Floristic composition and environmental relationships of *Sphagnum*-dominated communities in Victoria

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Abstract: Floristic community types and their environmental correlates are described for *Sphagnum*-dominated communities throughout Victoria. Current threats to the condition of these communities are outlined, with an assessment of their conservation status. Sites from lowland (350 m) to alpine (1780 m) areas were surveyed and seven floristic groups were recognised using cluster analysis and non-metric multi-dimensional scaling techniques. The strongest floristic gradients corresponded to altitude, temperature, rainfall, geology and current condition. Several of the sites surveyed were degraded, with some sites heavily impacted by cattle grazing or invaded by weeds. While some floristic groups, particularly sub-alpine bogs, are reserved in national parks, others such as montane and lowland bogs occur on forestry and private land tenures. Reservation has not protected some sites from threatening processes, most notably in alpine national parks, where cattle grazing has seriously degraded many of these *Sphagnum* peatland communities to either disclimax communities or isolated moss beds no longer functioning ecologically as peatlands. Further surveys of *Sphagnum*-dominated communities elsewhere in Victoria are warranted, especially montane and lowland areas. The results suggest *Sphagnum*-dominated communities will require conservation planning and management action throughout their geographic range in Victoria.

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Introduction

In Australia, *Sphagnum* peatlands (sensu Gore 1983) are found primarily in montane, sub-alpine and alpine areas in poorly-drained topographic settings with nutrient-poor, acidic conditions. *Sphagnum* peatlands can be defined as distinct ecosystems where *Sphagnum* moss provides at least 30% of species cover and is the dominant peat former (Whinam et al. 2003). They are generally small in area, restricted in distribution, and have relatively few plant species. The distribution of *Sphagnum* peatlands is largely limited by evapotranspiration in the warmest months (Whinam et al. 2003). They occur in areas where there is a seasonally stable high watertable and where there is a constant supply of surface or seepage water.

The bulk of Australian *Sphagnum* peatlands are found in Tasmania (Whinam et al. 2001), with occurrences in the Australian Capital Territory and New South Wales (Millington 1954, Clarke and Martin 1999, Costin 1954, Costin et al. 2000, Whinam and Chilcott 2002). *Sphagnum*-dominated communities influence the hydrology of catchments (Costin 1962), but are susceptible to disturbance (Wahren et al. 1999) and climate change (Whinam et al. 2003).

In Victoria, the most detailed floristic descriptions of peatlands are those of Kestel (1993) who described 37 peatland sites, including their prehistories, conservation values, threats and reservation status. The distribution and composition of Victorian subalpine and alpine *Sphagnum* communities have been described by McDougall (1982) and Walsh et al. (1986) who both recognise these communities as either ‘alpine bog’ or ‘fen’, or as part of a ‘wet closed-heathland complex that occurs on deep peats’. Farrell and Ashton (1973) and Ashton and Hargreaves (1983) present local descriptions of wetlands for the Benison High Plains and Lake Mountain respectively. Most recently, Wahren et al. (1999) described the small-scale floristic composition and structure of wetlands, including *Sphagnum* bogs, on the Bogong High Plains with respect to peat depth, altitude and cattle disturbance. *Sphagnum* has been recorded as present, but not dominant, in other parts of Victoria, for example in the Otway Ranges (Meagher & Rankin 1996).

The ecology of subalpine *Sphagnum* bogs has been well studied in Victoria, particularly in relation to long-term disturbance impacts by, and recovery from, cattle grazing (Lawrence 1999, Wahren et al. 1999, 2001) and short-term recovery after fire (Wahren & Walsh 2000). The most potent threat to the survival of *Sphagnum* peatlands in Victoria is cattle grazing. The degradation of *Sphagnum* peatlands by cattle grazing in sub-alpine areas has been identified for more than 50 years (Wahren et al. 1999). The slope grooming and drainage works associated with ski slopes have led to severe degradation of the *Sphagnum* peatlands at Mt Buller. There has also been some illegal moss harvesting in parts of the Central Highlands (ANCA 1996, authors pers. obs.) while near Dinner Plain, trial harvesting of *Sphagnum* has been attempted (McDougall 2001). Due to a long history of disturbance and continuing threats, alpine and subalpine bogs have been listed as threatened communities in Victoria under the Flora and Fauna Guarantee Act (1988).

This study aims to: (a) determine the floristic composition and environmental gradients of *Sphagnum*-dominated peatlands across their altitudinal range in Victoria; (b) identify threats to these communities, and (c) describe the current condition of Victorian *Sphagnum* peatlands. We identify *Sphagnum* peatlands with significant nature conservation value, evaluate threats and propose mitigation methods.

Methods

Site selection

Sites were selected in Victoria for surveying from herbarium records, *A Directory of Significant Wetlands* (ANCA 1996), previous publications (especially Kestel 1993) and on the advice of our botanical colleagues. In total, 48 sites were identified and floristic surveys were conducted during January and March 2002 (see Appendix 1). In general, we defined *Sphagnum* peatlands as being usually greater than 0.25 ha (Whinam et al. 1989, 2001, Whinam & Chilcott 2002), but did survey smaller sites if the *Sphagnum* moss occupied distinct habitats (e.g. sinkholes, Whinam et al. 2001), or were remnants in larger degraded peatlands (Whinam & Chilcott 2002). Several sites that were reported to us as *Sphagnum* peatlands were found to be reduced to only handfuls of moss, and so are not included in these analyses (e.g. Mt Samaria Park, Mt Pilot State Park, Whitfield area, Mt Torbreck).

Field methods

As in previous comparative studies (Whinam et al. 2001, Whinam & Chilcott 2002), in each peatland, one 10 × 10 m quadrat was placed in a representative part of the vegetation and the percentage cover abundances of all species were recorded. Species nomenclature follows Ross (2000). At each site, we also recorded species present outside the quadrat and physical characteristics including aspect, slope, percent bare peat, mean peat depth (measured at three locations within the quadrat with a 2 m stainless steel probe) and mean height between hummocks and hollows to describe surface morphology (n = 3 observations). Moss stem length was recorded for *Sphagnum* as an indicator of growth rates (Clymo 1973), a measure of vigour and an indicator of the rate of decomposition (Whinam & Buxton 1997). A CSIRO Inoculo soil pH test kit was used to estimate the pH of the humified peat in each quadrat. Grid references were recorded with a GPS (accuracy ± 10 m), and altitudes were determined from 1:25 000 topographic maps. Geology was determined from 1:100 000 geological maps.

The condition of sites was scored based on the amount of damaged *Sphagnum* moss, the amount of bare ground, degree of pugging caused by hooves, and drainage alteration (e.g. edge erosion). Condition was assessed as undamaged (0); light damage, where only minimal surface disturbance was evident (1); degraded, where there was a breakdown of surface morphology e.g. through repeated hoof trampling (2); modified, where the surface and edge morphology had broken down i.e. edge erosion from trampling and pugging caused by hooves (3); highly modified and degraded, where the surface morphology had broken down and only patches of isolated *Sphagnum* moss remain in disturbed, bare peat (4). The condition classes were based on previous studies of *Sphagnum* communities and their conservation status (Whinam et al. 1989, Whinam 1995, Whinam et al. 2001, Whinam & Chilcott 2002). These indicators are readily identifiable in the field and represent important changes in the condition of peatlands that indicate temporal degradational trends.

Analytical methods

The data consisted of 48 sites and 269 vascular taxa, from which singleton species (i.e. species found at only one site) were then deleted, leaving 135 species in the dataset for analyses. *Sphagnum* spp. and *Polytrichum juniperinum* were the only lower plants recorded to species level. Other bryophytes were recorded at only 2 sites at cover values of <1%. Owing to the high number of taxa with less than 5% cover or cover values of >80% of dominant species, all data were converted to presence/absence prior to the analyses to give equal representation to species (Barmuta pers. comm.). Multivariate analysis of the data was performed using PATN (Belbin 1995). The Bray-Curtis coefficient (Faith et al. 1987) was used to represent floristic dissimilarity between sites.

Because floristic variation was anticipated to be relatively continuous, ordination was used to graphically represent the relationship between sites in multidimensional space with cluster analysis used to dissect the data for ease of description (Quinn & Keough 2002). Sites were ordinated by hybrid multidimensional scaling (HMDS) (Faith et al. 1987), with the semi-strong algorithm (Belbin 1991a). Multidimensional scaling has been shown to be the most robust method for ordinating community data (Kenkel & Orloci 1986, Minchin 1987, Quinn & Keough 2002). The ordination and classification methods used in these analyses follow those used for other regional analyses of *Sphagnum* communities (Whinam et al. 2001, Whinam & Chilcott 2002). The three-dimensional solution yielded a stress of 0.183. Groups were clustered by ß-flexible unweighted arithmetic average clustering (UPGMA) with ß=-0.1 (Belbin 1995).

The indicator value index (Dufrêne & Legendre 1997) was used to investigate the floristic characteristics of the groups in the resulting hierarchy. The indicator values were calculated by IndVal 2.0 (Dufrêne 1999) with equal weightings for the two components of the index, and 999 randomisations to assess significance at the 0.05 level.

To determine which climatic parameters, if any, may help to explain the vegetation patterns seen across sites, we used BIOCLIM to approximate energy and water balances at a given location (Nix & Bushby 1986). The BIOCLIM variables included in these analyses are defined in Table 1. Median values are given for environmental variables for each floristic group (Table 2), as they are more resistant to outlying values than means (Fowler & Cohen 1990).

Table 1. Codes and descriptions of bioclimatic variables from BIOCLIM (Houlder et al. 1999) and results of vector fitting of environmental variables and species richness to the three-dimensional ordination space.

n: number of observations**;** *R:* multiple correlation coefficient range of each variable. All correlations were significant to P < 0.05.

Variable name/(code)	*n*	*R*	Range
Altitude (m)(Alt)	48	0.891	500–1780
Geology (Geol)	48	0.470	sandstone, granite, phyllite schist/shale, Quaternary river terraces
Soil pH (PH)	48	0.651	4.5–6.5
Tendril length (cm) (AvTendril)	48	0.573	4–45
Peatland condition index (Condition)	48	0.623	0–4
[1]Annual mean temperature (ºC), (AnMeTemp)	48	0.895	5.0–13.2
[2]Annual mean precipitation (mm), (AnnPrec)	48	0.843	938–2442
[3]Precipitation of driest period (mm), (PrecDP)	48	0.804	17–97

[1]The annual mean of weekly mean temperatures. Each weekly mean temperature is the mean of that week's maximum and minimum temperature.

[2]The sum of all the monthly precipitation estimates.

[3]The precipitation of the driest week

The environmental variables were fitted to the ordination space by a vector-fitting approach (Dargie 1984, Bowman & Minchin 1987). The vectors are the directions through the configuration where the sites have maximum correlations (r) with the environmental variables. For each fitted vector, significance was tested by a Monte-Carlo randomisation procedure (Table 1) that compares the derived maximum correlation with the distribution produced from random permutations of the values of the environmental variables These analyses were performed by the principal axis correlation (PCC) routines in PATN (Belbin 1991b).

Results

The location of *Sphagnum* peatlands surveyed in Victoria and their floristic groups are shown in Figure 1. There is a regional grouping of the floristics of Victorian *Sphagnum* communities, that reflects the environmental variables of altitude and geology. A summary of environmental variables for each floristic group is presented in Table 2.

Two hundred and sixty-nine vacular plant species, comprising 250 native and 19 exotic species, were recorded in the survey across 48 sites. A total of 134 singleton species (excluded from analysis) were recorded at 34 sites, varying from one to eleven singletons per site. The highest numbers of singleton species occur in Group 4 (29 species), Group 7 (28 species) and Group 6 (26 species). High numbers of singletons occur at lower altitude sites with generally higher species richness, reflecting higher levels of disturbance of *Sphagnum* peatlands. Mean species richness (indigenous and exotic species) across all sites was 20 species per 100 m^2.

Community classification

Pattern analysis of species data resulted in seven groups being identified (see dendrogram, Fig. 2). Further dissection of the groups was not supported by indicator values for

Table 2. *Sphagnum* communities in Victoria, (with group numbers from the clustering in brackets). Ranges and median values (bold type) of environmental variables and species richness.

Peatland condition: (0) undamaged; (1) light damage, where only minimal surface disturbance was evident; (2) degraded, where there was a breakdown of surface morphology, e.g. through repeated hoof trampling; (3) modified , where the surface and edge morphology has broken down, i.e. edge erosion from trampling and pugging caused by hooves; (4) highly modified and degraded where the surface morphology has broken down and only patches of isolated *Sphagnum* moss remain in disturbed, bare peat

Floristic group/community	No. plots	Altitude (m)	Mean annual temp. (°C) (mm	Mean annual precip.) (mm)	Precip-itation driest period	pH	Mean moss stem length	Peatland condition (cm)	Species richness (0–4)
Bogong *Sphagnum* sub-alpine plots (Group 1)	17	1350–1780 **1640**	5.0–7.4 **5.6**	1695–2442 **2282**	78–97 **92**	4.5–6.0 **5.0**	4–20 **8**	0–4 **1**	11–23 **15**
Ungrazed sub-alpine *Sphagnum* peatlands (Group 2)	11	1420–1620 **1480**	5.5–7.3 **5.9**	1785–1918 **1870**	76–84 **81**	5.0–6.0 **5.0**	8–34 **12**	0–1 **0**	15–34 **20**
Relic alpine *Sphagnum* peatlands (Group 3)	5	1700–1740 **1700**	5.2–5.3 **5.3**	1675–2434 **1675**	74–95 **74**	4.5–6.0 **5.0**	8–12 **10**	2–4 **3**	9–25 **21**
Montane fern-*Sphagnum* peatlands (Group 4)	5	500–1280 **900**	7.3–12.1 **9.3**	938–1767 **1601**	44–69 **59**	5.5–6.0 **5.5**	5–23 **20**	0–1 **1**	15–31 **22**
Aquatic *Sphagnum falcatulum* fen (Group 5)	1	1120 **1120**	8.6 **8.6**	1518 **1518**	66 **66**	6.0 **6.0**	14 **14**	2 **2**	15 **15**
Degraded *Sphagnum* valley fens (Group 6)	4	900–1750 **1250**	5.2–9.0 **7.5**	1228–2369 **1752**	17–95 **54**	4.5–6.5 **6.0**	8–10 **10**	1–4 **3**	20–31 **22**
Montane shrubby *Sphagnum* fens (Group 7)	5	350–500 **350**	12.1–13.2 **13.1**	940–1179 **1165**	43–56 **55**	6.0 **6.0**	20–45 **32**	1–3 **3**	23–32 **28**

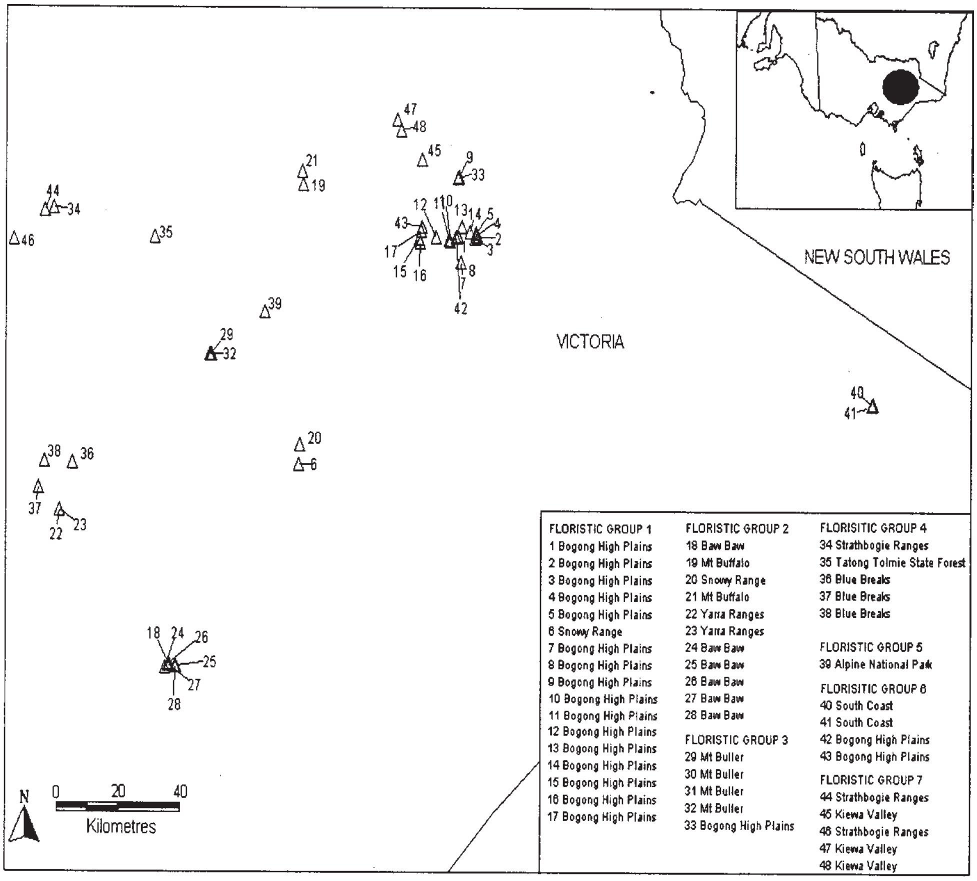

Fig. 1. Distribution of *Sphagnum* peatlands in Victoria. See text for descriptions of floristic groups.

species at lower nodes in the hierarchy because most of these nodes did not have significant ($P < 0.05$) indicator species associated with them.

The community classification, including significant ($P < 0.01$) indicator species for each of the final groups, is shown in Figs. 3 and 4, and the full hierarchically arranged two-way table of species by site groups together with indicator values is given in Appendix 2. A summary of species occurrence for each floristic group is shown in Appendix 3. The analysis yielded seven identifiable *Sphagnum* peatland types with a major split between alpine/sub-alpine sites (Groups 1 to 3) and montane sites (Groups 4 to 7), (Fig. 3). These seven types and their environmental attributes are described below.

Floristic group 1. Bogong *Sphagnum* sub-alpine peatlands

This group of Bogong sub-alpine peatlands has *Oreobolus distichus* as its distinguishing species, with *Astelia alpina, Baeckea gunnina, Richea continentis, Epacris petrophila* and *Celmisia tomentella* as constants. This was the most common *Sphagnum* community surveyed. *Sphagnum cristatum* cover ranged between 50–90% (median 80%), with one occurrence of *S. novo-zelandicum*. The condition of the sites varied considerably from two intact ungrazed sites to sites badly degraded by cattle grazing. Only one of the 17 sites in this group does not occur on the Bogong High Plains, but instead occurs on the Snowy Range. The altitude of sites in this group ranges from 1350 m to 1780 m (median 1640 m). While not having as cold annual mean temperature as Floristic Group 3 (median 5.6°C), these sites have the highest annual precipitation (median 2282 mm) and greatest precipitation in the driest period (median 92 mm). The landscape position of most of the sites is valley bogs. The geology is granite and phyllite schist/shale, and the median pH is 5.0. The sites have a moderate peat depth (median 70 cm), with short moss stem length (median 8.0 cm) and low to moderate species richness (median of 15) and low weediness (3 occurrences). Most of these sites show signs of 'pugging' caused by cattle hooves which results in exposed bare peat.

Floristic group 2. Ungrazed sub-alpine *Sphagnum* peatlands

The distinguishing species for this group is *Thelymitra venosa*, with *Acaena novae-zelandiae, Blechnum penna-marina* and *Lagenophora stipitata* common to the group. *Sphagnum cristatum* ranged between 15–95% cover (median 62%), with one occurrence of *Sphagnum falcatulum*. The absence of cattle damage in the *Sphagnum* peatlands and their intact condition is notable in this group of 11 sites. Ungrazed sub-alpine *Sphagnum* peatlands occur at Baw Baw, Mt Buffalo and the Snowy Range at altitudes ranging from 1420 m to 1620 m (median 1480 m). Annual mean temperature is 5.9 °C (median), with annual precipitation ranging from 1785 mm to 1912 mm (median 1870 mm). The geology for these sites is granite, with a median pH of 5.0 and a peat depth of 77 cm (median). The median moss stem length is 12.0 cm for the group, which has a moderate species richness (median 20) and low weediness (3 species). The landscape position of these sites is valley bog and headwater bog.

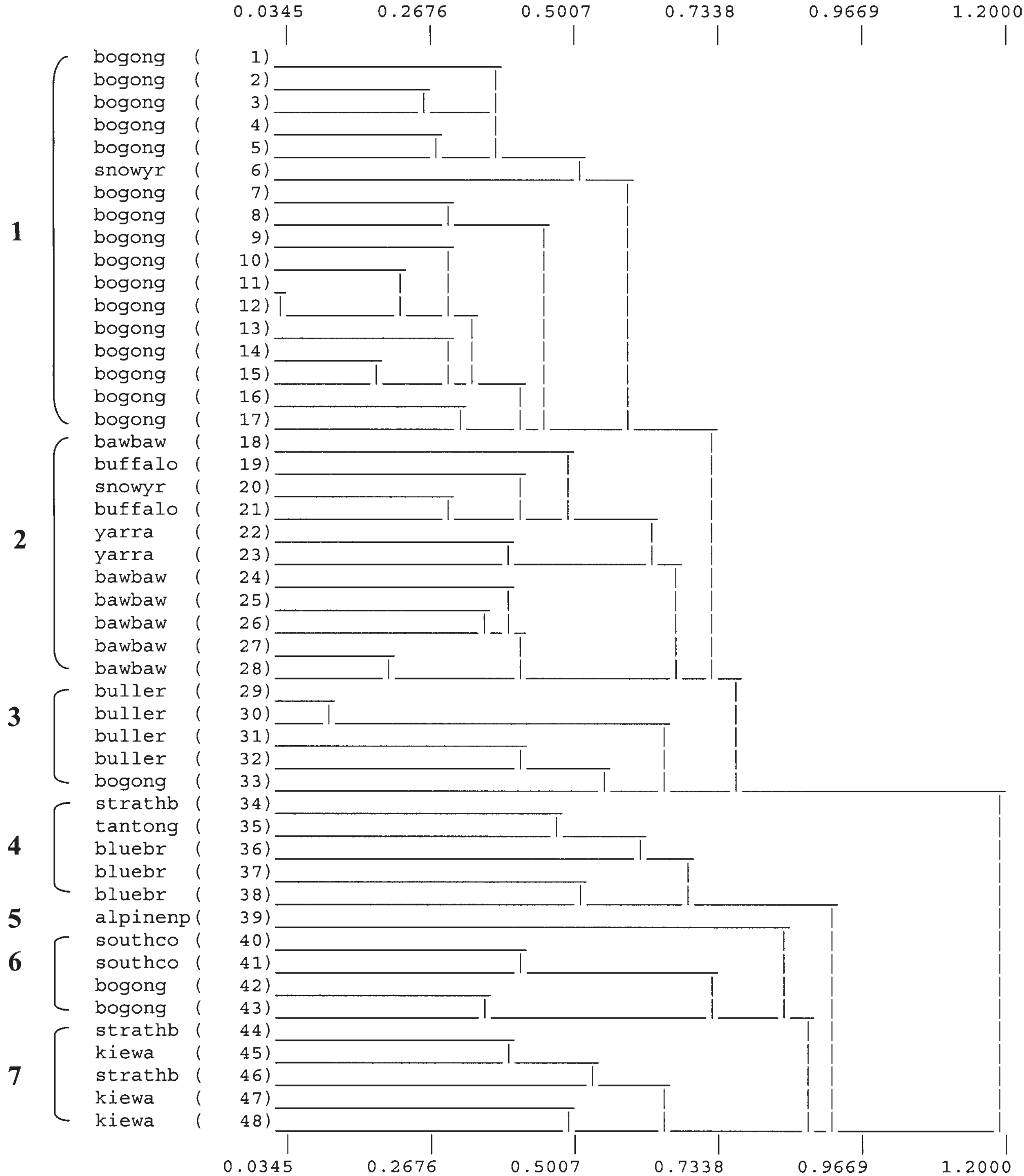

Fig. 2. Dendrogram from the UPGMA clustering of *Sphagnum* plots in Victoria. Plots are listed by region. The dissimilarity is displayed on the top edge of the dendrogram, while 'Level' (displayed) along the bottom edge of the dendrogram denotes the fusions for reference to the two-way table of indicator species displayed in Appendix 2.

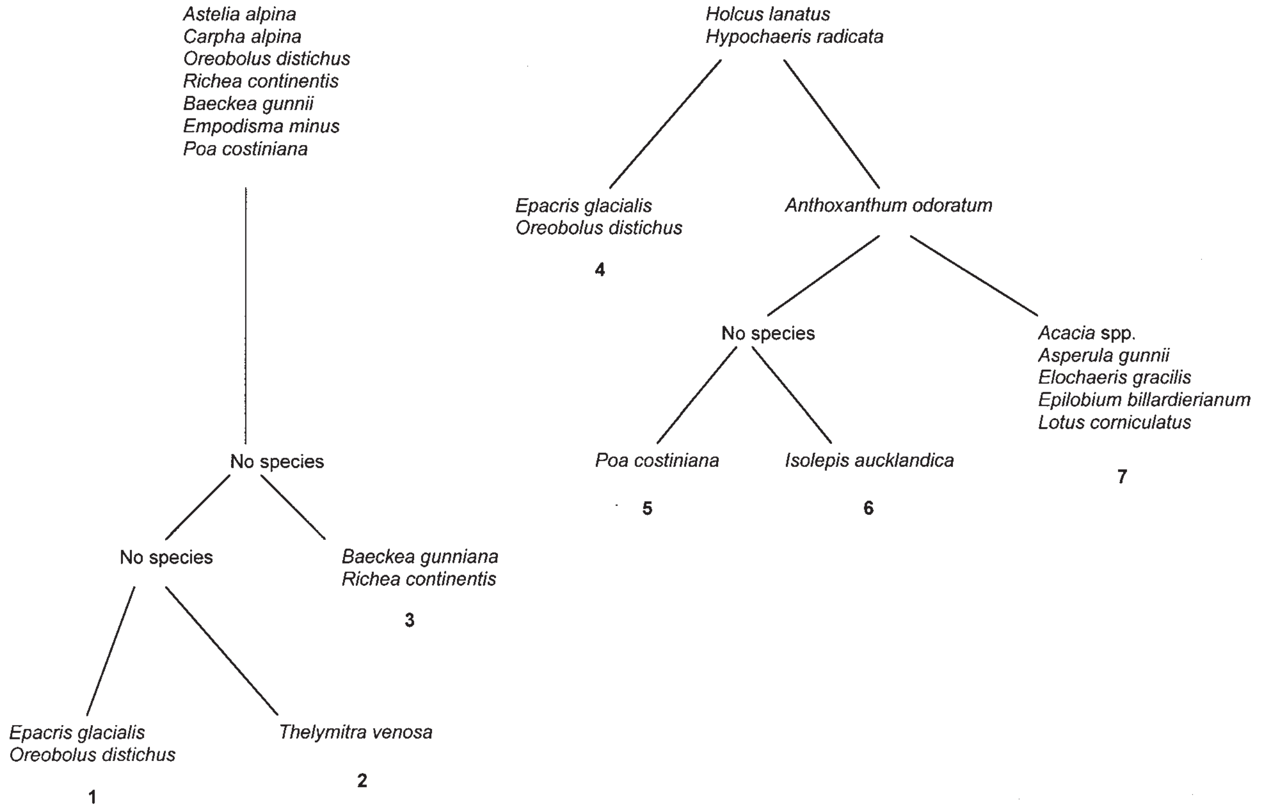

Fig. 3. Diagrammatic representation of floristic classification showing indicator species and levels significant at 0.001. Bold text denotes the 7 floristic groups (see text for group definitions).

Floristic group 3. Relic (sensu McDougall 1982) sub-alpine *Sphagnum* peatlands

The distinguishing species for this group is *Richea continentis*, with *Epacris paludosa*, *Oreobolus distichus*, and *Baeckea gunniana* common to the group. *S. cristatum* cover is low, ranging between 7–40% (median 20%). The sites in this group are seriously degraded or modified alpine *Sphagnum* peatlands, primarily headwater bogs at Mt Buller affected by ski trail development and associated maintenance. The sites range in altitude from 1700 to 1740 m and have an annual mean temperature of 5.3 °C (median) with annual precipitation ranging from 1785 to 1918 mm. The geology is primarily granite, with a median pH of 5.0, and a median peat depth of 51 cm. Median moss stem length is 10.0 cm and there is moderate species richness (median 21) which includes a high number of weeds (12 occurrences).

Floristic group 4. Montane fern-*Sphagnum* peatlands

The distinguishing species for montane fern-*Sphagnum* peatlands include *Blechnum penna-marina*, *Acaena novae-zelandiae* and *Carex appressa*, with *Chionogentias muelleriana* and *Olearia algida* constant. Cover of *Sphagnum cristatum* ranges between 60–95% (median 78%), with *Sphagnum novo-zelandicum* (5% cover) recorded at one site. These sites include generally small, valley bogs and hanging bogs that occur primarily in the Blue Breaks and Strathbogie Ranges in moderately good condition, although with extensive weed invasion from the surrounding vegetation (13 occurrences). They range in altitude from 500 m to 1280 m (median 900 m), with an annual mean temperature between 7.3 °C and 12.1 °C, and an annual precipitation ranging from 938 mm to 1767 mm. The geology for this group is mainly granite, with a median pH of 5.0 and peat depths ranging from 42 cm to 121 cm. The median moss stem length is 20 cm and median species richness is 22.

Floristic group 5. Aquatic *Sphagnum falcatulum* fen

This group consists of a single basin fen site at Lake Cobbler (altitude 1120 m), where *Sphagnum falcatulum* (55% cover) forms a fringe around part of the artificial lake and floats out across the water surface. Other distinguishing and common species include *Poa costiniana*, *Baumea gunnii, Lepidosperma* sp. and *Luzula modesta*. The fringing *Sphagnum* has been degraded by four wheel drive vehicles associated with camping at the lake. The pH is 6.0 at this sandstone site, with 94 cm peat depth and 14 cm moss stem length and low species richness (15), which includes only 1 weed species.

Floristic group 6. Degraded montane *Sphagnum* valley fens

The distinguishing species for this group of disturbed and/or modified sites is *Isolepis aucklandica,* with *Gonocarpus micranthus* and *Cotula alpina* common to the group. *Sphagnum cristatum* cover ranges between 25–100% (median 70%). These sites are generally montane valley fens that range from 900 m to 1750 m altitude (median 1250 m), with an annual mean temperature of between 5.2 °C and 9.0 °C (median 7.5 °C) and annual precipitation ranging from 1228 mm to 2369 mm (median 1752 mm). The geology is granite and phyllite schist/shale, with a pH ranging between 4.5 and 6.5 (median 6.0) and a peat depth of between 20 cm to 187 cm (median 65.5 cm). The median moss stem length is 10.0 cm for the group, which has moderate species richness (median 22), that reflects the high number of weed species (12 occurrences).

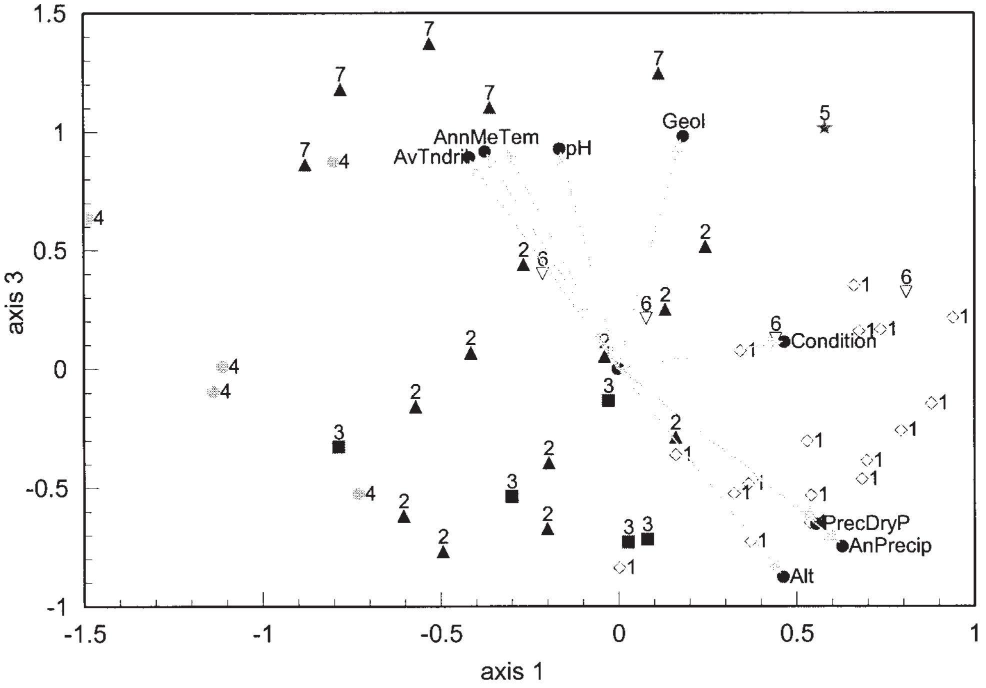

Fig. 4a

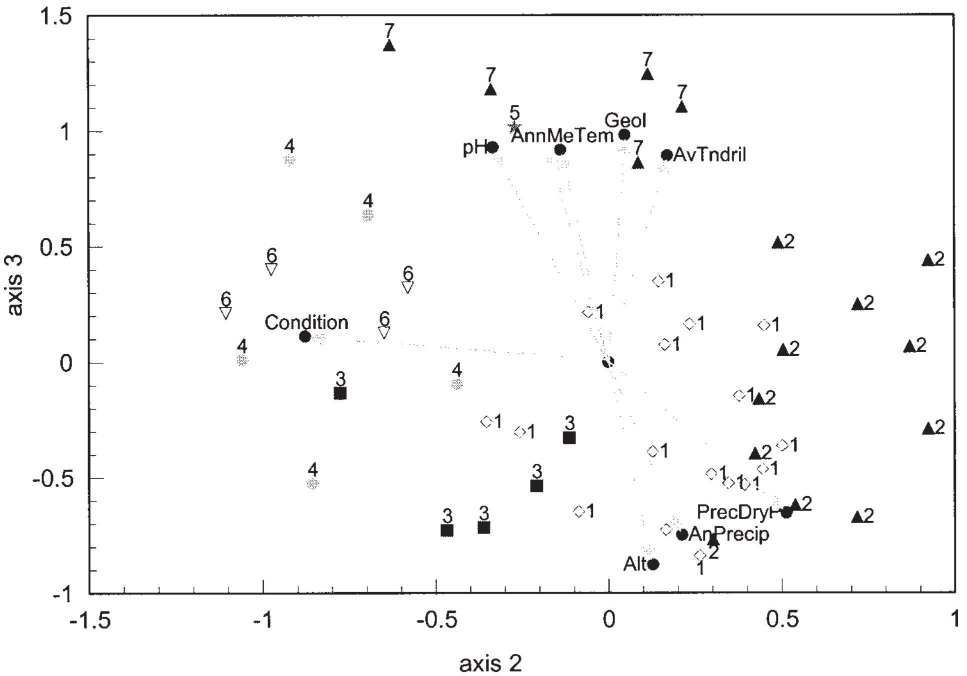

Fig. 4b

Fig. 4. HMDS in three dimensions, showing sites and significant ($p<0.01$) fitted vectors for environmental variables and species richness with respect to (a) axis 1 v 3, and (b) axis 2 v 3. Abbreviations for environmental variables are: Alt = altitude; Geol = Geology; AnMeTemp = annual mean temperature; AnnPrec = annual precipitation; PrecDP = precipitation of driest period.

Floristic group 7. Lowland shrubby *Sphagnum* fens

Distinguished by *Anthoxanthum odoratum*, *Eleocharis gracilis*, *Epilobium billardierianium*, *Lotus corniculatus* and *Asperula gunnii*, with a shrub overstorey of *Baeckea utilis*, *Callistemon pallidus*, these sites are valley fens. Cover of *Sphagnum cristatum* ranges between 35–80% (median 60%). All five sites are located on private land at altitudes of 350 m to 500 m in the Strathbogie Ranges and Kiewa Valley areas and subject to varying levels of cattle or horse grazing. The annual mean temperature is 13.1 °C (median), and annual precipitation is 1165 mm (median). The sites occur on granite and Quaternary river terraces, all with a pH of 6.0. The median peat depth for the group is 67 cm. The group has a median moss stem length of 32 cm, and a high species richness (median 28), that includes the highest number of weed species (27 occurrences).

Ordination of vegetation data and correlation with environmental variables

The MDS ordination (Fig. 4) shows how floristic groups are related to one another and the environmental vectors of maximum correlation ($P<0.01$). Group 7 is strongly influenced by increasing annual mean temperature, decreasing acidity and increased average moss stem length (Fig. 4a). Group 1 sites are strongly associated with increasing altitude, increasing annual precipitation and increasing precipitation in the driest month (Fig. 4a). Group 6 sites are strongly associated with decreasing condition (Fig. 4b) while Group 2 represents sites in the most intact condition (Figs 4a, b).

We recorded some form of disturbance at 60% of the sites surveyed, with more than one disturbance recorded at 15% of sites. Cattle trampling/grazing damage was the most common peatland disturbance recorded (29%). Other common signs of disturbance recorded were: weed invasion (13%), ski slope developments (8%), horse trampling (6%) and four wheel drive vehicles (4%), as well as drought, fire, moss poaching, deer damage, drainage alterations and trampling by humans. Most undisturbed *Sphagnum*-dominated communities were in Baw Baw National Park.

Discussion

The classification of the floristics of *Sphagnum*-dominated communities in Victoria shows regional clustering, a trend also found in *Sphagnum* peatlands in New South Wales and the Australian Capital Territory (Whinam & Chilcott 2002), and to a lesser extent, in Tasmania (Whinam et al. 2001). The regional clustering of the floristic composition of peatlands was related primarily to altitude, climate and geology.

The level of peatland degradation was also a significant environmental vector. The most disturbed sites surveyed contained the highest number of introduced species and also have a high native species richness. Almost half the sites (48%) contained at least one exotic species, with a total of 19 exotic species recorded. The most commonly recorded weeds were *Hypochoeris radicata* and *Holcus lanatus*. *Juncus effusus*, a recent serious invader of Victorian sub-alpine areas (McMorran 2002), was recorded at three sites. Weed eradication from *Sphagnum* peatlands is difficult, as eradication will generally be restricted to manual removal. The high water content of these peatlands and their role in catchment water dispersal generally precludes the use of chemical controls. These disturbed sites also tend to have a neutral pH (6.0), lacking the acidity commonly associated with *Sphagnum* bogs (Clymo 1973). This suggests that whilst *Sphagnum* is present, these sites can only be considered as marginal (restricted to peatland margins or drainage lines) or remnant *Sphagnum* peatlands, where *Sphagnum* moss now constitutes only a small percentage of the disclimax peatland vegetation cover. Further work could be done to develop more quantitative indices of change than the qualitative condition classes we have used.

The degraded state of many of the remaining *Sphagnum* peatlands suggests that there is a strong case for listing cattle grazing, under the Victorian Flora and Fauna Guarantee, as a threatening process to the conservation of *Sphagnum* peatlands in Victoria. Twenty-four plant species recorded in our survey are listed as rare and six as vulnerable in Victoria under the Flora and Fauna Guarantee 1988. Nationally, eight species are listed as rare (Leigh & Briggs 1996).

While many of the alpine and subalpine *Sphagnum* peatlands of Victoria are in the Alpine, Baw Baw and Mt Buffalo National Parks, few of the lowland and montane *Sphagnum* peatlands are reserved for conservation. The majority of *Sphagnum* peatlands surveyed are either *Sphagnum* remnants or severely degraded peatlands. Unfortunately, reservation has not equated with protection from the many activities that currently threaten the survival of *Sphagnum* peatlands in Victoria, including cattle grazing, forestry operations, ski slope development, fire and *Sphagnum* moss harvesting. There are two sub-alpine *Sphagnum* bogs in excellent condition on the Bogong High Plains, both of which are excluded from cattle grazing. One occurs on land outside the Alpine National Park (managed by the Alpine Resorts Commission) and the other in a long-term cattle exclosure at Rocky Valley (Maisie Carr's plot, Carr & Turner 1959, Wahren et al. 1999) within the National Park.

There have been repeated calls by researchers to remove cattle grazing from the Victorian Alps (Wahren et al. 1999, 2001) and our data supports these calls. We observed extensive damage by cattle and/or horses in montane, sub-alpine and alpine *Sphagnum* communities in Victoria. Damage varied from the occasional hoof print and exotic species presence (notably *Salix cinerea*), to the 'pugging' of the peatlands through to complete destruction of the peatlands, where rafts of dislodged vegetation were observed floating in streams. Preferential grazing of palatable forbs and graminoids (e.g. *Caltha introloba*, *Carex gaudichaudiana*) in *Sphagnum* bogs combined with trampling, can lead to increased dominance of unpalatable shrub species (Costin et al. 1959). Less immediate threats are posed by actions associated with forestry operations. The recent massive bushfires in the montane and alpine areas of Victoria demonstrate the vulnerability of this community to fire (Whinam 1995), but it is too early to predict the long-term ecological impacts of the fire on these sites. Our data provides a baseline from which to monitor changes in these peatlands, and post-fire studies are underway (C-H. Wahren & W. Papst, pers. comm.).

Modifications associated with ski slope development are likely to be influencing the *Sphagnum* moss beds at Mt Buller, Falls Creek and Mt Baw Baw. At Mt Buller only degraded remnants now occupy headwater depressions, suggesting that more extensive peatlands occurred in the past.

Moss harvesting also threatens the future integrity of peatlands in Victoria. The impacts of moss harvesting in *Sphagnum* peatlands in Australia and New Zealand have been previously identified (Whinam & Buxton 1997). The small total acreage of the available *Sphagnum* resource in Victoria indicates that moss harvesting would not be ecologically sustainable because of the long recovery periods required between harvests (Whinam & Buxton 1997).

The use of off-road vehicles has resulted in severe degradation of some *Sphagnum* peatlands. For example, at the aquatic *Sphagnum falcatulum* fen at Lake Cobbler, vehicular access has resulted in severe degradation of this very wet peatland. Vehicle barriers are necessary to prevent further degradation.

Several of the sites surveyed are of conservation significance due to their intact condition and floristic dissimilarity and have been identified in previous studies as requiring more formal protection. These sites include Snobs Creek, Tom Burns and Storm Creek in the Central Highlands (Kershaw et al. 1997), the Delegate River sites on the edge of the Errinundra Plateau (ANCA 1996), Tolmie State Forest in the Strathbogie Ranges and the Lake Cobbler fen. There should be more formal recognition of the outstanding condition and conservation significance of many of the *Sphagnum* peatlands at Mt Baw Baw. Continued protection of Maisie Carr's long-term ungrazed plots in the Alpine National Park is required.

Conclusion

Our analyses of *Sphagnum* peatlands in Victoria have shown a regional trend in the floristic variation of communities (related to geology, altitude and climate) and have, as in many previous surveys (ANCA 1996, Wahren et al. 1999, 2001), identified cattle grazing as the most immediate threatening process for the conservation of these peatlands. Other risks to the conservation of *Sphagnum* peatlands in Victoria include forestry operations, through fire and increased sedimentation, activities associated with ski resorts and moss harvesting (ANCA 1996).

This survey has described the floristic composition of *Sphagnum* peatlands in Victoria and their condition, prior to the 2003 bushfire, as well as identifying threats. The future for many of these *Sphagnum* peatlands is bleak, especially when the impacts of increased temperatures and altered rainfall patterns predicted with global warming are considered (Whinam et al. 2003). Many of the sites surveyed are likely to continue to deteriorate without management actions that mitigate against cattle grazing and related impacts.

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Appendix 1: Summary of site characteristics for *Sphagnum* peatlands in Victoria.

Abbreviations: F, Floristic Group; Pcc, Peatland conditon class*; Pd, Peat depth average (cm); SR, Species richness; Asp°, Aspect (degrees); S, slope (degrees); NP, National Park; Ski Res, Ski resort; SR, State Reserve; FSR, Forestry State Reserve; Quat: Quaternary

F	Region	Tenure	Pcc*	Alt.(m)	Geology	Threats	pH	Pd	SR	Asp°	S°
1	Bogong High Plains	NP	0	1600	phyllite schist/shale	none	4.5	72	15	150	2
1	Bogong High Plains	NP	3	1500	granite	none	4.5	65	13	100	7
1	Bogong High Plains	NP	0	1600	granite	none	5	120	15	180	0
1	Bogong High Plains	NP	1	1500	granite	none	6	65	17	300	130
1	Bogong High Plains	NP	1	1350	phyllite schist/shale	weeds	5	74	17	350	6
1	Snowy Range	NP	2	1600	granite	fire, cattle grazing/trampling	5	120	15	300	4
1	Bogong High Plains	NP	2	1520	granite	cattle grazing/trampling	5	40	23	270	2
1	Bogong High Plains	NP	2	1520	granite	cattle grazing/trampling	5	123	18	330	2
1	Bogong High Plains	NP	1	1750	phyllite schist/shale	none	4.5	72	15	5	5
1	Bogong High Plains	NP	0	1660	granite	none, fenced	5	104	17	360	2
1	Bogong High Plains	NP	2	1660	granite	cattle grazing/trampling	5	54	15	30	0.5
1	Bogong High Plains	NP	1	1640	phyllite schist/shale	cattle grazing/trampling	5.5	87	14	300	2
1	Bogong High Plains	Ski Res.	0	1740	phyllite schist/shale	none	4.5	42	11	150	0
1	Bogong High Plains	NP	1	1700	phyllite schist/shale	horse trampling	4.5	79	17	180	10
1	Bogong High Plains	NP	1	1780	phyllite schist/shale	weeds, cattle grazing/trampling	4.5	61	15	240	13
1	Bogong High Plains	NP	2	1780	phyllite schist/shale	cattle grazing/trampling	5.5	38	15	240	2
1	Bogong High Plains	NP	4	1710	phyllite schist/shale	cattle grazing/trampling	5.5	41	17	70	2
2	Baw Baw	NP	0	1450	granite	none	5	55	29	130	0
2	Mt Buffalo	NP	0	1420	granite	none	5	92	20	10	1
2	Snowy Range	NP	1	1620	granite	horse trampling	5	34	18	210	3
2	Mt Buffalo	NP	0	1480	granite	none	5.5	50	20	0	0
2	Yarra Ranges	NP	0	1520	granite	none	5.5	48	19	0	0
2	Yarra Ranges	NP	0	1520	granite	drought	6	106	19	160	1
2	Baw Baw	NP	0	1470	granite	none	5	77	22	60	7
2	Baw Baw	NP	0	1510	granite	none	5	58	34	10	3
2	Baw Baw	NP	0	1470	granite	none	5	88	28	260	1
2	Baw Baw	NP	0	1470	granite	none	5.5	92	15	60	5
2	Baw Baw	NP	0	1540	granite	none		80	18	30	1
3	Mt Buller	Ski Res.	3	1700	granite	skiing	5	89	10	340	8
3	Mt Buller	Ski Res.	4	1700	granite	skiing	4.5	75	9	340	12
3	Mt Buller	Ski Res.	2	1700	granite	skiing	5	51	31	330	90
3	Mt Buller	Ski Res.	4	1720	granite	skiing, weeds	6	50	21	240	4
3	Bogong High Plains	NP	2	1740	phyllite schist/shale	trampling (horses, people)	5	33	25	150	9
4	Strathbogie Ranges	private	1	500	granite	pigs, deer	5.5	75	31	30	4
4	Tatong-Tolmie SF	SR	1	800	phyllite schist/shale	weeds	6	42	25	60	<1
4	Blue Breaks	FSR	0	900	granite	none	5.5	122	22	0	0
4	Blue Breaks	FSR	0	1220	granite	4WD vehicles	5.5	112	17	310	0
4	Blue Breaks	FSR	1	1280	granite	moss poaching	5.5	93	15	180	2
5	Alpine NP	NP	2	1120	sandstone	4WD vehicles	6	94	15	40	1
6	South Coast	NP	0	900	granite	drought	6	187	21	0	0
6	South Coast	NP	2	900	granite	fire, drain construction, cattle grazing/trampling	4.5	98	20	0	
6	Bogong High Plains	NP	3	1600	phyllite schist/shale	drain construction, cattle grazing/trampling	6.5	33	23	130	0
6	Bogong High Plains	NP	4	1750	phyllite schist/shale	weeds, cattle grazing/trampling	6	30	31	45	6
7	Strathbogie Ranges	private	3	500	granite	cattle grazing/trampling	6	110	30	90	3
7	Kiewa Valley	private	3	350	Quat. river terraces	cattle grazing/trampling	6	75	26	20	1
7	Strathbogie Ranges	private	3	480	granite	cattle grazing/trampling, weeds	6	67	28	280	2
7	Kiewa Valley	private	1	350	Quat. river terraces	none	6	75	32	40	3
7	Kiewa Valley	private	2	350	Quat. river terraces	none	6	49	23	340	0

* Definitions of peatland condition class (Pcc): (0) undamaged; (1) light damage, where only minimal surface disturbance was evident; (2) degraded, where there was a breakdown of surface morphology e.g. through repeated hoof trampling; (3) modified, where the surface and edge morphology has broken down i.e. edge erosion from trampling and pugging caused by hooves; (4) highly modified and degraded where the surface morphology has broken down and only patches of isolated *Sphagnum* moss remain in disturbed, bare peat

Appendix 2: Two way table of species by final site groups (Groups 1–7).

Group size (in parentheses) and indicator values. * Denotes introduced species.

Species	**L**	**1 (17)**	**2 (11)**	**3 (5)**	**4 (5)**	**5 (1)**	**6 (4)**	**7 (5)**	**IndVal (48)**
Sphagnum cristatum	1	17	10	5	4	0	4	5	93.75
Empodisma minus	1	17	11	5	0	1	4	1	81.25
Baeckea gunnii	1	16	9	5	0	0	2	2	70.83
Poa costiniana	1	14	11	5	0	1	2	1	70.83
Carex gaudichaudiana	1	16	7	1	0	1	4	1	62.5
Epacris paludosa	1	7	8	5	3	0	2	3	58.33
Holcus lanatus *	2	0	0	0	2	1	3	5	73.33
Hypochaeris radicata *	2	0	1	3	4	0	3	3	56.41
Hypericum japonicum	2	2	0	0	3	0	3	2	47.89
Baeckea utilis	2	0	0	0	3	0	2	2	46.67
Hydrocotyle sibthorpioides	2	0	0	0	1	0	1	2	26.67
Gonocarpus sp.	2	0	0	0	1	0	1	1	20
Eucalyptus camphora	2	0	0	0	1	0	0	1	13.33
Geranium potentilloides	2	0	0	0	1	0	0	1	13.33
Gonocarpus tetragynus	2	0	0	0	1	0	0	1	13.33
Gratiola peruviana	2	0	0	0	1	0	0	1	13.33
Richea continentis	2	16	11	5	2	0	1	0	77.88
Oreobolus distichus	2	14	5	1	0	0	0	0	60.61
Astelia alpina	2	11	10	1	0	0	1	0	60.61
Carpha alpina	2	10	6	1	0	0	0	0	51.52
Celmisia tomentella	2	11	3	2	0	0	0	0	48.48
Blechnum penna-marina	3	0	3	0	5	0	0	0	91.67
Acaena nova-zealandiae	3	0	1	1	5	0	1	0	86.16
Carex appressa	3	1	2	4	4	1	0	0	57.55
Rubus fruticosus *	3	0	0	0	3	0	0	2	45
Acacia melanoxylon	3	0	0	0	2	0	0	0	40
Histiopteris incisa	3	0	0	0	2	0	0	0	40
Hydrocotyle hirta	3	0	0	0	2	0	0	0	40
Leptospermum grandifolium	3	0	0	0	2	0	0	0	40
Mentha australis	3	0	0	0	2	0	0	0	40
Tasmannia victoriana	3	0	0	0	2	0	0	0	40
Carex breviculmis	3	0	0	1	2	0	0	0	37.18
Isolepis sp.	3	1	2	0	3	0	0	3	36.33
Lagenifera stipitata	3	6	5	2	3	0	0	0	36.22
Euchiton involucratus	3	0	0	0	2	0	0	1	32
Epilobium gunnianum	3	0	1	0	2	0	0	2	25.38
Schoenus calyptratus	3	1	0	0	1	0	0	0	17.37
Sphagnum novo-zelandicum	3	1	0	0	1	0	0	0	17.37
Wittsteinia spp.	3	0	1	0	1	0	0	0	17.37
Deyeuxia brachyathera	3	0	2	0	1	0	0	0	15.35
*Anthoxanthum odoratum**	4	0	0	0	0	0	0	5	100
Eleocharis gracilis	4	0	0	0	0	0	0	4	80
Epilobium billardierianium	4	0	0	0	1	0	0	4	64
Acacia spp.	4	0	0	0	0	0	0	3	60
Lotus corniculatus *	4	0	0	0	0	0	0	3	60
Asperula gunnii	4	5	8	0	1	1	0	5	55.74
no species	4								
Nertera depressa	5	2	3	0	0	1	0	0	86.84
Lepidosperme sp.	5	0	0	0	0	1	1	0	80
Polytrichum sp.	5	1	1	0	1	1	0	0	79.33
Luzula modesta	5	0	4	2	0	1	0	2	63.22
Baloskion australe	5	7	0	0	0	1	0	2	62.03
Baumea gunnii	5	0	0	0	2	1	0	3	50
Isolepis aucklandica	5	4	2	2	0	0	4	0	80.49
Tasmannia xerophila	5	0	0	0	0	0	2	0	50
Trifolium repens *	5	0	0	0	0	0	2	0	50
Olearia algida	7	0	8	1	0	0	0	0	57.04
Callistemon sieberi	7	0	6	0	0	0	0	0	54.55
Chionogentias diemensis	7	0	6	0	0	0	0	0	54.55
Thelymitra venosa	7	5	8	0	0	0	0	0	51.78

Appendix 3: Summary of species occurrence in Victorian *Sphagnum* peatland floristic groups.

* denotes introduced species; spp. indicates genus where singleton species have been combined for analyses.

Floristic Group / **No. of sites**	**1** (17)	**2** (10)	**3** (5)	**4** (4)	**5** (1)	**6** (4)	**7** (5)
Acacia melanoxylon	0	0	0	2	0	0	0
Acacia spp.	0	0	0	0	0	0	3
Acaena novae-zelandiae	0	1	1	5	0	1	0
**Acetosella vulgaris*	0	0	2	0	0	0	0
**Agrostis capillaris*	0	0	1	0	0	1	0
Agrostis spp.	0	0	0	1	0	2	0
**Anthoxanthum odoratum*	0	0	0	0	0	0	5
Arthropodium milleflorum	0	0	0	0	0	0	2
Asperula gunnii	5	8	0	1	1	0	5
Astelia alpina	11	10	1	0	0	1	0
Baeckea gunniana	16	9	5	0	0	2	2
Baeckea utilis	0	0	0	3	0	2	2
Baloskion australe	7	0	0	0	1	0	2
Baumea gunnii	0	0	0	2	1	0	3
Blechnum penna-marina	0	3	0	5	0	0	0
Brachyscome obovata	0	2	0	0	0	0	0
Callistemon pallidus	1	0	0	0	0	0	1
Callistemon sieberi	0	4	0	0	0	0	0
Caltha introloba	0	6	0	0	0	0	0
Carex appressa	1	2	4	4	1	0	0

Floristic Group	**1**	**2**	**3**	**4**	**5**	**6**	**7**
No. of sites	(17)	(10)	(5)	(4)	(1)	(4)	(5)
Carex breviculmis	0	0	1	2	0	0	0
Carex gaudichaudiana	16	7	1	0	1	4	1
Carex spp.	2	0	2	0	0	1	1
Carpha alpina	10	6	1	0	0	0	0
Celmisia asteliifolia	3	2	0	0	0	0	0
Celmisia pugioniformis	1	4	0	0	0	0	0
Celmisia tomentella	11	3	2	0	0	0	0
Chiloglottis sp.	1	1	1	0	0	0	0
Chionogentias diemensis	0	6	0	0	0	0	0
Chionogentias muelleriana	1	1	0	0	0	0	0
Coprosma moorei	1	1	0	0	0	0	0
Cotula alpina	1	0	2	0	0	2	0
Craspedia coolaminica	0	3	1	0	0	0	0
Craspedia jamesii	0	3	0	0	0	0	0
Craspedia spp.	1	1	1	0	0	0	0
Deyeuxia brachyathera	0	2	0	1	0	0	0
Deyeuxia monticola	0	3	0	0	0	0	0
Diplapsis hydrocotyle	1	2	0	0	0	0	0
Diplaspis spp.	1	1	0	0	0	0	0
Drosera arcturi	5	5	0	0	0	0	0
Drosera spp.	1	0	0	0	0	0	1
Eleocharis gracilis	0	0	0	0	0	0	4
Empodisma minus	17	11	5	0	1	4	1
Epacris breviflora	0	2	0	1	0	2	0
Epacris glacialis	13	0	0	0	0	2	0
Epacris paludosa	7	8	5	3	0	2	3
Epacris petrophila	9	1	0	0	0	2	0
Epacris spp.	2	0	0	0	1	0	0
Epacris sp. *A*	0	2	0	0	0	0	0
Epilobium billardierianium	0	0	0	1	0	0	4
**Epilobium ciliatum*	1	1	2	0	0	0	0
Epilobium gunnianum	0	1	0	2	0	0	2
Erigeron bellidioides	1	4	0	0	0	0	0
Erigeron nitidus	6	0	0	0	0	2	0
Eriocaulon scariosum	0	0	0	0	0	0	2
Erogrostis sp.	0	0	0	0	0	0	2
Eucalyptus camphora subsp. *relicta*	0	0	0	1	0	0	1
Eucalyptus ovata	0	0	0	0	0	1	2
Eucalyptus spp.	0	1	0	0	0	2	1
Euchiton collinus	1	0	0	1	0	1	0
Euchiton involucratus	0	0	0	2	0	0	1
Euchiton sp.	0	0	1	0	0	2	1
Euphrasia collina subsp. *paludosa*	0	1	1	0	0	0	0
Euphrasia gibbsiae	0	3	0	0	0	0	0
Euphrasia sp.	0	2	0	0	0	0	0
**Festuca rubra*	0	0	2	0	0	0	0
Geranium potentilloides	0	0	0	1	0	0	1
Gonocarpus micranthus	5	2	1	0	0	3	2
Gonocarpus montanus	0	0	1	1	0	0	3
Gonocarpus sp.	0	0	0	1	0	1	1
Gonocarpus tetragynus	0	0	0	1	0	0	1
Gratiola peruviana	0	0	0	1	0	0	1
Hakea microcarpa	1	0	0	0	0	1	2
Hierochloe redolens	0	1	2	0	0	0	0
Histiopteris incisa	0	0	0	2	0	0	0
**Holcus lanatus*	0	0	0	2	1	3	5
Hydrocotyle hirta	0	0	0	2	0	0	0
Hydrocotyle sibthorpioides	0	0	0	1	0	1	2
Hydrocotyle sp.	1	1	0	1	0	1	3
Hypericum japonicum	2	0	0	3	0	3	2
**Hypochoeris radicata*	0	1	3	4	0	3	3
Isachne globosa	0	0	0	0	0	0	2
Isolepis aucklandica	4	2	2	0	0	4	0
Isolepis sp.	1	2	0	3	0	0	3
Isolepis sp. *B*	0	2	0	0	0	0	0
Isotoma axillaris	0	0	0	0	0	0	2
Isotoma fluvitalis	0	0	0	0	0	0	2
**Juncus effusus*	1	0	1	0	0	1	0
Juncus holoschoenus	0	0	0	0	0	0	2
Juncus prismatocarpus	0	0	0	0	0	0	2
**Juncus* sp.	0	1	0	2	0	1	4
Lagenifera stipitata	6	5	2	3	0	0	0
Lepidosperma sp.	0	0	0	0	1	1	0
Leptospermum grandifolium	0	0	0	2	0	0	0
Leptospermum lanigerum	0	0	0	0	0	2	1
**Lotus corniculatus*	0	0	0	0	0	0	3
Luzula modesta	0	4	2	0	1	0	2
Luzula novae-combriae	0	0	2	0	0	0	0
Luzula sp.	1	0	1	1	0	1	0
Lycopodium fastigiatum	4	0	2	0	0	0	0
Mentha australis	0	0	0	2	0	0	0
Myriophyllum pedunculatum	0	1	0	0	0	0	1
Nertera depressa	2	3	0	0	1	0	0
Olearia algida	0	8	1	0	0	0	0
Oreobolus distichus	14	5	1	0	0	0	0
Oreomyrrhis eriopoda	0	0	2	0	0	1	0
Oreomyrrhis pulvenifera	0	1	2	0	0	0	0
Pimelea alpina	1	1	0	0	0	0	0
Plantago euryphylla	0	0	2	0	0	1	0
Poa costiniana	14	11	5	0	1	2	1
Poa hothamensis	1	0	1	0	0	0	0
Polytrichum juniperinum	2	2	1	0	0	1	0
Polytrichum sp.	1	1	0	1	1	0	0
**Prunella vulgaris*	0	0	0	1	0	0	2
Pultenaea sp.	0	2	0	0	0	0	0
Ranunculus pimpinellifolius	1	0	2	0	0	0	2
Rhynchospora brownii	0	0	0	0	0	0	2
Richea continentis	16	11	5	2	0	1	0
**Rubus fruticosus aggregate*	0	0	0	3	0	0	2
Rytidosperma nivicola	0	2	0	0	0	0	0
Schoenus calyptratus	1	0	0	1	0	0	0
Schoenus sp.	0	2	0	0	0	0	0
Sphagnum cristatum	17	10	5	4	0	4	5
Sphagnum falcatulum	0	1	0	0	1	0	0
Sphagnum novo-zelandicum	1	0	0	1	0	0	0
Stylidium graminifolium	6	3	0	0	0	0	0
Tasmannia vickeriana	0	0	0	2	0	0	0
Tasmannia xerophila	0	0	0	0	0	2	0