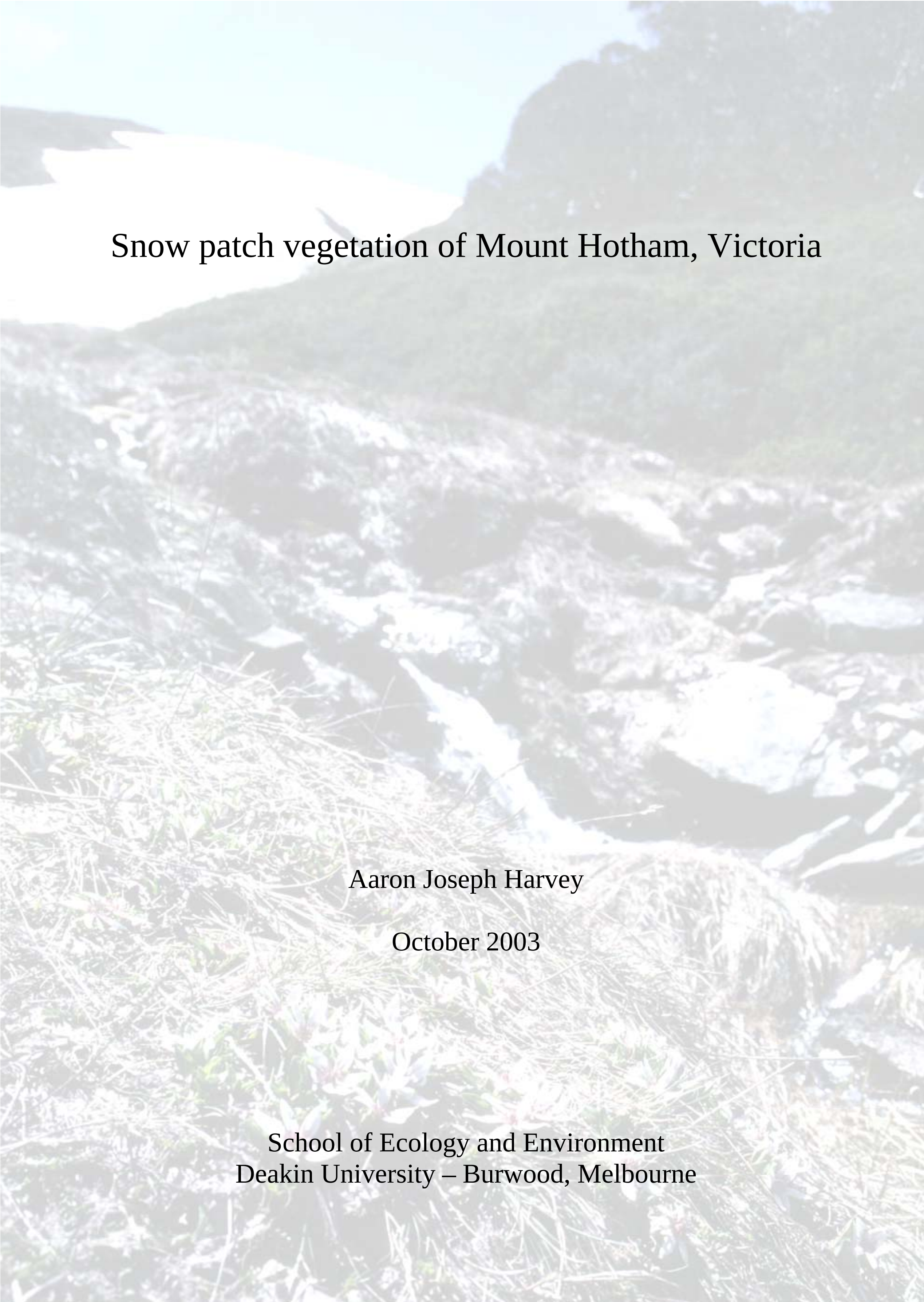

Snow patch vegetation of Mount Hotham, Victoria

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October 2003

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STATEMENT OF RESPONSIBILITY

The work described in this thesis is submitted for the Bachelor of Science (Honours), at Deakin University.

This thesis is a result of research undertaken by Aaron Joseph Harvey alone, except where otherwise acknowledged. No part of this work has been submitted for any other award to any other university or institution.

Signed………………………………………… Date……../…..…/………

ACKNOWLEDGEMENTS

First and foremost I would like to thank my wife Melissa for her kind and generous support over the last 16 months. Her assistance and encouragement has been invaluable. My parents, Dennis and Jan have also been unwavering in their support and encouragement.

I would also like to thank my supervisor Dr. John Jenkin for his thoughtful and considered comments and input throughout the project; Matt Dell for discussions on plant and community classifications and statistical techniques and theory. As well as Dr. Dianne Simmons for assistance with the statistical package PATN and John Reid from the Royal Botanic Gardens Melbourne for assistance and access to the Victorian reference collection held within the Melbourne Herbarium.

Finally, this project would not have been possible without the assistance and support of the Mt Hotham Alpine Resort Management Board, specifically, Tom Pelly and Simon 'Reggie' Jones for allowing access to the Mt Hotham Alpine Resort, accommodation and general office support.

Plant collection and survey work within the Mt Hotham Alpine Resort was conducted with permission from the Mt Hotham Alpine Resort Management Board, Parks Victoria and the Department of Sustainability and Environment under permit number 10002184.

ABSTRACT

The snow patch vegetation of the Mt Hotham Alpine Resort was studied to determine its floristic composition, identify floristic and physiognomic units and quantify selected environmental variables.

A total of 133 vascular plant taxa were recorded in the study. This comprised nine introduced taxa, 32 rare and eight vulnerable taxa in Victoria and one rare taxon and one vulnerable taxon in Australia. Ordination of the floristic data divided the snow patch vegetation into three groups: alpine snow patches, subalpine snow patches and *Caltha introloba* herbfield. Alpine snow patches were the largest group surveyed and included characteristic taxa such as *Poa fawcettiae*, *Luzula acutifolia* subsp. *acutifolia*, *Rytidosperma nudiflorum*, *Celmisia asteliifolia* and *Aciphylla glacialis*. Subalpine snow patches had a higher mean cover of *Poa hothamensis* var. *hothamensis* and shrub taxa. *Caltha introloba* herbfield was characterised by the presence of *Caltha introloba*, *Carpha nivicola, Drosera arcturi* and *Oreobolus distichus*. Two-way table analysis of the floristic data revealed four distinct floristic communities within alpine snow patches; *Austrodanthonia alpicola / Brachyscome nivalis* herbfield, *Celmisia* herbfield, mixed grassland and *Poa fawcettiae* grassland.

Based on the results from this study a proposed typology for the classification of snow patch vegetation has been described. This typology recognises alpine snow patch, subalpine snow patch and *Caltha introloba* herbfield at the Ecological Vegetation Class level. It is recommended that the Mt Hotham Alpine Resort Management Board adopt this typology and apply it to snow patch vegetation within the Resort, enhancing conservation management actions and protection of snow patch vegetation at Mt Hotham.

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1. INTRODUCTION

The alpine flora of Victoria has been well studied with numerous reports outlining and describing the vegetation of the Bogong High Plains (see Costin 1957a; Carr and Turner 1959a; McDougall 1982; Williams 1987; Williams and Ashton 1987; Wahren 1997; Wahren *et al.* 1994; Williams and Costin 1994; Wahren *et al.* 1999; Wahren *et al.* 2001a; Wahren *et al.* 2001b) and other alpine areas (see Scott 1974; Walsh *et al.* 1984; Walsh *et al.* 1986; Strickland and Strickland 1997). An exception to this is the snow patch vegetation (see description below) of the Bogong High Plains, which has received only minor attention (McDougall 1982; Wahren 1997; Venn 2001; Wahren *et al.* 2001a).

In light of this discrepancy and the increasing land-use pressures facing the Mt Hotham alpine environment, this study was designed to clarify the description and classification of snow patch vegetation within the Mt Hotham Alpine Resort.

1.1 Snow patch research and ecology

Snow patch research originated in Europe with numerous botanists (eg. Wahlenberg 1812; Kerner 1863; Christ 1892; Stebler and Schroter 1892; Engler 1901; Brockmann 1907; Arber 1910; Rübel 1912; Braun-Blanquet 1913; and others cited in Harshberger 1929) studying the flora of snow patches in the Swiss Alps (Harshberger 1929). Harshberger (1929) credits Wahlenberg (1812) as being the first botanist to describe small depressions and valleys in which snow persists longer than the surrounding area and in 1835, Heer named these areas 'Schneetälchen' (Harshberger 1929).

Harshberger (1929) was the first North American scientist to publish preliminary work on the snow patches of America, focusing on the snow patch plants of the White Mountains, Glacier National Park and Mount Rainer. This work was aimed at arousing interest in the study of snow patches by American botanists and ecologists (Harshberger 1929).

In 1932 Braun-blanquet published his world renowned Pflanzensoziologie (Plant Sociology) and divided alpine plants into two types:

1. Chionophilous species – which favour snow and are found only in areas where they are covered by late season snow (eg. snow patches); and
2. Chionophobous species – which are injured by snow and are not found where snow lies for longer duration.

Following this early descriptive work, snow patch research experienced a resurgence in the late 1950's and 1960's with several definitive books and research papers focusing on snow patch ecology, including Gjærevoll (1956, cited in Wahren 1997), Warren Wilson (1958), Billings and Bliss (1959), Johnson and Billings (1962), Holway and Ward (1963) and Billings and Mooney (1968). These books and papers as well as more recent literature are reviewed and discussed in this thesis, in an Australian context, with examples from the Kosciuszko region of New South Wales and the Bogong High Plains of Victoria.

Snow patches are relatively rare in Tasmania, with only one snow patch near the peak of Frenchman's Cap comparing in its duration to those of the Kosciuszko region

(Kirkpatrick 1983). The more continental location of mainland alpine areas has been cited by Kirkpatrick (1983; 1997) as the cause of colder winters and longer and more consistent snow cover in these areas, when compared to the Tasmanian alpine environment. Therefore, Tasmanian snow patch vegetation is only examined briefly in this thesis, in a broad discussion on the distribution of snow patch vegetation in Australia.

The accumulation and persistence of snow in patches has been attributed to precipitation, topography, wind and the influence of landform features such as depressions, hillsides and mountains (Billings and Bliss 1959; Johnson and Billings 1962; Billings and Mooney 1968; Burrows 1978; Isard 1986; Roche and Allard 1997). Snow accumulates in the lee of these landform features and may be permanent or persist for many months or even for several years (Costin 1954; Holway and Ward 1963; McVean 1969; Burrows 1977; Helm 1982; Isard 1986; Atkin and Collier 1992).

Snow patches in Australia have been recorded on the lee side of landform features such as slopes, depressions, spurs, ridges and mountains, with a south to southeasterly aspect (Costin 1954; Costin 1957a; McVean 1969; McDougall 1982; Atkin and Collier 1992; Wahren 1997; Wahren *et al.* 2001a). Snow patches in the Kosciuszko region, generally persist for 6-9 months, with snow melt not complete until February or early March (Costin 1954; McVean 1969; Costin *et al.* 1973; Atkin and Collier 1992; Osborne *et al.* 1998). On the Bogong High Plains snow patches have a shorter duration of snow lie, with snow melt complete by late December, or in some years as late as early February (McDougall 1982; Williams 1987; Wahren 1997; Wahren *et al.* 2001a).

Snow patches may range from a few square metres to several hectares in size (Costin 1954; Billings and Bliss 1959; Bliss 1969; Helm 1982; McDougall 1982; Wahren 1997; Costin *et al.* 2000). In Australia, snow patches covering the breadth of these ranges have been recorded by Costin (1954), and Costin *et al.* (2000) in the Kosciuszko region and by McDougall (1982), Wahren (1997) and Wahren *et al.* (2001a) on the Bogong High Plains in Victoria.

In Scandinavia, Gjærevoll (1956) published an account of the alpine snow bed plant communities of the region noting that the distribution of snow influences plant communities in alpine areas. Resulting in rather stable mosaics of vegetation types, which follow the isolines of snow melt (Körner 1999). This influence of snow on vegetation has been well studied and Helm (1982) divided it into four factors:

1. Insulation of vegetation (see Karrasch 1973; Walker *et al.* 1993);
2. Shortened growing season (see Cox 1933; Johnson and Billings 1962; Holway and Ward 1963; Kudo 1991, 1992; Galen and Stanton 1993; Walker *et al.* 1993; Razzhivin 1994; Galen and Stanton 1995);
3. Source of melt-water (see Billings and Bliss 1973; Johnson and Billings 1962; Oberhauer and Billings 1981; Isard 1986; Walker *et al.* 1993); and
4. Soil movement (see Costin *et al.* 1973; Caine 1995).

The influence of these factors on snow patches, results in vegetation primarily dominated by herbaceous species that are tolerant of a reduced growing season (Cox 1933; Johnson and Billings 1962; Holway and Ward 1963; Kudo 1991, 1992; Galen and Stanton 1993; Walker *et al.* 1993; Razzhivin 1994; Galen and Stanton 1995). In northern hemisphere snow patches, where snow lies for longer periods of duration, vascular plants are replaced by non-vascular plants (i.e. lichens and bryophytes) (Billings and Bliss 1969; Billings and Mooney 1968; Flock 1978; Benedict 1990; Woolgrove and Woodin 1994; Fryday 1996).

Australian snow patches are dominated by herbaceous vascular plants with a low cover of shrub species (Costin 1954; McVean 1969; McDougall 1982; Wahren 1997; Wahren *et al.* 2001a; Costin *et al.* 2000). McVean (1969), Atkin and Collier (1992) and Costin *et al.* (2000) have described floristic and structural variation within snow patch vegetation of the Kosciuszko region, including upper snow patch vegetation dominated by a fjaeldmark community and lower snow patch vegetation dominated by short alpine herbfield. The bryophyte or lichen dominated late lying snow patches of the northern hemisphere have not been recorded, due to the shorter snow lie within snow patches of Australia (Wahren 1997; Good 1998; Wahren *et al.* 2001a).

Webb (1947) was one of the first researchers to comment on the accumulation of aeolian (wind blown) dust in alpine environments, noting the presence of aeolian calcareous dust received by the European Alps. This was followed by Costin (1954), who commented on the addition of small quantities of aeolian dust to alpine humus soils of the Kosciuszko region, importantly noting that the quantity of dust received by a given area was proportional to the duration of snow lie.

Warren Wilson (1958) was one of the first researchers to study the nature, origin and ecological significance of aeolian (or occasionally water transported) dirt or debris on snow patches. In these late snow areas, Warren Wilson (1958) observed the deposition of dirt after snowmelt suggesting that this affects the character of the soil and vegetation.

Subsequent research throughout the world, by Walker and Costin (1971) in southeastern Australia; Thorn and Darmody (1980) and Liator (1987) in the Front Range, Colorado; Munn and Spackman (1990) in Indian Basin Wyoming (cited in Johnston 2001); and more recently by Johnston (2001) in southeastern Australia, confirmed Warren Wilson's (1958) original premise that the influx of aeolian dust influences the characteristics and composition of alpine soil.

In Australia, Walker and Costin (1971) and Johnston (2001) both found that snow patch soils of the Kosciuszko region contained a distinct mineralogy and particle size commensurate with the addition of aeolian dust. The origin of this dust is thought to be from the semi-arid and arid zones of inland Australia (Costin 1954; Walker and Costin 1971; Costin 1986; Johnston 2001).

Whilst the above factors have been well studied the presence of microorganisms within snow patches has received considerably less attention. Algae, bacteria, fungi and single celled animals have been recorded from snow patches throughout the world (Fogg 1967; Hoham and Blinn 1979; Hoham *et al.* 1993; Ling 1996 cited in Marchant 1998). In Australia, Marchant (1998) has recorded six algal taxa as well as various bacteria, fungi, lichen and single celled animals from snow patches of the Kosciuszko region. The role of these algae and other microorganisms in snow patch ecology is not well known.

The term snow patch as applied to alpine vegetation, has been variously referred to as a snowpocket (Braun-blanquet 1932), snowbank (Billings and Bliss 1959), snow bed (Gjærevoll 1956), snow patch (Harsberger 1929) and snowpatch (McDougall 1982). In this thesis the term snow patch as first described by Harshberger (1929) and more recently applied by Wahren (1997), has been adopted, with the bank or patch of snow described as a snow patch and the associated vegetation as snow patch vegetation.

1.2 Snow patch classification and distribution in Australia, with particular reference to Victoria

In Australia, areas of long duration snow lie were first referred to by Tadgell (1922), after a summer visit to the Bogong High Plains. This visit included stops at Mt Hotham and Mt Feathertop with Tadgell (1922, p. 107) commenting that snow

> "…remains often till after Christmas and New Year in large deep drifts of nearly a quarter of a mile long by a quarter of a mile wide, when not exposed to the wind."

In an account of the Kosciuszko region flora, McLuckie and Petrie (1927) made a similar observation to Tadgell (1922), noting the presence of snow, which in places lay frequently as drifts throughout the summer.

The first comprehensive description and classification of snow patch vegetation in Australia, was completed by Costin (1954), as part of an extensive study of the ecosystems of the Monaro region of New South Wales (including the Kosciuszko region). This was followed by a broader classification and description of the high mountain vegetation of the Australian Alps (Costin1957a).

The snow patch vegetation of Australia is restricted to the upper subalpine and alpine zones of the Kosciusko region of New South Wales, the Bogong High Plains in Victoria and the highlands of Tasmania (Costin 1954; Carr and Turner 1959a; McVean 1969; McDougall 1982; Kirkpatrick 1983; Gibson and Kirkpatrick 1985; Walsh *et al.* 1986; Atkin and Collier 1992; Lynch and Kirkpatrick 1995; Wahren 1997; Costin *et al.* 2000; Wahren *et al.* 2001a). It is easily recognizable after the snow has melted (Green and Osborne 1994) and is one of the rarest landscapes types in Australia, as it occupies less than 1% of the alpine region, which in turn occupies less than 1% of Australia (Wahren *et al.* 2001a).

In Victoria, the term snow patch was first applied to vegetation of the Bogong High Plains by Carr and Turner (1959a), whose ecological research focused on grassland communities and the response of soils and vegetation to the exclusion of cattle grazing (Carr and Turner 1959b). Carr and Turner (1959a) identified five types of alpine grasslands:

1. Grassland A – Closed tussock grassland;
2. Grassland B – Open tussock grassland;
3. Grassland B_1- Open tussock grassland with shrubs;
4. Grassland C – Open tussock grassland, rich in herbs; and
5. Grassland D – *Carex* grassland (snow patch vegetation).

Table 1 outlines Carr and Turner's (1959a) description of grassland D and provides a chronological comparison of snow patch vegetation description and classification in Victoria.

Table 1. Chronological comparison of snow patch vegetation description and classification within the Victoria Alps (Carr and Turner 1959a#, p. 32; McDougall 1982*, p. 56–57;Wahren 1997 and Wahren *et al.* 2001a^).

Grassland D#	**Short turf snowpatch***	**Subalpine snowpatch^**
" This community is recognised by the dominance of *Carex hebes* , which forms a thin, fairly uniform turf. *Poa australis* (Ledge Grass), *Danthonia nudiflora,* and *Trisetum spicatum* also occur, together with a great variety of herbs. Small shrubs, although inconspicuous, are always present. Grassland D is found on all but the steepest and most sheltered of the snow patches, i.e. areas usually with a southerly or easterly apsect on which the snow persists beyond the general thaw".	"Tussock forming *Poa* , characteristic of uits 5A, 5B and 5C, is virtually absent from this unit which is found on moderate slopes of sheltered aspect. Snow remains on these sites one to two months longer than on adjoining units, usually 3A, 5B or 10. Plants are shorter in this habitat and rarely exceed exceed 10cm. Short turf snowpatch is equivalent to the grassland D of Carr and Turner (1959) and undoubtedly has parallels with some of the snowpatches of the Snowy Mountains." 5A, 5B, 5C - tussock grassland, 3A - open heathland, 10 - herbland/sedgeland Mean slope: 15° Size: 50 - 10 000m² Dominant species: *Carex hebes, P. hothamensis, Viola bentonicifolia*	Altitude: 1640 - 1750m Mean slope: 20° Size: 600 - 19 000m² Dominant species: *P. hothamensis, C. hebes* and *R. nudiflorum* Total species richness: 43
Poa australis = *Poa hothamensis* *Danthonia nudiflora* = *Rytidosperma nudiflorum*	**Diuturnal snowpatch*** "The unit is very restricted in distribution. It occurs only on large, concave, sheltered slopes at high altitude. Such sites exist only to the north of Mt Nelse; on Spion Kopje spur, Mt Bogong, Mt Nelse North and Mt Nelse itself. These summits and ridges are highly exposed and much winter snow is blown onto their sheltered slopes where it accumulates. Snow-melt is not complete until mid-summer. Very few species are capable of existing on these sites of the shortest growing season. The upper parts of the snowpatches, where snow remains the longest, are dominated by *Celmisia asteliifolia.* Downslope, where soil is usually deeper, dominance is gradually attained by *Poa fawcettiae.* Very few members of the dense stands of *Celmisia asteliifolia* flower in one season. Reproduction is probably primarily vegetative." Mean slope: 20° Size: up to several hectares Dominant species: *C. asteliifolia, C. hebes, P. fawcettiae, Luzula acutifolia* Total species richness: 30	**Alpine snowpatch^** Altitude: generally >1750m Mean slope: 26° Size: 1100 - 20 000m² Dominant species: *C. asteliifolia* and *P. fawcettiae* Total species richness: 37

McDougall's (1982) broad study of alpine vegetation within the Bogong High Plains provided the next description of snow patch vegetation in Victoria. McDougall (1982) described and mapped two types (Table 1) of snow patch communities:

1. Short Turf snow patch; and
2. Diuturnal snow patch (*L. diuturnis* – of long duration).

Table 1 outlines McDougall's (1982) description of these two snow patch types. The Soil Conservation Authority (1984) published the mapping phase of McDougall's (1982) study in 1983, 1984 and 1985 as a series 1:10 000 map sheets. These map sheets formed the basis for snow patch delineation on the Bogong High Plains, including the Mt Hotham Alpine Resort.

The definition and description by McDougall (1982) of snow patch vegetation of the Bogong High Plains was used by the Scientific Advisory Committee (1992a) in its final recommendation on a nomination, for the listing of alpine snow patch communities under schedule 2 of the *Flora and Fauna Guarantee Act* 1988. The Minister for Conservation and Environment accepted this nomination in 1992 (Scientific Advisory Committee 1992a). The specific definition used by the Scientific Advisory Committee (1992a) to describe 'Alpine Snow Patch Community' was that proposed by McDougall (1982) as either short turf snow patch or diuturnal snow patch (Table 1).

In 1994, Jenkin conducted a broad survey of snow patch vegetation within the Mt Hotham Resort as part of a proposal to build a new ski lift within the Australia Drift area. The findings of this survey led Jenkin (1994) to state that the designation of snow patch vegetation within the Resort as short turf snow patch (as delineated by the Soil Conservation Authority (1984)) was inappropriate based on three key observations of snow patch vegetation at Mt Hotham:

1. *Poa fawcettiae* a densely caespitose and tussock forming graminoid (Vickery 1970) was the dominant grass in snow patch vegetation (Jenkin 1994), whereas McDougall (1982) stated that in short turf snow patches, tussock forming *Poa* was virtually absent;
2. The sward within snow patch vegetation was commonly much taller than 10cm (Jenkin 1994), whereas McDougall (1982) stated that in short turf snow patches plants rarely exceed 10 cm in height; and
3. *Carex hebes* formed only a minor component within snow patches and dominance or co-dominance by this taxa was restricted to infrequent and dispersed patches around 1 m in diameter, whereas McDougall (1982) stated that short turf snow patch is equivalent to grassland D as defined by Carr and Turner (1959a) which is dominated by *Carex hebes*, forming a thin fairly uniform turf.

Based on these observations Jenkin (1994) concluded that the snow patch vegetation of Mt Hotham more closely conformed to diuturnal snow patch than short turf snow patch and that it would have been much better had McDougall (1982) separated diuturnal snow patch into diuturnal snow patch *Celmisia* herbfield and diuturnal snow patch *Poa fawcettiae* grassland. Jenkin (1994) also suggested that at Mt Hotham it appeared that a further category was required to classify the open vegetation occurring on steeper rocky slopes, which differed from the *Poa fawcettiae* grassland of gentler slopes. In light of these comments, Jenkin (1994) concluded that there was a need for a revision of current concepts and descriptions of snow patch vegetation in the Mt Hotham area.

This is particularly evident when proposed and future development of ski industry infrastructure at Mt Hotham is considered. For example, several recent flora survey assessments at Mt Hotham erroneously classify snow patch vegetation as short turf snow patch (see Rosengren *et al.* 1993, 1996; ARUP 1996, 1998; McMahon *et al.* 1998).

This need for a revision was partially addressed in a study of the vegetation of the Bogong High Plains by Wahren (1997) and Wahren *et al.* (2001a), with two types (Table 1) of snow patch vegetation described:

1. Subalpine snow patch; and
2. Alpine snow patch.

Wahren (1997) and Wahren *et al.* (2001a) recognised two main structural and one minor structural assemblage within alpine snow patches - closed herbfields, grasslands and open herbfields on a stony substratum, respectively.

Wahren (1997) and Wahren *et al.* (2001a) recorded some altitudinal stratification (downslope) of vegetation, but this was not consistent across sites. The only sites to exhibit altitudinal stratification of vegetation were comparatively large alpine snow patches, for example: Mt Nelse = 140 000m^2, Mt Nelse North No. 1 = 110 000m^2 and Mt Nelse North No.2 = 100 000m^2. Within these large snow patches, *Celmisia asteliifolia* was predominant on the upper slopes and *Poa fawcettiae* on the mid to lower slopes with some open herbfield occupying the lower slopes. Wahren (1997) and Wahren *et al.* (2001a) suggested that these larger snow patches more closely conformed to McDougall's (1982) description of diuturnal snow patches, where *Celmisia asteliifolia* dominated upper slopes and lower slopes were dominated by *Poa fawcettiae.* Wahren (1997) and Wahren *et al.* (2001a) speculated that the upper slopes of these larger snow patches are probably drier and that the middle and lower slopes have higher soil moisture levels, similar to that recorded by Atkin and Collier (1992) in snow patches of the Kosciuszko region. Additionally, it was suggested that the altitudinal stratification of larger snow patches may be associated with differences in soil depth, with middle and lower slopes containing deeper soils (Wahren 1997; Wahren *et al.* 2001a).

The concerns of Jenkin (1994), the earlier work of McDougall (1982) and the more recent work by Wahren (1997) and Wahren *et al.* (2001a) formed the basis for this study, which specifically aimed to:

1. Determine and describe the floristic composition of snow patches at Mt Hotham;
2. Identify floristic and physiognomic units within snow patches at Mt Hotham;
3. Describe selected environmental variables for snow patches at Mt Hotham; and
4. Discuss the management and conservation implications of snow patch classification and delineation within the Mt Hotham Alpine Resort.

2. MATERIALS AND METHODS

2.1 Study area

Mt Hotham is the highest of all the Victorian Alpine Ski Resorts with a summit elevation of 1861 metres (Rosengren *et al.* 1993). The resort encompasses approximately 3 450 ha, with 245.5 ha available for downhill skiing (ARUP 1998). It is approximately 365 kilometres north-east of Melbourne and 520 kilometres south-west of Canberra (by road) (Rosengren *et al.* 1993).

Fifteen snow patches, as defined by McDougall (1982) and mapped by the Soil Conservation Authority (1984) were surveyed within the cadastral boundary of the Mt Hotham Alpine Resort (Figure 1). These snow patches were selected to cover the range and variation of snow patch vegetation within the Resort. Table 2 assigns a unique identifier for each site and outlines geographic and sampling information.

2.1.1 Geology and Geomorphology

The Mt Hotham Resort lies on the Great Dividing Range and includes part of the upper reaches of the Kiewa, Mitta Mitta, Ovens and Dargo (Mitchell) River catchments (Rosengren *et al.* 1993; WBM Oceanics 2003). The bedrock of the Mt Hotham Alpine Resort is low-grade metasediment, specifically slaty mudstones, phyllites and orthoquartzite of Middle to Upper Ordovician age (Rosengren *et al.* 1993). Remnants of once extensive basalt lava flows, overly the Ordovician rocks, forming flat-topped summits at Mt Loch, Mt Higginbotham and Mt Little Higginbotham (Rosengren *et al.* 1993).

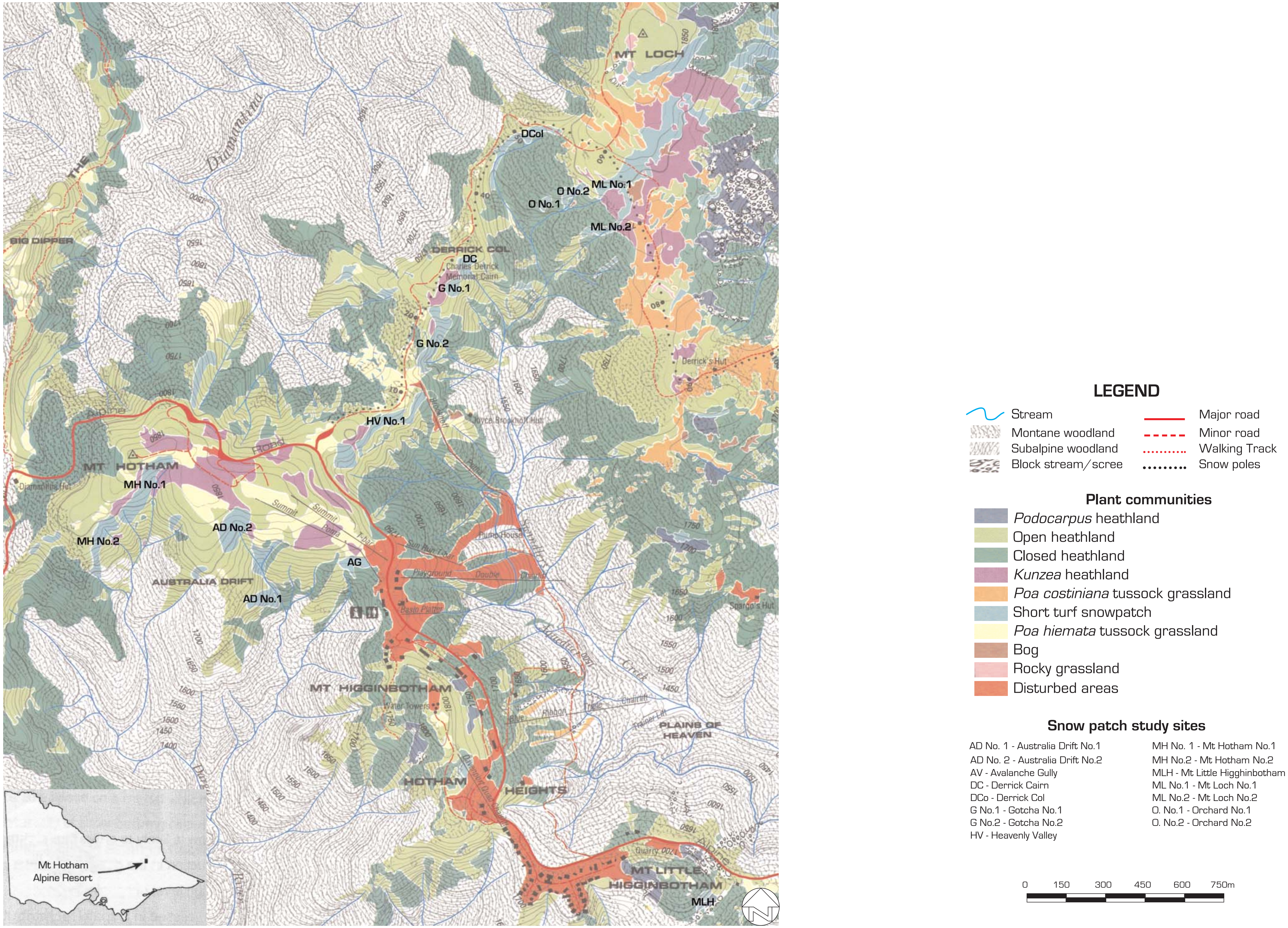


Figure 1. Plant communities and study sites of Mt Hotham Alpine Resort (adapted from Soil Conservation Authority 1984).

Table 2. Summary of geographic and sampling information for the 15 snow patch sites. Quadrat size was $6m^2$.

Site name and site number (unique identifier)	Location longitude	latitude	Altitude (m a.s.l.)	No. of quadrats sampled
Australia Drift No. 1	147°07'55"	36°58'55"	1700	18
Australia Drift No.2	147°07'50"	36°58'45"	1830	18
Avalanche Gully	147°08'10"	36°58'40"	1770	12
Derrick Cairn	147°08'32"	36°58'05"	1780	12
Derrick Col	147°08'55"	36°58'44"	1700	12
Gotcha No. 1	147°08'30"	36°58'02"	1760	12
Gotcha No. 2	147°08'30"	36°58'25"	1720	12
Heavenly Valley	147°08'20"	36°58'03"	1770	18
Mt Hotham No.1	147°07'25"	36°58'40"	1820	18
Mt Hotham No. 2	147°07'15"	36°58'45"	1770	18
Mt Little Higginbotham	147°09'20"	36°59'50"	1700	12
Mt Loch No.1	147°09'05"	36°57'54"	1800	12
Mt Loch No. 2	147°09'05"	36°57'58"	1760	12
Orchard No.1	147°09'55"	36°57'56"	1750	12
Orchard No.2	147°09'52"	36°57'55"	1720	12

The Bogong High Plains, including Mt Hotham, unlike alpine areas of New South Wales and Tasmania, did not undergo a period of glaciation (Galloway 1963; Peterson 1971; Rosengren and Peterson 1988; Galloway 1989; Kiernan 1996; Galloway *et al.* 1998). Instead they experienced periglacial activity of varying degrees (Galloway 1989; Galloway *et al.* 1998; Rosengren *et al.* 1993; McMahon *et al.* 1998).

Active periglacial features include the movement of soil and vegetation by the growth of needle ice; rock scratching, movement and cracking; limited sorting of coarse and fine debris on bare ground and solifluction below long lasting snow patches where soil and stone moves down slope *en masse* (Costin *et al.* 1964; Costin and Wimbush 1973; Costin *et al.* 1973; Galloway 1989). Rosengren *et al.* (1993, 1996) and McMahon *et al.* (1998) have recorded active periglacial features such as rock cracking, scratching and movement at Mt Hotham.

Fossil periglacial features include solifluction lobes or deposits, which are sheets of stony debris ranging from boulders to fine material. These deposits originated as slowly creeping layers of rocks, but are now largely immobilised under soil and vegetation (Galloway 1989; Rosengren *et al.* 1993). These features have also been recorded throughout Mt Hotham particularly within and/or adjacent to snow patches (Rosengren *et al.* 1993, 1996; McMahon *et al.* 1998).

Nivation hollows are another type of periglacial feature; described by Galloway *et al.* (1998) as a spoon shaped hollow with steep back walls a few metres high and fronted by an apron of transported debris which is usually soft and boggy in summer. Rosengren *et al.* (1993) recorded the presence of several small nivation hollows on the south and south-easterly slopes of the Mt Loch- Mt Hotham ridge. These nivation hollows were described as bowl-shaped valley heads located at the head of several tributaries leading in to Swindler's Creek. The broad basin below Derrick Col is the most visible example (Rosengren *et al.* 1993).

2.1.2 Soils

The soils of the Mt Hotham region are mainly derived from *in situ* material and are predominantly alpine humus soils with smaller areas of skeletal soil and isolated areas of alpine fen or bog peats (Rosengren *et al.* 1993; Uren and McMahon 2002). Alpine humus soils are highly organic and strongly acidic throughout the profile, they are characterised by dark humic upper horizons, gradational texture, good structure and an abundance of stones. Alpine humus soils can be up to 1 metre deep and these deeper soils are generally located on the lower parts and at the base of moderately steep slopes (~20%), they also occur on higher slopes with a northerly or westerly aspect (Rosengren, *et al.* 1993; Uren and McMahon 2002).

Skeletal soils are very shallow, varying in depth from several centimetres up to 30cm. They are low in organic matter and contain a higher proportion of stones and gravel, than alpine humus soils (Uren and McMahon 2002). Both skeletal and alpine humus soils are found within snow patches (ARUP 1996).

2.1.3 Climate

Climatic data for Mt Hotham have been collected since 1925, however the records are fragmentary and include at least three known changes in the position of the station (Rosengren *et al.* 1996). The most recently compiled data is that by Ruddell *et al.* (1990), which revealed that the daily mean annual temperature at Mt Hotham is

4.9°C. In summer, the daily mean temperature is 11.1°C, whilst in winter it is –1.0°C. The mean daily maximum temperature in summer is 15.7°C and the mean daily minimum temperature in winter is –3.4°C. The lowest temperature recorded at Mt Hotham is –12.8°C.

Average total annual precipitation at Mt Hotham, including both snowfall and rainfall is 1494 mm. Thunderstorms with high intensity rainfall are prevalent in summer, while snowfalls occur on an average of 75.4 days annually (Ruddell *et al.* 1990).

The average maximum snow depth at Mt Hotham is 150cm at 1845 m A.S.L. Snowfalls that create and maintain a persistent snow cover usually begin about mid-June and continue intermittently until early September. A deep cover does not usually begin until July (Ruddell *et al.* 1990).

At Mt Hotham, the prevailing winds are from the west and north-west (ARUP 1996) and as a result snow accumulates on the leeward, south-east facing aspects of ridges and outcrops (Ruddell *et al.* 1990; Rosengren *et al.* 1993; ARUP 1996).

2.1.4 Vegetation of Mt Hotham

The vegetation of the Mt Hotham Alpine Resort has been described by McDougall (1982) and mapped by the Soil Conservation Authority (1984), resulting in ten broad subformations (*sensu* Costin 1954) (Table 3). McDougall (1982) further divided some of these subformations into different vegetation units (floristic communities) and more recent work by Rosengren *et al.* (1993; 1996), ARUP (1996) and McMahon *et al.* (1998) has seen various updates and re-classifications of Mt Hotham vegetation.

Table 3. Subformations and floristic communities of Mt Hotham Alpine Resort (adapted from McDougall 1982; Soil Conservation Authority 1984; Rosengren *et al.* 1993; 1996; McMahon *et al.* 1998).

Subformation	Floristic community	Character species
Alpine Tussock Grassland	*Poa costiniana* tussock grassland	*Poa costiniana*
	Poa hiemata tussock grassland	*Poa hiemata*
Bog	Candle Heath - *Sphagnum* Bog	*Richea continentis*
Podocarpus heathland	*Podocarpus* heathland	*Podocarpus lawrencei*
Short Alpine Heath Complex	*Grevillea* - *Kunzea* heathland	*Kunzea muelleri*
		Grevillea australis
	Acacia heathland	*Acacia alpina*
Short Alpine Herbfield	*Caltha* herbfield	*Caltha introloba*
Snow patch	Short turf snow patch	See section 1.2 & Table 1
Snow Gum Woodland	*Podolobium* - *Bossiaea* community	*Eucalyptus pauciflora*
(Subalpine Woodland)		*Podolobium alpestre*
		Bossiaea foliosa
Stream Complex	*Poa* - *Carex* grassland	*Poa helmsii*
		Carex appressa
	Celmisia sericophylla herbfield	*Celmisia sericophylla*
	Boulder Stream Snow Gum Woodland	*Eucalyptus pauciflora*
Tall Alpine Heath	Tall Alpine Heath	*Eucalyptus pauciflora*
		Pimelea axiflora subsp. *alpina*
		Bossiaea foliosa
Tall Alpine Herbfield	Closed herbfield	Various Asteraceae species
	Open heath	*Grevillea australis*

In this broad outline of vegetation at Mt Hotham, the term subformation is applied as a subordinate synthetic structural unit exhibiting the same structural subform irrespective of floristic composition (Costin 1954). Floristic community is applied as a group of species that are similar in terms of structure and response to major environmental variables such as landform, geology, soil, altitude, aspect, slope and rainfall (Woodgate *et al.* 1994; Oates and Taranto 2001). Character species are species that consistently and frequently occur in a floristic community (Woodgate *et al.* 1994; Oates and Taranto 2001)

The work of McDougall (1982), Rosengren *et al.* (1993; 1996), ARUP (1996) and McMahon *et al.* (1998) has been used to generate a broad list of subalpine and alpine vegetation subformations and floristic communities found within the Mt Hotham Resort (Table 3). Montane woodland communities have been omitted from this report, as they are only a minor component of the Resort's vegetation.

Alpine tussock grassland includes *Poa costiniana* and *Poa hiemata* tussock grassland. *Poa costiniana* tussock grassland is generally found on basalt areas and contains dense tussocks of *P. costiniana* and periodically water filled depressions (McDougall 1982; Soil Conservation Authority 1984). *Poa hiemata* tussock grassland contains a variety of herbaceous species within the inter-tussock spaces. It is predominantly found on gentle slopes of metamorphic rock type (McDougall 1982; Soil Conservation Authority 1984).

Bog vegetation is found in permanently wet sites, normally composed of a *Sphagnum* layer with a sparse to dense cover of shrubs (McDougall 1982; Soil Conservation

Authority 1984; Rosengren *et al.* 1993; 1996). In addition to *Sphagnum*, this community is dominated by *Richea continentis* at Mt Hotham (Rosengren *et al.* 1993; 1996).

Podocarpus heathland is a distinctive and highly specialized community that is characterised by the sprawling, aromatic shrub *Podocarpus lawrencei*. This community contains very few species and occurs exclusively on block streams (McDougall 1982; Soil Conservation Authority 1984).

Short alpine heath complex contains *Grevillea – Kunzea* and *Acacia* dominated heathlands. The *Grevillea – Kunzea* community is characterised by *Grevillea australis* and *Kunzea muelleri* and is generally found above the tree line (Rosengren *et al.* 1993; 1996). It is comparable to McDougall’s (1982) *Kunzea* heathland. The *Acacia* community is characterised by *Acacia alpina* and has a variable shrub canopy (Rosengren *et al.* 1993; 1996).

Short alpine herbfield at Mt Hotham occurs as *Caltha* herbfield. This community is very restricted in its distribution being found at the base of snow patches (Rosengren *et al.* 1996) and was listed under the *Flora and Fauna Guarantee Act* 1988 in 1992 as *Caltha introloba* herbland community (Scientific Advisory Committee 1992b).

Short turf snow patch has been described in detail under section 1.2 and is defined in Table 1.

Snow Gum Woodland (Subalpine Woodland) is the most widespread subformation within the Mt Hotham Alpine Resort, occupying a large portion of the subalpine zone (Rosengren *et al.* 1993; ARUP 1996). Several floristic communities have been recognised within this subformation including a *Podolobium – Bossiaea* community (Rosengren *et al.* 1993); additional communities have been insufficiently sampled at Mt Hotham.

The Stream complex includes *Poa – Carex* grassland, *Celmisia* herbfield and Boulder Stream Snow Gum Woodland. *Poa – Carex* grassland is restricted to drainage lines where there has been considerable soil accumulation (ARUP 1996). *Celmisia* herbfield is dominated by the Victorian endemic *Celmisia sericophylla*, which is found along sheltered rocky stream crevices, and spring fed alluvial fans or terraces (Rosengren *et al.* 1993). Boulder Stream Snow Gum Woodland has a very restricted range and is floristically distinct from the more widespread Snow Gum Woodland (Rosengren *et al.* 1993).

Tall alpine heath is floristically related to the Snow Gum Woodland *Podolobium – Bossiaea* community and has been recorded from intermediate sites between Snow Gum Woodland and Short Alpine Heath of the alpine zone (Rosengren *et al.* 1993; ARUP 1996).

Tall alpine heath, stream complex and *Poa – Carex* grassland can extend well into the zone occupied by *Eucalyptus pauciflora* (McDougall 1982; Rosengren *et al.* 1993; 1996).

Tall alpine herbfield includes closed herbfield and open heath components. The closed herbfield is dominated by numerous members of the Asteraceae family, whereas, the open heath component is dominated by *Grevillea australis* (Rosengren *et al.* 1993).

Disturbed areas, whilst not a recognised floristic community, were mapped by the Soil Conservation Authority (1984) due to their frequent occurrence within the Mt Hotham village and associated ski runs as well as around Spargo's hut (Figure 1). Some of the disturbed ski runs have been revegetated with introduced species (Soil Conservation Authority 1984), which have persisted.

2.2 Sampling of vegetation and environmental variables

A preliminary survey of snow patches as mapped by the Soil Conservation Authority (1984) and defined by McDougall (1982) was undertaken before the vegetation sampling and environmental variables were measured. As part of this preliminary survey a visual estimate of snow cover was recorded for each snow patch at approximately 18-day intervals beginning on the 20/21st of September 2002 and continuing until the 10/11th of October 2003. Snow cover was visually estimated as a percentage of snow patch area covered by snow (i.e. 100% = complete snow cover with no visible snow patch vegetation evident).

2.2.1 Vegetation classification

Following the preliminary survey, a review of work by McDougall (1982), Jenkin (1994), Wahren (1997) and Wahren *et al.* (2001a) and an examination of aerial photographs from March 1999 (1: 16 000), a floristic survey was completed during December 2002 and January/February 2003.

A stratified quadrat sampling technique was used. Fifteen snow patch sites were selected using the Soil Conservation Authority (1984) vegetation map and the aerial photographs. Each snow patch was assigned a unique identifier (Table 2).

All snow patches were located within the cadastral boundary of the Mt Hotham Alpine Resort. Quadrat size was determined using a species area curve (Watson 1859, cited in Williams 1964; Rosenweig 1995) from sample data collected from two snow patch sites (Australia Drift No.2 and Mt Loch No.1). In both cases, there was no significant increase in the number of species recorded after a quadrat size of $6m^2$ (3m x 2m) had been reached. This was also considered an appropriate size for comparison with other snow patch studies (e.g. McDougall 1982; Jenkin 1994; Wahren 1997;Wahren *et al.* 2001a).

Due to the floristic variation (between upper and lower altitudinal zones) that has been recorded by Atkin and Collier (1992) and Costin *et al.* (2000) in snow patches of the Kosciuszko area, sampling was stratified into three altitudinal zones – upper, mid and lower (Wahren 1997; Wahren *et al.* 2001a).

One transect was completed for each altitudinal zone with six quadrats spaced equally along the transect for a minimum of 18 quadrats per snow patch for five sites. The first and last quadrat, were located outside the ‘visually distinct’ (homogenous) snow patch area. Due to unforeseen circumstances – the 2003 January/February bushfires, ten snow patch sites were sampled with only 12 quadrats per site; these quadrats were located within the visually distinct snow patch vegetation. The altitudinal distance between each zone varied from 5m to 40 m depending on snow patch size. A total of 210 quadrats were sampled across the 15 sites.

Vegetation structure for each quadrat was assigned to one of five physiognomic classes based on Specht (1981):

- Closed-heath – shrub cover 70-100%;
- Open-heath – shrub cover 30-70%;
- Grassland – graminoids predominate, grass cover 30-70%;
- Closed herbfield – non-graminoid herbs predominate, herb cover 70-100%; and
- Open herbfield – herb cover 30-50%.

All vascular plant taxa occurring within the quadrat were recorded together with an abundance value (visual estimate) for each species using the Domin-Krajina scale as developed by Krajina in 1933 (cited in Mueller-Dombois and Ellenberg 1974).

Domin-Krajina	Cover %
• 10 any number, with complete cover	~100
• 9 any number, with more than ¾ but less than complete cover	> 75
• 8 any number, with ½ - ¾ cover	50-75
• 7 any number, with ⅓ - ½ cover	33-55
• 6 any number, with ¼ - ⅓ cover	25-33
• 5 any number, with 1/10 - ¼ cover	10-25
• 4 any number, with 1/20 – 1/10 cover	5-10
• 3 scattered, with cover under 1/20	1-5
• 2 very scattered, with small cover	< 1
• 1 seldom, with insignificant cover	
• + solitary, with insignificant cover	

Any plants that could not be identified in the field were collected for closer examination and at some sites a lack of floral material prevented identification of some taxa beyond genus level. Other taxonomic difficulties encountered, included:

- *Poa* species – this genus is difficult to identify taxonomically with many taxa exhibiting a degree of morphological plasticity, as a response to the local environment (Vickery 1970). This plasticity has resulted in intermediate populations of several taxa being common above the treeline (Costin *et al.* 2000). This was particularly evident in this study with *Poa costiniana*, *P. hiemata* and *P. fawcettiae*.
- *Cotula alpina* and *Leptinella filicula* – these taxa were difficult to separate in the field, most specimens conformed to *C. alpina*.
- *Celmisia* taxa – this genus was recently revised by Gray and Given (1999) and two taxa – *Celmisia pugioniformis* and *Celmisia costiniana* (both of which were previously known as *Celmisia asteliifolia* sens. lat.) were listed as being common throughout snow patches of the Bogong High Plains. Depauperate specimens of *C. pugioniformis* and *C. costiniana* are difficult to separate in the field with the key diagnostic character - flattened tomentum, visible only under high magnification (Gray and Given, 1999; Walsh and Entwistle 1999). In the interests of efficiency and to limit large collections of material, *C. pugioniformis* and *C. costiniana* were placed together in a species aggregate *C. costiniana/pugioniformis* agg. for identification purposes (*C. pugioniformis* appeared to be more abundant during this study). For comparison between previous studies and nomenclatural continuity, this aggregate has been referred to as *Celmisia asteliifolia* throughout this thesis.

In general, most taxa were distinguishable by their habit, structure and other features. However, where necessary collections were made of fertile material and compared to the National Herbarium of Victoria reference collection, at the Royal Botanic Gardens Melbourne.

Nomenclature follows that of Cross *et al.* (2001), which is based on nomenclature applied by Walsh and Entwistle (1994; 1996; 1999), as updated by Ross (2000). Except for *Stylidium armeria*, which follows Raulings and Ladiges (2001), *Leptorhynchos squamatus* subsp. *alpinus*, which follows Flann *et al.* (2002) and *Xerochrysum subundulatum*, which follows Wilson (2002).

2.2.2 Environmental variables

A range of environmental variables was recorded for each snow patch. The cover of rock and bare ground was recorded within each quadrat using the Domin-Krajina scale. Mean slope, mean aspect, area of site and altitude was recorded for the whole site. The mean slope and aspect for each snow patch were measured with a clinometer and compass, respectively. The altitude for each site was estimated from the midpoint of each snow patch using the Mt Hotham 1:25 000 topographic map sheet. Each transect was visually assessed for slope shape – concave, flat or convex and the site as a whole was visually assessed for geomorphic features such as solifluction lobes /deposits, terraces/benches, stony pavements, nivation hollows and any active or fossil periglacial features.

Soil depth was recorded by pushing a metal probe into the ground until bedrock was hit or the depth exceeded the length of the probe (60cm). Five measurements were taken in each quadrat, one in each corner and once in the centre (Venn 2001; Wearne and Morgan, 2001).

Soil pH was measured in each zone (upper, mid and lower) by taking six random soil cores, each 50 x 70 mm. These were bulked, sieved and mixed in a 1:5 ratio of soil:water suspension and then analysed using an electronic pH meter. Soil moisture content was measured gravimetrically in early summer (10^{th} December, 2002). Stratified sampling was used with six random soil cores, 50 x 70 mm, collected from each zone (upper, mid and lower). All samples were wrapped in aluminium foil and stored in sealable plastic bags (Reynolds, 1970) until weighed, 24 hours after being collected. Soil moisture content was estimated gravimetrically following Reynolds (1970) with samples weighed, dried at 105°C for 24 hours and then re-weighed to calculate the moisture content as a percentage of soil dry weight. However, due to the summer fires (January/February 2003) the soil pH and soil moisture sampling were not completed.

2.3 Data analysis

For a succinct and comprehensive outline of the various methods that may be used for the description and analysis of vegetation see Wahren (1997). A combination of ordination techniques, as described by Wahren (1997) have been used throughout this thesis. In addition to those methods described by Wahren (1997), a classification routine (PATN, Belbin 1987) has also been used to provide additional analysis of vegetation patterns including community definition, in an easy to interpret two-way table. The combination of ordination and classification techniques was designed to facilitate and maximise comparisons with results from previous studies of snow patch vegetation on the Bogong High Plains (eg. McDougall 1982; Wahren 1997; Wahren *et al.* 2001a).

The Domin-Krajina cover data from each quadrat were converted to mid-range percent cover values for use in data matrices for non-metric multidimensional scaling (Wahren 1997) and converted values for PATN analysis (Table 4).

Dendrograms were generated using PRIMER® v. 5.2.0 (2001) and the group-averaging and hierarchical agglomerative clustering technique defaults. Global Non-metric Multidimensional Scaling (NMDS) was used to ordinate the floristic data using the Bray-Curtis similarity coefficient (Clarke and Warwick 1994).

Ordinations were performed in two and three dimensions with 30 random starts and 999 iterations based on mid-range percent cover values and presence/absence data (Wahren 1997). Ordination techniques were employed to compare floristic variation between and within snow patches and between zones of snowpatches.

For the ordinations 'Goodness of fit' was tested by Kruskal's stress value (Kruskal 1964), with stress values below 0.2 recommended, as values above this threshold may lead to misleading interpretations (Minchin 1987; Clarke 1993).

The ANOSIM routine (PRIMER® v. 5.2.0 2001) was used to test the difference between groups of the NMDS configuration (Clarke 1993). Group membership was defined prior to the ordination (e.g. vegetation structure – open heathland, open herbfield, grassland, etc. or altitude – alpine, subalpine).

Table 4. Domin-Krajina cover scale converted to mid points for use in data matrices for non-metric multidimensional scaling and converted values for PATN analysis.

Domin-Krajina	**Cover %**	**Converted mid-point values**	**PATN converted values**
10	~100	100.00	
9	> 75	87.50	5
8	50-75	62.50	
7	33-55	41.50	4
6	25-33	29.00	
5	10-25	17.50	3
4	5-10	7.50	
3	1-5	3.00	2
2	< 1	1.00	
1		0.50	1
+		0.25	

The percentage contribution of each important taxon was determined with the SIMPER routine (PRIMER® v. 5.2.0 2001). Taxa are listed in order of their contribution to the mean similarity among samples up to a cumulative percent contribution of 95% or mean dissimilarity between groups up to a cumulative percent contribution of 70%.

PATN (Belbin 1987) was used to classify quadrat data and identify floristic communities. PATN uses a community analysis module based on similarity ratings between samples, using percent cover data (Belbin 1987). The two-way table was hand sorted into subjective arrangements, considering cover-abundance values rather than just presence/absence data (Woodgate *et al.* 1994). Species that occurred in less than 2% of quadrats (n=5) were excluded from the final display, unless their occurrence was considered ecologically significant. This procedure identified characteristic taxa and produced a two-way table containing data in a sorted form with quadrats and taxa grouped into floristic communities.

2.3.1 Software

The statistical software package PRIMER® (Plymouth Routines in Multivariate Ecological Research) version 5.2.0 for Windows® was used for ordinations, cluster analysis, SIMPER and ANOSIM routines. PATN® (Belbin 1987) was used for classification routines and the construction of the two-way table. SPPS® version 10.0.5 for Windows® was used to analyse the difference between soil depths.

3. RESULTS

3.1 Environmental site data

The mean aspect for sampled snow patches ranged from 102° (E by S) at Australia Drift No.1 to 200° (SSW) at Derrick Col and the mean slope ranged from 17° at Mt Loch No.1 to 34° at Mt Loch No.2. The size of sampled snow patches ranged from 3000m^2 at Mt Little Higginbotham to 26 100m^2 at Mt Hotham No.1. The shape of slopes varied across sites, from flat and/or concave upper slopes through to flat/concave/convex middle slopes and convex to flat lower slopes. The mean cover of rock per zone ranged from a high of 38% in the upper zone of Australia Drift No. 1 to a low of 2% in the lower zone of Mt Little Higginbotham. The mean cover of bare ground ranged from a low of 2% at several sites to a high of 13 % in the lower zone of Orchard No.2. Mean soil depth ranged from 5.4cm in the middle zone of Australia Drift No. 1 to 23.3cm in the lower zone of Mt Loch No.1. Environmental site data for all sites have been summarised in Table 5.

Analysis of mean soil depths between upper and lower zones of alpine snow patch sites, revealed a significant difference between zones (t –2.350, $df = 154$, $P = .020$) (Figure 2).

Snow cover data were first measured for all sites on the 20/21st of September 2002 when all sites were completely covered (100%) by snow and the final measurement was taken on the 10/11th October 2003 when all sites were 100% covered by snow (Table 6).

Table 5. Summary of environmental site data for the 15 snow patch sites of Mt Hotham Alpine Resort.

Snow patch zone and site	Aspect (°)	Slope (°)	Size (m2)	Slope shape	Mean cover of rock (%)	Mean cover of bare ground (%)	Mean soil depth (cm)
upper				Flat	35	3	7.0
middle				Flat	33	2	5.4
lower				Flat	19	2	8.0
Australia Drift No. 1	102	29	9800		29	2	6.8
upper				Concave	25	3	16.4
middle				Convex	24	3	10.2
lower				Flat	7	5	16.6
Australia Drift No.2	143	18	20000		19	4	14.4
upper				Flat	10	4	12.2
middle				Flat	42	5	14.0
lower				Flat	51	2	9.1
Avalanche Gully	177	30	9200		34	4	11.7
upper				Concave	29	6	9.4
middle				Flat	10	10	16.7
lower				Convex	5	5	16.4
Derrick Cairn	151	24	6900		15	7	14.1
upper				Concave	3	10	25.1
middle				Convex	5	4	27.1
lower				Flat	3	2	38.3
Derrick Col	200	10	8400		4	5	30.2
upper				Flat	17	4	14.5
middle				Concave	15	2	9.0
lower				Flat	42	6	9.9
Gotcha No.1	161	19	5300		25	4	11.1
upper				Flat	19	7	16.5
middle				Flat	24	5	9.6
lower				Flat	17	13	11.2
Gotcha No. 2	130	27	15400		20	8	12.4
upper				Concave	23	5	8.5
middle				Convex	19	3	10.4
lower				Flat	10	3	10.3
Heavenly Valley	126	27	15200		17	4	9.7
upper				Concave	10	2	25.0
middle				Convex	5	3	17.4
lower				Flat	11	3	14.0
Mt Hotham No. 1	148	28	26100		9	2	18.8

upper				Concave	38	2	5.7
middle				Concave	25	4	14.0
lower				Flat	21	5	13.3
Mt Hotham No. 2	128	25	16100		28	4	11.0
upper				Flat	4	7	17.5
middle				Flat	3	9	22.1
lower				Flat	2	3	19.5
Mt Little Higginbothan	124	31	3000		3	6	19.7
upper				Concave	29	9	10.8
middle				Convex	4	5	17.5
lower				Flat	2	6	23.3
Mt Loch No. 1	157	17	7500		11	7	17.2
upper				Concave	27	6	9.0
middle				Flat	26	11	11.4
lower				Flat	21	13	19.3
Mt Loch No. 2	168	34	6100		25	10	13.2
upper				Concave	17	5	13.3
middle				Flat	6	4	24.7
lower				Flat	4	10	22.8
Orchard No. 1	183	30	2600		9	6	20.2
upper				Concave	27.5	5.25	12.6
middle				Concave	2	2	22.0
lower				Flat	11	2	20.1
Orchard No. 2	183	30	5300		14	3	18.2

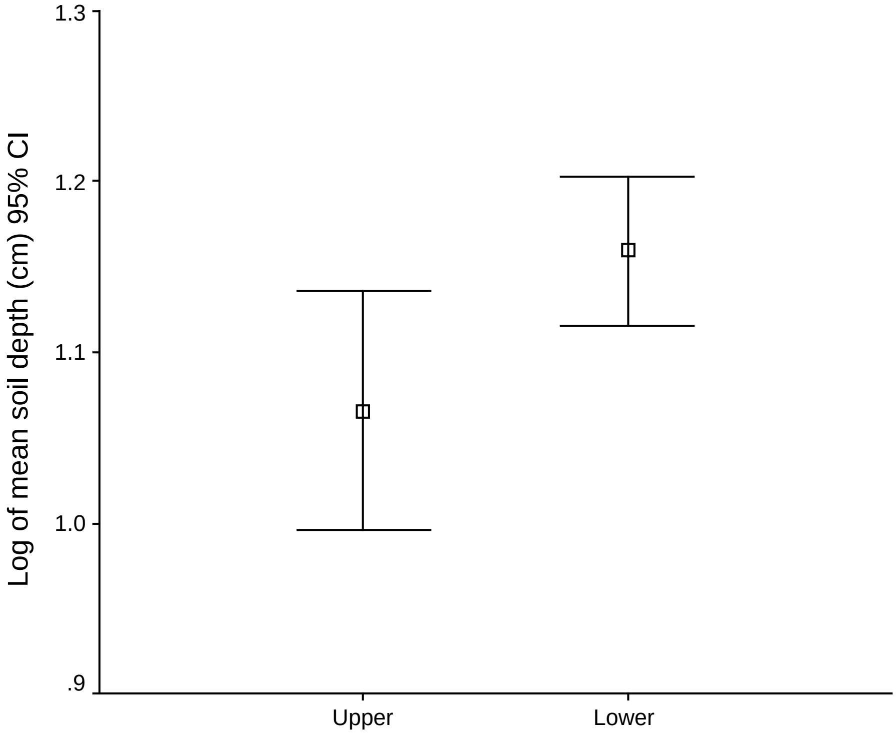


Figure 2. Comparison of upper and lower altitudinal zones for logged mean soil depths at alpine snow patch sites within the Mt Hotham Alpine Resort.

Table 6. Visually estimated snow cover for each snow patch site at Mt Hotham Alpine Resort.

Site name and site number	**Snow cover#**							
	20/21st Sep.	**10/11thOct.**	**30/31st Oct.**	**20/21st Nov.**	**10/11th Dec.**	**10/11th June**	**20/21st Sep.**	**10/11th Oct.**
			2002				**2003**	
Australia Drift No.1	100%	80%	50%	0%	0%	100%	100%	100%
Australia Drift No.2	100%	80%	40%	10%	0%	100%	100%	100%
Avalanche Gully	100%	80%	60%	5%	0%	100%	100%	100%
Derrick Cairn	100%	90%	70%	5%	0%	100%	100%	100%
Derrick Col	100%	60%	5%	0%	0%	100%	100%	100%
Gotcha No.1	100%	90%	40%	0%	0%	100%	100%	100%
Gotcha No.2	100%	40%	10%	0%	0%	100%	100%	100%
Heavenly Valley	100%	40%	20%	0%	0%	100%	100%	100%
Mt Hotham No.1	100%	100%	40%	10%	0%	100%	100%	100%
Mt Hotham No.2	100%	100%	30%	10%	0%	100%	100%	100%
Mt Little Higginbotham	100%	60%	5%	0%	0%	100%	100%	100%
Mt Loch No.1	100%	60%	40%	0%	0%	100%	100%	100%
Mt Loch No.2	100%	70%	40%	5%	0%	100%	100%	100%
Orchard No.1	100%	80%	30%	0%	0%	100%	100%	100%
Orchard No.2	100%	80%	5%	0%	0%	100%	100%	100%

Snow cover was visually estimated as a percentage of snowpatch area covered by snow
(i.e. 100% = complete snow cover, no visible snowpatch vegetation)

3.2 Floristic composition of Mt Hotham snow patch vegetation

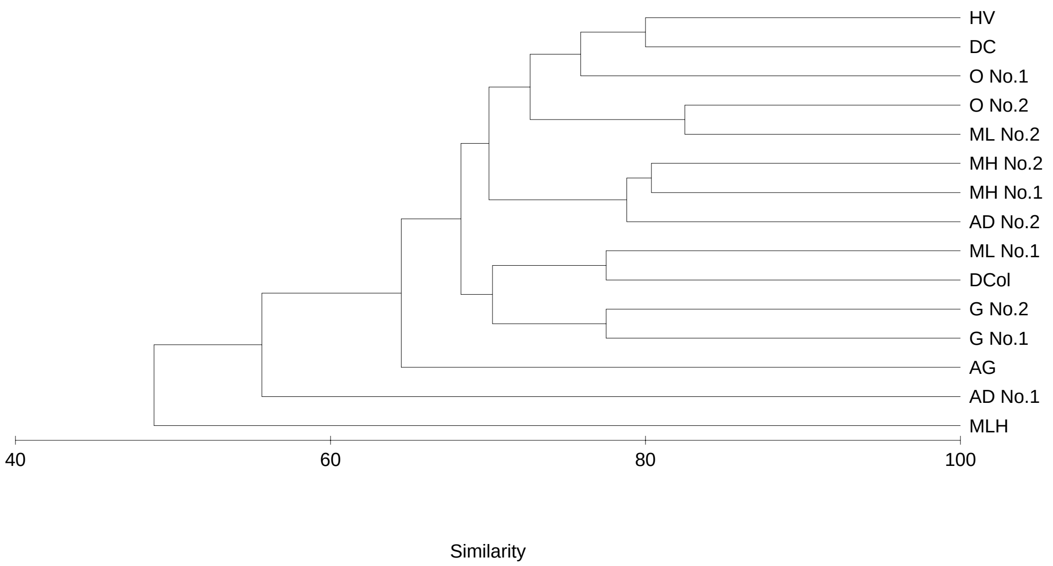
A total of 133 vascular plant taxa were recorded in 210 quadrats (Appendix 1). These comprised nine exotic taxa, 32 rare and eight vulnerable taxa in Victoria (Victorian Rare or Threatened Species); and one rare taxon and one vulnerable listed taxon in Australia (Australian Rare or Threatened Species).

3.2.1 Cluster analysis and ordination

Cluster analysis and ordination of samples from the 15 snow patch sites within the Mt Hotham Alpine Resort, based on presence/absence (Figure 3a and b) and percent cover data (Figure 4a and b) separated sites into three groups, one large and two discrete groups:

1. Alpine snow patches - Australia Drift No. 2 (Figure 5a), Avalanche Gully, Derrick Cairn, Derrick Col, Gotcha No.1, Gotcha No.2, Mt Hotham No. 1, Mt Hotham No.2, Mt Loch No.1, Mt Loch No.2, Orchard No.1, Orchard No.2;
2. Subalpine snow patch - Mt Little Higginbotham (Figure 5b); and
3. Open herbfield - Australia Drift No.1 (Figure 6).

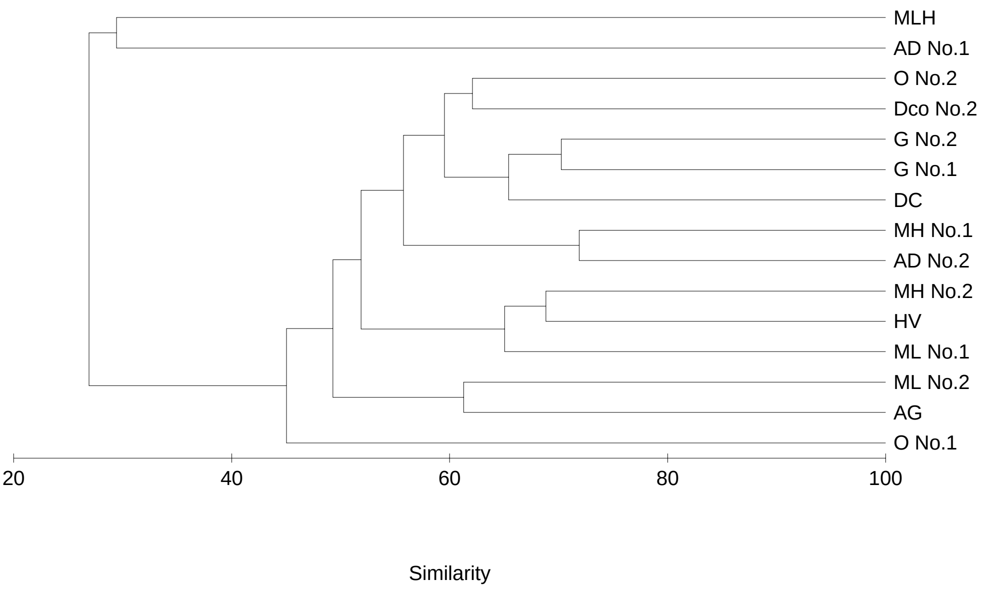
(a)



(b)

Figure 3. All snow patch sites based on presence/absence data (a) Cluster analysis dendrogram (b) Ordination plot.
MLH: Mt Little Higginbotham; AD No.1: Australia Drift No. 1; AG: Avalanche Gully; G No. 1: Gotcha No.1; G No. 2: Gotcha No. 2; DCol: Derrick Col; ML NO.1: Mt Loch No.1; ML No.2: Mt Loch No.2; AD No.2: Australia Drift No. 2; MH No.1: Mt Hotham No. 1; MH No.2: Mt Hotham No.2; ML No.2: Mt Loch No.2; O No.1: Orchard No.1; O No.2: Orchard No.2; DC: Derrick Cairn; HV: Heavenly Valley

(a)



(b)

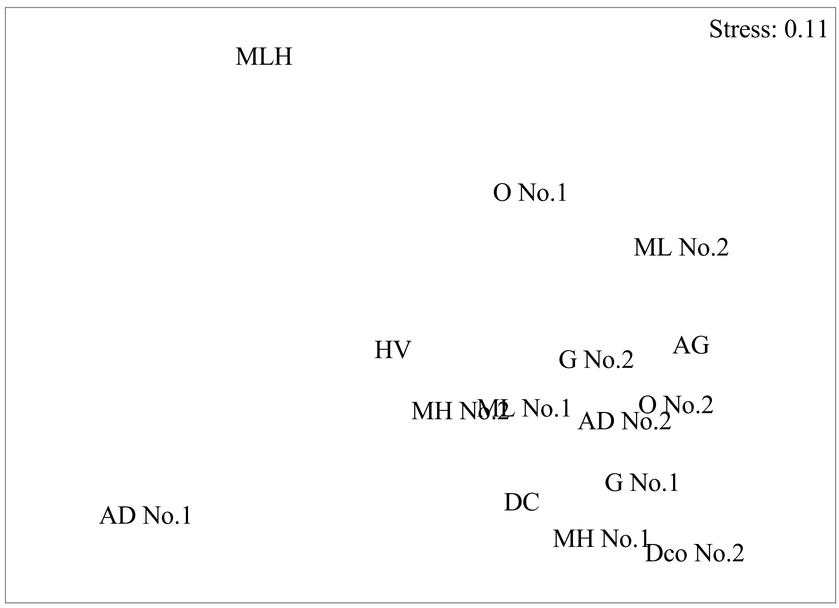


Figure 4. All snow patch sites based on percent cover data (a) Cluster analysis dendrogram (b) Ordination plot.
MLH: Mt Little Higginbotham; AD No.1: Australia Drift No. 1; AG: Avalanche Gully; G No. 1: Gotcha No.1; G No. 2: Gotcha No. 2; DCol: Derrick Col; ML NO.1: Mt Loch No.1; ML No.2: Mt Loch No.2; AD No.2: Australia Drift No. 2; MH No.1: Mt Hotham No. 1; MH No.2: Mt Hotham No.2; ML No.2: Mt Loch No.2; O No.1: Orchard No.1; O No.2: Orchard No.2; DC: Derrick Cairn; HV: Heavenly Valley

(a)

(b)

Figure 5. (a) Australia Drift No. 2 an alpine snow patch, showing remaining snow on 21/11/02 (b) Subalpine snow patch on Mt Little Higginbotham, showing remaining snow on 30/10/02.

Figure 6. Open herbfield of Australia Drift No. 1 is partially covered by snow in the lower right corner on 30/10/02. Melt water from other snow patches (eg. Australia Drift No. 2 upper left corner and unnamed snow patch in centre of figure) are irrigating this snow patch.

3.2.2 ANOSIM and SIMPER routines

Results from single factor ANOSIM contrasting alpine snow patches, subalpine snow patches and open herbfield, showed a significant difference between groups, with both presence/absence ($R = 0.73$, $P < 0.001$) and percent cover data ($R = 0.66$, $P < 0.001$) separating these groups.

Analysis of these groups using SIMPER revealed mean cover (%) of characteristic taxa in alpine snow patches (Table 7), subalpine snow patches (Table 8) and open herbfield (Table 9). The five taxa with the highest mean cover (%) (characteristic taxa) for each community have been listed in red.

The SIMPER routine was utilised to highlight those taxa useful for discriminating between the vegetation groups. The average dissimilarity between: alpine and subalpine snow patches was 87.39 % (Table 10), open herbfield and alpine snow patches was 95.61 % (Table 11) and open herbfield and subalpine snow patches was 92.84 % (Table 12).

Table 7. Mean cover (%) of characteristic alpine snow patch taxa. Taxa are listed in order of their contribution to the mean similarity among samples, up to a cumulative percent contribution (Cum %) of 95%. Denotes * introduced taxa.

Taxon	**Mean cover (%)**	**Cum (%)**
Poa fawcettiae	26.1	32.3
Luzula acutifolia subsp. *acutifolia*	10.0	46.1
Rytidosperma nudiflorum	10.7	56.2
Celmisia asteliifolia	10.2	64.6
Aciphylla glacialis	7.7	71.5
*Hypochoeris radicata**	3.9	75.8
*Acetosella vulgaris**	2.6	79.4
Brachyscome nivalis	2.6	81.6
Austrodanthonia alpicola	4.3	83.6
Grevillea australis	7.1	85.4
Moss species	2.8	87.2
Trisetum spicatum subsp. *australiense*	2.4	88.9
Oreomyrrhis eriopoda	1.2	90.2
Craspedia aurantia	1.6	91.4
Carex hebes	1.5	92.5
Erigeron nitidus	1.5	93.4
Poa hothamensis var. *hothamensis*	2.4	94.2
Leucopogon montanus	2.6	95.0

Table 8. Mean cover (%) of characteristic subalpine snow patch taxa. Taxa are listed in order of their contribution to the mean similarity among samples, up to a cumulative percent contribution (Cum %) of 95%. Denotes * introduced taxa.

Taxon	**Mean cover (%)**	**Cum (%)**
Celmisia asteliifolia	30.46	23.96
Pimelea axiflora subsp. *axiflora*	9.31	35.03
Poa hothamensis var. *hothamensis*	9.38	45.19
*Acetosella vulgaris**	5.62	54.16
Brachyscome rigidula	8.46	62.29
Hovea montana	17.96	69.51
Grevillea australis	14.94	76.59
Ajuga australis	2.38	79.27
Carex breviculmis	2.29	81.72
*Hypochoeris radicata**	3.04	84.03
Trisetum spicatum subsp. *australiense*	2.12	86.12
Olearia phlogopappa var. *flavescens*	6.79	88.07
Craspedia jamesii	2.23	89.75
Euphrasia crassiuscula subsp. *crassiuscula*	3.79	91.03
Epilobium sarmentaceum	2.9	92.3
Craspedia aurantia	1.62	93.34
Aciphylla glacialis	2.88	94.26
Cotula alpina	1.67	95.08

Table 9. Mean cover (%) of characteristic open herbfield taxa. Taxa are listed in order of their contribution to the mean similarity among samples, up to a cumulative percent contribution (Cum %) of 95%. Denotes * introduced taxa.

Taxon	**Mean cover (%)**	**Cum (%)**
Caltha introloba	23.17	30.64
Brachyscome tadgellii	11.04	45.87
Carpha nivicola	9.12	54.45
Poa costiniana	13.75	62.74
Carex gaudichaudiana	5.04	69.07
Oreobolus distichus	12.79	74.83
Rytidosperma nudiflorum	8.21	79.08
Acaena novae-zelandiae	4.83	82.9
Celmisia sericophylla	4.31	85.66
Schoenus calyptratus	2.5	88.28
*Hypochoeris radicata**	4.15	90.74
Viola betonicifolia subsp. *betonicifolia*	2.17	92.88
Drosera arcturi	3.75	94.77
Moss species	1.38	95.49

Table 10. Mean cover (%) of important taxa discriminating between alpine and subalpine snow patches. Taxa are listed in order of their contribution to the mean dissimilarity among samples up to a cumulative percent (Cum %) of 70%.

Taxon	**Mean cover (%)**		**Cum (%)**
	Alpine	**Subalpine**	
Celmisia asteliifolia.	10.4	30.5	12.7
Poa fawcettiae	29.3	0.0	24.7
Hovea montana	0.0	18.0	32.4
Grevillea australis	1.4	14.9	38.6
Luzula acutifolia subsp. *acutifolia*	11.3	0.0	43.3
Rytidosperma nudiflorum	11.8	1.1	48.0
Poa hothamensis var. *hothamensis*	2.3	9.4	51.9
Pimelea axiflora subsp. *alpina*	1.5	9.3	55.6
Brachyscome rigidula	0.4	8.5	59.2
Aciphylla glacialis	8.0	2.9	62.6
Olearia phlogopappa var. *flavescens*	0.2	6.8	65.3
Bossiaea foliosa	0.0	5.2	67.4
Austrodanthonia alpicola	4.8	0.0	71.6

Table 11. Mean cover (%) of important taxa discriminating between *Caltha* herbfield and alpine snow patches. Taxa are listed in order of their contribution to the mean dissimilarity among samples up to a cumulative percent (Cum %) of 70%. Denotes * introduced taxa.

Taxon	**Mean cover (%)**		**Cum (%)**
	Open herbfield	**Alpine**	
Poa fawcettiae	0.0	29.3	11.7
Caltha introloba	23.2	0.1	21.0
Poa costiniana	15.2	3.3	27.5
Rytidosperma nudiflorum	8.2	11.8	33.2
Oreobolus distichus	12.8	0.0	38.1
Luzula acutifolia subsp. *acutifolia*	0.3	11.3	42.7
Brachyscome tadgellii	11.0	0.0	47.1
Celmisia asteliifola	0.4	10.4	51.2
Carpha nivicola	9.1	0.0	54.8
Aciphylla glacialis	0.0	8.0	58.0
*Hypochoeris radicata**	4.2	4.4	60.2
Austrodanthonia alpicola	0.6	4.8	62.4
Acaena novae-zelandiae	4.8	0.2	64.4
Carex gaudichaudiana	5.0	0.0	66.5
Celmisia sericophylla	4.3	0.4	68.4
*Agrostis capillaris**	5.2	0.0	70.3

Table 12. Mean cover (%) of important taxa discriminating between subalpine snow patches and *Caltha* herbfield. Taxa are listed in order of their contribution to the mean dissimilarity among samples up to a cumulative percent (Cum %) of 70%.

Taxon	**Mean cover (%)**		**Cum (%)**
	Open herbfield	**Subalpine**	
Celmisia asteliifolia.	0.4	30.5	11.1
Caltha introloba	23.2	0.0	19.45
Hovea montana	0.0	18.0	26.11
Poa costiniana	15.2	0.0	31.61
Grevillea australis	3.1	14.9	37.07
Oreobolus distichus	12.8	0.0	41.46
Brachyscome tadgellii	11.0	0.0	45.37
Poa hothamensis var. *hothamensis*	0.3	9.4	48.72
Pimelea axiflora subsp. *alpina*	0.0	9.3	52.04
Rytidosperma nudiflorum	8.2	1.1	55.3
Carpha nivicola	9.1	0.0	58.55
Brachyscome rigidula	0.3	8.5	61.58
Olearia phlogopappa var. *flavescens*	0.0	6.8	63.86
Bossiaea foliosa	0.0	5.2	65.76

3.2.3 Classification

Classification of the quadrat data using PATN (Belbin 1987) from all sites based on percent cover data grouped open and closed heathland quadrats together, open herbfield (*Caltha* herbfield) quadrats together and revealed four discrete floristic communities within a broader alpine snow patch flora: *Austrodanthonia alpicola/Brachyscome nivalis* herbfield, *Celmisia* herbfield, mixed grassland (co-dominated by *Poa fawcettiae* and *Rytidosperma nudiflorum*) and *Poa fawcettiae* grassland (Table 13). The characteristic taxa cover values have been boxed in red to highlight the characteristic taxa of each floristic community.

Table 13. Sorted two-way table of quadrats from Mt Hotham Alpine Resort.

		Alpine Snow Patch	Alpine Snow Patch	Alpine Snow Patch	Alpine Snow Patch	
Community	**Open and closed heathland**	***Austrodanthonia alpicola/Brachyscome nivalis* herbfield**	***Celmisia* herbfield**	**Mixed grassland**	***Poa fawcettiae* grassland**	**Open herbfield**
Quadrats	m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m	m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m	m m m m m m m m m m m m m m m m m m m m m m m m	m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m	m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m m	m m m m m m m m
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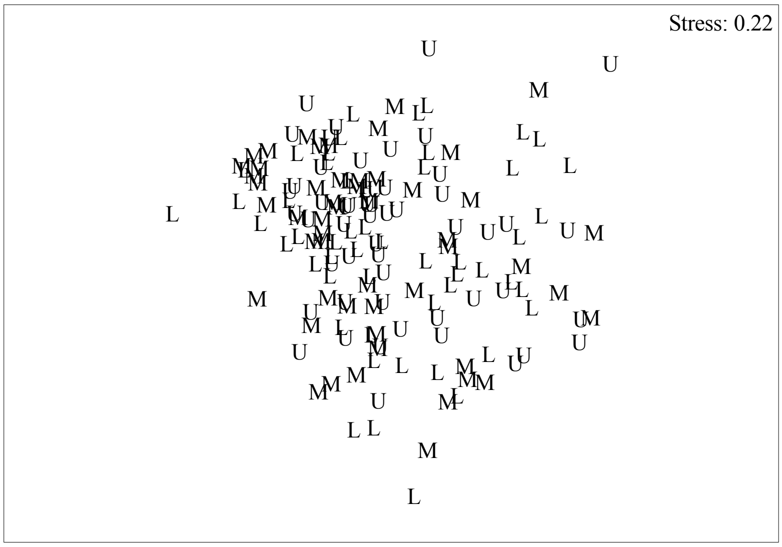
	0 0 0 0 1 0 1 0 0 1 0 1 0 0 1 0 0 0 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 0 1 1 1	0 0 0 1 1 0 0 0 0 1 1 0 0 0 1 0 0 0 0 0 1 0 0 0 1 0 0 0 0 1 0 1 1 2 1 1 1 1 1 1	0 2 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	0 0 1 1 1 1 0 0 0 0 0 0 0 1 1 0 0 1 1 1 1 0 1 1 0 0 0 0 0 1	0 1 0 1 1 0 0 2 0 0 0 1 2 2 0 0 2 2 0 1 1 2 0 0 0 0 0 1 1 0 0 0 0 0 0 1 1 1 1 1 1 1 2 0 1 1 1 1 2 0 0 0 0 1 0 0 0 0 0 1 1 1 0 0 0 0 1	0 0 0 0 0 0 0 0
	0 1 0 1 5 9 0 9 0 1 1 3 0 3 2 3 2 1 0 2 3 4 3 4 0 3 5 1 6 6 5 5 0 5 5 3 2 2 2	2 2 3 1 8 9 9 9 9 0 1 4 4 4 0 4 4 8 8 8 0 4 5 5 0 5 5 8 9 4 7 4 4 0 3 3 4 3 3 4	2 0 8 9 9 9 9 7 9 9 7 9 7 8 8 8 9 9 9 5 5 5 5 6	1 1 0 1 1 4 0 0 6 7 5 7 5 3 4 5 8 7 6 6 7 5 6 7 5 6 6 6 7 6 6	2 6 7 2 2 3 2 0 3 3 9 8 0 0 4 7 0 1 6 2 3 0 3 8 7 9 6 1 1 8 8 8 1 4 4 7 7 8 8 8 8 9 0 2 1 2 6 7 0 2 5 6 7 7 6 6 7 8 7 2 6 4 2 3 2 3 2	0 1 0 1 1 1 4 0
Species	1 3 6 8 1 9 0 3 7 3 9 5 1 7 3 5 6 4 2 8 0 8 5 2 4 9 9 0 2 2 0 4 9 2 5 8 0 1 6 7	1 8 4 4 8 1 2 4 3 5 1 3 7 5 6 6 8 2 4 1 1 9 6 0 7 7 2 8 5 0 7 1 2 0 4 5 6 6 7 9	0 6 7 6 7 0 8 6 0 1 7 5 9 0 5 6 2 4 3 2 7 3 6 1	0 7 4 0 3 8 5 8 1 1 1 8 5 1 7 3 3 1 4 8 4 8 5 3 4 4 3 5 4 0 3	2 6 9 8 9 2 9 3 7 8 6 9 1 5 4 0 9 0 6 5 0 4 9 9 6 8 8 9 6 0 7 6 1 1 2 5 8 2 3 1 4 9 2 3 7 3 9 0 7 0 9 7 5 2 2 9 2 5 3 2 7 3 6 3 7 5 4	2 1 9 6 4 5 0 4
Grev aust	5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 3 5 5 5 5 5 5 5 5 5 5 5 5 5 2 3 5 5 1 1 4 3 1 2	1 2 3 1 1	1 1 1	1 1	3 2 1	
Leuc mont	1 5 1 3 1 5 2 5 5 2 2 1 1 1 3 1 1	1 1 1 3 2 3 2 1 1 1	2 1 2 1 1 1 1 1 4 3 3 5 5 5	3 1 1 1 1 2	1 1 1 1 1 1 1 1 2 1 1 1 2 1 1 1 1 1	
Poa hotha	1 2 5 2 2 1 2 2 2 3 2 1 1 1 2 3 5 3 1 1 1 1 1 1 1 1	2 2 3 1 1 1 2 2 3 3 1 1 3 3 2	2 1 1 2 2 1 1 1 1	1 2 5 3 2 2	3 3 4 3 1 1 1 1 1	1
Pime axif	2 3 3 2 2 3 1 1 1 3 2 3 3 1 2 1 1	2 3 5 1 2 2 1 1 5 5 3	2 4 2 1 1 1 2 1 1 1 1 1 1	5 3 1	1	
Poa hiem	1 1 3 3 1 1 3 3 1 1 2 1 1		1			
Kunz muel	5 5 5 5 5					
Aust alpi	3 4 3 4 2 2 3 1 1 1	5 5 3 2 3 1 1 3 5 1 2 5 5 5 5 3 3 4 5 5 5 5 5 5 5 5 5 1 3 3	1	2 2	2 3 1 2 1 1 3 1 1	
Agro venu	1 1 1 1 1 1	2 1 2 1 1 1 1 1 1 1 1 2 2 5 1 1 1 1 1 1 2 3 2 1 1 1 3 5		1 1 3 2 2 1 1 1 1 1 1 1 1	1 1 1 1 1	1
Luzu nova	1 1 1 2 2 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1 1	1 2 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
Brac rigi	2 3 1 2 2 5 1 1 1	1 1 2 2 2 3	2 2 1 1 1	1 1 1 3 1 1	1	
Leuc albi	2 2 1 1 2 1	1 2 3 2 2 1 1 5 1 5 2 5 2 2 3 5 3 5 1	2	2 1 3 5 3 3 3		
Brac niva	1 1 1 1 1 1 1 1 1 1 1	2 1 1 1 3 2 2 1 1 1 1 1 2 2 1 1 1 3 1 2 1 1 2 3 2 1 2 1 2 1 2 1 3 2	2 1 1 2 1 1 1 1 1 2 2 1 1	1 1 1 1 2 1 1 2 1 1 2 1 2 2 1 2	1 1 2 2 1 2 2 1 2 1 1 2 1 2 1 1 1 1 2 3 2 1 1 1 2 3 2 1 1 1 1 1 1 1 1	1
Cras cool	1 1 1 1 1 1 2 2	1 1 1 5 2 5 1 1	1 1	1 1 1 1 2 3 1 1 3 2 1 1	1 1 1 1 1 1	
Care brev	1 1 2 2 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1	1 1 1 1 1 1 1	1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1	
Celm aste	1 1 2 1 1 3 1 2 2 2 3 3 3 5 2 3 1 1 2 1 2 2 1 1 2 2 3 3 1 1 1	3 5 5 5 5 5 5 2 5 5 5 1 3 3 3 3 1 3 1 1 2 2 1 1 5 3 1 1 2	5 3 5 5 5 5 5 5 5 5 5 5 5 5 5 5 4 3 2 5 5 5 5 5	1 2 3 2 3 1 1 2 2 2 3 1 2 1 1 1	2 2 1 2 2 3 1 3 2 3 1 3 1 1 2 1 1 3 1 5 3 3 3 3 3 3 3 1 1 4 1 1 1 1	1
Poa fawc	1 4 4 2 1 2 1 3 1	1 1 2 3 5 3 1 3 3 2 5 5 5 5 3 3 3 2 2 2 3 5 5 3	5 5 3 3 4 1 1 3 3 4 2 2 3 3 3 2 3 3 2	2 1 2 3 3 3 3 5 5 5 5 5 5 5 5 5 5 4 4 3 4 4 2 2	3 5 5 5 5 5 5 5 5 5 5 5 5 4 5 5 5 5 5 4 5 5 5 5 5 5 5 5 5 5 5 5 3 5 5 5 5 5 5 5 1 2 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	
Luz acut	2 1 2 1 1 1 1 1 1 1 1 1 1 1	5 5 5 3 5 3 3 2 2 2 3 1 1 2 5 5 5 5 2 1 5 2 1 2 3 1 4 2 5 2 3 3 2 4 2 3 5 3 3 5	1 1 3 1 2 1 2 2 1 2 2 2 3 5 3 3 2 2 1	1 1 2 2 1 1 2 2 2 1 3 3 2 3 2 1 2 1 3 3 2 3 1 3	5 3 5 3 5 3 5 2 3 3 3 2 3 2 2 2 1 1 4 4 3 1 1 1 3 3 2 1 5 3 5 3 2 2 3 3 5 2 2 2 2 2 2 2 3 1 1 1 1 1 1 1 1 2 1 1	1 1
Acip glac	1 3 1 2 1 3 3 1 1 1 2 2 1 1 1 1	1 1 5 5 3 1 1 3 5 5 1 1 1 1 3 2 1 2 1 3 1 1	1 1 2 1 1 2 1 2 2 2 1 1 1 1 1 1 2 1	1 1 1 1 1 1 1 1 1 1 1 2 1 1	2 1 2 3 2 3 3 3 5 3 3 1 2 3 5 3 5 3 3 3 2 3 4 3 3 3 5 5 5 4 4 3 3 3 3 5 3 2 3 2 2 3 5 1 1 1 1 1 2 1 1 1 1 2 2 1 1 1 1 2 2 2	1
Ryti nudi	1 1 1 1 1 1 1 1 1 1 1 1 2 1 2 1 1	1 2 5 5 2 1 2 2 2 2 1 3 5 5 3 5 3 1 3 5 1 1 1 2 5 2 2 2 3 3 1 3 3 3	1 1 2 1 2 2 1 1 1	5 3 5 5 5 5 3 1 2 3 5 5 5 4 3 2 3 5 5 3 3 3 5 5 5 5 5 5	1 2 3 2 1 1 2 2 2 1 4 1 4 5 5 5 4 5 3 2 3 2 1 2 2 1 1 1 1 2 1 1 2 2 2 1 2 2 1 2 3 4 4 2	1 1 1 4
*Acet vulg**	1 1 1 1 1 1 1 1 1 1 1 1 3 1 1 1 1 1 1 1 1 1 1 1 1 3 1 1 2 1 1 1 1	1 1 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 3 1 1 1 1 1 2 1 1 1 1 2 1 1 1 1 1 1 1 1 3 2 2	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1 1 2 1 1 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	2 1 1 1 2 1 1 1 2 1 1 1 1 2 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1 1 1 2 1 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
Oreo erio	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 1 1 1 1 1 1 2 1 1 1 1 1 1 2 2	1 1 1 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1
*Hypo radi**	1 2 1 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 2 1 1	1 1 2 1 1 1 1 1 1 1 2 1 1 2 2 2 3 3 1 2 5 1 1 1 2 1 1 1 1 1 1 2 1 2 2 3 3 3 3	1 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1	3 5 1 1 2 1 3 1 1 2 1 1 1 3 1 3 2 3 3 3 2 1 1 2 1 1 2 1 1 1	1 1 1 2 2 3 1 1 2 1 2 1 1 1 2 2 2 2 1 1 1 1 1 1 2 1 1 1 2 3 2 1 1 1 1 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 1 1	1 1 1
Care hebe	1 1 1 2 1 1	1 1 1 1 1 1 1 1 1 2 3 3 1	1 1 1 1	1 1 1 1 1 1 1 1 1 1 2 1 1 2 1 1 1 1 1 1 1 1	1 1 3 2 1 1 1 1 1 1 1 1 1 1 1 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
Erig niti	2 1 1 1 1 2 1 1 1 1 1 2 1 1 1	1 2 1 3 1 1 2 2 1 1 1 1 2 1 1 1 1 1 1 1 2	1 3 1 1 1 1 1 1 1 1 2 1 1 1 1	1 1 2 1 1 1 1 1 1 2 1 3 1 1 1 1 1	1 1 1 1 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
Euch ford		2 1 1 2 1 1 1 2 2 1 2 1 1 1 1 1	1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 2 1 2 1 3 1 3 1 1 1 1 1	1 1 1 1 1 1 1 1 2 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	
Micr Sp2	1 1 2 2 1 1 1 1 1 1 1 1	1 1 1 1 3 1 1 1 1	1 1 1 1 1 1 1 1 2 1 2 1 1 1 1 1 1	1 1 1 1 1 2 1	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 1 2 1 1 1 2 1 1	
Tri spi	1 1 1 1 1 1 1 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 2 1 2 2 5 3 1 1 1 1 1 2 1 1 2 2 1 1 2 1 2 2	1 1 1 1 1 1 2 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 2 1 1 1 1 1 1 1 1 2	1 1 1 1 1 3 2 2 1 1 5 1 1 1 2 2 1 1 1 1 3 3 2 1 1 1 1 1 2 1 1 1 1	1
Moss Spec	1 1	2 2 2 2 2 2 1 5 2 5 5 2 3 3 1 3 5 1 2 1 2 1 3 1 1 1 2 2 1 3 2 3	1 1 1 1 1 1 2 1 2 2 2 2 2 1 1 1 1	1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1 1 1 1 1 3 3 3 3 2 1 2 3 1 1 1 1 1 1	1 2 1 1
Eup crc	1 1 1 1 1	1 2 3 5 1	1 2 3 1 3 3 3 2 2 2 1 1	2 1 3 1	1 1 5 5 5 3 3 3 2 1	
Brac tadg	2			2 5 2 3		1 2 3 2 1 2
Car gau	1			1 1 1		1 2 1 3 2 2 1 1
Scho caly				1		1 1 2 1 2 1 1
Cal int	1			1		5 5 3 5 5 5 2 5
Oreo dist						4 3 5 5 1
Car niv						3 4 2 3 3 2 1
Dros arct						3 3 1 1 1 1 1
Celm seri						3 2 1 1 1 3 5 1
Acae nova	2 2 1 3 1 1 2 1 1 1 1 1 1 1 1 1 1	3	1 1 1 1 1 1	3 2 1 1 1 1 1 1	1 1 1 1 1 1	1 2
Viol beto	1 1 1 2 1 1 1 1 1 1 1 1	1 1 1 2	1 1 1 1 1 1 1 1	1 2 1 1 1 1 1 1 1 1 1 1	1 1 1 1 1 1 1 1	1 1 1 1 1
Plan eurp	1 1 1 1 1 1 1 1	1 1 1 1 1	1 1 1 1 1 1 1 1	1 1 2 1 1 1 1 1 1 1	1 1 1 1 1 1 1	1
Sene pinn	1 1 1 1 1 1 1 1		1	1 1 2 1 1 2	1 3 1 1 1	
Aspe gunn	1 1 1 1 1 1 1 1 1 1		1 1 1 1 1 1 1 1 1 1	1 1	1 1	
Ranu vict	1 1 1 1 1 1 1 1		1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 1 1	1 1 1 1 1 1	
Wahl glor	1 1 1 1 1	1 1 1 1 1	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1 1 1	1 1 1 1 1 1 1 1 1 1 1 1	
Cras jame	2 3 1 1 1 2 2 1 1 1	1 1 3 1 1 1	1 1 1 1 1 1 1 1 1 1 1 3 3 1 1 1 1 1 1	2 1 2 1 1 1	1 1 1 1 1 1 1 2 1	
Sene pect	1 1 3	2 5 3 3 5	1	1 1	1 1 1 2 2 1 2 3 1	1
Agro muel	1	1 1 2 2 1			1 1 2 1 1 1	1
Euch arge	1 1	1 1 1 1 1 1 1 1	1	1 1 1 1 1 1 1	1 1 1 1 1 1 1 1 1 1 1 1 1	1
Brac spat	1 1	1 1 3 5 1 2 2 1 1 1		1	2 2 1 1 1 1	
Deye cras	1 1 1 1 1 1	1 3 2 1 1 1	1 1 1 1 1 1		1 1 1 1	
Ewar nubi	1 1 1	2 3 3		2	1 1 1 1 1	
Pime alpi	1 1 1 1 1 1 3 1 1 1 1 1 1 1 1 1 1	1 2 1 1 1 2 1	2 2 1 1 1 2 1 2 1	1 1 1 1	1 2 1 1 2 1 2	
Poa saxi	1	1 3 1	1		1 1 1 2 1	
Pras tadg	1	1	1	1 1 1 1	1 1 1 1 1 1 1	1
Poa cost	1 1 3 1 1	1	2 1 1 1 3 1 1 1	3 5 5 5 5 5 5 3 2 1 1	2 1 1 1 3 3 5 5 2 1 1 1 2 2 3	1 1 2 3 4 1
Erig bell	1 1 1	1 1 1 1 2	1 1	2 1	1 1 1	
Olea fros	1 1	2 1 2 3		1 2 1	1	
Scle sing	1 1 1 1 1 1 1	1 1	2 1 1	1 1	1 1 1 1	
Cotu alpi	1 1 3 2 1		2 1 1 1 1 1	1 1 1 1	1 1 1 1 1 1 1	
Luzu mode	1 1 1 1 1 1		1	1 1	1 1 1 1 1 1 1 1	
Lyco fast	2 1	1 3 1 1	1 1 1	3 1 1 1 1 1 1 3	1 1 1 1 2 1	
Scle bifl	1	1 1 1	1 1 1	1 2 4 1	2 2 2	
Aju aus	1 2 1 1 1		1 1 1 1 1			
Ranu eich	1 1 1 1 1 1 1		1 1 1 1	1	1 1	
Card lila	1 1 1 1 1 1		1 1 1			
Sene gunn	1 1 1 1 1 1 1		1 1 1 1		1 1	
Aspe pusi	1 3 3 1 1	1		1	1	
Epil sarm	1 2 1 1 3 1 1		1 1			
Hove mont	1 4 4 5 5 5		1			
Olea phlo	1 5 5 1 3 5 3 1 1		1 1 1 1 1 2 2	2		

3.3 Comparison of zones within snow patch sites

Ordination plots of pooled samples from the alpine snow patch sites using percent cover and presence/absence data from three different zones (upper, middle and lower) are shown in Figure 7 (a) and (b). The upper, middle or lower zones did not separate clearly using percent cover or presence/absence data. Single factor ANOSIM supported this with no significant difference between zones based on percent cover data (R= 0.003, P=0.595) or presence/absence data (R=0.002, P=0.338).

(a)



(b)

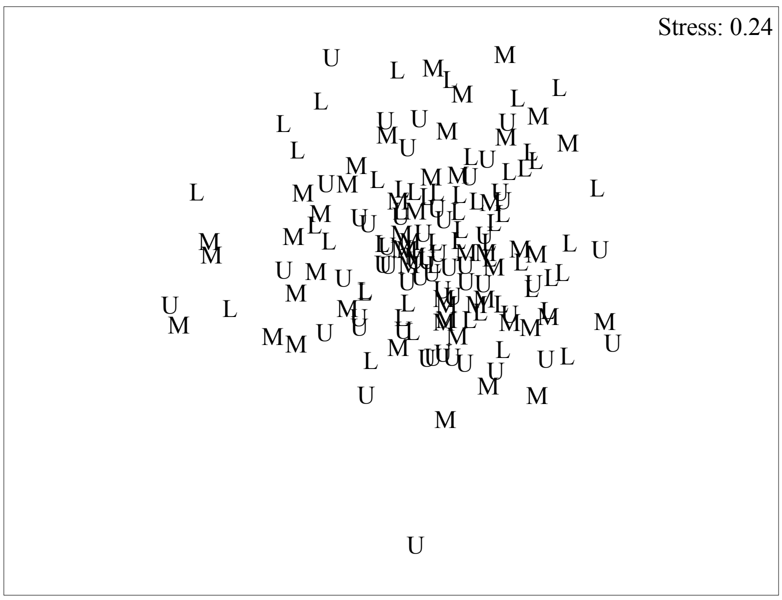


Figure 7. Comparison of zones within alpine snow patch sites (pooled data) (a) Ordination plot of zones within snow patch sites based on percent cover data (b) Ordination plot of zones within snow patch sites based on presence/absence data. U: upper; M: middle; L: lower.

4. DISCUSSION

4.1 Floristic composition and physiognomic units of snow patch communities at Mt Hotham

The snow patch vegetation sampled at Mt Hotham separated into three groups (*sensu* Wahren 1997; Wahren *et al.* 2001a) based on floristic composition, one large and two discrete groups:

1. Alpine snow patch;
2. Subalpine snow patch; and
3. Open herbfield (*Caltha introloba* herbfield).

4.1.1 Alpine snow patch

This first large group was labelled alpine snow patch vegetation as the results most closely conformed to the findings of Wahren (1997) and Wahren *et al.* (2001a), who have completed the most recent treatment of snow patch classification and description on the Bogong High Plains. Wahren (1997) and Wahren *et al.* (2001a) recorded *Poa fawcettiae* and *Celmisia asteliifolia* as the most common taxa of alpine snow patch vegetation and also identified closed herbfield and grassland as the two main structural assemblages within alpine snow patches.

The alpine snow patch group included: Australia Drift No. 2, Avalanche Gully, Derrick Cairn, Derrick Col, Gotcha No. 1 and No. 2, Heavenly Valley, Mt Hotham No. 1 and No. 2, Mt Loch No. 1 and No. 2 and Orchard No. 1 and No. 2. The characteristic plant taxa (*sensu* Woodgate *et al.* 1994) of these alpine snow patches were graminoids such as *Poa fawcettiae*, *Luzula acutifolia* subsp. *acutifolia* and *Rytidosperma nudiflorum* and forbs such as *Celmisia asteliifolia* and *Aciphylla* *glacialis*. Grasslands and herbfields were the major structural assemblages recorded within these snow patches. These structural assemblages were further classified into four discrete floristic communities: mixed grassland (co-dominated by *Poa fawcettiae* and *Rytidosperma nudiflorum*), *Poa fawcettiae* grassland, *Austrodanthonia alpicola* / *Brachyscome nivalis* herbfield and *Celmisia* herbfield within a broader alpine snow patch flora. Each of these floristic communities exhibits floristic gradations within snow patches, with environmental site factors determining the presence or absence of a particular floristic community within a snow patch. These factors are outlined in Table 14 and discussed in section 4.2.

The characteristic taxa (selected from Table 7 based on mean cover) and environmental factors of alpine snow patches within the Mt Hotham Alpine Resort are summarised and compared to other relevant studies in Table 14. This comparison is examined in further detail in section 4.3.1.

The concave shape of middle and lower slopes recorded by Wahren (1997) and Wahren *et al.* (2001a) for some of the larger alpine snow patches on the Bogong High Plains was recorded for several of the Mt Hotham alpine snow patch sites. Wahren (1997) and Wahren *et al.* (2001a) attribute the formation of these concavities or hollows (in middle to lower slopes) to periglacial processes that operated during the Pleistocene. The evidence for this was recorded on the mid to lower slopes of Mt Nelse, Mt Nelse North and Cope Hut where solifluction lobes and terraces were recorded (Wahren 1997; Wahren *et al.* 2001a). During this study localized concavities or hollows were recorded at Australia Drift No. 2, Derrick Cairn (Figure 8a), Gotcha No. 1 and Mt Hotham No. 1 and No. 2 (Figure 8b); and solifluction lobes/terraces were recorded at Gotcha No. 1, Mt Hotham No. 2, Orchard No. 1 and Orchard No. 2.

Table 14. Comparison of floristic and environmental data recorded for short turf snow patch, diuturnal snow patch, alpine snow patch (McDougall 1982; Wahren 1997; Wahren *et al.* 2001a) and Mt Hotham alpine snow patches.

	Short turf snow patch^	**Diuturnal snow patch^**	**Alpine snow patch#**	**Mt Hotham alpine snow patches**
Mean slope	15°	20°	26°	25°
Aspect	85° - 170°	90° - 180°	-	126° - 200°
Size	50 - 10 000m2	up to several hectares	1100 - 140 000m2	5300 - 26 100m2
Altitude	-	-	generally > 1750m	1720-1830m
Characteristic taxa	*Carex hebes*	*Celmisia asteliifolia*	*Celmisia asteliifolia*	*Celmisia asteliifolia*
	Poa hothamensis	*Poa fawcettiae*	*Poa fawcettiae*	*Poa fawcettiae*
	Viola betonicifolia	*Luzula acutifolia*		*Luzula acutifolia* subsp. *acutifolia*
		Carex hebes		*Rytidosperma nudiflorum*
				Aciphylla glacialis

^ McDougall (1982)

Wahren (1997) and Wahren *et al.* (2001a)

(a)

(b)

Figure 8. (a) Nivation hollow (yellow arrow) in middle/lower zone of Derrick Cairn 30/10/02. (b) Nivation hollow in middle/lower zone of Mt Hotham No. 2 21/11/02.

These localized concavities and solifluction lobes/terraces are fossil periglacial features, similar to those recorded by Rosengren *et al.* (1993) for Mt Hotham and by Galloway *et al.* (1998) for the Kosciuszko region. Active periglacial features such as the movement of soil and vegetation by the growth of needle ice, rock scratching, movement and cracking were also recorded during this survey (Figure 9a and b). These features are evidence of nivation processes (Galloway *et al.* 1998) and support the work of Costin *et al.* (1973) who found that snow patches on Mt Twynam (Kosciuszko region) exert a considerable force on the soil surface (0.2 – 37.9 Mpa).

The floristic communities identified within alpine snow patches of the Mt Hotham Alpine Resort are worthy of further investigation as the relationship between and within communities may provide insights into snow patch distribution and ecology. For example, the *Austrodanthonia alpicola* / *Brachyscome nivalis* herbfield is analogous to the *Austrodanthonia alpicola – Brachyscome nivalis* herbfield recorded by Costin (1954) and Costin *et al.* (2000) for the Kosciuszko region, where it is restricted to rock faces, crevices and shady boulders. In the Victorian Alps this community has been recorded by Costin (1957, 1962) but not in more recent studies by McDougall (1982), Wahren (1997) or Wahren *et al.* (2001a); although Jenkin (1994) did note the presence of an open mixed grass and herb vegetation type that occurred on steep, rocky slopes. During this study, *Austrodanthonia alpicola* / *Brachyscome nivalis* herbfield was recorded within ten (i.e. Australia Drift No. 2, Avalanche Gully, Derrick Cairn, Derrick Col, Gotcha No.2, Heavenly Valley, Mt Hotham No.2, Mt Loch No. 1 and No.2, and Orchard No. 2) of the thirteen alpine snow patch sites, however its distribution was restricted to rocky and cliff like areas. Typically, the quadrats containing *Austrodanthonia alpicola* / *Brachyscome nivalis* herbfield had a very high mean cover (40%) of rock.

(a)

(b)

Figure 9. Evidence of nivation processes within alpine snow patches of the Mt Hotham Alpine Resort (a) Rock scratching and movement within Australia Drift No. 2. (b) Rock cracking within Mt Hotham No. 2.

4.1.2 Subalpine snow patch

Mt Little Higgingbotham was the only subalpine snow patch site sampled during this study. The higher mean cover provided by *Poa hothamensis* var. *hothamensis* (9.38%) and the shrubs *Pimelea axiflora* subsp. *alpina* (9.31%), *Hovea montana* (17.96%) and *Grevillea australis* (14.94%) were useful in identifying this snow patch as more closely conforming to the description for subalpine snow patches by Wahren (1997) and Wahren *et al.* (2001a). The characteristic plant taxa of this site were *Celmisia asteliifolia*, *Pimelea axiflora* subsp. *alpina*, *Poa hothamensis* var. *hothamensis*, *Brachyscome rigidula, Hovea montana* and *Grevillea australis.* In particular, Wahren (1997) and Wahren *et al.* (2001a) state that the presence of snow grasses, was for the most part, useful in discriminating between snow patch types, with *Poa hiemata* and *P. hothamensis* (see above) mainly occurring on subalpine snow patches and *P. fawcettiae* (see section 4.1.1) predominating on alpine snow patches. Furthermore, six of twelve sampled quadrats were classified as heathland (*sensu* Specht 1981) at Mt Little Higginbotham (Figure 10a), similar to the observations of Wahren (1997) and Wahren *et al.* (2001a) that subalpine snow patches have a higher cover of shrubs with areas covered by open heath and shrubs above a herbfield layer.

4.1.3 Open herbfield (*Caltha introloba* herbfield)

Australia Drift No.1 was the only site sampled that contained open herbfield vegetation. This vegetation did not fit the descriptions by McDougall (1982), Wahren (1997) or Wahren *et al.* (2001a) for snow patch vegetation. The characteristic taxa were *Brachyscome tadgellii, Caltha introloba* (Figure 10b), *Carex gaudichaudiana, Carpha nivicola*, *Drosera arcturi*, *Oreobolus distichus* and *Schoenus calyptratus.*

(a)

(b)

Figure 10. (a) Mt Little Higginbotham showing patches of heathland over a herbfield layer; silvery grey areas are *Celmisia asteliifolia* 21/11/02. (b) *Caltha introloba* starts flowering under the snow 11/10/02.

Wahren (1997) and Wahren *et al.* (2001a) recorded similar vegetation at four of the larger snow patch sites on the Bogong High Plains and described it as an open herbfield on a stony substratum. This vegetation most closely conforms to *Caltha introloba* herbland community, as listed under the *Flora and Fauna Guarantee Act* 1988 (Scientific Advisory Committee 1992b). This community is restricted in Victoria and generally found below snow patches on flat, rocky sites with a constant flow of water (McDougall 1982; Scientific Advisory Committee, 1992b; Wahren 1997; Wahren *et al.* 1999; Wahren *et al.* 2001a). During this study, vegetation dominated by the characteristic taxa of *Caltha introloba* herbland community was also observed (but not sampled), within and above the Avalanche Gully alpine snow patch, and below the Mt Hotham No.1, Derrick Cairn and Orchard No. 1 alpine snow patches.

4.2 Zones within snow patches of Mt Hotham

No significant altitudinal stratification of vegetation was found between the upper, middle and lower zones of snow patches at Mt Hotham. The absence of significant altitudinal vertical stratification of vegetation supports the overall findings of Wahren (1997) and Wahren *et al.* (2001a) for the Bogong High Plains, but contrasts with McDougall's (1982) description for diuturnal snow patches and that for snow patch vegetation of the Kosciusko region (Costin 1954; McVean 1969; Atkin and Collier 1992; Costin *et al.* 2000).

The results from this study and the findings of Wahren (1997) and Wahren *et al.* (2001a), that altitudinal stratification of vegetation as a function of slope position was not consistent across sites, suggests that McDougall's (1982) description of diuturnal snow patch vegetation occurring in bands on the Bogong High Plains only occurs on the largest snow patch sites (>100 000m2). This is supported by the results from Mt Hotham, where no altitudinal stratification of vegetation was observed and the largest snow patch sampled was Mt Hotham No.1 at 26 100m^2.

Fjaeldmark vegetation similar to that described for snow patches of the Kosciuszko region (Costin 1954; McVean 1969; Atkin and Collier 1992; Costin *et al.* 2000) was not recorded during this study and has not been recorded elsewhere on the Bogong High Plains (McDougall 1982; Wahren 1997; Wahren *et al.* 2001a). However, vegetation similar to the short alpine herbfield described by Costin (1954); McVean (1969), Atkin and Collier (1992) and Costin *et al.* (2000) was recorded at the Australia Drift No.1 site as open herbfield (see 4.1.3).

The absence of obvious altitudinal stratification of vegetation within snow patches of the Bogong High Plains, when compared to that of the Kosciuszko region, was suggested by Wahren (1997) and Wahren *et al.* (2001a) to be a function of the longer period of snow lie in the Kosciuszko region with snow melt not complete until February or early March (Costin 1954; McVean 1969; Costin *et al.* 1973; Atkin and Collier 1992). This may be compared with the Bogong High Plains where snow melt is complete by late January, or early February (McDougall 1982; Wahren 1997).

Snow cover data collected during this study for Mt Hotham (Table 6) showed a considerably reduced period of snow lie, when compared to McDougall (1982) and Wahren's (1997) comments, with snow melt complete for all snow patches within the Mt Hotham Alpine Resort by the 10/11th of December (Table 6). However, interpretation of the snow cover data is limited, due to interannual variability (Osborne *et al.* 1998), as they only cover a very short period of time. Ruddell *et al.*

(1990) suggest that a period of 50 years would be required for establishing significant trends for mean precipitation.

Although, the results from this study do not support altitudinal stratification of vegetation within snow patches at Mt Hotham, the author's personal observations during this study revealed what appeared to be a visually distinct pattern of *Celmisia asteliifolia* dominating the upper and outer edges of some snow patches (eg. Figure 11a). The observed pattern of zonation may have been concealed during this study due to limitations associated with the sampling methodology, where the upper zone sampled may not have been accurately placed within the 'true' upper zone of the snow patch. This could be overcome in future studies of a long term nature where snow lie data could be collected for a site over a number of years, to accurately determine the extent of the snow patch.

It is hypothesized that the observed pattern may be attributable to a snow cover and/or moisture gradient, influencing floristic distribution and resulting in a semi-circular (upper and outer zones) pattern of zonation occurring at some snow patches. Wahren's (1997) results for larger alpine snow patches on the Bogong High Plains provide support for this hypothesis, with *Celmisia asteliifolia* occupying the drier upper zone, *Poa fawcettiae* occupying the wetter middle zone and open herbfield located in the lower zone, where it is fed by snow melt water. Wahren (1997) notes that even though snow melt pattern is generally consistent across sites, with the central zone of all snow patches the last to melt, the duration of the soil moisture gradient is insufficient to influence vegetation patterns at all sites, except for very large snow patches. At Mt Hotham, snow melt patterns were similar to those reported by Wahren (1997) with the central zone generally the last to melt (e.g. Figure 11b).

(a)

(b)

Figure 11. (a) Australia Drift No. 2 showing a visually distinct band of grey/ green *Celmisia asteliifolia* around the upper and outer zone 8/01/03 (b) Australia Drift No. 2 showing remaining snow located predominantly in the middle and central zone of the snow patch vegetation 30/10/02.

This hypothesis is supported by Venn (2001) who concluded that snowmelt patterns together with other associated environmental factors are probably one of the main influences affecting the distribution of community types (e.g. heathland, herbfield, etc.) and species richness within snowpatches on the Bogong High Plains.

An alternative hypothesis is that soil depth influences floristic distribution within snow patches with *Poa fawcettiae* dominating the deeper soils of the lower zone and *Celmisia asteliifolia* occupying the shallow and rocky soils of the upper zone. Supporting this hypothesis are the results from soil depth testing of alpine snow patch quadrats during this study, where a significant difference between upper and lower zones was recorded (Figure 2). The lower zones of alpine snow patches contained significantly deeper soils. This is consistent with the findings of Rosengren *et al.* (1993) and Uren and McMahon (1998) who found that deeper alpine humus soils at Mt Hotham were generally located at the base of moderately steep slopes (~20%). McDougall (1982), Wahren (1997) and Wahren *et al.* (2001a) also observed that for larger snow patches of the Bogong High Plains, lower zones contained deeper soils that were dominated by *Poa fawcettiae.*

It may also be that snow cover, soil moisture and soil depth are all influencing floristic distribution within snow patches, but that within smaller snow patch sites, this distribution is not evident. Whilst the floristic analysis from this study does not support altitudinal stratification of vegetation, it is worthy of further research, focusing on the role of snow duration and melt as well as soil depth and composition and snow patch size in driving floristic distribution within snow patches.

4.3 Conservation and management of snow patch vegetation within the Mt Hotham Alpine Resort

Snow patch vegetation is one of the rarest vegetation types in Australia with snow patches occupying less than 1% of the alpine landscape, which in turn, occupies less than 1% of Australia (Wahren *et al.* 2001a). In addition, to its rarity in a landscape context, snow patch vegetation at Mt Hotham contains a large number of rare and vulnerable taxa. For example, 32 rare and eight vulnerable taxa in Victoria (Victorian Rare or Threatened Species) and one rare taxon and one vulnerable listed taxon in Australia (Australian Rare or Threatened Species) were recorded during this study (Appendix 1). This high number of rare or threatened taxa highlights the specialized and restricted environmental niche that snow patches occupy. Some of these taxa such as *Luzula acutifolia* subsp. *acutifolia* were abundant (mean cover 10%) in sampled alpine snow patches at Mt Hotham, but are generally restricted to these areas, where patches of late lying snow regularly occur (Walsh and Entwistle 1994; Wahren 1997). The implications of this rarity for the snow patch vegetation of the Mt Hotham Alpine Resort are discussed below in the context of a proposed typology for the classification of snow patch vegetation, an evaluation of snow patch condition and conservation management recommendations for the Mt Hotham Alpine Resort Management Board.

4.3.1 Proposed typology for snow patch vegetation of the Mt Hotham Alpine Resort

Wahren (1997) and Wahren *et al.* (2001a) state that their description of alpine snow patches includes the vegetation described by McDougall (1982) as diuturnal snow patch, but that this vegetation type was only observed at very large snow patch sites (see section 4.2).

The variation between the findings of McDougall (1982), Wahren (1997) and Wahren *et al.* (2001a) are probably partly attributable to their methods for selecting vegetation units. McDougall's (1982) classification method was primarily based on presence or absence rather than variation in quantity compared to Wahren (1997) and Wahren *et al.* (2001a) whose results were based on relative abundance, rather than composition. The use of ordination and classificatory techniques in this thesis was designed to overcome these limitations and facilitate the comparison of results from different studies.

The unclear nature of snow patch classification is compounded, when considering the collective designation of snow patch vegetation units by the Scientific Advisory Committee (1992a) as 'Alpine Snowpatch Community' for *Flora and Fauna Guarantee Act* 1988 listing (Jenkin 1994). Jenkin (1994) suggested that by any definition alpine snow patch vegetation comprises a number of different 'communities' and therefore is not appropriately designated under the term 'Alpine Snowpatch Community' (Scientific Advisory Committee 1992a). This anomaly has been highlighted in a broader context by Downe (2001) in a paper on the mapping of listed *Flora and Fauna Guarantee Act* 1988 'communities'. Downe (2001) suggests that where the term 'community' has been used for listing nominations under the *Flora and Fauna Guarantee Act* 1988, its use has been quite lax and sometimes includes assemblages of taxa that form an Ecological Vegetation Class (EVC).

In addition to concerns regarding the use of the term 'community', Jenkin (1994) also recorded three key observations (see pp. 10-11) of snow patch vegetation at Mt Hotham, which led him to state that the snow patches of the Mt Hotham Alpine

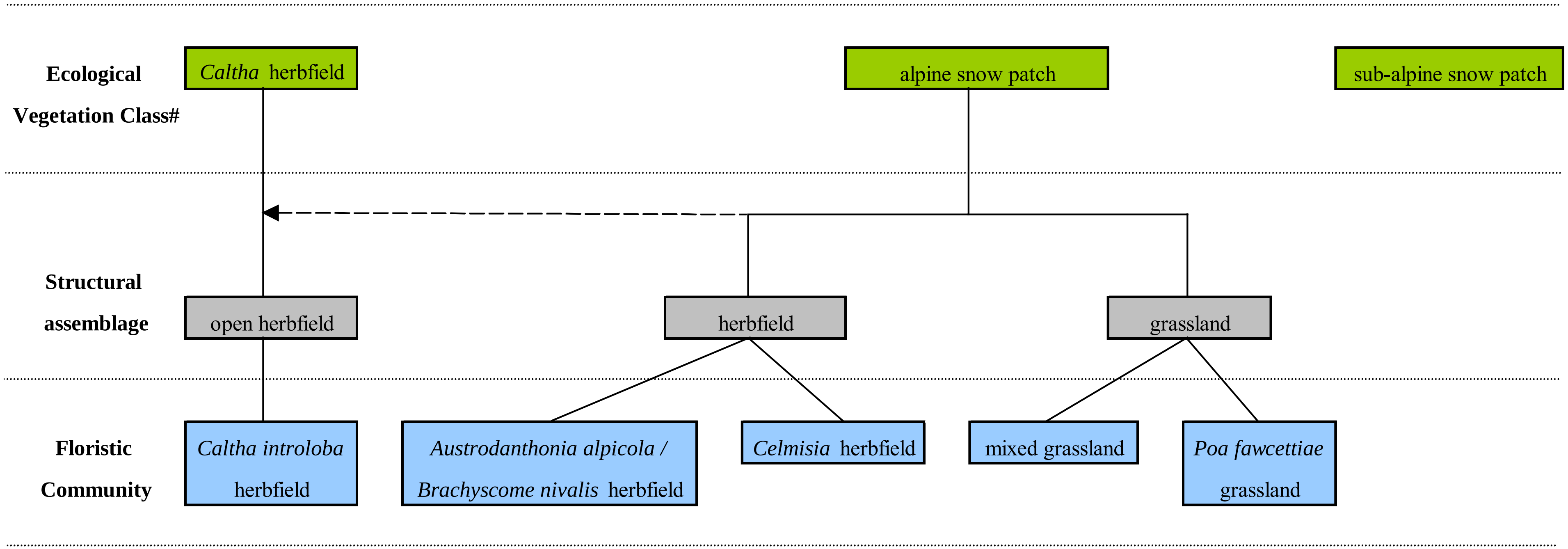
Resort did not fit McDougall's (1982) description of short turf snow patch. These three observations were supported by the results from this study.

Specifically:

1. Tussock forming *Poa fawcettiae* was one of the dominant (characteristic) taxa recorded within alpine snow patches with a mean cover of 26%;
2. The sward of plants in alpine snow patches at Mt Hotham commonly exceeded 10 cm in height; and
3. *Carex hebes* was not recorded as a dominant taxa in alpine snow patches, with a mean cover of only 1.5% and a maximum cover of 17.5% in only one quadrat out of 156 alpine snow patch quadrats.

In view of these results, Jenkin's (1994) concerns regarding the delineation and description of snow patch vegetation at Mt Hotham are well founded. These concerns were partially addressed by Wahren (1997) and Wahren *et al.* (2001a) in their description of snow patch vegetation of the Bogong High Plains. It is proposed, that based on the results presented in this thesis, that the description by Wahren (1997) and Wahren *et al.* (2001a) for alpine snow patches be adopted for classification of snow patches within the Mt Hotham Alpine Resort. It is also proposed that the description by Wahren (1997) and Wahren *et al.* (2001a) be applied at the EVC level (see definition below Figure 12) and that within these snow patches various structural assemblages and floristic communities be recognised (Figure 12). The use of the term EVC for snow patch classification recognises the ecological processes that characterise snow patches as well as considering their floristics and structure (Woodgate *et al.* 1994).

Figure 12. Proposed typology for classification of alpine and subalpine snow patches and *Caltha introloba* herbfield within Mt Hotham Alpine Resort.



#Ecological Vegetation Class (EVC) has been used in the sense of Woodgate *et al.* (1994) as the highest level in a hierarchy of vegetation typology and consists of one or a number of floristic communites that appear to be associated with a recognisable environmental niche and exist under a common regime of ecological processes within a particular environment. EVCs are defined by the ecological processes which charcaterise them, as well as their as their floristics and structure.

The application of the EVC typology will provide a basis for identifying and delimiting coherent alpine and subalpine snow patch vegetation within the Resort and has the potential to be applied in a wider context across the Bogong High Plains (this would be subject to additional sampling and mapping limitations). The use of the EVC framework, recognises the unique environmental niche that snow patches occupy, whilst also allowing for the combination of structural assemblages within an EVC based on floristic composition, vegetation structure, landform, environmental and ecological characteristics (Woodgate *et al.* 1994; Department of Natural Resources and Environment 2000). This is supported by the findings of Wahren (1997) and Wahren *et al.* (2001a) who noted that environmental factors such as duration of snow lie, altitude, slope and latitude were consistently and significantly correlated with the floristic composition of snow patch vegetation on the Bogong High Plains.

The proposed typology outlined in Figure 12 is primarily based on results from this study at Mt Hotham and only justifies the classification of alpine snow patch vegetation at the EVC level within the narrow context of the Mt Hotham Alpine Resort. Future research on snow patch vegetation should focus on sampling across the Bogong High Plains and attempt to describe and define snow patches within the EVC framework. Any final description should include comments on its distinct visual appearance within a landscape context (*sensu* Williams 1987), as well as other non-floristic descriptive comments such as the environmental and ecological characteristics listed in Table 14.

4.3.2 Condition of snow patch vegetation within the Mt Hotham Alpine Resort

The condition of snow patches within the Mt Hotham Alpine Resort has been assessed in relation to the proportion of bare ground, as a measure of general snow patch condition (Costin 1957b; Wahren *et al.* 2001a). Bare ground of snow patches at Mt Hotham was ≤10% mean cover for all snow patch sites. This contrast's with the results of Wahren (1997) and Wahren *et al.* (2001a) for the Bogong High Plains, where bare ground exceeded 20% cover at most sites. Wahren (1997) and Wahren *et al.* (2001a) attributed this high cover of bare ground to the preferential grazing of snow patches by domestic cattle, which graze parts of the Bogong High Plains in summer.

The significantly lower mean cover of bare ground, recorded by this study for snow patches at Mt Hotham, is also a noteworthy improvement on Costin's (1957b) broad qualitative catchment assessment of the Bogong High Plains and environs. Costin (1957b) recorded snow patches in the Mt Hotham region as all being adversely affected by cattle grazing, with soils and vegetation in some cases being almost completely removed. This improvement is more than likely due to the absence of cattle grazing at Mt Hotham and Mt Loch since 1961 (Cabena 1979). It is also consistent with results from the Kosciuszko region where the absence of grazing has seen a significant improvement in the condition of the alpine and subalpine landscape (Williams and Costin 1994).

The low bare ground cover values, recorded for snow patches of the Mt Hotham area, support comments by Farrell and Jeremiah (1991), Wahren (1997) and Wahren *et al.* (2001a) that grazing by domestic cattle is a potential threat to snow patch vegetation.

Furthermore, that grazing combined with the short growing season and natural disturbance regime (i.e. frost heave, wind, etc.) of snow patches means that there is a high risk of soil erosion on snow patches of the Bogong High Plains. From a conservation perspective, the reduced cover of bare ground recorded for snow patches at Mt Hotham, supports actions to remove or limit domestic cattle grazing on the Bogong High Plains (eg. Victorian National Parks Association *et al.* 2002). The absence of grazing at Mt Hotham for over 40 years has provided the impetus for snow patches of the area to recover significantly from a very degraded state.

4.3.3 Implications for management and conservation of snow patch vegetation within the Mt Hotham Alpine Resort.

Management of snow patch vegetation within the Mt Hotham Alpine Resort must consider the condition and delineation of snow patch vegetation within the cadastral boundary of the Resort. The Mt Hotham Alpine Resort Management Board must also consider its primary environmental management objective, to ensure that policies and management practices across the Resort protect and where possible enhance its rare and vulnerable biodiversity (Mt Hotham Alpine Resort Management Board 2002). In view of these factors it is recommended that the Mt Hotham Alpine Resort Management Board:

1. Adopt the proposed typology outlined in Figure 12 for classification of snow patch vegetation within the Resort;
2. Update its mapping information to reflect recent scientific research; and
3. Commission a floristic survey of snow patches, not sampled during this study, to determine appropriate classification and delineation.

Delineation of snow patch vegetation within the Mt Hotham Alpine Resort is currently based on the Soil Conservation Authority (1984) Mt Hotham map sheet (Pelly *pers. comm.*). This map sheet marks all snow patches within the Resort as being short turf snow patches. Results from this study (see section 4.1.1) and the author's personal observations (of non-surveyed snow patches) indicate that the vast majority of snow patches within the Mt Hotham Alpine Resort more closely conform to the description of Wahren (1997) and Wahren *et al.* (2001a) for alpine snow patch vegetation. As part of the Mt Hotham Alpine Resort Management Board's update of mapping information, it is recommended that the snow patches surveyed during this study be classified under the typology in Figure 12 and that any data from the commissioned floristic survey be added to the Resorts mapping system.

The implementation of these recommendations will further the Mt Hotham Alpine Resort Management Board's knowledge of snow patch vegetation within the Resort and ensure that any future development that may impact on snow patch vegetation is assessed in the context of the most up-to-date and recent scientific research.

5. CONCLUSION

The snow patch vegetation of Mt Hotham separated into three groups; alpine snow patch, subalpine snow patch and *Caltha introloba* herbfield (*sensu* Wahren 1997; Wahren *et al.* 2001a). The alpine snow patch vegetation was further divided into four distinct floristic communities including *Austrodanthonia alpicola* / *Brachyscome nivalis* herbfield, *Celmisia* herbfield, mixed grassland (co-dominated by *Poa fawcettiae* and *Rytidosperma nudiflorum*) and *Poa fawcettiae* grassland. Each of these floristic communities exhibits floristic gradations within snow patches, with environmental site factors determining the presence or absence of a particular floristic community within a snow patch.

Based on the results from this study and the work of Wahren (1997) and Wahren *et al.* (2001a) a typology has been designed for the classification of snow patch vegetation. Under this typology it is proposed that alpine snow patches, subalpine snow patches and *Caltha introloba* herbfield are classified at the EVC level, and that within alpine snow patches four distinct floristic communities are recognised.

The implementation of the EVC typology will provide a framework for the accurate description of snow patch vegetation that considers, ecological and environmental factors, as well as the floristic composition and structure of snow patches. This typology creates a basis for future conservation management of snow patch vegetation within the Mt Hotham Alpine Resort.

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7. PERSONAL COMMUNICATION

Pelly, Tom. (2003). Manager – Resort and Environmental Services. Mt Hotham Alpine Resort Management Board. Mt Hotham.

Appendix 1. Total flora list

Denotes taxa listed as vulnerable (V) or rare (R) Nationally (AROTS)
Denotes taxa listed as vulnerable (v) or rare (r) in Victoria (VROTS)
Denotes taxa introduced (*) to Victoria

FERNS AND ALLIED PLANTS

Lycopodiaceae

			Lycopodium fastigiatum R.Br.	Mountain Clubmoss

Blechnaceae

			Blechnum penna-marina subsp. *alpina* (R. Br.) T.C. Chambers & P.A. Farrant	Alpine Water-fern

Dryopteridaceae

			Polystichum proliferum (R. Br.) C. Presl	Mother Shield-fern

CONIFERS

Podocarpaceae

			Podocarpus lawrencei subsp. *lawrencei* Hook. f.	Mountain Plum-pine

MONOCOTYLEDONS

Anthericaceae

			Arthropodium milleflorum s.s. (DC.) J.F. Macbr.	Pale Vanilla-lily

Cyperaceae

			Carex breviculmis R. Br.	Common Grass-sedge
			Carex gaudichaudiana Kunth.	Fen Sedge
			Carex hebes Nelmes	Mountain Sedge
			Carpha nivicola F. Muell.	Broad-leaf Flower-rush
			Isolepis crassiuscula Hook. f.	Alpine Club-sedge
			Isolepis habra Edgar (Sojak)	Wispy Club-sedge
			Oreobolus distichus F. Muell.	Fan Tuft-rush
			Schoenus calyptratus Kuk.	Alpine Bog-sedge
	v		*Uncinia ?sulcata* K. L. Wilson	Small Hook-sedge

Juncaceae

	v		*Juncus antarcticus* Hook. F.	Cushion Rush
	r		*Luzula acutifolia* subsp. *acutifolia* Nordensk.	Sharp-leaf Woodrush
	v		*Luzula atrata* Edgar	Slender Woodrush
			Luzula modesta Buchenau	Southern Woodrush
			Luzula novae-cambriae Gand.	Coarse Woodrush

Phormiaceae

			Dianella tasmanica Hook. f.	Tasman Flax-lily

Poaceae

		*	*Agrostis capillaris* var. *aristata* (Parn.) Druce	Brown-top Bent
		*	*Agrostis capillaris* var. *capillaris* L.	Brown-top Bent
	r		*Agrostis muelleriana* Vickery	Mueller's Bent
			Agrostis venusta Trin.	Misty Bent
			Austrodanthonia alpicola Vickery (H.P. Linder)	Crag Wallaby-grass

	Deyeuxia carinata Vickery	Keeled Bent-grass
r	*Deyeuxia crassiuscula* Vickery	Thick Bent-grass
	Deyeuxia monticola var. *monticola* (Roemer & Schultes) Vickery	Mountain Bent-grass
*	*Festuca rubra* L.	Red Fescue
v	*Hierochloe submutica* F. Muell.	Alpine Holy-grass
	Poa costiniana Vickery	Bog Snow-grass
	Poa fawcettiae Vickery	Horny Snow-grass
	Poa hiemata Vickery	Soft Snow-grass
	Poa hothamensis var. *hothamensis* Vickery	Ledge Grass
v	*Poa saxicola* R. Br.	Rock Poa
r	*Rytidosrerma nivicolum (* Vickery) Connor & Edgar	Snow Wallaby-grass
	Rytidosperma nudiflorum (P. Morris) Connor & Edgar	Alpine Wallaby-grass
	Trisetum spicatum subsp. *australiense* Hulten	Bristle Grass
	Orchidaceae	
	Prasophyllum tadgellianum R.S. Rogers	Small Alpine Leek-orchid
	DICOTYLEDONS	
	Apiaceae	
v	*Aciphylla glacialis* (F. Muell.) Benth.	Snow Aciphyll
r	*Diplaspis nivis* Van den Borre & Henwood	Snow Pennywort
	Oreomyrrhis ciliata Hook. F.	Fringed Caraway
	Oreomyrrhis eriopoda (DC.) Hook. f.	Australian Caraway
v	*Schizeilema fragoseum* (F. Muell.) Domin	Alpine Pennywort
	Trachymene humilis subsp. *breviscapa* (Domin) P.S. Short	Alpine Trachymene
	Asteraceae	
*	*Achillea millefolium* L.	Milfoil (Yarrow)
	Brachyscome nivalis F. Muell.	Snow Daisy
	Brachyscome rigidula (DC.) G.L.R. Davis	
	Brachyscome spathulata subsp. *spathulata* Gaudich.	Spoon Daisy
r	*Brachyscome tadgellii* Tovey & P. Morris	Tadgell's Daisy
r	*Celmisia costiniana* M. Gray & Given	Carpet Snow-daisy
r	*Celmisia latifolia* (F. Muell. ex Benth.) M. Gray & Given	Victorian Snow-daisy
	Celmisia pugioniformis M. Gray & Given	Slender Snow-daisy
v	*Celmisia sericophylla* J.H. Willis	Silky Snow-daisy
r	*Celmisia tomentella* M. Gray and Given	Silver Snow-daisy
	Chrysocephalum semipapposum (Labill.) Steetz in Lehm.	Clustered Everlasting
	Cotula alpina (Sieber ex Spreng.)	Alpine Cotula
r	*Craspedia aurantia* J. Everett & Joy Thomps.	Orange Billy-buttons
	Craspedia coolaminica J. Everett & Joy Thomps.	Ashen Billy-buttons
r	*Craspedia crocata* J. Everett & Joy Thomps.	Crimson Billy-buttons
r	*Craspedia jamesii* J. Everett & Joy Thomps.	Green Billy-buttons
r	*Ewartia nubigena* (F. Muell.) Beauverd	Silver Ewartia
	Erigeron bellidioides (Hook. f.) S.J. Forbes & D.I. Morris	Hairy Fleabane
	Erigeron nitidus S.J. Forbes	Varnished Fleabane
	Euchiton argentifolius (N.A. Wakef.) Anderb.	Silver Cudweed
r	*Euchiton fordianus* (M. Gray) P.S. Short in Wilson	Alpine Cudweed
	Helichrysum rutidolepis s.l. DC.	Pale Everlasting
*	*Hypochoeris radicata* L.	Cat's Ear
	Leptinella filicula (Hook. f.) Hook. f.	Mountain Cotula
r	*Leptorhynchos squamatus* subsp. *alpinus* Flann	Alpine Buttons
	Leucochrysum albicans subsp. *albicans* var. *albicans* (A. Cunn.) Paul G. Wilson	Hoary Sunray

		Microseris sp. 2 sensu Jeanes (1999)	Alpine Yam-daisy
R	r	*Olearia frostii* (F. Muell.) J.H. Willis	Bogong Daisy-bush
	r	*Olearia phlogopappa* var. *flavescens* (Hutch.) J.H. Willis	Dusty Daisy-bush
	r	*Ozothamnus alpinus* Anderb.	Alpine Everlasting
		Picris angustifolia subsp. *merxmuelleri* Lack & S. Holzapfel	Highland Picris
		Rhodanthe anthemoides (Spreng.) Paul G. Wilson	Chamomile Sunray
		Senecio gunnii (Hook. f.) Belcher	Mountain Fireweed
	r	*Senecio pectinatus* var. *major* F. Muell. ex Belcher	Alpine Groundsel
		Senecio pinnatifolius var. *pleiocephalus* A. Rich	Variable Groundsel
	*	*Taraxacum officinale* L. spp. agg.	Mountain Dandelion
		Xerochrysum subundulatum (Sch.-Bip.) R.J. Bayer	Orange Everlasting
		Brassicaceae	
		Cardamine lilacina s.l. Hook.	Lilac Bitter-cress
		Campanulaceae	
		Wahlenbergia gloriosa Lothian	Royal Bluebell
		Caryophyllaceae	
		Colobanthus affinus (Hook.) J.D. Hook.	Alpine Colobanth
	r	*Scleranthus biflorus* s.s. (J.R. Forst. & G. Forst.) Hook. f.	Twin-flower Knawel
	r	*Scleranthus singuliflorus* (F. Muell.) Mattf.	
		Stellaria pungens Brongn.	Prickly Starwort
		Crassulaceae	
		Crassula sieberiana (Schult. & Schult. f.) Druce	Sieber Crassula
		Droseraceaa	
		Drosera arcturi Hook.	Alpine Sundew
		Epacridaceae	
		Epacris gunnii Hook. F.	Ace of Spades
		Leucopogon hookeri Sond.	Mountain Beard-heath
	r	*Leucopogon montanus* (R. Br.) J.H. Willis	Snow Beard-heath
		Monotoca scoparia (Sm.) R. Br.	Prickly Broom-heath
		Fabaceae	
		Bossiaea foliosa A. Cunn. in Field	Leafy Bossiaea
		Hovea montana (Hook. f.) J.H. Ross	Alpine Rusty-pods
		Podolobium alpestre (F. Muell.) Crisp & P.H.. Weston	Alpine Podolobium
	*	*Trifolium repens* var. *repens* L.	White Clover
		Geraniaceae	
		Geranium potentilloides L'Hér. ex DC.	Cinquefoil Cranesbill
		Geranium sessiliflorum susp. *brevicaule* (Hook.) Carolin	Alpine Cranesbill
		Gentianaceae	
		Chionogentias muelleriana susbp. *muelleriana* L.G. Adams	Mueller's Snow-gentian
		Goodeniaceae	
		Goodenia hederacea subsp. *alpestris* Sm.	Ivy Goodenia
		Haloragaceae	
		Gonocarpus montanus (Hook. f.) Orchard	Mat Raspwort

	Lamiaceae	
	Prostanthera cuneata Benth.	Alpine Mint-bush
	Myrtaceae	
	Eucalyptus pauciflora subsp. *niphophila* (Maiden and Blakey) L.A.S. Johnson & Blaxell	Alpine Snow-gum
	Kunzea muelleri Benth.	Yellow Kunzea
	Onagraceae	
	Epilobium gunnianum Hausskn.	Gunn's Willow-herb
r	*Epilobium* ?*sarmentaceum* Hausskn.	Mountain Willow-herb
	Pimeliaceae	
	Pimelea alpina F. Muell. ex Meisn.	Alpine Rice-flower
r	*Pimelea axiflora* subsp. *alpina* (F. Muell. ex Benth.) Threlfall	Alpine Bootlace Bush
r	*Pimelea ligustrina* subsp. *ciliata* Threlfall	Fringed Rice-flower
	Plantaginaceae	
	Plantago euryphylla B.G. Briggs, Carolin & Pulley	Broad Plantain
	Polygonaceae	
*	*Acetosella vulgaris* Fourr.	Sheep Sorrel
	Portulacaceae	
	Neopaxia australasica (Hook. f.) O. Nilsson	White Purslane
	Proteaceae	
	Grevillea australis R. Br.	Alpine Grevillea
r	*Grevillea victoriae* subsp. *victoriae* F. Muell.	Royal Grevillea
	Orites lancifolia F. Muell.	Alpine Orites
	Ranunculaceae	
	Caltha introloba F. Muell.	Alpine Marsh-marigold
r	*Ranunculus eichlerianus* B.G. Briggs	Eichler's Buttercup
r	*Ranunculus gunnianus* Hook.	Gunn's Alpine Buttercup
r	*Ranunculus victoriensis* B.G. Briggs	Victorian Buttercup
	Rosaceae	
	Acaena novae-zelandiae Kirk	Bidgee-widgee
	Rubiaceae	
	Asperula gunnii Hook. f.	Mountain Woodruff
	Asperula pusilla Hook. f.	Alpine Woodruff
	Rutaceae	
	Asterolasia trymalioides F. Muell.	Alpine Star-bush
	Salicaceae	
*	*Salix cinera* subsp. *cinerea* L.	Grey Sallow
	Scrophulariaceae	
r	*Euphrasia crassiuscula* subsp. *crassiuscla* Gand.	Thick Eyebright
V r	*Euphrasia crassiuscula* subsp. *gladulifera* W.R. Baker	Thick Eyebright

	Stackhousiaceae	
r	*Stackhousia pulvinaris* F. Muell.	Alpine Stackhousia
	Stylidiaceae	
	Stylidium armeria (Labill.) Labill	Common Trigger Plant
	Violaceae	
	Hymenanthera aff. *dentata* (Alpine)	Tree Violet
	Viola betonicifolia subsp. *betonicifolia* Sm in Rees	Showy Violet
	Winteraceae	
	Tasmannia xerophila subsp. *xerophila* (P. Parm.) M. Gray	Alpine Pepper