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The peat-forming spring wetlands of the Strathbogie plateau – floristics and environmental relationships

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Abstract*:* Spring wetlands on the Strathbogie plateau were mapped using recent aerial photography to estimate their current and former extent. The floristic composition and relationships of the vegetation with topographic, environmental and land use variables were interpreted from an analysis of quadrat data. Wetland condition, threats to their persistence and future management requirements were also identified. More than half of the original wetland vegetation in the study area appears to have been lost, probably as a result of clearing for agriculture. Nine floristic assemblages, identified using agglomerative hierarchical clustering, were identified on acidic to mildly alkaline peat in five different hydrogeomorphic settings. One of these assemblages (Low Open Sedgeland) was uniquely confined to spring-fed mounds, not previously described in Victoria. A key to identification of these groups was developed. Floristic composition was correlated with climate and site disturbance but charcoal throughout sediment cores suggested that historical disturbance regimes included fire. Forested sites at higher elevations where grazing pressure appears to have been less intense were the least disturbed sites. Approximately 60% of the wetlands surveyed were assessed as showing signs of soil moisture loss but there was no evidence that water extraction via dams and known bores was a significant driver of current vegetation composition. Threats requiring management were related to habitat destruction and degradation, dysfunction of physical and biological processes, and changes to disturbance regimes. Establishment of native vegetation buffers and biomass management are likely to be of benefit for future management of spring wetland vegetation.

Key words: spring wetlands, disturbance, grazing, peat, management.

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Introduction

Wetlands are a threatened vegetation type worldwide as a result of human impact (Mitsch & Gosselink 2007). Ecosystems which are entirely dependent on groundwater represent less than 1% of the land mass of the Australian continent (Hatton & Evans 1998) and include well known wetlands such as the mound springs of the Great Artesian Basin, the wetlands of the Swan Coastal Plain, karstic ecosystems and riparian red gum stands associated with inland groundwater ecosystems (Hatton & Evans 1998).

Wetlands provide a range of ecosystem services related to catchment hydrology and support distinct plant communities restricted to inundated or seasonally inundated parts of the landscape by virtue of their adaptation to waterlogging (Keddy 2010). In agricultural landscapes, year round water availability has historically made spring wetlands vulnerable to land use pressures (Keddy 2010). Spring wetlands may also be at risk from extractive activities that deplete groundwater reserves because of their value as a year round and permanent water supply.

Classification of wetlands at landscape scale is typically linked to their role as functional units, based on hydrogeomorphic classes (Robertson & Fitzsimons 2004, Mitsch & Gosselink 2007) or hydrological setting (Ramsar Convention Bureau 1991). At the regional or management scale, these classes may be subdivided into ecological units based on the floristic and structural attributes of the vegetation (Fensham *et al*. 2004*a*).

In Victoria, wetlands have been mapped and classified as 127 different Ecological Vegetation Classes (EVCs), descriptive units encompassing a range of environmental variation from sea level to alpine regions including freshwater and saline systems (Department of Sustainability & Environment 2012). The primary intention of EVC mapping and classification is to provide an inventory of vegetation types for various planning and land management activities (Roberston & Fitzsimons 2004) and condition assessments (DSE 2012).

The delineation of Victorian spring wetland vegetation communities has been difficult, partly because examples are severely altered from their original condition and are patchily distributed across the landscape, and partly owing to a lack of systematic surveys. For example, the current EVC description for 'Spring-soak Woodland' is derived from only a handful of remnants in north-eastern Victoria, almost all of which consist of only a subset of species with fidelity to the EVC. Within any single EVC, a range of vegetation communities also occurs, according to local site environmental variation and/or disturbance history.

The relationships between wetland plant communities and environmental variables remain generally unquantified in south-eastern Australian classifications (Roberston & Fitzsimons 2004). To date, the most comprehensive ecological studies of spring wetland vegetation have focused on mound springs associated with the Great Artesian Basin (Fensham & Fairfax 2003, Fensham & Price 2004, Fensham *et al*. 2004*a*, Fensham *et al*. 2004*b*). Other studies have investigated the influence of water regime on vegetation patterns and ecosystem function with a view to formulating management directions at broader scales, although field-based vegetation community level studies are still generally lacking (Eamus *et al*. 2006, Raulings *et al*. 2010).

Spring wetlands are rare in the Victorian landscape, particularly at lower elevations. These wetlands are subject to a range of threats, the majority of which derive from land uses incompatible with their preservation and it is likely that most have been destroyed, or severely altered from their original condition since European settlement. To date, no systematic surveys have been conducted in spring wetlands or related groundwater dependent vegetation in Victoria, other than in alpine and subalpine areas (Ashton & Hargreaves 1983, Wahren *et al*. 1999, Whinam *et al*. 2003, Coates *et al*. 2012). Consequently, their floristic composition and contribution to biodiversity are poorly understood and any prescriptions for management are hampered by a current lack of knowledge of floristics, condition, threats and environmental relationships.

The wetlands surveyed in this study support remnant vegetation communities that have developed on and around groundwater-fed springs on the Strathbogie plateau in central Victoria and represent a unique ecosystem in the State. To contribute to an understanding of their management requirements applicable at the site scale, the aims of the current study were to, 1) describe the floristic variation, structure and environmental correlates of remnant spring wetlands; 2) determine their current and former extent, and 3) determine their current condition and threats to their persistence.

Methods

Study area

The study area covers 2 568 km^2 (Phillips *et al*. 2002) and is roughly 150 km northeast of Melbourne (37º 00' 30" S, 145º 27' 50" E; Figure 1). The plateau is part of a batholith consisting of two coarse-grained granite plutons, formed from a Middle to Upper Devonian intrusion (370–390 m.y.), with a mildly dissected surface of rolling to hilly tableland at about 320–700 m asl. The plateau straddles the Broken River and Goulburn River catchments and exerts major control over river patterns and groundwater flow (Phillips *et al*. 2002).

The hydrogeology of the Strathbogie Plateau has not been studied in detail but is thought to conform to a conceptual model for fractured rock aquifers, described by Stewardson *et al*. (2009). In their model, fluvial erosion through the weathered batholith surface has established valley floors in the erosion-resistant basement rock. Drainage is to the west-southwest, following the orientation of the basement surface, also the dominant surface flow direction of both plutons. Stewardson *et al*. (2009) proposed that the hills surrounding these valleys consist mostly of isolated fractured rock aquifers. Groundwater is discharged from these aquifers via springs located where river valleys intersect with basement rock. Owing to the orientation of the basement surface, springs on the west-southwest side of hills are likely to have a more persistent flow. More intermittent flows can be expected where groundwater discharge occurs at the intersection of hill surfaces and the aquifer water table. Springs are also most likely to occur along valley margins rather than within drainage lines. Palustrine-type wetlands (Ramsar Convention Bureau 1991) have developed around spring outlets at higher elevations on the plateau.

The nearest weather station is at Strathbogie, roughly 40 km to the north of the study area (36° 51' 50" S, 145° 44' 51" E). January and February are the hottest and driest months, with a mean maximum temperature of 27.3°C, mean minimum of 11.6°C and mean monthly precipitation of 46 mm (Bureau of Meteorology, online). The elevation of the plateau mediates the summer heat of the surrounding plains. Prevailing winds are variable, tending southerly to northerly and reaching the highest speeds (11–13 km/hr on average) between early spring and late summer, weakening over autumn and winter

Fig. 1. Location of the study, shown as the area of Strathbogie granite.

to about 9 km/hr. Winters are relatively cold and wet. The average maximum temperature in July is 10.1°C, the average minimum is 1.6°C, and mean precipitation is 123 mm. Rain (>1mm) falls for 91 days per year on average and snow may fall occasionally (Bureau of Meteorology, online). Rainfall and temperatures are likely to vary over the plateau with altitudinal and topographic variation.

The pre-European vegetation of the study area generally consisted of "lightly forested grassland, dotted with large granite outcrops and numerous springs and creeks" (McCall 1982 cited in Gubbins 2010). However, depressions where trees were cleared are still clearly visible in paddocks and imply that the vegetation may have been relatively dense on lower slopes. Much of the native vegetation was cleared in the mid to late 19th century and replaced with herbaceous pasture species.

The major current land use is grazing by domestic stock, predominantly cattle but also sheep (Carr *et al*. 2006). The consequences of disturbance by stock include soil compaction, localised turbidity, eutrophication via faeces and urine, pugging of soils and destruction of peat, and ponding of water in micro-topographic relief features resulting in increased water loss by evaporation (Carr *et al*. 2006). Water extraction by bores and construction of farm dams above or below springs are common on freehold land in the study area (Carr *et al*. 2006). Other disturbance includes draining of wetlands via channels and planting of high water-use trees, notably blue gum (*Eucalyptus globulus*) plantations adjacent to or near wetlands. The effect of plantations on watertables is unknown. Other major impacts to wetland condition are weed invasion by pasture species, inadvertent off-target damage to vegetation by poor herbicide use, and broadacre application of fertilisers (Carr *et al* 2006).

Bushfires were first recorded in 1851 in the region (White *et al*. 1990), although the precise area or whether the Strathbogie plateau burnt, is not clear. Fires occurred in the first half of the century in 1904, 1908, 1922, 1939 but none have been recorded since 1983 (Gubbins 2010). Fires are likely to have been extensively used to clear land around the time of settlement between 1841 and the early 20th century (Mackrell 1977, Mc Call 1982, both cited in Gubbins 2010), although clearing still occurred in the 1940s (J. Webb, "Kobyboyne" pers. comm.).

The study sites encompassed a range of peat-forming spring wetlands (mires). Peat was defined as organic sediments formed on permanently saturated organic soils and exceeding 20% dry weight (Whinam & Hope 2005, Hope *et al*. 2011). More specifically, the wetlands consist of fen and swamp forest (or wooded fen), as adapted for usage within Australasia (Whinam & Hope 2005, Hope *et al*. 2011). The term 'fen' is used to describe vegetation dominated by peat-forming graminoid species, while 'swamp forest' describes vegetation dominated by tall shrubs and trees (Whinam & Hope 2005). Sites allied with baseflow rivers and streams, flood plains or alluvial environments associated with flowing water were excluded.

Mapping

Wetlands in the study area were mapped in GIS (Arcview 3.3) using geo-rectified aerial photography (50 cm pixel resolution) collected in 2007. Mapping was also informed by field notes compiled from inspection of total wetland extent. These notes described the full range of vegetation communities and threats (see below). This allowed us to identify various vegetation types in the aerial images. The average size of the wetlands assessed was approximately 4 ha.

Additional data were extracted from 311 grid locations from a previous survey (Carr *et al*. 2006) and mapped if detectable in the imagery. In the absence of ground-truthing it was not possible to distinguish precise vegetation groups from aerial photographs. Therefore, all wetlands or sections thereof were mapped as one of four broad vegetation types: forest/woodland; shrubland; sedgeland/reedland, and 'remnant' (patches of *Juncus sarophorus*, *Carex* spp. and other non-woody vegetation associated with seepage areas in paddocks). The 'remnant' category was assumed to have once supported wetland vegetation and its total area was included to calculate the estimated (and conservative minimum) loss of wetland vegetation in the study area since European settlement. We made a number of assumptions to identify likely remnants, namely: the Strathbogies were largely forested at European settlement and paddocks are therefore an artefact of clearing, without the wetland vegetation that might once have existed there; peaty soils in paddocks once supported wetland vegetation communities all of which remains is a small number of rushes or sedges, mainly *Juncus sarophorus*; former areas of wetland are visible on aerial photography as darker areas most likely indicating wetter soils.

Vegetation survey

Forty-one wetlands identified in a previous study (Carr *et al*. 2006) were selected according to the following criteria: a range of condition states; accessibility; distinguishable on colour aerial photographs; spanned the geographic and altitudinal ranges of the study area; likely to represent the range of floristic compositional variation and with a known management history.

To describe the floristic variation of the wetlands, percent cover (estimated visually) of all vascular plant species and *Sphagnum* spp. was recorded in quadrats (10m x 10 m) in each of the 41 wetlands in September to November 2008. Quadrats were located near to the point of groundwater discharge and where the vegetation was considered most intact. Plant nomenclature follows Walsh & Stajsic (2006); community structural typology follows Specht *et al*. (1974) and EVC typology follows Department of Sustainability & Environment (2012).

In each quadrat geographic position; quadrat position in the wetland (centre, middle, outer); elevation (metres ASL); slope aspect and angle (using a Suunto compass and clinometer); percent cover (estimated visually to the nearest 10%) and depth of standing water were recorded. Synthetic climate parameters for a range of rainfall and temperature variables were generated for each quadrat using the BIOCLIM module (Nix and Busby 1986) of the ANUCLIM package (Houlder *et al*. 2005).

A condition descriptor derived from the proportion of three variables was used as a surrogate for site condition in each quadrat [(% pugging + % tracks + % weed cover)/100]. The proportion of the ground covered by pugging and tracks was estimated visually. Weed cover (percent), weed species richness and native species richness were derived from the floristic survey. Other variables recorded were proportion of the wetland perimeter buffered by vegetation with >25% native species cover (estimated in the field and using GIS); overall wetland buffer width (estimated in the field and using GIS); distance and direction (upslope, downslope, across slope) to the nearest dam; distance to the nearest bore, and years fenced.

A sediment core (50 mm x 1 m gouge auger, Dormer Engineering) was taken in each quadrat to determine the depth of the peat layer and the depth to the impermeable layer. The presence of charcoal particles was recorded as an indication as to whether sites were likely to have been burnt at any time in the past. Three soil samples were collected at a depth of 15 cm in each quadrat and bulked for the following analyses: pH of the A horizon (TPS Digital pH meter calibrated with a buffer solution to pH 7, 1:1 ratio of soil to de-ionized distilled water, using 20 gm of soil : 20 ml of water); % moisture and % organic content of the A horizon (measured using loss on ignition, Dean 1974).

To determine the degree to which compositional variation might be associated with landform morphology, each quadrat was assigned to one of five hydrogeomorphic classes based on landform setting and hydrologic dynamics (Semeniuk & Semeniuk 1997). These classes were derived from slope angle and land surface shape and fell into two categories. Topogenous sites were those situated on more or less flat terrain below slopes or within basins, with no outlet, a single outlet or both inlets and outlets (Ryadin & Jeglum 2006). These sites appeared to receive water from springs situated throughout the drainage line and/or lateral slopes, as well as a significant amount from sub-surface flows and surface run-off. Soligenous sites were generally associated with slope-breaks, receiving groundwater at its point of expression above the surface, with only minor inflows from soil water drainage and surface runoff (Ryadin & Jeglum 2006).

Hydrogeomorphic classes were: 1, Vales: broad depressions flanked by hillslopes <5^0 (topogenous); 2, gullies: flanked by hillslopes >5^0 (topogenous); 3, slopes <5^0: flat or near flat, or with a distinct concave depression (soligenous); 4, slopes >5^0: sloping, or with a distinct concave depression (soligenous); and 5, mounds: convex formations associated with spring vents (soligenous).

Threats

Threats, management issues and other site parameters that might influence wetland condition or function, or might require management in future were noted during field mapping. These included: land use; recent or planned changes to land use/management; physical threats; vegetation connectivity (as a measure of overall intactness and fragmentation); vegetation zonation (% of identifiable floristic assemblages intact, estimated visually in the field and from aerial photography); the proportion of wetland soils that were dry/damp and wet/waterlogged (estimated in quadrats and data combined for each wetland site) and any obvious qualitative or quantitative changes to the water regime (Department of Sustainability & Environment 2006). Dry soils clearly contained no or very little moisture and damp soils had limited or no ability to release excess water when a handful of soil was manually compressed; saturated or waterlogged soils were identified as having excess water present, which was freely released with or without light compression.

Analytical methods

To identify vegetation groups, floristic data were analysed by hierarchical agglomerative clustering using average linkage (Oksanen 2011). Species that occurred in fewer than 10% of quadrats were excluded. Compositional dissimilarities were calculated using the Bray-Curtis co-efficient (Faith *et al.* 1987). Unique clusters were identified at the nine group level, considered sufficient to represent the range of vegetation communities observed in the field. A dendrogram was constructed to display group similarity and a dichotomous key was devised to assist with recognition of the vegetation groups in the field.

Differences in mean soil organic and moisture content were compared among hydrogeomorphic classes using a One-way Analysis of Variance. Quadrat variables according to floristic groups were compared using interval plots (Minitab 2010). Pearsons Product-Moment correlation co-efficient was used to test for significant relationships between organic and moisture content, pH, slope angle, precipitation, altitude. Results were considered significant if $P < 0.05$.

The Bray Curtis dissimilarity matrix of floristic data was then ordinated using non-metric multidimensional scaling (NMDS) from several random starts until a solution with the smallest acceptable stress was reached. To determine an appropriate dimensionality, the solution was chosen that provided the most reduction in stress (McCune & Grace 2002). Quadrats were then plotted in the ordination space and labelled according to cluster group membership. To determine the degree to which compositional variation could be explained by wetland management and/or environmental attributes, directional vectors for the variables measured during the quadrat survey were fitted through the ordination space (Kantvilas and Minchin 1989). Only those variables which satisfied the assumption of linearity and normality were used, tested by fitting surfaces of each of the variables to the ordination and using the Johnson transformation (Minitab 2010).

Data manipulation, statistical analyses and graphics were conducted using Program R Version 2.14.1 (R Development Core Team 2011) with packages MASS (Venables & Ripley 2002) and Vegan version 2.1–14 (Oksanen *et al.* 2012) and Minitab® 16.1.0 Statistical Software (Minitab Inc. 2010).

Threats were compiled and allocated to ecological risk categories (Auld & Keith 2008) to give general context to address potential management issues.

Results

Mapping

A total area of 1646 hectares of wetlands vegetation and remnant wetland vegetation was mapped from aerial photos, representing 0.65% of the total study area. Four broad structural vegetation types were recognised at a landscape scale, representing a gradient of canopy cover: (i) treeless vegetation of fens dominated by rushes, reeds or sedges; (ii) shrublands; (iii) swamp forest and woodland and (iv) remnants dominated by rushes and grasses.

'Remnant' accounted for most (58%; Table 1) of all mapped wetland vegetation and forest/woodland the least (2.5%; Table 1). Roughly one quarter of the vegetation mapped was dominated by sedges and reeds and roughly 15% was shrub-dominated (Table 1).

The full extent of wetlands could not be accurately assessed from aerial imagery for two reasons. Firstly, wetlands were difficult to detect when they were under tree canopy, and the limited areas mapped within the forest or woodland category were mostly those that had been detected during the field surveys. Therefore, the total area of this wetland type is likely to be substantially underestimated. Secondly, in many parts of the study area, particularly in the south, wetland vegetation that would be expected to occur around the numerous dams and drainage lines was not discernible in aerial photos.

Table 1. Broad wetland vegetation types mapped within the study area (1,646 ha).

Vegetation type	Number of polygons mapped	Mapped area (hectares)	% of mapped wetlands
Forest/woodland	65	41.8	2.5
Shrub-dominated	303	247.7	15.1
Sedge/reed-dominated	572	398.2	24.2
Remnant	805	958.6	58.2

Vegetation survey

Two hundred and three species were recorded from 68 quadrats in 47 wetlands. Quadrats were fairly uniformly spread over a range of altitudes (300–620 m). Fewer quadrats were sampled at lower altitudes (20% were below 500 m) than at higher altitudes, indicating that these sites were relatively rare. The introduced pasture species *Holcus lanatus*, *Anthoxanthum odoratum* and *Lotus corniculatus* were ubiquitous components of ground layers, and were recorded in more than 70% of quadrats.

The majority of quadrats (41) consisted of soligenous systems associated with a break in steep slopes (>5^0) or gentle slopes (<5^0) where bedrock or an impermeable layer was at, or close to the surface. Just over half of these sites were located on broadly planar land surfaces, with the remainder in broadly concave depressions. Runoff from these sites sometimes converged into distinct drainage lines.

Six soligenous sites were recorded on 'mounds' located on steep or gently sloping hillsides. Spring-fed mounds appear to be an undescribed landform element in Victoria. They were distinctly convex and usually about 2–4 m in diameter. Mounds had a clearly defined vent and are likely to have been formed by localised upwelling of groundwater, resulting in unstable, raised areas of saturated peat. Related, larger landform features have been described elsewhere as mound springs, associated with the Great Artesian Basin (Fensham *et al*. 2004*a*, *b*), tumulus (organic mound) springs in Western Australia (Blyth & English 1996), and spring-fen mounds or groundwater mounds in Europe, North America and Japan (Ryadin & Jeglum 2006, Tomita 2008). Topogenous sites were situated in vales (17) and in gullies (7). These sites received water from inflow and from springs situated along banks, or via mounds situated within the main drainage lines.

Cores were taken from 47 quadrats but high water content prevented successful extraction from the remainder of quadrats, particularly in mounds. The stratigraphy of sites was reasonably consistent throughout the study area. All sites, with few exceptions, consisted of an A horizon between 3 and 80 cm deep comprising reddish-brown peat or (rarely) organic loam, overlying grey to yellow-grey medium clays generally from about 85–100 cm and an impermeable layer situated above weathering bedrock. Mounds tended to contain unconsolidated gravels or fine sands in the region above the impermeable layer, at approximately 2 m depth. An increase in moisture was detected below the impermeable layer at two sites, suggesting the presence of perched water tables.

Charcoal was recorded at the boundary between peat and clay layers and throughout the deeper clay layers but less commonly in the upper peat layer. Soil A horizons were acidic (pH 5) to mildly alkaline (pH 7.9). Most sites were peat (>70% of sites), with the remainder organic loam (i.e. having <20% organic content).

Moisture content was highly variable among quadrats, ranging from only 20% at the driest site to 95% at saturated sites. The organic content of the A horizon varied from 6% to 80% among quadrats. The highest accumulation of organic content was on mounds, although the sample size was small (6 sites). However, there was no statistically

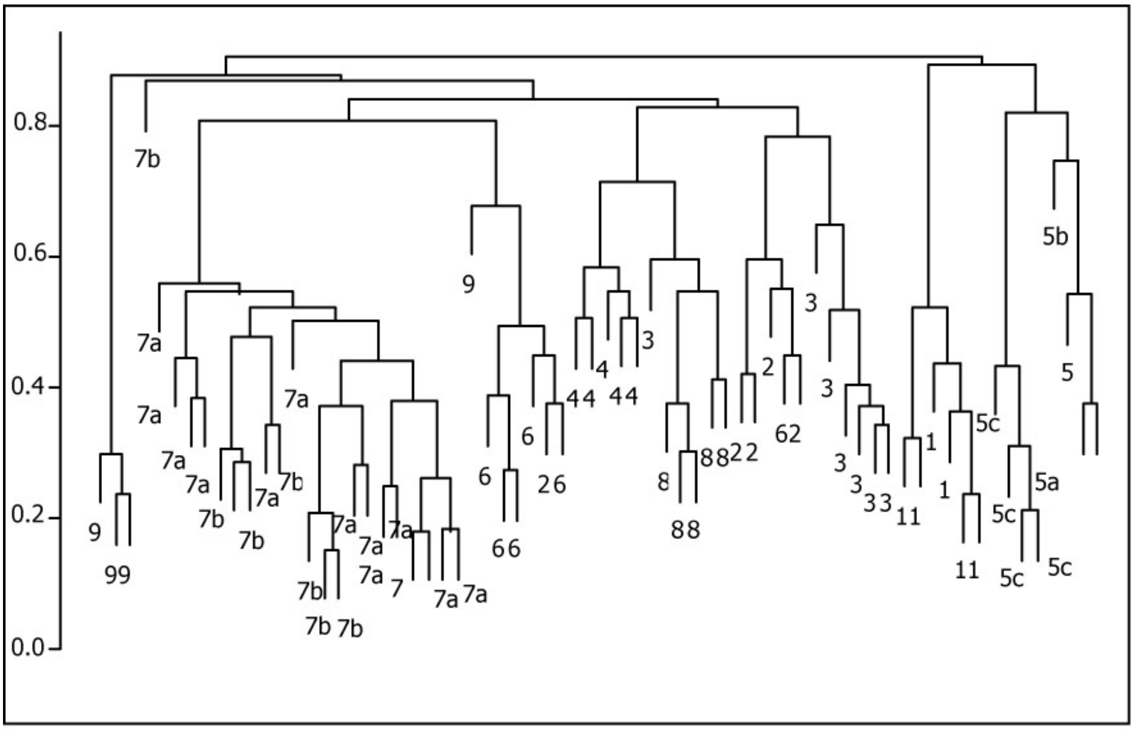

Fig. 2. Dendrogram produced from agglomerative hierarchical clustering of floristic data. Clusters are labelled by floristic group membership. The lengths of the vertical lines represent Bray-Cutis dissimilarity.

significant difference in mean moisture content or organic content of the A horizon among hydrogeomorphic classess (P <0.05). There was a strong positive relationship between organic content and moisture content (r = 0.84, P <0.001), suggesting that peat was better developed in wetlands that showed less signs of drying out, at least toward the wetland centre where quadrats were typically sampled.

Vegetation groups

Nine floristic assemblages were derived from the floristic survey, although there was a degree of overlap in the composition of some of the vegetation groups (Figure 2). There were some significant differences between various vegetation groups for altitude, soil moisture, organic content, rainfall, temperature, native species richness, weed species richness, weed cover, buffer width and length and years fenced, distance to the nearest bore, percent pugging and disturbance (Table 2). However, no group was consistently different from any other and there was a large amount of variation in the data (Table 2).

Group 1. *Phragmites australis* Reedland

Dominated by tall dense to mid-dense stands (> 50% cover) of *Phragmites australis* with a sparse to moderately dense (5–60% cover) mid-stratum of sedges such as *Carex appressa, Carex fascicularis* or *Carex gaudichaudiana* (Appendix 1). The ground layer is predominantly introduced species, particularly *Holcus lanatus* and *Lotus corniculatus*. *Eucalyptus camphora* subsp. *humeana*, *Leptospermum lanigerum* and *Dicksonia antarctica* are recorded as occasional emergents. Mean native species richness (7) in this group is half or less than that recorded in other groups, significantly so in some cases (P < 0.05; Table 2).

Distributed across the study area at a range of altitudes (380–590 m) but mainly at sites with relatively low mean annual rainfall (829 mm), this community is confined to saturated, topogenous sites with standing water in the central zone of vales or gullies (mean soil moisture = 77%).

Referable to Tall Marsh (EVC# 821).

Table 2. Mean values (±SD) of environmental variables recorded for each vegetation group.
Means that do not share a letter are significantly different.

Group	1	2	3	4	5	6	7	8	9
Peat depth (cm)	14±4.8^{A}	4±1.4^{A}	26±27^{A}	28±18^{A}	20±11.3^{A}	36±17^{A}	21±13^{A}	18±25^{A}	14±3^{A}
pH	7.2±0.3^{A}	6.6±0.7^{A}	6.4±0.4^{A}	6.9±0.2^{A}	6.5±0.9^{A}	6.6±0.5^{A}	6.7±0.6^{A}	6.7±0.6^{A}	6.9±0.1^{A}
% organic	43±20^{AB}	28±23^{AB}	24±21^{B}	63±12^{A}	34±15^{A}	43±18^{AB}	52±21^{AB}	52±26^{AB}	38±28^{AB}
% moisture	77±15^{AB}	60±22^{AB}	53±22^{AB}	88±5^{A}	64±21^{AB}	75±23^{AB}	80±14^{A}	84±8^{AB}	73±10^{AB}
Altitude (m)	472±86^{C}	459±45^{C}	543±29^{AB}	382±103^{C}	582±33^{A}	545±32^{AB}	533±49^{AB}	507±94^{AB}	578±41^{AB}
Mean annual precipitation (mm)	829±78^{AB}	793±24^{B}	947±70^{A}	811±124^{AB}	845±96^{AB}	904±108^{AB}	902±68^{AB}	933±55^{AB}	844±46^{AB}
Mean annual temperature (°C)	12.1±0.5^{A}	12.1±0.2^{AB}	11.9±0.2^{AB}	12.3±0.7^{A}	12±0.5^{AB}	11.8±0.5^{AB}	11.6±0.2^{B}	11.9±0.3^{AB}	11.8±0.4^{AB}
Native species richness	7.3±3.9^{C}	9.2±4.9^{BC}	21.3±7.4^{A}	17.6±2.3^{ABC}	17.1±6.1^{ABC}	19.2±7.3^{AB}	15.3±6.5^{ABC}	15.8±4.6^{ABC}	22±6.4^{AB}
Weed species richness	5.5±2.4^{B}	6.8±1.5^{AB}	6.9±1.9^{AB}	10±2.1^{A}	7.4±2.1^{AB}	9±2.6^{AB}	5.7±2.2^{B}	7.2±2.8^{AB}	5.8±2.1^{AB}
Weed cover (%)	19±17.2^{ABC}	43±12^{A}	25±11.1^{ABC}	31±26.8^{AB}	7±6.1^{C}	19±11.5^{ABC}	12±11.9^{BC}	13±9.8^{BC}	3±2.5^{BC}
Buffer width (m)	26±47^{AB}	21±35^{AB}	34±32^{AB}	0^{B}	151±216^{A}	27±29^{AB}	30±42^{B}	0^{B}	61±28^{AB}
Buffer length (m)	17±27^{AB}	34±65^{AB}	34±34^{AB}	0^{B}	70±41^{A}	57±56^{AB}	23±28^{B}	0^{B}	58±30^{AB}
Years fenced	3.2±4.5^{AB}	1.2±2.2^{B}	3.1±3.8^{AB}	0.1±0.2^{B}	2.5±3.8^{B}	4.2±3.8^{AB}	2.6±3.5^{B}	0.5±0.5^{B}	11.3±12.5^{A}
Distance to bore (m)	3617±1710^{AB}	2304±1681^{B}	1477±851^{B}	6440±1831^{A}	3513±2262^{B}	920±550^{B}	2588±1422^{B}	3640±2251^{AB}	2795±1344^{B}
Distance to dam upslope (m)	0^{A}	12±27^{A}	0^{A}	40±89^{A}	15±25^{A}	0^{A}	27±49^{A}	142±275^{A}	20±40^{A}
Distance to dam downslope (m)	432±279^{A}	226±173^{A}	119±162^{A}	80±148^{A}	366±582^{A}	97±101^{A}	174±277^{A}	76±98^{A}	48±59^{A}
Distance to dam across slope (m)	0^{A}	0^{A}	23±41^{A}	44±67^{A}	9±25^{A}	13±33^{A}	54±162^{A}	0^{A}	10±20^{A}
% pugging	0.5±0.5^{B}	0.5±0.6^{B}	2±3.5^{B}	35±40^{A}	1±1.7^{B}	2±1.5^{B}	1±1.4^{B}	3±2^{B}	2±2.4^{B}
% tracks	1±2^{A}	3±2^{A}	2±1.9^{A}	6±13.3^{A}	8±7.7^{A}	4.8^{A}	5±4.6^{A}	0^{A}	8±4^{A}
Disturbance	0.2±0.2^{ABC}	0.5±0.1^{AB}	0.3±0.1B^{C}	0.7±0.4^{A}	0.2±0.1^{C}	0.3±0.1B^{C}	0.2±0.1^{C}	0.2±0.1^{C}	0.1±0.1^{C}

Group 2. *Juncus sarophorus – Carex appressa* Sedgeland

This community is dominated by *Juncus sarophorus* and *Carex appressa* (30–70% combined cover) and a moderately dense to dense ground layer (30–80% cover) mainly consisting of introduced pasture species such as *Holcus lanatus*, *Anthoxanthum odoratum* and *Lotus corniculatus*. *Eucalyptus camphora*, *Acacia melanoxylon* and *Leptospermum lanigerum* are occasional emergents (Appendix 1).

Juncus sarophorus – Carex appressa Sedgeland is common on both topogenous vales across a range of elevations (390–500 m) at sites with relatively low mean annual rainfall (793 mm). It occurs on drier sites than group 1 (Table 2) and is commonly seen as remnant wetland vegetation in paddocks along shallow drainage lines and at the margins of wetlands.

Referable to Wet Verge Sedgeland (EVC# 932).

Group 3. *Baeckea utilis* Shrubland

Dominated by moderately dense stands (> 40% cover) of *Baeckea utilis* to 4 m high and occasionally co-dominated by *Epacris brevifolia* or *Leptospermum continentale* (Appendix 1). The ground layer mainly consists of exotic grasses and herbs (*Holcus lanatus*, *Anthoxanthum odoratum*, *Lotus corniculatus*) but also with a high level of species richness (Table 2). Co-occurring native species include *Poa helmsii* and other monocot species (e.g. *Baumea rubiginosa*, *Arthropodium milleflorum*, *Luzula meridionalis*). Native herbs are less consistently represented but may include *Gonocarpus micranthus*, *Hydrocotyle* spp., *Drosera peltata*, *Craspedia paludosa* or *Euchiton involucratus*. *Eucalyptus camphora* may be an occasional emergent.

Confined to the northern Strathbogies at higher elevations (500–575 m), *Baeckea utilis* Shrubland tends to occur as isolated thickets in soligenous situations along breaks in gentle or steeper slopes on shallow soils, at the margins of *Eucalyptus camphora* open forest and as discontinuous patches in cleared paddocks. Soil moisture and organic content values were the lowest recorded during the survey (53% and 24% respectively; Table 2).

Referable to Perched Boggy Shrubland (EVC# 185).

Group 4. *Leptospermum lanigerum – Baumea rubiginosa* Open Shrubland

This community occurs on wet sites dominated by *Leptospermum lanigerum* (10–30% cover) to 1.5 m

Key to Groups

1. Trees absent or sparse (cover <5%), dominated by shrubs, reeds, rushes or sedges 2
1. Trees present (cover >5%), or if absent or sparse not dominated by rushes, reeds or sedges (shrubs usually present) 3

2. Shrubs (*Leptospermum* spp., *Baeckea utilis*) dominant 8
2. Reeds, rushes or sedges dominant 10

3. Swamp woodland with ground layer or understorey of shrubs or coral fern (>25%) 4
3. Swamp woodland with ground layer of sedges and/or other ferns 5

4. Swamp woodland with ground layer dominated by coral fern ....GROUP 9
4. Swamp woodland with understorey dominated by shrubs............8

5. Swamp woodland with ground layer of sedges, bracken and *Blechnum* ....GROUP 5b
5. Swamp woodland with ground layer mainly of sedges (>25%) 6

6. Open swamp forest with a ground layer dominated by *Gahnia* or *Carex* 7
6. Swamp woodland with a ground layer dominated by *Baumea*............GROUP 7a

7. Open swamp forest with a ground layer dominated by *Gahnia sieberiana* ....GROUP 5a
7. Open swamp forest with a ground layer dominated by *Carex appressa*............GROUP 5c

8. Understorey consisting of tall shrub thickets (2 m)9
8. Understorey consisting of low shrubs (< 2m)............GROUP 4

9. Open swamp forest or shrubland dominated by *Leptospermum lanigerum* ....GROUP 6
9. Open swamp forest or shrubland dominated by *Baeckea utilis* ....GROUP 3

10. Tall reedland (> 2m)............GROUP 1
10. Dominated by rushes or sedges............11

11. Dominated by rushes (*Juncus*)............GROUP 2
11. Dominated by sedges 12

12. Swamp woodland, ground layer dominated by *Baumea*............GROUP 7a
12. Sedgeland, swamp gum absent 13

13. *Baumea* spp. >25% cover............14
13. Small graminoids and forbs dominant (< 25% cover) ....GROUP 8

14. *Gleichenia* and *Baumea* spp. co-dominant ....GROUP 9
14. *Baumea* dominant ....GROUP 7b

(occasionally taller) and *Baumea rubiginosa* with a high diversity of graminoid and herbaceous species in the ground layer (Appendix 1). These include *Holcus lanatus*, *Eleocharis gracilis*, *Juncus planifolius*, *Phragmites australis*, *Schoenus* spp., *Isolepis* spp., *Triglochin striata*, *Utricularia dichotoma* and *Hypericum japonicum*.

The community is found at significantly lower mean elevation (380 m, $P < 0.001$) than any other group except 1 and 2 (Table 2). It occurs in soligenous settings around spring outlets within vales as well as on gentle or steeper slopes to the south of the study area. Soils had high organic and moisture content (Table 2). Disturbance was also significantly higher than in any other group except 1 and 2 ($P < 0.001$; Table 2). The presence of remnant stands of *Leptospermum lanigerum* suggests that this community may eventually regenerate to Thicket Swamp Forest (see below) in the absence of stock disturbance.

Referable to Perched Boggy Shrubland (EVC# 185) and Swamp Scrub (EVC# 53).

Group 5. *Acacia melanoxylon* Swamp Forest

This group contains three related swamp forest communities dominated by *Acacia melanoxylon* distributed over a soil moisture gradient and distinguished by understorey composition. Different disturbance histories are also likely to have determined the current floristic composition of the understoreys but sites also had low weed cover (Table 2). Quadrats were located on gently sloping terrain and within vales and gullies; however, low moisture content (Table 2) suggests that most sites appear to be drying out.

Referable to Fern Swamp (EVC# 721) and Swampy Woodland (EVC# 937).

Group 5a. *Acacia melanoxylon – Gahnia sieberiana* Open Swamp Forest

Dominated by *Acacia melanoxylon* with occasional *Eucalyptus globulus* to 25 m with >25% cover (Appendix 1). The ground layer is dominated by *Gahnia sieberiana* (20–40% cover), a sparse cover of grasses (*Poa helmsii*, *Poa labillardieri*, *Microlaena stipoides*) and small sedge or herb species. *Baumea rubiginosa* is occasionally locally dominant. *Baeckea utilis* may also be present and *Eucalyptus camphora* is an occasional co-dominant.

Open Swamp Forest is confined to steeper slopes and gullies at higher elevations (around 600 m) in the north Strathbogies. Sites are on gully slopes or drainage lines and are topo-soligenous. This community is likely to be a remnant vegetation type formerly more widespread in drainage lines.

Group 5b. *Acacia melanoxylon – Eucalyptus camphora* Swamp Woodland

Recorded from a single quadrat within state forest but distinguished from groups 5a and 5c by a higher cover of bracken and lower cover of native herbs and small sedges (Appendix 1). Swamp Woodland consists is dominated by *Acacia melanoxylon* and *Eucalyptus camphora* to 25 m (20% cover) with a moderately dense ground layer (50% cover) dominated by *Carex appressa*, *Carex fascicularis*, *Blechnum nudum*, *Pteridium esculentum*, *Poa helmsii* and remnant *Dicksonia antarctica*.

This community was recorded on a soligenous gentle slope in one of the most elevated parts of the study area (595 m).

The quadrat is a rare example of *Eucalyptus camphora* forest unmodified by agricultural practices, although past disturbances are likely to have included selective logging in the surrounding dry sclerophyll forest and higher fire frequencies than in agricultural land. Grass and other graminoid cover is lower overall (20% *cf.* 40%) and bracken cover higher (10% *cf.* <1%) than in the previous group.

Group 5c. *Acacia melanoxylon – Carex appressa* Open Swamp Forest

At most sites this community consists of *Acacia melanoxlyon* (to 20 m) with *Eucalyptus camphora*, *Leptospermum lanigerum* and *Dicksonia antarctica* at some sites (Appendix 1). Canopy cover is generally >10% but may be lower at disturbed sites. The understorey is dominated by a dense cover of *Carex appressa* (70–90%) and minor species *Cyperus lucidus* and/or *Blechnum* spp., with a sparse cover (<5%) of introduced species such as *Holcus lanatus* and *Lotus corniculatus*.

Open Swamp Forest occurred in gullies and vales at higher altitudes across the study area. Sites were structurally modified and reasonably species poor, but had relatively low weed cover and were thus considered to be in moderate to good condition. Two sites had been fenced for five years.

Group 6. *Eucalyptus camphora – Leptospermum lanigerum* Thicket Swamp Forest

This group is distinguished by well-developed stands of *Leptospermum lanigerum* (>50% cover, to 10 m high) with *Eucalyptus camphora* or occasionally *Acacia melanoxylon* emergent above the dense canopy, generally sparse (<10% cover) but occasionally with up to 25% cover (Appendix 1). The understorey is generally quite open, and mainly consists of a sparse cover of younger *Leptospermum lanigerum* individuals, and blackberry at some sites. The ground layer is open to moderately dense (15–50% cover) and is made up of sedges, grasses and ferns which may include *Gahnia sieberiana*, *Poa helmsii*, *Blechnum minus*, and a sparse cover of *Baumea rubiginosa* or occasionally *Gleichenia microphylla*. Minor ground layer species include a mix of small sedges and herbs (e.g. *Eleocharis gracilis*, *Isolepis* spp., *Acaena novae–zelandiae*, *Gonocarpus micranthus* and exotics (e.g. *Hypochaeris radicata*, *Lotus corniculatus*, *Holcus lanatus*).

The community appears to be confined to cooler, high rainfall areas (500–570 m) on slopes to the north of the study area.

Referable to Swamp Scrub (EVC# 53), Riparian Scrub (EVC# 191) with elements of Fern Swamp.

Group 7. *Eucalyptus camphora* Swamp Woodland

Nearly a third of quadrats (22) were allocated to this group, which contained a degree of floristic and structural variation among quadrats. However, all quadrats were characterised by a moderately dense to dense cover (>50%) of *Baumea rubiginosa*, or less frequently *Baumea planifolia*.

Referable to Swampy Woodland (EVC# 937).

7a. *Eucalyptus camphora – Baumea rubiginosa* Swamp Woodland

This vegetation community is characterised by very wet peat with well-developed organic content (Table 2) and a sparse to moderate cover (5–50%) of trees and/or tall shrubs (5–20 m) consisting of *Eucalyptus camphora*, *Leptospermum lanigerum* or occasionally *Baeckea utilis* at drier sites (Appendix 1). The second stratum consists of a sparse cover (< 25%) of smaller shrubs (< 2m high), typically *Leptospermum continentale* and/or *Baeckea utilis*. *Baumea rubiginosa* forms a dense ground layer (50–100%) and *Phragmites australis* may develop on very wet sites excluded from grazing. Minor ground layer species are *Blechnum minus*, *Hydrocotyle* spp., *Epilobium* spp., *Gonocarpus micranthus* and small graminoids such as *Juncus* spp. and *Eleocharis gracilis*. Introduced exotics were generally less abundant than in group 7b.

Eucalyptus camphora – Baumea rubiginosa Swamp Woodland was recorded in the central wetland zone at higher elevations (440 m–590 m). Quadrats were higher in native species richness than group 7b (17 *cf.* 10), with lower mean cover of weeds (7% *cf.* 20% cover). Almost all sites were recorded on gentle to steep soligenous slopes and occasionally in vales and gullies.

7b. *Baumea rubiginosa* or *Baumea planifolia* Closed Sedgeland

This community is lacking in trees, but may occasionally include a sparse cover (<10%) of tall shrubs (*Leptospermum continentale* and/or *Baeckea utilis)*. It is dominated by tall, moderately dense to dense swards (>50%) of *Baumea rubiginosa* which may grow to 2 m high (Appendix 1). *Baumea planifolia* is dominant at some sites, mostly to the north of the study area. Ground layer species generally include grasses, other small graminoids and herbs such as *Poa helmsii*, *Eleocharis gracilis*, *Juncus* spp., *Epilobium* spp. and occasionally *Sphagnum* spp. Introduced exotic species *Holcus lanatus*, *Hypochaeris radicata* and *Anthoxanthum odoratum* are also prominent in the ground layer.

Baumea rubiginosa/*Baumea planifolia* Closed Sedgeland occurs at higher elevations (420–590 m) in the central, mid and outer wetland zones. Sites were mostly located on gentle to steep soligenous slopes, mounds and occasionally in vales.

Group 8. *Elaeocharis gracilis* Low Sedgeland

Low Sedgeland is dominated by *Eleocharis gracilis* and a suite of small sedges and herbs (60–80% combined cover) forming a low (<0.3 m) turf (Appendix 1). Associated species typically include *Hydrocotyle sibthorpioides*, *Epilobium* spp., *Drosera peltata*, *Schoenus maschalinus*, *Schoenus apogon*, *Isolepis subtillissima*, *Isolepis inundata*, *Juncus articulatus*, *Juncus planifolius* and *Lotus corniculatus*. *Holcus lanatus* may be locally dominant at the spring vent.

Sites occur on waterlogged, soligenous spring-fed mounds with high organic content (Table 2). The community is mainly distributed in cooler, high rainfall areas but is occasionally

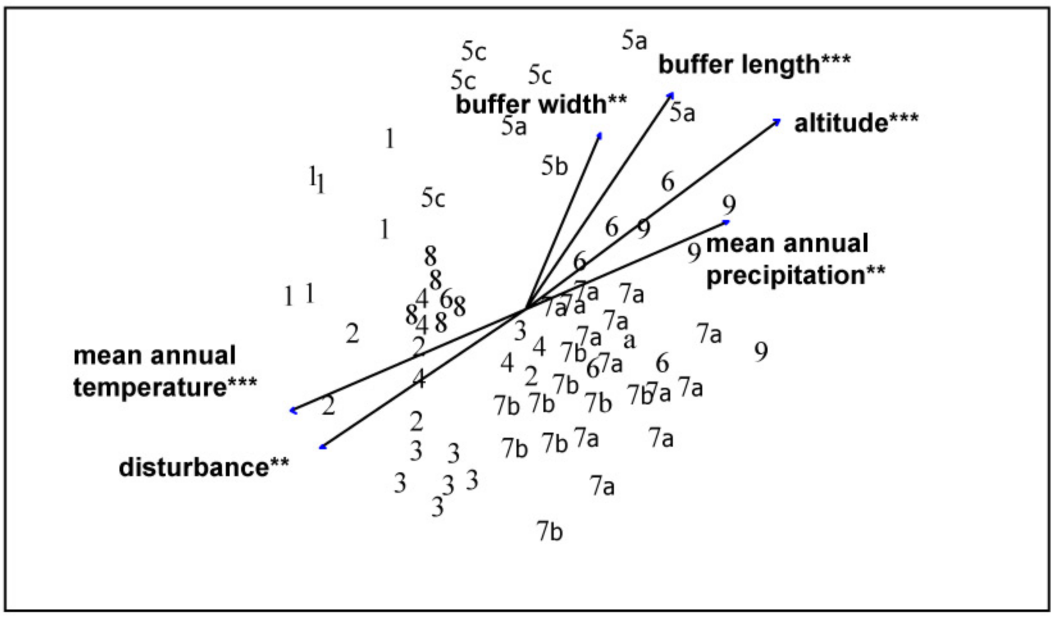

Fig. 3. Distribution of quadrats within the 3-dimensional ordination space, dimensions 1 and 2.
Points are labelled by cluster group membership and vectors of maximum correlation; fitted vectors correlation co-efficients (r2) and statistical significance. ** <0.01; *** < 0.001. Vector lengths are proportional to strength of correlation.

found at lower altitudes (350–570 m). Mounds occur within forest and in open paddocks.

No referable EVC.

Group 9. *Eucalyptus camphora – Acacia melanoxylon – Gleichenia microphylla* Swamp Woodland

This group consists of species rich sites with an understorey characterised by a dense cover of *Gleichenia microphylla* (40–80%). Other understorey species may include *Baumea rubiginosa* and *Pteridium esculentum. Acacia melanoxylon* and/or *Eucalyptus camphora* are the dominant tree species (3–20 m, <25% cover) and *Leptospermum lanigerum* may be locally dominant in the second stratum (Appendix 1). The ground layer consists of a very sparse cover of small sedges, herbs and grasses but *Holcus lanatus* and other exotics commonly recorded elsewhere in the study area are sparse.

Sites are located on slopes in cool, elevated areas (520–620 m). All sites are on gentle to steep soligenous slopes but are showing signs of deterioration, as evidenced by large areas of *Gleichenia* either dead or dying.

Referable to Swampy Woodland (EVC# 937).

NMDS attained a minimum stress of 0.17 in three dimensions. In the plane bounded by dimensions 1 and 2, floristic composition was correlated with variables related to climate and disturbance (Figure 3). The least disturbed sites, with fewer tracks, less pugging and lower weed cover, consisted of forest and woodland which were better buffered by native vegetation, and situated in cooler, more elevated locations than disturbed sites. These were *Acacia melanoxylon* Swamp Forest (Group 5), *Eucalyptus camphora – Leptospermum lanigerum* Open Swamp Forest (Group 6) and *Eucalyptus camphora – Acacia melanoxylon – Gleichenia microphylla* Swamp Woodland (Group 9).

At the opposite end of this trend were treeless sites with higher mean annual temperatures at lower elevations and sites to the north of the study area with higher levels of disturbance. These groups were *Juncus sarophorus* Sedgeland (Group 2), *Baeckea utilis* Shrubland (Group 3) and *Leptospermum lanigerum – Baumea rubiginosa* Open Shrubland (Group 4).

A third compositional trend (dimensions 1 and 3, Figure 4), was correlated with the vector for native species richness. Quadrats with high species richness mainly belonged to Group 6 (*Eucalyptus camphora – Leptospermum lanigerum* Open Swamp Forest) and Group 9 (*Eucalyptus camphora – Acacia melanoxylon – Gleichenia microphylla* Swamp Woodland). However, while the vector was highly significant in relation to site positions on the ordination, the raw data indicated that the relationship between richness and vegetation groups was weaker. There was also a weak correlation between floristic composition and the number of years that some of these sites had been fenced. This suggests that stock exclusion may have positive benefits; however, almost all sites that had been fenced for five or more years were located to the north of the study area on soils with relatively low (< 60%) moisture content, implying that compositional variation may be attributable in part, to establishment of species suited to drier soils.

The relationship between floristic composition and distance upslope to a dam was also weakly significant (Figure 4). While dams were further upslope (> 150 m) of quadrats in Group 1 (*Phragmites* Reedland) and Group 2 (*Juncus* Sedgeland), inspection of the raw data revealed that there was no consistent relationship between this variable and other groups.

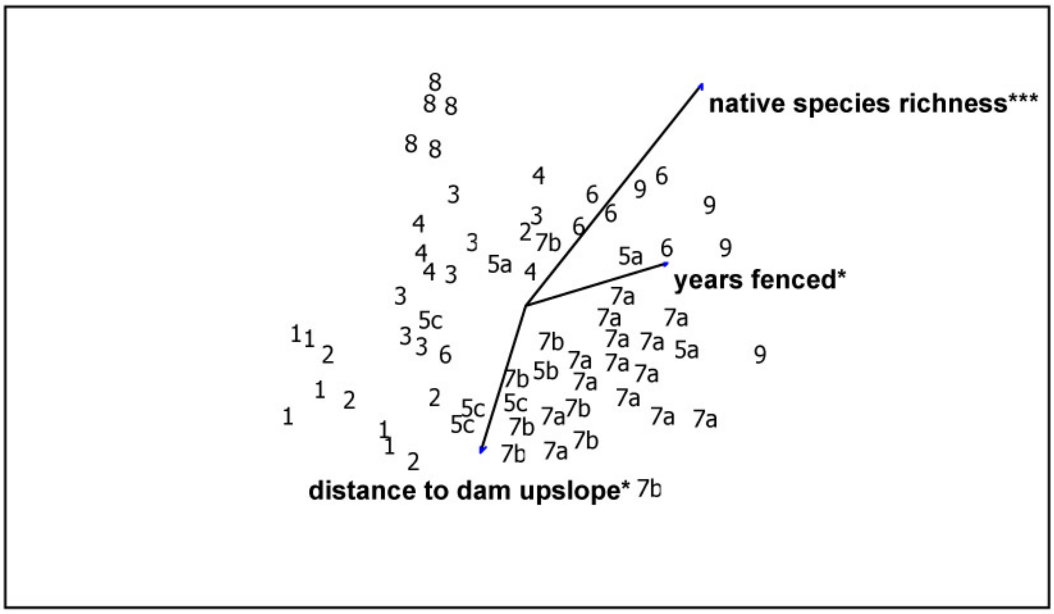

Fig. 4. Distribution of quadrats within the 3-dimensional ordination space, dimensions 1 and 3.
Points are labelled by cluster group membership and vectors of maximum correlation; fitted vectors correlation co-efficients (r^2) and statistical significance. * < 0.05; *** < 0.001. Vector lengths are proportional to strength of correlation.

Current and potential threats

Habitat destruction and degradation

Changes in land cover: trends in land use change included an increase in the area of farm land converted to hardwood or softwood plantations, viticulture and horticulture (10% of sites visited).

Grazing: only seven quadrats were currently grazed (<10%). Pugging and tracks were the most frequently recorded threat, but severity was generally low with the exception of cleared mound areas or very wet areas. Grazing was also the most common land use within 250 m of wetlands (82%).

Weed invasion: high levels of weed cover were recorded. *Holcus lanatus*, *Lotus corniculatus* and *Hypochaeris radicata* were the three most frequently recorded weeds, occurring in more than 80% of quadrats. *Rubus* spp. (blackberry) were recorded in approximately 50% of wetlands but were rarely abundant, probably because of high investment in control measures by landowners.

Earthworks and extraction: excavation in the form of dams or channels or water extraction via pipes was observed in 30% of the wetlands visited. Landforming (e.g. embankments) was observed less frequently (< 10%) and was generally associated with roadworks or redirection of water (e.g. around culverts).

Dysfunction of physical and biological processes

Reduction in wetland area: 60% of wetlands were assessed as showing signs of drying out, defined as having more than 50% of their area consisting of dry or damp soil (as distinct from saturated or waterlogged soil). This observation was made in another guise by long-term landowners who frequently commented on the extent to which areas of land, previously boggy 20 years ago, were now traversable in a vehicle. At least some vegetation zonation (> 25% intact) was detected at one third of wetlands. However, almost 50% of wetlands assessed showed no sign of zonation, with a small proportion having 10–20% of the presumably original vegetation zones remaining.

Fragmentation: assumed loss of connectivity was observed in 40% of wetland systems, as a result of general land clearing.

Degradation and clearing of buffers: vegetation with a significant component (> 25%) of native species surrounding wetlands was absent from or sparse (< 0.1 ha) in 60% of wetlands. Of the remaining wetlands, only one site (on public land) was completely surrounded by forest and there were few wetlands (< 20% of sites) with buffers > 0.5 ha.

Changes to disturbance regimes

Increased interspecific competition: Sedge cover in excess of 50% was measured in 37% of quadrats and greater than 75% cover was measured in 18% of quadrats (predominantly *Baumea rubiginosa* or *Eleocharis gracilis*).

Fire: charcoal was recorded in 52% of quadrats, indicating that fire occurred historically throughout the study area.

Discussion

Floristic composition

Most vegetation communities were referable to published EVCs with the exception of group 8 (*Elaeocharis gracilis* Low Sedgeland), which was confined to an undescribed landform element (spring-fed mounds) in Victoria. None of the other floristic groups identified by clustering was confined to any particular hydrogeomorphic class.

We did not attempt to describe vegetation zonation. Intact zones were mostly indistinguishable in the field, having been disrupted as a consequence of various disturbances since European settlement, altered hydrological states and subsequent changes to vegetation structure and composition. The lack of clear or consistent delineation between floristic groups on the basis of substrate properties, landscape setting, or other variables is not surprising. Rather, the results describe the floristic assemblages currently present within the landscape, across a range of elevations and degrees of disturbance. The results suggest that hydrogeomorphic classification is unlikely to provide a suitable basis for conservation and management of remnant vegetation because landform setting and hydrologic dynamics alone do not differentiate the range of floristic assemblages present within these wetlands at the scale the study was conducted.

The structural and floristic variation within the range of landform settings and differing management histories across the study area make it virtually impossible to reconstruct the pre European vegetation and there were few if any examples of the presumed original forests. It seems reasonably likely that the extant vegetation is derivative from wet forest, swamp woodlands and shrublands or thickets dominated by *Acacia melanoxylon*, *Eucalyptus camphora*, *Leptospermum lanigerum*, *Leptospermum continentale* and/or *Baeckea utilis*, with a groundlayer consisting mainly of sedges (Cyperaceae) but including a range of forbs and at some sites, *Sphagnum* spp.

Sediment cores showed a distinct zone separating peat and clay layers but which frequently contained charcoal particles throughout, a pattern which was remarkably consistent all over the study area. This may indicate some sudden environmental change such as the arrival of Europeans who used fire to clear vegetation and to provide green feed for sheep (White *et al*. 1990). As a consequence, peat development may be relatively recent, with water tables rising in response to tree removal. Recent palynological work in three wetlands in the southern part of the study area dated these sites between 1,100 years to a mere 100 years old, lending support to the notion that some wetlands in the study area are an artefact of vegetation clearing (Gubbins 2010). The transformation of swamp forest to sedgeland has also been seen after burning in some northern hemisphere wetlands (von Grootjans *et al*. 2005). Evidence of charcoal is common in swamps (Whinam & Hope 2005) and charcoal was also frequently recorded throughout the deeper clay layers, suggesting that fire has also occurred (either naturally or as a result of Aboriginal burning) over the longer-term.

Current variation in vegetation composition of spring wetlands on the Strathbogie plateau is related to climate, intensity of land use and management. The least disturbed sites (lower weed cover, less soil disturbance) consisted of forested vegetation which was more likely to occur at higher elevations where grazing pressure appears to have been historically less intense, occurred in State Forest or was confined to relatively steep slopes not targeted for clearing. All of these sites were well buffered by native vegetation and most were distant from upslope dams although the vector for the latter variable was relatively weak.

Treeless vegetation (Groups 2, 3, 4 and 8) was the most highly disturbed and was often associated with wetlands in open paddocks where the ground was pugged and the vegetation had been grazed down to a short turf. These sites undoubtedly represent the vegetation which has been most highly modified since European settlement. Nonetheless, native species were well represented in some of these groups, notably groups 3, 4 and 8. This implies a functional shift in the vegetation, whereby an array of minor species has been able to flourish with increased light availability and control of competitors under a regime of grazing.

There was little or no evidence in the data that water extraction via dams and known bores was a significant driver of vegetation composition at the quadrat scale; indeed, there were few bores mapped within 100 m of any study site and only 149 licensed bores across the Strathbogie plateau, equivalent to a bore density of approximately 1 per 6 km^2, estimated as less than 5% of a base-level groundwater discharge rate (Stewardson *et al*. 2009).

Soil properties, including moisture content, were not related to variation in floristic composition and were not significantly correlated with disturbance. This tends to suggest that land use has affected the vegetation more directly through clearing and reducing structural complexity, than indirectly through hydrological changes. However, sampling was focussed in the wetter, central wetland areas, where the effects of drying are less likely to be detectable than in the outer wetland areas. Outer zones with shallower soils and greater seasonality in moisture levels would be expected to show trends toward drying earlier than central zones, and might be adversely impacted by any decrease in water availability.

A more accurate inventory of the current number and extent of bores and dams, and the total volumes of water extraction including groundwater discharge rates and both the distribution and pumping rates of groundwater bores (Stewardson *et al*. 2009) may provide more information. One site was close to Dropmore Spring, used since 1931 and with a flow of 0.03 L/s; however, no comparable data were available for other springs or bores. Stewardson *et al*. (2009) concluded that on average, the influence of groundwater extractions on spring discharge is likely to be small. Thus, the most likely explanation for soil drying is reduced spring discharge in recent years primarily as a consequence of the sequence of lower annual rainfall totals experienced in the Strathbogie Ranges over the last decade (Stewardson *et al*. 2009).

We also observed obvious signs of soils drying out at forest/woodland sites which were among some of the least disturbed and were excluded from stock grazing, but had clearly deteriorated in recent years. These sites were situated on slope breaks with ground layers characterised mainly by large dead or dying colonies of *Gleichenia microphylla* or by dense stands of *Gahnia sieberiana* and at one site, remnant *Sphagnum*. However, it is difficult to determine to what extent loss of soil moisture and wetland contraction is attributable to the dam above or to longer-term climatic changes. Nevertheless, these soil drying trends were indicated at the scale of overall site condition. This is further supported by the results of the mapping, which determined (conservatively) nearly a 60% loss of wetland vegetation, as indicated by the extent of 'remnant' vegetation in paddocks.

Threats and management

Mapping revealed that wetlands within the study area are likely to have decreased, conservatively, by nearly two thirds of their original extent, as a result of historical clearing and grazing (and possibly interruptions to hydrology). The main impact on vegetation is likely to be loss of vegetation zonation and replacement of indigenous wetland species by native or introduced dryland species. The wetlands surveyed were vulnerable to a range of threats which could be grouped into three categories: habitat destruction and degradation, dysfunction of physical and biological processes and changes to disturbance regimes.

The major consequences of grazing are eutrophication resulting from pollution by urine and faeces, disturbance and destruction of peat, selective grazing of palatable species, a reduction in the area of soil available for survival and reproduction of native species, and conditions more suitable for establishment of weeds. Ubiquitous exotic pasture species have virtually replaced the ground layer at many sites, favoured by high soil moisture, soil disturbance and increased nutrient levels from broadacre fertilising.

The specific measurement of seasonal inundation was beyond the scope of the study, although many landowners drew attention to this as a likely threat. Loss of the natural range of water regimes (extent and degree of saturation) will further exacerbate the loss of vegetation zonation or loss of understorey dominants which characterises wetland systems, and which has already occurred at most sites. This may result from a long-term decrease in precipitation, from human-induced changes in the surrounding landscape, or from both of these factors.

The role of native vegetation buffers is likely to be most beneficial in maintaining connectivity, reducing access to stock, improving water quality by filtering surface run-off, and making an important contribution to local biodiversity. Buffers consisted of forested vegetation as well as native grassland which had established when wetlands had been fenced off to exclude stock. Some were dominated by an array of native species, in particular *Themeda australis,* but this depended on past land management such as fertilizer use and extent of ploughing. These buffers require management in the form of sheep grazing or preferably burning, to maintain the somewhat serendipitous establishment of native vegetation that has occurred around wetland sites.

An emerging industry on the Strathbogie plateau is conversion of farmland to blue gum plantations. The replacement of herbaceous vegetation with monocultures may have potential to disrupt wetland hydrology and some biological interactions. We speculate that impacts might include a loss of pollinators, an increase in predators and herbivores, loss of resilience to disease and pathogens (Auld & Keith 2008), or a reduction in ground water availability through transpiration.

Recent conservation efforts have focussed on fencing wetlands to exclude livestock from some of the wetlands, almost all of which occur on private property. An unforeseen consequence of exclusion has been an increase in dominance of large, highly competitive reeds and sedges (e.g. *Phragmites australis*, *Baumea rubiginosa*). Ongoing risks to vegetation quality include increased interspecific competition leading to exclusion of other species and reduction in species diversity, particularly minor or rare inter-tussock species such as *Eriocaulon scariosum* (Department of Sustainability and Environment 2005). Advantages at these sites include provision of habitat protection from predators for native fauna by dense ground layers.

Recent experimental trials have found that regular biomass removal by grazing, burning or slashing is likely to be necessary to control large sedges and weeds but restoration of species richness in Closed Sedgeland presents a substantial challenge (Coates & Tolsma 2012). Most wetlands are highly modified and it will be futile to attempt to restore them to some idealised, pre-European state. Ongoing experimental trials over timeframes of three to five years are still needed to determine specific management prescriptions.

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Appendix 1. Examples of vegetation groups and distribution of frequent species in quadrats

Cover–abundance classes:
1 = 0.5–1%; 2 = 1–5%; 3 = 5–15%; 4 = 15–25%; 5 = 25–50%; 6 = 50–75%; 7 = 75–100%.
Introduced species are indicated by '*'.

Group 1. *Phragmites australis* Reedland

**Anthoxanthum odoratum*	010001
Baumea rubiginosa	000211
Blechnum minus	000011
Blechnum nudum	000001
Callitriche stagnalis	000001
Carex appressa	003550
Carex fascicularis	000511
Carex gaudichaudiana	130000
**Cirsium vulgare*	110100
Cyperus lucidus	010000
Dicksonia antarctica	000001
Epilobium pallidiflorum	001010
Eucalyptus camphora	000020
Galium australe	101101
Glyceria australis	311011
**Glyceria maxima*	003000
**Holcus lanatus*	542301
Isolepis inundata	000001
**Juncus bufonius*	000001
Juncus planifolius	000001
Juncus sarophorus	320001
Leptospermum lanigerum	000010
**Lotus corniculatus*	031111
**Mimulus moschatus*	000001
Phragmites australis	657556
Poa helmsii	000100
Pteridium esculentum	001001
**Rubus fruticosus*	001001
**Rumex crispus*	110000
Stellaria angustifolia	000001
Epilobium sp.	001001
Isolepis sp.	000001

Group 2. *Juncus sarophorus – Carex appressa* Sedgeland

Acacia melanoxylon	00010
Acaena novae–zelandiae	00111
**Anthoxanthum odoratum*	32331
**Briza minor*	00001
Baumea rubiginosa	02023
Blechnum minus	00010
Callitriche stagnalis	10000
Carex appressa	01353
Carex gaudichaudiana	20000
Centella cordifolia	00001
**Cirsium vulgare*	11000
Cyperus lucidus	10012
Eleocharis gracilis	00011
Epilobium billardierianum subsp. hydrophilum	00010
Epilobium pallidiflorum	10300
Eucalyptus camphora	00010
Glyceria australis	10000
Gonocarpus micranthus	00010
**Holcus lanatus*	51534
Hydrocotyle sibthorpioides	00001
**Hypochaeris radicata*	01112
Isotoma fluviatilis	00101
Juncus planifolius	00011
Juncus sarophorus	55234
Leptospermum lanigerum	00020
**Lotus corniculatus*	21121
Luzula meridionalis	00010
**Mimulus moschatus*	00010
Phragmites australis	01000
Poa helmsii	02043
Poa labillardieri	00001
Ranunculus glabrifolius	00001
**Rubus fruticosus*	00001
**Rumex crispus*	10000
Senecio sp.	00100
**Trifolium dubium*	00001
Utricularia dichotoma	00100

Group 3. *Baeckea utilis* Shrubland

Acacia melanoxylon	0100001
**Anthoxanthum odoratum*	3134333
Arthropodium milleflorum	1111000
Baeckea utilis	5653673
Baumea rubiginosa	0222223
Blechnum minus	0000011
Callitriche stagnalis	0011010
Carex appressa	0001010
Carex gaudichaudiana	1040001
Drosera peltata	0111001
Eleocharis gracilis	0131015
Epacris breviflora	2010330
Eucalyptus camphora	0100002
Euchiton involucratus	0011011
Geranium potentilloides	0001001
Gleichenia microphylla	0000001
Gonocarpus micranthus	1121300
Goodenia elongata	1001000
**Gratiola peruviana*	0010010
Histiopteris incisa	0000101
**Holcus lanatus*	3513322
Hydrocotyle hirta	1100000
Hydrocotyle sibthorpioides	0001011
Hypericum japonicum	0011001
**Hypochaeris radicata*	1211110
Juncus sarophorus	1000011
Juncus sp.	0010011
Leptospermum continentale	0105000
Leptospermum lanigerum	0000024
Lilaeopsis polyantha	0000011
**Lotus corniculatus*	1111022
Luzula meridionalis	1111101
Poa helmsii	3200300
Poa labillardieri	1000010
Ranunculus glabrifolius	1000010
Poa sieberiana	0100000
Poa tenera	0201000
**Rubus fruticosus*	0100201

Group 4. *Leptospermum lanigerum – Baumea rubiginosa* Open Shrubland

**Anthoxanthum odoratum*	33210
**Briza minor*	11000
Baumea rubiginosa	21332
Blechnum minus	01110
Carex gaudichaudiana	11011
Centella cordifolia	10010
**Centaurium erythraea*	10001
**Cirsium vulgare*	01001
Drosera peltata	10110
Eleocharis gracilis	23143
Eriocaulon scariosum	10110
Epilobium gunnianum	00100
Epilobium pallidiflorum	01001
Eucalyptus camphora	01000
Geranium potentilloides	00011
Glyceria australis	11001
Gonocarpus micranthus	00110
**Holcus lanatus*	34323
Hypericum japonicum	10111
**Hypochaeris radicata*	31111
Isolepis inundata	00110
**Isolepis levynsiana*	10100
Isolepis subtilissima	00100
**Juncus articulatus*	00023
**Juncus bufonius*	00100
Juncus planifolius	31122
Juncus sarophorus	11001
Leptospermum lanigerum	03333
**Lotus corniculatus*	22111
**Mimulus moschatus*	10010
Phragmites australis	03014
Poa helmsii	00101
Schoenus apogon	41141
Schoenus maschalinus	31111
**Sonchus asper*	11011
Utricularia dichotoma	10201
Triglochin striata	20312

Group 5a. *Acacia melanoxylon – Gahnia sieberiana* Open Swamp Forest

Acacia melanoxylon	254
Acaena novae–zelandiae	101
**Anthoxanthum odoratum*	010
Baeckea utilis	100
Baumea planifolia	101
Baumea rubiginosa	100
Blechnum nudum	031
Carex appressa	010
Cassinia longifolia	101
**Cerastium glomeratum*	011
Chiloglottis vallida	111
**Cirsium vulgare*	110
Dichondra repens	010
Eucalyptus camphora	400
Euchiton involucratus	010
Gahnia sieberiana	545
Geranium potentilloides	100
Gonocarpus micranthus	100
Gonocarpus tetragynus	101
Goodenia elongata	100
**Gratiola peruviana*	010
**Holcus lanatus*	131
Hydrocotyle spp.	111
**Hypochaeris radicata*	111
Isotoma fluviatilis	110
Leptospermum continentale	100
Mentha laxiflora	100
Microlaena stipiodes	211
Poa helmsii	100
Poa labillardieri	101
Poa tenera	001
Polystichum proliferum	010
Pteridium esculentum	111
**Rubus laciniatus*	101
**Rubus fruticosus*	010
Senecio minimus	101
Schoenus maschalinus	010

Group 5b. *Acacia melanoxylon – Eucalyptus camphora* Swamp Woodland

Acacia melanoxylon	1
**Anthoxanthum odoratum*	2
Blechnum nudum	4
Carex appressa	3
Carex fascicularis	2
Cyperus lucidus	1
Dicksonia antarctica	1
Eucalyptus camphora	4
Gahnia sieberiana	1
Galium australe	1
Geranium potentilloides	1
**Holcus lanatus*	2
Hydrocotyle hirta	1
**Lotus corniculatus*	1
Mentha laxiflora	1
Poa helmsii	2
Pteridium esculentum	3

Group 5c. *Acacia melanoxylon – Carex appressa* Open Swamp Forest

Acacia melanoxylon	0524
Acaena novae–zelandiae	1110
**Acetosella vulgaris*	0011
**Anthoxanthum odoratum*	0101
Baumea rubiginosa	1000
Blechnum minus	1011
Blechnum nudum	1301
Callitriche stagnalis	0011
Carex appressa	6777
Carex fascicularis	1000
**Cerastium glomeratum*	0001
**Cirsium vulgare*	0111
Cyperus lucidus	0211
Dicksonia antarctica	0130
Eleocharis gracilis	1000
*Epilobium billardieria*num subsp. *billardieria*num	1000
*Epilobium billardieria*num subsp. *hydrophilum*	1000
Eucalyptus camphora	0500
Galium australe	0121

*Geranium potentilloide*s	0011
Histiopteris incisa	0001
**Holcus lanatus*	3111
**Hypochaeris radicata*	1011
Isolepis inundata	1010
**Isolepis levynsiana*	1000
Isolepis subtilissima	1000
Juncus planifolius	1000
Juncus sarophorus	1000
Juncus sp.	1000
Leptospermum lanigerum	2000
**Lotus corniculatus*	2011
Mentha laxiflora	0100
**Mimulus moschatus*	0110
Poa helmsii	0100
**Rubus fruticosus*	1101
Schoenus maschalinus	1000
**Sonchus asper*	0010
Stellaria angustifolia	0010
**Trifolium repens*	0010

Group 6. *Eucalyptus camphora – Leptospermum lanigerum* Thicket Swamp Forest

Acacia melanoxylon	000120
Acaena novae–zelandiae	111011
**Anthoxanthum odoratum*	301004
Baeckea utilis	000110
Baumea rubiginosa	220202
Blechnum minus	130111
Callitriche stagnalis	010101
Carex appressa	100010
Chiloglottis vallida	001100
**Cirsium vulgare*	101011
Dicksonia antarctica	000010
Eleocharis gracilis	201212
Epilobium billardierianum subsp. hydrophilum	100002
Eucalyptus camphora	003350
Euchiton involucratus	001111
Gahnia sieberiana	003450
Galium australe	111011
Geranium potentilloides	001011
Gleichenia microphylla	000230
Glyceria australis	001110
**Glyceria maxima*	000004
Gonocarpus micranthus	100111
Histiopteris incisa	000110
**Holcus lanatus*	312311
Hydrocotyle spp.	001101
Hypericum japonicum	000011
**Hypochaeris radicata*	111111
Isolepis spp	010100
Isotoma fluviatilis	001010
**Juncus articulatus*	000110
**Juncus bufonius*	011000
Juncus planifolius	100101
Leptospermum lanigerum	656656
**Lotus corniculatus*	211311
Luzula meridionalis	000011
Mentha laxiflora	000110
Microlaena stipiodes	001110
Poa helmsii	511000
Pterostylis falcata	001010
**Rubus fruticosus*	131111
Sphagnum novozelandicum	000100

Group 7a. *Eucalyptus camphora* Swamp Woodland

Eucalyptus camphora	44001223205020
Acacia melanoxylon	01000200001110
Leptospermum continentale	02001000111110
Baeckea utilis	12000000000005
Baumea rubiginosa	55766656555565
Gymnoschoenus sphaerocephalus	00000000050000
Acaena novae–zelandiae	01110110001111
Carex appressa	00000201001201
Carex gaudichaudiana	00001000110000
Gahnia sieberiana	03000200000000
Eleocharis gracilis	00210011211010
Isolepis subtilissima	10000301100100
Juncus planifolius	00101101100100
Juncus sarophorus	00000101102010
Schoenus maschalinus	00000100100100
**Anthoxanthum odoratum*	03111011111131

Blechnum minus	00220111111100
Dicksonia antarctica	00000200000000
Phragmites australis	00000232024000
**Holcus lanatus*	11111212221221
Poa helmsii	10122121111020
Gleichenia microphylla	50202000430000
Sphagnum novozelandicum	00007000100010
Gonocarpus micranthus	01111010111011
**Hypochaeris radicata*	01111111110011
**Lotus corniculatus*	00011111111111
Hypericum japonicum	00011001110110
Craspedia paludosa	00001000110000
Eriocaulon scariosum	00100000000000
Epilobium billardierianum subsp. *billardierianum*	00001100010100
Epilobium billardierianum subsp. *hydrophilum*	00110000000000
Epilobium gunnianum	00100010100000
Euchiton involucratus	01000000100011
Galium australe	00000111000100
Geranium potentilloides	00000100101010
**Rubus fruticosus*	00000101001110
Goodenia elongata	01000000110000
Hydrocotyle spp.	01011001110001
Centella cordifolia	01010000100001
Luzula meridionalis	00000010010010
**Mimulus moschatus*	00000101001100

Group 7B. *Baumea rubiginosa* or *Baumea planifolia* Closed Sedgeland

Acaena novae–zelandiae	01100000
**Anthoxanthum odoratum*	00111142
Baeckea utilis	00003001
Baumea planifolia	00003015
Baumea rubiginosa	77765552
Blechnum minus	00001010
Carex appressa	20010000
Carex fascicularis	00000200
Craspedia paludosa	00000001
Drosera peltata	00000001
Eleocharis gracilis	01101110
Epilobium billardierianum subsp. *billardierianum*	02100001
Epilobium billardierianum subsp. *hydrophilum*	01000000
Epilobium pallidiflorum	10010100
Gahnia sieberiana	00001000
Galium australe	10001000
**Glyceria maxima*	00000100
Gonocarpus micranthus	00001110
**Gratiola peruviana*	10000100
Hemarthria uncinata	00000001
**Holcus lanatus*	13353452
Hydrocotyle sp.	00000010
Hydrocotyle hirta	01000000
Hypericum japonicum	00000010
**Hypochaeris radicata*	02111110
Isotoma fluviatilis	10000000
**Juncus articulatus*	00000001
Juncus planifolius	00101000
Juncus sarophorus	01121100
Leptospermum continentale	01000133
Lilaeopsis polyantha	00000100
**Lotus corniculatus*	11211111
Luzula meridionalis	00000110
Poa helmsii	02013421
Ranunculus glabrifolius	00010100
Poa sieberiana	00000001
Poa tenera	00000001
Pteridium esculentum	02100000
Sphagnum sp.	00001100
Stellaria angustifolia	10010100

Group 8. *Elaeocharis gracilis* Low Sedgeland

**Acetosella vulgaris*	01000
**Anthoxanthum odoratum*	10110
**Briza minor*	10010
Baumea rubiginosa	10011
Carex gaudichaudiana	10000
Dichondra repens	00100
Drosera peltata	00120
Eleocharis gracilis	57644
Eriocaulon scariosum	00010

Epilobium billardierianum subsp. *billardierianum*	00001
Epilobium billardierianum subsp. *hydrophilum*	11010
Epilobium pallidiflorum	10000
Eucalyptus camphora	01000
Euchiton involucratus	11010
Gonocarpus micranthus	00010
Goodenia elongata	00100
Hemarthria uncinata	01100
**Holcus lanatus*	12222
Hydrocotyle sibthorpioides	30131
**Hypochaeris radicata*	11110
Isolepis inundata	01101
**Isolepis levynsiana*	01010
Isolepis subtilissima	32000
Isotoma fluviatilis	10000
**Juncus articulatus*	10101
Juncus bufonius	01010
Juncus planifolius	11111
Juncus sarophorus	01110
Juncus sp.	02020
Lilaeopsis polyantha	10000
**Lotus corniculatus*	01033
Luzula meridionalis	10010
Phragmites australis	20000
Poa helmsii	00110
Schoenus apogon	02110
Schoenus maschalinus	01332
Stellaria angustifolia	00212
Thelymitra sp.	00110
Utricularia dichotoma	10000

Group 9. *Eucalyptus camphora – Acacia melanoxylon – Gleichenia microphy*lla Swamp Woodland

Acacia melanoxylon	1121
Acaena novae–zelandiae	0111
**Anthoxanthum odoratum*	1112
Baumea planifolia	2000
Baumea rubiginosa	4111
Blechnum minus	1010
Blechnum nudum	0013
Callitriche stagnalis	0011
Carex appressa	0010
Centella cordifolia	0100
Dicksonia antarctica	0012
Eleocharis gracilis	0122
Eriocaulon scariosum	0100
Eucalyptus camphora	1401
Euchiton involucratus	0011
Gahnia sieberiana	0104
Gleichenia microphylla	7674
Gonocarpus micranthus	1114
Goodenia elongata	0001
**Gratiola peruviana*	0011
**Holcus lanatus*	1111
Hydrocotyle hirta	0001
Hydrocotyle sibthorpioides	0010
Hypericum japonicum	0111
**Hypochaeris radicata*	1111
Isolepis inundata	0101
Isolepis subtilissima	0111
Isotoma fluviatilis	0001
Juncus planifolius	1111
Leptospermum lanigerum	0224
**Lotus corniculatus*	0011
Mentha laxiflora	0011
Pteridium esculentum	1111
Schoenus maschalinus	0210
Utricularia dichotoma	0100
Viola hederacea	0110