	± 0.45		
Live vegetation % cover	89.00	± 4.00	22.58	± 0.24		
Scorched *Sphagnum* % cover			6.91	± 4.10		
Dead *Empodisma* % cover	10.48	± 1.78	0.02	± 0.02		
Water % cover	0.80	± 0.45	4.52	± 0.93		
Shrubs % cover	35.11	± 6.07	2.75	± 0.08		
Mean shrub height (cm)	37.06	± 3.63	4.75	± 0.17		
Mean height of tallest shrubs (cm)	67.17	± 1.54	6.92	± 0.58		
Litter % cover	15.58	± 0.93	7.26	± 1.08		
Bare peat % cover	0.17	± 0.10	6.18	± 4.17		
Fixed litter % cover	11.00	± 2.00	76.83	± 0.92		

Table 6.24: The percentage frequency of Central Highlands montane quadrats (0.25 m²) containing seedlings in April 2010. These data are from the two montane transects that were resampled post-fire, a total of 120 quadrats.

Species	**Montane quadrats frequency (%)**
Baeckea gunniana	12
Empodisma minus	62
Epacris spp.	79
Eucalyptus delegatensis	1
Leionema phylicifolium	3
Olearia algida	4
Richea victoriana	51

Sphagnum cristatum was not abundant at this peatland before the fires and provided a mean cover of only 7%, which had been reduced to less than 1% by April 2010. The transects at Storm Creek were originally classified as Western montane wet heath (Chapters 3 and 4) and were dominated by *Empodisma minus*, *Epacris paludosa*, *Richea victoriana*, and *Baeckea gunniana*, with some *Carex gaudichaudiana*, *Epacris microphylla* var. *rhombifolia*, *Astelia alpina* and *Nertera granadensis* amongst other species. 'Blow-in' species from neighbouring non-wetland communites were also recorded in montane transects 14 months after the fires; these included *Eucalyptus delegatensis* and *Leionema phylicifolium*.

6.4 DISCUSSION

6.4.1 Fire patterns in peatland vegetation

The wet heath transects affected by the December 2006 fires were burnt over 70-100% of their surface area at generally moderate to high severity. By contrast, the extent of fire-damage to bog transects was 0-70%. The *Sphagnum*-dominated areas burnt less and, while this is partly because they retain moisture, it is largely because of the relationship between *Sphagnum* and vascular plants, particularly shrubs, which are important fire-promoters (Gill 1993). The nutrient-poor characteristics of heathland and peatland environments favours sclerophyllous shrubs, which are generally low in moisture content and sometimes high in volatile oils (e.g. Myrtaceae), and this further increases susceptibility to ignition (Specht 1979, 1981, Keith et al. 2002). Higher shrub cover increases canopy connectivity and thus the capacity of fire to spread (Keith et al. 2002). Under optimum conditions, the high continuous 'blanket' cover and competitive abilities of *Sphagnum* in trapping moisture and nutrients, restrict and reduce shrub cover and stature (Van Breeman 1995), thus reducing connectivity and flammability. In northern hemisphere boreal peatlands, tree presence is restricted to drier microsites (Ohlson et al. 2001) and these are prone to occasional fires (Wein 1983, Robinson and Moore 2000), albeit infrequently (Kuhry 1994, Pitkanen 1999) in comparison with south-east Australia (Kershaw and Strickland 1989, McKenzie 1997) and New Zealand (Clarkson 1997, McGlone and Wilmhurst 1999).

In studies of wild-fire dynamics, slope gradient is an important factor influencing fire severity. Fire generally moves and spreads rapidly up steeper slopes, especially with the prevailing wind (Luke and McArthur 1978). The *Sphagnum*-dominated bog areas on the Snowy Range tended to occur on gentle slopes and valley floors; thus, they were in less fire-prone topographic positions. Compared with bog, the shrub-dominated wet heath areas tended to be nearer peatland margins and woodland or forest, better drained, on shallower peat, steeper slopes, and marginally drier aspects. Furthermore, they frequently abut and merge with shrub-dominated non-wetland heath communities, thus enhancing canopy connectivity. These factors increase the potential for wet heath communities to burn when fire occurs in the surrounding landscape (Williams et al. 2008). The differences in topographic distribution between wet heath and bog concur with the observations of previous researchers in Victoria (McDougall 1982, Walsh et al. 1984, Wahren 1997).

Post-fire analysis of fire-patterns in non-wetland vegetation on the Bogong High Plains after the 2003 fires determined that 87% of closed heath plant communities were affected, 59% of open heath, and 13% of grassland areas (Williams et al. 2006). There was a strong correlation between the extent of burning and mean pre-fire shrub cover values in these communities, which were typically greater than 50% in closed heath, and less than 20% in grassland (McDougall 1982). Shrub cover is also strongly correlated with slope gradient, which is highest in closed heath and lowest in grassland (McDougall 1982, Wahren 1997, Williams et al. 2006). The *Sphagnum*-dominated bog transects examined in this study were similar to grassland in terms of area fire-affected (21%), while the shrub-dominated wet heath transects were similar to closed heath (89%). This was also directly proportional to the mean pre-fire shrub cover and height in these communities; highest cover values and tallest heights were recorded in wet heath transects. Analysis of grassland, open heath, closed heath, wet heath and bog vegetation in the Kosciuszko National Park after the 2003 fires produced similar results (Walsh and McDougall 2004). However, in that particular post-fire analysis, bog and wet heath were treated as one vegetation grouping, thus, the extent of burning was not significantly less than closed heath.

Correlations between burning patterns and plant vital attributes

While species composition in bog and wet heath formations was relatively similar, they differed in structure and the abundance of key species, most notably the cover of *Sphagnum cristatum* and myrtaceous shrub species. *Sphagnum* cover was significantly higher in bog transects and myrtaceous shrub cover significantly higher in wet heath. Myrtaceous shrubs are arguably better adapted to their more fire-prone niche in peatlands. Both *Baeckea gunniana* and *Callistemon pityoides* resprouted vigorously from stem-bases after the fire, as previously observed in burnt wetlands elsewhere (Walsh and McDougall 2004). Some recruitment from seed was also observed, although generally less in the case of the latter species. *Callistemon pityoides* is serotinous, retaining seed in woody capsules in the shrub canopy, a strategy that is common in fire-prone heathlands at lower altitude (Keith et al. 2002). Two other serotinous shrub species were recorded in peatland transects; one of these is also myrtaceous, however neither were common, and both were resprouting from the base. *Leptospermum myrtifolium* was recorded in some Myrtaceous wet heath quadrats; *Hakea microcarpa* (family Proteaceae) was an occasional presence in some wet heath transects, but appeared to be more common in neighbouring non-wetland open heath.

In plant communities at lower elevations, ericaceous species are considered to be well adapted to fire, with recruitment of seedlings generally fire-cued (Keith 1997, Gilmour et al. 2000, Wills and Read 2002, 2007), and many species capable of resprouting. However, there is evidence to suggest that some ericaceous species that grow in less fire-prone environments and niches are less responsive to fire related germination cues (Thomas et al. 2003). There are many ericaceous species in montane, subalpine and alpine plant communities in Victoria (e.g. *Leucopogon*, *Acrothamnus*, *Epacris*, *Richea*, *Pentachondra*, McDougall and Walsh 2007) and fire-response and regeneration strategies are variable. Nine different ericaceous species were recorded in the peatland transects established for the regional floristic studies (Chapters 3 and 4). Six of these appear to be incapable of resprouting if subjected to 100% crown damage during fires (J. Shannon *pers. obs*., Walsh and McDougall 2004). At the same time, limited recruitment was observed in most of these species in unburnt areas, although in some, recruitment was significantly enhanced in the post-fire environment (e.g. *Epacris paludosa*). Obligate-seeder species are considered to be at a disadvantage in fire-prone wet heath communities at lower elevation, because of competition from previously established species that have the capacity to resprout (Specht 1981, Keith et al. 2002). Hence, as a plant strategy it is more common in ‘stressful’ environments where vegetation gaps are common and there is less competition from established species (Pausas and Bradstock 2007, Clarke and

Knox 2002). In these peatlands the ‘stress’ and lower productivity are related to low temperature and short growing seasons rather than lack of moisture (Williams and Costin 1994), as in semi-arid environments. Hence, the competitive superiority of resprouter species is perhaps sufficiently diminished to provide more opportunities for obligate-seed regenerators.

6.4.2 Early patterns of regeneration

Most examinations of post-fire recovery trends in southern hemisphere peatlands have concluded that the cover of live vegetation returns to pre-fire levels after 5-10 years (Timmins 1992, Clarkson 1997, Wahren and Walsh 2000, Johnson 2001). However this can be slower in less favourable locations and microsites. The pre-fire structure and abundance of dominant species like *Sphagnum* and the common shrubs takes 15-20 years or longer to return (Wimbush et al. 1979, Timmins 1992, Wahren and Walsh 2000). Most obligate-seeding shrubs in particular are slow to recover to pre-fire cover abundance, especially ericaceous species (Wahren and Walsh 2000, Johnson 2001, Norton and de Lange 2003). The overall vegetation cover in fire-affected transects after 28 months was approximately 75%, but less in wet heath transects. Resprouting and rhizomatous species were quick to respond, especially graminoids. For example, the scale-rush *Empodisma minus* had generally exceeded pre-fire cover values in most transects by 28 months post-fire. Sedges like *Carex gaudichaudiana* thrived in the post-fire environment and had increased cover relative to pre-fire.

In most cases it appears that this dominance by graminoids and herbaceous vegetation is short to medium-term only, while the ‘slow to respond’ species recover (Timmins 1992, Norton and de Lange 2003). In other cases, dominance by graminoids may be indicative of drier peatland conditions and more permanent vegetation change. The cover of *Empodisma minus* in peatlands at Mt Buffalo 14 years after a fire in 1985 was twice its pre-fire level (Wahren and Walsh 2000). In the same study, the myrtaceous shrub *Baeckea gunniana* was also more abundant than pre-fire, perhaps indicating a steady post-fire change in structure from *Sphagnum*-dominated bog, to shrub-dominated wet heath. Furthermore, *Richea continentis*, had not recovered to pre-fire abundance levels, having declined from 8 to 1% cover. The cover of *Richea* in wet heath transects declined from 21% to 3% over the three-year period spanning the 2006-2007 fires, and from 15% to 9% in bog transects.

It is important to note the influence of patches of unburnt vegetation along transects on these results and figures. The bog formation transects were not significantly different at any of the three time stages, indicating that vegetation cover and structure were not substantially altered by the fires, even in the short-term. This is largely due to the greater proportional representation of unburnt area along these transects. While *Empodisma minus* cover had exceeded pre-fire levels in bog transects, this had not yet occurred in the more severely burnt wet heath transects. The increased cover in bog transects did appear to be largely due to the post-fire behaviour of *Empodisma* in unburnt and lightly scorched quadrats. It appeared to be benefitting from a reduction in the vigour and competitiveness of *Sphagnum cristatum* during the early post-fire period. *Epacris paludosa* and *Baeckea gunniana*, while still below pre-fire cover levels after 28 months, were near pre-fire frequencies of occurrence, and were responding rapidly as observed in other studies (Wahren and Walsh 2000, McDougall 2007).

Of the two wet heath community types, Myrtaceous wet heath appears the better adapted to fire. This community type is most similar to the '*Baeckea gunniana – Callistemon pityoides – Sphagnum cristatum* wet heathland' community type of McDougall and Walsh (2007). Fire regime and fire response may be the environmental factors most responsible for the differences between this community and the '*Richea continentis – Carpha nivicola – Sphagnum cristatum* wet heathland' community type of McDougall and Walsh (2007). The Tall wet heath communities of this examination appear to be an ecotone between the latter and adjacent non-wetland heath communities, hence are a 'disclimax' community in a state of 'flux'. The pre-fire cover of *Richea continentis* is often greatest in long unburnt Tall wet heath devoid of *Sphagnum*.

Like the other common peatland shrubs, *Richea continentis* expands and increases in cover as *Sphagnum* recedes. However, of all the peatland shrubs, it is the most susceptible to fire-induced mortality in these microsites. Therefore, the mosaic of *Sphagnum*-dominated, shrub-dominated, and sedge-dominated areas in peatlands is partly a function of cyclic pattern and process (Watt 1947, Costin 1954, Ashton and Hargreaves 1983). The larger patches dominated by shrubs, restiads and graminoids, which are generally drier, more disturbance prone, and devoid of *Sphagnum*, are probably ecotones which are vulnerable to colonisation by non-wetland species after a fire.

These more ‘marginal’ peatland communities have experienced the largest short-term change to structure. Some of these would appear to be at risk of crossing ‘ecological thresholds’ and trending towards ‘alternative’ stable states (Wilson and Agnew 1993, Beisner et al. 2003, Suding et al. 2004). They have also experienced the greatest increase in species richness and exotic species numbers during the post-fire period. Many of the species colonising are from adjacent non-wetland communities, including eucalypt species, *Grevillea australis* (open heath), *Hovea montana* (open heath), and *Poa* species. Colonisation of freshly exposed peat surfaces by exotic species after fire has been observed elsewhere in southern hemisphere peatlands (Timmins 1992, Johnson 2001, Walsh and McDougall 2004, McDougall 2007).

In the Central Highlands transects, colonising species from neighbouring non-wetland vegetation included *Leptospermum grandifolium*, *Eucalyptus pauciflora*, and *Leionema phylicifolium*. Other species considered more peripheral to peatlands also appeared to be ‘moving’; these included *Olearia algida* and *Ozothamnus* sp.1. Regeneration has not yet been recorded in some of the less common shrub species, including *Epacris petrophila* and *Epacris microphylla* var. *rhombifolia*. The latter was common before the fires in some montane sites; both appear incapable of vegetative regeneration. Seedlings of these species are yet to be positively located.

Sphagnum recovery is variable but generally slow where burning was severe. However, in the Snowy Range montane transects it was relatively rapid, despite being severely fire-affected. At Mount Buffalo, in north-eastern Victoria, *Sphagnum cristatum* required 15 years to reach pre-fire cover levels (Wahren and Walsh 2000). The fluctuations in cover during the 15-year period of that study were possibly a response to alternating favourable and unfavourable growing seasons. In south-eastern Australia, *Sphagnum* species rely upon vegetative regeneration from surviving cells after fire, provided that conditions are moist enough (Wahren et al. 1999a). In sections where the species has been removed, re-establishment depends upon surface-water transported *Sphagnum* fragments from neighbouring intact sections. Regeneration post-fire from protected surviving cells within hummocks has also been observed in the northern hemisphere, where regeneration via spore germination was also recorded (Clymo and Duckett 1986). Sporophyte production appears to be rare in south-east Australian *Sphagnum* species (Farrell and Ashton 1973, Wahren et al. 1999a), although this phenomenon was witnessed over several autumns (March-April) in isolated small patches within sites affected by fire in 2003 (J. Shannon *pers. obs.*). The incidence of *Sphagnum* recruitment from spores is unknown in Australian peatlands, but has been observed in southern New Zealand peatlands (Johnson 2001).

Of particular interest is the response of *Astelia alpina*. Fourteen months after the February 2009 fires, *Astelia alpina* had regained its previous cover levels. Species of *Astelia* are common in montane and subalpine herbfield, wet heath, and bog vegetation in New Zealand, Tasmania, and southern South America (Pisano 1983, Kirkpatrick 1983, Gibson and Kirkpatrick 1985b). Similar post-fire responses in *Astelia* species have been noted in Tasmania (Ratkowsky and Ratkowsky 1976, Kirkpatrick and Dickinson 1984) and New Zealand (Allen and Partridge 1988, Johnson 2001). Indeed, they seem capable of expanding after fire in some more fire-sensitive montane /subalpine communites in Tasmania, together with other graminoid species (Kirkpatrick and Dickinson 1984).

The key species in this examination were all present by 24 months post-fire. Therefore, they are arguably not fire-sensitive, unlike for example some species in Tasmanian montane and subalpine communities. The keystone species in some Coniferous heath and Deciduous heath areas in Tasmania were eliminated by a single fire and appear unlikely to return to these areas given their documented limited seed dispersal capabilities (Kirkpatrick and Dickinson 1984). That said, the two Victorian species of *Richea* are obligate seeders, and appear to take 6-10 years to reach flowering and seed production stage, which is slower than the other key peatland shrub species. Therefore, these species are the most susceptible in the event of future increases in fire-frequency. Most of the nine *Richea* species that occur in Tasmania, are similarly slow to respond after fire (Ratkowsky and Ratkowsky 1976, Kirkpatrick and Dickinson 1984). The absence of *Richea continentis* from montane peatlands in the Snowy Range region and fire-prone subalpine Myrtaceous wet heath vegetation is likely to be partially linked to the prevailing fire-regime. The presence of *Richea victoriana* in montane peatlands in the Central Highlands region (west of the 'Macalister' line, see Chapter 4), often adjacent to *Nothofagus cunninghamii*, is consistent with a less variable rainfall regime, higher humidity, and longer mean inter-fire periods than in the former region.

6.4.3 Regeneration niche

The mix of microsite types in severely burnt areas is important. The micro-topographic diversity aids recovery of initial structure and provides a variety of different regeneration niches (Grubb 1977). The inter-hummock spaces were utilised by seedling regenerators. Indeed, recruitment from seed in hummocks was uncommon. However, scorched hummocks were important to resprouting species and this study has shown that shrub species in particular are afforded some protection from fire when growing initially in a continuous high cover of *Sphagnum*. Some of the more fire-sensitive shrub species are more likely to survive and recover in these microsites than in inter-hummock spaces. This was true for *Richea continentis* and the other ericaceous species. *Empodisma minus* also commonly resprouts from hummocks and hollows, but recruits from soil-stored seed in hollows only. Many herbaceous species take advantage of the exposed peat surfaces of inter-hummock spaces post-fire, including *Drosera peltata* and creeping species like *Scaevola hookeri*, *Gonocarpus micranthus* and *Nertera granadensis*. Species from many of the same genera appear to perform similar post-fire roles in burnt New Zealand peatlands (Timmins 1992, Johnson 2001).

The third ‘patch’ or microsite type in the post-fire mosaic were the unburnt patches, which act as refugia for fire-sensitive species (*Richea*), and also sources from which *Sphagnum* expands and recolonises burnt sections (Wahren and Papst 1999, McDougall 2007). Most of the common shrub species are also capable of vegetative spread. They generally expand through the aid of layering stems and adventitious roots, in unison with the ‘carpet’ of spreading *Sphagnum cristatum*. This, too, is an important method of post-fire shrub recovery. Unburnt shrubs in these virtual ‘islands’ of unburnt vegetation continue to flower and produce seed while the new cohort in burnt patches are developing to maturity.

CHAPTER 7

SYNTHESIS, CONCLUSIONS AND FUTURE RESEARCH

In this thesis, peatland communities were studied in eastern Victoria across a broad geographical, altitudinal and topographic range. Peatlands cover less than 1% of the land area above 1000 m elevation in eastern Victoria and are therefore strongly influenced by adjoining plant communities, ecological processes, and introduced forms of disturbance. Data was collected from south-western regions, which are close to Bass Strait and have an oceanic influence on their climate, and north-eastern regions with stronger continental influences. The elevation range was from sites surrounded by montane forest to those in alpine landscapes. In these areas, peatlands occur in treeless valley bottoms, on poorly drained lower valley slopes, and ‘seepage’ areas in steeper mid-slope positions.

The purpose of the study was twofold. The first broad aim was to describe and examine structural and compositional differences in peatland communities *within* and *between* sub-regions across eastern Victoria. Past research has focussed mostly on subalpine and alpine peatlands so it was unclear how peatlands, more broadly, can be characterised in Victoria. The second broad aim was to examine peatland patterns and processes, recruitment and regeneration, and some factors that influence these, specifically hydrology and disturbance. Two major landscape-scale fire ‘episodes’ occurred in the high country of south-east Australia during this research (2006-07 and 2009). This created the opportunity to examine aspects of peatland ecology that may not arise again for several decades.

Here, I summarise the major findings in relation to my research questions, and highlight future areas of ecological investigation that I consider require further research.

7.1 Patterns associated with gradients in altitude and topography

Peatlands span several vegetation formations; surface water is widespread at one end of the spectrum and uncommon at the opposite end. These formations are fen, bog (valley, raised), and wet heath. In Australia, New Zealand and other parts of the southern hemisphere, the presence and abundance of restiads is perhaps a better method of distinguishing ‘bog’ from ‘fen’ than the presence of *Sphagnum* (Agnew 1993, Van Breeman 1995, Whinam and Hope 2005, Clarkson and Clarkson 2006). Fens are mostly associated, in all regions of the world, with dominance by species of *Carex*, which is correlated with higher pH and nutrient availability.

The distribution of the four formation types sampled in this thesis is largely determined by topography, regardless of altitude. Sedge- and graminoid-dominated fens, devoid of restiads, occurred on the flat (< 2% slope) valley floors of larger stream catchments (Figure 7.1). *Sphagnum*-, sedge- and restiad-dominated valley bogs occurred on gentle slopes (2-4%), often adjacent to larger ‘fen’ pools. Raised bogs mostly occurred in more sloping locations (4-15%) and were dominated by *Sphagnum*, restiads and dwarf shrubs. Shrub- and restiad-dominated wet heaths were generally in the better drained locations, often in seepage areas on quite steep slopes (4 to 20%) (Figure 7.2).

The environmental and structural variables most associated with the differences between bog (valley, raised) and wet heath were peat depth, shrub cover, shrub height, litter and aspect dryness; all of these were greater in wet heath communities, with the exception of peat depth. Bogs were most associated with a higher prominence of *Sphagnum cristatum*, *Carex gaudichaudiana*, *Empodisma minus* and *Richea continentis*. Wet heaths were mostly associated with higher percent cover of the shrubs *Baeckea gunniana* and *Epacris paludosa*, except in exposed alpine areas where *Epacris glacialis*, *Astelia alpina* and *Empodisma minus* were dominant. In higher rainfall montane areas, fens were dominated by *Carex* and *Poa*, but contained taller shrubs (e.g. *Richea victoriana*, *Leptospermum grandifolium*, *Epacris microphylla* var. *rhombifolia*), and the small fern *Blechnum penna-*

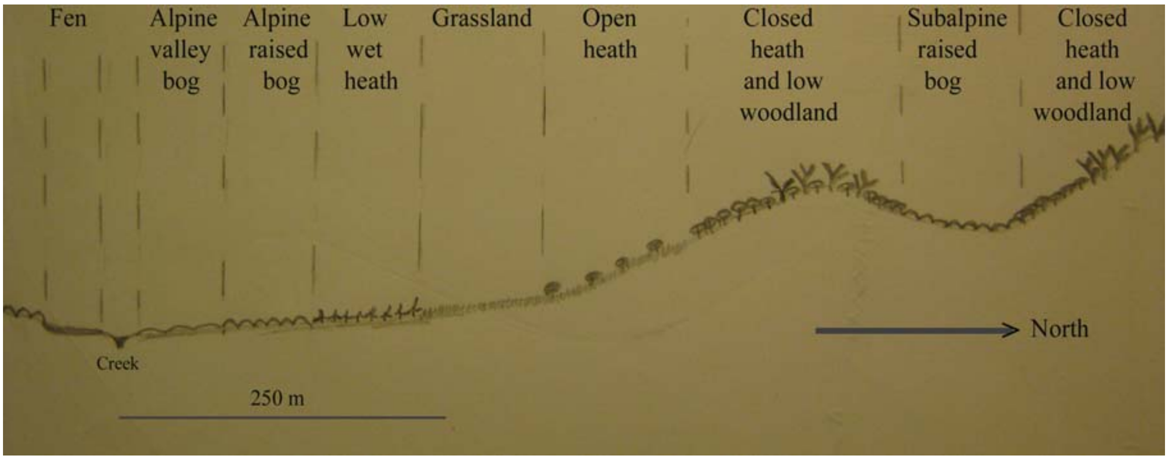


Figure 7.1: Landscape context of peatland communities at higher elevations (~ 1650-1750 m). The diagram shows the relationships between peatland communities, other non-wetland vegetation, slope and aspect. Raised bog communites in some sheltered sites at high elevation are floristically consistent with Subalpine raised bog, despite sometimes occurring at marginally higher altitudes than Alpine raised bog.

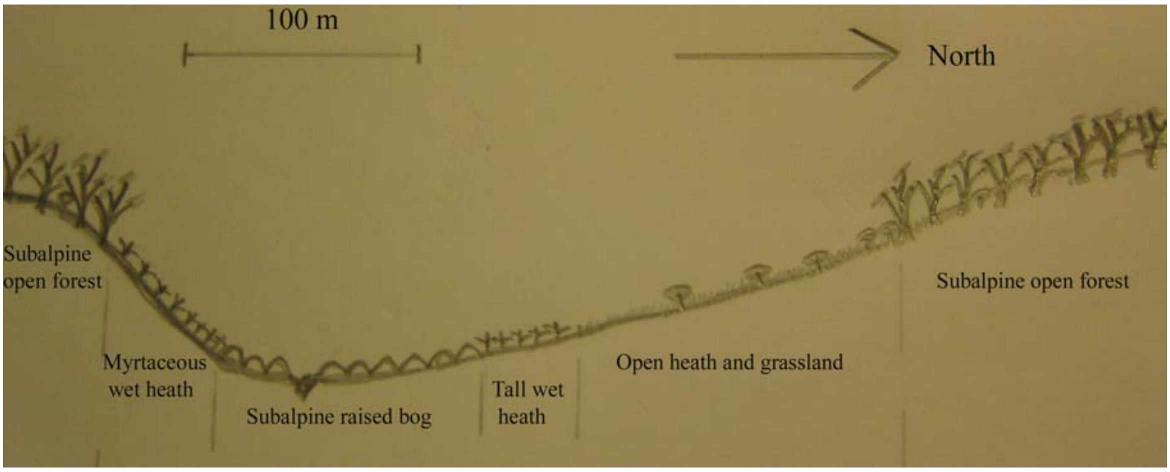


Figure 7.2: Landscape context of peatland communities at Cave Gate Creek in the Snowy Range region (~ 1400-1500 m). The diagram shows the relationships between peatland communities, other non-wetland vegetation, slope and aspect.

marina. The nutrient availability in these may be influenced by seepage and run-off from adjacent tall open forests.

The biggest changes associated with increasing altitude occurred in the raised bog and wet heath sub-formations. In montane and lower subalpine areas, the wet heath communities were dominated in equal measure by myrtaceous and ericaceous shrub species, with restiads, and an assortment of other shrub families also being represented to varying degrees (Proteaceae, Asteraceae, Fabaceae). In alpine and more exposed subalpine wet heaths, the shrub complement was dominated by ericaceous species and the vegetation structure a more diverse mix of these and hard-leaved graminoids (*Astelia*, *Oreobolus*), restiads (*Empodisma*), herbs (*Gentianella*, *Diplaspis*, *Celmisia*), and grasses (*Poa*, *Rytidosperma*). A similar altitudinal progression was evident in raised bogs with many of the same species involved, but with the inclusion of *Sphagnum cristatum*. Restiads, in particular *Empodisma minus*, were prominent in all wet heath and bog communities, but reached their highest cover abundances in montane and lower subalpine areas.

The environmental and structural variables most often associated with these altitudinal vegetation changes were distance to woodland or forest, lowest period moisture index, precipitation of the driest quarter, radiation of the driest quarter, and shrub height. The former three were generally greater at higher elevation; the latter two were greater at lower elevation (Figure 7.3). These correlations were strongest and most evident in the transition from subalpine to alpine areas. Peat depth was generally more associated with the topographic gradient, being deeper in lower topographic positions. However, as might be intuitively expected, it was also partly negatively correlated with altitude. Temperatures are less limiting in montane and lower subalpine communities; thus, biomass accumulation more rapid, and peat depths greater. Montane peatlands have also generally been functioning as such for longer (Kershaw and Strickland 1989, McKenzie 1997, Martin 1999).

7.2 Peatland vegetation patterns associated with gradients in oceanicity

A similar progression in peatland vegetation to that associated with increasing altitude can also be detected with movement south-west across the highland areas of Victoria. An approximate bio-geographical dividing line is provided by the Macalister Valley, which runs south to Gippsland from the Great Diving Range, and separates the Baw Baw-Central Highlands region in the west, from the remaining more eastern and northern

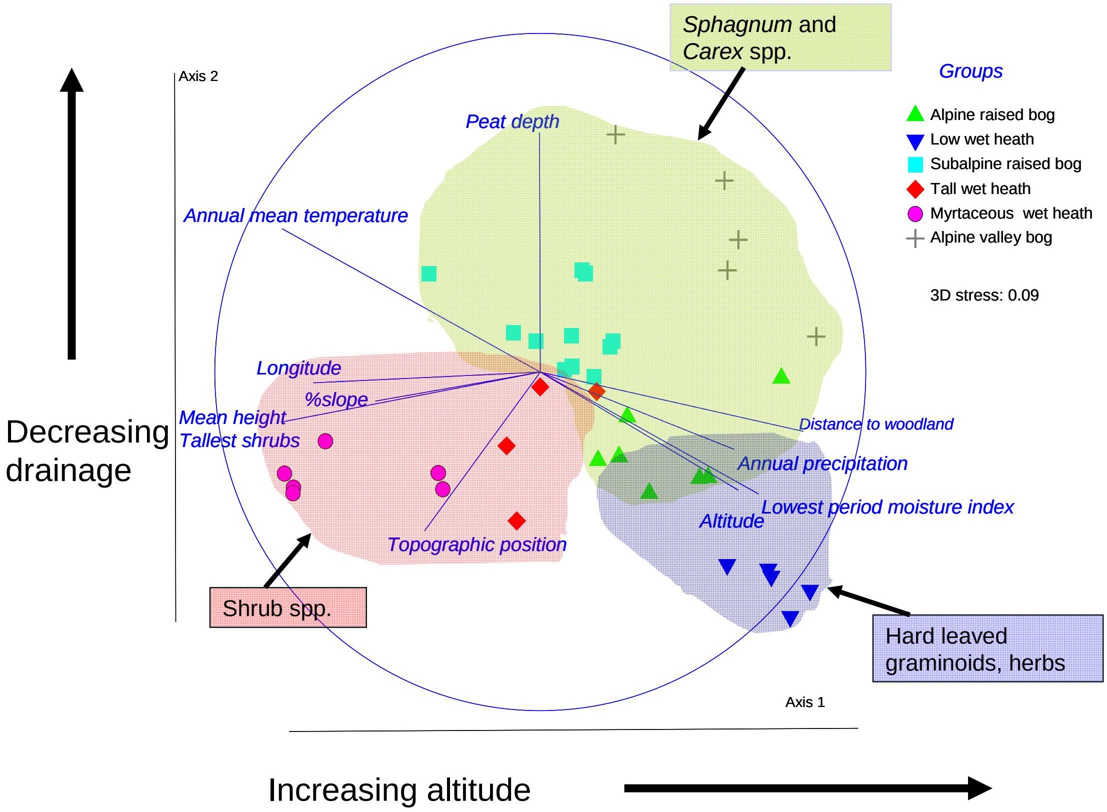


Figure 7.3: Ordination of transects from the Bogong region based on the frequency of occurrence data. This illustrates the relationships between altitude, topography and peatland vegetation patterns. The differences in plant group dominance are also indicated.

regions. The montane peatlands west of the 'Macalister line' differed from those further east in both context and composition. In context, they are associated with tall open forests containing *Eucalyptus delegatensis* and *Eucalyptus nitens*, and cool temperate rainforest with *Nothofagus cunninghamii*. The peatlands contained *Richea victoriana* and *Epacris microphylla* var. *rhombifolia*, species either absent or rare from montane peatlands in the east. Montane peatlands in the east were associated with open forest or, in some cases woodland, including species like *Eucalyptus rubida*, *E. dalrympleana*, and *E. stellulata*. Peatland vegetation in these areas east of the Macalister Valley was similar to montane wet heaths in southern NSW and far East Gippsland (Keith 2004, Ladd 1979a) containing species like *Baloskion australe*, *Baumea gunnii*, *Comesperma retusum*, and *Callistemon pityoides*. These are either rare or absent from 'western' montane peatlands.

The differences are perhaps more pronounced at subalpine elevations. Raised bogs in the east are more *Sphagnum* and shrub-dominated. Those in the west, like those in alpine areas of the east (> 1650 m), are a more even mix of shrubs, hard-leaved graminoids, restiads, and herbs. These include species like *Astelia*, *Oreobolus*, *Gentianella*, *Euphrasia*, *Carpha*, *Coprosma* and *Rytidosperma*. The most useful explanatory BIOCLIM variables were precipitation of the driest quarter, moisture index of the driest quarter, mean temperature of the coldest period, temperature range variables, and lowest period radiation. All of these were higher in western peatland sites at equivalent elevations, except for the temperature range variables and ‘lowest period radiation’, which were higher in the north-east. These are correlated with estimated values for hygric continentality (west of the Macalister 32-38°, east of the Macalister 36-42°), suggesting that more oceanic climatic conditions prevail in the south-western regions. Similar, albeit stronger vegetation gradients are associated with peatlands at higher latitudes elsewhere in the southern hemisphere (Gibson and Kirkpatrick 1985b, Kleinebecker et al. 2007). Many of the same plant groups, species and genera are involved in these regions also.

7.3 Peatland vegetation patterns associated with differences in microclimate and hydrological characteristics

The floristic and structural differences associated with topographic variation are linked to drainage and thus, water table behaviour. Water table levels in several of the peatland communities described in Chapter 3 were monitored over periods of up to three years. Peat depths in both valley bogs and raised bogs were often greater than one metre and more than two metres in some locations. The water table in valley bog areas is constantly within 25 cm of the surface in all but the driest months of the driest years (Figure 7.4). In Raised bog areas, water table levels were slightly lower, but still relatively stable, and mostly in the 15-35 cm below surface range during the warmer months. Tall wet heath communities generally occur on more decomposed peats, still relatively deep (0.5-1.5 m), but depth to water table was more variable and generally in the 20-50 cm below surface range. The low wet heath communities in exposed areas above 1650 m occur on shallow, dried peat (25-45 cm deep). The water table was highly variable in these areas. Surface

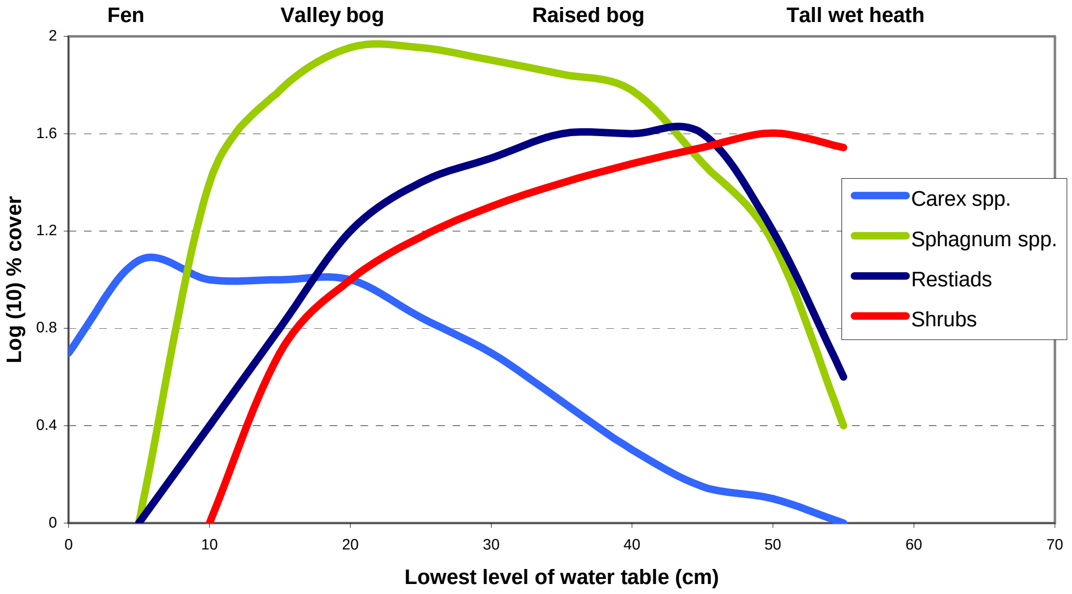


Figure 7.4: Relationship between water table, vegetation formations and cover of key plant groups.

water was possible even during the warmer months, and periods when water tables were below the underlying bedrock were common in the drier months of the year. In general, high, stable water tables favoured *Sphagnum*, sedges and some ericaceous shrub species; lower, more variable water table levels favoured shrubs in general, taller shrub stature, and higher grass cover. Restiads displayed a broad water level tolerance, but were absent from fens, and most abundant in 15-40 cm below surface water table range.

The temperature data collected during water table monitoring also gave insights into microclimatic differences between the communities. Some of the more sheltered Raised bog and Tall wet heath communities appear to accumulate greater depths of snow in the winter months and remain snow covered for longer. This reduces exposure to the winter extremes of wind and low temperature. The common peatland shrubs *Epacris paludosa* and *Baeckea gunniana* are more associated with these communities than the more exposed ‘alpine’ raised bogs and low wet heaths, which accumulate less winter snow and are frost-prone even during the warmer months. *Epacris paludosa*, in particular, is rare in the exposed high altitude peatlands on the Bogong High Plains. In these locations it is replaced by *Epacris glacialis* and, to a lesser extent, *Epacris celata*. The more exposed raised bogs and low wet heaths generally showed greater diversity in vegetation structure and composition, except in the wettest areas dominated by valley bogs and fens.

7.4 Fire patterns in peatlands and early regeneration trends

Climate change scenarios for south-eastern Australia predict drier conditions and more frequent and intense droughts (Hennessy et al. 2005). Drier climates are likely to increase the fire frequency in many parts of the world, including south-eastern Australia (Overpeck et al. 1990, Hennessy et al. 2005), and it is therefore important to understand how this is likely to affect the extent, composition and structure of peatland plant communities.

There has been ample opportunity in the last decade to study the effects of fire on Victorian peatlands. Large wildfires have affected highland areas in the centre and east of the state on three separate occasions (2003, 2006-2007, 2009). Prior to these, fires of similar scale and severity had not occurred in the region for more than 60 years. The synthesis of research and observations from these episodes suggest that the extent of fire incursion into peatlands is dependent on proximity to forest or closed non-wetland heath communities (Figure 7.5). The distribution of these in mountain areas is determined by temperature extremes, slope, soil depth and drainage. The distances separating forest, woodland and closed heath, from peatland areas, increases with altitude and declining slope (Figure 7.6). Hence, on the gentle slopes of the highest plains (e.g. Bogong), peatland communities are more often adjacent to grassland or open heathland. Futhermore, the structural diversity and lower shrub stature of ‘exposed’ peatland communities contributes to this lower flammability. Slow growing chionophilous species like *Epacris glacialis*, *Oreobolus distichus*, *Carpha nivicola*, *Gentianella muelleriana* and *Celmisia pugioniformis* are prominent here. All are characteristic of harsh, wet,

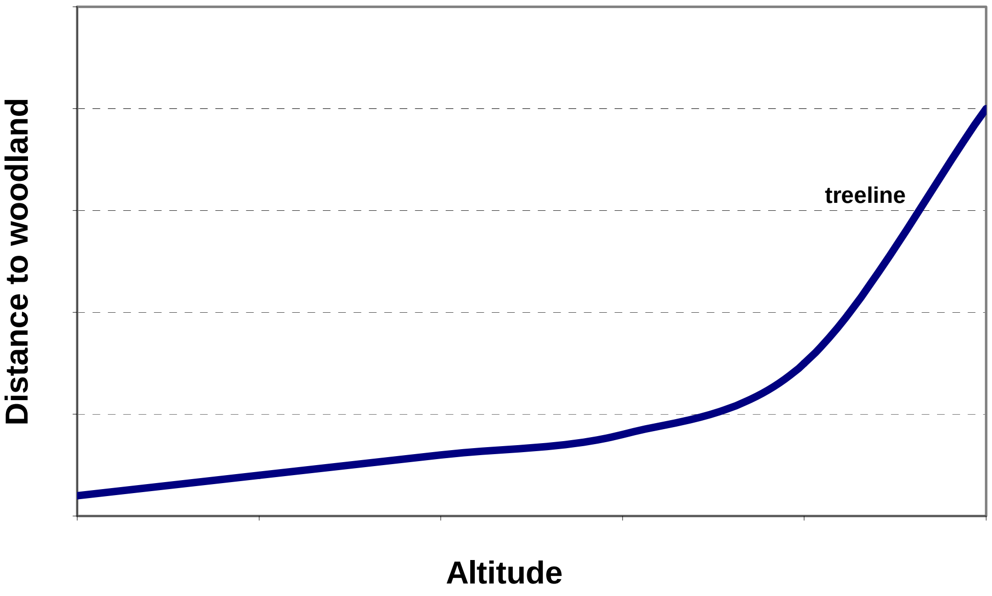


Figure 7.5: Relationship between altitude and the mean distance between peatland boundaries and forest or woodland boundaries.

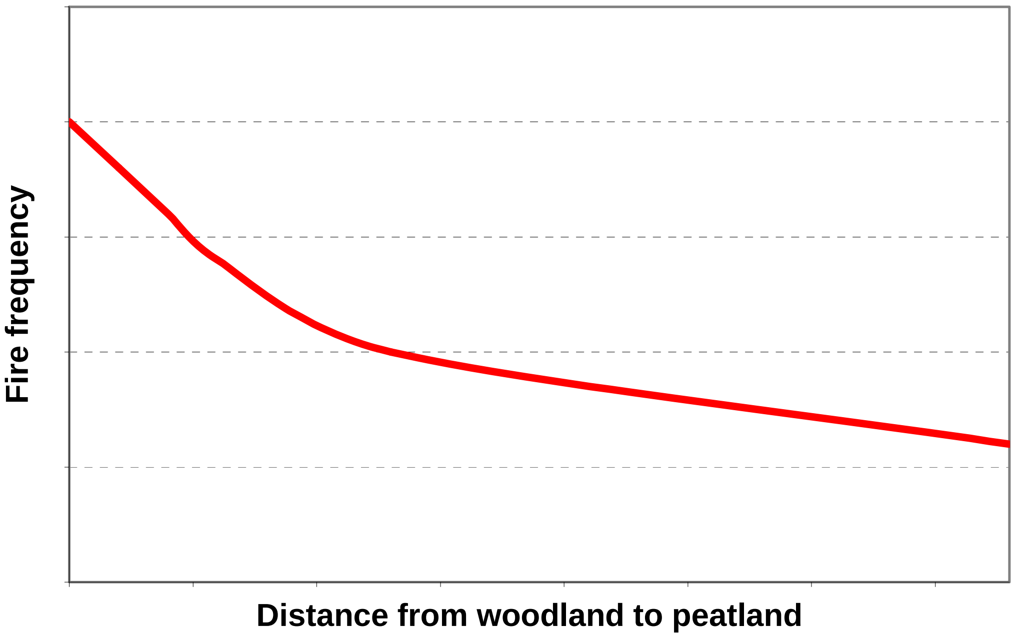


Figure 7.6: Generalised relationship for fire frequency and spatial separation between woodland and peatland.

windswept, communities elsewhere in the southern hemisphere in which fire seldom if ever occurs.

On steeper slopes and at lower elevations, peatlands more often adjoin shrub- and tree-dominated non-wetland communities (closed heath, open forest, tall open forest). Hence, in these areas the cycle of major disturbance (fire) is more linked to that of the surrounding vegetation. Thus, the grass- and herb-dominated adjoining communities can provide peatlands with a buffer from severe burning on occasions when large fires occur in nearby montane or subalpine forests.

Within peatlands, it was the *Sphagnum*-dominated areas that were least affected by fire. Both the microclimate (frost, cold-air drainage) and the high water tables serve to limit shrub cover and stature, which inturn, limits fire incursion and the severity of burning. Fire-sensitive obligate-seeder shrubs like *Richea continentis* are adept at coexisting with *Sphagnum* in these areas and are afforded some refuge from fire. The shrub-dominated wet heaths in the better drained areas of peatlands are more often close to neighbouring forest, especially at lower elevations. These were more severely affected by fire. The dominant shrub species in these communities were generally those better adapted to fire, by either resprouting vigorously (*Baeckea*, *Callistemon*, *Hakea*), or rapidly recruiting from soil-stored seed (*Epacris paludosa*). The common peatland grass *Poa costiniana* is more abundant in these communities and resprouts vigorously. Subsequent flowering of this species in the first one or two growing seasons is enhanced and widespread compared to long unburnt areas (pyrogenic flowering).

Thus, early stages of post-fire regeneration are dominated by graminoids, rhizomatous species, resprouting shrubs, and the creeping bare-peat colonising herbs (*Gonocarpus*, *Scaevola*, *Nertera*, *Asperula*). The species that benefit most in the early recovery phase (0-5 yrs) are the above mention herbs, and graminoids such as *Carex*, *Poa*, *Luzula*, *Schoenus* and *Isolepis*. Those species whose overall presence is little affected by fire in the short to medium term include *Astelia alpina*, which continues growing from an apical meristem that is protected by a thick basal leaf-sheath. The abundance of this species in

peatlands severely burnt in February 2009 had returned to pre-fire levels within 18 months. Restiad species also recovered rapidly, both vegetatively and from seed. In some cases the cover of *Empodisma minus*, 28 months after the December 2006 fires, was greater than pre-fire.

The two most common and widespread shrub species, although diminished in cover in severely affected communities, are arguably little affected. *Baeckea gunniana* has maintained pre-fire frequencies of occurrence, largely via vegetative means; *Epacris paludosa* has done this also, via prolific seedling recruitment and vigorous early growth. The species most affected in the short to medium term are *Richea continentis* and *Sphagnum*. The former, although common in *Sphagnum*-dominated communities pre-fire, reached its highest cover abundances in some wet heaths which were subsequently severely burnt. In these areas there has been little, if any, post-fire seedling recruitment and recovery. Rapidly responding species like *Poa*, *Baeckea*, and some non-wetland species appear to be expanding into these gaps (e.g. *Grevillea australis*, non-wetland graminoids).

Water table level was also monitored in some recently burnt hummocks and hollows. Recovery of vegetation cover has been rapid in burnt lawn areas (> 50% cover) where depth to water table is generally 10-20 cm during the growing season. Monitored levels in large, severely burnt hummocks were considerably lower and in the 30-70 cm below surface range during the same period. Vegetation recovery in these microsites has been much slower; overall percent ground cover is still below 40%. Grasses and non-wetland species appear to be establishing in these.

The recovery of *Sphagnum* has been variable. In some severely burnt but sheltered montane transects, percent cover had returned to pre-fire levels by 28 months post-fire. *Sphagnum* recovery has been slower in some wet heath communities in which pre-fire cover was less than 30%. It is too soon to determine whether these are longer-term trends or just part of the spatial and temporal variability associated with post-fire regeneration in high altitude peatlands.

All these data suggest that within the ‘peatland vegetation complex’ fire-regimes are variable, and the species contained vary accordingly in their method of recovery, speed of recovery, and general fire tolerance. This variation in fire regime is generally correlated with altitude, but within each altitude ‘zone’ topographic factors can enhance or ameliorate the influence of allogenic influences (e.g. proximity to forest communities). Therefore, in some montane areas, where the surrounding landscape is generally dominated by open forest or tall open forest, local relief can produce ‘cold-air drainage’ of variable strength. In the montane locations where this influence is particularly strong, frost-hollow grasslands and heathlands can occur on the gentle lower valley slopes. These contain species normally seen at higher elevation (Farrell and Ashton 1973, Slatyer 1989). Peatlands associated with these appear to be less frequently or extensively affected by fire than those at equivalent elevations in hillside seepage areas, where abutted by open forest. This pattern is also seen in subalpine and alpine areas although the contrasts in context are gradually reduced in accordance with the diminishing cover of trees in the surrounding landscape.

The two separate fires and regional differences

The relationship between peatland communities and surrounding vegetation also changes at equivalent altitudes along the oceanicity-continentality gradient, best illustrated by the presence of tall open forest and cool temperate rainforest west of the ‘Macalister line’, and open forest and woodland east of the ‘line’. The eucalypt species in montane and subalpine areas of the Snowy Range and Dargo High Plains area mostly regenerate vegetatively via lignotubers and epicormic buds (e.g. *E. pauciflora*, *E. rubida*, *E. dalrympleana*). The Baw Baw-Central Highlands subalpine sites were also surrounded by lignotuberous species (*E. pauciflora*), but montane sites abutted tall open forest and cool temperate rainforest. The eucalypt species are fire-sensitive in these areas, easily fire-killed, and regenerate from canopy stored seed (*E. delegatensis*).

With this in mind, it is interesting to speculate about the differences between the 2006-2007 ‘Great Divide’ fires, which only affected peatlands east of the Macalister Valley, and the February 2009 ‘Black Saturday’ fires, which only affected those in the west. The former burnt over a period of many weeks, mostly at low to moderate severity; the 2009 fires burnt at higher severity over a relatively shorter period (Table 7.1). The December 2006 fires burnt 90% or more of the understorey vegetation in the montane /subalpine tableland areas, most of the tree-canopy in these areas was not consumed. Burning in peatlands was patchy, and most contained a mosaic of burnt and unburnt areas at various scales (Tolsma and Shannon 2007). The 2009 fires in the Central Highlands montane-subalpine areas were generally of higher severity, consuming both understorey and canopy. Most peatland areas were severely burnt, with few (if any) unburnt patches (Tolsma and Shannon 2009). Therefore, the peatlands in each region appear to reflect the fire-regimes of the surrounding landscape and the vital attributes of the common or dominant species.

Average time intervals between major fires are likely to be longer in the regions west of the Macalister Valley. It has been estimated that prior to 1830 (settlement) fire occurred in the higher altitude areas of Victoria and New South Wales approximately once or twice per century (Banks 1989, McCarthy and Tolhurst 2000, Zylstra 2006, Williams et al. 2008). East of the Macalister Valley in Victoria it was possibly slightly more frequent above 1000 m elevation (twice?). At equivalent altitudes west of the ‘Macalister line’ it may have been slightly less frequent (once?). The postulated differences in fire-frequency are correlated with the documented geographical differences in the timing of the peak fire period in eastern and southern Australia. In southern New South Wales, the peak period is late spring and early summer; in south-west Victoria it is late summer and early autumn (Fox 1999, Keith et al. 2002). The highland areas are spread along this gradient, thus the peak period is generally December-January, east of the ‘Macalister line’, and January-February, west of the ‘line’.

Table 7.1: Comparison of the regions affected by the 2006-2007 and 2009 fires.

	Region	
Attribute	**Central Highlands**	**Snowy Range**
Surrounding vegetation types	Tall open forest Cool temperate rainforest Open forest Closed heath	Open forest Woodland Open heath Grassland
Productivity in adjacent vegetation	High biomass production	Moderate biomass production
Montane tree-canopy species characteristics	High proportion of fire-sensitive obligate seed regenerators	Low proportion of fire-sensitive obligate seed regenerators
General vegetation structure	Grassland rare in montane and subalpine areas	Grassland common in montane and subalpine areas
Comparison of recent landscape-scale fires in montane and subalpine areas	Began early February Short fire High mean fire severity Ground layer vegetation and tree-canopy consumed Few if any unburnt sections in peatlands	Began early December Long fire Moderate mean fire severity Ground layer vegetation consumed tree-canopy mostly intact Mosaic burning in peatlands. 'Islands' and patches of unburnt vegetation.
Estimated pre-European fire regime above 1000 m	Mean interval between fires ~ 60-100 years High mean fire severity	Mean interval between fires ~ 40-60 years Moderate mean fire severity
Climate	High rainfall, reliable, moderate seasonality and moderate variability. More frequent cloud cover and higher humidity	Moderate - high rainfall, high variability less cloud cover, lower mean humidity
Astelia	*Astelia* common in subalpine sites	*Astelia* uncommon in subalpine sites
Richea spp.	*Richea victoriana* in montane peatlands	No *Richea* spp. in montane peatlands
Nothofagus	Often in adjacent to montane & subalpine peatlands	Absent

Recovery of pre-fire vegetation structure in peatlands is likely to be more rapid where a mosaic of burnt and unburnt patches exists. Vegetative expansion from unburnt patches can be relatively rapid. Therefore, peatlands severely burnt in February 2009 are likely to require more time to recover pre-fire vegetation structure. Prior to 2003, the majority of highland peatlands in Victoria had not been affected by fire for at least 50 years. However, in most of those affected by fire in recent years, there are patches that escaped burning and therefore may not directly experience fire for another 50 years or more.

7.5 Future work

Pattern and process, post-fire regeneration, key species autecology, hydrology

In Australia, some researchers have attempted to unravel the processes of cyclic regeneration and succession in peatlands (Costin 1954, Ashton and Hargreaves 1983, Wahren 2001b). The different successional stages are represented in space within most peatlands. The ideas surrounding cyclic regeneration involving distinct ‘pioneer’, ‘building’, ‘mature’, ‘degenerate’ stages (*sensu* Watt 1947) have been examined in alpine grasslands and heathlands on the Bogong High Plains (Williams and Ashton 1987a, 1987b, Williams 1990, 1992). Similar cycles can be identified in local peatland communities, except the dominant life-forms involved are shrubs and mosses, rather than shrubs and grasses. For example, in some subalpine raised bogs on gentle to moderate slopes there is evidence of a cycle involving *Sphagnum* senescence on hummock faces exposed to the sun. Shrub and restiad species invade these, mostly vegetatively. Over time the shrub stature in these patches increases, then shrub senescence occurs, and limited shrub seedling recruitment takes place, together with *Sphagnum* reinvasion from adjacent sheltered hummock flanks.

It seems to me that all the major peatland shrubs are capable of recruiting from soil-stored seed during inter-fire periods. In most of these, seedling recruitment is significantly higher during the early post-fire period. This is also true of the most fire-sensitive species, *Richea continentis*, however it is slow to do so, taking two or three years to appear in appreciable numbers. Little is known about the autecology of the major shrub species, although it is thought that most are long-lived (50-100 yrs or more). Estimates of the age of some *Callistemon* shrubs derived from growth-ring counts are over 100 yrs (J. Shannon pers.obs.). Some *Richea* stems have been aged at 80 yrs in the lower subalpine zone (1400 m) (K. McDougall pers.comm.). *Baeckea gunniana* and *Epacris paludosa* are possibly not as long lived (50 yrs?). It is probably safe to assume that all can persist in the long absence of fire. Time taken to reproductive maturity for seedlings recruited after fire varies between species. Seedlings of *Baeckea gunniana* and *Epacris paludosa* were flowering within four years. *Richea continentis* appears to take at least six or seven years, depending on altitude.

Disturbance by introduced livestock and other feral animals is likely to have enhanced shrub recruitment in peatlands in two ways. Firstly, indirectly via alteration to hydrology, and enhancement of drainage (Wimbush and Costin 1979, McDougall 1989, Wahren 1997). Secondly, more directly via creation of microsites for seedling recruitment. A similar process involving shrub recruitment in grassland gaps created by livestock disturbance has been widely identified (Williams and Ashton 1987b, Williams 1992).

Thus, some of the wet heath transects monitored in this thesis represent expressions of long-term drying and or the effects of introduced disturbance (horses, cattle, deer, infrastructure). Many of these were severely burnt; thus, fire serves to reinforce and expose the longer-term trend in the peatland conditions; trends that are often less apparent during the generally long inter-fire periods. Each fire entrenches the trend direction, by creating opportunities for less peatland tolerant species to establish, and making it more difficult for key peatland species to regenerate and persist. Of course, this is partly a natural process, but examples of a ‘vegetation switch’ (Wilson and Agnew 1993) in the opposite direction, are hard to find in the case of peatlands in south-eastern Australia. Some of the wet heath transects established in 2006 that were subsequently burnt are possibly in a transition process to non-wetland heath or grassland. Continued monitoring of these ‘marginal’ peatland areas over coming decades could answer this question.

The transects that were burnt in the December 2006 fires are now five years post-fire. Floristic and environmental data were collected from these only seven or eight months before the fires. Post-fire monitoring studies that have the benefit of such recently collected pre-fire data are rare. Therefore, continued monitoring of these transects at regular intervals (five years?) has the potential to provide accurate determinations of the time taken to achieve pre-fire structure and identify directional trends in more marginal or transitional peatland communities.

Data collection from water table monitoring wells (loggers) has continued to the present. There is now close to five years data for some locations. The last 18 months has seen well above average precipitation across the areas studied, in contrast to the period examined in this thesis, which was generally drier than average. The more recent data, when supplemented with continued monitoring, will give a clearer picture of the amount of inter-annual variability possible. There is also the potential to identify longer-term hydrological trends in some locations.

Other interesting questions about local peatland ecology:

- Which peatland species groups develop mycorrhizal relationships? How important are they to ericaceous species, a plant group in which they are known to occur?

- Below ground biomass production by vascular plants in local peatlands is, in theory, likely to be greater than above ground (Weltzin et al. 2000). Inferences have been drawn in this thesis about above ground competition between key peatland species. What are the implications of below-ground competition in peatlands, especially in situations where the space available for roots is limited by high water tables? For example, field observations suggest that seedlings of *Baeckea gunniana* produce root networks more rapidly than the seedlings of other common shrub species.

- How much genetic diversity is there in local populations of *Sphagnum cristatum*? Sporophytes are rarely observed in Victoria and the process appears to be uncommon. Nothing is known about the incidence of recruitment from spores generally or the role of this in regeneration after disturbance.

- Some seedbank data was collected during the course of this thesis. This has not been attempted in the peatlands of the region before. A more thorough examination of this aspect of peatland ecology would be beneficial. Initial investigations suggest that the seedbank is dominated by ericaceous species, with densities similar to those for *Calluna vulgaris*, the dominant ericaceous species in Scottish peatlands (Legg et al. 1992, Miller 2003) (densities of 1000-10,000 per m^2). There appears to be strong similarities between seedbank composition and standing vegetation composition (J. Shannon unpublished data 2010). More detailed and extensive seedbank studies would complement general investigations of the autecology of the key species.

- Ant nests are common in some peatland microsites (mostly hummocks). What role do they play in nutrient recycling? Presumably they are responsible for seed predation? Do they favour the seed of particular species? Could this have important implications for the persistence of some species in marginal communities (e.g. lack of *Richea* seedlings in some burnt wet heaths)?

7.6 Final thoughts

Peatlands, like other plant communities in highland areas of eastern Victoria appear to be resilient and can recover from fire given sufficient time before its return. However, the extent of fire incursion over the last eight years is alarming. Of the five sub-regions studied in this thesis, four have been fire-affected to varying (but significant) degrees. Only the Baw Baw region has escaped fire altogether. This may be coincidental, but given the predominance of tall open forest and cool temperate rainforest in this region (higher than anywhere else in the Eastern Highlands), it may well be partly a manifestation of the natural long-term fire regime. Average fire-intervals here are probably longer than elsewhere in the Eastern Highlands.

The peatland communities of the region have expanded and contracted naturally throughout the Holocene, long before European arrival in Australia. They are dynamic ecosystems, albeit over centuries and millennia, rather than decades. Anthropogenic influences are certainly putting pressure on local peatland communities. The introduced threats to local peatlands are well known (livestock grazing, feral animals, exotic species, some recreation activities). Steps to remove, control and manage these must continue. This will at least ensure that these communities can respond to fluctuations in climate and endogenous disturbance as they always have.

APPENDICES

Appendices CHAPTER 3

In order to conserve space, some of the appendices tables have been removed. These are indicated by an asterix (*) next to the table number in the text. The full version of the appendices, containing all tables, is on the accompanying CD (attached to back cover).

Table A3.1 Species recorded in transects. Family and functional group category are also indicated. Status: w = peatland species, m = marginal peatland species, * = introduced species, n = non-peatland species.

Shrub species	**Family**	**Functional group**	**status**
Baeckea gunniana	Myrtaceae	myrtaceous shrub	w
Baeckea latifolia	Myrtaceae	myrtaceous shrub	m
Callistemon pityoides	Myrtaceae	myrtaceous shrub	w
Comesperma retusum	Polygalaceae	other shrub	w
Epacris breviflora	Ericaceae	ericaceous shrub	w
Epacris celata	Ericaceae	ericaceous shrub	w
Epacris glacialis	Ericaceae	ericaceous shrub	w
Epacris gunni	Ericaceae	ericaceous shrub	m
Epacris microphylla var. *rhombifolia*	Ericaceae	ericaceous shrub	w
Epacris paludosa	Ericaceae	ericaceous shrub	w
Epacris petrophila	Ericaceae	ericaceous shrub	m
Exocarpus nanus	Santalaceae	other shrub	m
Hakea microcarpa	Proteaceae	other shrub	m
Leptospermum grandifolium	Myrtaceae	myrtaceous shrub	m
Leptospermum myrtifolium	Myrtaceae	myrtaceous shrub	m
Leucopogon pilifer	Ericaceae	ericaceous shrub	m
Olearia algida	Asteraceae	other shrub	m
Ozothamnus sp. 1	Asteraceae	other shrub	m
Pimelea alpina	Thymelaeaceae	other shrub	m
Pultenaea capitellata	Fabaceae	other shrub	m
Pultenaea fasciculata	Fabaceae	other shrub	m
Pultenaea tenella	Fabaceae	other shrub	m
Richea continentis	Ericaceae	ericaceous shrub	w
Richea victoriana	Ericaceae	ericaceous shrub	w
Salix cinerea	Salicaceae	other shrub	*
Stackhousia pulvinaris	Stackhousiaceae	other shrub	m
Tasmannia vickeriana	Winteraceae	other shrub	m
Tasmannia xerophila	Winteraceae	other shrub	m
Wittsteinia vacciniacea	Alseuosmiaceae	other shrub	m

Monocot species	**Family**	**Functional group**	**status**
Agrostis capillaris	Poaceae	other monocot	*
Agrostis spp.	Poaceae	other monocot	m
Anthoxanthum odoratum	Poaceae	other monocot	*
Astelia alpina var. *novae-hollandiae*	Asteliaceae	Astelia	w
Baloskion australe	Restionaceae	restiad	w
Baumea gunnii	Cyperaceae	other sedge	w
Carex appressa	Cyperaceae	Carex spp.	w
Carex blakei	Cyperaceae	Carex spp.	w
Carex breviculmis	Cyperaceae	Carex spp.	m
Carex echinata	Cyperaceae	Carex spp.	w
Carex gaudichaudiana	Cyperaceae	Carex spp.	w
Carex hebes	Cyperaceae	Carex spp.	m
Carex jackiana	Cyperaceae	Carex spp.	w
Carex sp.	Cyperaceae	Carex spp.	w
Carpha alpina	Cyperaceae	other sedge	w
Carpha nivicola	Cyperaceae	other sedge	w
Chiloglottis valida	Orchidaceae	other monocot	m
Deyeuxia carinata	Poaceae	other monocot	m

Monocot species (continued)	**Family**	**Functional group**	**status**
Empodisma minus	Restionaceae	restiad	w
Festuca rubra	Poaceae	other monocot	*
Gahnia sieberiana	Cyperaceae	other sedge	w
Herpolirion novae-zelandiae	Phormiaceae	other monocot	w
Hierochloe redolens	Poaceae	other monocot	m
Holcus lanatus	Poaceae	other monocot	*
Isolepis aucklandica	Cyperaceae	other sedge	w
Isolepis crassiuscula	Cyperaceae	other sedge	w
Isolepis sp.	Cyperaceae	other sedge	w
Isolepis subtilissima	Cyperaceae	other sedge	w
Juncus alexandri	Juncaceae	other monocot	w
Juncus articulatus	Juncaceae	other monocot	*
Juncus australis	Juncaceae	other monocot	w
Juncus effusus	Juncaceae	other monocot	*
Juncus falcatus	Juncaceae	other monocot	w
Juncus sandwithii	Juncaceae	other monocot	w
Luzula modesta	Juncaceae	other monocot	w
Oreobolus distichus	Cyperaceae	other sedge	w
Oreobolus oxycarpus	Cyperaceae	other sedge	w
Oreobolus pumilio	Cyperaceae	other sedge	w
Poa costiniana	Poaceae	other monocot	w
Poa labillardiera	Poaceae	other monocot	w
Poa sp.	Poaceae	other monocot	m
Prasophyllum spp.	Orchidaceae	other monocot	m
Rytidosperma nivicola	Poaceae	other monocot	w
Schoenus calyptratus	Cyperaceae	other sedge	w
Thelymitra cyanea	Orchidaceae	other monocot	w

Herbaceous dicot species	**Family**	**Functional group**	**status**
Acaena novae-zelandiae	Rosaceae	herb	m
Acetosella vulgaris	Polygonaceae	herb	*
Aciphylla simplicifolia	Apiaceae	herb	m
Asperula gunnii	Rubiaceae	herb	w
Brachyscome obovata	Asteraceae	herb	w
Brachyscome tenuiscarpa	Asteraceae	herb	m
Cardamine sp.	Brassicaceae	herb	m
Celmisia pugioniformis	Asteraceae	herb	m
Celmisia tomentella	Asteraceae	herb	w
Cerastium glomeratum	Caryophyllaceae	herb	*
Coprosma moorei	Rubiaceae	herb	w
Coprosma perpusilla	Rubiaceae	herb	w
Cotula alpina	Asteraceae	herb	w
Craspedia spp.	Asteraceae	herb	m
Diplaspis nivis	Apiaceae	herb	w
Drosera arcturi	Droseraceae	herb	w
Drosera peltata	Droseraceae	herb	m
Epilobium gunnianum	Onagraceae	herb	w
Erigeron nitidus	Asteraceae	herb	m
Erigeron paludicola	Asteraceae	herb	w

Herbaceous dicot species (continued)	**Family**	**Functional group**	**status**
Erigeron tasmanicus	Asteraceae	herb	m
Euchiton fordianus	Asteraceae	herb	m
Euphrasia gibbsiae subsp. *subglabrifolia*	Scophulariaceae	herb	w
Gentianella cunninghamii	Gentianaceae	herb	w
Geranium potentilloides	Geraniaceae	herb	m
Gonocarpus micranthus	Haloragaceae	herb	w
Gonocarpus montanus	Haloragaceae	herb	m
Hydrocotyle algida	Apiaceae	herb	w
Hydrocotyle hirta	Apiaceae	herb	w
Hydrocotyle laxiflora	Apiaceae	herb	m
Hypericum japonicum	Clusiaceae	herb	w
Hypochoeris radicata	Asteraceae	herb	*
Lagenophora montanus	Asteraceae	herb	m
Leptostigma reptans	Rubiaceae	herb	m
Lobelia surrepens	Campanulaceae	herb	w
Mimulus moschatus	Scophulariaceae	herb	*
Myriophyllum pedunculatum	Haloragaceae	herb	w
Neopaxia australasica	Portulacaceae	herb	m
Nertera granadensis	Rubiaceae	herb	w
Oreomyrrhis ciliata	Apiaceae	herb	w
Oschatzia cuneifolia	Apiaceae	herb	w
Plantago alpestre	Plantaginaceae	herb	m
Psychrophila introloba	Ranunculaceae	herb	w
Ranunculus collinus	Ranunculaceae	herb	w
Ranunculus graniticola	Ranunculaceae	herb	m
Ranunculus gunnianus	Ranunculaceae	herb	w
Ranunculus muelleri	Ranunculaceae	herb	m
Ranunculus pimpinellifolius	Ranunculaceae	herb	w
Schizeilema fragoseum	Apiaceae	herb	m
Senecio pectinatus	Asteraceae	herb	m
Stylidium sp.	Stylidiaceae	herb	m
Trifolium repens	Fabaceae	herb	*
Utricularia monanthos	Lentibulariaceae	herb	w
Veronica sp.2	Scophulariaceae	herb	w
Viola fuscoviolacea	Violaceae	herb	m
Viola hederacea	Violaceae	herb	m
Wahlenbergia ceracea	Campanulaceae	herb	m
Bryophytes, ferns, club mosses	**Family**	**Functional group**	**status**
Blechnum penna-marina	Blechnaceae	other bryophytes and ferns	w
Gleichenia dicarpa	Gleicheniaceae	other bryophytes and ferns	w
Blindia robusta	Seligeriaceae	other bryophytes and ferns	w
Lycopodium spp.	Lycopodiaceae	other bryophytes and ferns	m
Polytrichum spp.	Polytrichaceae	other bryophytes and ferns	w
Sphagnum cristatum	Sphagnaceae	Sphagnum spp.	w
Sphagnum novo-zelandicum	Sphagnaceae	Sphagnum spp.	w

Other non wetland species occasionally recorded in quadrats

Shrubs and trees	**Family**	**status**
Asterolasia trymalioides	Rutaceae	n
Bossiaea foliosa	Fabaceae	n
Eucalyptus dalrympleana	Myrtaceae	n
Eucalyptus delegatensis	Myrtaceae	n
Eucalyptus pauciflora	Myrtaceae	n
Grevillea australis	Proteaceae	n
Hovea montana	Fabaceae	n
Kunzea muelleri	Myrtaceae	n
Leionema phylicifolium	Rutaceae	n
Leucopogon montanus	Ericaceae	n
Olearia erubescens	Asteraceae	n
Olearia frostii	Asteraceae	n
Phebalium squamulosum	Rutaceae	n
Pimelea axiflora subsp. *alpina*	Thymelaeaceae	n
Podolobium alpestre	Fabaceae	n
Pultenaea muelleri	Fabaceae	n
Monocot species	**Family**	n
Austrodanthonia sp.	Poaceae	n
Deyeuxia sp.	Poaceae	n
Poa ensiformis	Poaceae	n
Poa fawcettiae	Poaceae	n
Poa hothamensis	Poaceae	n
Herbaceous dicots	**Family**	n
Ajuga australis	Lamiaceae	n
Brachyscome decipiens	Asteraceae	n
Erigeron bellidioides	Asteraceae	n
Goodenia hederacea	Goodeniaceae	n
Lagenophora stipitata	Asteraceae	n
Leptorhyncos sp.	Asteraceae	n
Oreomyrrhis eriopoda	Apiaceae	n
Plantago euryphylla	Plantaginaceae	n
Ranunculus victoriensis	Ranunculaceae	n
Scleranthus biflorus	Caryophyllaceae	n
Senecio gunnii	Asteraceae	n
Senecio sp.	Asteraceae	n
Stellaria pungens	Caryophyllaceae	n

Table A3.2: List of the thirty-eight transects (= plots) used in the **Bogong region** study. Location details and community type classification included.

Transect	Code	Alt.	Lat.	Long.	Zone	Catchment	Community type
Anvil Bog	**anv**	1710	36.90	147.28	Alpine	Kiewa	Alpine raised bog
Boulder Bog 1	**bb1**	1700	36.92	147.25	Alpine	Kiewa	Low wet heath
Boulder Bog 2	**bb2**	1700	36.92	147.25	Alpine	Kiewa	Alpine raised bog
Boulder Bog 3	**bb3**	1710	36.92	147.25	Alpine	Kiewa	Alpine raised bog
Buckety Plain 1	**bp1**	1540	36.94	147.34	Subalpine	Mitta Mitta	Subalpine raised bog
Buckety Plain 2	**bp2**	1540	36.94	147.34	Subalpine	Mitta Mitta	Tall wet heath
Callistemon Bog 1	**ca1**	1470	36.88	147.38	Subalpine	Mitta Mitta	Myrtaceous wet heath
Callistemon Bog 2	**ca2**	1470	36.88	147.38	Subalpine	Mitta Mitta	Myrtaceous wet heath
Cemetery Spur 1	**cm1**	1520	36.87	147.38	Subalpine	Mitta Mitta	Subalpine raised bog
Cemetery Spur 2	**cm2**	1520	36.87	147.38	Subalpine	Mitta Mitta	Subalpine raised bog
Cemetery Spur 21	**c21**	1570	36.87	147.38	Subalpine	Mitta Mitta	Myrtaceous wet heath
Cope Creek 1	**cc1**	1690	36.92	147.28	Alpine	Kiewa	Low wet heath
Cope Creek 2	**cc2**	1690	36.92	147.28	Alpine	Kiewa	Alpine raised bog
Cope Creek 3	**cc3**	1690	36.92	147.28	Alpine	Kiewa	Low wet heath
Cope Creek Lower	**ccl**	1660	36.91	147.27	Alpine	Kiewa	Low wet heath
Cope East 1	**ce1**	1700	36.93	147.29	Subalpine	Mitta Mitta	Tall wet heath
Cope East 2	**ce2**	1690	36.93	147.29	Subalpine	Mitta Mitta	Subalpine raised bog
Cope Saddle	**csa**	1640	36.93	147.25	Alpine	Mitta Mitta	Alpine valley bog
Cope South 1	**cs1**	1610	36.94	147.28	Subalpine	Mitta Mitta	Alpine valley bog
Cope South 2	**cs2**	1610	36.94	147.28	Subalpine	Mitta Mitta	Subalpine raised bog
Cope South 3	**cs3**	1610	36.94	147.28	Subalpine	Mitta Mitta	Subalpine raised bog
Cope South 4	**cs4**	1610	36.94	147.28	Subalpine	Mitta Mitta	Tall wet heath
Heathy Spur 1	**hs1**	1720	36.86	147.32	Alpine	Kiewa	Alpine raised bog
Heathy Spur 2	**hs2**	1720	36.86	147.32	Alpine	Kiewa	Alpine raised bog
Langfords Gap 1	**lg1**	1620	36.88	147.33	Subalpine	Mitta Mitta	Subalpine raised bog
Langfords Gap 2	**lg2**	1620	36.88	147.33	Subalpine	Mitta Mitta	Tall wet heath
North-west Bog 1	**nw1**	1720	36.89	147.27	Alpine	Kiewa	Low wet heath
North-west Bog 2	**nw2**	1720	36.89	147.27	Alpine	Kiewa	Alpine raised bog
Malcolm Plain 1	**mp1**	1380	37.03	147.28	Subalpine	Mitta Mitta	Subalpine raised bog
Malcolm Plain 2	**mp2**	1380	37.03	147.28	Subalpine	Mitta Mitta	Subalpine raised bog
North Buckety Plain 1	**nb1**	1540	36.94	147.34	Subalpine	Mitta Mitta	Myrtaceous wet heath
North Buckety Plain 2	**nb2**	1540	36.94	147.34	Subalpine	Mitta Mitta	Myrtaceous wet heath
Pretty Valley 1650 no. 1	**pv1**	1650	36.91	147.24	Alpine	Kiewa	Alpine valley bog
Pretty Valley 1650 no. 2	**pv2**	1650	36.91	147.24	Alpine	Kiewa	Alpine valley bog
Pretty Valley Central	**pvc**	1650	36.91	147.24	Alpine	Kiewa	Alpine valley bog
Track 107	**t07**	1580	36.87	147.38	Subalpine	Mitta Mitta	Myrtaceous wet heath
Wild Horse Creek 1	**wh1**	1430	36.88	147.39	Subalpine	Mitta Mitta	Subalpine raised bog
Wild Horse Creek 2	**wh2**	1430	36.88	147.39	Subalpine	Mitta Mitta	Subalpine raised bog

Table A3.5: Species contributing to differences between **Subalpine raised bog (SRB)** and **Alpine valley bog (AVB)** based on the **Bogong region transects, (a) Frequency data, (b) cover data**. The species listed contribute between 81% and 98% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they are most prominent.

(a): Frequency data. (SRB) and (AVB). Mean dissimilarity = 43.5%.

More common in SRB	**freq. SRB**	**freq. AVB**	**Av.Diss**	**Diss/SD**	**Contrib%**
Epacris paludosa	**57.3**	2.7	4.1	1.9	9.4
Baeckea gunniana	**60.9**	7.6	3.9	2.1	9.0
Baloskion australe	**54.8**	10.0	3.6	1.6	8.4
Richea continentis	**80.6**	47.4	3.1	1.4	7.2
Celmisia spp.	**22.1**	0.0	1.7	0.9	3.8
Asperula gunnii	**14.6**	0.0	1.1	1.1	2.4
Juncus falcatus	**10.7**	2.7	0.8	0.6	1.9
Nertera granadensis	**11.2**	0.3	0.7	0.5	1.7
More common in AVB					
Epacris glacialis	0.0	**56.3**	4.2	1.6	9.6
Carex echinata	0.0	**39.4**	2.9	1.2	6.8
Carex gaudichaudiana	68.8	**95.3**	2.1	1.4	4.9
Carpha spp.	10.2	**30.3**	2.1	1.6	4.7
Isolepis spp.	4.3	**23.0**	1.7	0.8	3.9
Polytrichum spp.	0.2	**12.0**	0.9	0.5	2.1
Similar frequency in both					
Epacris celata	40.6	45.5	2.4	1.5	5.5
Poa costiniana	37.2	33.3	2.3	1.5	5.2
Erigeron paludicola	7.1	10.3	0.8	1.3	1.9
Oreomyrrhis ciliata	5.4	5.0	0.6	0.6	1.5
Oreobolus distichus	5.8	4.5	0.6	0.8	1.3

(**b**) **Cover data. (SRB) and (AVB).** (up to 96%). Mean dissimilarity = 29.2%.

Higher % cover in SRB	**cover% SRB**	**cover% AVB**	**Av.Diss**	**Diss/SD**	**Contrib%**
Epacris paludosa	**12.1**	0.2	4.5	1.5	15.3
Empodisma minus	**19.9**	8.9	4.1	1.5	14.2
Richea continentis	**15.0**	6.8	3.9	1.4	13.4
Baeckea gunniana	**7.8**	0.1	2.9	1.7	9.8
Baloskion australe	**2.4**	0.3	0.8	1.1	2.9
Higher % cover in AVB					
Carex gaudichaudiana	1.1	**8.7**	2.9	3.4	9.8
Epacris glacialis	0.0	**3.5**	1.3	1.0	4.4
Carex echinata	0.0	**2.3**	0.9	0.6	3.0
Carpha spp.	0.6	**1.8**	0.6	1.7	2.0
Similar % cover in both					
Sphagnum cristatum	78.1	90.0	5.2	1.7	17.9
Epacris celata	2.9	3.2	1.1	1.4	3.7

Table A3.6: Species contributing to differences between **Alpine raised bog** (**ARB)** and **Subalpine raised bog (SRB)** based on the **Bogong region transects, (a) Frequency data, (b) cover data**. The species listed contribute between 81% and 98% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they are most prominent.

(a): Frequency data. **(ARB) and (SRB).** Mean dissimilarity = 39.3%.

More common in ARB	**freq. ARB**	**freq. SRB**	**Av.Diss**	**Diss/SD**	**Contrib%**
Epacris glacialis	**43.1**	0.0	2.9	1.1	7.3
Astelia alpina	**41.0**	1.1	2.7	4.0	6.8
Carpha spp.	**32.4**	10.2	2.0	1.4	5.1
Drosera arcturi	**21.7**	0.0	1.5	0.8	3.7
Oreobolus distichus	**21.4**	5.8	1.3	1.2	3.3
Rytidosperma nivicola	**20.0**	0.0	1.3	1.1	3.4
Erigeron paludicola	**17.6**	7.1	1.1	1.2	2.9
Diplaspis nivis	**16.7**	0.0	1.1	0.6	2.7
Thelymitra cyanea	**11.0**	0.8	0.7	0.6	1.9
More common in SRB					
Carex gaudichaudiana	23.3	**68.8**	3.4	1.7	8.5
Baloskion australe	10.0	**54.8**	3.4	1.5	8.7
Epacris celata	20.7	**40.6**	2.6	1.5	6.7
Asperula gunnii	2.9	**14.6**	0.9	1.0	2.3
Nertera granadensis	0.0	**11.2**	0.7	0.5	1.7
Similar frequency in both					
Richea continentis	92.6	80.6	1.1	1.0	2.9
Sphagnum cristatum	89.3	96.0	0.7	1.0	1.8
Baeckea gunniana	65.2	60.9	1.7	1.4	4.4
Epacris paludosa	54.1	57.3	2.5	1.3	6.5
Poa costiniana	48.6	37.2	2.0	1.5	5.1
Celmisia spp.	34.1	22.1	1.9	1.7	4.7

(b): Cover data. **(ARB) and (SRB)**. Mean dissimilarity = 25.9%.

Higher % cover in ARB	**cover% ARB**	**cover% SRB**	**Av.Diss**	**Diss/SD**	**Contrib%**
Astelia alpina	**3.6**	0.0	1.3	1.4	5.1
Epacris glacialis	**2.5**	0.0	0.9	0.9	3.5
Carpha spp.	**1.8**	0.6	0.7	1.1	2.6
Oreobolus distichus	**1.3**	0.1	0.5	0.8	1.8
Poa costiniana	**1.1**	0.6	0.3	1.1	1.3
Higher % cover in SRB					
Richea continentis	9.8	**15.0**	3.2	1.4	12.5
Baeckea gunniana	5.9	**7.8**	1.8	1.2	7.0
Epacris celata	1.9	**2.9**	1.2	1.2	4.7
Baloskion australe	0.1	**2.4**	0.9	1.1	3.3
Carex gaudichaudiana	0.8	**1.1**	0.4	1.3	1.6
Similar % cover in both					
Sphagnum cristatum	70.1	78.1	6.9	1.8	26.7
Empodisma minus	19.4	19.9	3.5	1.4	13.6
Epacris paludosa	11.0	12.1	3.3	1.3	12.6

Table A3.7: Species contributing to differences between **Subalpine raised bog (SRB) and Tall wet heath (TWH)** based on the **Bogong region, (a) Frequency data, (b) cover data**. The species listed contribute between 81% and 98% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they are most prominent.

(a): Frequency data. (SRB) and (TWH). Mean dissimilarity = 35.9.

More common in SRB	**freq. SRB**	**freq. TWH**	**Av.Diss**	**Diss/SD**	**Contrib%**
Baloskion australe	**54.8**	30.8	3.3	1.4	9.3
Carex gaudichaudiana	**68.8**	45.0	3.0	1.4	8.3
Sphagnum cristatum	**96.0**	66.3	2.6	0.9	7.2
Juncus falcatus	**10.7**	0.0	0.7	0.5	1.8
More common in TWH					
Erigeron paludicola	7.1	**35.4**	2.1	1.2	5.7
Celmisia spp.	22.1	**33.3**	2.0	1.3	5.7
Poa costiniana	37.2	**65.0**	1.9	1.3	5.2
Asperula gunnii	14.6	**31.3**	1.8	1.2	5.0
Oreobolus distichus	5.8	**22.9**	1.3	1.1	3.7
Diplaspis nivis	0.0	**14.6**	0.8	0.6	2.2
Thelymitra cyanea	0.8	**14.2**	0.8	0.6	2.2
Lycopodium sp.	2.4	**8.3**	0.6	1.0	1.6
Astelia alpina	1.1	**7.1**	0.5	1.1	1.3
Stylidium sp.	0.2	**7.9**	0.4	0.6	1.2
Similar frequency in both					
Epacris paludosa	57.3	64.6	2.4	1.5	6.8
Richea continentis	80.6	58.8	2.3	1.4	6.4
Baeckea gunniana	60.9	83.8	2.0	1.4	5.4
Epacris celata	40.6	48.8	1.9	1.4	5.4
Nertera granadensis	11.2	13.3	1.2	1.0	3.3
Carpha spp.	10.2	13.3	1.1	1.0	2.9

(b): Cover data. (SRB) and (TWH). Mean dissimilarity = 44.6%.

Higher % cover in SRB	**cover% SRB**	**cover% TWH**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**78.1**	34.7	17.3	1.9	38.8
Empodisma minus	**19.9**	8.6	4.6	1.5	10.4
Epacris celata	**2.9**	2.1	1.0	1.1	2.3
Baloskion australe	**2.4**	0.8	0.9	1.2	1.9
Carex gaudichaudiana	**1.1**	0.8	0.4	1.3	0.8
Higher % cover in TWH					
Richea continentis	15.0	**23.2**	8.5	1.5	19.1
Baeckea gunniana	7.8	**23.1**	6.1	2.7	13.6
Epacris paludosa	12.1	**15.7**	3.9	1.5	8.6
Oreobolus distichus	0.1	**1.1**	0.4	0.8	0.9

Table A3.8: Species contributing to differences between **Tall wet heath (TWH)** and **Myrtaceous wet heath (MWH)** based on the **Bogong region transects, (a) Frequency data, (b) cover data**. The species listed contribute between 81% and 98% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they are most prominent.

(a): Frequency data. (TWH) and (MWH). Mean dissimilarity = 47.2%

More common in TWH	**freq. TWH**	**freq. MWH**	**Av.Diss**	**Diss/SD**	**Contrib%**
Richea continentis	**58.8**	0.0	4.1	1.5	8.6
Carex gaudichaudiana	**45.0**	0.3	2.8	1.2	5.9
Sphagnum cristatum	**66.3**	29.7	2.8	1.6	5.9
Erigeron paludicola	**35.4**	0.0	1.9	1.1	4.1
Celmisia spp.	**33.3**	13.9	1.8	1.4	3.9
Oreobolus distichus	**22.9**	0.0	1.2	1.0	2.6
More common in MWH					
Baloskion australe	30.8	**63.1**	3.3	1.6	7.0
Asperula gunnii	31.3	**72.5**	2.9	2.0	6.2
Luzula modesta	4.2	**40.8**	2.4	1.2	5.0
Pultenaea fasiculata	0.0	**32.2**	2.0	1.3	4.2
Oreobolus oxycarpus	0.0	**32.2**	2.0	1.4	4.2
Callistemon pityoides	0.0	**30.3**	1.9	1.9	4.1
Agrostis sp.	1.3	**23.6**	1.5	1.1	3.2
Gonocarpus micranthus	2.1	**19.7**	1.2	1.1	2.5
Pultenaea capitellata	0.0	**18.1**	1.1	0.8	2.3
Comesperma retusum	0.0	**16.7**	1.0	1.3	2.2
Similar frequency					
Epacris paludosa	64.6	86.4	2.1	1.2	4.5
Poa costiniana	65.0	65.0	1.2	1.2	2.6
Epacris celata	48.8	35.6	1.2	1.4	2.6

(b): Cover data. (TWH) and (MWH). Mean dissimilarity = 53.5%.

Higher % cover in TWH	**cover% TWH**	**cover% MWH**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**34.7**	10.4	15.1	1.5	28.2
Richea continentis	**23.2**	0.0	12.9	1.0	24.0
Oreobolus distichus	**1.1**	0.0	0.6	0.8	1.0
Higher % cover in MWH					
Empodisma minus	8.6	**14.6**	3.6	1.2	6.7
Oreobolus oxycarpus	0.0	**6.0**	3.2	1.0	5.9
Poa costiniana	0.8	**4.7**	2.0	2.0	3.8
Callistemon pityoides	0.0	**3.1**	1.7	2.1	3.1
Baloskion australe	0.8	**1.6**	0.9	0.8	1.6
Pultenaea fasiculata	0.0	**1.5**	0.8	1.1	1.5
Pultenaea capitellata	0.0	**0.9**	0.5	0.7	0.9
Luzula modesta	0.0	**0.8**	0.5	0.8	0.9
Similar % cover in both					
Baeckea gunniana	23.1	15.1	4.3	1.9	8.0
Epacris paludosa	15.7	12.2	4.3	1.4	8.0
Epacris celata	2.1	1.5	0.8	1.2	1.5

Table A3.9: Species contributing to differences between **Alpine raised bog** (**ARB)** and **Low wet heath (LWH)** based on the **Bogong region transects, (a) Frequency data, (b) cover data**. The species listed contribute between 81% and 98% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they are most prominent.

(a): Frequency data. (ARB) and (LWH). Mean dissimilarity 42.5%

More common in ARB	**freq. ARB**	**freq. LWH**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**89.3**	14.3	5.0	4.0	11.7
Baeckea gunniana	**65.2**	33.3	2.3	1.3	5.4
Epacris paludosa	**54.1**	1.0	3.6	1.4	8.4
Carpha spp.	**32.4**	8.3	1.9	1.4	4.4
Carex gaudichaudiana	**23.3**	13.0	1.4	1.1	3.4
Drosera arcturi	**21.7**	1.3	1.4	0.8	3.3
Erigeron paludicola	**17.6**	8.0	1.0	1.2	2.4
More common in LWH					
Epacris glacialis	43.1	**99.3**	3.8	1.3	8.9
Poa costiniana	48.6	**85.7**	2.7	1.3	6.3
Astelia alpina	41.0	**76.0**	2.3	1.8	5.3
Celmisia spp.	34.1	**66.0**	2.2	1.7	5.2
Gentianella sp.	6.4	**28.0**	1.4	1.8	3.3
Oreobolus distichus	21.4	**45.0**	1.9	1.5	4.5
Similar frequency in both					
Richea continentis	**92.6**	69.7	1.8	1.3	4.3
Epacris celata	**20.7**	14.7	1.8	0.8	4.2
Rytidosperma nivicola	**20.0**	12.3	1.1	1.2	2.7
Diplaspis nivis	16.7	**25.3**	1.9	1.0	4.5
Baloskion australe	10.0	**15.3**	1.4	0.6	3.2

(b): Cover data. (ARB) and **(LWH).** Mean dissimilarity 67.2%.

Higher % cover in ARB	**cover% ARB**	**cover% LWH**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**70.1**	3.3	29.5	3.8	43.9
Epacris paludosa	**11.0**	0.3	4.8	1.4	7.1
Baeckea gunniana	**5.9**	1.5	2.0	1.1	3.0
Carpha spp.	**1.8**	0.1	0.8	1.0	1.2
Higher % cover in LWH					
Astelia alpina	3.6	**26.8**	10.1	1.8	15.1
Epacris glacialis	2.5	**23.4**	9.4	2.1	14.0
Oreobolus distichus	1.3	**3.2**	1.3	1.1	1.9
Celmisia spp.	0.5	**2.6**	0.9	1.9	1.4
Poa costiniana	1.1	**2.1**	0.7	1.4	1.0
Similar % cover in both					
Empodisma minus	19.4	19.6	3.4	1.5	5.1
Richea continentis	9.8	10.6	2.1	1.5	3.1
Epacris celata	1.9	1.3	1.1	0.8	1.7

Table A3.10: Species contributing to differences between **Alpine raised bog** (**ARB)** and **Alpine valley bog (AVB)** based on the **Bogong region transects, (a) Frequency data, (b) cover data**. The species listed contribute between 81% and 98% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they are most prominent.

(a): Frequency data. (ARB) and (AVB). Mean dissimilarity = 49.6%.

More common in ARB	**freq. ARB**	**freq. AVB**	**Av.Diss**	**Diss/SD**	**Contrib%**
Baeckea gunniana	**65.2**	7.6	4.1	2.4	8.3
Epacris paludosa	**54.1**	2.7	3.8	1.5	7.6
Richea continentis	**92.6**	47.4	3.3	1.6	6.6
Astelia alpina	**41.0**	0.0	2.9	4.3	5.8
Celmisia spp.	**34.1**	0.0	2.4	2.2	4.8
Drosera arcturi	**21.7**	0.3	1.5	0.8	3.0
Oreobolus distichus	**21.4**	4.5	1.3	1.2	2.7
Rytidosperma nivicola	**20.0**	2.0	1.3	1.1	2.7
Diplaspis nivis	**16.7**	0.0	1.1	0.6	2.2
More common in AVB					
Carex gaudichaudiana	23.3	**95.3**	5.1	2.6	10.3
Epacris celata	20.7	**45.5**	2.9	1.5	5.8
Carex echinata	0.0	**39.4**	2.8	1.2	5.6
Isolepis spp.	0.5	**23.0**	1.6	0.7	3.2
Polytrichum spp.	0.5	**12.0**	0.9	0.5	1.8
Similar frequency in both					
Epacris glacialis	43.1	56.3	3.1	1.3	6.3
Poa costiniana	48.6	33.3	2.7	1.4	5.5
Carpha spp.	32.4	30.3	1.7	1.4	3.4
Baloskion australe	10.0	10.0	1.2	0.6	2.4
Erigeron paludicola	17.6	10.3	1.1	1.3	2.2

(b): Cover data. (ARB) and (AVB). Mean dissimilarity = 32.3%.

Higher % cover in ARB	**cover% ARB**	**cover% AVB**	**Av.Diss**	**Diss/SD**	**Contrib%**
Epacris paludosa	**11.0**	0.2	4.2	1.4	13.0
Empodisma minus	**19.4**	8.9	4.2	1.4	13.0
Baeckea gunniana	**5.9**	0.1	2.3	1.4	7.0
Astelia alpina	**3.6**	0.0	1.4	1.4	4.3
Oreobolus distichus	**1.3**	0.0	0.5	0.9	1.6
Poa costiniana	**1.1**	0.4	0.4	1.0	1.2
Celmisia spp.	**0.5**	0.0	0.2	1.1	0.6
Higher % cover in AVB					
Carex gaudichaudiana	0.8	**8.7**	3.1	3.3	9.6
Epacris celata	1.9	**3.2**	1.3	1.5	4.0
Carex echinata	0.0	**2.3**	0.9	0.6	2.8
Similar % cover in both					
Sphagnum cristatum	70.1	90.0	9.1	1.5	28.1
Richea continentis	9.8	6.8	1.9	1.3	5.9
Epacris glacialis	2.5	3.5	1.3	1.1	4.1
Carpha spp.	1.8	1.8	0.7	1.6	2.1

Table A3.11: Species contributing to differences between **Alpine raised bog** (**ARB)** and **Tall wet heath (TWH)** based on the **Bogong region transects, (a) Frequency data, (b) cover data**. The species listed contribute between 81% and 98% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

(a) Frequency data. (ARB) and (TWH). Mean dissimilarity = 41.1

Species	**freq. ARB**	**freq. TWH**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Epacris glacialis	43.1	0.0	2.8	1.0	6.8	6.8
Epacris celata	20.7	48.8	2.7	2.2	6.6	13.4
Carex gaudichaudiana	23.3	45.0	2.6	1.2	6.2	19.6
Epacris paludosa	54.1	64.6	2.6	1.5	6.2	25.9
Sphagnum cristatum	89.3	66.3	2.3	0.9	5.5	31.4
Astelia alpina	41.0	7.1	2.3	2.3	5.5	36.9
Richea continentis	92.6	58.8	2.1	1.3	5.2	42.1
Asperula gunnii	2.9	31.3	2.1	1.2	5.1	47.2
Poa costiniana	48.6	65.0	2.0	1.3	5.0	52.1
Erigeron paludicola	17.6	35.4	2.0	1.4	4.9	57.0
Baloskion australe	10.0	30.8	1.9	0.9	4.7	61.7
Carpha spp.	32.4	13.3	1.8	1.3	4.4	66.1
Celmisia spp.	34.1	33.3	1.7	1.5	4.2	70.3
Oreobolus distichus	21.4	22.9	1.5	1.3	3.6	73.8
Diplaspis nivis	16.7	14.6	1.5	0.8	3.5	77.4
Baeckea gunniana	65.2	83.8	1.5	1.7	3.5	80.9
Drosera arcturi	21.7	0.0	1.4	0.8	3.5	84.3
Rytidosperma nivicola	20.0	0.0	1.3	1.1	3.2	87.5
Thelymitra cyanea	11.0	14.2	1.2	0.8	2.8	90.3

(b) Cover data. (ARB) and (TWH). Mean dissimilarity = 46.9%.

Species	**cover% ARB**	**cover% TWH**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Sphagnum cristatum	70.08	34.67	15.08	1.37	32.16	32.16
Richea continentis	9.78	23.18	8.91	1.32	18.99	51.15
Baeckea gunniana	5.9	23.1	7.05	2.96	15.03	66.18
Empodisma minus	19.4	8.63	4.75	1.45	10.12	76.3
Epacris paludosa	10.98	15.66	4.19	1.45	8.93	85.24
Astelia alpina	3.56	0.33	1.35	1.26	2.88	88.12
Epacris celata	1.94	2.07	1.15	1.29	2.46	90.57
Epacris glacialis	2.45	0	1.02	0.92	2.18	92.76
Carpha spp.	1.84	0.73	0.71	1.1	1.51	94.26
Oreobolus distichus	1.33	1.05	0.61	1.04	1.31	95.57
Carex gaudichaudiana	0.75	0.83	0.43	1.04	0.92	96.48
Poa costiniana	1.05	0.8	0.37	1.2	0.78	97.26
Baloskion australe	0.09	0.82	0.34	0.75	0.72	97.98
Celmisia spp.	0.54	0.36	0.18	1.15	0.39	98.37

Table A3.12: Species contributing to differences between **Low wet heath (LWH**) and **Tall wet heath (TWH)** based on the **Bogong region transects, (a) Frequency data, (b) cover data**. The species listed contribute between 81% and 98% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

(a) Frequency data. (LWH) and (TWH). Mean dissimilarity = 53.9.

Species	**freq. LWH**	**freq. TWH**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Epacris glacialis	99.3	0.0	6.7	4.8	12.5	12.5
Astelia alpina	76.0	7.1	4.6	2.9	8.5	21.0
Epacris paludosa	1.0	64.6	4.0	3.0	7.4	28.4
Baeckea gunniana	33.3	83.8	3.4	2.2	6.3	34.6
Sphagnum cristatum	14.3	66.3	3.4	1.8	6.2	40.9
Epacris celata	14.7	48.8	2.9	2.3	5.4	46.3
Celmisia spp.	66.0	33.3	2.7	1.4	5.0	51.3
Carex gaudichaudiana	13.0	45.0	2.6	1.2	4.9	56.2
Richea continentis	69.7	58.8	2.3	1.6	4.3	60.5
Oreobolus distichus	45.0	22.9	2.2	1.4	4.2	64.6
Baloskion australe	15.3	30.8	2.2	0.9	4.0	68.6
Erigeron paludicola	8.0	35.4	2.0	1.2	3.7	72.3
Asperula gunnii	6.0	31.3	2.0	1.2	3.6	75.9
Poa costiniana	85.7	65.0	1.9	1.3	3.5	79.5
Gentianella sp.	28.0	0.4	1.8	2.3	3.3	82.8
Diplaspis nivis	25.3	14.6	1.8	0.9	3.3	86.1
Carpha spp.	8.3	13.3	0.8	1.2	1.5	87.5
Nertera granadensis	0.0	13.3	0.8	0.9	1.5	89.0
Rytidosperma nivicola	12.3	0.0	0.8	1.2	1.4	90.4

(b) Cover data. (LWH) and (TWH). Mean dissimilarity = 78.7%.

Species	**cover% LWH**	**cover% TWH**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Sphagnum cristatum	3.3	34.7	14.9	1.7	19.0	19.0
Astelia alpina	26.8	0.3	12.5	2.0	15.9	34.8
Epacris glacialis	23.4	0.0	11.4	2.4	14.5	49.3
Richea continentis	10.6	23.2	10.5	1.3	13.3	62.6
Baeckea gunniana	1.5	23.1	10.4	5.4	13.2	75.8
Epacris paludosa	0.3	15.7	7.4	1.9	9.4	85.1
Empodisma minus	19.6	8.6	5.4	1.9	6.8	91.9
Oreobolus distichus	3.2	1.1	1.4	1.1	1.8	93.7
Epacris celata	1.3	2.1	1.2	1.3	1.5	95.3
Celmisia spp.	2.6	0.4	1.1	2.0	1.4	96.6
Poa costiniana	2.1	0.8	0.7	1.3	0.9	97.5
Baloskion australe	0.2	0.8	0.4	0.8	0.5	98.0

Table A3.13: Species contributing to differences between **Alpine raised bog (ARB)** and **Myrtaceous wet heath (MWH)** based on the **Bogong region transects, (a) Frequency data, (b) cover data**. The species listed contribute between 81% and 98% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

(a) Frequency data. (ARB) and (MWH). Mean dissimilarity = 59.4

Species	freq. ARB	freq. MWH	Av.Diss	Diss/SD	Contrib%	Cum.%
Richea continentis	92.6	0.0	5.8	10.8	9.7	9.7
Asperula gunnii	2.9	72.5	4.3	2.3	7.2	16.9
Sphagnum cristatum	89.3	29.7	3.6	2.2	6.1	23.0
Baloskion australe	10.0	63.1	3.6	2.0	6.0	29.0
Epacris glacialis	43.1	0.0	2.6	1.1	4.4	33.4
Astelia alpina	41.0	0.0	2.6	4.2	4.3	37.7
Luzula modesta	1.2	40.8	2.4	1.3	4.1	41.8
Epacris paludosa	54.1	86.4	2.4	1.2	4.0	45.9
Epacris celata	20.7	35.6	2.2	3.1	3.8	49.6
Pultenaea fasiculata	0.0	32.2	2.0	1.3	3.3	52.9
Oreobolus oxycarpus	0.0	32.2	1.9	1.4	3.3	56.2
Carpha spp.	32.4	1.7	1.9	1.4	3.3	59.4
Poa costiniana	48.6	65.0	1.9	1.3	3.3	62.7
Callistemon pityoides	0.0	30.3	1.9	2.0	3.2	65.8
Celmisia spp.	34.1	13.9	1.7	1.6	2.8	68.6
Baeckea gunniana	65.2	90.3	1.6	1.4	2.6	71.2
Agrostis sp.	0.2	23.6	1.5	1.1	2.5	73.7
Carex gaudichaudiana	23.3	0.3	1.4	0.9	2.4	76.1
Drosera arcturi	21.7	0.0	1.4	0.8	2.3	78.4
Oreobolus distichus	21.4	0.0	1.3	1.3	2.2	80.6
Rytidosperma nivicola	20.0	0.0	1.2	1.1	2.1	82.7
Gonocarpus micranthus	0.0	19.7	1.2	1.2	2.0	84.7
Erigeron paludicola	17.6	0.0	1.1	1.1	1.8	86.5
Pultenaea capitellata	0.0	18.1	1.1	0.8	1.8	88.3
Comesperma retusum	0.0	16.7	1.0	1.3	1.7	90.0
Diplaspis nivis	16.7	0.0	1.0	0.6	1.7	91.7

(b) Cover data. (ARB) and (MWH). Dissimilarity = 62.8%.

Species	cover% ARB	cover% MWH	Av.Diss	Diss/SD	Contrib%	Cum.%
Sphagnum cristatum	70.1	10.4	29.2	2.6	46.6	46.6
Richea continentis	9.8	0.0	4.8	3.4	7.6	54.2
Baeckea gunniana	5.9	15.1	4.5	2.0	7.2	61.4
Empodisma minus	19.4	14.6	4.1	1.5	6.5	67.9
Epacris paludosa	11.0	12.2	3.7	1.5	5.9	73.8
Oreobolus oxycarpus	0.0	6.0	2.9	1.0	4.6	78.4
Astelia alpina	3.6	0.0	1.8	1.4	2.8	81.2
Poa costiniana	1.1	4.7	1.8	1.7	2.8	84.0
Callistemon pityoides	0.0	3.1	1.5	2.1	2.4	86.4
Epacris celata	1.9	1.5	1.3	1.3	2.0	88.4
Epacris glacialis	2.5	0.0	1.2	0.9	2.0	90.3
Carpha spp.	1.8	0.0	0.9	1.0	1.4	91.7
Pultenaea fasiculata	0.0	1.5	0.7	1.1	1.2	92.9
Baloskion australe	0.1	1.6	0.7	0.7	1.1	94.0
Oreobolus distichus	1.3	0.0	0.7	0.9	1.1	95.1

Table A3.14: Species contributing to differences between **Low wet heath (LWH)** and **Myrtaceous wet heath (MWH)** based on the **Bogong region transects, (a) Frequency data, (b) cover data**. The species listed contribute between 81% and 98% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

(a) Frequency data. (LWH) and (MWH). Mean dissimilarity = 67.8.

Species	freq. LWH	freq. MWH	Av.Diss	Diss/SD	Contrib%	Cum.%
Epacris glacialis	99.3	0.0	6.3	8.7	9.4	9.4
Epacris paludosa	1.0	86.4	5.4	5.8	8.0	17.4
Astelia alpina	76.0	0.0	4.8	4.4	7.0	24.4
Richea continentis	69.7	0.0	4.4	3.1	6.5	30.9
Asperula gunnii	6.0	72.5	4.2	2.1	6.1	37.0
Baeckea gunniana	33.3	90.3	3.7	2.6	5.4	42.4
Baloskion australe	15.3	63.1	3.5	1.9	5.2	47.6
Celmisia spp.	66.0	13.9	3.3	2.4	4.8	52.4
Oreobolus distichus	45.0	0.0	2.8	2.2	4.1	56.5
Luzula modesta	0.0	40.8	2.5	1.3	3.8	60.3
Epacris celata	14.7	35.6	2.3	3.2	3.4	63.6
Pultenaea fasiculata	0.0	32.2	2.0	1.3	2.9	66.6
Oreobolus oxycarpus	0.0	32.2	2.0	1.4	2.9	69.5
Callistemon pityoides	0.0	30.3	1.9	2.0	2.8	72.3
Gentianella sp.	28.0	0.0	1.7	2.6	2.6	74.9
Poa costiniana	85.7	65.0	1.6	1.5	2.4	77.3
Sphagnum cristatum	14.3	29.7	1.6	1.0	2.4	79.7
Diplaspis nivis	25.3	0.0	1.5	0.8	2.2	81.8
Agrostis sp.	10.3	23.6	1.4	1.2	2.1	83.9
Gonocarpus micranthus	0.3	19.7	1.2	1.2	1.8	85.7
Pultenaea capitellata	0.0	18.1	1.1	0.8	1.6	87.3
Comesperma retusum	0.0	16.7	1.0	1.3	1.5	88.9
Stylidium sp.	0.0	14.4	0.9	1.1	1.4	90.2

(b) Cover data. (LWH) and (MWH). Mean dissimilarity = 76.5%.

Species	cover% LWH	cover% MWH	Av.Diss	Diss/SD	Contrib%	Cum.%
Astelia alpina	26.8	0.0	15.4	2.1	20.2	20.2
Epacris glacialis	23.4	0.0	14.0	2.3	18.4	38.5
Baeckea gunniana	1.5	15.1	8.0	5.8	10.5	49.0
Epacris paludosa	0.3	12.2	7.0	2.9	9.1	58.2
Richea continentis	10.6	0.0	6.2	2.2	8.1	66.3
Sphagnum cristatum	3.3	10.4	6.0	0.9	7.9	74.2
Empodisma minus	19.6	14.6	3.6	1.4	4.8	79.0
Oreobolus oxycarpus	0.0	6.0	3.5	1.0	4.5	83.5
Oreobolus distichus	3.2	0.0	1.9	1.0	2.5	86.0
Callistemon pityoides	0.0	3.1	1.8	2.1	2.4	88.4
Poa costiniana	2.1	4.7	1.6	1.4	2.1	90.4
Celmisia spp.	2.6	0.2	1.4	2.1	1.8	92.2
Epacris celata	1.3	1.5	1.3	1.2	1.7	93.9
Pultenaea fasiculata	0.0	1.5	0.9	1.1	1.2	95.1
Baloskion australe	0.2	1.6	0.8	0.7	1.1	96.2
Pultenaea capitellata	0.0	0.9	0.5	0.7	0.7	96.9
Luzula modesta	0.0	0.8	0.5	0.8	0.7	97.5
Asperula gunnii	0.1	0.8	0.4	1.6	0.6	98.1

Table A3.15: Species contributing to differences between **Subalpine raised bog (SRB)** and **Myrtaceous wet heath (MWH)** based on the **Bogong region transects, (a) Frequency data, (b) cover data**. The species listed contribute between 81% and 98% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

(a) Frequency data. (SRB) and (MWH). Mean dissimilarity = 50.0.

Species	**freq. SRB**	**freq. MWH**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Richea continentis	80.6	0.0	5.3	3.1	10.7	10.7
Carex gaudichaudiana	68.8	0.3	4.5	3.0	9.0	19.6
Sphagnum cristatum	96.0	29.7	4.2	2.6	8.5	28.1
Asperula gunnii	14.6	72.5	3.8	1.9	7.6	35.7
Luzula modesta	6.4	40.8	2.3	1.3	4.7	40.3
Epacris paludosa	57.3	86.4	2.2	1.2	4.4	44.7
Baloskion australe	54.8	63.1	2.2	1.3	4.4	49.1
Baeckea gunniana	60.9	90.3	2.1	1.3	4.1	53.2
Pultenaea fasiculata	0.0	32.2	2.0	1.3	4.1	57.3
Oreobolus oxycarpus	1.5	32.2	2.0	1.4	3.9	61.3
Poa costiniana	37.2	65.0	1.9	1.3	3.8	65.0
Callistemon pityoides	2.1	30.3	1.9	1.9	3.8	68.8
Epacris celata	40.6	35.6	1.7	1.5	3.3	72.1
Celmisia spp.	22.1	13.9	1.6	1.1	3.3	75.4
Agrostis sp.	0.9	23.6	1.5	1.1	3.1	78.4
Gonocarpus micranthus	2.9	19.7	1.3	1.2	2.5	80.9
Pultenaea capitellata	0.0	18.1	1.1	0.8	2.2	83.2
Comesperma retusum	0.0	16.7	1.0	1.3	2.1	85.2
Stylidium sp.	0.2	14.4	1.0	1.2	1.9	87.2
Isolepis spp.	4.3	15.0	0.9	0.9	1.8	89.0
Nertera granadensis	11.2	6.4	0.9	0.8	1.8	90.7

(b) Cover data. (SRB) and (MWH). Mean dissimilarity = 61.4%.

Species	**cover% SRB**	**cover% MWH**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Sphagnum cristatum	78.1	10.4	31.6	3.7	51.4	51.4
Richea continentis	15.0	0.0	6.9	1.7	11.2	62.6
Baeckea gunniana	7.8	15.1	3.9	2.6	6.3	68.9
Empodisma minus	19.9	14.6	3.8	1.4	6.2	75.1
Epacris paludosa	12.1	12.2	3.5	1.5	5.6	80.7
Oreobolus oxycarpus	0.0	6.0	2.7	1.0	4.4	85.1
Poa costiniana	0.6	4.7	1.9	2.1	3.0	88.1
Callistemon pityoides	0.4	3.1	1.4	2.0	2.3	90.4
Baloskion australe	2.4	1.6	1.1	1.2	1.8	92.2
Epacris celata	2.9	1.5	1.1	1.0	1.8	94.0
Pultenaea fasiculata	0.0	1.5	0.7	1.1	1.1	95.1
Carex gaudichaudiana	1.1	0.0	0.5	1.4	0.8	95.9
Pultenaea capitellata	0.0	0.9	0.4	0.8	0.7	96.6
Luzula modesta	0.0	0.8	0.4	0.8	0.6	97.3
Asperula gunnii	0.1	0.8	0.3	1.5	0.5	97.8
Carpha spp.	0.6	0.0	0.3	0.6	0.4	98.2

Table A3.16: Species contributing to differences between **Low wet heath (LWH)** and **Alpine valley bog (AVB)** based on the **Bogong region transects, (a) Frequency data, (b) cover data**. The species listed contribute between 81% and 98% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

(a) Frequency data. (LWH) and (AVB). Mean dissimilarity = 58.7%.

Species	**freq. LWH**	**freq. AVB**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Sphagnum cristatum	14.3	98.6	6.2	4.7	10.5	10.5
Carex gaudichaudiana	13.0	95.3	6.0	4.1	10.2	20.7
Astelia alpina	76.0	0.0	5.4	4.6	9.2	29.9
Celmisia spp.	66.0	0.0	4.7	4.3	7.9	37.8
Poa costiniana	85.7	33.3	4.0	1.6	6.8	44.6
Epacris glacialis	99.3	56.3	3.1	1.2	5.3	50.0
Epacris celata	14.7	45.5	3.0	1.5	5.2	55.1
Oreobolus distichus	45.0	4.5	2.9	2.0	4.9	60.0
Carex echinata	0.0	39.4	2.9	1.1	4.9	64.9
Richea continentis	69.7	47.4	2.6	1.6	4.4	69.3
Baeckea gunniana	33.3	7.6	2.1	1.6	3.5	72.9
Gentianella sp.	28.0	0.0	2.0	2.6	3.3	76.2
Carpha spp.	8.3	30.3	1.9	1.5	3.2	79.4
Diplaspis nivis	25.3	0.0	1.7	0.8	2.8	82.2
Isolepis spp.	0.0	23.0	1.6	0.7	2.7	84.9
Baloskion australe	15.3	10.0	1.5	0.7	2.6	87.5
Polytrichum spp.	0.0	12.0	0.9	0.5	1.5	89.1
Agrostis sp.	10.3	6.0	0.8	1.5	1.4	90.4

(b) Cover data. (LWH) and (AVB). Mean dissimilarity = 79.9%.

Species	**cover% LWH**	**cover% AVB**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Sphagnum cristatum	3.25	89.95	39.02	10.49	48.83	48.83
Astelia alpina	26.81	0.00	11.83	2.09	14.80	63.64
Epacris glacialis	23.35	3.47	9.09	1.95	11.38	75.02
Empodisma minus	19.62	8.89	4.83	2.46	6.05	81.06
Carex gaudichaudiana	0.15	8.73	3.87	3.96	4.85	85.91
Richea continentis	10.62	6.79	2.80	1.40	3.51	89.42
Epacris celata	1.27	3.19	1.44	1.45	1.80	91.21
Oreobolus distichus	3.16	0.03	1.43	1.04	1.79	93.00
Celmisia spp.	2.57	0.00	1.15	2.55	1.44	94.44
Carex echinata	0.00	2.27	1.06	0.62	1.33	95.78
Poa costiniana	2.09	0.39	0.82	1.42	1.03	96.81
Carpha spp.	0.08	1.75	0.78	1.85	0.97	97.78
Baeckea gunniana	1.47	0.05	0.64	1.51	0.80	98.57

Table A3.17: Species contributing to differences between **Tall wet heath (TWH)** and **Alpine valley bog (AVB)** based on the **Bogong region transects, (a) Frequency data, (b) cover data**. The species listed contribute between 81% and 98% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

(a) Frequency data. (TWH) and (AVB). Mean dissimilarity = 52.8%.

Species	**freq. TWH**	**freq. AVB**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Baeckea gunniana	83.8	7.6	5.4	4.6	10.3	10.3
Epacris paludosa	64.6	2.7	4.1	3.0	7.8	18.1
Epacris glacialis	0.0	56.3	4.1	1.5	7.7	25.9
Carex gaudichaudiana	45.0	95.3	3.9	1.3	7.3	33.2
Poa costiniana	65.0	33.3	2.9	1.6	5.5	38.7
Carex echinata	0.0	39.4	2.9	1.1	5.4	44.1
Sphagnum cristatum	66.3	98.6	2.8	0.9	5.4	49.5
Richea continentis	58.8	47.4	2.8	1.3	5.4	54.8
Asperula gunnii	31.3	0.0	2.5	1.3	4.7	59.5
Erigeron paludicola	35.4	10.3	2.2	1.4	4.1	63.6
Celmisia spp.	33.3	0.0	2.2	1.3	4.1	67.7
Baloskion australe	30.8	10.0	2.1	0.9	4.0	71.6
Epacris celata	48.8	45.5	1.8	1.2	3.4	75.1
Carpha spp.	13.3	30.3	1.8	1.3	3.4	78.4
Isolepis spp.	0.0	23.0	1.6	0.7	3.0	81.5
Oreobolus distichus	22.9	4.5	1.3	1.0	2.5	84.0
Polytrichum spp.	0.0	12.0	0.9	0.5	1.7	85.7
Diplaspis nivis	14.6	0.0	0.8	0.6	1.6	87.3
Nertera granadensis	13.3	0.3	0.8	0.9	1.6	88.9
Thelymitra cyanea	14.2	0.0	0.8	0.6	1.5	90.4

(b) Cover data. (TWH) and (AVB). Mean dissimilarity = 59.4%.

Species	**cover% TWH**	**cover% AVB**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Sphagnum cristatum	34.7	90.0	23.4	2.4	39.4	39.4
Baeckea gunniana	23.1	0.1	9.6	6.3	16.1	55.5
Richea continentis	23.2	6.8	9.2	1.1	15.5	71.0
Epacris paludosa	15.7	0.2	6.4	1.9	10.8	81.8
Carex gaudichaudiana	0.8	8.7	3.3	3.3	5.6	87.4
Epacris glacialis	0.0	3.5	1.4	1.0	2.4	89.8
Empodisma minus	8.6	8.9	1.4	1.9	2.3	92.1
Epacris celata	2.1	3.2	1.0	1.4	1.7	93.8
Carex echinata	0.0	2.3	1.0	0.6	1.7	95.5
Carpha spp.	0.7	1.8	0.6	1.5	1.0	96.4
Oreobolus distichus	1.1	0.0	0.4	0.8	0.7	97.2
Baloskion australe	0.8	0.3	0.4	0.9	0.6	97.8
Poa costiniana	0.8	0.4	0.3	1.4	0.4	98.2

Table A3.18: Species contributing to differences between **Myrtaceous wet heath (MWH)** and **Alpine valley bog (AVB)** based on the **Bogong region transects, (a) Frequency data, (b) cover data**. The species listed contribute between 81% and 98% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

(a) Frequency data. (MWH) and (AVB). Mean dissimilarity = 70.4%.

Species	**freq. MWH**	**freq. AVB**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Carex gaudichaudiana	0.3	95.3	6.5	9.5	9.2	9.2
Epacris paludosa	86.4	2.7	5.7	6.6	8.1	17.2
Baeckea gunniana	90.3	7.6	5.7	5.5	8.0	25.3
Asperula gunnii	72.5	0.0	4.8	2.5	6.9	32.1
Sphagnum cristatum	29.7	98.6	4.6	2.8	6.5	38.7
Epacris glacialis	0.0	56.3	3.8	1.6	5.5	44.1
Baloskion australe	63.1	10.0	3.7	2.0	5.3	49.4
Richea continentis	0.0	47.4	3.2	1.7	4.5	53.9
Poa costiniana	65.0	33.3	2.8	1.5	4.0	57.9
Carex echinata	0.0	39.4	2.7	1.2	3.8	61.8
Luzula modesta	40.8	3.0	2.6	1.3	3.7	65.4
Pultenaea fasiculata	32.2	0.0	2.1	1.3	3.0	68.4
Oreobolus oxycarpus	32.2	0.0	2.1	1.4	3.0	71.4
Callistemon pityoides	30.3	0.0	2.1	2.0	2.9	74.4
Carpha spp.	1.7	30.3	2.0	1.7	2.8	77.2
Epacris celata	35.6	45.5	1.8	1.7	2.5	79.7
Isolepis spp.	15.0	23.0	1.8	1.0	2.5	82.2
Agrostis sp.	23.6	6.0	1.5	1.2	2.1	84.3
Gonocarpus micranthus	19.7	0.0	1.3	1.2	1.9	86.2
Pultenaea capitellata	18.1	0.0	1.2	0.8	1.7	87.8
Comesperma retusum	16.7	0.0	1.1	1.3	1.5	89.4
Celmisia spp.	13.9	0.0	1.0	0.7	1.5	90.8

(b) Cover data. (MWH) and (AVB). Mean dissimilarity = 79.4%.

Species	**cover%MWH**	**cover% AVB**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Sphagnum cristatum	10.4	90.0	39.8	4.4	50.1	50.1
Baeckea gunniana	15.1	0.1	7.5	8.1	9.4	59.5
Epacris paludosa	12.2	0.2	5.9	3.0	7.5	67.0
Carex gaudichaudiana	0.0	8.7	4.4	4.0	5.5	72.5
Richea continentis	0.0	6.8	3.3	1.5	4.2	76.7
Empodisma minus	14.6	8.9	3.0	1.4	3.7	80.4
Oreobolus oxycarpus	6.0	0.0	2.9	1.0	3.7	84.1
Poa costiniana	4.7	0.4	2.1	2.2	2.6	86.7
Epacris glacialis	0.0	3.5	1.7	1.0	2.2	88.9
Callistemon pityoides	3.1	0.0	1.5	2.1	1.9	90.8
Epacris celata	1.5	3.2	1.2	1.6	1.6	92.4
Carex echinata	0.1	2.3	1.2	0.6	1.5	93.9
Carpha spp.	0.0	1.8	0.9	1.8	1.1	95.0
Pultenaea fasiculata	1.5	0.0	0.8	1.1	0.9	95.9
Baloskion australe	1.6	0.3	0.8	0.7	0.9	96.8
Pultenaea capitellata	0.9	0.0	0.5	0.7	0.6	97.4
Luzula modesta	0.8	0.0	0.4	0.8	0.5	98.0
Asperula gunnii	0.8	0.0	0.4	1.7	0.5	98.4

Table A3.19: Species contributing to differences between **Low wet heath (LWH)** and **Subalpine raised bog (SRB)** based on the **Bogong region transects, (a) Frequency data, (b) cover data**. The species listed contribute between 81% and 98% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

(a) Frequency data. (LWH) and (SRB). Mean dissimilarity = 57.8.

Species	**freq. LWH**	**Freq. SRB**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Epacris glacialis	99.3	0.0	6.9	7.6	11.9	11.9
Sphagnum cristatum	14.3	96.0	5.7	4.3	9.8	21.7
Astelia alpina	76.0	1.1	5.1	4.4	8.8	30.5
Carex gaudichaudiana	13.0	68.8	3.9	2.1	6.8	37.3
Epacris paludosa	1.0	57.3	3.9	1.8	6.8	44.0
Poa costiniana	85.7	37.2	3.5	2.1	6.0	50.0
Baloskion australe	15.3	54.8	3.4	1.5	5.9	55.9
Celmisia spp.	66.0	22.1	3.2	1.9	5.5	61.4
Oreobolus distichus	45.0	5.8	2.7	1.9	4.7	66.1
Epacris celata	14.7	40.6	2.7	1.5	4.7	70.8
Baeckea gunniana	33.3	60.9	2.3	1.4	4.0	74.8
Richea continentis	69.7	80.6	2.0	1.4	3.4	78.2
Gentianella sp.	28.0	0.0	1.9	2.6	3.2	81.4
Diplaspis nivis	25.3	0.0	1.6	0.8	2.8	84.2
Carpha spp.	8.3	10.2	0.9	0.9	1.6	85.8
Asperula gunnii	6.0	14.6	0.9	1.1	1.5	87.3
Rytidosperma nivicola	12.3	0.0	0.8	1.2	1.4	88.6
Agrostis sp.	10.3	0.9	0.7	0.9	1.2	89.8
Nertera granadensis	0.0	11.2	0.7	0.5	1.2	91.0

(b) Cover data. (LWH) and (SRB). Mean dissimilarity = 74.1%.

Species	**cover% LWH**	**cover% SRB**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Sphagnum cristatum	3.3	78.1	31.6	7.5	42.6	42.6
Astelia alpina	26.8	0.0	11.1	2.1	15.0	57.6
Epacris glacialis	23.4	0.0	10.0	2.5	13.5	71.1
Epacris paludosa	0.3	12.1	5.1	1.5	6.8	78.0
Richea continentis	10.6	15.0	3.8	1.4	5.2	83.1
Empodisma minus	19.6	19.9	3.1	1.4	4.2	87.3
Baeckea gunniana	1.5	7.8	2.7	1.3	3.6	90.9
Epacris celata	1.3	2.9	1.3	1.2	1.8	92.7
Oreobolus distichus	3.2	0.1	1.3	1.0	1.8	94.5
Celmisia spp.	2.6	0.2	1.0	2.2	1.3	95.8
Baloskion australe	0.2	2.4	1.0	1.1	1.3	97.1
Poa costiniana	2.1	0.6	0.7	1.3	0.9	98.0

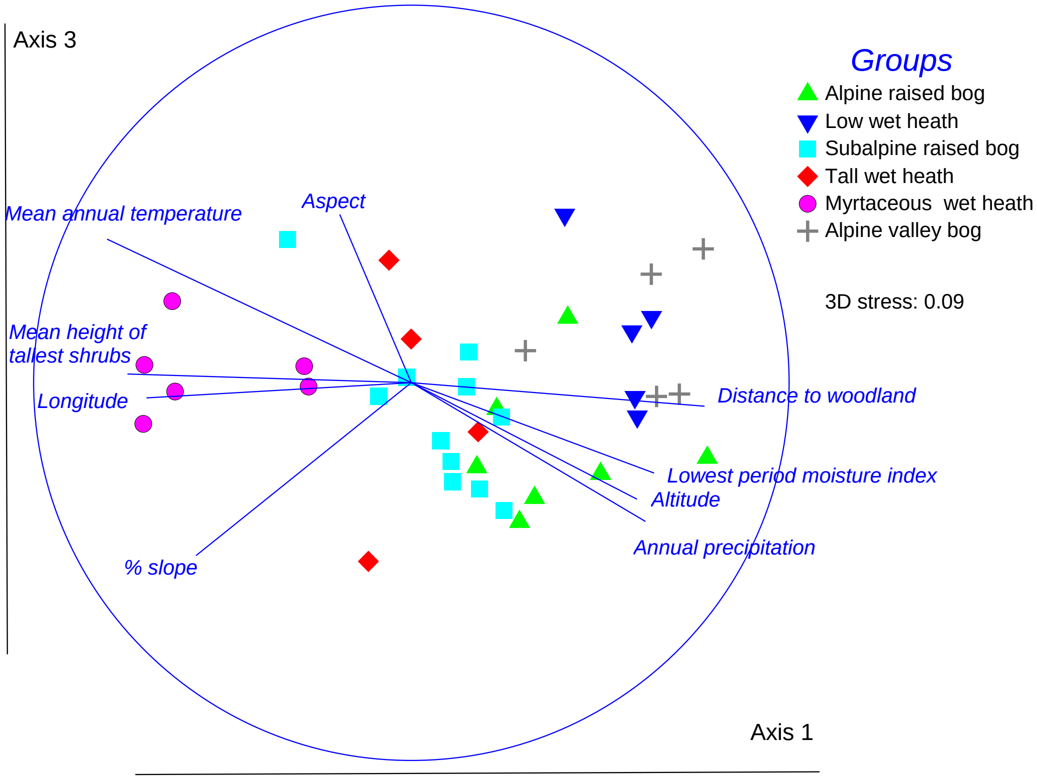


Figure A3.1: Three dimensional ordination configuration derived from the **Bogong region frequency data** (Axis 1 v Axis 3). The trend directions of significantly correlated factors are indicated.

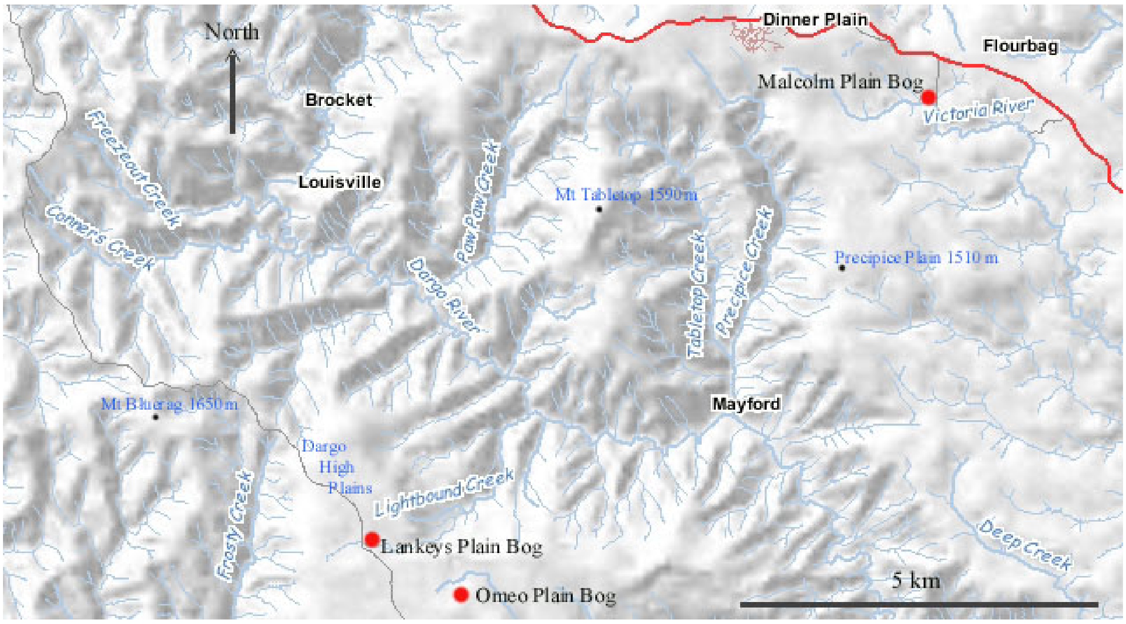


Figure A3.2: Map of the upper Dargo River and upper Victoria river region showing the location of the Dargo High Plains sites and the Malcolm Plain site (Bogong region). The Victoria river and streams on the eastern third of the map are north of the divide and flow into the Mitta Mitta river. The Dargo river and streams on the western (left) two thirds of the map are within the Mitchell river catchment.

Table A3.24: List of the transects (= plots) used in the **Snowy Range-Dargo High Plains region** study. Location details and community type classification included.

Transect	**Code**	**Alt.**	**Lat.**	**Long.**	**Zone**	**Catchment**	**Community type**
Cave Gate Creek 2	**cg2**	1420	37.30	146.73	Subalpine	Macalister	Myrtaceous wet heath
Cave Gate Creek 1	**cg1**	1400	37.30	146.73	Subalpine	Macalister	Subalpine raised bog
Lankey's Plain 1	**lp1**	1580	37.11	147.16	Subalpine	Mitchell	Subalpine raised bog
Lankey's Plain Fenced Plot	**lpe**	1560	37.11	147.16	Subalpine	Mitchell	Subalpine raised bog
Omeo Plain 1	**op1**	1540	37.12	147.17	Subalpine	Mitchell	Subalpine raised bog
Snowy Range South	**ss**	1580	37.37	146.75	Subalpine	Macalister	Subalpine raised bog
Snowy Range West 1	**sw1**	1580	37.35	146.76	Subalpine	Macalister	Subalpine raised bog
Guy's Hut Bog	**gh**	1400	37.29	146.75	Subalpine	Mitchell	Tall wet heath
Lankey's Plain 2	**lp2**	1580	37.11	147.16	Subalpine	Mitchell	Tall wet heath
Omeo Plain 2	**op2**	1540	37.12	147.17	Subalpine	Mitchell	Tall wet heath
Piemans Creek 1	**pc1**	1440	37.29	146.75	Subalpine	Mitchell	Tall wet heath
Piemans Creek 2	**pc2**	1450	37.29	146.74	Subalpine	Mitchell	Tall wet heath
Snowy Range West 2	**sw2**	1580	37.35	146.76	Subalpine	Macalister	Tall wet heath
Bennison Plain 1	**ben**	1290	37.46	146.74	Montane	Macalister	Montane valley bog
Bennison Plain 2	**ben2**	1270	37.46	146.74	Montane	Macalister	Montane valley bog
Dairy Farm Flat 1	**df1**	1150	37.50	147.04	Montane	Mitchell	Montane valley bog
Morass Creek 1	**mc1**	1140	37.49	146.90	Montane	Mitchell	Montane valley bog
Morgan's Gully 1	**mg1**	1000	37.48	146.98	Montane	Mitchell	Montane valley bog
Morgan's Gully 2	**mg2**	1000	37.48	146.98	Montane	Mitchell	Montane valley bog
Moroka Bridge	**mb**	1035	37.50	146.96	Montane	Mitchell	Montane valley bog
Moroka Hut	**mh**	1040	37.50	146.96	Montane	Mitchell	Montane valley bog
Dairy Farm Flat 2	**df2**	1150	37.50	147.04	Montane	Mitchell	Myrtaceous wet heath
Morass Creek 2	**mc2**	1140	37.49	146.90	Montane	Mitchell	Myrtaceous wet heath

Table A3.27: Species contributing to differences between between **Subalpine raised bog (SRB)** and **Tall wet heath (TWH)** based on the **Snowy Range-Dargo High Plains region transects, (a) frequency data, (b) cover data**. The species listed contribute between 70% and 94% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher value for the ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they are most prominent.

(a): **Frequency data**. **(SRB)** and **(TWH)**. (up to 70%). Mean dissimilarity = 38.8%.

More common in SRB	**freq.SRB**	**freq.TWH**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**94.2**	46.1	3.7	2.6	9.6
Baloskion australe	**25.8**	5.8	2.1	0.8	5.5
Carpha spp.	**14.2**	0.3	1.2	0.6	3.0
Nertera granadensis	**12.8**	4.2	1.1	0.7	2.9
Celmisia spp.	**10.0**	3.3	0.8	1.2	2.0
More common in TWH					
Asperula gunnii	10.8	**38.6**	2.6	1.2	6.8
Epacris celata	10.0	**31.7**	2.2	1.3	5.6
Poa costiniana	8.1	**30.0**	1.8	1.4	4.6
Callistemon pityoides	2.8	**20.6**	1.6	0.8	4.1
Psychrophila introloba	3.6	**9.4**	0.9	0.7	2.2
Similar frequency in both					
Richea continentis	80.3	61.9	2.9	1.3	7.4
Epacris paludosa	73.1	58.9	1.9	1.4	5.0
Empodisma minus	97.2	80.0	1.7	0.6	4.3
Carex gaudichaudiana	73.6	77.5	1.6	1.5	4.2
Baeckea gunniana	68.6	66.1	1.3	1.4	3.3

(b): **Cover data. (SRB)** and **(TWH)**. (up to 94%). Mean dissimilarity = 45.9%.

Higher % cover in SRB	**Av.cover SRB**	**Av.cover TWH**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**75.8**	26.1	21.8	3.3	47.4
Epacris paludosa	**18.0**	13.9	3.9	1.4	8.4
Empodisma minus	**9.8**	4.3	2.6	0.9	5.7
Sphagnum novo-zelandicum	**1.5**	0.7	0.8	0.7	1.7
Baloskion australe	**1.0**	0.1	0.5	0.6	1.0
Higher % cover in TWH					
Carex spp.	1.3	**3.2**	1.2	0.7	2.6
Callistemon pityoides	0.3	**4.9**	2.1	0.7	4.5
Epacris celata	0.3	**3.4**	1.4	0.8	3.0
Poa costiniana	0.2	**1.5**	0.6	1.0	1.3
Similar % cover in both					
Richea continentis	18.1	19.7	6.5	1.4	14.1
Baeckea gunniana	8.8	11.4	2.6	1.3	5.6

Table A3.28: Species contributing to differences between **Montane valley bog (MVB)** and **Myrtaceous wet heath (MWH)** based on the **Snowy Range-Dargo High Plains region transects, (a) frequency data, (b) cover data**. The species listed contribute between 70% and 94% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by higher values for the ratio of dissimilarity to standard deviation of dissimilarity (Diss./SD). The species have been sorted according to the community type in which they are most prominent.

(a) Frequency data. **(MVB)** and **(MWH)**. Mean dissimilarity = 47.6%

More common in MVB	**freq.MVB**	**freq.MWH**	**Av.Diss**	**Diss/SD**	**Contrib%**
Carex gaudichaudiana	**94.8**	5.0	7.4	7.1	15.5
Sphagnum cristatum	**86.0**	45.0	3.9	1.2	8.2
Luzula modesta	**25.0**	7.8	1.7	1.3	3.6
Epacris breviflora	**21.0**	5.6	1.7	0.9	3.5
Poa costiniana	**17.7**	8.9	1.4	0.8	2.9
Veronica sp.2	**17.1**	0.6	1.3	0.8	2.8
Ranunculus collinus	**12.3**	0.0	1.0	0.8	2.0
More common in MWH					
Epacris paludosa	55.0	**93.3**	3.1	1.3	6.6
Baeckea gunniana	40.6	**90.0**	4.1	1.9	8.6
Baumea gunnii	11.0	**31.1**	2.0	1.6	4.2
Sphagnum novozelandicum	4.2	**14.4**	1.1	1.3	2.4
Callistemon pityoides	1.5	**39.4**	3.1	3.0	6.6
Similar frequency in both					
Asperula gunnii	52.9	35.6	2.9	1.2	6.0
Baloskion australe	40.6	51.7	3.5	1.4	7.4
Poa spp.	12.7	11.7	1.4	0.8	3.0

(b) Cover data. (MVB) and **(MWH).** Mean dissimilarity = 43.7%

Higher % cover in MVB	**Av.cover MVB**	**Av.cover MWH**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**51.8**	15.4	19.5	1.7	44.6
Carex spp.	**4.6**	0.1	2.4	1.4	5.4
Epacris breviflora	**2.0**	0.9	1.2	0.9	2.7
Sphagnum novozelandicum	**2.1**	0.6	1.1	0.5	2.6
Higher % cover in MWH					
Epacris paludosa	9.8	**13.8**	3.9	1.4	8.9
Baeckea gunniana	5.3	**12.5**	3.8	1.6	8.8
Callistemon pityoides	0.2	**6.8**	3.4	2.7	7.8
Similar % cover in both					
Empodisma minus	28.5	27.5	4.6	1.1	10.6

Table A3.29: Species contributing to differences between **Subalpine raised bog (SRB)** and **Myrtaceous wet heath (MWH)** based on the **Snowy Range-Dargo High Plains region transects, (a) frequency data, (b) cover data**. The species listed contribute between 70% and 94% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by higher values for the ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they are most prominent.

(b) **Frequency data. (SRB)** and **(MWH).** Mean dissimilarity = 46.5%.

More common in SRB	**freq.SRB**	**freq.MWH**	**Av.Diss**	**Diss/SD**	**Contrib%**
Richea continentis	**80.3**	0.0	6.6	2.4	14.1
Carex gaudichaudiana	**73.6**	5.0	5.6	4.5	12.1
Sphagnum cristatum	**94.2**	45.0	4.3	1.2	9.2
Carpha spp.	**14.2**	4.4	1.4	0.7	2.9
Nertera granadensis	**12.8**	6.1	1.3	0.7	2.7
More common in MWH					
Baloskion australe	25.8	**51.7**	3.8	1.3	8.2
Callistemon pityoides	2.8	**39.4**	3.0	2.8	6.5
Asperula gunnii	10.8	**35.6**	2.5	1.5	5.4
Baumea gunnii	0.0	**31.1**	2.4	1.7	5.2
Sphagnum novozelandicum	4.2	**14.4**	1.1	1.3	2.3
Similar frequency in both					
Epacris paludosa	73.1	93.3	1.8	1.2	4.0
Baeckea gunniana	68.6	90.0	1.8	1.6	3.9

(b) **Cover data. (SRB)** and **(MWH).** Mean dissimilarity = 58.4%.

Higher % cover in SRB	**Av.cover SRB**	**Av.cover MWH**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**75.8**	15.4	28.2	3.0	48.3
Richea continentis	**18.1**	0.0	8.4	1.5	14.4
Epacris paludosa	**18.0**	13.8	3.6	1.2	6.2
Sphagnum novozelandicum	**1.5**	0.6	0.7	0.7	1.2
Higher % cover in MWH					
Empodisma minus	9.8	**27.5**	8.2	2.5	14.0
Callistemon pityoides	0.3	**6.8**	2.9	2.6	5.0
Baeckea gunniana	8.8	**12.5**	2.6	2.0	4.4
Baloskion australe	1.0	**1.3**	0.7	1.1	1.2

Table A3.30: Species contributing to differences between **Subalpine raised bog (SRB)** and **Montane valley bog (MVB)** based on the **Snowy Range-Dargo High Plains region transects, (a) frequency data, (b) cover data**. The species listed contribute between 70% and 94% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss./SD). The species have been sorted according to the community type in which they are most prominent.

(a): Frequency data. **(SRB)** and **(MVB)**. Mean dissimilarity = 40.7%.

More common in SRB	**freq.SRB**	**freq.MVB**	**Av.Diss**	**Diss/SD**	**Contrib%**
Richea continentis	80.3	0.0	6.3	2.5	15.4
Nertera granadensis	12.8	7.9	1.3	0.8	3.3
Carpha spp.	14.2	1.0	1.2	0.6	2.9
Celmisia spp.	10.0	0.4	0.8	1.2	1.9
More common in MVB					
Asperula gunnii	10.8	52.9	3.4	1.6	8.4
Luzula modesta	1.4	25.0	1.8	1.4	4.5
Epacris breviflora	0.0	21.0	1.6	0.8	4.0
Poa costiniana	8.1	17.7	1.3	0.8	3.3
Veronica sp.2	0.0	17.1	1.3	0.8	3.1
Poa spp.	0.0	12.7	0.9	0.6	2.3
Ranunculus collinus	0.0	12.3	0.9	0.8	2.3
Baumea gunnii	0.0	11.0	0.8	0.9	2.0
Similar frequency in both					
Baloskion australe	25.8	40.6	3.2	1.3	7.8
Baeckea gunniana	68.6	40.6	2.6	1.5	6.3
Epacris paludosa	73.1	55.0	2.4	1.3	5.8
Carex gaudichaudiana	73.6	94.8	1.9	1.5	4.6
Epacris celata	10.0	7.9	1.2	0.9	2.9
Sphagnum cristatum	94.2	86.0	0.9	1.1	2.3

(b): Cover data. **(SRB)** and **(MVB).** Mean dissimilarity = 39.1%.

Higher % cover in SRB	**Av.cover SRB**	**Av.cover MVB**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**75.8**	51.8	10.9	1.6	27.9
Richea continentis	**18.1**	0.0	7.5	1.5	19.1
Epacris paludosa	**18.0**	9.8	4.3	1.4	11.0
Higher % cover in MVB					
Empodisma minus	9.8	**28.5**	7.8	1.6	20.0
Carex spp.	1.3	**4.6**	1.4	1.2	3.7
Epacris breviflora	0.0	**2.0**	0.9	0.8	2.2
Similar % cover in both					
Baeckea gunniana	8.8	5.3	2.3	1.3	5.9
Sphagnum novozelandicum	1.5	2.1	1.2	0.6	3.0
Baloskion australe	1.0	0.8	0.6	0.9	1.4

Table A3.31: Species contributing to differences between **Tall wet heath (TWH)** and **Montane valley bog (MVB)** based on the **Snowy Range-Dargo High Plains region transects, (a) frequency data, (b) cover data**. The species listed contribute between 70% and 94% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss./SD). The species have been sorted according to the community type in which they are most prominent.

(a) Frequency data. (TWH) and **(MVB**). Mean dissimilarity = 46.1%

More common in TWH	**freq.TWH**	**freq.MVB**	**Av.Diss**	**Diss/SD**	**Contrib%**
Richea continentis	61.9	0.0	4.9	2.0	10.6
Epacris celata	31.7	7.9	2.3	1.2	5.0
Poa costiniana	30.0	17.7	2.0	1.4	4.3
Callistemon pityoides	20.6	1.5	1.6	0.8	3.4
More common in MVB					
Sphagnum cristatum	46.1	86.0	3.1	1.8	6.8
Veronica sp.2	7.2	17.1	1.3	1.0	2.9
Baloskion australe	5.8	40.6	2.9	1.3	6.3
Luzula modesta	5.6	25.0	1.7	1.4	3.6
Poa spp.	1.9	12.7	1.0	0.6	2.1
Ranunculus collinus	0.8	12.3	0.9	0.8	1.9
Epacris breviflora	0.0	21.0	1.6	0.8	3.5
Baumea gunnii	0.0	11.0	0.8	0.9	1.8
Similar frequency in both					
Empodisma minus	80.0	96.7	1.7	0.7	3.6
Carex gaudichaudiana	77.5	94.8	1.6	1.2	3.5
Baeckea gunniana	66.1	40.6	2.5	1.5	5.4
Epacris paludosa	58.9	55.0	2.1	1.4	4.5
Asperula gunnii	38.6	52.9	2.7	1.4	5.9

(b) Cover data. **(TWH)** and **(MVB**). Mean dissimilarity = 54.8%.

Higher % cover in TWH	**Av.cover TWH**	**Av.cover MVB**	**Av.Diss**	**Diss/SD**	**Contrib%**
Richea continentis	**19.7**	0.0	9.7	1.4	17.6
Epacris paludosa	**13.9**	9.8	4.2	1.4	7.7
Baeckea gunniana	**11.4**	5.3	3.6	1.6	6.7
Callistemon pityoides	**4.9**	0.2	2.3	0.7	4.3
Epacris celata	**3.4**	0.2	1.6	0.8	2.9
Poa costiniana	**1.5**	0.5	0.7	1.1	1.3
Higher % cover in MVB					
Sphagnum cristatum	26.1	**51.8**	12.8	1.5	23.3
Empodisma minus	4.3	**28.5**	12.1	2.0	22.0
Carex spp.	3.2	**4.6**	2.1	1.2	3.8
Sphagnum novo-zelandicum	0.7	**2.1**	1.2	0.5	2.1
Epacris breviflora	0.0	**2.0**	1.1	0.8	1.9

Table A3.32: Species contributing to differences between **Tall wet heath (TWH)** and **Myrtaceous wet heath (MWH)** based on the **Snowy Range-Dargo High Plains region transects, (a) frequency data, (b) cover data**. The species listed contribute between 70% and 94% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss./SD). The species have been sorted according to the community type in which they are most prominent.

(a): Frequency data. (TWH) and **(MWH)**. Mean dissimilarity = 51.9

More common in TWH	**freq.TWH**	**freq.MWH**	**Av.Diss**	**Diss/SD**	**Contrib%**
Carex gaudichaudiana	77.5	5.0	5.9	3.3	11.4
Richea continentis	61.9	0.0	5.1	1.9	9.9
Epacris celata	31.7	0.0	2.4	1.1	4.6
Poa costiniana	30.0	8.9	1.9	1.3	3.6
More common in MWH					
Baloskion australis	5.8	51.7	3.7	1.3	7.2
Epacris paludosa	58.9	93.3	2.8	1.7	5.4
Callistemon pityoides	20.6	39.4	2.5	1.9	4.9
Baumea gunnii	0.0	31.1	2.4	1.7	4.6
Sphagnum novozelandicum	5.6	14.4	1.3	1.4	2.4
Poa spp.	1.9	11.7	0.9	0.8	1.7
Similar frequency in both					
Sphagnum cristatum	46.1	45.0	2.8	1.4	5.4
Asperula gunnii	38.6	35.6	2.6	1.2	5.0
Baeckea gunniana	66.1	90.0	2.0	1.3	3.9
Empodisma minus	80.0	100.0	1.8	0.6	3.5

(b): Cover data. (TWH) and **(MWH).** Mean dissimilarity = 54.7

Higher % cover in TWH	**Av.cover TWH**	**Av.cover MWH**	**Av.Diss**	**Diss/SD**	**Contrib%**
Richea continentis	**19.7**	0.0	11.2	1.4	20.4
Sphagnum cristatum	**26.1**	15.4	9.6	1.2	17.5
Epacris celata	**3.4**	0.0	1.8	0.8	3.4
Carex spp.	**3.2**	0.1	1.8	0.7	3.3
Poa costiniana	**1.5**	0.3	0.8	1.0	1.4
Higher % cover in MWH					
Empodisma minus	4.3	**27.5**	13.6	4.1	24.9
Callistemon pityoides	4.9	**6.8**	3.8	1.4	6.9
Baloskion australe	0.1	**1.3**	0.7	1.3	1.2
Similar% cover in both					
Epacris paludosa	13.9	13.8	3.9	1.2	7.0
Baeckea gunniana	11.4	12.5	2.8	1.5	5.2
Hakea microcarpa	0.8	0.7	0.7	0.8	1.3
Sphagnum novozelandicum	0.7	0.6	0.6	0.9	1.2

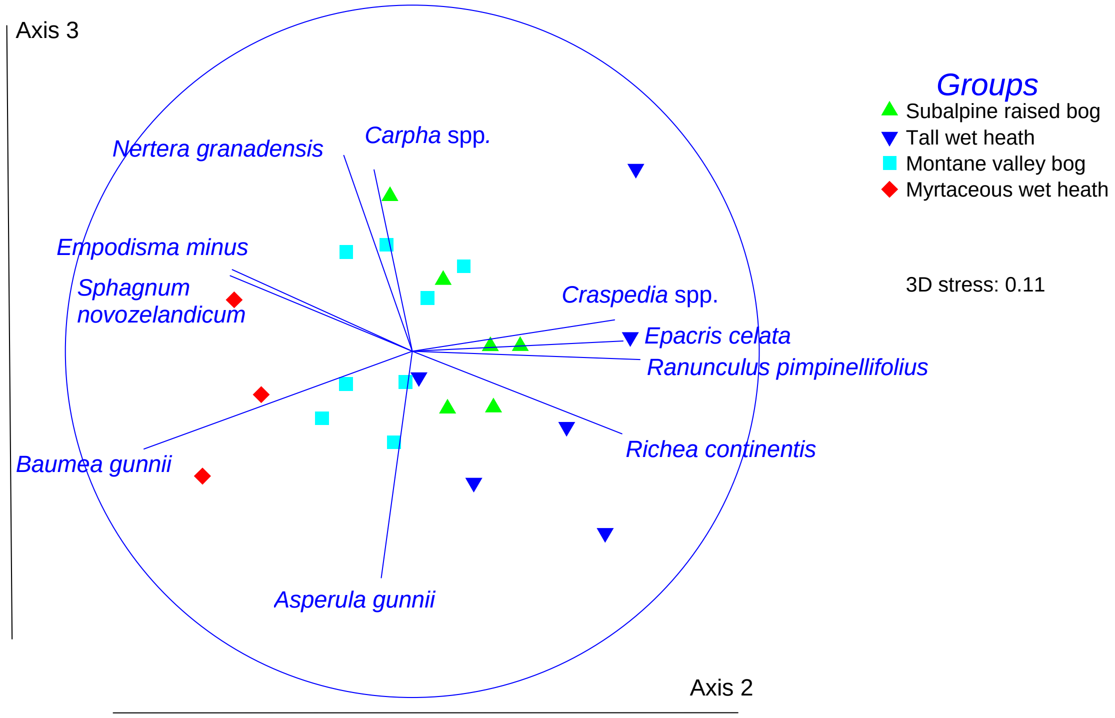


Figure A3.3: Three dimensional ordination graph derived from **Snowy Range-Dargo High Plains region frequency data** (Axis 2 v Axis 3). The trend directions of strongly correlated species are indicated. The unit circle indicates the strength of the relationship for each vector.

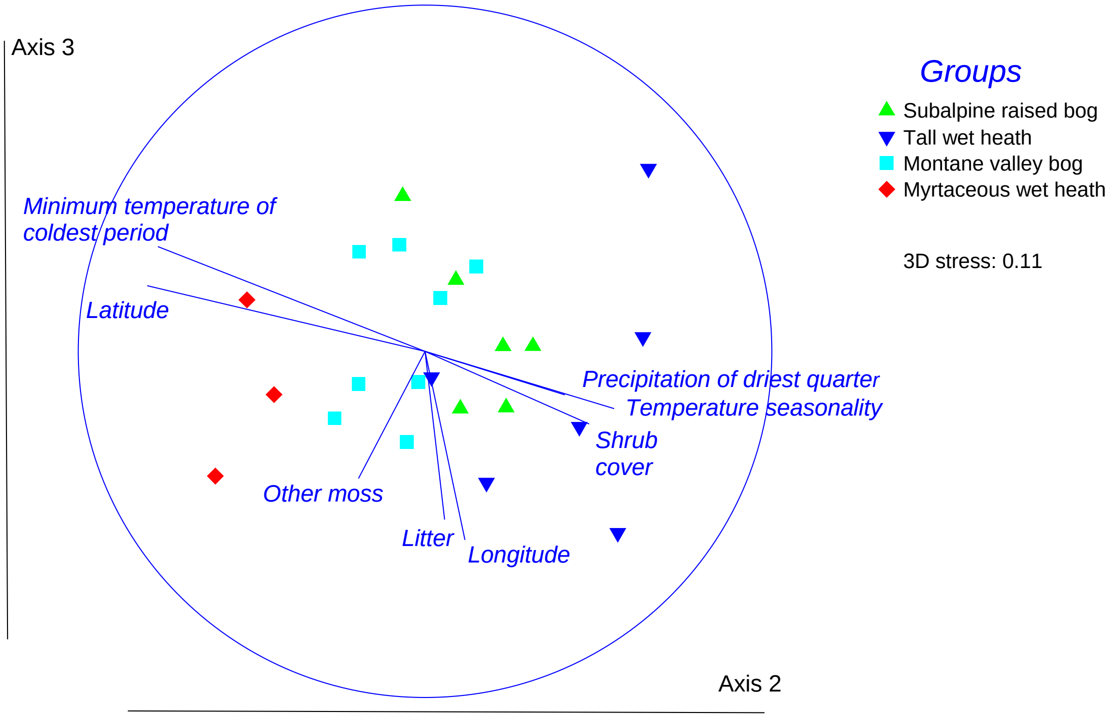


Figure A3.4: Three dimensional ordination graph derived from **Snowy Range-Dargo High Plains region frequency data** (Axis 2 v Axis 3). The trend directions of significantly correlated factors are indicated.

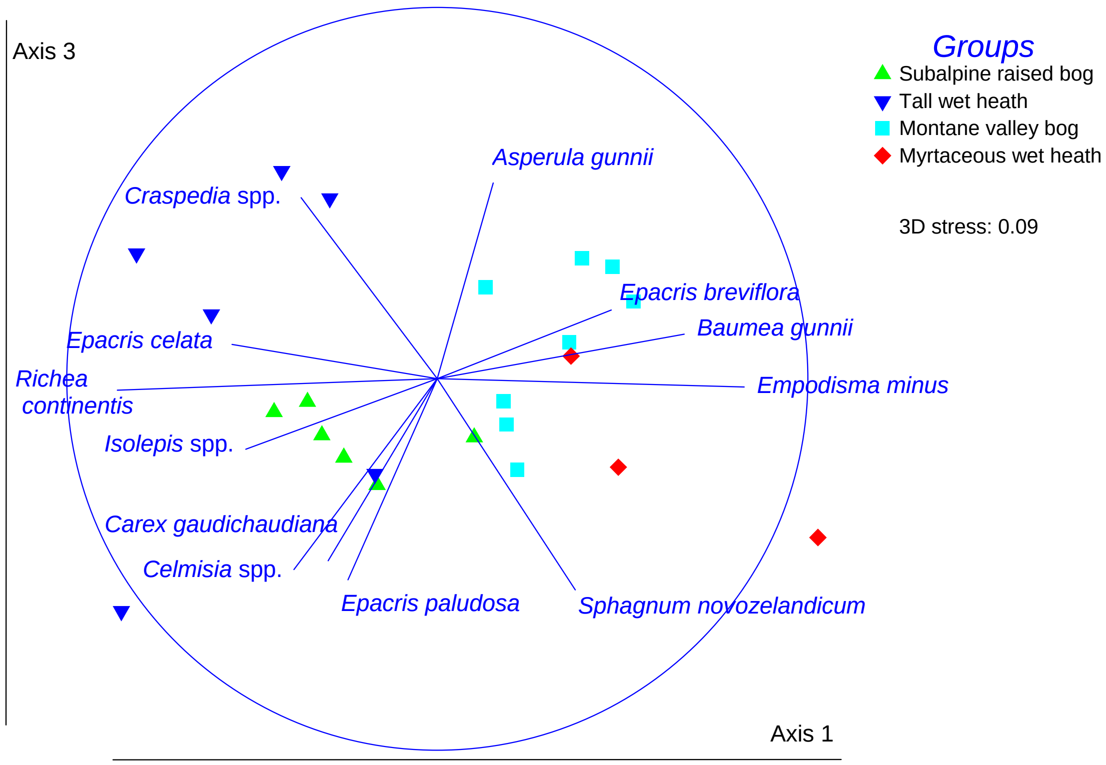


Figure A3.5: Three dimensional ordination graph derived from **Snowy Range-Dargo High Plains region cover data** (Axis 1 v Axis 3). The trend directions of strongly correlated species are indicated.

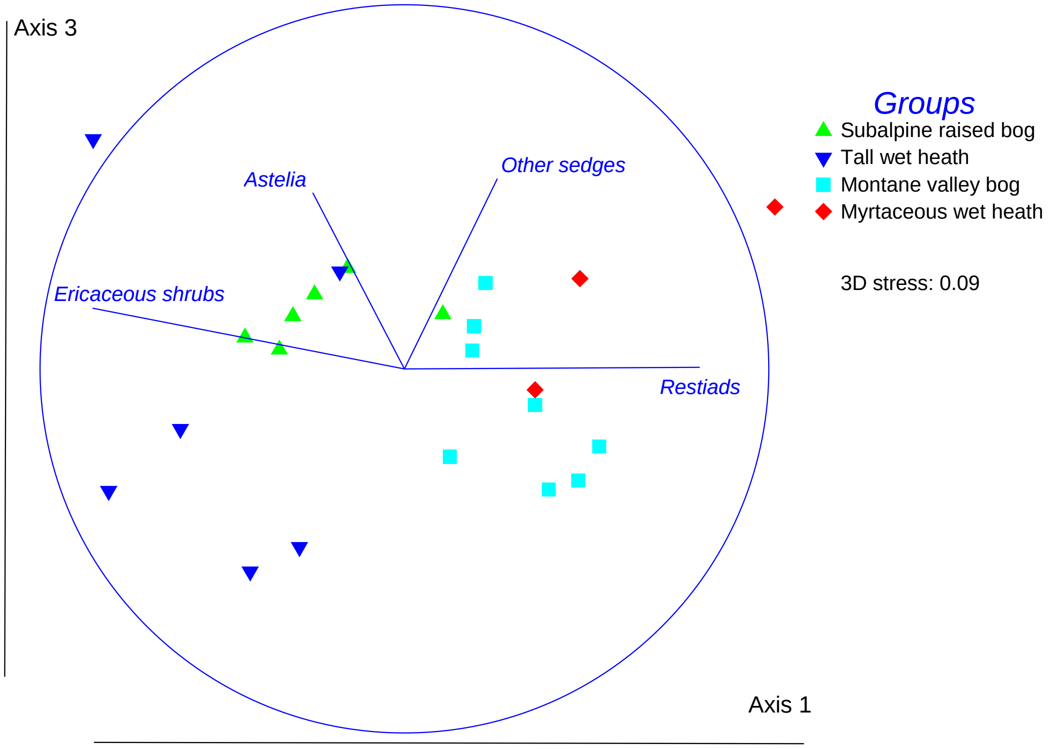


Figure A3.6: Three dimensional ordination graph derived from **Snowy Range-Dargo High Plains region cover data** (Axis 1 v Axis 3). The trend directions of significantly correlated plant functional groups are indicated.

Table A3.37: List of the twenty-eight transects used in the **Baw Baw-Central Highlands region** study. Location details and community type classification included.

Transect	Code	Alt.	Lat.	Long.	Zone	Catchment	Community type
Bullfight 1	**bf1**	1400	37.44	145.92	Subalpine	Goulburn	W'tn subalpine raised bog
Freemans Flat 1	**ff1**	1510	37.83	146.29	Subalpine	Tanjil	W'tn subalpine raised bog
Gwinear Flat 1	**gf1**	1480	37.84	146.31	Subalpine	Thomson	W'tn subalpine raised bog
Long Flat (Echo north) 1	**lf1**	1400	37.48	145.88	Subalpine	Goulburn	W'tn subalpine raised bog
Pauciflora Flat 2	**pf2**	1440	37.83	146.27	Subalpine	Tanjil	W'tn subalpine raised bog
Sandys Flat 1	**sf1**	1490	37.83	146.28	Subalpine	Tanjil	W'tn subalpine raised bog
Triangle Junction 2	**tj2**	1430	37.48	145.87	Subalpine	Goulburn	W'tn subalpine raised bog
Bullfight 2	**bf2**	1400	37.44	145.92	Subalpine	Goulburn	W'tn subalpine wet heath
Bullfight 3	**bf3**	1400	37.44	145.92	Subalpine	Goulburn	W'tn subalpine wet heath
Freemans Flat 2	**ff2**	1520	37.83	146.29	Subalpine	Tanjil	W'tn subalpine wet heath
Gwinear Flat 2	**gf2**	1480	37.84	146.31	Subalpine	Thomson	W'tn subalpine wet heath
Long Flat (Echo north) 2	**lf2**	1400	37.48	145.88	Subalpine	Goulburn	W'tn subalpine wet heath
Pauciflora Flat 1	**pf1**	1430	37.83	146.27	Subalpine	Tanjil	W'tn subalpine wet heath
Sandys Flat 2	**sf2**	1495	37.83	146.28	Subalpine	Tanjil	W'tn subalpine wet heath
The Morass	**tm**	1330	37.82	146.25	Subalpine	Tanjil	W'tn subalpine wet heath
Triangle Junction 1	**tj1**	1430	37.48	145.87	Subalpine	Goulburn	W'tn subalpine wet heath
Little River 1	**lr1**	1110	37.44	145.82	Montane	Goulburn	W'tn montane fen
Little River 2	**lr2**	1120	37.44	145.82	Montane	Goulburn	W'tn montane fen
Newlands Central	**nc**	1050	37.77	146.19	Montane	Thomson	W'tn montane fen
Tom Burns Creek 1	**tb1**	1080	37.38	145.82	Montane	Goulburn	W'tn montane fen
Tom Burns Creek 2	**tb2**	1090	37.38	145.82	Montane	Goulburn	W'tn montane fen
Upper Yarra Track	**uyt**	1060	37.78	146.20	Montane	Thomson	W'tn montane fen
Storm Creek 1	**sc1**	1175	37.44	145.81	Montane	Goulburn	W'tn montane wet heath
Storm Creek 2	**sc2**	1175	37.44	145.81	Montane	Goulburn	W'tn montane wet heath
Stronachs Camp 1	**st1**	1150	37.75	146.21	Montane	Thomson	W'tn montane wet heath
Stronachs Camp 2	**st2**	1165	37.75	146.21	Montane	Thomson	W'tn montane wet heath
Thomson Fen	**tf**	1035	37.77	146.18	Montane	Thomson	W'tn montane wet heath
Upper Thomson	**ut**	1040	37.76	146.16	Montane	Thomson	W'tn montane wet heath

Table A3.40: Species contributing to differences between **Western montane fen (WMF)** and **Western montane wet heath (WMW)** based on the **Baw Baw-Central Highlands region transects**, (a) frequency data, (b) cover data. The species listed contribute between 70% and 95% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss./SD). The species have been sorted according to the community type in which they are most prominent.

(a) Frequency data. (WMF) and **(WMW).** Mean dissimilarity = 70.6%.

More common in WMF	**freq.WMF**	**freq.WMW**	**Av.Diss**	**Diss/SD**	**Contrib%**
Richea victoriana	90.3	43.6	4.8	1.8	6.7
Sphagnum cristatum	76.7	38.3	4.7	1.7	6.7
Carex appressa	57.8	3.3	5.5	1.5	7.8
Polytrichum spp.	43.6	10.6	4.2	1.2	6.0
Blechnum penna-marina	38.1	2.2	3.6	1.3	5.0
Poa spp.	37.8	0.3	3.8	1.4	5.4
Epacris microphylla var. *rhombifolia*	22.2	7.2	2.4	1.0	3.4
Epacris breviflora	21.4	0.0	2.1	0.7	3.0
Leptospermum grandifolium	13.6	0.0	1.4	0.8	1.9
Tasmannia xerophila	10.8	0.0	1.1	0.6	1.5
More common in WMW					
Empodisma minus	0.0	94.7	9.4	10.4	13.4
Epacris paludosa	0.0	83.3	8.3	4.3	11.8
Baeckea gunniana	0.0	44.4	4.5	2.2	6.3
Nertera granadensis	0.3	16.1	1.6	0.8	2.2
Similar frequency in both					
Carex gaudichaudiana	63.1	79.4	3.9	1.1	5.5
Olearia algida	22.2	14.7	2.7	1.1	3.8

(b) **Cover data. (WMF)** and **(WMW).** Mean dissimilarity = 79.3%.

Higher % cover in WMF	**cov.WMF**	**cov.WMW**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**48.9**	15.5	19.8	1.4	24.9
Richea victoriana	**20.7**	2.6	10.4	2.0	13.1
Polytrichum spp.	**8.0**	1.1	4.7	1.0	6.0
Carex appressa	**6.3**	0.3	3.4	1.0	4.2
Epacris microphylla var. *rhombifolia*	**4.1**	0.5	2.5	0.8	3.1
Higher % cover in WMW					
Epacris paludosa	0.0	**25.0**	13.9	2.9	17.5
Empodisma minus	0.0	**22.0**	12.3	3.0	15.5
Baeckea gunniana	0.0	**5.3**	2.9	1.4	3.7
Similar % cover in both					
Carex gaudichaudiana	3.5	4.1	2.3	1.2	2.9

Table A3.41: Species contributing to differences between **Western subalpine wet heath (WSW)** and **Western montane wet heath (WMW)** based on the **Baw Baw-Central Highlands region transects**, (a) frequency data, (b) cover data. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss./SD). The species listed contribute up to 95% to the mean dissimilarity of the groups concerned and are listed according to the community in which they are most prominent.

(a) Frequency data. (WSW) and **(WMW).** Mean dissimilarity = 56.8%.

More common in WSW	**freq.WSW**	**freq.WMW**	**Av.Diss**	**Diss/SD**	**Contrib%**
Richea continentis	**60.3**	0.0	5.6	2.1	9.9
Astelia alpina	**49.6**	1.7	4.1	1.8	7.3
Poa costiniana	**36.4**	0.3	3.4	1.3	5.9
Gentianella sp.	**28.9**	0.0	2.5	1.6	4.5
Asperula gunnii	**22.1**	6.7	2.0	1.1	3.5
Carpha spp.	**18.3**	0.0	1.5	0.9	2.7
Celmisia spp.	**16.1**	0.0	1.4	1.0	2.4
Epacris petrophila	**15.1**	0.0	1.5	0.5	2.6
Erigeron paludicola	**12.9**	0.0	1.2	0.9	2.1
Euphrasia gibbsiae	**12.2**	0.0	1.0	0.8	1.7
Rytidosperma nivicola	**7.4**	0.0	0.6	0.7	1.0
Oreobolus distichus	**6.9**	0.0	0.6	0.8	1.0
More common in WMW					
Carex gaudichaudiana	6.3	**79.4**	6.8	2.7	12.0
Richea victoriana	4.4	**43.6**	3.7	1.7	6.6
Polytrichum spp.	0.0	**10.6**	1.0	0.8	1.7
Epacris microphylla var. *rhombifolia*	0.0	**7.2**	0.7	1.1	1.2
Juncus alexandri	0.0	**5.3**	0.5	0.4	0.8
Similar frequency in both					
Empodisma minus	98.9	94.7	0.5	1.1	0.9
Epacris paludosa	66.1	83.3	3.1	1.0	5.5
Baeckea gunniana	46.7	44.4	2.8	1.5	4.9
Sphagnum cristatum	31.2	38.3	2.5	1.4	4.4
Nertera granadensis	18.7	16.1	1.9	1.2	3.4
Olearia algida	18.1	14.7	1.7	1.2	3.1
Callistemon pityoides	7.6	7.8	1.2	0.7	2.0

(b) Cover data. (WSW) and **(WMW).** Mean dissimilarity = 48.5%.

Higher % cover in WSW	**cov.WSW**	**cov.WMW**	**Av.Diss**	**Diss/SD**	**Contrib%**
Richea continentis	**13.0**	0.0	7.6	0.9	15.7
Astelia alpina	**8.2**	0.3	4.9	1.0	10.1
Epacris petrophila	**1.4**	0.0	0.9	0.4	1.8
Poa costiniana	**1.2**	0.0	0.7	0.5	1.5
Higher % cover in WMW					
Richea victoriana	0.3	**2.6**	1.6	1.3	3.2
Carex gaudichaudiana	0.1	**4.1**	2.4	1.1	4.9
Similar % cover in both					
Empodisma minus	24.2	22.0	5.6	1.2	11.5
Epacris paludosa	13.7	25.0	8.0	1.4	16.4
Sphagnum cristatum	10.6	15.5	6.8	1.4	14.0
Baeckea gunniana	7.7	5.3	3.7	1.3	7.6
Callistemon pityoides	1.4	1.3	1.3	0.7	2.7
Olearia algida	1.3	0.7	0.9	0.8	1.8

Table A3.42: Species contributing to differences between **Western subalpine raised bog (WSR)** and **Western subalpine wet heath (WSW)** based on the **Baw Baw-Central Highlands region transects**, (a) frequency data, (b) cover data. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss./SD). The species listed contribute up to 95% to the mean dissimilarity of the groups concerned and are listed according to the community in which they are most prominent.

(a) Frequency data. (WSR) and **(WSW).** Mean dissimilarity = 44.1%.

More common in WSR	**freq.WSR**	**freq.WSW**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	79.8	31.2	3.6	1.9	8.2
Carpha spp.	38.3	18.3	2.6	1.3	5.9
Erigeron paludicola	34.6	12.9	2.2	1.3	5.1
Nertera granadensis	33.5	18.7	1.9	1.3	4.3
Carex gaudichaudiana	22.1	6.3	1.8	0.7	4.2
Isolepis spp.	20.4	2.6	1.4	1.6	3.1
Sphagnum novozelandicum	15.0	2.8	1.1	1.2	2.5
Brachyscome obovata	11.2	0.7	0.9	0.7	2.0
Drosera arcturi	11.0	4.3	0.8	1.1	1.9
Thelymitra cyanea	10.1	3.0	0.6	1.2	1.4
Poa spp.	6.9	0.6	0.5	0.5	1.2
Juncus sandwithii	6.7	0.8	0.5	0.7	1.2
More common in WSW					
Baeckea gunniana	25.9	46.7	2.4	1.4	5.5
Epacris petrophila	0.5	15.1	1.2	0.5	2.6
Callistemon pityoides	0.0	7.6	0.6	0.5	1.3
Similar frequency in both					
Epacris paludosa	58.3	66.1	2.9	1.2	6.6
Richea continentis	46.9	60.3	2.1	1.3	4.8
Astelia alpina	54.4	49.6	2.3	1.6	5.1
Poa costiniana	45.4	36.4	2.1	1.4	4.8
Gentianella sp.	24.3	28.9	1.4	1.3	3.1
Asperula gunnii	20.4	22.1	1.6	1.2	3.7
Olearia algida	11.8	18.1	1.3	1.1	3.0
Celmisia spp.	11.5	16.1	0.9	0.9	2.1
Euphrasia gibbsiae	14.5	12.2	1.2	1.2	2.6
Rytidosperma nivicola	13.3	7.4	1.1	0.9	2.5
Psychrophila introloba	8.3	5.7	0.8	0.5	1.9

(b) Cover data. (WSR) and **(WSW).** Mean dissimilarity = 53.9%.

Higher % cover in WSR	**cov.WSR**	**cov.WSW**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	47.2	10.6	19.0	2.4	35.2
Carpha spp.	3.4	0.7	1.8	0.9	3.3
Sphagnum novozelandicum	3.3	0.8	1.8	0.9	3.3
Carex gaudichaudiana	1.9	0.1	1.1	0.5	2.0
Higher % cover in WSW					
Richea continentis	5.4	13.0	5.3	0.8	9.8
Baeckea gunniana	1.9	7.7	3.5	1.2	6.5
Similar % cover in both					
Empodisma minus	20.6	24.2	6.1	1.3	11.4
Epacris paludosa	12.9	13.7	5.8	1.4	10.8
Astelia alpina	6.1	8.2	4.0	1.0	7.5

Table A3.43: Species contributing to differences between **Western subalpine raised bog (WSR)** and **Western montane fen (WMF)** based on the **Baw Baw-Central Highlands region transects**. Useful distinguishing species are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss./SD). The species listed contribute up to 95% to the mean dissimilarity of the groups.

(a) Frequency data. (WSR) and **(WMF).** Mean dissimilarity = 85.6%.

More common in WSR	**freq.WSR**	**freq.WMF**	**Av.Diss**	**Diss/SD**	**Contrib%**
Empodisma minus	**98.3**	0.0	7.7	12.7	9.0
Epacris paludosa	**58.3**	0.0	4.4	1.9	5.2
Astelia alpina	**54.4**	0.0	4.3	2.8	5.0
Richea continentis	**46.9**	0.0	3.7	2.0	4.3
Poa costiniana	**45.4**	0.0	3.6	2.2	4.2
Carpha spp.	**38.3**	0.0	2.9	1.1	3.4
Erigeron paludicola	**34.6**	0.0	2.6	1.1	3.0
Nertera granadensis	**33.5**	0.3	2.6	1.3	3.0
Baeckea gunniana	**25.9**	0.0	2.0	1.5	2.4
Gentianella sp.	**24.3**	0.0	1.9	1.9	2.2
Asperula gunnii	**20.4**	0.0	1.6	1.0	1.8
Isolepis spp.	**20.4**	1.7	1.5	1.6	1.8
Sphagnum novozelandicum	**15.0**	0.0	1.2	1.1	1.4
Euphrasia gibbsiae	**14.5**	0.0	1.1	1.0	1.3
Rytidosperma nivicola	**13.3**	0.0	1.0	0.7	1.2
Celmisia spp.	**11.5**	0.0	0.9	1.4	1.0
Brachyscome obovata	**11.2**	0.0	0.9	0.6	1.1
More common in WMF					
Richea victoriana	0.0	**90.3**	7.1	5.4	8.3
Carex gaudichaudiana	22.1	**63.1**	4.4	1.3	5.1
Carex appressa	0.0	**57.8**	4.5	1.6	5.3
Polytrichum spp.	1.7	**43.6**	3.3	1.0	3.9
Blechnum penna-marina	0.0	**38.1**	2.9	1.3	3.4
Poa spp.	6.9	**37.8**	2.8	1.4	3.2
Epacris microphylla var. *rhombifolia*	0.0	**22.2**	1.7	0.7	2.0
Epacris breviflora	0.0	**21.4**	1.7	0.7	2.0
Leptospermum grandifolium	0.0	**13.6**	1.1	0.8	1.3
Similar frequency in both					
Sphagnum cristatum	79.8	76.7	2.0	1.1	2.3
Olearia algida	11.8	22.2	2.0	1.0	2.3

(b) **Cover data. (WSR)** and **(WMF).** Mean dissimilarity = 67.1%.

Higher % cover in WSR	**cov.WSR**	**cov.WMF**	**Av.Diss**	**Diss/SD**	**Contrib%**
Empodisma minus	**20.6**	0.0	9.7	2.0	14.5
Epacris paludosa	**12.9**	0.0	6.1	1.2	9.1
Astelia alpina	**6.1**	0.0	2.9	0.8	4.3
Richea continentis	**5.4**	0.0	2.6	2.0	3.8
Carpha spp.	**3.4**	0.0	1.7	0.8	2.5
Sphagnum novozelandicum	**3.3**	0.0	1.6	0.8	2.3
Higher % cover in WMF					
Richea victoriana	0.0	**20.7**	10.2	2.3	15.2
Polytrichum spp.	0.0	**8.0**	4.1	0.9	6.1
Carex appressa	0.0	**6.3**	3.0	1.0	4.4
Epacris microphylla var. *rhombifolia*	0.0	**4.1**	2.0	0.7	3.0
Leptospermum grandifolium	0.0	**3.3**	1.6	0.9	2.3
Similar % cover in both					
Sphagnum cristatum	47.2	48.9	13.3	1.5	19.9
Carex gaudichaudiana	1.9	3.5	2.0	0.9	3.0

Table A3.44: Species contributing to differences between **Western subalpine raised bog (WSR)** and **Western montane wet heath (WMW)** based on the **Baw Baw-Central Highlands region transects**, (a) frequency data, (b) cover data. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss./SD). The species listed contribute up to 95% to the mean dissimilarity of the groups concerned and are listed according to the community in which they are most prominent.

(a) Frequency data. (WSR) and **(WMW).** Mean dissimilarity = 58.9%.

More common in WSR	**freq.WSR**	**freq.WMW**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**79.8**	38.3	3.4	1.7	5.8
Astelia alpina	**54.4**	1.7	4.3	2.7	7.4
Richea continentis	**46.9**	0.0	3.9	2.0	6.6
Poa costiniana	**45.4**	0.3	3.7	2.1	6.3
Carpha spp.	**38.3**	0.0	3.1	1.1	5.3
Erigeron paludicola	**34.6**	0.0	2.7	1.1	4.6
Nertera granadensis	**33.5**	16.1	2.5	1.4	4.2
Gentianella sp.	**24.3**	0.0	2.0	1.9	3.3
Isolepis spp.	**20.4**	0.0	1.7	1.6	2.9
Asperula gunnii	**20.4**	6.7	1.6	1.0	2.7
Sphagnum novozelandicum	**15.0**	3.3	1.3	1.2	2.1
Euphrasia gibbsiae	**14.5**	0.0	1.2	1.0	2.0
Rytidosperma nivicola	**13.3**	0.0	1.1	0.7	1.8
Celmisia spp.	**11.5**	0.0	0.9	1.4	1.6
Brachyscome obovata	**11.2**	0.0	1.0	0.6	1.6
Drosera arcturi	**11.0**	0.0	0.9	1.0	1.5
Thelymitra cyanea	**10.1**	0.0	0.8	1.4	1.4
Pyschrophila introloba	**8.3**	0.0	0.6	0.4	1.1
More common in WMW					
Carex gaudichaudiana	22.1	**79.4**	5.1	1.9	8.7
Baeckea gunniana	25.9	**44.4**	2.2	1.4	3.7
Richea victoriana	0.0	**43.6**	3.6	1.9	6.1
Polytrichum spp.	1.7	**10.6**	0.9	0.9	1.5
Callistemon pityoides	0.0	**7.8**	0.6	0.4	1.0
Similar frequency in both					
Olearia algida	11.8	14.7	1.4	1.0	2.3
Epacris paludosa	58.3	83.3	3.0	1.2	5.2

(b) Cover data. (WSR) and **(WMW).** Mean dissimilarity = 52.0%.

Higher % cover in WSR	**cov.WSR**	**cov.WMW**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**47.2**	15.5	17.7	1.9	34.0
Astelia alpina	**6.1**	0.3	3.1	0.8	5.9
Richea continentis	**5.4**	0.0	2.9	2.0	5.5
Carpha spp.	**3.4**	0.0	1.9	0.8	3.6
Sphagnum novozelandicum	**3.3**	0.3	1.7	0.9	3.3
Higher % cover in WMW					
Baeckea gunniana	1.9	**5.3**	2.3	1.2	4.4
Richea victoriana	0.0	**2.6**	1.5	1.3	2.8
Similar % cover in both					
Empodisma minus	20.6	22.0	5.5	1.3	10.6
Epacris paludosa	12.9	25.0	8.5	1.6	16.4
Carex gaudichaudiana	1.9	4.1	2.4	1.1	4.6

Table A3.45: Species contributing to differences between **Western subalpine wet heath (WSW)** and **Western montane fen (WMF)** based on the **Baw Baw-Central Highlands region transects**, (a) frequency data, (b) cover data. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss./SD). The species listed contribute up to 95% to the mean dissimilarity of the groups concerned and are listed according to the community in which they are most prominent.

(a) Frequency data. (WSW) and **(WMF).** Mean dissimilarity = 92.4%.

More common in WSW	**freq.WSW**	**freq.WMF**	**Av.Diss**	**Diss/SD**	**Contrib%**
Empodisma minus	**98.9**	0.0	8.6	7.9	9.3
Epacris paludosa	**66.1**	0.0	5.6	1.8	6.0
Richea continentis	**60.3**	0.0	5.3	2.1	5.7
Astelia alpina	**49.6**	0.0	4.1	1.8	4.4
Baeckea gunniana	**46.7**	0.0	4.0	1.5	4.3
Poa costiniana	**36.4**	0.0	3.2	1.3	3.4
Gentianella sp.	**28.9**	0.0	2.4	1.6	2.6
Asperula gunnii	**22.1**	0.0	2.0	1.1	2.2
Nertera granadensis	**18.7**	0.3	1.6	1.1	1.7
Carpha spp.	**18.3**	0.0	1.4	0.9	1.6
Celmisia spp.	**16.1**	0.0	1.3	1.0	1.4
Epacris petrophila	**15.1**	0.0	1.4	0.5	1.5
Erigeron paludicola	**12.9**	0.0	1.1	0.9	1.2
Euphrasia gibbsiae	**12.2**	0.0	0.9	0.8	1.0
More common in WMF					
Richea victoriana	4.4	**90.3**	7.5	4.0	8.1
Sphagnum cristatum	31.2	**76.7**	4.6	1.7	5.0
Carex gaudichaudiana	6.3	**63.1**	5.3	1.4	5.7
Carex appressa	0.0	**57.8**	5.0	1.6	5.4
Polytrichum spp.	0.0	**43.6**	3.7	1.0	4.1
Blechnum penna-marina	0.0	**38.1**	3.2	1.3	3.5
Poa spp.	0.6	**37.8**	3.3	1.4	3.5
Epacris microphylla var. *rhombifolia*	0.0	**22.2**	1.9	0.7	2.0
Epacris breviflora	0.0	**21.4**	1.9	0.7	2.0
Leptospermum grandifolium	0.0	**13.6**	1.2	0.8	1.3
Tasmannia xerophila	0.0	**10.8**	0.9	0.6	1.0
Similar frequency in both					
Olearia algida	18.1	22.2	2.5	1.3	2.7

(b) Cover data. **(WSW)** and **(WMF).** Mean dissimilarity = 89.0%.

Higher % cover in WSW	**cov.WSW**	**cov.WMF**	**Av.Diss**	**Diss/SD**	**Contrib%**
Empodisma minus	**24.2**	0.0	12.8	2.5	14.4
Epacris paludosa	**13.7**	0.0	7.3	1.6	8.2
Richea continentis	**13.0**	0.0	6.7	0.9	7.6
Astelia alpina	**8.2**	0.0	4.5	1.1	5.0
Baeckea gunniana	**7.7**	0.0	4.1	1.2	4.6
Higher % cover in WMF					
Sphagnum cristatum	10.6	**48.9**	20.2	1.4	22.7
Richea victoriana	0.3	**20.7**	11.2	2.3	12.5
Polytrichum spp.	0.0	**8.0**	4.5	0.9	5.1
Carex appressa	0.0	**6.3**	3.3	1.0	3.7
Epacris microphylla var. *rhombifolia*	0.0	**4.1**	2.3	0.7	2.5
Carex gaudichaudiana	0.1	**3.5**	1.9	0.9	2.1
Leptospermum grandifolium	0.0	**3.3**	1.7	0.9	1.9

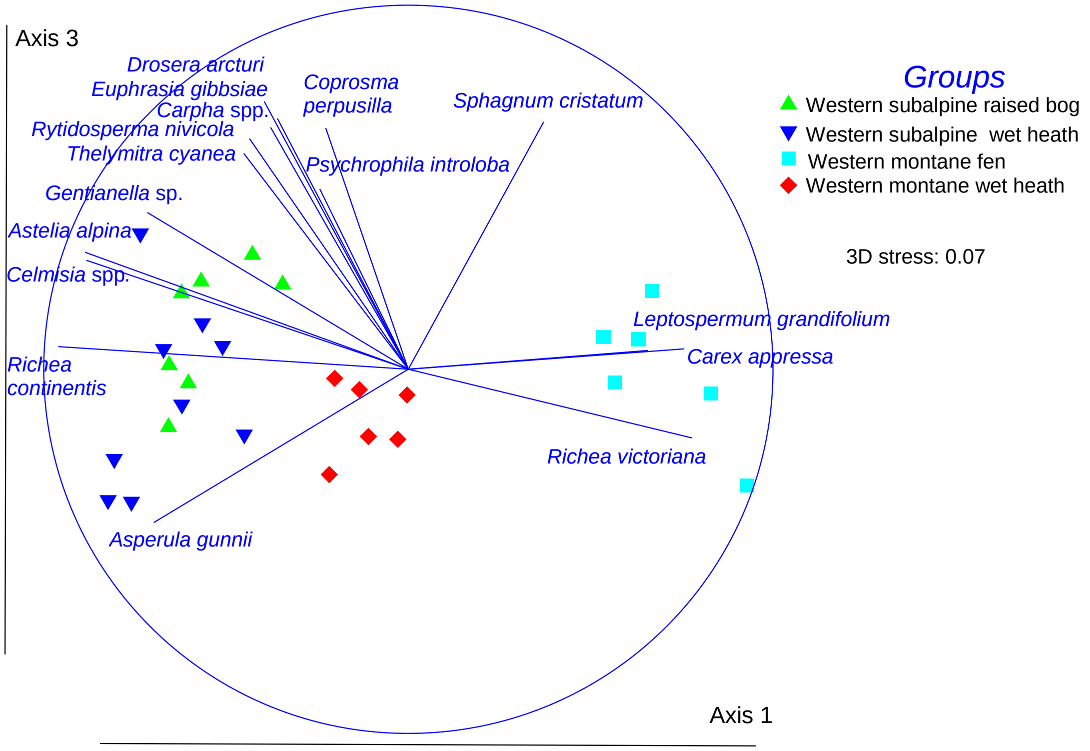


Figure A3.7: Three dimensional ordination graph derived from the **Baw Baw-Central Highlands region frequency data** (Axis 1 v Axis 3). The trend directions of significantly correlated species are indicated.

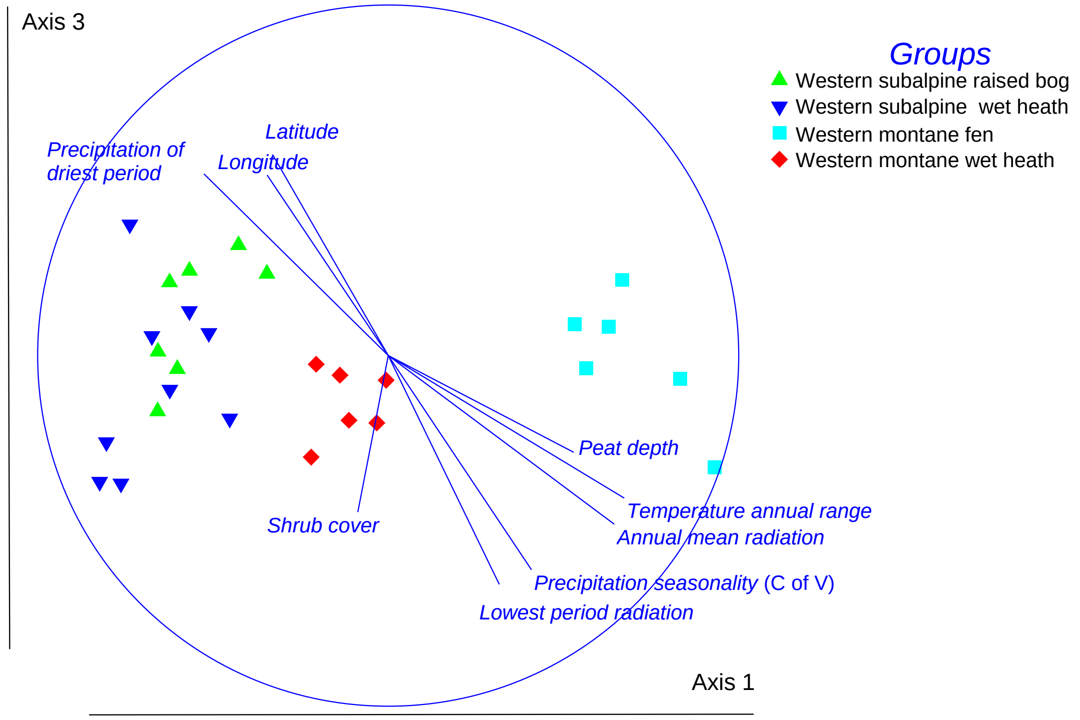


Figure A3.8: Three dimensional ordination graph derived from the **Baw Baw-Central Highlands region frequency data** (Axis 1 v Axis 3). The trend directions of significantly correlated factors are indicated.

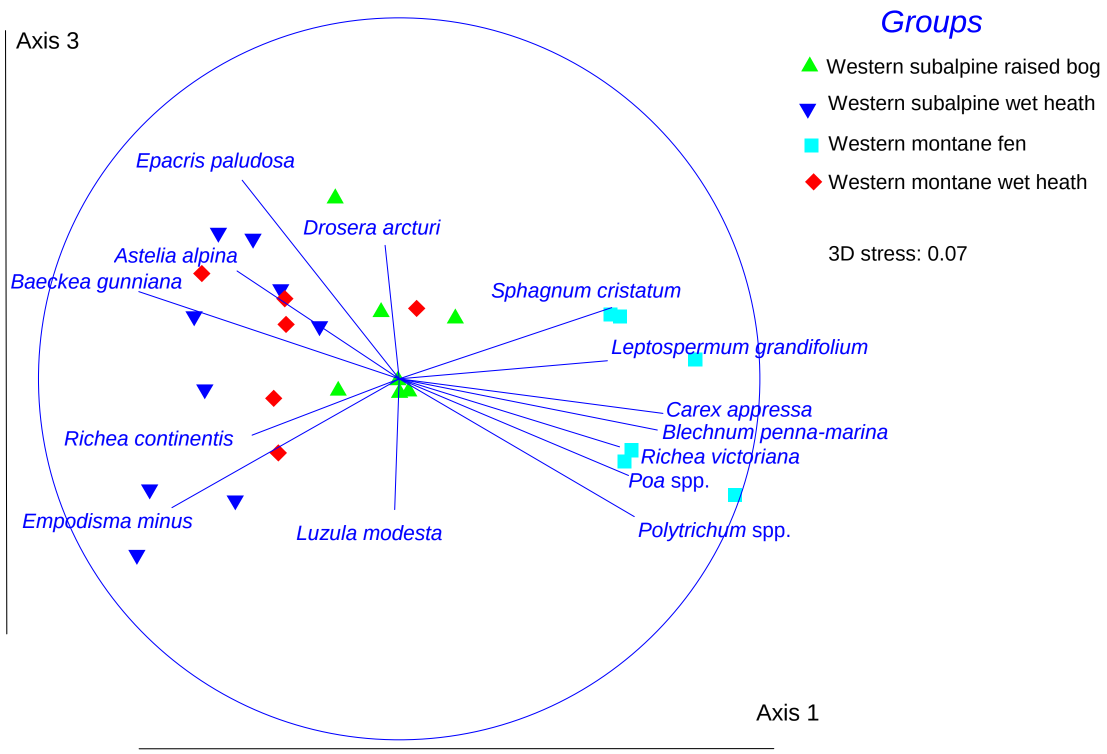


Figure A3.9: Three dimensional ordination graph derived from the **Baw Baw-Central Highlands region cover data** (Axis 1 v Axis 3). The trend directions of significantly correlated species are indicated.

Appendices CHAPTER 4

In order to conserve space, some of the appendices tables have been removed. These are indicated by an asterix (*) next to the table number in the text. The full version of the appendices, containing all tables, is on the accompanying CD (attached to back cover).

Table A4.4: Species contributing to mean dissimilarity between transects in **Montane valley bog (MVB)** and the **montane transects in Myrtaceous wet heath (MWH),** based on the **montane transects (a) frequency data and (b) cover data**. (The equivalent data comparing Western montane wet heath and Western montane fen can be found in the appendices section of Chapter 3). The species listed contribute more than 80% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

(a): Frequency data. (MVB) and **montane (MWH).** Mean dissimilarity = 42.0%

Species	**Av.freq(MVB)**	**Av.freq(MWH)**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Carex gaudichaudiana	94.8	3.3	7.0	8.6	16.6	16.6
Baeckea gunniana	40.6	87.5	3.6	2.0	8.5	25.1
Baloskion australe	40.6	77.5	3.4	1.4	8.1	33.2
Callistemon pityoides	1.5	42.5	3.2	2.5	7.6	40.8
Epacris paludosa	55.0	90.8	2.7	1.3	6.4	47.2
Baumea gunnii	11.0	44.2	2.6	2.5	6.1	53.3
Asperula gunnii	52.9	53.3	1.9	1.4	4.6	57.8
Sphagnum cristatum	86.0	67.5	1.8	1.5	4.2	62.0
Poa spp.	12.7	17.5	1.6	1.1	3.7	65.7
Epacris breviflora	21.0	8.3	1.5	0.9	3.6	69.3
Luzula modesta	25.0	11.7	1.4	1.4	3.4	72.7
Poa costiniana	17.7	13.3	1.2	0.8	2.9	75.6
Veronica sp.2	17.1	0.8	1.2	0.8	2.9	78.5
Ranunculus spp.	12.3	0.0	0.9	0.8	2.1	80.6
Hakea microcarpa	0.0	10.0	0.7	1.2	1.7	82.3
Sphagnum novozelandicum	4.2	9.2	0.7	1.2	1.7	84.0
Epacris celata	7.9	0.0	0.7	0.4	1.5	85.6
Oreobolus distichus	0.2	9.2	0.6	1.2	1.5	87.1
Nertera granadensis	7.9	3.3	0.6	0.7	1.4	88.5
Juncus sandwithii	7.5	0.0	0.6	0.7	1.3	89.8
Comesperma retusum	0.2	7.5	0.5	1.0	1.3	91.1

(b): **Cover data. (MVB)** and **montane (MWH).** Mean dissimilarity = 36.8%

Species	**Av.cov(MVB)**	**Av.cov(MWH)**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
Sphagnum cristatum	51.8	23.1	14.0	1.7	37.9	37.9
Empodisma minus	28.5	27.5	4.3	1.0	11.7	49.6
Epacris paludosa	9.8	17.1	4.1	1.3	11.0	60.6
Callistemon pityoides	0.2	7.4	3.5	2.3	9.6	70.2
Baeckea gunniana	5.3	11.4	3.0	1.5	8.2	78.4
Carex gaudichaudiana	4.6	0.2	2.2	1.4	5.9	84.3
Epacris breviflora	2.0	1.3	1.1	1.1	3.1	87.4
Sphagnum novozelandicum	2.1	0.5	1.1	0.5	2.9	90.2

Table A4.5: Species contributing to differences between **Montane valley bog (MVB)** and **Western montane wet heath (WMW)** based on the **montane transects (a) Frequency data, (b) cover data**. The species listed contribute more than 80% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they were most prominent.

(a): Frequency data. (MVB) and **(WMW).**. Mean dissimilarity = 45.0%

Common in MVB and rare or absent in WMW	**Av.freq(MVB)**	**A.freq(WMW)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Asperula gunnii	**52.9**	6.7	4.1	1.7	9.2
Baloskion australe	**40.6**	0.0	3.5	1.3	7.8
Luzula modesta	**25.0**	1.1	2.1	1.4	4.7
Epacris breviflora	**21.0**	0.0	1.9	0.8	4.1
Poa costiniana	**17.7**	0.3	1.6	0.7	3.6
Veronica sp.2	**17.1**	0.3	1.4	0.8	3.2
Poa spp.	**12.7**	0.3	1.1	0.6	2.4
Ranunculus spp.	**12.3**	0.0	1.0	0.8	2.3
Baumea gunnii	**11.0**	0.0	0.9	0.9	2.1
Epacris celata	**7.9**	0.0	0.8	0.4	1.7
Juncus sandwithii	**7.5**	0.0	0.6	0.8	1.4
Common in WMW and rare or absent in MVB					
Richea victoriana	0.0	**43.6**	3.9	1.9	8.8
Olearia algida	0.0	**14.7**	1.3	0.8	2.9
Polytrichum sp.	1.9	**10.6**	1.0	0.9	2.1
Callistemon pityoides	1.5	**7.8**	0.8	0.5	1.7
Epacris microphylla var. *rhombifolia*	0.0	**7.2**	0.7	1.1	1.5
Shared species					
Sphagnum cristatum	**86.0**	38.3	4.4	1.8	9.7
Carex gaudichaudiana	**94.8**	79.4	1.7	1.0	3.8
Empodisma minus	**96.7**	94.7	0.5	1.1	1.2
Sphagnum novozelandicum	**4.2**	3.3	0.6	0.7	1.2
Epacris paludosa	55.0	**83.3**	3.1	1.3	6.9
Baeckea gunniana	40.6	**44.4**	2.4	1.4	5.3
Nertera granadensis	7.9	**16.1**	1.6	1.0	3.5

(b): **Cover data. (MVB) and (WMW).** Mean dissimilarity = 47.1%

Higher % cover in MVB	**Av.cov(MVB)**	**Av.cov(WMW)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**51.8**	15.5	19.5	2.0	41.3
Sphagnum novozelandicum	**2.1**	0.3	1.1	0.5	2.3
Epacris breviflora	**2.0**	0.0	1.1	0.8	2.4
Higher % cover in WMW					
Epacris paludosa	9.8	**25.0**	8.5	1.6	18.1
Richea victoriana	0.0	**2.6**	1.4	1.3	3.1
Callistemon pityoides	0.2	**1.3**	0.7	0.5	1.6
Similar % cover in both					
Empodisma minus	28.5	22.0	6.0	1.1	12.8
Baeckea gunniana	5.3	5.3	2.5	1.5	5.3
Carex gaudichaudiana	4.6	4.1	2.0	1.3	4.2

Table A4.6: Species contributing to differences between **Myrtaceous wet heath (MWH)** and **Western montane fen (WMF)** based on the **montane transects (a) Frequency data, (b) cover data**. The species listed contribute more than 80% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they were most prominent.

(a): Frequency data. (MWH) and (WMF). Mean dissimilarity = 86.4%

Common in MWH and rare or absent in WMF	**Av.freq(MWH)**	**Av.freq(WMF)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Empodisma minus	**100.0**	0.0	8.3	11.2	9.6
Epacris paludosa	**90.8**	0.0	7.5	14.8	8.7
Baeckea gunniana	**87.5**	0.0	7.2	19.8	8.3
Baloskion australe	**77.5**	0.0	6.3	4.2	7.3
Asperula gunnii	**53.3**	0.0	4.4	11.2	5.1
Baumea gunnii	**44.2**	0.0	3.6	19.1	4.2
Callistemon pityoides	**42.5**	0.0	3.6	2.7	4.2
Poa costiniana	**13.3**	0.0	1.1	3.0	1.2
Common in WMF and rare or absent in MWH					
Richea victoriana	0.0	**90.3**	7.5	5.3	8.7
Carex gaudichaudiana	3.3	**63.1**	5.1	1.4	5.9
Carex appressa	0.0	**57.8**	4.8	1.5	5.5
Polytrichum sp.	3.3	**43.6**	3.5	1.0	4.1
Blechnum penna-marina	0.0	**38.1**	3.1	1.3	3.6
Epacris microphylla var. *rhombifolia*	0.0	**22.2**	1.8	0.7	2.1
Olearia algida	0.0	**22.2**	1.8	0.7	2.1
Leptospermum grandifolium	2.5	**13.6**	1.1	0.9	1.3
Tasmannia xerophila	0.0	**10.8**	0.9	0.6	1.0
Shared species					
Sphagnum cristatum	67.5	76.7	2.5	1.4	2.9
Poa spp.	17.5	37.8	2.4	1.1	2.8
Epacris breviflora	8.3	21.4	2.0	0.9	2.3

(b): Cover data. (MWH) and (WMF). Mean dissimilarity = 78.8%

Higher % cover in MWH	**Av.cov(MWH)**	**Av.cov(WMF)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Empodisma minus	**27.5**	0.0	14.1	12.4	17.9
Epacris paludosa	**17.1**	0.0	8.8	9.3	11.2
Baeckea gunniana	**11.4**	0.0	5.9	5.8	7.4
Callistemon pityoides	**7.4**	0.0	3.8	2.4	4.8
Higher % cover in WMF					
Sphagnum cristatum	23.1	**48.9**	15.4	1.2	19.6
Richea victoriana	0.0	**20.7**	10.9	2.3	13.9
Polytrichum sp.	0.0	**8.0**	4.4	0.9	5.5
Carex appressa	0.0	**6.3**	3.2	1.0	4.0
Epacris microphylla var. *rhombifolia*	0.0	**4.1**	2.2	0.7	2.8
Carex gaudichaudiana	0.2	**3.5**	1.8	0.8	2.3
Leptospermum grandifolium	0.0	**3.3**	1.6	0.8	2.1

Table A4.11: Species contributing to differences between **Tall wet heath (TWH)** and **Western subalpine raised bog (WSR)** based on the **subalpine transects, (a) Frequency data, (b) cover data**. The species listed contribute more than 80% to the dissimilarities between groups. Useful distinguishing species are those that have a high dissimilarity score (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species listed according to the community type in which they were most prominent.

(a): Frequency data. **(TWH)** and **(WSR).** Mean dissimilarity = 53.6%

Species more common in TWH	**Av.freq.(TWH)**	**Av.freq.(WSR)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Baeckea gunniana	**73.2**	25.9	3.3	2.2	6.1
Carex gaudichaudiana	**64.5**	22.1	3.8	1.6	7.1
Epacris celata	**38.5**	0.0	2.6	1.6	4.8
Asperula gunnii	**35.7**	20.4	2.1	1.2	3.9
Baloskion australe	**15.8**	0.0	0.9	0.6	1.7
Oreobolus distichus	**12.5**	3.1	0.8	0.8	1.5
Callistemon pityoides	**12.3**	0.0	0.9	0.5	1.6
Species more common in WSR					
Astelia alpina	2.8	**54.4**	3.6	2.4	6.8
Carpha spp.	5.5	**38.3**	2.6	1.2	4.8
Erigeron paludicola	15.7	**34.6**	2.3	1.2	4.3
Nertera granadensis	7.8	**33.5**	2.1	1.3	3.9
Gentianella sp.	0.5	**24.3**	1.6	1.8	3.1
Sphagnum novozelandicum	3.3	**15.0**	1.1	1.1	2.1
Euphrasia gibbsiae	0.0	**14.5**	1.0	1.0	1.8
Rytidosperma sp.	0.0	**13.3**	0.9	0.7	1.7
Isolepis spp.	2.8	**12.8**	0.9	1.0	1.6
Olearia algida	1.2	**11.8**	0.8	0.8	1.4
Brachyscome obovata	0.0	**11.2**	0.8	0.6	1.5
Drosera arcturi	0.0	**11.0**	0.8	1.0	1.4
Thelymitra cyanea	5.7	**10.1**	0.9	1.2	1.6
Similar frequencies in both					
Richea continentis	60.7	46.9	2.4	1.5	4.5
Epacris paludosa	61.2	58.3	2.3	1.5	4.3
Sphagnum cristatum	54.2	79.8	2.3	1.3	4.3
Poa costiniana	44.0	45.4	1.8	1.3	3.3
Celmisia tomentella	15.3	11.5	1.2	1.2	2.2
Empodisma minus	86.5	98.3	1.0	0.5	1.9
Psychrophila introloba	5.7	8.3	0.8	0.5	1.5

(b): Cover data. (TWH) and **(SRB).** Mean dissimilarity = 52.3%

Higher % cover in TWH	**Av.cover.(TWH)**	**Av.cover.(WSR)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Richea continentis	**21.1**	5.4	8.3	1.0	15.9
Baeckea gunniana	**16.1**	1.9	6.7	2.0	12.8
Callistemon pityoides	**3.0**	0.0	1.4	0.5	2.7
Higher % cover in WSR					
Sphagnum cristatum	29.5	**47.2**	10.7	1.3	20.5
Empodisma minus	6.0	**20.6**	7.1	1.3	13.6
Astelia alpina	0.1	**6.1**	2.9	0.8	5.5
Carpha spp.	0.3	**3.4**	1.7	0.9	3.2
Sphagnum novozelandicum	0.4	**3.3**	1.6	0.9	3.1
Similar cover % in both					
Epacris paludosa	14.6	12.9	5.2	1.4	10.0
Carex gaudichaudiana	2.3	1.9	1.6	0.7	3.1

Table A4.12: Species contributing to differences between **Myrtaceous wet heath (MWH)** and **Western subalpine raised bog (WSR)** based on the **subalpine transects, (a) Frequency data, (b) cover data**. The species listed contribute more than 80% to the dissimilarities between groups. Useful distinguishing species are those that have a high dissimilarity score (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species listed according to the community type in which they were most prominent.

(a): Frequency data. **(MWH)** and **(WSR).** Mean dissimilarity = 62.9%

Species more common in MWH	**Av.freq.(MWH)**	**Av.freq.(WSR)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Baeckea gunniana	91.0	25.9	4.4	3.2	6.9
Asperula gunnii	62.1	20.4	3.2	1.6	5.2
Baloskion australe	54.1	0.0	3.5	1.7	5.5
Luzula modesta	35.0	0.3	2.2	1.1	3.4
Callistemon pityoides	30.7	0.0	2.1	2.2	3.3
Epacris celata	30.5	0.0	1.9	1.9	3.1
Pultenaea fasciculata	27.6	0.0	1.7	1.1	2.7
Oreobolus oxycarpus	27.6	3.3	1.7	1.2	2.6
Agrostis spp.	20.2	0.0	1.3	1.0	2.1
Species more common in WSR					
Sphagnum cristatum	25.5	79.8	3.6	1.8	5.8
Nertera granadensis	7.1	33.5	2.0	1.3	3.1
Carpha spp.	3.3	38.3	2.5	1.2	3.9
Carex gaudichaudiana	1.4	22.1	1.6	0.6	2.5
Astelia alpina	0.0	54.4	3.6	2.6	5.8
Richea continentis	0.0	46.9	3.2	1.9	5.0
Erigeron paludicola	0.0	34.6	2.2	1.1	3.5
Gentianella sp.	0.0	24.3	1.6	1.8	2.5
Similar frequencies in both					
Epacris paludosa	88.1	58.3	2.5	1.2	4.0
Poa costiniana	55.7	45.4	1.9	1.2	3.1

(b): Cover data. (MWH) and (WSR). Mean dissimilarity = 64.1%

Higher % cover in MWH	**Av.cover.(MWH)**	**Av.cover.(WSR)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Baeckea gunniana	**15.0**	1.9	7.3	4.7	11.4
Oreobolus oxycarpus	**5.1**	0.1	2.8	0.8	4.3
Poa costiniana	**4.0**	0.8	1.9	1.7	2.9
Callistemon pityoides	**3.4**	0.0	2.0	2.0	3.1
Higher % cover in WSR					
Sphagnum cristatum	8.9	**47.2**	22.1	2.0	34.4
Astelia alpina	0.0	**6.1**	3.4	0.8	5.3
Richea continentis	0.0	**5.4**	3.0	2.0	4.6
Carpha spp.	0.0	**3.4**	2.0	0.8	3.1
Sphagnum novozelandicum	0.1	**3.3**	1.8	0.8	2.8
Carex gaudichaudiana	0.0	**1.9**	1.2	0.5	1.8
Similar cover % in both					
Empodisma minus	16.5	20.6	5.4	1.2	8.4
Epacris paludosa	11.5	12.9	5.3	1.4	8.3

Table A4.13: Species contributing to differences between **Subalpine raised bog (SRB)** and **Western subalpine wet heath (WSW)** based on **subalpine transects, (a) Frequency data, (b) cover data**. The species listed contribute more than 80% to the dissimilarities between groups. Useful distinguishing species are those that have a high dissimilarity score (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species listed according to the community type in which they were most prominent.

(a): Frequency data. **(SRB)** and **(WSW).** Mean dissimilarity = 50.6%

Species more common in SRB	**Av.freq.(SRB)**	**Av.freq.(WSW)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	95.4	31.2	5.0	2.4	9.9
Carex gaudichaudiana	70.5	6.3	5.0	2.5	9.9
Baloskion australe	44.6	0.0	3.3	1.2	6.6
Epacris celata	29.8	0.0	2.2	1.1	4.3
Species more common in WSW					
Astelia alpina	2.2	49.6	3.5	1.7	6.9
Gentianella sp.	0.0	28.9	2.1	1.6	4.2
Olearia algida	0.0	18.1	1.5	1.0	2.9
Epacris petrophila	0.0	15.1	1.2	0.5	2.4
Erigeron paludicola	5.5	12.9	1.1	1.0	2.1
Euphrasia gibbsiae	0.0	12.2	0.8	0.8	1.7
Similar frequencies in both					
Epacris paludosa	62.8	66.1	2.9	1.3	5.8
Richea continentis	80.5	60.3	2.6	1.4	5.2
Baeckea gunniana	63.7	46.7	2.6	1.4	5.1
Poa costiniana	26.9	36.4	2.1	1.3	4.1
Nertera granadensis	11.8	18.7	1.7	1.2	3.3
Carpha spp.	11.6	18.3	1.6	1.0	3.2
Asperula gunnii	13.3	22.1	1.6	1.2	3.2
Celmisia spp.	17.8	16.1	1.5	1.0	3.0

(**b): Cover data. (SRB) and (WSW).** Mean dissimilarity = 58.8%

Higher % cover in SRB	**Av.cover.(SRB)**	**Av.cover.(WSW)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**77.3**	10.6	29.3	5.4	49.9
Epacris celata	**2.0**	0.0	0.9	0.8	1.5
Baloskion australe	**1.9**	0.0	0.8	0.9	1.4
Higher % cover in WSW					
Astelia alpina	0.1	**8.2**	3.7	1.1	6.2
Similar % cover in both					
Richea continentis	16.1	13.0	6.3	1.4	10.7
Empodisma minus	16.3	24.2	5.5	1.4	9.3
Epacris paludosa	14.2	13.7	4.2	1.3	7.1
Baeckea gunniana	8.2	7.7	2.8	1.4	4.7

Table A4.21: Comparison of the altitudes of the **subalpine plots.**

Groups	**Number of plots**	**Elevation range (m)**	**Mean altitude (m)**
Subalpine raised bog & tall wet heath	27	1380 - 1700	1534 ± 17.6
Myrtaceous wet heath, Western subalpine raised bog & Western subalpine wet heath	23	1330 - 1580	1462 ± 13.2

Table A4.24: Species contributing to differences between **Alpine raised bog (ARB)** and **Western subalpine wet heath (WSW)** based on the **alpine and subalpine transects, (a) Frequency data, (b) cover data**. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Sim/SD). The species have been sorted according to the community type in which they were most prominent.

(a): Frequency data. **(ARB)** and **(WSW).** Mean dissimilarity = 46.6%

More common in ARB	**Av.freq (ARB)**	**Av.freq (WSW)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**89.3**	31.2	4.2	2.2	9.0
Epacris glacialis	**43.1**	0.0	3.0	1.0	6.5
Celmisia spp.	**34.1**	16.1	1.9	2.1	4.1
Carpha spp.	**32.4**	18.3	2.0	1.3	4.3
Carex gaudichaudiana	**23.3**	6.3	1.7	1.0	3.6
Drosera arcturi	**21.7**	4.3	1.6	0.8	3.4
Oreobolus distichus	**21.4**	6.9	1.3	1.1	2.8
Epacris celata	**20.7**	0.0	1.5	0.6	3.2
Rytidosperma sp.	**20.0**	7.4	1.3	1.1	2.9
Diplaspis nivis	**16.7**	0.0	1.1	0.6	2.4
More common in WSW					
Gentianella sp.	6.4	**28.9**	1.7	1.4	3.6
Asperula gunnii	2.9	**22.1**	1.6	1.1	3.4
Olearia algida	0.0	**18.1**	1.4	1.0	2.9
Nertera granadensis	0.0	**18.7**	1.3	1.1	2.9
Epacris petrophila	0.0	**15.1**	1.1	0.5	2.4
Similar frequency in both					
Epacris paludosa	54.1	66.1	3.0	1.3	6.5
Poa costiniana	48.6	36.4	2.5	1.4	5.4
Richea continentis	92.6	60.3	2.5	1.4	5.3
Baeckea gunniana	65.2	46.7	2.4	1.3	5.1
Astelia alpina	41.0	49.6	2.0	2.0	4.3

(b): Cover data. (ARB) and **(WSW).** Mean dissimilarity = 56.1%

Higher % cover in WSW	**Av.cover (ARB)**	**Av.cover (WSW)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**70.1**	10.6	27.2	3.2	48.5
Epacris glacialis	**2.5**	0.0	1.2	0.9	2.0
Epacris celata	**1.9**	0.0	0.9	0.6	1.6
Carpha spp.	**1.8**	0.7	0.8	1.1	1.4
Higher % cover in WSW					
Astelia alpina	3.6	**8.2**	3.0	1.0	5.4
Similar % cover in both					
Richea continentis	9.8	13.0	5.0	1.1	9.0
Empodisma minus	19.4	24.2	5.0	1.3	8.9
Epacris paludosa	11.0	13.7	4.5	1.3	8.0
Baeckea gunniana	5.9	7.7	2.8	1.4	5.1
Poa costiniana	1.1	1.2	0.7	0.8	1.3

Table 4.25: Species contributing to differences between **Low wet heath (LWH)** and **Western subalpine raised bog (WSR)** based on the **alpine and subalpine transects, (a) Frequency data, (b) cover data**. The species listed contribute more than 80% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they were most prominent.

(a): Frequency data. **(LWH)** and **(WSR).** Mean dissimilarity = 56.4%

More common in LWH	**Av.freq (LWH)**	**Av.freq (WSR)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Epacris glacialis	**99.3**	0.0	6.7	8.0	11.9
Poa costiniana	**85.7**	45.4	2.8	1.6	5.0
Celmisia spp.	**66.0**	11.5	3.6	2.9	6.3
Oreobolus distichus	**45.0**	3.1	2.8	2.0	4.9
Diplaspis nivis	**25.3**	0.0	1.6	0.8	2.8
More common in WSR					
Sphagnum cristatum	14.3	**79.8**	4.4	3.6	7.9
Epacris paludosa	1.0	**58.3**	3.8	1.8	6.7
Carpha spp.	8.3	**38.3**	2.5	1.3	4.4
Erigeron paludicola	8.0	**34.6**	2.1	1.2	3.7
Nertera granadensis	0.0	**33.5**	2.2	1.3	4.0
Asperula gunnii	6.0	**20.4**	1.2	0.9	2.0
Sphagnum novozelandicum	0.0	**15.0**	1.1	1.1	1.9
Similar frequency in both					
Astelia alpina	76.0	54.4	1.9	1.6	3.4
Richea continentis	69.7	46.9	2.1	1.5	3.8
Baeckea gunniana	33.3	25.9	1.5	1.6	2.7
Gentianella sp.	28.0	24.3	1.0	1.5	1.8
Rytidosperma sp.	12.3	13.3	1.1	1.1	2.0
Carex gaudichaudiana	13.0	22.1	1.8	0.9	3.3

(b): Cover data. (LWH) and **(WSR).** Mean dissimilarity = 69.6%

Higher % cover in LWH	**Av.cover (LWH)**	**Av.cover (WSR)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Astelia alpina	**26.8**	6.1	10.8	1.7	15.4
Epacris glacialis	**23.4**	0.0	11.7	2.4	16.8
Richea continentis	**10.6**	5.4	3.2	1.6	4.6
Oreobolus distichus	**3.2**	0.1	1.5	1.0	2.2
Higher % cover in WSR					
Sphagnum cristatum	3.3	**47.2**	21.8	3.1	31.4
Epacris paludosa	0.3	**12.9**	6.1	1.2	8.8
Carpha spp.	0.1	**3.4**	1.7	0.8	2.5
Sphagnum novozelandicum	0.0	**3.3**	1.6	0.8	2.3
Similar % cover in both					
Empodisma minus	19.6	20.6	4.4	1.2	6.4

Table 4.26: Species contributing to differences between **Alpine valley bog (AVB)** and **Western subalpine wet heath (WSW)** based on the **alpine and subalpine transects, (a) Frequency data, (b) cover data**. The species listed contribute more than 80% to the dissimilarities between groups. The most useful species for distinguishing between groups are those that have a high dissimilarity percentage (Av.Diss) and low variability indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD). The species have been sorted according to the community type in which they were most prominent.

(a): Frequency data. **(AVB)** and **(WSW).** Mean dissimilarity = 65.7%

More common in AVB	**Av.freq (AVB)**	**Av.freq (WSW)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**98.6**	31.2	5.4	2.6	8.2
Carex gaudichaudiana	**95.3**	6.3	7.1	4.4	10.8
Epacris glacialis	**56.3**	0.0	4.5	1.6	6.8
Epacris celata	**45.5**	0.0	3.6	1.7	5.5
Carex echinata	**39.4**	0.0	3.2	1.1	4.8
Carpha spp.	**30.3**	18.3	2.0	1.4	3.1
Isolepis spp.	**23.0**	2.6	1.8	0.7	2.7
More common in WSW					
Epacris paludosa	2.7	**66.1**	5.0	1.8	7.5
Astelia alpina	0.0	**49.6**	3.7	1.8	5.7
Baeckea gunniana	7.6	**46.7**	3.4	1.4	5.1
Gentianella sp.	0.0	**28.9**	2.2	1.6	3.4
Asperula gunnii	0.0	**22.1**	1.9	1.1	2.8
Nertera granadensis	0.3	**18.7**	1.5	1.1	2.2
Olearia algida	0.0	**18.1**	1.5	1.0	2.3
Celmisia spp.	0.0	**16.1**	1.2	1.0	1.8
Epacris petrophila	0.0	**15.1**	1.2	0.5	1.9
Similar frequency in both					
Richea continentis	47.4	60.3	2.7	1.5	4.2
Poa costiniana	33.3	36.4	2.7	1.3	4.2

(b): Cover data. (AVB) and **(WSW).** Mean dissimilarity = 76.9%

Higher % cover in AVB	**Av.cover (AVB)**	**Av.cover (WSW)**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	**90.0**	10.6	37.0	7.3	48.1
Carex gaudichaudiana	**8.7**	0.1	4.0	4.0	5.2
Epacris glacialis	**3.5**	0.0	1.6	1.0	2.1
Epacris celata	**3.2**	0.0	1.5	1.5	2.0
Higher % cover in WSW					
Empodisma minus	8.9	**24.2**	7.1	1.6	9.3
Epacris paludosa	0.2	**13.7**	6.3	1.6	8.2
Richea continentis	6.8	**13.0**	5.2	1.0	6.7
Astelia alpina	0.0	**8.2**	3.9	1.1	5.1
Baeckea gunniana	0.1	**7.7**	3.6	1.2	4.7

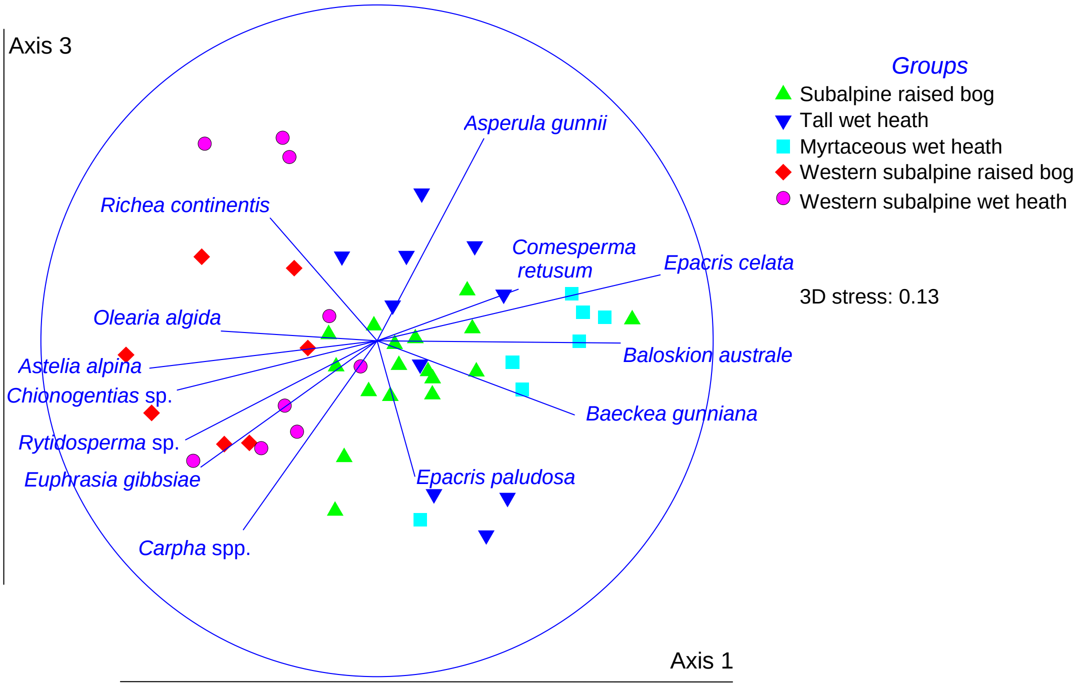


Figure A4.1: Three-dimensional ordination graph derived from the **subalpine transects frequency data** (Axis 1 v Axis 3). The trend directions of strongly correlated species are indicated.

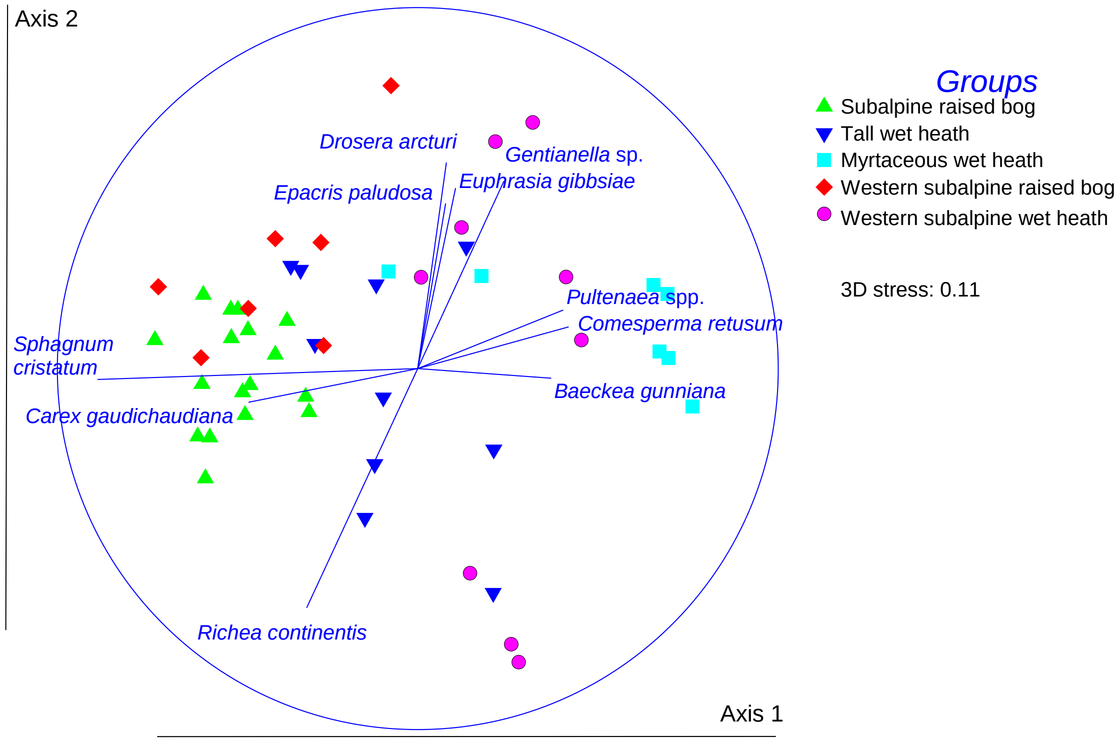


Figure A4.2: Three-dimensional ordination graph derived from the **subalpine transects cover data** (Axis 1 v Axis 2). The trend directions of strongly correlated species are indicated.

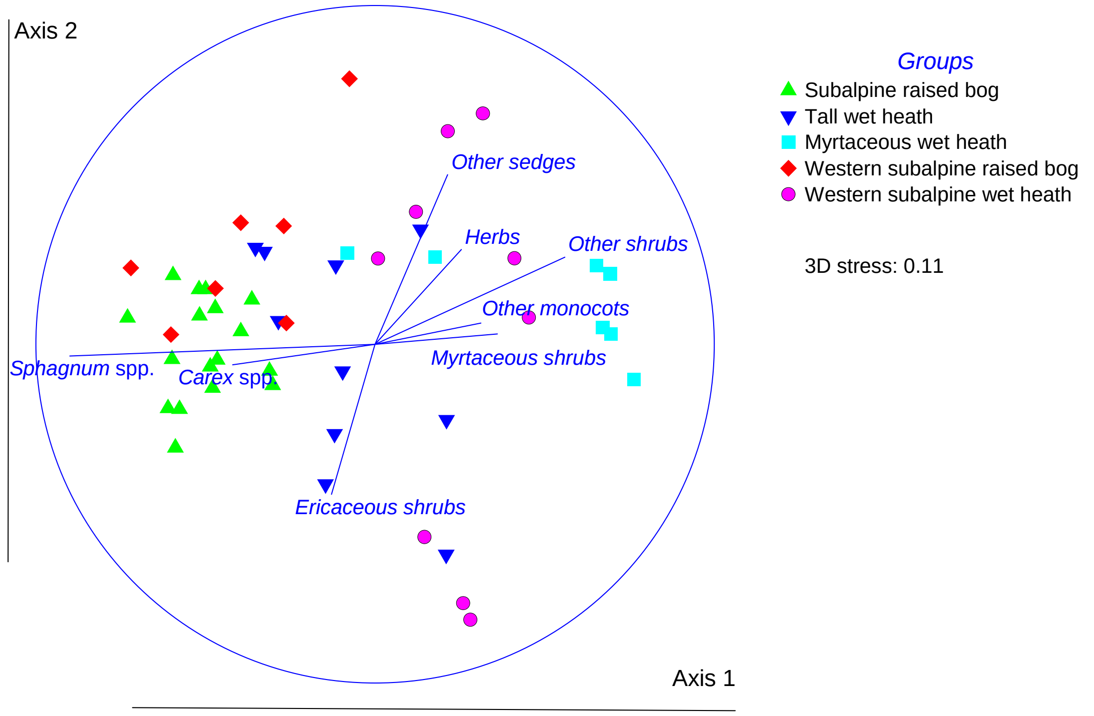


Figure A4.3: Three-dimensional ordination graph derived from the **subalpine transects cover data** (Axis 1 v Axis 2). The trend directions of strongly correlated plant functional groups are indicated.

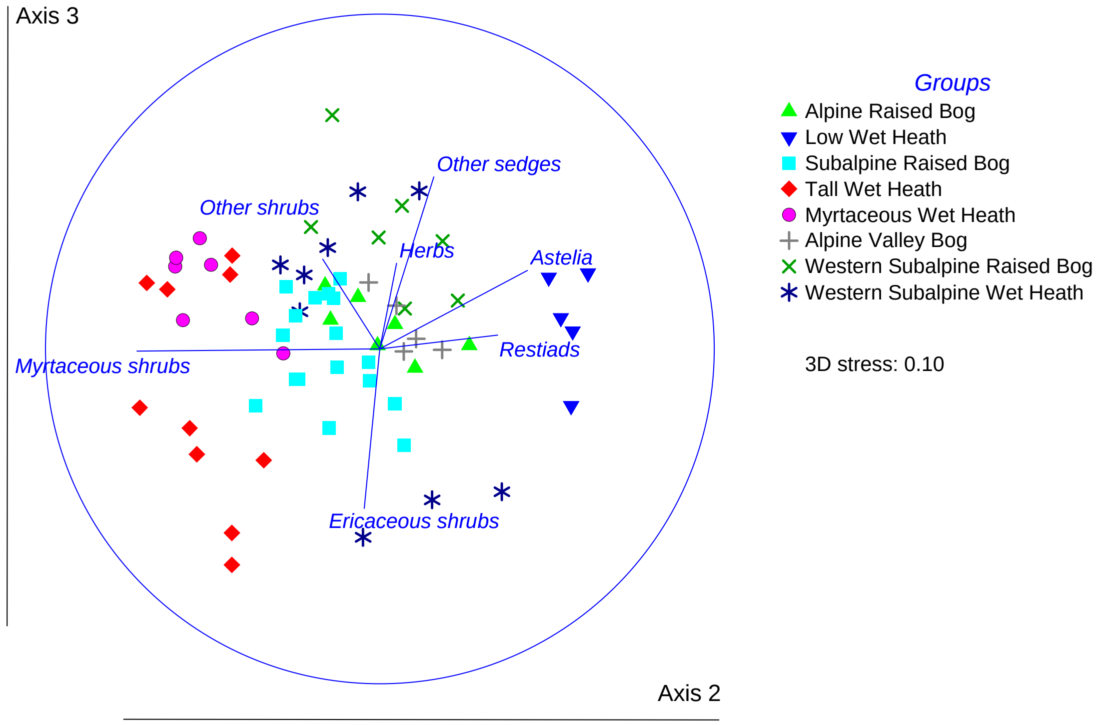


Figure A4.4: Three-dimensional ordination graph derived from the **alpine and subalpine transects cover data** (Axis 2 v Axis 3). The trend directions of strongly correlated plant functional groups are indicated.

Appendices CHAPTER 5

In order to conserve space, some of the appendices tables have been removed. These are indicated by an asterix (*) next to the table number in the text. The full version of the appendices, containing all tables, is on the accompanying CD (attached to back cover).

Table A5.1: Bureau of Meteorology monthly precipitation totals (mm) from **Rocky Valley** (Station 83043: 147.29°E, 36.88°S, 1661 m) for the period January 2006 to December 2010. * Note: the 2006 total is incomplete and derived from 11 months only (no data for April 2006).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2006	54	19	81	ND*	171	53	222	58	99	32	77	11	875*
2007	108	104	284	65	290	199	263	172	163	113	173	216	2149
2008	138	121	80	114	87	127	321	217	145	41	227	168	1784
2009	73	15	75	241	117	157	375	350	272	199	193	65	2132
2010	211	169	232	255	90	196	193	472	334	284	278	336	3049

Table A5.2: Bureau of Meteorology monthly precipitation totals (mm) from **Mount Wellington** (Station 85304: 146.86°E, 37.50°S, 1559 m)) for the period January 2008 to December 2010. * Note: the 2008 total is incomplete and derived from 11 months only (no data for January 2008). Mount Wellington is approximately 5 km south-east of Wellington Plain.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2008	ND	18	30	36	38	63	128	96	42	30	199	107	788*
2009	10	51	40	49	29	15	56	60	108	201	122	97	837
2010	70	208	64	37	157	100	29	96	46	112	183	111	1212

Table A5.3: Basic descriptive statistics for **water table position relative to the surface (cm)** at each well site. Mean water table position for each month, standard error of the mean, standard deviation, maximum and minimum readings. ND = no data.

	PV1650 Valley bog				**Boulder Bog Raised bog**				**Boulder Bog Low wet heath**			
Month	mean (cm)	std	max.	min.	mean (cm)	std	max.	min.	mean (cm)	std	max.	min.
Apr-07	-15.8 ± 0.1	1.8	-8.1	-17.6	-46.7 ± 0.1	2.3	-34.4	-49.7	-23.6 ± 0.2	3.8	-4.7	-25.0
May-07	-12.2 ± 0.1	2.5	-0.7	-14.6	-41.2 ± 0.2	3.3	-20.9	-45.3	-17.3 ± 0.4	6.8	2.0	-25.0
Jun-07	-10.6 ± 0.1	2.1	-0.6	-13.1	-36.9 ± 0.1	1.5	-31.0	-39.0	-10.7 ± 0.2	3.2	-2.5	-15.9
Jul-07	-11.3 ± 0.1	1.8	-1.7	-12.5	-37.3 ± 0.1	1.3	-29.6	-38.6	-13.7 ± 0.2	3.9	-0.6	-19.1
Aug-07	-8.6 ± 0.1	2.4	-0.5	-11.6	-35.1 ± 0.1	2.0	-25.7	-37.4	-8.9 ± 0.2	4.7	6.6	-16.2
Sep-07	-6.7 ± 0.1	1.7	-0.8	-9.0	-31.7 ± 0.1	2.4	-22.2	-34.4	-2.7 ± 0.1	2.1	3.5	-6.8
Oct-07	-10.9 ± 0.1	2.3	-3.3	-14.4	-31.7 ± 0.1	2.4	-22.8	-35.0	-5.3 ± 0.2	3.7	1.0	-12.0
Nov-07	-11.4 ± 0.1	2.4	-3.0	-14.6	-32.1 ± 0.1	1.7	-23.4	-34.1	-10.0 ± 0.3	5.3	1.3	-20.4
Dec-07	-11.1 ± 0.1	2.4	-0.6	-14.0	-31.4 ± 0.1	1.5	-23.0	-33.7	-13.3 ± 0.3	5.6	2.1	-22.5
Jan-08	-13.5 ± 0.2	3.7	-0.9	-20.7	-32.9 ± 0.1	2.0	-23.5	-37.4	-20.7 ± 0.3	5.9	0.1	-25.1
Feb-08	-11.2 ± 0.1	1.5	-4.4	-14.1	-33.6 ± 0.1	1.9	-27.1	-37.6	-19.8 ± 0.3	5.6	0.3	-25.0
Mar-08	-14.2 ± 0.2	2.9	-7.6	-19.8	-40.9 ± 0.2	2.9	-31.3	-45.8	-26.2 ± 0.1	2.6	-15.3	-30.0
Apr-08	-10.8 ± 0.1	1.5	-3.1	-12.1	-42.6 ± 0.2	4.0	-26.3	-48.5	-27.4 ± 0.3	5.6	-2.5	-30.0
May-08	-9.1 ± 0.1	1.5	-3.2	-11.0	-39.6 ± 0.2	4.0	-30.9	-46.4	-21.6 ± 0.3	5.9	-5.2	-29.9
Jun-08	-8.3 ± 0.1	1.7	-1.1	-10.2	-33.0 ± 0.2	2.9	-26.3	-39.3	-15.8 ± 0.4	7.7	-1.3	-29.2
Jul-08	-10.0 ± 0.1	1.5	-5.3	-11.2	-31.8 ± 0.0	0.8	-28.6	-33.2	-16.5 ± 0.1	2.8	-8.4	-20.9
Aug-08	-9.5 ± 0.1	2.4	3.9	-10.8	-32.7 ± 0.1	1.7	-21.5	-34.9	-23.8 ± 0.3	5.3	2.0	-28.9
Sep-08	-3.9 ± 0.2	3.0	3.9	-8.0	-26.7 ± 0.2	3.7	-15.8	-30.7	-5.0 ± 0.3	6.0	2.1	-14.6
Oct-08	-7.9 ± 0.1	2.8	1.3	-12.2	-25.0 ± 0.1	2.4	-15.3	-28.1	-5.3 ± 0.2	4.7	2.1	-14.1
Nov-08	-8.9 ± 0.1	2.7	0.6	-12.4	-26.7 ± 0.1	1.7	-18.4	-28.8	-10.7 ± 0.2	4.4	-2.8	-18.7
Dec-08	-9.8 ± 0.1	2.5	1.2	-13.5	-24.9 ± 0.1	1.2	-17.4	-26.9	-9.6 ± 0.2	4.1	4.0	-16.5
Jan-09	-16.0 ± 0.2	3.0	-6.4	-22.7	-28.2 ± 0.1	2.8	-21.6	-36.2	-25.5 ± 0.3	5.6	-4.2	-30.7
Feb-09	-19.8 ± 0.2	2.8	-15.3	-25.6	-39.2 ± 0.3	5.6	-31.4	-51.3	-30.2 ± 0.0	0.1	-30.1	-30.4
Mar-09	-16.6 ± 0.2	3.7	-6.9	-26.3	-51.2 ± 0.3	6.1	-30.4	-61.0	-29.6 ± 0.1	2.6	-5.1	-30.3
Apr-09	-12.5 ± 0.2	3.0	0.9	-17.1	-51.5 ± 0.5	9.1	-21.8	-61.6	-24.6 ± 0.5	8.6	1.4	-30.4
May-09	-9.2 ± 0.1	1.9	1.4	-11.5	-34.5 ± 0.3	5.2	-20.2	-46.1	-13.1 ± 0.2	4.1	2.0	-19.3
Jun-09	-7.9 ± 0.1	2.2	3.9	-10.0	-31.3 ± 0.1	2.2	-16.1	-32.9	-12.9 ± 0.2	4.2	4.5	-19.1
Jul-09	-6.7 ± 0.1	2.0	1.5	-8.4	-29.0 ± 0.1	1.4	-22.8	-30.4	-9.1 ± 0.2	3.5	2.8	-13.8
Aug-09	-2.8 ± 0.2	3.1	5.4	-7.0	-26.9 ± 0.1	2.8	-14.0	-30.2	-5.5 ± 0.3	5.4	4.6	-14.2
Sep-09	-2.2 ± 0.1	1.5	3.6	-4.0	-22.7 ± 0.1	2.6	-13.4	-25.5	0.5 ± 0.1	2.4	4.8	-3.9
Oct-09	-3.0 ± 0.1	2.0	2.5	-6.5	-22.9 ± 0.1	1.3	-16.6	-24.8	0.3 ± 0.1	1.3	3.8	-3.1
Nov-09	-9.8 ± 0.2	3.5	2.4	-16.3	-25.4 ± 0.1	1.8	-16.1	-29.3	ND			
Dec-09	-11.1 ± 0.1	2.3	-4.2	-15.5	-26.0 ± 0.1	1.8	-21.3	-30.9	ND			
Jan-10	-14.0 ± 0.3	5.1	3.1	-24.4	-27.3 ± 0.1	2.6	-12.5	-32.8	ND			
Feb-10	-11.8 ± 0.3	5.8	2.0	-25.9	-28.4 ± 0.1	2.6	-17.0	-33.2	ND			
Mar-10	-7.5 ± 0.2	3.0	3.9	-11.9	-25.2 ± 0.1	2.4	-14.7	-31.3	ND			
Apr-10	-5.6 ± 0.1	2.5	4.9	-8.5	-24.7 ± 0.1	2.3	-10.3	-27.5	ND			

Table A5.4: Basic descriptive statistics for **water table position relative to the surface (cm)** at each well site. Mean water table position for each month, standard error of the mean, standard deviation, maximum and minimum readings. ND = no data.

	Cope East Tall wet heath					**Cope South Valley bog**					**Cope South Raised bog**				
Month	mean	(cm)	std	max.	min.	mean	(cm)	std	max.	min.	mean	(cm)	std	max.	min.
Apr-07	-34.1	± 0.3	6.3	-14.4	-41.7	-11.5	± 0.1	1.8	-4.6	-14.1	-35.3	± 0.2	3.5	-26.2	-39.1
May-07	-24.0	± 0.2	4.2	-10.0	-30.2	-10.7	± 0.1	1.1	-5.3	-12.6	ND				
Jun-07	ND					ND					ND				
Jul-07	ND					ND					ND				
Aug-07	ND					ND					ND				
Sep-07	ND					ND					ND				
Oct-07	-21.1	± 0.1	2.2	-13.0	-24.4	-1.6	± 0.1	1.1	4.9	-3.7	-11.1	± 0.1	1.1	-6.1	-13.2
Nov-07	-21.6	± 0.1	2.8	-9.6	-26.1	-1.3	± 0.1	1.4	3.9	-3.6	-10.4	± 0.1	1.1	-6.6	-12.5
Dec-07	-23.0	± 0.2	3.5	-9.8	-28.5	-1.5	± 0.1	1.4	5.8	-3.7	-12.2	± 0.1	2.0	-5.0	-17.3
Jan-08	-24.6	± 0.3	5.2	-9.3	-33.8	-1.6	± 0.1	1.5	5.5	-3.6	-17.4	± 0.2	3.3	-7.2	-23.0
Feb-08	-22.6	± 0.2	3.6	-8.5	-29.6	-0.5	± 0.1	1.0	4.1	-2.5	-16.8	± 0.2	2.9	-8.5	-22.3
Mar-08	-29.6	± 0.3	6.2	-11.7	-41.4	-3.6	± 0.1	1.8	-0.4	-7.0	-22.7	± 0.2	3.7	-13.8	-28.8
Apr-08	-28.0	± 0.4	7.4	-7.5	-39.3	-5.0	± 0.1	2.1	3.4	-7.9	-20.0	± 0.2	3.1	-8.5	-24.0
May-08	-22.8	± 0.3	5.4	-10.2	-31.8	-6.7	± 0.1	2.3	-2.4	-10.4	-18.3	± 0.1	2.5	-11.3	-22.2
Jun-08	-20.4	± 0.2	3.5	-10.2	-26.0	-7.6	± 0.1	1.9	-3.0	-11.0	-16.8	± 0.1	2.8	-9.9	-21.2
Jul-08	-21.3	± 0.0	1.0	-16.7	-22.3	-6.7	± 0.0	0.8	-1.3	-8.0	-13.6	± 0.1	1.6	-6.9	-16.5
Aug-08	-22.3	± 0.1	1.6	-11.3	-23.4	-4.4	± 0.1	1.0	-0.3	-6.3	-9.1	± 0.1	1.7	-0.4	-11.8
Sep-08	-15.0	± 0.2	3.5	-2.2	-19.0	-1.7	± 0.0	0.7	-0.8	-3.4	-2.9	± 0.1	1.8	1.4	-6.0
Oct-08	-18.3	± 0.2	3.6	-8.2	-24.8	ND					-4.0	± 0.1	1.1	0.1	-6.7
Nov-08	-21.1	± 0.2	4.3	-8.7	-27.2	ND					-6.2	± 0.1	1.6	-3.8	-9.6
Dec-08	-20.5	± 0.1	2.5	-9.1	-25.5	ND					-6.4	± 0.1	1.6	1.0	-9.6
Jan-09	-29.9	± 0.3	6.4	-12.0	-48.3	-8.5	± 0.2	3.1	4.3	-13.3	-13.1	± 0.2	3.8	-0.3	-22.2
Feb-09	-45.9	± 0.4	7.7	-24.0	-55.6	-11.0	± 0.1	2.3	-5.5	-17.1	-20.0	± 0.2	4.5	-10.8	-29.1
Mar-09	-47.1	± 0.5	10.3	-13.0	-55.7	-13.8	± 0.1	2.8	-4.3	-17.5	-23.5	± 0.3	4.8	-11.0	-30.5
Apr-09	-39.9	± 0.7	13.6	-9.5	-55.6	-12.4	± 0.2	3.4	0.5	-17.2	-20.8	± 0.3	6.5	-3.4	-29.9
May-09	-20.3	± 0.2	3.7	-10.2	-32.6	-11.7	± 0.1	2.3	-7.3	-17.2	-16.5	± 0.1	2.7	-6.5	-21.3
Jun-09	-21.9	± 0.2	3.9	-6.5	-26.8	-9.0	± 0.1	1.8	-5.6	-13.5	-16.4	± 0.1	2.8	-1.2	-19.1
Jul-09	-18.9	± 0.1	2.3	-13.0	-22.7	-4.0	± 0.0	0.9	-2.6	-5.5	-10.0	± 0.1	2.2	-5.8	-13.5
Aug-09	-17.5	± 0.2	3.9	-2.1	-22.9	-0.7	± 0.1	1.7	2.7	-2.6	-4.8	± 0.1	1.4	-1.0	-6.9
Sep-09	-14.3	± 0.1	1.7	-6.9	-17.2	3.3	± 0.0	0.4	4.0	2.6	-2.7	± 0.0	0.9	-0.2	-4.2
Oct-09	-16.5	± 0.1	2.4	-8.3	-21.0	3.2	± 0.0	0.8	4.3	0.9	-2.5	± 0.0	0.8	0.0	-5.1
Nov-09	-21.7	± 0.2	4.3	-8.8	-31.5	-0.3	± 0.1	1.0	1.6	-3.7	-11.0	± 0.2	3.1	-3.9	-15.9
Dec-09	-23.1	± 0.2	4.1	-10.4	-34.0	-1.9	± 0.1	1.6	1.7	-5.4	-15.6	± 0.1	2.3	-8.2	-21.0
Jan-10	-28.2	± 0.4	7.3	-5.7	-43.3	-4.8	± 0.1	2.4	0.4	-9.3	-21.1	± 0.2	4.7	-6.7	-28.6
Feb-10	-23.2	± 0.5	8.9	-4.3	-45.8	ND					-19.6	± 0.3	4.7	-6.3	-30.4
Mar-10	-17.6	± 0.2	4.1	-4.7	-28.2	ND					-15.9	± 0.1	2.4	-8.8	-22.1
Apr-10	-18.1	± 0.2	3.8	-2.6	-23.7	ND					-14.5	± 0.1	1.3	-3.9	-16.0

Table A5.5: Basic descriptive statistics for **water table position relative to the surface (cm)** at each well site. Mean water table position for each month, standard error of the mean, standard deviation, maximum and minimum readings. ND = no data.

	Cope Creek Low wet heath					**Wallaces Tr'k no. 3 Raised bog**					**Horror Bog no.7 Burnt hm'k**				
Month	mean	(cm)	std	max.	min.	mean	(cm)	std	max.	min.	mean	(cm)	std	max.	min.
Apr-07	-13.6	± 0.1	2.1	-3.9	-15.6	ND					ND				
May-07	-10.4	± 0.2	3.3	5.7	-13.8	ND					ND				
Jun-07	ND					ND					ND				
Jul-07	ND					ND					ND				
Aug-07	ND					ND					ND				
Sep-07	ND					ND					ND				
Oct-07	7.9	± 0.1	1.2	10.8	5.0	ND					-62.7	± 0.1	2.1	-54.0	-66.2
Nov-07	6.2	± 0.0	0.5	7.7	4.5	-18.3	± 0.2	4.3	-5.9	-24.9	-62.3	± 0.1	2.7	-45.1	-66.5
Dec-07	4.7	± 0.1	1.1	8.0	2.6	-19.4	± 0.2	3.9	-6.7	-26.6	-63.1	± 0.2	4.2	-39.3	-67.6
Jan-08	3.1	± 0.1	1.3	6.2	-1.4	-22.8	± 0.2	4.4	-6.9	-28.0	-66.5	± 0.2	3.9	-42.7	-72.7
Feb-08	-0.8	± 0.1	2.7	7.5	-6.4	-20.7	± 0.2	3.5	-7.4	-26.0	-71.2	± 0.2	3.2	-57.9	-76.2
Mar-08	-13.8	± 0.3	5.3	-0.9	-23.2	-22.9	± 0.2	3.3	-7.4	-27.1	-79.9	± 0.1	2.7	-72.1	-84.1
Apr-08	-12.8	± 0.2	2.9	4.2	-16.7	-21.1	± 0.2	3.2	-5.7	-24.3	-84.2	± 0.3	5.8	-52.7	-92.7
May-08	-9.7	± 0.1	2.5	-2.6	-13.9	-18.7	± 0.2	3.4	-7.7	-22.9	-77.9	± 0.3	5.9	-61.3	-89.9
Jun-08	-7.0	± 0.1	2.2	-0.1	-10.7	-17.4	± 0.2	3.3	-6.5	-22.1	-66.2	± 0.3	5.4	-50.1	-75.2
Jul-08	-6.8	± 0.1	1.3	-2.1	-8.0	-17.2	± 0.1	2.0	-6.4	-19.8	-65.6	± 0.0	0.8	-63.3	-67.1
Aug-08	-7.5	± 0.1	2.4	8.2	-8.7	-17.0	± 0.1	2.0	-4.3	-18.1	-68.9	± 0.2	3.9	-44.0	-72.2
Sep-08	1.8	± 0.3	5.7	9.5	-5.6	-12.2	± 0.2	3.7	1.5	-17.1	-51.8	± 0.4	7.2	-29.5	-62.0
Oct-08	1.0	± 0.3	6.4	9.3	-10.8	-17.7	± 0.3	6.2	-4.3	-26.8	-50.4	± 0.2	3.5	-39.0	-56.8
Nov-08	-8.4	± 0.2	3.3	6.5	-12.5	-20.0	± 0.3	5.9	-5.5	-27.8	-54.2	± 0.2	3.8	-34.2	-58.6
Dec-08	-8.3	± 0.1	2.9	7.9	-12.9	-19.9	± 0.3	5.2	-4.4	-28.7	-50.0	± 0.2	3.8	-31.9	-55.2
Jan-09	-17.6	± 0.3	5.0	-6.2	-26.9	-23.2	± 0.2	3.9	-3.4	-29.4	-60.1	± 0.3	4.9	-46.2	-69.8
Feb-09	-29.1	± 0.1	2.1	-21.8	-31.1	-23.6	± 0.2	3.4	-16.1	-30.1	-75.6	± 0.2	3.8	-68.4	-83.1
Mar-09	-27.0	± 0.3	5.7	-9.2	-31.6	-22.2	± 0.2	3.9	-4.1	-27.0	-85.6	± 0.3	5.3	-61.6	-93.5
Apr-09	-16.4	± 0.3	5.9	-0.3	-31.7	-19.6	± 0.3	5.6	-0.5	-25.9	-83.5	± 0.7	12.5	-37.8	-97.8
May-09	-11.2	± 0.1	1.7	-2.4	-13.2	-16.8	± 0.2	4.1	-3.9	-22.5	-62.5	± 0.3	6.2	-41.2	-72.2
Jun-09	-10.2	± 0.1	2.4	10.4	-12.1	-18.3	± 0.2	4.2	-0.4	-22.1	-60.8	± 0.2	4.3	-30.1	-65.8
Jul-09	-8.6	± 0.1	2.1	3.3	-10.0	-16.3	± 0.2	3.1	-5.9	-19.3	-54.8	± 0.2	3.5	-41.8	-60.2
Aug-09	-5.3	± 0.2	3.1	10.3	-9.4	-12.0	± 0.2	4.2	0.5	-18.8	-51.3	± 0.4	7.4	-22.9	-61.5
Sep-09	-2.7	± 0.1	2.1	8.7	-5.9	-9.6	± 0.2	3.2	0.8	-14.6	-44.7	± 0.1	2.8	-27.7	-47.6
Oct-09	-3.6	± 0.1	2.0	3.2	-7.9	-11.9	± 0.2	3.4	-4.3	-18.9	-45.1	± 0.1	1.6	-36.4	-47.9
Nov-09	-9.8	± 0.2	3.2	2.8	-15.0	-21.2	± 0.3	6.1	-4.0	-28.8	-52.4	± 0.2	4.2	-30.0	-59.5
Dec-09	-11.7	± 0.2	3.1	-1.8	-19.3	-22.6	± 0.2	4.5	-6.7	-29.8	-57.0	± 0.2	3.7	-46.6	-65.4
Jan-10	-19.1	± 0.4	7.9	4.5	-30.6	-23.1	± 0.3	5.7	1.5	-30.7	-58.2	± 0.4	7.0	-24.9	-69.5
Feb-10	-16.6	± 0.4	7.2	0.8	-30.6	-20.8	± 0.3	5.5	-2.7	-30.9	-64.1	± 0.4	6.5	-33.3	-71.6
Mar-10	-12.1	± 0.2	3.6	0.9	-17.4	-18.8	± 0.3	5.2	-1.9	-25.2	-53.6	± 0.4	7.6	-27.5	-68.9
Apr-10	-10.3	± 0.2	3.3	8.9	-14.1	-17.0	± 0.3	4.8	3.0	-22.5	-53.5	± 0.3	6.0	-20.9	-60.5

Table A5.6: Basic descriptive statistics for **water table position relative to the surface (cm)** at each well site. Mean water table position for each month, standard error of the mean, standard deviation, maximum and minimum readings. ND = no data.

	Wallaces no. 5 Burnt hm'k					**Wellington Plain Raised bog**					**Wellington Plain Low wet heath**				
Month	mean	(cm)	std	max.	min.	mean	(cm)	std	max.	min.	mean	(cm)	std	max.	min.
Nov-07	-34.1	± 0.2	2.9	-29.1	-39.8	ND					ND				
Dec-07	-34.1	± 0.2	3.7	-27.0	-40.2	ND					ND				
Jan-08	-38.4	± 0.2	4.6	-29.0	-47.3	ND					-20.8	± 0.6	12.5	-1.3	-34.8
Feb-08	-43.5	± 0.2	2.9	-34.8	-46.9	-17.7	± 0.0	0.8	-16.4	-19.7	-3.4	± 0.1	2.3	-0.2	-9.0
Mar-08	-52.5	± 0.1	2.6	-46.6	-57.7	-18.5	± 0.1	1.3	-15.9	-20.6	-17.2	± 0.4	7.8	-2.6	-30.0
Apr-08	-53.2	± 0.1	2.7	-43.5	-55.9	-17.9	± 0.0	0.9	-15.9	-18.9	-17.2	± 0.3	4.9	-1.4	-25.6
May-08	-50.0	± 0.2	3.5	-36.7	-57.2	-17.6	± 0.0	0.9	-15.4	-19.0	-16.5	± 0.2	4.7	1.9	-24.3
Jun-08	-43.5	± 0.2	4.3	-29.8	-49.0	-17.4	± 0.1	1.1	-15.3	-19.2	-10.0	± 0.3	6.2	0.4	-20.4
Jul-08	-41.7	± 0.1	2.5	-29.0	-44.3	-15.5	± 0.0	0.6	-13.9	-16.7	-5.2	± 0.1	1.4	-0.4	-8.5
Aug-08	-42.4	± 0.2	3.9	-18.4	-44.5	-15.2	± 0.0	0.7	-11.6	-16.0	-3.1	± 0.1	1.3	1.9	-5.3
Sep-08	-25.0	± 0.3	5.6	-9.8	-34.9	-13.8	± 0.0	0.8	-10.6	-15.3	3.1	± 0.1	1.3	5.2	-0.5
Oct-08	-30.3	± 0.2	4.7	-20.1	-39.9	-15.7	± 0.1	1.0	-12.0	-17.3	-2.6	± 0.1	2.4	1.4	-9.3
Nov-08	-36.0	± 0.3	5.6	-24.1	-42.1	-15.6	± 0.1	2.3	-7.9	-19.1	-6.3	± 0.4	7.1	3.4	-21.1
Dec-08	-27.8	± 0.2	3.2	-21.2	-33.8	-14.8	± 0.1	1.5	-9.7	-18.1	0.3	± 0.1	2.0	3.6	-3.7
Jan-09	-41.0	± 0.3	6.7	-27.0	-50.8	-18.6	± 0.1	2.0	-15.5	-23.5	-20.4	± 0.5	10.2	-2.1	-30.5
Feb-09	-50.0	± 0.1	1.2	-47.0	-52.7	-20.6	± 0.1	2.2	-13.9	-25.0	-29.5	± 0.2	3.5	-8.1	-30.5
Mar-09	-51.5	± 0.2	3.6	-36.7	-57.3	-21.0	± 0.1	2.4	-14.6	-25.3	-29.5	± 0.2	3.0	-10.0	-30.4
Apr-09	-53.3	± 0.4	7.3	-23.7	-60.7	-21.7	± 0.1	2.0	-17.4	-26.9	-28.1	± 0.3	6.4	-6.6	-31.4
May-09	-44.7	± 0.2	3.8	-33.5	-52.5	-21.5	± 0.1	1.8	-15.3	-23.2	-28.6	± 0.3	6.2	-3.2	-31.3
Jun-09	-40.2	± 0.2	4.4	-21.0	-44.7	-20.1	± 0.0	0.9	-17.5	-21.5	-21.8	± 0.3	5.1	-1.5	-28.4
Jul-09	-32.5	± 0.2	2.9	-22.0	-37.1	-17.5	± 0.1	1.0	-15.1	-19.9	-11.1	± 0.2	4.0	1.6	-17.9
Aug-09	-26.3	± 0.3	6.4	-9.2	-36.6	-15.8	± 0.1	1.3	-12.6	-18.0	-2.5	± 0.3	5.6	2.1	-13.4
Sep-09	-23.2	± 0.1	2.1	-13.5	-26.4	-14.1	± 0.1	1.0	-10.6	-15.4	1.8	± 0.0	0.8	2.4	-1.3
Oct-09	-26.4	± 0.2	2.9	-18.6	-33.1	-13.2	± 0.0	0.7	-11.5	-14.8	2.4	± 0.1	1.4	7.2	-3.5
Nov-09	-40.1	± 0.3	5.3	-24.8	-49.8	-16.3	± 0.1	1.3	-12.5	-18.8	-1.8	± 0.3	5.9	7.2	-15.8
Dec-09	-44.6	± 0.2	4.0	-29.6	-52.1	-15.7	± 0.1	1.0	-12.7	-17.8	0.0	± 0.2	4.6	6.9	-13.6
Jan-10	-44.8	± 0.3	5.7	-22.9	-52.8	-18.6	± 0.1	1.6	-15.3	-21.1	-18.8	± 0.4	8.5	3.6	-26.5
Feb-10	-47.0	± 0.3	6.0	-23.6	-53.4	-17.0	± 0.1	2.3	-12.5	-22.0	-9.2	± 0.7	12.4	6.9	-26.5
Mar-10	-40.7	± 0.3	6.4	-19.0	-51.7	-15.1	± 0.0	0.5	-13.7	-15.9	-1.9	± 0.2	3.1	5.0	-9.1
Apr-10	-39.6	± 0.3	5.9	-14.7	-45.5	ND					ND				

Table A5.7: Basic descriptive statistics for **water table position relative to the surface (cm)** at each well site. Mean water table position for each month, standard error of the mean, standard deviation, maximum and minimum readings. ND = no data.

	Cope South S1 Burnt lawn				**Cope South S2 Burnt lawn**			
Month	mean (cm)	std	max.	min.	mean (cm)	std	max.	min.
Dec-08	-9.4 ± 0.1	1.0	-6.4	-11.2	-10.2 ± 0.2	3.7	-7.1	-28.4
Jan-09	-9.7 ± 0.1	1.5	-3.4	-14.2	-12.8 ± 0.2	3.6	-7.3	-20.9
Feb-09	-16.8 ± 0.2	4.4	-10.3	-24.4	-26.6 ± 0.3	5.5	-18.6	-37.9
Mar-09	-26.1 ± 0.2	3.4	-12.6	-29.2	-34.5 ± 0.3	4.8	-23.2	-38.8
Apr-09	-26.7 ± 0.2	4.3	-10.4	-29.4	-33.4 ± 0.4	8.0	-6.1	-39.0
May-09	-22.4 ± 0.2	3.4	-12.9	-27.2	-29.0 ± 0.3	6.5	-11.4	-40.8
Jun-09	-18.6 ± 0.1	2.8	-8.9	-22.5	-27.8 ± 0.3	6.4	-6.1	-35.7
Jul-09	-11.2 ± 0.2	3.9	-4.8	-15.9	-14.5 ± 0.1	2.5	-8.8	-18.4
Aug-09	-3.0 ± 0.1	1.3	-1.1	-5.0	-7.9 ± 0.1	2.6	-2.1	-11.6
Sep-09	-0.3 ± 0.0	0.6	1.4	-1.1	-4.7 ± 0.0	0.5	-2.6	-5.4
Oct-09	0.0 ± 0.0	0.4	0.5	-0.5	-4.6 ± 0.0	0.3	-3.3	-5.6
Nov-09	-1.3 ± 0.1	1.1	1.7	-3.6	-3.7 ± 0.1	2.1	-0.6	-8.7
Dec-09	-2.9 ± 0.1	1.0	1.1	-5.6	-2.6 ± 0.1	1.6	-0.6	-6.3
Jan-10	-5.2 ± 0.1	2.1	2.6	-11.4	-8.7 ± 0.2	3.6	-4.4	-18.5
Feb-10	-6.5 ± 0.1	2.3	2.1	-13.0	-13.3 ± 0.3	5.2	-7.9	-24.1
Mar-10	-2.8 ± 0.1	1.8	1.6	-7.6	-4.3 ± 0.1	2.8	-0.6	-9.3
Apr-10	-1.5 ± 0.0	0.8	3.4	-2.7	-0.6 ± 0.0	0.2	-0.3	-1.1

Table A5.8: Basic descriptive statistics for **water table position relative to the surface (cm)** at each well site. Mean water table position for each month, standard error of the mean, standard deviation, maximum and minimum readings. ND = no data.

	Cope South S3 Raised bog				**Cope South S4 Tall wet heath**			
Month	mean (cm)	std	max.	min.	mean (cm)	std	max.	min.
Dec-08	-17.6 ± 0.2	3.3	-13.6	-32.2	-27.0 ± 0.3	5.5	-22.4	-49.2
Jan-09	-22.3 ± 0.2	4.0	-10.2	-32.4	-32.8 ± 0.3	6.0	-23.1	-42.7
Feb-09	-30.0 ± 0.3	5.0	-19.1	-39.0	-41.9 ± 0.2	3.3	-35.2	-49.2
Mar-09	-34.2 ± 0.3	5.3	-18.5	-41.0	-43.5 ± 0.3	4.9	-33.3	-51.0
Apr-09	-31.4 ± 0.4	7.6	-9.1	-40.9	-38.0 ± 0.3	5.2	-28.3	-46.1
May-09	-24.5 ± 0.2	3.3	-11.2	-30.4	-28.8 ± 0.1	2.6	-21.6	-34.6
Jun-09	-24.0 ± 0.2	3.5	-4.5	-27.7	-27.7 ± 0.1	2.8	-12.6	-31.4
Jul-09	-19.3 ± 0.2	2.9	-13.3	-23.5	-22.0 ± 0.1	2.1	-18.1	-25.3
Aug-09	-10.3 ± 0.2	2.9	2.0	-14.9	-17.3 ± 0.1	1.6	-9.0	-19.6
Sep-09	-6.9 ± 0.1	1.3	-0.6	-8.3	-15.5 ± 0.0	0.9	-10.7	-16.5
Oct-09	-6.5 ± 0.0	1.0	-1.1	-8.5	-15.5 ± 0.0	0.8	-12.7	-17.1
Nov-09	-9.3 ± 0.1	1.8	-0.7	-13.0	-17.8 ± 0.1	2.0	-11.4	-23.8
Dec-09	-12.2 ± 0.2	3.2	-2.8	-19.4	-21.6 ± 0.2	4.7	-12.6	-32.5
Jan-10	-19.3 ± 0.3	6.0	-1.0	-27.9	-32.3 ± 0.4	7.4	-11.2	-39.6
Feb-10	-17.8 ± 0.3	6.3	-0.4	-29.4	-30.6 ± 0.4	6.5	-11.2	-39.6
Mar-10	-11.8 ± 0.2	4.0	-2.2	-21.8	-25.2 ± 0.3	5.9	-12.7	-38.2
Apr-10	-9.0 ± 0.1	2.0	4.5	-11.4	-19.1 ± 0.2	2.9	-6.3	-23.5

Table A5.9: The number of **frosts per month** at the different water table well microsites: (a) between April 2007 and November 2008, (b) between December 2008 and April 2010. Site acronyms are as follows: Bbrb = Boulder Bog Raised bog, Bblw = Boulder Bog low wet heath, Pvvb = PV1650 Valley bog, Csrb = Cope South Raised bog, Csvb = Cope South Valley bog, Cetw = Cope East Tall wet heath, Ccklw = Cope Creek Low wet heath, Hrbh = Horror Bog well no. 7 Burnt hummock, Wlbh = Wallaces Track well no. 5 Burnt hummock, Wlrb = Wallaces Track well no. 3 Raised bog, Wtrb = Wellington Plain Raised bog, Wtlw = Wellington Plain Low wet heath, Css1 = Cope South Well S1 Burnt lawn, Css2 = Cope South Well S2 Burnt lawn, Css3 = Cope South Well S3 Raised bog, Css4 = Cope South Well S4 Tall wet heath, ND = No data.

(a)

month	Bbrb	Bblw	Pvvb	Csrb	Csvb	Cetw	Ccklw	Hrbh	Wlrb	Wlbh	Wtrb	Wtlw
Apr-07	8	17	11	15	3	1	ND	ND	ND	ND	ND	ND
May-07	4	7	5	ND	2	2	ND	ND	ND	ND	ND	ND
Jun-07	11	9	8	ND	ND	ND	ND	ND	ND	ND	ND	ND
Jul-07	0	0	0	ND	ND	ND	ND	ND	ND	ND	ND	ND
Aug-07	3	1	1	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sep-07	17	21	16	ND	ND	ND	ND	ND	ND	ND	ND	ND
Oct-07	12	11	10	8	5	4	12	9	0	0	ND	ND
Nov-07	0	6	8	0	0	0	7	0	0	0	ND	ND
Dec-07	1	2	1	1	0	0	2	1	1	1	ND	ND
Jan-08	0	1	0	0	0	0	0	0	0	0	0	0
Feb-08	2	3	4	0	0	0	9	3	0	2	1	0
Mar-08	2	3	4	0	0	0	10	4	0	3	1	0
Apr-08	7	16	17	5	0	0	20	11	0	11	8	0
May-08	8	18	16	10	8	4	18	14	9	13	9	8
Jun-08	7	9	11	8	10	3	13	9	11	12	8	10
Jul-08	1	1	3	0	0	1	5	3	3	3	16	16
Aug-08	0	0	0	0	0	0	0	0	0	0	0	0
Sep-08	2	3	0	0	ND	1	7	4	0	4	10	11
Oct-08	6	9	4	0	ND	7	17	9	9	10	9	6
Nov-08	0	1	2	0	ND	0	7	1	2	2	3	1

(b)

month	Bbrb	Bblw	Pvvb	Csrb	Csvb	Cetw	Ccklw	Hrbh	Wlrb	Wlbh	Wtrb	Wtlw	Css1	Css2	Css3	Css4
Dec-08	0	6	1	0	ND	0	7	1	0	0	3	2	1	4	4	3
Jan-09	0	7	1	0	0	1	9	3	0	2	3	2	1	3	4	3
Feb-09	0	4	1	0	0	0	9	2	0	1	0	2	1	2	3	2
Mar-09	0	7	0	0	1	0	17	2	0	2	3	5	1	2	10	2
Apr-09	0	18	7	3	6	1	24	8	0	10	9	3	10	17	18	15
May-09	5	23	15	6	12	7	25	15	6	20	16	9	23	22	22	21
Jun-09	6	11	11	0	18	8	21	16	9	14	17	11	19	22	20	16
Jul-09	2	4	0	0	6	2	16	7	0	3	13	9	1	7	0	2
Aug-09	0	0	0	0	3	0	17	8	0	6	12	2	0	0	0	1
Sep-09	5	1	4	0	10	4	18	10	0	11	12	1	0	6	3	11
Oct-09	0	3	4	0	8	2	17	7	3	7	7	1	0	11	1	9
Nov-09	0	1	0	0	0	0	9	1	0	1	0	0	0	3	0	2
Dec-09	0	ND	0	1	0	0	9	1	0	1	2	0	0	2	1	2
Jan-10	0	ND	0	0	0	0	3	0	0	1	0	0	0	0	0	0
Feb-10	0	ND	0	0	0	0	8	1	0	2	1	0	0	3	1	1
Mar-10	0	ND	0	2	2	0	11	3	0	4	1	0	2	6	3	3
Apr-10	1	ND	0	4	3	0	15	5	0	6	ND	ND	4	7	5	5

Table A5.11: Basic descriptive statistics for **temperatures (°C)** at well sites. Number of observations, mean daily temperature, standard error of the mean, standard deviation, maximum and minimum readings. ND = no data.

	Cope South Valley bog					**Cope South Raised bog**					**Horror Bog no. 7 Burnt hm'k**				
Month	n	mean °C	std	max	min	n	mean °C	std	max	min	n	mean °C	std	max	min
Apr-07	360	6.7 ± 0.3	5.7	20.0	-3.5	360	5.8 ± 0.3	6.6	20.5	-6.4		ND			
May-07	372	6.6 ± 0.2	4.0	17.4	-4.5	81	6.3 ± 0.3	2.8	12.6	-1.6		ND			
Jun-07		ND					ND					ND			
Jul-07		ND					ND					ND			
Aug-07		ND					ND					ND			
Sep-07		ND					ND					ND			
Oct-07	341	7.8 ± 0.3	5.3	21.7	-4.5	341	7.4 ± 0.3	6.1	24.6	-5.7	342	7.2 ± 0.3	6.1	22.8	-7.3
Nov-07	360	11.2 ± 0.3	6.1	26.6	0.6	360	10.6 ± 0.4	6.9	27.4	-1.3	359	11.1 ± 0.4	7.7	31.3	-1.6
Dec-07	372	12.9 ± 0.3	5.7	28.1	-0.9	372	12.2 ± 0.3	6.5	29.2	-2.6	372	12.9 ± 0.4	7.6	36.2	-4.4
Jan-08	372	15.3 ± 0.3	5.9	27.9	2.2	372	14.3 ± 0.4	6.9	29.5	0.6	372	16.6 ± 0.5	9.0	37.1	-0.1
Feb-08	348	11.2 ± 0.3	5.9	23.8	-0.1	348	10.8 ± 0.4	6.7	27.2	-1.5	348	11.4 ± 0.4	8.3	29.8	-3.0
Mar-08	359	11.0 ± 0.3	6.4	25.6	-0.7	372	10.1 ± 0.4	6.9	27.8	-0.9	372	11.5 ± 0.5	9.4	34.8	-3.4
Apr-08	360	5.4 ± 0.2	4.7	16.1	-1.9	360	4.5 ± 0.3	4.9	17.3	-3.3	360	4.6 ± 0.3	6.1	20.9	-5.4
May-08	372	2.6 ± 0.2	4.0	14.0	-7.5	372	2.1 ± 0.2	3.8	13.8	-7.9	372	2.0 ± 0.2	4.6	16.1	-9.5
Jun-08	360	1.9 ± 0.1	2.8	10.3	-4.1	360	2.5 ± 0.1	2.4	8.5	-3.7	360	1.4 ± 0.2	2.9	12.4	-5.8
Jul-08	372	0.1 ± 0.0	0.4	0.4	-2.0	372	2.1 ± 0.0	0.4	2.5	0.1	372	-0.3 ± 0.0	0.7	1.0	-4.5
Aug-08	372	0.2 ± 0.0	0.0	0.3	0.1	372	2.6 ± 0.0	0.1	3.0	2.5	372	-0.2 ± 0.0	0.1	0.1	-0.6
Sep-08	360	2.6 ± 0.2	2.9	14.2	0.0	360	3.6 ± 0.1	2.0	13.0	1.2	360	1.9 ± 0.2	3.9	19.9	-2.6
Oct-08	272	8.7 ± 0.2	3.3	17.3	1.1	359	7.8 ± 0.2	3.5	17.0	1.4	371	7.8 ± 0.4	7.0	24.3	-5.9
Nov-08		ND				360	9.5 ± 0.1	2.2	15.4	5.6	360	9.1 ± 0.3	6.5	25.8	-5.7
Dec-08		ND				371	11.0 ± 0.2	3.9	20.9	1.9	372	10.7 ± 0.3	6.7	26.8	-6.0
Jan-09	259	15.9 ± 0.4	7.1	31.2	0.8	371	14.0 ± 0.3	6.7	30.3	1.2	371	15.9 ± 0.5	8.8	38.0	-5.9
Feb-09	336	12.9 ± 0.4	7.2	27.7	-1.4	336	12.5 ± 0.4	6.8	27.8	-0.2	336	13.4 ± 0.5	8.3	35.7	-2.8
Mar-09	372	10.0 ± 0.3	6.2	22.2	-2.0	372	9.6 ± 0.3	6.0	22.4	-0.4	372	10.1 ± 0.4	6.8	27.6	-2.8
Apr-09	360	5.1 ± 0.3	5.6	21.5	-3.8	360	5.2 ± 0.3	5.2	22.7	-2.4	360	4.8 ± 0.3	5.9	24.8	-4.5
May-09	204	1.3 ± 0.3	3.7	10.9	-4.9	372	1.9 ± 0.1	2.7	10.4	-2.9	372	1.4 ± 0.2	3.4	12.9	-5.3
Jun-09	360	0.2 ± 0.2	3.1	8.9	-7.5	360	1.3 ± 0.1	1.5	7.3	-2.0	360	0.1 ± 0.1	2.7	8.2	-6.4
Jul-09	372	-0.5 ± 0.1	1.1	0.4	-4.9	372	1.4 ± 0.0	0.2	1.7	0.8	372	-0.6 ± 0.1	1.3	0.6	-6.2
Aug-09	372	0.3 ± 0.1	1.2	4.3	-4.5	372	1.6 ± 0.0	0.2	1.9	0.8	372	0.2 ± 0.1	1.5	5.2	-4.3
Sep-09	360	3.1 ± 0.2	4.4	15.3	-6.5	360	3.0 ± 0.1	2.0	10.0	0.0	360	2.4 ± 0.2	3.9	15.7	-6.7
Oct-09	372	5.0 ± 0.3	5.9	22.2	-6.0	372	4.8 ± 0.2	3.4	17.6	0.7	372	4.6 ± 0.3	5.9	24.3	-4.8
Nov-09	276	12.1 ± 0.4	6.5	25.5	-1.9	359	11.9 ± 0.3	6.0	27.7	-1.3	359	12.7 ± 0.4	7.6	29.2	-2.1
Dec-09	372	12.5 ± 0.4	6.8	26.5	-1.8	372	12.4 ± 0.4	7.6	30.1	-2.2	372	13.0 ± 0.4	8.2	31.5	-3.1
Jan-10	372	14.9 ± 0.4	7.0	28.8	0.6	372	14.5 ± 0.4	7.9	30.8	0.3	372	15.5 ± 0.4	8.4	34.0	-0.7
Feb-10	336	13.3 ± 0.3	6.1	26.3	-1.3	336	13.2 ± 0.4	6.8	28.7	-1.7	336	13.2 ± 0.4	6.6	28.5	-2.3
Mar-10	372	10.8 ± 0.3	6.1	24.1	-3.3	372	10.5 ± 0.3	6.7	26.0	-3.7	372	10.3 ± 0.3	6.5	26.4	-4.8
Apr-10	360	7.1 ± 0.3	5.4	19.6	-5.0	360	6.8 ± 0.3	5.8	22.3	-5.3	360	6.3 ± 0.3	5.3	23.4	-6.5

Table A5.12: Basic descriptive statistics for temperatures (°C) at well sites. Number of observations, mean daily temperature, standard error of the mean, standard deviation, maximum and minimum readings. ND = no data.

	Cope East Tall wet heath					**Cope Creek Low wet heath**					**Wallaces Tr'k no. 3 Raised bog**				
Month	n	mean °C	std	max	min	n	mean °C	std	max	min	n	mean °C	std	max	min
Oct-07	341	6.4 ± 0.3	5.3	22.3	-4.8	339	6.4 ± 0.3	6.0	20.7	-10.0	56	7.7 ± 0.5	4.0	17.7	0.6
Nov-07	359	9.8 ± 0.3	6.6	30.9	-0.1	360	9.4 ± 0.4	6.9	25.5	-5.1	359	10.7 ± 0.3	6.4	26.4	0.3
Dec-07	372	11.2 ± 0.3	6.4	31.6	-0.5	372	10.9 ± 0.3	6.4	27.2	-4.9	372	12.2 ± 0.3	6.1	29.3	-3.2
Jan-08	372	13.3 ± 0.3	6.6	30.5	-0.1	372	13.4 ± 0.4	7.1	28.7	-0.4	372	14.6 ± 0.3	6.7	29.1	1.7
Feb-08	348	9.1 ± 0.2	4.4	19.8	0.7	348	9.4 ± 0.4	7.5	25.0	-6.6	348	10.6 ± 0.4	6.6	24.3	-2.0
Mar-08	372	8.6 ± 0.2	4.7	20.4	0.0	372	9.0 ± 0.4	8.4	28.1	-6.0	371	10.5 ± 0.4	6.9	27.0	-0.9
Apr-08	360	3.4 ± 0.2	3.0	10.7	-1.6	360	3.5 ± 0.3	6.5	18.3	-9.0	360	5.0 ± 0.2	4.3	16.2	-1.3
May-08	372	1.4 ± 0.1	2.4	7.2	-6.1	372	1.2 ± 0.3	5.8	15.5	-14.4	372	2.2 ± 0.2	3.6	11.7	-7.4
Jun-08	360	1.4 ± 0.1	2.0	6.7	-3.4	360	1.1 ± 0.2	3.7	12.8	-8.5	360	1.6 ± 0.1	2.7	9.6	-5.6
Jul-08	372	0.4 ± 0.0	0.5	0.8	-2.3	372	-0.3 ± 0.1	1.2	1.3	-8.5	372	0.2 ± 0.0	0.6	0.7	-3.9
Aug-08	372	0.8 ± 0.0	0.0	0.9	0.7	372	0.4 ± 0.0	0.1	0.6	0.0	372	0.4 ± 0.0	0.1	0.5	0.1
Sep-08	360	1.5 ± 0.1	2.1	14.6	-2.3	360	2.0 ± 0.2	3.5	13.6	-4.8	360	0.3 ± 0.0	0.3	3.2	-2.0
Oct-08	360	5.9 ± 0.3	5.2	20.3	-3.3	372	6.6 ± 0.4	6.8	22.6	-6.8	372	6.6 ± 0.3	6.4	22.3	-6.3
Nov-08	360	7.3 ± 0.3	5.0	22.4	-1.5	360	7.9 ± 0.4	6.8	26.4	-7.6	360	8.6 ± 0.3	6.1	25.3	-4.8
Dec-08	372	9.1 ± 0.3	5.0	23.8	-1.7	372	9.1 ± 0.3	6.4	22.7	-11.0	371	10.4 ± 0.3	5.3	24.2	-1.4
Jan-09	372	12.3 ± 0.3	6.6	27.6	-2.8	372	12.8 ± 0.5	9.1	31.6	-10.8	372	13.5 ± 0.2	4.4	26.1	3.6
Feb-09	336	10.7 ± 0.3	5.4	25.3	0.5	336	11.4 ± 0.5	8.5	29.5	-9.5	336	12.7 ± 0.2	4.3	23.9	4.6
Mar-09	372	7.8 ± 0.2	3.9	17.1	-0.1	372	8.6 ± 0.4	7.8	23.5	-6.9	372	10.0 ± 0.2	3.1	18.3	3.6
Apr-09	360	3.8 ± 0.2	3.5	15.0	-2.6	360	3.4 ± 0.4	7.6	23.2	-13.7	360	5.9 ± 0.2	3.0	15.5	1.8
May-09	372	1.0 ± 0.1	1.9	7.1	-4.0	372	1.1 ± 0.3	6.0	14.7	-10.7	372	1.9 ± 0.1	2.0	8.1	-3.0
Jun-09	360	0.0 ± 0.1	1.8	6.4	-4.8	360	-0.7 ± 0.2	4.4	10.7	-14.0	360	0.6 ± 0.1	1.7	6.5	-3.8
Jul-09	372	0.0 ± 0.0	0.5	0.4	-2.9	372	-1.6 ± 0.2	3.1	2.4	-16.4	372	0.4 ± 0.0	0.3	0.6	-0.7
Aug-09	372	0.4 ± 0.0	0.0	0.6	0.3	372	0.2 ± 0.1	2.7	10.8	-8.1	372	0.4 ± 0.0	0.2	0.7	-0.2
Sep-09	360	1.6 ± 0.1	2.5	10.2	-3.8	360	2.3 ± 0.3	5.3	16.5	-10.7	360	0.6 ± 0.1	1.1	6.7	-1.7
Oct-09	372	3.5 ± 0.2	4.4	18.1	-3.1	372	4.0 ± 0.3	6.5	22.6	-10.5	372	3.7 ± 0.3	4.9	21.7	-2.5
Nov-09	359	11.2 ± 0.3	5.7	24.9	-0.7	359	10.9 ± 0.4	8.1	26.4	-8.0	359	12.1 ± 0.3	5.7	26.1	-0.7
Dec-09	372	10.9 ± 0.3	6.1	27.1	-0.2	372	10.6 ± 0.4	7.8	26.8	-7.3	372	12.3 ± 0.3	6.1	27.5	0.6
Jan-10	372	12.3 ± 0.3	5.4	25.6	1.9	372	12.6 ± 0.4	7.9	28.1	-3.4	372	14.1 ± 0.3	5.8	27.1	2.4
Feb-10	336	11.4 ± 0.2	4.0	22.7	1.3	336	11.5 ± 0.4	7.0	24.3	-6.4	336	13.0 ± 0.3	4.7	24.2	2.4
Mar-10	372	8.8 ± 0.2	3.6	17.3	-0.4	372	9.1 ± 0.4	7.3	23.7	-8.4	372	10.2 ± 0.2	4.2	20.9	1.1
Apr-10	360	5.8 ± 0.2	3.1	12.1	-1.1	360	5.4 ± 0.3	6.4	18.8	-11.5	360	6.7 ± 0.2	3.5	15.1	-0.5

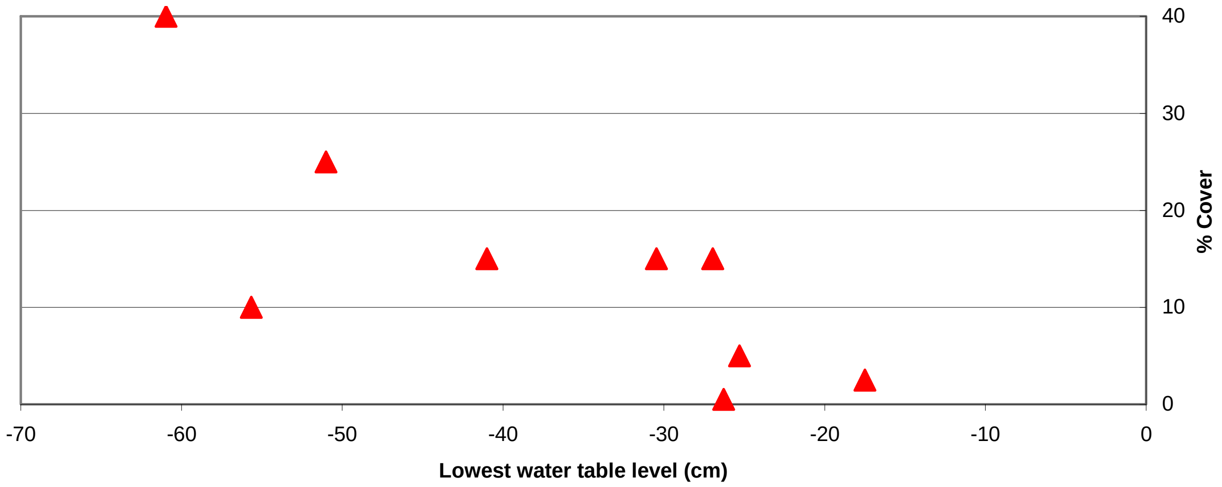


Figure A5.1: Lowest water table level vs % cover of restiads (mostly *Empodisma minus*).

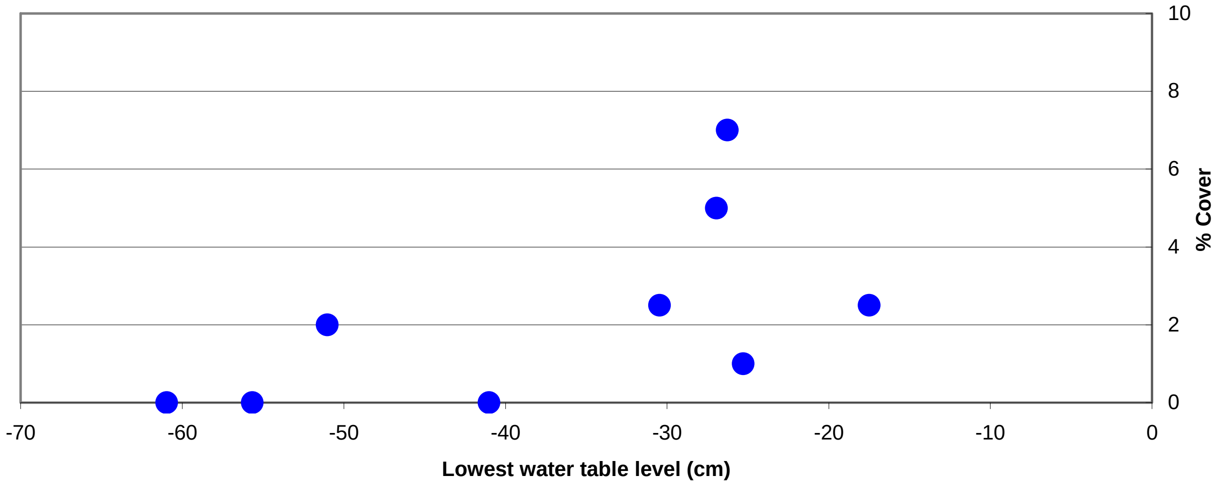


Figure A5.2: Lowest water table level vs % cover of *Carex gaudichaudiana*.

Appendices CHAPTER 6

In order to conserve space, some of the appendices tables have been removed. These are indicated by an asterix (*) next to the table number in the text. The full version of the appendices, containing all tables, is on the accompanying CD (attached to back cover).

Table A6.1: **Summary of the 17 transects affected by fire in December 2006**. Measurements for shrub cover, shrub height, peat depth and litter cover were taken before the fires. Post-fire measurements were taken four months afterwards.

Transect	Altitude	Peat depth (cm)	Shrub cover %	Mean height tallest shrubs (cm)	Litter % cover	% fire affected	Mean intensity
Bennison Plain 1	1290	110	17	30	4	0	0.0
Bennison Plain 2	1280	88	16	44	4	0	0.0
Dairy Farm Flat 1	1150	91	22	70	13	72	1.6
Morgans Gully 1	1000	181	5	38	4	0	0.0
Morgans Gully 2	1000	193	21	54	9	32	0.6
Moroka Hut	1050	128	16	44	9	0	0.0
Cave Gate Creek 2	1420	26	26	46	5	100	2.8
Dairy farm Flat 2	1150	110	31	89	14	95	2.4
Cave Gate Creek 1	1400	114	25	35	1	46	0.7
Lankey's Plain Exc. Pl	1560	81	48	36	3	0	0.0
Omeo Plain 1	1540	58	57	59	10	45	1.7
Snowy Range South	1580	81	42	29	1	0	0.0
Snowy Range West 1	1590	55	47	28	4	40	1.2
Omeo Plain 2	1540	38	63	53	14	77	2.9
Piemans Creek 1	1450	62	58	44	5	95	2.1
Piemans Creek 2	1460	153	26	37	15	93	2.3
Snowy Range West 2	1590	42	42	42	17	76	2.0

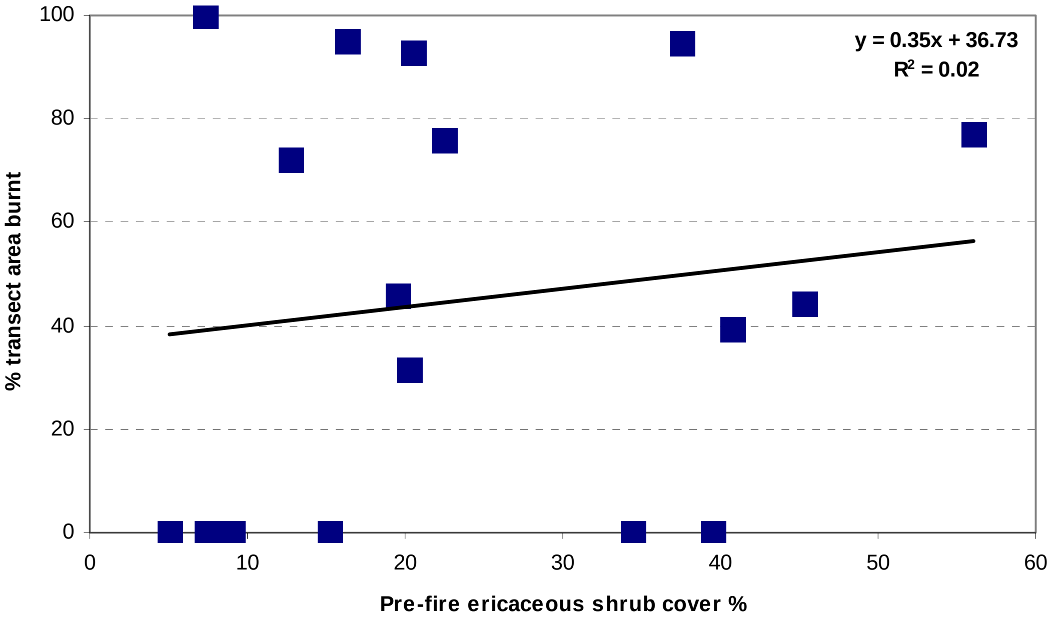


Figure A6.1: The relationship between **pre-fire percent cover of ericaceous shrubs and the extent of fire damage** to transects in the December 2006 fires. The regression equation and R² value is included in the top right corner of the graph.

Table A6.2: **Changes in the cover of key species between April 2006 (7-months pre-fire) and April 2007 (4-months post-fire).** The data are from SIMPER analysis of the 10 fire affected sites. The listed species contribute most to the differences between pre-fire and 4-months post-fire cover. The species listed contribute more than 80% to the dissimilarities between groups. Useful distinguishing species are those that have a high dissimilarity score (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

	Mean % cover				
Species	**pre-fire**	**4-months post-fire**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	39.1	21.6	20.9	1.4	31.8
Empodisma minus	14.4	3.0	10.2	1.0	15.6
Richea continentis	13.0	2.6	9.1	0.9	13.8
Epacris paludosa	12.7	3.8	8.0	1.7	12.2
Baeckea gunniana	11.2	2.0	7.4	1.5	11.2
Carex gaudichaudiana	2.1	2.9	2.5	0.8	3.7
Callistemon pityoides	2.6	0.4	2.2	0.8	3.3
Epacris celata	1.3	0.0	0.9	0.4	1.4
Poa costiniana	1.1	0.5	0.8	0.9	1.2
Epacris breviflora	0.9	0.0	0.6	0.3	1.0
Average dissimilarity = 65.8					

Table A6.3: **Changes in the cover of key species between April 2006 (7-months pre-fire) and April 2009 (28-months post-fire).** The data are from SIMPER analysis of the 10 fire affected sites. The listed species contribute most to the differences between pre-fire and 28-months post-fire cover. The species listed contribute more than 80% to the dissimilarities between groups. Useful distinguishing species are those that have a high dissimilarity score (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

	Mean % cover				
Species	**pre-fire**	**28 months post-fire**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	39.1	29.9	14.5	1.4	27.9
Empodisma minus	14.4	14.7	7.6	1.2	14.7
Richea continentis	13.0	3.7	7.0	0.9	13.5
Epacris paludosa	12.7	8.6	5.4	1.4	10.4
Baeckea gunniana	11.2	5.7	3.8	1.4	7.4
Carex gaudichaudiana	2.1	5.4	3.1	0.9	6.0
Callistemon pityoides	2.6	1.4	1.8	1.0	3.4
Asperula gunnii	0.3	2.6	1.5	0.8	2.9
Poa costiniana	1.1	1.8	1.1	0.9	2.1
Epacris celata	1.3	0.3	0.9	0.4	1.7
Sphagnum novozelandicum	0.6	0.8	0.6	0.9	1.2
Epacris breviflora	0.9	0.1	0.5	0.4	1.0
Gonocarpus micranthus	0.0	0.7	0.4	0.7	0.8
Hydrocotyle spp.	0.0	0.6	0.4	0.4	0.7
Average dissimilarity = 51.8					

Table A6.4: **Changes in the cover of key species between April 2007 (4-months post-fire) and April 2009 (28-months post-fire).** The data are from SIMPER analysis of the 10 fire affected sites. The listed species contribute most to the differences between 4-months post-fire and 28-months post-fire cover. The species listed contribute more than 80% to the dissimilarities between groups. Useful distinguishing species are those that have a high dissimilarity score (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

	Mean % cover				
Species	**4 months post-fire**	**28 months post-fire**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	21.6	29.9	19.6	1.5	31.3
Empodisma minus	3.0	14.7	10.7	1.1	17.1
Epacris paludosa	3.8	8.6	6.1	1.1	9.8
Carex gaudichaudiana	2.9	5.4	4.7	0.8	7.5
Baeckea gunniana	2.0	5.7	4.4	0.9	7.0
Richea continentis	2.6	3.7	4.0	0.8	6.4
Asperula gunnii	0.4	2.6	2.5	0.8	4.0
Poa costiniana	0.5	1.8	1.7	0.8	2.8
Callistemon pityoides	0.4	1.4	1.6	0.7	2.5
Sphagnum novozelandicum	0.3	0.8	0.8	0.9	1.2
Hydrocotyle spp.	0.1	0.6	0.7	0.5	1.1
Gonocarpus micranthus	0.1	0.7	0.6	0.7	1.0
Baumea gunnii	0.1	0.5	0.5	0.4	0.8
Luzula modesta	0.1	0.5	0.4	1.3	0.6
Average dissimilarity = 62.6					

Table A6.5: **Changes in the cover of key species in the six fire-affected wet heath transects between April 2006 (7-months pre-fire) and April 2007 (4-months post-fire).** The data are from SIMPER analysis of the 6 fire-affected wet heath transects. The listed species contribute most to the differences between pre-fire and 4-months post-fire cover. The species listed contribute more than 80% to the dissimilarities between groups. Useful distinguishing species are those that have a high dissimilarity score (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

	Mean % cover in Wet heath				
Species	**pre-fire**	**4 months post-fire**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	23.3	7.9	17.7	1.6	22.9
Empodisma minus	12.4	0.8	12.4	0.9	16.0
Richea continentis	13.9	1.4	11.9	0.9	15.4
Baeckea gunniana	12.3	1.5	10.6	2.1	13.7
Epacris paludosa	9.1	1.0	8.5	1.6	11.0
Carex gaudichaudiana	2.9	3.9	4.1	1.0	5.2
Callistemon pityoides	4.1	0.6	3.7	1.2	4.9
Epacris celata	2.2	0.0	1.7	0.5	2.2
Average dissimilarity = 77.2					

Table A6.6: **Changes in the cover of key species in the six fire-affected wet heath transects between April 2006 (7-months pre-fire) and April 2009 (28-months post-fire).** The data are from SIMPER analysis of the 6 fire-affected wet heath transects. The listed species contribute most to the differences between pre-fire and 28-months post-fire cover. The species listed contribute more than 80% to the dissimilarities between groups. Useful distinguishing species are those that have a high dissimilarity score (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

	Mean % cover in Wet heath transects				
Species	**pre-fire**	**28 months post-fire**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	23.3	15.5	9.9	1.4	17.6
Richea continentis	13.9	1.9	8.6	0.9	15.3
Empodisma minus	12.4	9.2	7.6	1.1	13.6
Baeckea gunniana	12.3	5.9	5.0	1.6	9.0
Carex gaudichaudiana	2.9	7.2	4.8	1.1	8.5
Epacris paludosa	9.1	3.8	4.6	1.4	8.1
Callistemon pityoides	4.1	2.2	2.7	1.3	4.7
Aserula gunnii	0.4	3.3	2.2	1.0	3.9
Poa costiniana	1.4	2.6	1.7	1.1	2.9
Epacris celata	2.2	0.5	1.5	0.6	2.7
Epacris breviflora	1.5	0.1	0.9	0.5	1.7
Sphagnum novozelandicum	0.8	0.9	0.9	1.0	1.6
Hydrocotyle spp.	0.0	0.9	0.7	0.6	1.2
Average dissimilarity = 56.2					

Table A6.7: **Changes in the cover of key species in the six fire-affected wet heath transects between April 2007 (4-months post-fire) and April 2009 (28-months post-fire).** The data are from SIMPER analysis of the 6 fire-affected wet heath transects. The listed species contribute most to the differences between 4-months post-fire and 28-months post-fire cover. The species listed contribute more than 80% to the dissimilarities between groups. Useful distinguishing species are those that have a high dissimilarity score (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

	Mean % cover in Wet heath transects				
Species	**4 months post-fire**	**28 months post-fire**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	7.9	15.5	14.3	1.3	20.8
Empodisma minus	0.8	9.2	11.3	1.1	16.5
Carex gaudichaudiana	3.9	7.2	7.9	1.1	11.5
Baeckea gunniana	1.5	5.9	6.3	1.0	9.2
Epacris paludosa	1.0	3.8	4.2	1.4	6.1
Aserula gunnii	0.4	3.3	4.1	0.9	6.0
Richea continentis	1.4	1.9	3.1	0.8	4.6
Poa costiniana	0.7	2.6	3.0	1.0	4.5
Callistemon pityoides	0.6	2.2	2.8	0.9	4.1
Hydrocotyle spp.	0.2	0.9	1.3	0.6	1.8
Sphagnum novozelandicum	0.4	0.9	1.2	1.0	1.7
Gonocarpus micranthus	0.1	0.9	1.1	0.9	1.6
Baumea gunnii	0.1	0.6	0.8	0.5	1.2
Epacris celata	0.0	0.5	0.7	0.5	1.0
Average dissimilarity = 68.5					

Table A6.8: **Changes in the cover of key species in the four fire-affected bog transects between April 2006 (7-months pre-fire) and April 2007 (4-months post-fire)**. The data are from SIMPER analysis of the 4 fire-affected bog transects. The listed species contribute most to the differences between pre-fire and 4-months post-fire cover. The species listed contribute more than 80% to the dissimilarities between groups. Useful distinguishing species are those that have a high dissimilarity score (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

	Mean % cover				
Species	**Bog pre-fire**	**Bog 4 months post-fire**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	62.9	42.1	12.4	1.3	32.5
Empodisma minus	17.3	6.3	7.2	1.1	18.9
Epacris paludosa	18.0	8.0	6.2	1.8	16.2
Richea continentis	11.6	4.4	5.9	1.0	15.3
Baeckea gunniana	9.6	2.9	3.9	1.4	10.1
Average dissimilarity = 38.2					

Table A6.9: **Changes in the cover of key species in the four fire-affected bog transects between April 2006 (7-months pre-fire) and April 2009 (28-months post-fire).** The data are from SIMPER analysis of the 4 fire-affected bog transects. The listed species contribute most to the differences between pre-fire and 28-months post-fire cover. The species listed contribute more than 80% to the dissimilarities between groups. Useful distinguishing species are those that have a high dissimilarity score (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

	Mean % cover				
Species	**Bog pre-fire**	**Bog 28 months post-fire**	**Av.Diss**	**Diss/SD**	**Contrib%**
Sphagnum cristatum	62.9	51.4	7.8	1.5	25.6
Empodisma minus	17.3	22.9	6.9	1.3	22.5
Richea continentis	11.6	6.5	5.0	1.2	16.3
Epacris paludosa	18.0	15.7	4.5	1.6	14.6
Baeckea gunniana	9.6	5.4	2.4	1.2	7.7
Carex gaudichaudiana	0.9	2.7	0.8	2.5	2.7
Asperula gunnii	0.2	1.7	0.7	1.2	2.1
Average dissimilarity = 30.6					

Table A6.10: **Changes in the cover of key species in the four fire-affected bog transects between April 2007 (4-months post-fire) and April 2009 (28-months post-fire).** The data are from SIMPER analysis of the 4 fire-affected bog transects. The listed species contribute most to the differences between 4-months post-fire and 28-months post-fire cover. The species listed contribute more than 80% to the dissimilarities between groups. Useful distinguishing species are those that have a high dissimilarity score (Av.Diss) and low variability, indicated by a higher ratio of dissimilarity to standard deviation of dissimilarity (Diss/SD).

	Mean % cover				
Species	**Bog 4 months post-fire**	**Bog 28 months post-fire**	**Av.Diss**	**Diss/SD**	**Contrib%**
Empodisma minus	6.3	22.9	9.5	1.3	26.8
Sphagnum cristatum	42.1	51.4	8.2	1.2	23.1
Epacris paludosa	8.0	15.7	6.3	1.2	17.8
Richea continentis	4.4	6.5	4.3	1.0	12.1
Baeckea gunniana	2.9	5.4	2.4	1.3	6.9
Asperula gunnii	0.3	1.7	0.8	1.2	2.3
Carex gaudichaudiana	1.4	2.7	0.8	1.6	2.3
Average dissimilarity = 35.4					

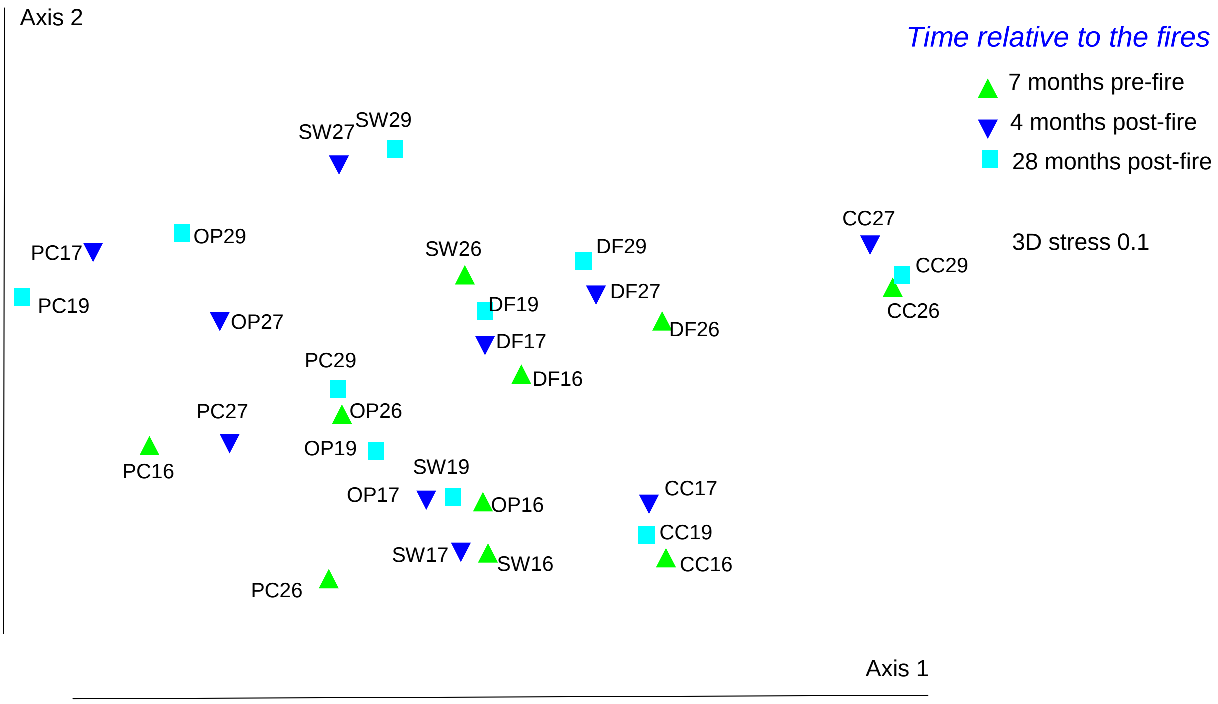


Figure A6.2: Three dimensional ordination graph based on the **frequency data for the 10 sites directly affected by fire in December 2006**. Initial sampling was in April 2006. The first post-fire survey was in April 2007, and the second in April 2009. The site and year codes are as for the time relative to the fires cover data ordination (see figure 6.15). The two letters and first digit are the transect code; the last digit refers to the year of sampling (6 = 2006, 7 = 2007, 9 = 2009).

REFERENCES

Agnew, A.D.Q., Rapson, G.L., Sykes, M.T. and Wilson, J.B. (1993). The functional ecology of *Empodisma minus* (Hook. f.) Johnson & Cutler in New Zealand ombrotrophic mires. *New phytologist* **124**, 703-710.

Aldrick, J.M., Hook, R.A., van de Graaff, R.H.M., Nicholson, B.M., O'Beirne, D.A., Schoknecht, N.R. (1988). A Study of the Land in the Catchment of the Gippsland Lakes. (Melbourne: Victorian Department of Conservation, Forests and Lands. Technical communication series publication no. **19**).

Allen, R.B. and Partridge, T.R. (1988). Effects of spring and autumn fires on the composition of *Chionochloa rigida* Tussock Grassland, New Zealand. *Vegetatio* **76**, 37-44.

Anderson, J.A.R. (1983). The tropical peat swamps of western Malesia. In 'Ecosystems of the World (4b). Mires: Swamp, Bog, Fen and Moor. Regional studies'.(Ed. A.J.P. Gore) pp.181-199. (Elsevier Scientific Publishing Company. Amsterdam).

Andrus, R.E. (1986). Some aspects of *Sphagnum* ecology. *Canadian Journal of Botany* **64**, 416-426.

Asada, T., Warner, B.G., Banner, A. (2003a). Growth of mosses in relation to climate factors in a hyper-maritime coastal peatland in British Columbia, Canada. *Bryologist* **106**, 516-527.

Asada, T., Warner, B.G., Pojar, J. (2003b). Environmental factors responsible for shaping an open peatland-forest complex on the maritime north coast of British Columbia. *Canadian Journal of Forest Research* **33**, 2380-2394.

Ashton, D.H. (1981). Fire in tall open forests. In 'Fire and the Australian Biota'. (Eds A.M. Gill, R.H. Groves, and I.R. Noble) pp. 339-366. (Australian Academy of Science. Canberra).

Ashton, D.H. and Hargreaves, G.R. (1983). Dynamics of subalpine vegetation at Echo Flat, Lake Mountain, Victoria. *Proceedings of the ecological society of Australia* **12**, 35-60.

Ashton, D.H. and Williams, R.J. (1989). Dynamics of subalpine vegetation in the Victorian region. In 'The Scientific Significance of the Australian Alps'. (Ed. R. Good) pp. 143-168. (Australian Academy of Science. Canberra).

Australian Academy of Science (1957). A Report on the Condition of the High Mountain Catchments of New South Wales and Victoria. (Australian Academy of Science. Canberra).

Banks, J.C. (1989). A history of forest fire in the Australian Alps. In ‘The Scientific Significance of the Australian Alps’. (Ed. R. Good.) pp. 265-280. (Australian Academy of Science. Canberra).

Barker, W.R. (1986). Biogeography and evolution in *Euphrasia* (Scophulariaceae), particularly relating to Australasia. In ‘Flora and Fauna of Alpine Australasia’. (Ed. B.A. Barlow) pp. 499-510 (CSIRO. Melbourne).

Barry, R.G. (2008). Mountain Weather and Climate. (Cambridge University Press. United Kingdom).

Beadle, N.C.W. (1954). Soil phosphate and the delimitation of plant communities in eastern Australia I. *Ecology*. **35** (3), 370-375.

Beadle, N.C.W. (1962). Soil phosphate and the delimitation of plant communities in eastern Australia II. *Ecology* **43** (2), 281-288.

Beisner, B.E., Haydon, D.T. and Cuddington, K. (2003). Alternative stable states in ecology. *Frontiers in Ecology and Environment* **1** (7), 376-382.

Bell, J.N.B. and Tallis, J.H. (1974). The response of *Empetrum nigrum* to different mire water regimes, with special reference to Wybunbury Moss, Cheshire and Featherbed Moss, Derbyshire. *Journal of Ecology* **62**, 75-95.

Bell, K.L. and Bliss, L.C. (1979). Autecology of *Kobresia bellardi*: Why winter snow accumulation limits local distribution. *Ecological monographs* **49**, 377-402.

Billings, W.D. A. (1973). Arctic and alpine vegetations: similarities, differences, and susceptibility to disturbance. *Biological Science* **23**, 697-704.

Billings, W.D. and Mooney, H.A. (1968). The Ecology of Arctic and Alpine Plants. *Biological Review* **43**, 481-529.

Blackford, J. (2000). Palaeoclimatic records from peat bogs. *Trends in Ecology and Evolution* **15** (5), 193-198.

Bliss, L.C. (1979). Vascular plant vegetation of the southern circum-polar region in relation to antarctic, alpine and arctic vegetation. *Canadian Journal of Botany* **57**, 2167-2178.

Bragazza, L., Gerdol, R. and Rydin, H. (2003). Effects of mineral and nutrient imput on mire bio-geochemistry in two geographical regions. *Journal of Ecology* **91**, 417-426.

Bray, R.J. and Curtis, J.T. (1957). An ordination of the upland forest communities of Southern Wisconsin. *Ecological Monographs* **27**, 325-349.

Breeuwer, A., Robroek, B.J.M., Limpens, J., Heijmans, M.M.P.D., Schouten, M.G.C. and Berendse, F. (2009). Decreased summer water table depth affects peatland vegetation. *Basic and Applied Ecology* **10**, 330-339.

Bridgham, S.D., Johnston, C.A., Pastor, J. and Updegraff, K. (1995). Potential feedbacks of northern wetlands on climate change: an outline of an approach to predict climate-change impact. *Bioscience* **45**, 262-274.

Broome, L.S. and Mansergh, I.M. (1989). The Mountain Pygmy Possum *Barramys parvus* (Broome): An Alpine Endemic. In ‘The Scientific Significance of the Australian Alps’. (Ed. R. Good) pp. 241-264 (Australian Academy of Science. Canberra).

Brown, A., Horsfield, D. and Thompson, D.B.A. (1993a). A new biogeographical classification of the Scottish Uplands I. Descriptions of vegetation blocks and their spatial variation. *Journal of Ecology* **81**, 207-230.

Brown, A., Birks, H.J.B. and Thompson, D.B.A. (1993b). A new biogeographical classification of the Scottish Uplands II. Vegetation - environment relationships. *Journal of Ecology* **81**, 231-251.

Brown, M.J. (1999). Buttongrass Moorlands. In ‘Vegetation of Tasmania’. (Eds J.B. Reid, R.S. Hill, M.J. Brown, and M.J. Hovenden) pp.286-303. (Commonwealth of Australia).

Bureau of Meteorology Victoria (1993). Climate of Victoria. In 'Flora of Victoria'. Volume One. (Eds D.G. Foreman and N.G. Walsh) pp. 47-60. (National herbarium of Victoria. Inkata Press. Melbourne).

Busby, J.R. and Brown, M.J. (1994). Southern Rainforests. In 'Australian Vegetation’. Second edition. (Ed. R.H. Groves.) pp. 131-55. (Cambridge University Press. Great Britain).

Cabena, P.B. (1980). Grazing the High Country: an historical and political geography of high country grazing in Victoria, 1835-1935. MA thesis, Department of Geography, University of Melbourne.

Campbell, E.O. (1964). The restiad peat bogs at Motumaoho and Moanatuatua. *Transactions of the Royal Society of New Zealand: Botany* 2, 219-227.

Campbell, E.O. (1983). Mires of Australia. In ‘Ecosystems of the World (4b). Mires: Swamp, Bog, Fen and Moor. Regional studies’. (Ed. A.J.P. Gore) pp.153-180. (Elsevier Scientific Publishing Company. Amsterdam).

Campbell, I.C., McKaige, M.E. and Lake, P.S. (1986). The fauna of Australian high mountain streams: ecology, zoogeography and evolution. In 'Flora and Fauna of Alpine Australasia'. (Ed.B.A. Barlow) pp. 83-104 (CSIRO. Melbourne).

Carr, G.W. (1993). Exotic flora of Victoria and its impact on indigenous biota. In 'Flora of Victoria'. Volume one. (Eds D.B. Foreman, and N.G. Walsh) pp. 256-297. (National Herbarium of Victoria. Inkata Press. Melbourne).

Carr, S.G.M. and Turner, J.S. (1959). The ecology of the Bogong High Plains I. The environmental factors and the grassland communities. *Australian Journal of Botany* **7** (1), 12-33.

Champness, S.S. and Morris, K. (1948). The population of buried viable seeds in relation to contrasting pasture and soil types. *Journal of Ecology* **36**, 149-173.

Chapin, F.S., Bret-Harte, M.S., Hobbie, S.E. and Zhong, H. (1996). Plant functional types as predictors of transient responses of Arctic vegetation to global change. *Journal of Vegetation Science* **7** (3), 347-358.

Charman, D. (2002). Peatlands and Environmental Change. (John Wiley & Sons Limited. Chichester. England).

Chessman, B.C. (1995). Rapid assessment of rivers using macroinvertebrates: A procedure based on habitat specific sampling, family level identifications and a biotic index. *Australian Journal of Ecology* **20**, 122-129.

Clarke, K.R.A. (1993). Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* **18**, 117-143.

Clarke, K.R. and Gorley, R.N. (2001). Primer V.5: User manual/ tutorial. Primer-E., Plymouth.

Clarke, P.J. and Knox, K.J.E. (2002). Post-fire response of shrubs in the tablelands of eastern Australia: do existing models explain habitat differences? *Australian Journal of Botany* **50**, 53-62.

Clarke, P.J. and Martin, A.R.H. (1999). *Sphagnum* peatlands of the Kosciuszko National Park in relation to altitude, time and disturbance. *Australian Journal of Botany* **47**, 519-536.

Clarkson, B.R. (1997). Vegetation recovery following fire in two waikato peatlands at Whangamarino and Moanatuatua, New Zealand. *New Zealand Journal of Botany* **35**, 167-179.

Clarkson, B.R. and Clarkson, D.D. (2006). Restiad Bogs in New Zealand. In ‘The Biology of Peatlands (Eds H. Rydin and J. Jeglum) pp. 228-233. (Oxford University Press.).

Clymo, R.S. (1973). The growth of Sphagnum: some effects of environment. *Journal of Ecology* **61**, 849-69.

Clymo, R.S. (1983). Peat. In ‘Ecosystems of the World (4a). Mires: Swamp, Bog, Fen and Moor. General studies’. (Ed. A.J.P. Gore) pp.159-224. (Elsevier Scientific Publishing Company. Amsterdam).

Clymo, R.S. (1984). The limits to peat bog growth. *Philosophical Transactions of the Royal Society of London. (B) Biological Science* **303**, 605-654.

Clymo, R.S. and Duckett, J.G. (1986). Regeneration of *Sphagnum*. *New Phytologist* **102**, 589-614.

Clymo, R.S. and Hayward, P.M. (1982). The ecology of *Sphagnum.* In ‘Bryophyte Ecology’. (Ed. A.J.E. Smith) pp. 229-289. (Chapman and Hall. London).

Cochrane, G.W., Quick, G.W. and Spencer-Jones, D. (1995). Introducing Victorian Geology. (Geological Society of Australia. Melbourne).

Collins, P. (2006). Burn: the epic story of bushfire in Australia. (Allen and Unwin. Crows Nest, New South Wales. Australia).

Common, I.F.B. (1954). A study of the ecology of the adult Bogong moth *Agrotis infusa* (Boisd.) (Lepidoptera: Noctuidae), with special references to its behaviour during migration and aestivation. *Australian Journal of Zoology* **2**, 223-262.

Conn, B.J. (1993). Natural Regions and Vegetation of Victoria. In 'Flora of Victoria'. Volume One. (Eds D.B. Foreman and N.G. Walsh) pp. 79-158. (National herbarium of Victoria. Inkata Press. Melbourne.).

Costin, A.B. (1954). A study of the ecosystems of the Monaro Region of New South Wales. (Government Printer. Sydney).

Costin, A.B. (1957). The high mountain vegetation of Australia. *Australian Journal of Botany* **5**, 173-189.

Costin, A.B. (1962a). The soils of the high plains. *Proceedings of the Royal Society of Victoria* **75**, 291-299.

Costin, A.B. (1962b). Ecology of the high plains. *Proceedings of the Royal Society of Victoria* **75**, 327-337.

Costin, A.B., Gray, M., Totterdell, C. and Wimbush, D. (2000). Kosciuszko alpine flora. (2nd edition. CSIRO publishing. Collingwood, Australia).

Couwenberg, J. (2005). A simulation model of mire patterning – revisited. *Ecography* **28**, 653-661.

Couwenberg, J. and Joosten, H. (2005). Self-organisation in raised bog patterning: the origin of microtope zonation and mesotope diversity. *Journal of Ecology* **93**, 1238-1248.

Crawford, R.M.M. (1983). Root survival in flooded soils. In 'Ecosystems of the World (4a). Mires: Swamp, Bog, Fen and Moor. General studies'. (Ed. A.J.P. Gore) pp.257-283. (Elsevier Scientific Publishing Company. Amsterdam).

Cremer, K.W. (1995). Willows spreading by seed – implications for river management in Australia. *Australian Journal of Soil and Water Conservation* **8** (4), 18-27.

Crowden, R.K. (1999). Alpine Vegetation. In 'Vegetation of Tasmania'. (Eds J.B. Reid, R.S. Hill, M.J. Brown and M.J. Hovenden) pp.333-356. (Commonwealth of Australia).

Davies, P.W., McLean, C.B. Bell, T.L. (2003). Root survey and isolation of fungi from alpine epacrids (Ericaceae). *Australian Mycologist* **22**, 4-10.

Dickinson, K.J.M., Chague-Goff, C., Mark, A.F. and Cullen, L. (2002). Ecological processes and trophic status of two low-alpine patterned mires, south-central South Island, New Zealand. *Austral Ecology* **27**, 369-384.

Dodson, J.R., De Salis, T., Myers, C.A. and Sharp, A.J. (1994). A thousand years of environmental change and human impact in the alpine zone at Mt Kosciusko, New South Wales. *The Australian Geographer* **25**, 77-87.

Douglas, J.G. (1993). Geology and Geomorphology of Victoria. In 'Flora of Victoria'. Volume One. (Eds D.B. Foreman and N.G. Walsh) pp. 24-46. (National Herbarium of Victoria. Inkata Press. Melbourne.).

Downes, R.G. (1961). The Victorian high plains - the environment and its use. *Proceedings of the Royal Society of Victoria* **75**, 339-347.

Drosdowsky, W. and Williams, M. (1991). The Southern Oscillation in the Australian region I: Anomolies at the extremes of the oscillation. *Journal of Climate* **4** (6), 619-638.

Du Rietz, G.E. (1954). Die Mineralbodenwasserzeigergrenze als Grundlage einer naturlichen Zweigliederung der nord-und mitteleuropaischen Moore. *Vegetatio* **5-6**, 571-585.

Esplin, B., Gill, A.M. and Enright, N.J. (2003). Report of the Inquiry into the 2002-2003 Victorian Bushfires. (State Government of Victoria. Melbourne).

Farrell, T.P. and Ashton, D.H. (1973). Ecological studies of the Bennison High Plains. *Victorian Naturalist* **90**, 286-298.

Fischer, J., Lindenmayer, D.B., Nix, H.A., Stein, J.L. and Stein, J.A. (2001). Climate and Animal distribution: A climatic analysis of the Australian Marsupial *Trichosaurus caninus*. *Journal of Biogeography* **28** (3), 293-304.

Flood, J.M. (1980). The Moth hunters. Aboriginal pre-history of the Australian Alps. (Australian Institute of Aboriginal Studies. Canberra).

Forbes, S.J., Walsh, N.G. and Gullan, P.K. (1982). Vegetation of East Gippsland. *Muelleria* **5**, 53-113.

Fox, M.D. (1999). Present environmental influences on the Australian flora. In 'Flora of Australia'. Volume one, Introduction. (Eds A.E. Orchard & H.S. Thomson) pp. 205-250. (CSIRO, Collingwood. Victoria).

Frenzel, B. (1983). Mires - repositories of climatic information or self-perpetuating ecosystems? In 'Ecosystems of the World (4a). Mires: Swamp, Bog, Fen and Moor. General studies'. (Ed. A.J.P. Gore) pp. 35-65. (Elsevier Scientific Publishing Company. Amsterdam).

Frith, H.J. (1969). Birds of the Australian high country. (A.H. and A.W. Reed. Sydney).

Galloway, R.W. (1989). Glacial and periglacial features of the Australian Alps. In 'The Scientific Significance of the Australian Alps. (Ed. R. Good) pp. 55-67 (Australian Academy of Science. Canberra).

Gams, H. (1931). Die Klimatische Begrenzung von Pflanzenarealen und die verteilung der hygrischen kontinentalität in den Alpen. I. Teil, Zeitschr. Ges.f.Erdkunde, Berlin, Nr. 9/10, 321-346.

Garnett, M.H., Ineson, P. and Stevenson, A.P. (2000). Effects of burning and grazing on carbon sequestration in a Pennine blanket bog, UK. *The Holocene* **10** (6), 729-36.

Gerdol, R. (1995). The growth dynamics of *Sphagnum* based on field measurements in a temperate bog and on laboratory cultures. *Journal of Ecology* **83**, 431-437.

Gibbons, F. and Rowan, J. (1993). Soils in relation to vegetation in Victoria. In 'Flora of Victoria'. Volume one. (Eds. D.B. Foreman and N.G. Walsh) pp. 159-194. (National Herbarium of Victoria. Inkata Press. Melbourne).

Gibson, N. and Hope, G. (1986). On the origin and evolution of Australasian alpine cushion plants. In 'Flora and Fauna of Alpine Australasia: Ages and Origins'. (Ed. B.A. Barlow) pp. 63-81. (CSIRO. Australia).

Gibson, N. and Kirkpatrick, J.B. (1985a). Vegetation and flora associated with localised snow accumulation at Mount Field West, Tasmania. *Australian Journal of Ecology* **10**, 91-99.

Gibson, N. and Kirkpatrick, J.B. (1985b). A comparison of the cushion plant communities of New Zealand and Tasmania. *New Zealand Journal of Botany* **23**, 549-566.

Gill, A.M. (1993). Interplay of Victoria's flora with fire. In 'Flora of Victoria'. Volume one. (Eds. D.B. Foreman and N.G. Walsh) pp. 212-226. (National Herbarium of Victoria. Inkata Press. Melbourne).

Gilmour, C.A. and Crowden, R.K. and Koutoulis, A. (2000). Heat shock, smoke and darkness; partner cues in promoting seed germination in *Epacris tasmanica* (Epacridaceae). *Australian Journal of Botany* **48**, 603-609.

Glaser, P.H. (1992). Raised bogs in eastern North America - regional controls for species richness and floristic assemblages. *Journal of Ecology* **80**, 535-554.

Good, R.B. (1992). Kosciuszko Heritage - The Conservation Significance of Kosciuszko National Park. (National Parks and Wildlife Service and Surrey Beatty & Sons. Sydney).

Gore, A.J.P. (1983a). Ecosystems of the World (4a). Mires: Swamp, Bog, Fen and Moor. General studies. (Elsevier Scientific Publishing Company. Amsterdam).

Gore, A.J.P. (1983b). Ecosystems of the World (4b). Mires: Swamp, Bog, Fen and Moor. Regional Studies. (Elsevier Scientific Publishing Company. Amsterdam).

Gorham, E. (1991). Northern peatlands: role in the carbon cycle and probable responses to climatic warming. *Ecological Applications* **1**, 182-195.

Green, K. and Osborne, W.S. (1994). Wildlife of the Australian Snow Country. (Reed. Chatsworth, NSW).

Griffiths, T. (2001). Forests of Ash: An environmental history. (Cambridge University Press. United Kingdom).

Grime, J.P. (1979). Plant strategies and vegetation processes. (John Wiley. Chichester).

Grover, S.P.P. (2006). Carbon and water dynamics of peat soils in the Australian Alps. Unpublished PhD thesis, La Trobe University, Bundoora. Victoria.

Grover, S.P.P., McKenzie, B.M., Baldock, J.A. and Papst, W.A. (2005). Chemical characterisation of bog peat and dried peat of the Australian Alps. *Australian Journal of Soil Research* **43**, 1-9.

Grubb, P.J. (1977). The maintenance of species richness in plant communities: the importance of regeneration niche. *Biological Review* **52**, 107-145.

Gullen, P.K., Walsh, N.G. and Forbes, S.J. (1981). Vegetation of the Gippsland Lakes catchment. *Muelleria* **4**, 333-383.

Gunnarson, U. and Rydin, H. (2000). Nitrogen fertilisation reduces *Sphagnum* production in Swedish bogs. *New Phytologist* **147**, 527-537.

Hayward, P.M. and Clymo, R.S. (1982). Profiles of water content and pore size in *Sphagnum* and peat, and their relation to peat bog ecology. *Proceedings of the Royal Society of London B Biological Sciences* **215**, 299-325.

Hayward, P.M. and Clymo, R.S. (1983). The growth of *Sphagnum*: experiments on, and simulations of some effects of light flux and water table depth. *Journal of Ecology* **71**, 845-863.

Heinze, D.A., Broome, L.S. and Mansergh, I.M. (2004). A review of the ecology and conservation of the Mountain Pygmy Possum *Barramys parvus*. In 'The Biology of Australian Possums and Gliders'. (Eds. R. Golingay, S. Jackson) pp. 254-267. (Surrey Beatty & Sons. Sydney).

Helms, R. (1893). Report on the grazing leases of the Mount Kosciuszko plateau. *Agriculture Gazette of New South Wales* **4**, 530-531.

Hennessy, K. Lucas, C. Nichols, N., Bathols, J., Suppiah, R. and Ricketts, J. (2005). Climate change impacts on fire-weather in south-east Australia. (Australian Government Bureau of Meteorology, CSIRO Marine and Atmospheric Research, Bushfire CRC, Aspendale. Victoria).

Hogg, E.H., Lieffers, V.J. and Wein, R.W. (1992). Potential Carbon losses from peat profiles: effects of temperature, drought cycles and fire. *Ecological Applications* **2**, 298-306.

Holden, J. and Burt, T.P. (2003). Hydrological studies on blanket peat: the significance of the acrotelm - catotelm model. *Journal of Ecology* **91**, 86-102.

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics* **6**, 65-70.

Hope, G., Nanson, R. and Flett, I. (2009). The peat-forming mires of the Australian Capital Territory. Technical Report **19**. (Territory and Municipal Services Canberra).

Hope, G. and Southern, W. (1983). Organic deposits of the southern tablelands region, New South Wales. New South Wales Parks and Wildlife Service, Sydney (unpublished report).

Hope, G., Whinam, J. and Good, R. (2005). Methods and preliminary results of post-fire experimental trials of restoration techniques in the peatlands of Namadgi (ACT) and Kosciuszko National Parks (NSW). *Ecological Management and Restoration* **6** (3), 214-217.

Houlder, D.J. and Hutchinson, M.F., Nix, H.A. and McMahon, J.P. (2000). ANUCLIM user guide Version 5.0 In. (Centre of Resource and Environmental Studies, Australian National University. Canberra).

Howard, T.M. and Ashton, D.H. (1973). The distribution of *Nothofagus cunninghamii* rainforest. *Proceedings of the Royal Society of Victoria* **85**, 47-76.

Hunter, J.T. and Bell, D. (2007). Vegetation of montane bogs in east flowing catchments of northern New England, New South Wales. *Cunninghamia* **10**, 77-92.

Ingram, H.A.P. (1978). Soil layers in mires: function and terminology. *Journal of Soil Science* **29**, 224-227.

Ingram, H.A.P. (1983). Hydrology. In ‘Ecosystems of the World (4a). Mires: Swamp, Bog, Fen and Moor. General studies’. (Ed. A.J.P. Gore) pp.257-283. (Elsevier Scientific Publishing Company. Amsterdam).

Ingram, H.A.P. and Bragg, O.M. (1984). The diplotelmic mire: some hydrological consequences reviewed. In ‘7th International Peat Congress, Dublin’. pp 220-234 (Irish National Peat Committee).

Isbell, R.F. (1996). The Australian Soil Classification. (CSIRO Publishing, Melbourne).

Jackson, W.D. (1999a). The Tasmanian Environment. In ‘Vegetation of Tasmania’. (Eds J.B. Reid, R.S. Hill, M.J. Brown and M.J. Hovenden) pp.11-38. (Commonwealth of Australia).

Jarrad, F.C., Wahren, C-H., Williams, R.J. and Burgman, M.A. (2008). Impacts of experimental warming and fire on phenology of subalpine open-heath species. *Australian Journal of Botany* **56**, 617-629.

Johnson, D. (1974). The Alps at the Crossroads. (Victorian National Parks Association. Melbourne).

Johnson, E.A. (1977a). A multivariate analysis of the niches of plant populations in raised bogs I. Niche dimensions. *Canadian Journal of Botany* **55**, 1201-1210.

Johnson, J.B. and Steingraeber, D.A. (2003). The vegetation and ecological gradients of calcareous mires in South Park valley, Colorado. *Canadian Journal of Botany* **81**, 201-219.

Johnson, P.N. (2001). Vegetation recovery after fire on a southern New Zealand peatland. *New Zealand Journal of Botany* **39**, 251-267.

Joosten, H. and Clarke, D. (2002). Wise use of mires and peatlands: background and principles including a framework for decision making. (International Mire Conservation Group and International Peat Society. Finland).

Keith, D.A. (1997). Combined effects of heat shock, smoke and darkness on germination of *Epacris stuartii* Stapf., an endangered fire-prone Australian shrub. *Oecologia* **112**, 340-344.

Keith, D.A. (2004). Montane Bogs and Fens. In 'Ocean floors to desert dunes: the native vegetation of New South Wales and ACT'. (Department of Environment and Conservation (NSW). Hurstville).

Keith, D.A., McCaw, L.W. and Whelan, R.J. (2002). Fire regimes in Australian Heathlands and their effects on plants and animals. In 'Flammable Australia: The fire regimes and biodiversity of a continent'. (Eds R.A. Bradstock, J.E. Williams and M.A. Gill) pp. 199-237. (Cambridge University Press. United Kingdom).

Keith, D.A. and Myerscough, P.J. (1993). Floristics and soil relations of upland swamp vegetation near Sydney. *Australian Journal of Ecology* **18**, 325-344.

Kershaw, A.P. , McKenzie, G.M., Porch, N., Roberts, R.G., Brown, J., Heijnis, H., Orr, M.L., Jacobsen, G. and Newall, P.R. (2007). A high resolution record of vegetation and climate through the last glacial cycle from Caledonia Fen, southeastern highlands of Australia. *Journal of Quaternary Science* **22** (5), 481-500.

Kershaw, A.P. and Strickland, K.M. (1989). The development of alpine vegetation on the Australian mainland. In ' The Scientific Significance of the Australian Alps'. (Ed. R. Good) pp. 113-126 (Australian Academy of Science. Canberra).

Keuper, F., Dorrepaal, E., Van Bodegom, P.M., Aerts, R., Van Logtestijn, R.S.P., Callaghan, T.V. and Cornelissen, J.H.C. (2010). A race for space? How *Sphagnum fuscum* stabilizes vegetation composition during long-term climate manipulations. *Global Change Biology*, doi: 10.1111/j.1365-2486.2010.02377.x

Kirkpatrick, J.B. (1983). Treeless plant communities in the Tasmanian high country. *Proceedings of the Ecological Society of Australia* **12**, 61-77.

Kirkpatrick, J.B. (1989). The comparative ecology of mainland Australian and Tasmanian alpine vegetation. In ‘The Scientific Significance of the Australian Alps. (Ed. R. Good) pp. 127-142 (Australian Academy of Science. Canberra).

Kirkpatrick, J.B. (1997). Alpine Tasmania: An illustrated guide to the flora and vegetation. (Oxford University Press. United Kingdom).

Kirkpatrick, J.B. and Bridle, K.L. (1998). Environmental relationships of floristic variation in the alpine vegetation of south-eastern Australia. *Journal of Vegetation Science* **9**, 251-260.

Kirkpatrick, J.B. and Bridle, K.L. (1999). Environment and floristics of ten Australian alpine vegetation formations. *Australian Journal of Botany* **47**, 1-21.

Kirkpatrick, J.B. and Dickinson, K.J.M. (1984). The impact of fire on Tasmanian alpine vegetation and soils. *Australian Journal of Botany* **32**, 613-629.

Kirkpatrick, J.B. and Gibson, N. (1984). Dynamics of Tasmanian Bolster Heath String Fen. *Vegetatio* **58**, 71-78.

Kirkpatrick, J.B. and Nunez, M. (1980). Vegetation-radiation relationships in mountainous terrain: eucalypt dominated vegetation in the Risdon hills, Tasmania. *Journal of Biogeography* **7**, 197-208.

Kirkpatrick, J.B. and Wells, J.M. (1987). The vegetation of the Great Northern Plain, north-eastern Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **122**, 145-164.

Kleinebecker, T., Holzel, N. and Vogel, A. (2007). Gradients of continentality and moisture in South Patagonian ombrotrophic peatland vegetation. *Folia Geobotanica* **42**, 363-382.

Kleinebecker, T., Holzel, N. and Vogel, A. (2010). Patterns and gradients of diversity in South Patagonian ombrotrophic peatland bogs. *Austral Ecology* **35**, 1-12.

Kruskal, J.B. (1964). Non-metric multidimensional scaling: a numerical method. *Pyschometrika* **29**, 115-29.

Kuczera, G. (1987). Prediction of water-yield reductions following a bush-fire in Ash-mixed species Eucalypt forest. *Journal of Hydrology* **94**, 215-236.

Kuhry, P. (1994). The role of fire in the development of *Sphagnum*-dominated peatlands in western boreal Canada. *Journal of Ecology* **82**, 899-910.

Ladd, P.G. (1979a). Past and present vegetation on the Delegate River in the highlands of eastern Victoria I. Present vegetation. *Australian Journal of Botany* **27**, 167-184.

Ladd, P.G. (1979b). Past and present vegetation on the Delegate River in the highlands of eastern Victoria II. From 12,000 B.P. to the present. Australian Journal of Botany **27**, 185-202.

Lawrence, R.E. (1999). Vegetation changes on the Bogong High Plains from the 1850s to the 1950s. Proceedings of the Royal Society of Victoria **111** (1), Transactions.

LCC. (1973). Report on the Melbourne Study Area. (Government Printers. Melbourne).

LCC. (1977). Report on the alpine study area. (Government Printers. Melbourne).

Legg, C.T., Maltby, E. and Proctor, M.C.F. (1992). The Ecology of Severe Moorland Fire on the North York Moors: Seed Distribution and Seedling Establishment of *Calluna vulgaris*. Journal of Ecology **80**, 737-752.

Leigh, J.H., Wimbush, D.J., Wood, D.H., Holgate, M.D., Slee, A.V., Stanger, M.G. and Forrester, R.I. (1987). Effects of Rabbit Grazing and Fire on a Subalpine Environment I. Herbaceous and Shrubby Vegetation. *Australian Journal of Botany* **35**, 433-464.

Lindenmayer, D.B. (1996). Wildlife and woodchips: Leadbeaters possum - a test case for sustainable forestry. (University of New South Wales Press. Sydney).

Lindenmayer, D.B., Nix, H.A., McMahon, J.P., Hutchinson, M.F. and Taunton, M.T. (1991). The conservation of Leadbeaters possum, *Gymnobelideus leadbeateri* McCoy, a case study of the use of bioclimatic modelling. *Journal of Biogeography* **18**, 371-383.

Luke, R.H. and McArthur, A.G. (1978). Bushfires in Australia. (Australian Government Publishing Service. Canberra).

Mackay, A.W. and Tallis, J.H. (1996). Summit type blanket mire erosion in the forest of Bowland, Lancashire, U.K: predisposing factors and implications for conservation. *Biological Conservation* 76 (1), 31-44.

Mallen, P.J. (1986). Introduced vascular plants in the high altitude and high latitude areas of Australia with particular reference to the Kosciuszko alpine area. In ‘Flora and Fauna of Alpine Australasia’. (Ed. B.A. Barlow) pp. 249-260 (CSIRO. Melbourne).

Mallick, A.U., Gimingham, C.H. and Rahman, A.A. (1984). Ecological effects of heather burning I. Water infiltration, moisture retention and porosity of the soil surface. *Journal of Ecology* **72**, 767-76.

Malmer, N. (1986). Vegetational gradients in relation to environmental conditions in northwestern European mires. *Canadian Journal of Botany* **64**, 375-383.

Malmer, N., Albinsson, C., Svensson, B.M. and Wallen, B. (2003). Interferences between *Sphagnum* and vascular plants: effects on plant community structure and peat formation. *Oikos* **100**, 469-482.

Malmer, N., Horton, D.G. and Vitt, D.H. (1992). Element concentrations in mosses and surface waters of western Canadian mires relative to precipitation chemistry and hydrology. *Ecography* **15**, 114-128.

Mark, A.F., Johnson, P.F., Dickinson, K.J.M. and McGlone, M.S. (1995). Southern hemisphere patterned mires, with emphasis on southern New Zealand. *Journal of the Royal Society of New Zealand* **25**, 23-54.

Martin, A.R.H. (1986). Late glacial and alpine pollen diagrams from the Koscuiszko National Park, New South Wales, Australia. *Review of Palaeobotany and Palynology* **47**, 367-409.

Martin, A.R.H. (1999). Pollen analysis of Digger's Creek Bog, Kosciuszko National Park: Vegetation history and tree-line change. *Australian Journal of Botany* **47**, 725-44.

McCarthy, G.J. and Tolhurst, K.G. (2000). Determination of sustainable fire-regimes in the Victorian Alps using plant vital attributes. (Centre for Forest Tree Technology. Report no. **31**. Department of Natural Resources and Environment. Victoria).

McDougall, K.L. (1982). The alpine vegetation of the Bogong High Plains. (Environmental studies publication no. **357**. Ministry of Conservation. Melbourne).

McDougall, K.L. (1989). The Effect of Excluding Cattle from a Mossbed on the Bogong High Plains, Victoria. (Arthur Rylah Institute for Environmental Research. Technical Series Report No. **95**. Department of Conservation, Forests and Lands. Melbourne).

McDougall, K.L. (1998). The alpine flora of Victoria. *Proceedings of the Royal Society of Victoria.* **110**.

McDougall, K.L. (2001). Growth rates of Sphagnum (*Sphagnum cristatum*) in a Victorian subalpine bog before and after harvesting. *Ecological Management and Restoration* **2** (2), 152-54.

McDougall, K.L. (2007). Grazing and fire in two subalpine peatlands. *Australian Journal of Botany* **55**, 42-47.

McDougall, K.L., Morgan, J.W., Walsh, N.G. and Williams, R.J. (2005). Plant invasions in treeless vegetation of the Australian Alps. *Perspectives in plant ecology, evolution and systematics* **7**, 159-171.

McDougall, K.L. and Walsh, N.G. (2007). Treeless vegetation of the Australian Alps. *Cunninghamia* **10** (1), 1-57.

McGlone, M.S., Moar, M.S. and Meurk, C.D. (1997). Growth and vegetation history of alpine mires on the Old Man Range, Central Otago, New Zealand. Arctic and Alpine Research **29** (1), 32-44.

McGlone, M.S. and Wilmshurst, J.M. (1999). A holocene record of climate, vegetation change and peat bog development, east Otago, South Island, New Zealand. *Journal of Quaternary Science* **14** (3), 239-254.

McKenzie, M.G. (1997). The late Quaternary vegetation history of the south-central highlands of Victoria, Australia I. Sites above 900 m. *Australian Journal of Ecology* **22**, 19-36.
McKenzie, M.G. (2002). The late Quaternary vegetation history of the south-central highlands of Victoria, Australia I. Sites below 900 m. *Austral Ecology* **27**, 32-54.

McVean, D.N. (1969). Alpine vegetation of the Central Snowy Mountains of New South Wales. *Journal of Ecology* **57**, 67-86.

Menadue, Y. and Crowden, R.K. (1995). Two new species of Epacridaceae for Victoria *Muelleria* **8** (3), 317-21.

Miller, G.R. and Cummins, R.P. (2003). Soil seedbanks of woodland, heathland, grassland, mire and montane communities, Cairngorm Mountains, Scotland. *Plant Ecology* **168**, 255-266.

Millington, R.J. (1954) Sphagnum bogs of the New England Plateau, New South Wales. *Journal of Ecology* **42**, 328-344.

Minchin, P.R. (1987). An evaluation of the relative robustness of techniques for ecological ordination. *Vegetatio* **69**, 89-107.

Moore, D.M. (1979). Southern oceanic wet heathlands (including magellanic moorland). In ‘Ecosystems of the World (9a). Heathlands and related shrublands. Descriptive studies’. (Ed. R.L. Specht) pp. 489-496. (Elsevier Scientific Publishing Company. Amsterdam).

Moore, P.D. and Bellamy, D.J. (1973). Peatlands. (Elek Science. London).

Moore, T.R., Roulet, N.T. and Waddington, J.M. (1998). Uncertainty in predicting the effect of climatic change on the carbon cycling of Canadian peatlands. *Climate change* **40**, 229-245.

Morgan, J.W. (2000). Orange Hawkweed *Hieracium auranticum*: a new naturalised species in alpine Australia. *The Victorian Naturalist* **117**, 50-51.

Morgan, S.W., Kirkpatrick, J.B. and di Folco, M. (2010). Wind-controlled linear patterning and cyclic succession in Tasmanian Sphagnum mires. *Journal of Ecology* doi: 10.1111/j.1365-2745.2009.01637.x

Morris, P.F. (1929). Ecology of Marysville and Lake Mountain. *The Victorian Naturalist* **46**, 34-42.

National Climate Centre (2006a). An exceptionally dry decade in parts of southern and eastern Australia: October 1996 - September 2006. Bureau of Meterology. Special Climate Statement no. **9**.

National Climate Centre. (2006b). Climate conditions preceeding the December 2006 south-east Australian bushfires. Bureau of Meterology. Special Climate Statement no. **10**.

Newnham, R.M., de Lange, P.J., Lowe, D.J. (1995). Holocene vegetation, climate and history of a raised bog complex, northern New Zealand based on palynology, plant macrofossils and tephrochronology. *The Holocene* **5**, 267-82.

Noble, I.R. and Slatyer, R.O. (1980). The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. *Vegetatio* **43**, 5-21.

Noble, I.R. and Slatyer, R.O. (1981). Concepts and models of succession in vascular plant communities subject to recurrent fire. In ‘Fire and the Australian Biota’. (Eds. A.M. Gill, R.H. Groves, and I.R. Noble) pp. 311-335. (Australian Academy of Science. Canberra).

Norton, D.A. and de Lange, P.J. (2003). Fire and vegetation in a temperate peat bog: implications for the management of a threatened species. *Conservation Biology* **17** (1), 138-148.

Ohlson, M., Okland, R.H., Nordbakken, J-F. and Dahlberg, B. (2001). Fatal interactions between Scots pine and Sphagnum mosses in bog ecosystems. *Oikos* **94**, 425-432.

Ollier, C.D. and Wyborn, D. (1989). Geology of Alpine Australia. In ‘The Scientific Significance of the Australian Alps. (Ed. R. Good) pp. 35-53 (Australian Academy of Science. Canberra).

Overpeck, J.T., Rind, D. and Goldberg, R. (1990). Climate induced changes in forest disturbance and vegetation. Nature **343**, 51-3.

Page, S.E., Siegert, F. Rieley, J.O., Boehm, H-D.V., Jaya, A. & Limin, S. (2002). The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature* **420**, 61-65.

Parsons, R.F. and Gibson, N. (2009). The cushion plants of lowland southern Australia. *Cunninghamia* **11** (2), 177-184.

Pausas, J.G. and Bradstock, R.A. (2007). Fire persistence traits of plants along a productivity and disturbance gradient in mediterranean shrublands of south-east Australia. *Global Ecology and Biogeography* **16**, 330-340.

Pellerin, S. and Lavoie, C. (2000). Peatland fragments of southern Quebec: recent evolution of their structure. *Canadian Journal of Botany* **78**, 255-265.

Peterson, J.A. (1971). The equivocal extent of glaciation in the south-eastern uplands of Australia. *Proceedings of the Royal Society of Victoria* **84**, 207-212.

Pisano, E. (1983). The Magellanic tundra complex. In 'Ecosystems of the World (4b). Mires: Swamp, Bog, Fen and Moor. Regional studies'. (Ed. A.J.P. Gore) pp. 295-329. (Elsevier Scientific Publishing Company. Amsterdam).

Pitkanen, A., Turenen, J. and Tolonen, K. (1999). The role of fire in the carbon dynamics of a mire, eastern Finland. *The Holocene* **9** (4), 453-62.

Pizzey, G. and Knight, K. (1997). Field Guide to the Birds of Australia. (Harper-Collins Publishers. Sydney).

Poulton, M. (2001). Willow woes. *Parkwatch* **207**. (Victorian National Parks Association. Melbourne).

Price, J.S. and Whitehead, G.S. (2004). The influence of past and present hydrological conditions on *Sphagnum* recolonisation and succession in a block-cut bog, Quebec. *Hydrological Processes* **18**, 315-328.

Proctor, M.C.F. (1994). Seasonal and shorter-term changes in surface water chemistry on four English ombrogenous bogs. *Journal of Ecology* **82**, 597-610.

Quinn, G., Burgman, M. and Carey, J. (2003). Multidimensional scaling. Melbourne University post-graduate lecture notes.

Quinn, G. and Keough, M.J. (2002). Experimental design and data analysis for biologists. (Cambridge University Press. United Kingdom).

Rapson, G.L., Sykes, M.T., Lee, W.G., Hewitt, A.E., Agnew, A.D.Q. and Bastow Wilson, J. (2006). Subalpine gully-head ribbon fens of the Lammerlaw and Lammermoor Ranges, Otago, New Zealand. *New Zealand Journal of Botany*. **44**, 351-375.

Ratcliffe, D.A. (1964). Montane Mires and Bogs. In 'The Vegetation of Scotland'. (Ed. J.H. Burnett) pp. 536-558. (Oliver and Boyd Ltd. Edinburgh).

Ratkowsky, D.A. and Ratkowsky, A.V. (1976). Changes in the abundance of the vascular plants of the Mt Wellington Range, Tasmania, following a severe fire. *Papers and proceedings of the Royal Society of Tasmania* **110**, 63-90.

Read, D.J. (1996). The structure and function of the ericoid mycorrhizal root. *Annals of Botany* **77**, 365-374.

Robinson, S.D. and Moore, T.R. (2000). The influence of permafrost and fire upon carbon accumulation in high boreal peatlands, North-West Territories, Canada. *Arctic, Antarctic and Alpine Research* **32** (2), 155-166.

Robroek, B.J.M. and Limpens, J., Breeuwer, A. and Schouten, M.G.C. (2007). Effects of water level and temperature on performance of four Sphagnum mosses. *Plant Ecology*. **190**, 97-100.

Rosengren, N. and Peterson, J.A. (1989). The heritage values and the geological and geomorphological significance of the Australian alpine zone. In ‘The Scientific Significance of the Australian Alps. (Ed. R. Good) pp. 187-204 (Australian Academy of Science. Canberra).

Rowe, R.K. (1967). A study of the land in the Victorian catchment of Lake Hume. (Soil Conservation Authority. Victoria).

Rowe, R.K. and Downes, R.G. (1960). Reconnaisance survey of the ecology and land-use in the catchment of Glenmaggie Reservoir. (Soil Conservation Authority. Victoria).

Ruah, W. (1939). Uber polsterformigen Wuchs. *Nova Acta Leopoldina* **7**, 267-508.

Rundle, A.S. (1977). A study of the land in the catchment of Lake Eildon. (Soil Conservation Authority. Victoria).

Ruuhijärvi, R. (1983). Finish mire types and their regional distribution. In ‘Ecosystems of the World (4b). Mires: Swamp, Bog, Fen and Moor. Regional studies’. (Ed. A.J.P. Gore) pp.47-67. (Elsevier Scientific Publishing Company. Amsterdam).

Rydin, H. (1985). Effect of water level on dessication of *Sphagnum* in relation to surrounding Sphagna. *Oikos* **45**, 374-379.

Rydin, H. and Jeglum, J. (2006). The Biology of Peatlands. (Oxford University Press. United Kingdom).

Shannon, J.M. (2003). Floristic composition and vegetation patterns in *Sphagnum*-dominated peatlands in the Central Highlands region, Victoria. Unpublished honours thesis. La Trobe University, Melbourne.

Shannon, J.M. and Morgan, J.W. (2007). Floristic variation in *Sphagnum*-dominated peatland communities of the Central Highlands, Victoria. *Cunninghamia* **10** (1), 59-77.

Sikora, L.J. and Keeney, D.R. (1983). Further aspects of soil chemistry under anaerobic conditions. In ‘Ecosystems of the World (4a). Mires: Swamp, Bog, Fen and Moor. General studies’. (Ed. A.J.P. Gore) pp. 247-256. (Elsevier Scientific Publishing Company. Amsterdam).

Silvola, J., Alm, J., Alholm, U., Nykanen, H. and Martikainen, P.J. (1996). Carbon dioxide fluxes from peat in boreal mires under varying temperature and moisture conditions. *Journal of Ecology* **84**, 219-228.

Sjors, H. (1948). Myrvegetation; Bergslagen. (Mire vegetation in Bergslagen, Sweden). *Acta Phytogeographica Suecica* **21**, 1-299.

Sjors, H. (1950). On the relation between vegetation and electrolytes in northern Swedish mire waters. *Oikos* **2**, 241-258.

Sjors, H. (1983). Mires of Sweden. In ‘Ecosystems of the World (4b). Mires: Swamp, Bog, Fen and Moor. Regional studies’. (Ed. A.J.P. Gore) pp. 69-94. (Elsevier Scientific Publishing Company. Amsterdam).

Slatyer, R.O. (1989). Alpine and valley bottom treelines. In ‘The scientific significance of the Australian Alps. (Ed. R. Good) pp. 169-184 (Australian Academy of Science. Canberra).

Soeterboek, C. (2008). Folk-Ecology' in the Australian Alps: Forest Cattlemen and the Royal Commissions of 1939 and 1946. *Environment and History* **14**, 241-263.

Specht, R.L. (1970). Vegetation. In ‘The Australian Environment’. Fourth edition. (Ed. G.W. Leeper) (CSIRO and Melbourne University Press. Melbourne).

Specht, R.L. (1979). The sclerophyllous (heath) vegetation of Australia: the eastern and central states. In ‘Ecosystems of the World (9a). Heathlands and related shrublands. Descriptive studies’. (Ed. R.L.Specht) pp. 125-210. (Elsevier Scientific Publishing Company. Amsterdam).

Specht, R.L. (1981). Responses to fires in heathlands and related shrublands. In 'Fire and the Australian Biota'. (Eds. A.M. Gill, R.H. Groves, and I.R. Noble) pp. 395-415. (Australian Academy of Science. Canberra).

Stephenson, H. (1980). Cattlemen and huts of the high plains. Graphic books (Armadale, Victoria. Australia).

Strack, M., Waller, M.F. and Waddington, J.M. (2006). Sedge succession and peatland methane dynamics: A potential feedback to climate change. *Ecosystems* **9**, 278-287.

Strickland, K. and Strickland, P. (1997). Subalpine flora of the Baw Baw Plateau, Victoria. (Kareelah. Balnarring).

Sturm, M., Racine, C. and Tape, K. (2001). Climate change - Increasing shrub abundance in the Arctic. *Nature* **411**, 546-547.

Sturm, M., Schimel, J., Michaelson, G., Welker, J.M., Oberbauer, S.F., Liston, G.E., Fahnestock, J. and Romanovsky, V.E. (2005). Winter biological processes could help convert Arctic tundra to shrubland. *Bioscience* **55** (1), 17-26.

Suding, K.N., Gross, K.L. and Houseman, G.R. (2004). Alternative states and positive feedbacks in restoration ecology. *Trends in Ecology and Evolution* **19** (1), 46-53.

Sylvester, E. (2009). Ionic regulation in an alpine peatland in the Bogong High Plains, Victoria, Australia. *Environmental Chemistry* **6**, 421-431.

Talent, J.A. (1965). Geomorphic forms and processes in the highlands of eastern Victoria. *Proceedings of the Royal Society of Victoria* **78**, 119-135.

Tallis, J.H. (1983). Changes in wetland communities. In 'Ecosystems of the World (4a). Mires: Swamp, Bog, Fen and Moor. General studies'. (Ed. A.J.P. Gore) pp. 311-347. (Elsevier Scientific Publishing Company. Amsterdam).

Tape, K., Sturm, M. and Racine, C. (2006). The evidence for shrub expansion in Northern Alaska and the Pan-Arctic. *Global Change Biology* **12**, 686-702.

Thiele, K.R. and Prober, S.M. (1999). Assessment of impacts of feral horses (*Equus callabus*) in the Australian Alps. Part 2. Outline of experimental monitoring programs for determining impacts of feral horses on flora and streams in the Cobberas-Tingaringy unit of the Alpine National Park. Report to the Australian Alps Liaison Committee.

Thomas, P.B., Morris, F.C. and Auld, T.D. (2003). Interactive effects of heat shock and smoke on germination of nine species forming soil seed banks within the Sydney region. *Austral Ecology* **28**, 674-683.

Thompson, K. and Hamilton, A.C. (1983). Peatlands and Swamps of the African continent. In 'Ecosystems of the World (4b). Mires: Swamp, Bog, Fen and Moor. Regional studies'. (Ed. A.J.P. Gore) pp. 331-374. (Elsevier Scientific Publishing Company. Amsterdam).

Timmins, S.M. (1992). Wetland vegetation recovery after fire: Eweburn Bog, Te Anau, New Zealand. *New Zealand Journal of Botany* **30**, 383-99.

Tolsma, A.D. and Shannon, J.M. (2007). Evaluating the rehabilitation needs of mossbeds in the Alpine and Mt Buffalo National Parks after the 2006/07 fires. Unpublished report to Parks Victoria. Arthur Rylah Institute for Environmental Research and La Trobe University.

Tolsma, A.D. and Shannon, J.M. (2009). An assessment of the management needs of mossbeds at Lake Mountain and the Baw Baw Plateau. Unpublished report to Parks Victoria. Arthur Rylah Institute for Environmental Research.

Turunen, J., Tomppo, E., Tolonen, K., and Reinikainen, A. (2002). Estimating carbon accumulation rates of undrained mires in Finland - application to boreal and subantarctic regions. *Holocene* **12**, 69-80.

Updegraff, K. and Bridgham, S.D., Pastor, J., Weisampel, P. and Harth, C. (2001). Response of CO2 and CH4 emissions from peatlands to warming and water table manipulations. *Ecological Applications* **11**, 311-326.

Van Breemen, N. (1995). How *Sphagnum* bogs down other plants. *Trends in Ecology and Evolution* **10** (7), 270-75.

Van Rees, H. (1984). Behaviour and diet of free-ranging cattle on the Bogong High Plains, Victoria. (Environmental Studies Report No. **409**. Department of Conservation, forests and Lands. Victoria).

Van Seters, T.E. and Price, J.S (2001). The impact of peat harvesting and natural regeneration on the water-balance of an abandoned cut-over bog, Quebec. *Hydrological Processes* **15**, 233-248.

Van Seters, T.E. and Price, J.S. (2002). Towards a conceptual model of hydrological change on an abandoned cut-over bog, Quebec. *Hydrological Processes* **16**, 1965-1981.

Verry, E.S. (1984). Microtopography and water table fluctuation in a *Sphagnum* mire. In ‘Proceedings of the 7th International Peat Congress, Dublin 1984’. Volume 2, pp. 11-31.

Verry, E.S. (1997). Hydrological processes of natural, northern forested wetlands. In ‘Northern forested wetlands: Ecology and management’. (Eds C.C. Trettin, M.F. Jurgensen, D.F. Grigal, M.R. Gale and J.K. Jeglum) pp. 163-188. (CRC Press. Boca Raton).

Vitt, D.H. and Bayley, S. (1984). The vegetation and water chemistry of four oligotrophic basin mires in northwestern Ontario. *Canadian Journal of Botany* **62**, 1485-1500.

Vitt, D.H., Halsey, L.A. and Zoltai, S.C. (1994). The bog landforms of continental western Canada in relation to climate and permafrost patterns. *Arctic and Alpine Research* **26**, 1-13.

Vitt, D.H., Horton, D.G., Slack, N.G. and Malmer, N. (1990). *Sphagnum* dominated peatlands of the hyper-oceanic British Columia coast: Patterns in surface water chemistry and vegetation. *Canadian Journal of Forest Research* **20**, 696-711.

Vitt, D.H. and Kuhry, P. (1992). Changes in moss-dominated wetland ecosystems. In ‘Bryophytes and Lichens in a changing environment’. (Eds J.W. Bates and A.M. Farmer) pp. 178-210. (Clarendon Press. Oxford).

Wagner, D.J. and Titus, J.E. (1984). Comparative dessication tolerance of two *Sphagnum* mosses. *Oecologia* **62**, 182-187.

Wahren, C-H.A. (1992a). Inspection of mossbeds near McNamara’s Hut, Bogong High Plains, April 1992. Report to Department of Conservation and Environment, Victoria.

Wahren, C-H.A. (1992b). Vegetation monitoring on the Dargo High Plains, report on reconnaissance April 1992: proposals for future work. Report to Department of Conservation and Environment, Victoria.

Wahren, C-H.A. (1997). Vegetation dynamics on the Bogong High Plains. Unpublished PhD thesis, Monash University, Clayton, Victoria.

Wahren, C-H.A. and Papst, W.A. (1999). Post-fire regeneration in subalpine vegetation on Holmes and Wellington Plains. Report to the Australian Alps Liaison Committee. December, 1999.

Wahren, C-H.A., Papst, W.A. and Williams, R.J. (1999a). Post-fire regeneration in Victorian alpine and subalpine vegetation. In ‘Australian Bushfire Conference, Albury, July 1999’.

Wahren, C-H.A., Papst, W.A. and Williams, R.J. (2001b). Early post-fire regeneration in subalpine heathland and grassland in the Victorian Alpine National Park, south-eastern Australia. *Austral Ecology* **26**, 670-679.

Wahren, C-H.A. and Walsh, N.G. (2000). Impact of fire in treeless subalpine vegetation at Mt Buffalo National Park, 1982-99. Report to the Australian Alps Liaison Committee. March, 2000.

Wahren, C-H.A., Williams, R.J. and Papst, W.A. (1999b). Alpine and subalpine wetland vegetation on the Bogong High Plains, south-eastern Australia. *Australian Journal of Botany* **47**, 165-88.

Wahren, C-H.A., Williams, R.J. and Papst, W.A. (2001a). Vegetation change and ecological processes in alpine and subalpine *Sphagnum* bogs of the Bogong High Plains, Victoria, Australia. *Arctic, Antarctic and Alpine Research* **33** (3), 357-68.

Walker, D. and Walker, P.M. (1961). Stratigraphic evidence of regeneration in some Irish Bogs. *Journal of Ecology* **49**, 169-185.

Walker, M.D., Wahren, C-H., Hollister, R.D., Henry, G.H.R. et al. (2006). Plant community responses to experimental warming across the tundra biome. *Proceedings of the National Academy of Sciences of the United States of America* **103**, 1342-1346.

Walker, S., Steel, J.B., Rapson, G.L., Roxburgh, S.H., King, W.M., Watkins, A.J., Myers, T.E., Keogh, J.A., McQueen, A.A.M., and Wilson, J.B. (2001). A *Chionochloa* / *Sphagnum* / cushion valley bog in east Otago, New Zealand. *New Zealand Journal of Ecology* **25** (1), 39-52.

Walsh, N.G., Barley, R.H. and Gullan, P.K. (1984). The alpine vegetation of Victoria excluding the Bogong High Plains region. (Environmental studies publication no. 376. Victorian Department of Conservation, Forests and Lands. Melbourne).

Walsh, N.G. and McDougall, K.L. (2004). Progress in the recovery of the flora of treeless subalpine vegetation in Kosciuszko National Park after the 2003 fires. *Cunninghamia* **8** (4), 439-452.

Walsh, N.G. and Stajsic, V. (2007). A Census of the Vascular Plants of Victoria. Eighth edition (National Herbarium of Victoria, Royal Botanic Gardens. Melbourne).

Walter, C. (1899). A trip to Victorian alps. *Victorian Naturalist* **16**, 81-87.

Walter, M.J. (2002). The population ecology of wild horses in the Australian Alps. Doctoral thesis. University of Canberra. Canberra.

Wardle, P. (1971). An explanation for alpine timberline. *New Zealand Journal of Botany* **9**, 371-402.

Watt, A.S. (1947). Pattern and process in the plant community. *Journal of Ecology* **35**, 1-22.

Wein, R.W. (1983). Fire behaviour and ecological effects in organic terrain. In ' The role of fire in northern circum-polar ecosystems'. (Eds R.W. Wein and D.A. Maclean) pp. 81-95. (John Wiley. New York).

Weltzin, J.F., Pastor, J., Harth, C., Bridgham, S.D., Updegraff, K., and Chapin, C.T. (2000). Response of bog and fen plant communities to warming and water-table manipulations. *Ecology* **81**, 3464-3478.

Western, A., Rutherford, I., Siriwardena, L., Lawrence, R., Ghadirian, P., Coates, F. and White, M. (2009). The geography and hydrology of high country peatlands in Victoria. Part 2: The influence of peatlands on catchment hydrology. (Arthur Rylah Institute for Environmental Research. Technical Report No. **174**. Department of Sustainability and Environment. Victoria).

Western, A., Siriwardena, L., Lawrence, R. and Rutherford, I. (2008). Sponges or wicks? What is the role of bogs in hydrological response on the Bogong High Plains? Water Down Under 2008 conference (La Trobe University. Wodonga).

Wheeler, B.D. and Proctor, M.C.F. (2000). Ecological gradients, subdivisions and terminology of north-west European mires. *Journal of Ecology* **88**, 187-203.

Wheton, P.H. and Haylock, M.R. and Galloway, R. (1996). Climate change and snow cover duration in the Australian Alps. *Climatic Change* **32**, 447-479.

Whinam, J., Barmuta, L.A. and Chilcott, N. (2001). Floristic description and environmental relationships of Tasmanian *Sphagnum* communities and their conservation management. *Australian Journal of Botany* **49**, 673-85.

Whinam, J. and Buxton, R. (1997). *Sphagnum* peatlands of Australasia: an assessment of harvesting sustainability. *Biological Conservation* **82** (1), 21-29.

Whinam, J., Chilcott, N. and Morgan, J.W. (2003a). Floristic composition and environmental relationships of *Sphagnum*-dominated communities in Victoria. *Cunninghamia* **8**(2), 162-174.

Whinam, J., Eberhard, S., Kirkpatrick, J. and Moscal, T. (1989). Ecology and conservation of Tasmanian *Sphagnum* peatlands. Tasmanian Conservation Trust. Hobart.

Whinam, J. and Hope, G. (2005). The Peatlands of the Australasian Region. *Stafia* **85**, 397-434.

Whinam, J., Hope, G.S., Clarkson, B.R., Buxton, R., Alspatch, P.A. and Adam, P. (2003b). *Sphagnum* in peatlands of Australasia: The resource, its utilisation and management. *Wetlands Ecology and Management* **11**, 37-49.

Whinam, J. and Kirkpatrick, J.B. (1995). Successional sequences in two Tasmanian valley *Sphagnum* peatlands. *Journal of Vegetation Science* **6**, 675-82.

Williams, R.J. (1987). Patterns of air temperature and accumulation of snow in subalpine heathland and grassland communities on the Bogong High Plains, Victoria. *Australian Journal of Ecology* **12**, 153-63.

Williams, R.J. (1990). Cattle grazing within subalpine heathland and grassland communities on the Bogong High Plains: disturbance, regeneration and the shrub-grass balance. *Proceedings of the Ecological Society of Australia* **16**, 255-265.

Williams, R.J. (1992). Gap dynamics in subalpine heathland and grassland vegetation in south-eastern Australia. *Journal of Ecology* **80**, 343-352.

Williams, R.J. and Ashton, D.H. (1987a). The composition, structure and distribution of heathland and grassland communities in the subalpine tract of the Bogong High Plains, Victoria. *Australian Journal of Ecology* **12**, 57-71.

Williams, R.J. and Ashton, D.H. (1987b). The effects of Disturbance and Grazing by Cattle on the Dynamics of Heathland and Grassland Communities on the Bogong High Plains, Victoria. *Australian Journal of Botany* **35**, 413-31.

Williams, R.J. and Costin, A.B. (1994). Alpine and subalpine vegetation. In ‘Australian Vegetation’. Second edition. (Ed. R.H. Groves). (Cambridge University Press. Great Britain).

Williams, R.J., Wahren, C-H., Bradstock, R.A. and Muller, W.J. (2006). Does alpine grazing reduce blazing? A landscape test of a widely held hypothesis. *Austral Ecology* **31**, 925-936.

Williams, R.J., Wahren, C-H., Tolsma, A.D., Sanecki, G.M., Papst, W.A., Myers, B.A., McDougall, K.L., Heinze, D.A. and Green, K. (2008). Large fires in Australian alpine landscapes: their part in the historical fire regime and their impacts on alpine biodiversity. *International Journal of Wildland Fire* **9** (2), 145-153.

Willis, J.H. (1945). Toorongo subalpine flora. *Victorian Naturalist* **61**, 176-180.

Willis, J.H. and Cohn, H.M. (1993). Botanical exploration of Victoria. In 'Flora of Victoria'. Volume One. (Eds D.B. Foreman and N.G. Walsh) pp. 61-78. (National Herbarium of Victoria. Inkata Press. Melbourne).

Wills, T.J. and Read, J. (2002). Effects of heat and smoke on germination of soil stored seed in a south-eastern Australian sand heathland. *Australian Journal of Botany* **50**, 197-206.

Wills, T.J. and Read, J. (2007). Soil seed bank dynamics in post-fire heathland succession in south-eastern Australia. *Plant Ecology*. **190**, 1-12.

Wilson, J.B. and Agnew, A.D.Q. (1993). Positive feed-back switches in plant communities. *Advances in Ecological Research* **23**, 263-336.

Wimbush, D.J. (1970). Hydrological studies on *Sphagnum* bogs in the Snowy Mountains. Masters thesis, University of New South Wales.

Wimbush, D.J. and Costin, A.B. (1979). Trends in vegetation at Kosciuszko. II. Subalpine range transects, 1959-1978. *Australian Journal of Botany* **27**, 789-831.

Zylstra, P. (2006). Fire History of the Australian Alps: Pre-history to 2003. (Australian Alps Liaison Committee).