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The Floristic Values of Wetlands in the Highlands and Strathbogie Ranges

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Arthur Rylah Institute for Environmental Research

GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

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The floristic values of wetlands in the Highlands and Strathbogie Ranges

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Front cover photo: *Eucalyptus camphora* Swamp Woodland, S. McAlpin property, Highlands (Sera Cutler).

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Summary

The Goulburn Broken Catchment Management Authority contracted the Arthur Rylah Institute for Environmental Research (ARI), in conjunction with the Department of Civil and Environmental Engineering at The University of Melbourne (UM), to investigate the floristics of spring soaks and upland soaks on the Strathbogie Plateau and their relationship with groundwater systems. This report addresses the vegetation component of the study.

A quadrat-based floristic survey was conducted at 71 sites that were representative of the physical and geographic distribution of the spring soak vegetation. Floristic data were classified using agglomerative hierarchical clustering, and non-metric multidimensional scaling and vector fitting were used to determine the degree to which compositional variation could be explained by site environmental and condition variables. Soil cores taken from each quadrat to describe site stratigraphy and were analysed for pH, moisture, and organic and carbonate content. Wetland complexes were mapped using recent aerial photography to determine their current extent and estimate their former extent. An assessment of wetland condition, threats to their persistence and future management requirements were interpreted from an analysis of quadrat data and from field observations.

Nine floristic assemblages and their environmental correlates were identified on five different morphological settings. Vegetation communities were mostly referable to published Ecological Vegetation Classes. However, not all groups were easily allocated to an EVC. Most sites consisted of acidic to mildly alkaline peat in the A horizon, overlying clays and an impermeable layer above decomposing granite bedrock. Charcoal was frequently observed throughout sediment cores, suggesting that fire may have been an historical component of wetland systems in the area. Moisture, organic content and carbonate content varied between sites, but there was no correlation between vegetation type and soil properties. Floristic composition and current condition were found to be determined by a combination of climate, intensity of land use and management. The least disturbed sites (characterised by lower weed cover and less soil disturbance) consisted of forested vegetation, which was more common at higher elevations where grazing pressure appears to have been historically less intense.

Mapping strongly indicated that more than half of the original wetland vegetation in the study area has been lost as a result of land clearing and altered land use. However, the true amount lost is likely to be substantially higher. There was no evidence in the data to show that water extraction via dams and known bores is a significant driver of vegetation composition at present.

A range of threats affecting wetland systems as well as individual sites were identified. Almost all landowners consulted during the survey commented that drying out posed the most immediate threat to wetlands. Approximately 60% of the wetlands surveyed were assessed as showing signs of soil moisture loss. Other threats requiring management were habitat destruction and land degradation, dysfunction of biological interactions, and changes to disturbance regimes. These prompted a range of recommendations based on a decision matrix which aimed to provide guidance for management activities. Further investigations into manipulated grazing methods and controlled use of fire are required to develop methods for biomass control and maintain species diversity.

1 Introduction

Goulburn Broken Catchment Management Authority (GBCMA) is one of 10 CMAs which manage terrestrial and aquatic natural resources in Victoria. Land use is diverse in the GBCMA region, ranging from urban settlement and agriculture to nature conservation. The Goulburn Broken River Health Strategy 2005–2015, incorporating the Goulburn Broken Wetland Strategy, identifies the key management issues and threats for a range of significant wetlands, including rare and significant wetlands such as spring soaks and Central Highlands peatlands. A two-stage Wetland Implementation Plan is being developed. The first stage identified 424 wetland sites and delineated 11 Ecological Vegetation Classes (EVCs) (Carr et al. 2006). A number of significant, rare or threatened flora and fauna species which rely on spring soaks, upland soaks, alpine and subalpine peatlands for habitat were recorded in the region (Carr et al. 2006). This project forms the second stage of the plan. The objective of this stage is to provide information on the floristics of upland swamps, springs and spring soaks in the Highlands and Strathbogie Ranges to inform their current and future management.

The Strathbogie batholith is of significance because it exerts major control over river patterns and groundwater flow (Phillips et al. 2002). The wetlands assessed in this study are vegetation communities that have developed on groundwater-fed wet areas on granite plateau and outwash slopes below 700 m, predominantly on organic soils. They comprise a range of groundwater-dependent vegetation assemblages within swampy drainage lines and boggy gullies, collectively described as Spring-soak Woodland (EVC 85), Perched Boggy Shrubland (EVC 185) and Swampy Woodland (EVC 937). Other EVCs that may also be of relevance either as fringing communities, closely related or poorly delineated complexes include Swamp Riparian Woodland (EVC 83), Swamp Scrub (EVC 53), Fern Swamp (EVC 721) and Riparian Scrub (EVC 191) (Frood 2008).

Spring soaks and upland soaks are rare in the landscape and are subject to a range of threats, the majority of which derive from land uses incompatible with their preservation (Department of Sustainability and Environment 2005a; Carr et al. 2006). It is estimated that approximately 80% of Spring-soak Woodland area has been destroyed since European settlement and almost all remnants are confined to private property (Department of Sustainability and Environment 2005b). No systematic surveys have been conducted in spring soaks or related systems. Consequently, their community composition, contribution to biodiversity in the GBCMA, hydrological function and relationship to other wetland systems are poorly understood.

The delineation of spring soak and upland soak vegetation communities has been difficult, partly because some EVCs are poorly delineated and partly because putative examples are severely altered from their original condition and are patchily distributed across the landscape. The current EVC description for Spring-soak Woodland has been 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. Associated EVCs are also poorly defined, due to a lack of systematic survey and a paucity of intact remnants (Frood 2008). In particular, the relationship between Swampy Riparian Woodland, Perched Boggy Shrubland and Swampy Woodland becomes difficult to elucidate where original streams have been modified or original vegetation has been cleared (Frood 2008). Consequently, any prescriptions for the management of these vegetation communities are hampered by a lack of knowledge of their floristics, condition, environmental attributes and hydrology.

This project reports on the floristic composition, environmental affinities, condition and threats to spring-soak vegetation communities. It will contribute to the implementation of the Wetland Implementation Plan and will recommend strategies and actions for the future management of groundwater-dependent wetlands in the Goulburn Broken catchment for biodiversity conservation.

1.1 Current land uses and threats

Much of the indigenous vegetation in the study area was cleared in the mid to late 19th century and replaced with herbaceous pasture species. Two major current land uses were identified by Carr et al. (2006):

- grazing by domestic stock, predominantly cattle but also sheep and horses; the consequences include soil compaction, localised turbidity, eutrophication from faeces and urine contamination, pugging of soils and destruction of peat, and ponding of water in micro-topographic features, resulting in increased water loss by evaporation
- water extraction by the construction of farm dams above or below spring soaks; bores are also common on freehold land in the study area.

A range of other associated activities have resulted in major direct and indirect alterations to the hydrological regimes, substrates and water quality, which have altered the structure, floristic composition and faunal habitats of the vegetation (Carr et al. 2006). These include:

- draining of wetlands via channels (Carr et al. 2006)
- planting of exotic trees with high water usage, notably willows (*Salix* species) and poplars (*Populus* species) within wetland vegetation, and Radiata Pine (*Pinus radiata*) and Southern Blue Gum (*Eucalyptus globulus*) plantations adjacent to or near wetlands; the effect of plantations on water tables is unknown (Carr et al. 2006)
- destruction of the peat layer by burning (e.g. as a result of the use of fire to control undesirable pasture plants such as rushes (Carr et al. 2006)
- grazing and browsing of vegetation by feral animals (rabbits, deer, hares, pigs) and indigenous mammals (Black Wallaby, Eastern Grey Kangaroo and Common Wombat) (Carr et al. 2006)
- weed invasion by pasture species (e.g. Yorkshire Fog Grass)
- inadvertent off-target damage to vegetation from the imprudent application of herbicides (e.g. spraying of blackberries, Carr et al. 2006)
- broadacre application of fertilisers
- planting of trees in peatlands and spring soaks to enhance habitat or amenity values (Carr et al. 2006).

1.2 Aims and scope

The results of the project will inform the Wetland Implementation Plan and best practice management of wetlands in the study area by identifying wetland types and condition, describing their floristic composition, evaluating the impacts of threats on floristic composition and vegetation condition, and identifying strategies and actions to address these threats.

The specific aims of the floristic component of the project were to:

1. assess the floristic composition and structure of spring soak wetlands
2. determine the current condition of spring soak wetlands
3. assess current and future threats to spring soak wetlands
4. identify knowledge gaps
5. recommend strategies and actions that protect or enhance the ecological values of spring soak wetlands.

2 Methods

2.1 Study area

2.1.1 Economic and social characteristics

The Goulburn Broken Catchment is situated in northern Victoria and is part of the Murray–Darling Basin. It comprises the catchments of the Goulburn and Broken rivers and part of the Murray River Valley. The catchment occupies 10.5% of Victoria and stretches from close to the outskirts of Melbourne in the south to the Murray River in the north. The Catchment includes one of Victoria's main water storages (Lake Eildon) and the Mount Buller Alpine Resort (GBCMA 2009).

The traditional owners of the area now bounded by the Shire of Murrindindi are believed to have been the Wujrungeri tribe and the Taungurung language speakers, with a population size estimated at around 1000 people at the time of European occupation (Context 2006). Over 200 000 people now live in the catchment (GBCMA 2009). European settlement dates back to the late 1830s, following reports of fine grazing land by explorers and surveyors Hume and Hovell in 1824 and Mitchell in 1836. These reports provided the impetus for the development of the wool industry in the region (White et al. 1990). The discovery of gold near Yea in the late 1850s accelerated development and population growth, but by 1890 gold mining had been replaced by agriculture-based industries which centred around larger towns (White et al. 1990). Land Acts passed by the Victorian Parliament between 1860 and 1869 made hundreds of thousands of hectares available for clearing and timber harvesting, and agriculture and timber industries became increasingly important for the local economy (White et al. 1990). Today, approximately 1.4 million hectares of the GBCMA is used for dryland agriculture and 270 600 ha for intensive irrigated agriculture, and 800 000 ha is public land. In addition, 70 000 ha of the North Central catchment forms part of the Shepparton Irrigation Region (GBCMA 2009).

Rapid population growth is occurring in some parts of the catchment, notably centres within commuting distance of Melbourne and the City of Greater Shepparton. The region has a large indigenous population as well as a large number of people from culturally and linguistically diverse backgrounds including people from many parts of Europe and the Middle East (GBCMA 2009). There has also been a pronounced demographic shift in the Highlands and Strathbogie area, with an increase in people moving from Melbourne to the region following the sale and subdivision of farming land. Of historical note are two remaining original properties in the area with dwellings constructed by Scottish settlers in the late 1840s, 'Habbies Howe' and 'Dropmore'.

The region supports major agricultural (dryland and irrigated), food processing, forestry and tourism industries. The major commodity is food, but wool, timber, tourism and recreation are also vitally important to the region's economy (GBCMA 2009). In the study area, land use is shifting from sheep and cattle grazing to a number of new industries which have developed in response to growing consumer demands, such as plantation forestry and viticulture. These industries may exert considerable pressure on water resources as new bores and dams are constructed to ensure a reliable water supply. Other examples are horticulture (e.g. truffle cultivation, cherry orchards), biodynamic beef farming, alpacas and mineral spring water extraction. Hobby farming is also popular.

2.1.2 Physical environment

The study area is on the Strathbogie plateau in the Victorian Highlands – Northern Fall Bioregion, which covers an area of approximately 1500 km^2 (Phillips et al. 2002), 150 km north-northeast of Melbourne. The plateau is part of a batholith formed from a Middle to Upper Devonian granitic intrusion (370 – 390 mya) and consists of a mildly dissected plateau of rolling to hilly tableland at about 320 – 700 m asl. The plateau consists of coarse-grained granite and is unusual in having a pronounced east–west elongation (Hergt et al. 2002). Reddish duplex or gradational soils have developed from the weathered granite, with gleyed sandy gradational soils and gleyed loams along drainage lines (Rundle and Rowe 1974). The plateau straddles the Broken and Goulburn catchments; however, in the former catchment most water drains into the Seven Creeks system, with only a minor amount of water draining to the Broken River (Rundle and Rowe 1974).

The nearest weather station to the study area is at Strathbogie, to the north of the study area (36°51'50" S, 145°44'51" E). February is the hottest and driest month, with a mean maximum temperature of 27.3 °C, mean minimum of 11.6 °C and mean monthly precipitation of 42 mm. The elevation of the plateau moderates the summer heat of the surrounding plains. Prevailing winds are variable, tending southerly to northerly and reaching the highest speeds (11–13 km/h) between early spring and late summer, weakening over autumn and winter to about 9 km/h. Winters are cool and wet, with an average maximum temperature of 10.1 °C, minimum of 1.6 °C, and mean maximum precipitation of 124 mm in July. Rain (> 1 mm) falls for 91 days per year on average and snow may fall occasionally (Rundle and Rowe 1974). Rainfall and temperatures are likely to vary over the plateau with altitudinal and topographic variation.

2.1.3 Vegetation

The pre-European vegetation of the study area generally consisted of a mosaic of Herb-rich Foothill Forest, with Shrubby Dry Forest on the lower slopes (Carr et al. 2006). Montane Dry Woodland occupies the upper slopes and plateau, and grassy dry forest complexes occur along the major river valleys (Carr et al. 2006). Depressions where trees were removed are still clearly visible in paddocks and indicate that the landscape was formerly forested. Riparian and swamp woodlands or scrubs (e.g. Perched Boggy Shrubland, Swampy Woodland, Swampy Riparian Woodland EVCs) occur in seasonally or permanently inundated areas or along watercourses.

2.1.4 Use of existing information

A number of sources provided a background to the study, as follows:

- Aerial photography (2007) and spatial layers of key physical characteristics (e.g. contours, geology, hydrology) as well as bores known to occur within the study area were incorporated into a GIS project database using ESRI ArcView 3.3 software.
- Previous studies, definitions and ecological processes associated with spring soaks and groundwater-dependent vegetation were identified from the national and international literature from a search of library databases.
- Existing quadrat data and species recorded in the study area were extracted from DSE’s Flora Information System (Viridans Biological Databases) and incorporated in a field data sheet.
- Some elements of the Index of Wetland Condition (DSE 2006) were selected and incorporated in a field data sheet.

Descriptions and benchmarks (where available) for nine EVCs were extracted and evaluated for their relevance to the study.

2.1.5 Consultation

Permission was sought from all land owners where spring soaks were surveyed on their properties.

2.2 Floristic composition

2.2.1 Definition

Spring soak wetlands are a type of mire restricted to unusual hydrological sources but are related to bogs, fens, moorlands and topogenous swamps throughout Australasia (Whinam and Hope 2005). The wetlands investigated in this study generally conform to the definition of fen or swamp forest, as adapted for usage within Australasia, which refers to the structure and life forms of peat-forming vegetation rather than trophic status (Whinam and Hope 2005). The term fen is used to describe peatlands where the water table is at the surface and dominated by graminoid species. The term swamp forest describes peatlands dominated by tall shrubs and trees (Whinam and Hope 2005). We include shrublands within this category. Definitions of peat are controversial but the term is generally used to describe any predominantly organic deposit formed in a wet environment (Gore 1983). In our study, peat was defined as organic sediments exceeding 20% dry weight (Whinam and Hope 2005) to variable depth. Sites investigated excluded alpine or subalpine peatlands or spring soaks in the eastern and north-eastern region of the CMA (Figure 1).

The study surveyed vegetation confined to regional or local water tables, and may have included perched water tables positioned above the local water table and separated by an impermeable layer (but subsequently independent of the hydrological issues that underpin the rationale of this study). True perched water tables may be rare in the study area, although this has not yet been determined.

Spring soak vegetation was defined as a range of floristic communities dependent on the surface expression of groundwater (Eamus et al. 2006). Sampling was restricted to wetlands where vegetation was clearly dependent on, or influenced by, groundwater at its point of expression above the land surface, as well as some surface runoff. Sites associated with baseflow rivers and streams, flood plains, and alluvial environments dominated by riparian vegetation associated with flowing water were excluded.

Quadrat surveys were undertaken to develop a classification of spring soak wetland vegetation within the study area, based on floristic composition and structure. The derived vegetation assemblages or groups were used as mapping units and as a foundation for describing the compositional variation within the study area.

2.2.2 Site selection

A total of 306 wetland sites identified in a previous survey (Carr et al. 2006) or from field assessments conducted by members of the project steering committee were mapped using GIS software (ArcView 3.3). A short list of 81 sites suitable for quadrat surveys was produced using a stratified approach to capture the geographic and environmental variation of the study area (Figure 1). In general, criteria for site selection were: a range of condition states; accessibility; readily visible on colour aerial photographs (hence large enough to comprise a mappable unit); spanned the geographic and altitudinal ranges of the study area; likely to represent the range of floristic communities present; and a known management history (e.g. fenced to exclude stock). The short list also included sites identified for the hydrological study by the University of Melbourne in the Seven Creeks catchment in the northeast of the study area (Figure 1). All quadrats were on granite.

Each quadrat site was positioned within a broader wetland system. These consisted of groundwater-dependent vegetation on saturated soils, as well as related vegetation communities occupying a range of soil moistures generally occurring within the wetland perimeter as identifiable zones. Some were considered likely to have been wetland communities modified to various degree by land use practices.

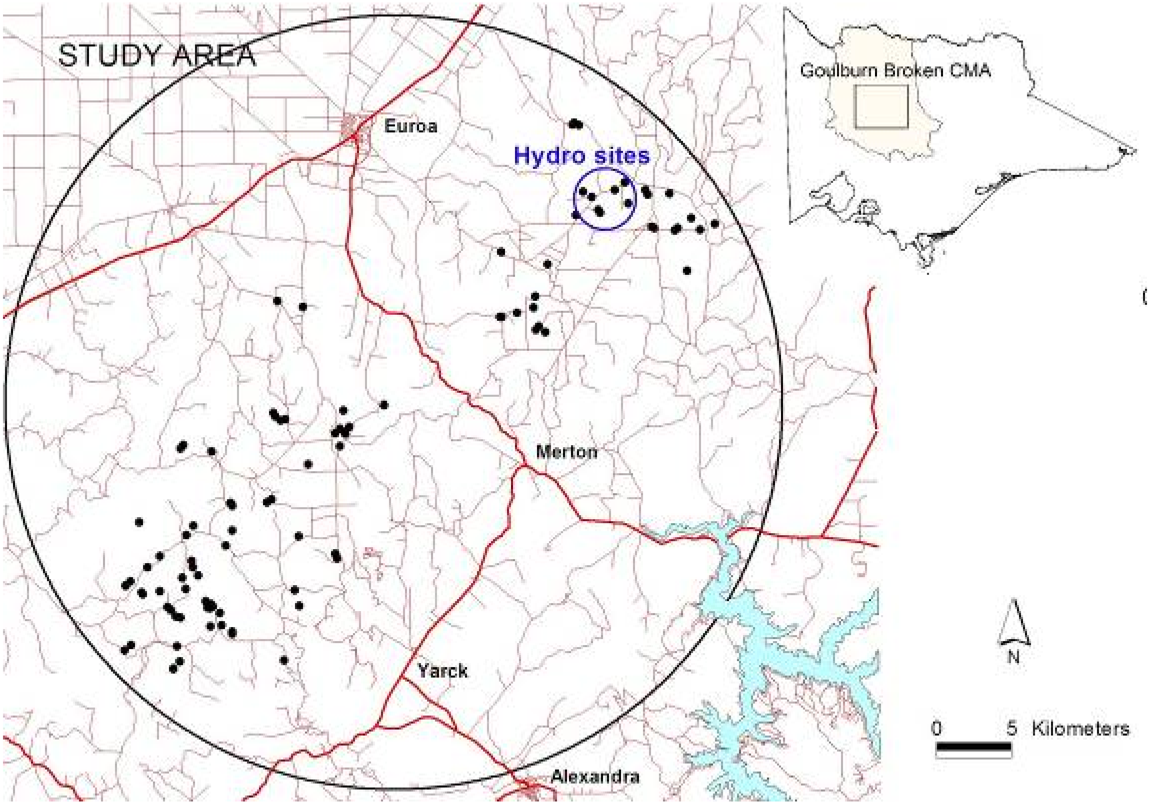

Figure 1. Sites short-listed for assessment across the study area. Quadrats sites are represented by black dots, and sites also selected for the hydrological study are circled in blue.

2.2.3 Data collection

Sampling was conducted using 10 m × 10 m quadrats at or near the point of expression of groundwater above the land surface, where the vegetation was most intact and characteristic of the presumed original wetland. At most sites, additional quadrats were sampled to capture the variation in floristic composition according to degree of soil saturation or perceived vegetation zonation. The survey was conducted from September to November 2008, when most dicotyledonous species were flowering and water tables were close to or at the land surface.

In each quadrat, the following general attributes were recorded:

- wetland label (unique number and property owner)
- sampling date and recorders
- geographic position: Australian Map Grid coordinates (GDA 94) measured using a Magellan Meridian or Garmin eTrex hand-held GPS
- quadrat position in the wetland (centre, middle, outer)
- vegetation community (general description)
- presence and percent cover of all vascular species and *Sphagnum* species (estimated visually)
- height and percent cover (estimated visually) of trees, tall shrubs (>2m high) and shrubs (< 2 m high), and percent cover of native and exotic grasses (Poaceae), other graminoids (sedges, reeds, rushes), herbaceous dicotyledons and ferns
- altitude: measured using a Magellan Meridian GPS or Garmin eTrex hand-held GPS

- aspect: measured using a Silva Sight Master compass. Categories were: 1 = NW, 2 = N and W 3 = NE and SW, 4 = S and E, 5 = SE, representing the estimated evaporation gradient in south-eastern Australia (Kirkpatrick and Nunez 1980; Kirkpatrick and Bridle 1998)
- slope: measured in degrees, using a Silva Clino Master clinometer
- rocks: percent cover (estimated visually)
- standing water: percent cover (estimated visually) and depth (measured using a metal ruler)
- synthetic climate parameters for a range of rainfall and temperature variables were generated for each quadrat using BIOCLIM (Nix and Busby 1986).

Plant nomenclature follows Walsh and Stajsic (2006); species conservation status follows Department of Sustainability and Environment (2005b). Community structural typology follows Specht et al. (1974).

Site morphology

Each quadrat was assigned to a morphological type based on site slope and shape properties. 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 and Jeglum 2006). These sites appeared to receive water from spring outlets situated throughout the drainage line or lateral slopes, as well as a significant amount from soil water and surface runoff.

Soligenous sites were generally associated with a break in the slope, receiving groundwater at its point of expression above the surface, with only a minor amount of soil water and surface runoff (Ryadin and Jeglum 2006). At many sites along drainage lines where the impermeable layer may lie relatively close to the surface, groundwater discharges had formed spring-seep lines and could be difficult to distinguish from creeklines.

Morphological categories identified were:

- vales — broad depressions flanked by hillslopes < 5° (topogenous)
- gullies: — flanked by hillslopes > 5° (topogenous)
- slopes < 5° — flat or near flat, or with a distinct concave depression (soligenous)
- slopes > 5° — sloping, or with a distinct concave depression (soligenous)
- mounds — convex formations associated with spring vents (soligenous).

Soils

Short sediment cores were taken to describe the stratigraphy of quadrats and to determine the depth of organic and mineral soils. Three soil samples were collected in each quadrat to a depth of 15 cm and bulked for pH and loss-on-ignition (LOI) analyses. The following data were recorded:

- colour of the A horizon, using a Munsell colour chart (Munsell undated)
- texture of the A horizon (McDonald et al. 1984)
- pH of the A horizon (using a TPS digital pH meter calibrated with a buffer solution to pH 7, and a 1 : 1 ratio of soil to de-ionized distilled water, using 20 g of soil : 20 mL of water)
- the percentage of moisture, organic matter and carbonate of the A horizon (measured using LOI; Dean 1974)
- peat depth and depth to the impermeable layer, using a 50 mm × 1 m gouge auger (Dormer Engineering)

- presence of charcoal particles or fragments.

2.2.4 Analytical methods — quadrat survey

The representativeness of the survey design was examined by plotting the cumulative number of quadrats sampled against altitude, which was considered the most variable environmental feature across the entire study area. Other environmental gradients may occur but would be difficult to identify, as quadrats were in an agricultural landscape subject to a range of disturbances and were all on granitic geology. To evaluate the effectiveness of the survey in capturing the amount of floristic variation, the cumulative number of species was plotted against the number of quadrats.

To determine the vegetation groups present in the study area and to provide a basis for mapping these in GIS, hierarchical agglomerative clustering using average linkage (Oksanen 2008) was applied to the floristic data to combine quadrats having similar composition and structure. To reduce 'noise' in the data, species that occurred in fewer than 10% of quadrats were excluded. Compositional dissimilarities were calculated using the Bray–Curtis coefficient (Faith et al. 1987) using cover classes as the unit of abundance. Unique clusters were identified at the nine group level, determined after some preliminary analyses and considered likely to represent the range of vegetation communities observed in the field. A dendogram was constructed to display group similarity. A dichotomous key was devised to assist with recognition of the vegetation groups in the field. These groups were also used as mapping units.

Differences between means of soil variables according to site morphological type, and between other quadrat variables according to floristic groups, were tested using analysis of variance followed by Tukey post hoc tests. Pearson's Product–Moment correlation coefficient was used to test for significant relationships between variables. Results were considered significant if $P < 0.05$.

Data manipulation, statistical analyses and graphics were conducted using the program R (R Development Core Team 2005) with MASS (Venables and Ripley 2002) and Vegan 1.15-1 (Oksanen et al. 2005), and Minitab Statistical Software (Minitab 2007). Bioclimatic variables were generated using the BIOCLIM module (Nix and Busby 1986) of the ANUCLIM package (Houlder et al. 2005).

2.3 Mapping

Wetlands were mapped using GIS software (ArcView 3.3) using geo-rectified aerial photography (50 cm pixel size, flown 2007) from Image Web Server (Department of Sustainability and Environment). Two overlapping images were available:

- study area north — Benalla-Strathbogie_2007oct17_air_vis_50cm_mga55.url
- study area south — Murrindindi_2007jan26_air_vis_50cm_mga55.url

Two small areas in the southeast and southwest of the study area were not covered by the aerial images, leading to an adjusted study area of 251 992 hectares (Figure 2).

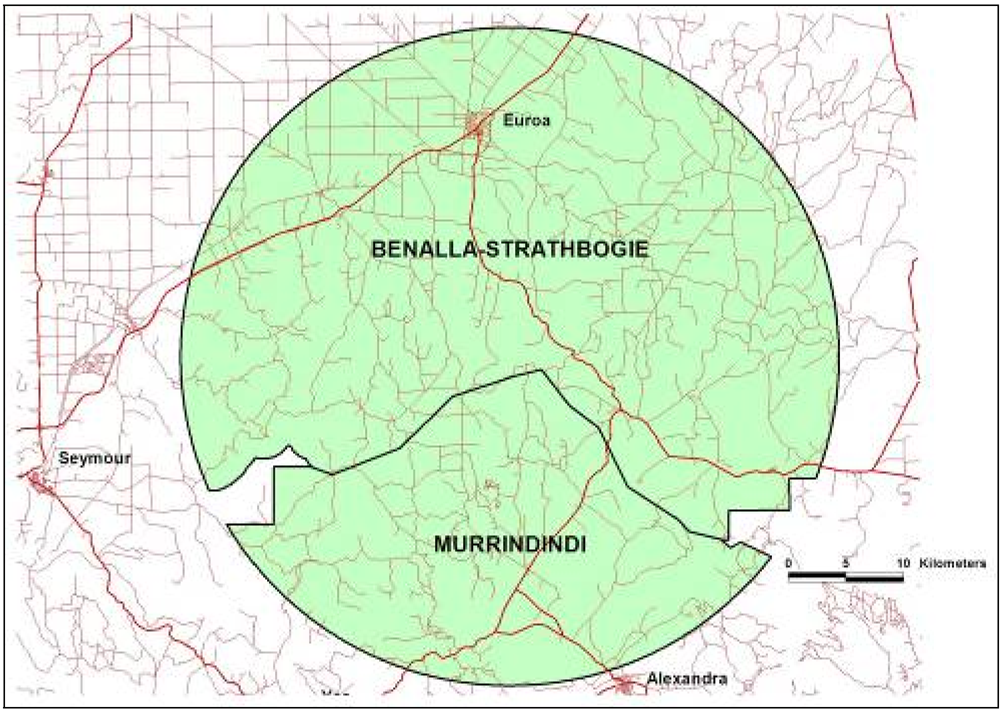

Figure 2. Extent of aerial photography available for the study area.

Sites that had been surveyed on the ground were mapped first using aerial images in conjunction with comprehensive mapping notes which described the vegetation and quadrat data collected during the surveys. This allowed us to determine the 'typical' appearance of various vegetation types in the aerial images. Not all mapped vegetation could be matched with a cluster group, so additional vegetation groups were described from field observations. All distinguishable areas were mapped as one of 16 vegetation communities in a single GIS layer.

A second mapping layer was then created that included the previously mapped sites and all other obvious spring soaks and intact or remnant wetlands in the study area. All 311 grid locations previously supplied by the GBCMA for known soaks or wetlands were individually located, and systems mapped if visible (and not already mapped). The aerial images were then systematically scanned at an on-screen scale of approximately 1 : 4000 to detect and map all other visible systems or paddock remnants in the study area. Particular attention was paid to areas where previous assessments had identified numerous soaks and wetlands, and to areas obviously associated with dams and drainage lines.

It was not possible to distinguish precise vegetation groups from aerial photographs in the absence of ground-truthing. Therefore, at the study area scale, all wetlands or sections thereof were mapped as one of four broad vegetation types:

- forest/woodland (very difficult to detect wetlands under canopy, hence mostly from on-ground surveys)
- shrubland (includes vegetation dominated by *Leptospermum* or *Baeckea*, with or without canopy emergents)
- sedgeland/reedland (non-shrubby vegetation, dominated by *Baumea*, *Carex*, *Typha*, *Juncus*, *Phragmites* or *Cyperus*, with or without emergent trees or shrubs)

- ‘paddock remnant’ (patches of *Juncus* and other non-woody vegetation associated with seepage areas; may include mounds).

The paddock remnant category was assumed to have once supported groundwater-dependent vegetation, and its total area was included to calculate the estimated (and conservative minimum) loss of wetland vegetation in the study area.

2.4 Current condition

The Index of Wetland Condition (IWC) (DSE 2006) was tested in the field at a number of sites. However, this was largely unsuccessful because the EVCs thought to be relevant to the study area were either poorly defined (eg. Spring Soak Woodland) or were of dubious relevance (e.g. riparian EVCs). In addition, many of the components of the IWC appeared to be not relevant to the systems sampled and appeared better suited to seasonally inundated wetlands at lower elevations or rainwater-fed systems. Consequently, the IWC was adapted to better suit the sites within the study area, an approach also used in previous studies (e.g. Tolsma et al. 2005). The following variables were recorded to describe the condition of the wetland vegetation in the study area and were also recorded during the quadrat survey:

- pugging: percent cover (estimated visually)
- tracks: percent cover (estimated visually)
- weeds: percent cover (estimated visually)
- management history: fenced, weed control, stock removal, revegetation, other
- proportion of the wetland perimeter buffered by vegetation with > 25% native species (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
- native species richness: number of native vascular species per quadrat
- weed species richness: number of introduced vascular species per quadrat.

A condition descriptor was derived from the proportion of three variables considered to be indicators of disturbance and used as a surrogate for site condition: (% pugging + % tracks + % weed cover)/100).

2.4.1 Analytical methods – condition

To produce a ‘map’ of quadrats in which sites having the most similar floristic composition are placed closest together, quadrat data were ordinated using non-metric multidimensional scaling (NMDS) from several random starts until a solution with the smallest acceptable stress was reached. Compositional dissimilarities were calculated using the Bray-Curtis coefficient (Faith et al. 1987). To determine an appropriate dimensionality, the solution was chosen that provided the most reduction in stress (McCune and 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 environmental characteristics, 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 2007). NMDS was conducted in R software (R Development Core Team 2005) using MASS (Venables and Ripley 2002) and Vegan 1.15-1 (Oksanen et al. 2005).

2.5 Current and future threats

2.5.1 Vegetation

Primary threats that would require management in the short term were collated from assessments of wetland systems on 33 properties and from field observations (Appendix 1). These were allocated to ecological risk categories (Auld and Keith 2008) and the results were used to prepare a management decision matrix. The average size of the wetlands assessed was approximately 4 ha. In addition to site characteristics recorded during the quadrat survey, observations at each broad wetland site included:

- land use
- recent or planned changes to land use/management
- physical threats
- vegetation connectivity
- vegetation zonation (% intact)
- the proportion of wetland soils that were dry/damp and wet/waterlogged (estimated in quadrats and data combined for each wetland site)
- general hydrology and any obvious qualitative or quantitative changes to the water regime.

2.6 Management

Consultation with landowners revealed that many wetlands had been fenced to improve the condition of the vegetation and soils with a view to reducing site disturbance from stock, predominantly cattle. The expected outcome of fencing was the preservation of existing native species, recruitment of new species, provision of habitat for native fauna, a reduction in weediness and prevention of further soil disturbance and eutrophication.

The effectiveness of current management was tested by comparing the number of years fenced against weed cover, native species richness, total vegetation cover, and soil and moisture properties, at fenced and unfenced sites. The results were used to evaluate the usefulness of management activities.

Information from the floristic and hydrological studies was combined to prepare a decision matrix that would assist land managers to prepare and implement management actions. The intent of the decision matrix is to identify priorities and outcomes for wetland habitat conservation that will:

- maintain or improve species diversity
- improve or maintain the overall condition of wetland sites
- maintain the current area
- maintain or improve hydrological function.

2.7 Study limitations

The study captured most of the geographical area where spring soak vegetation had been previously recorded in the GBCMA. However, a number of sites that are likely to represent an important component of the wetland vegetation in the north-east of the catchment were excluded. These include sites in the Glenrowan, Tolmie and Tatong districts, identified in previous studies as having conservation significance (Whinam et al. 2003). Further survey work to include sites in the North-East CMA would also enable a more complete picture of the condition and extent of spring soak vegetation. Subalpine and montane sites that are also located within the Goulburn-Broken catchment are an unrelated peatland vegetation type.

Time and budget constraints precluded a more comprehensive quadrat survey. A number of plant communities were identified during the mapping that were not included in the floristic survey, usually because they were at wetland margins and badly degraded. However, additional sampling to include these would contribute to a more comprehensive knowledge base and may help to further clarify relationships between wetland vegetation types.

3 Results and Discussion

3.1 3.1 Floristic composition

3.1.1 Representativeness

Seventy-one quadrats were sampled from 47 wetlands across the study area. These included the majority of sites identified as priority 1, plus a number of new sites (Figure 1). On inspection, some priority sites were unsuitable for sampling, or property owners were not contactable, or sites were in such a poor condition that they could not reasonably be allocated to a vegetation group. In these cases, alternatives were identified.

Quadrats were fairly uniformly spread over a range of altitudes (300 –620 m). This represented the dominant environmental gradient across the Strathbogie plateau (Figure 3). Fewer quadrats were sampled at lower altitudes (20% were below 500 m) than at higher altitudes, indicating that these sites were relatively rare. However, the cumulative distribution of species recorded in quadrats showed that sampling had adequately captured the range of species present (Figure 4).

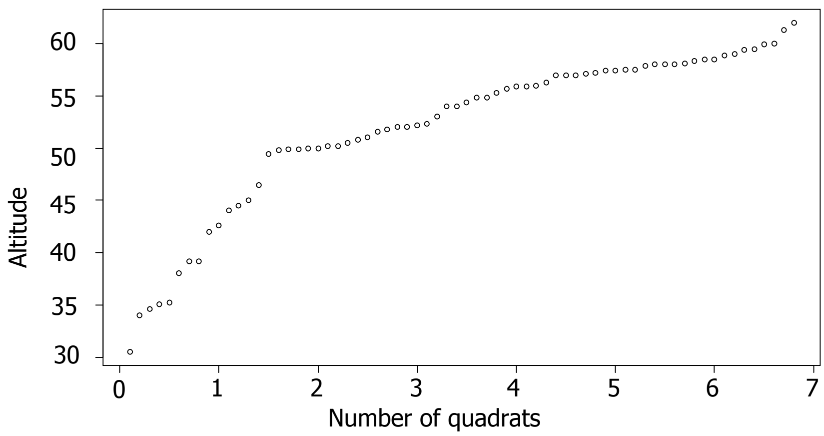

Figure 3. The distribution of quadrats across the altitudinal range of the study area.

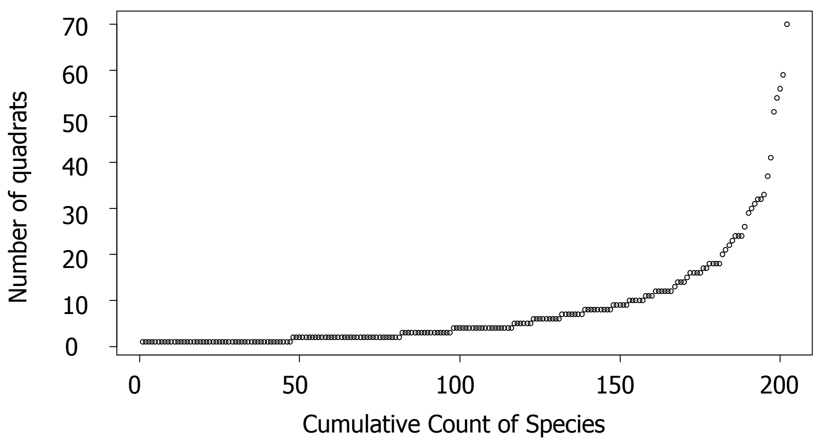

Figure 4. Cumulative count of species and number of quadrats.

3.1.2 Site morphology

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

Six additional soligenous sites were recorded on mounds on steep or gently sloping hillsides. Mounds appear to be an undescribed landform element in Victoria. They were distinctly convex and usually about 2–4 m in diameter. They had a clearly defined vent and are likely to have been formed by localised upwelling of groundwater, resulting in unstable, elevated areas of saturated peat. Similar landform features have been described elsewhere as mound springs associated with the Great Artesian Basin (Fensham et al. 2004), tumulus (organic mound) springs in Western Australia (Blyth and English 1996), and spring-fen mounds or groundwater mounds in Europe, North America and Japan (Ryadin and Jeglum 2006, Tomita 2008).

Topogenous sites were in vales (17) and gullies (7). These sites received water from inflow and from springs along banks, or from mounds within the main drainage lines.

3.1.3 Stratigraphy and soils

Cores were taken from 47 quadrats. A 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, had an A horizon between 3 and 80 cm deep of reddish-brown peat or organic loam, overlying grey to yellow grey medium clays generally from about 85 to 100 cm, and an impermeable layer above weathering bedrock (Figure 5). 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. However, no further investigation was possible with the type of gouge auger used, as it is intended for sampling soft sediments.

There was a clear boundary between peat and clay layers, which frequently contained charcoal particles. Evidence of charcoal is common in swamps (Whinam and Hope 2005). This may indicate some sudden environmental change such as the arrival of Europeans who used fire to clear vegetation and develop the present day agricultural landscape. Records indicate that squatters regularly burnt native pastures during drier weather to provide green feed for sheep (White et al. 1990). If this were the case then peat development may be relatively recent, with water tables rising as a result of tree removal. The transformation of swamp forest to sedgeland has also been seen after burning in some northern hemisphere sites (von Grootjans et al. 2005). However, no firm conclusions can be drawn in the absence of sediment dating. Charcoal was also frequently recorded throughout the deeper clay layers, suggesting that fire has occurred (either naturally or as a result of burning by Aboriginal people) over the longer-term. Bushfires were first recorded in in the region in 1851 (White et al. 1990), although the precise area, and whether it included the Strathbogie plateau, is not clear.

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). There was a significant difference ($P < 0.05$) in pH between gullies (mean pH = 6.1) and vales (mean pH = 7) (Figure 6), even though the analysis was based on a small number of samples.

Figure 5. Typical soil stratigraphies. Clockwise from upper left. The A horizon is peat of variable thickness, formed above grey to yellow grey clays with a dark grey impermeable layer at the base (~ 1m) or unconsolidated gravels and sands at the base of mound springs.

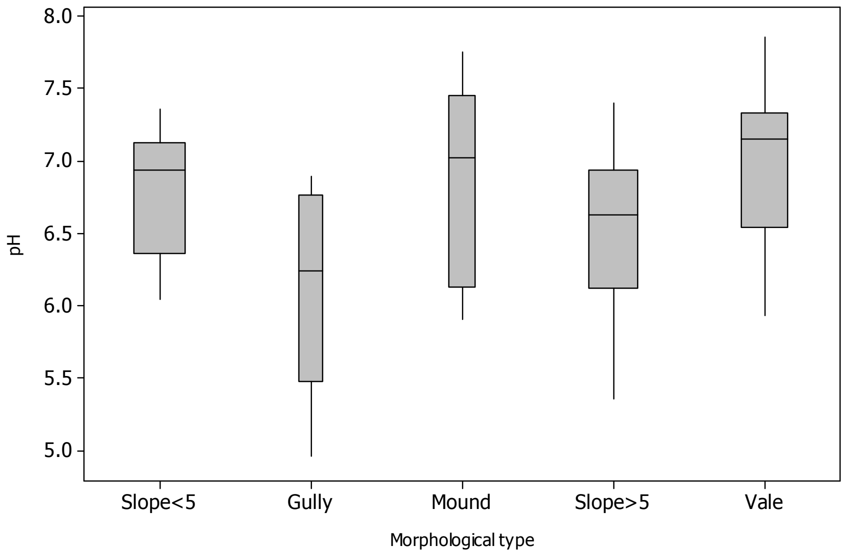

Figure 6. Boxplot of pH according to morphological type. Median (horizontal line in boxes) and quartiles are shown. Slope values are degrees. Box width is proportional to sample size (*n*): slope < 5° (20), gully (5), mound (7), slope > 5° (19), vale (17).

Moisture content was highly variable among quadrats, ranging from only 20% at the driest site to 95% at saturated sites. However, there was lno significant difference in the moisture content of the A horizon between morphological types ($P > 0.05$) (Figure 7).

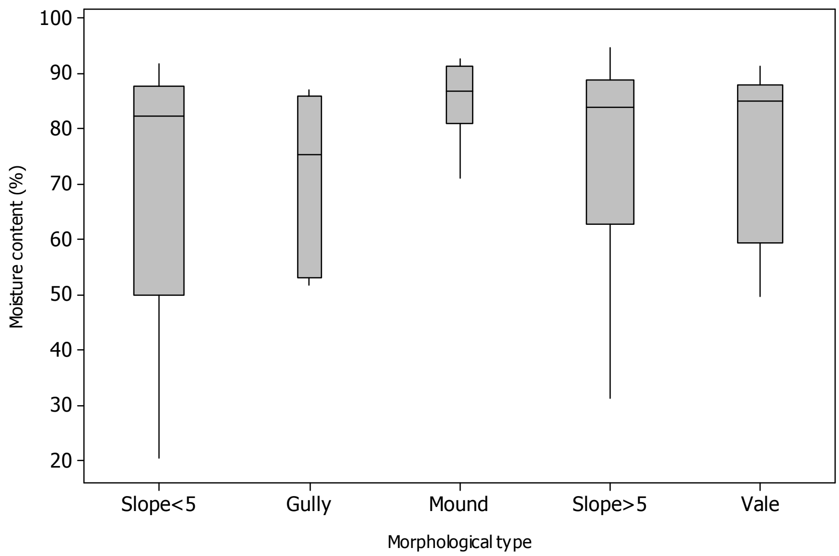

Figure 7. Boxplot of moisture content (%) according to morphological type. Median (horizontal line in boxes) and quartiles are shown. Slope values are degrees. Box width is proportional to sample size (*n*): slope < 5° (20), gully (5), mound (7), slope > 5° (19), vale (17).

The organic content of the A horizon ranged from 6% to 80% among quadrats. The highest accumulation of organic content was on mounds, although the sample size was small (6 sites), and there was no significant difference between morphological types ($P > 0.05$) (Figure 8).

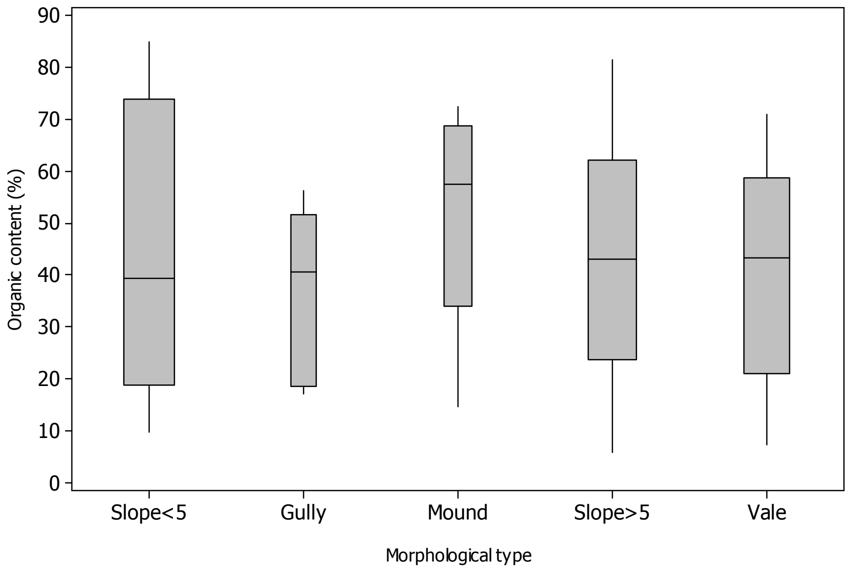

Figure 8. Boxplot of organic content (%) according to morphological type. Median (horizontal line in boxes) and quartiles are shown. Slope values are degrees. Box width is proportional to sample size (*n*): slope < 5° (20), gully (5), mound (7), slope > 5° (19), vale (17).

There was a strong positive relationship between organic content and moisture content. Wetter sites had higher percentages of decomposed organic matter than drier sites ($r = 0.84$, $P < 0.0001$) (Figure 9). Most sites where soil organic content was greater than 20% occurred where soil moisture was greater than 80%. This suggested that most sites where peat was well developed were showing little sign of drying out, at least toward the wetland centre where quadrats were typically sampled. Further sampling across the entire wetland area may provide a better indication of the extent of wetland contraction. Organic content and moisture content of the A horizon were significantly positively correlated ($P < 0.0001$).

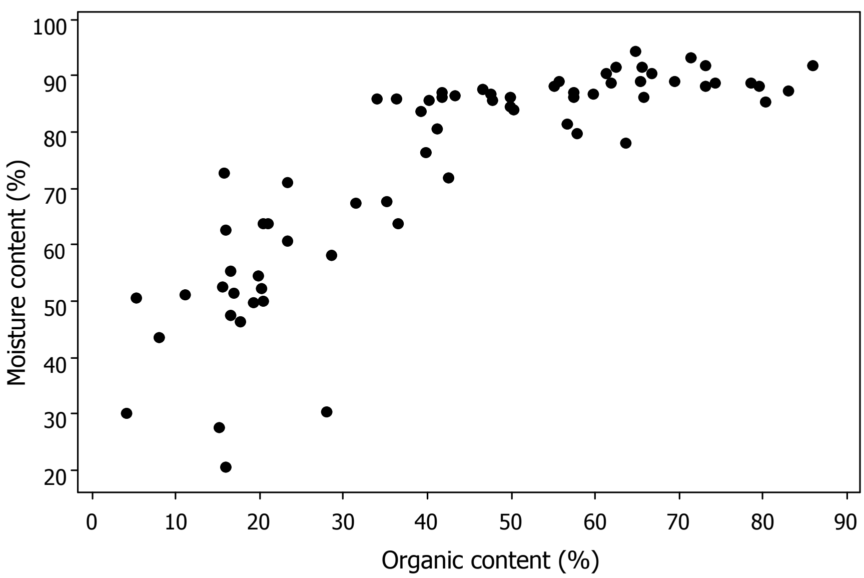

Figure 9. The relationship between organic content and moisture content.

Carbonate content was zero at approximately one third (17) of the sites and low overall. Where recorded, values ranged from 0.05% to 1.52% with some weak but not significant variation among morphological types (*P* > 0.05) (Figure 10). As a result, carbonate content will not be considered further.

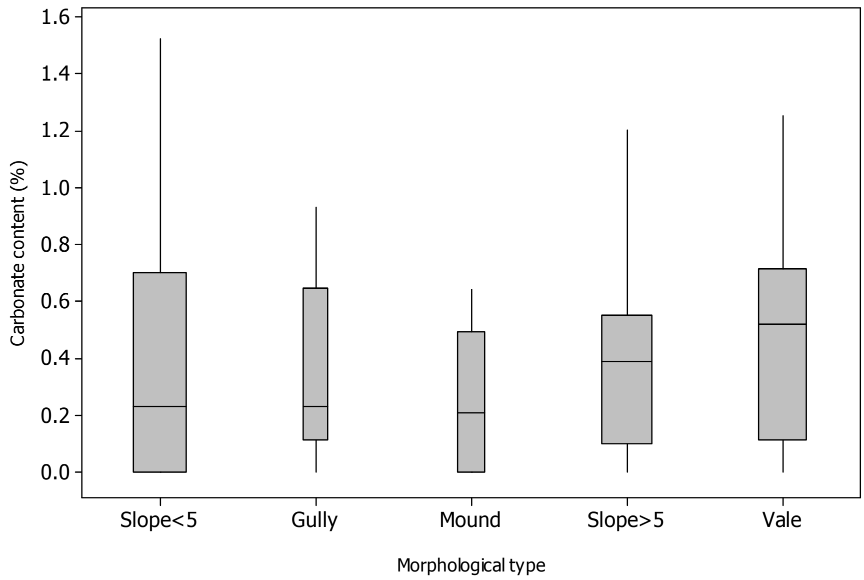

Figure10. Boxplot of carbonate content according to morphological type. Median (horizontal line in boxes) and quartiles are shown. Slope values are degrees. Box width is proportional to sample size (*n*): slope < 5° (20), gully (5), mound (7), slope > 5° (19), vale (17).

3.1.4 Rare or threatened species

Two hundred and three species were recorded in quadrats and during the quadrat survey and mapping, including 51 introduced species (Appendix 1). Six taxa having conservation significance in Victoria (DSE 2005b) were recorded around Strathbogie and Ruffy to the north of the study area — *Cardamine microthrix* (vulnerable), *Brachyscome ptychocarpa* (rare), *Montia fontana* subsp. *amporitana* (poorly known), *Hypoxis vaginata* var. *brevistigma* (poorly known), *Eriocaulon scariosum* (rare) and *Lepyrodia anarthria* (rare). In Victoria *L. anarthria* is known from only 12 records, the closest being near Mount Samaria to the west of the study area. Otherwise this species is confined largely to Far East Gippsland. Its occurrence suggests floristic affinities with swamps in other areas of eastern Australia, e.g. Wingeecarribee Swamp in southern NSW, which is dominated by *Lepyrodia anarthria*. *Eriocaulon scariosum* was generally confined to highly disturbed sites throughout the study area. Its occurrence in the study area is reminiscent of the ecology and distribution of the related, nationally threatened species *E. carsonii*, an endemic of spring wetlands in northern South Australia, New South Wales and Queensland, and characteristic of spring mounds in the Great Artesian Basin (Fensham and Price 2004).

Other species of interest include the rare sedge *Gymnoschoenus sphaerocephalus* (Button Grass), recorded at one site in the Highlands area. This species has previously been recorded in the Strathbogie area, although subsequent searches have failed to relocate any populations (Val Stasjic, Royal Botanic Gardens, pers. comm.). However, it is also known from the Buxton Gum reserve to the south-west of the study area, where it co-occurs with *Sphagnum cristatum* (White et al. 2006). In Victoria, Button Grass is more commonly found along the Victorian south coast, with scattered occurrences in the Grampians and Central Highlands, but is common throughout Tasmania.

3.1.5 Vegetation communities

Three broad structural vegetation types were recognised: (i) treeless vegetation of fens dominated by rushes, reeds or sedges (Groups 1, 2, 7b, 8); (ii) shrublands dominated by *Baeckea utilis*, *Leptospermum continentale* or *Leptospermum lanigerum* (Groups 3, 4); (iii) swamp forest and woodland dominated by *Eucalyptus camphora* subsp. *humeana*, *Acacia melanoxylon* or *Leptospermum lanigerum* (5, 6, 7a, 9). 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 identified groups may represent different stages of more or less homogenous swamp forest and shrublands dominated by *Eucalyptus camphora* subsp. *humeana*, *Acacia melanoxylon*, *Leptospermum lanigerum*, *L. continentale* and/or *Baeckea utilis*, and a mixture of sedges, reeds, grasses and herbs. Differing management histories have allowed some of these to become dominant over others, and there were very few examples of the presumed original swamp forests.

There was a degree of overlap in the composition of the vegetation groups (Figure 11). Some quadrats were considered misclassified and were re-allocated to other groups, and three were discarded after examination and comparison of species distributions. Sub-groups were identified within groups 5 and 7 to account for further floristic variation (Figure 11).

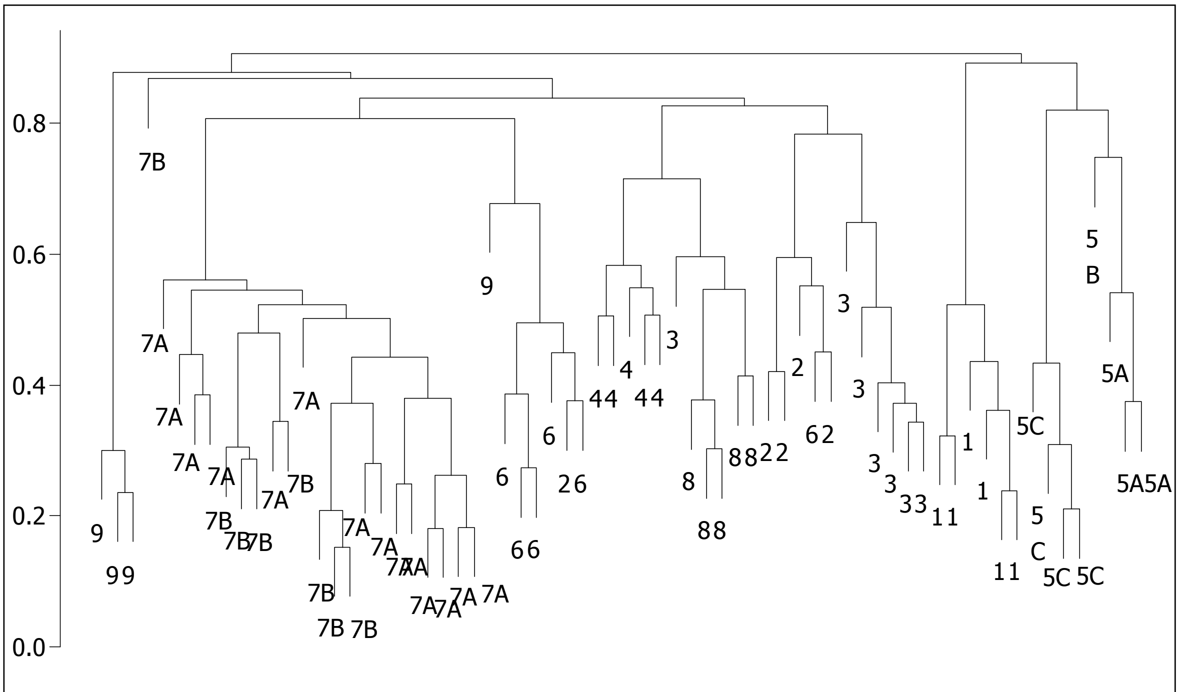

Figure 11. Dendogram produced from agglomerative hierarchical clustering of 68 quadrats. Clusters are labelled by floristic group membership. The lengths of the vertical lines represent Bray–Curtis dissimilarity.

Most vegetation communities were mostly referable to published EVCs (Table 1). However, group 6 (*Eucalyptus camphora – Leptospermum lanigerum* Open Swamp Forest) appeared to conform to the wetter examples of Swamp Woodland, with elements of Fern Swamp (D. Frood pers. comm.), and group 8 (*Elaeocharis gracilis* Low Sedgeland) was not referable to any EVC. None of the vegetation communities met the descriptors for the Spring Soak Woodland EVC.

Table 1. The relationship between floristic groups and EVCs.

EVC Group	Tall Marsh	Wet Verge Sedgeland	Perched Boggy Shrubland	Swamp Scrub	Riparian Scrub	Fern Swamp	Swampy Woodland	Undescribed
1. Reedland	✓							
2. Sedgeland		✓						
3. Baeckea shrubland			✓					
4. Open shrubland			✓	✓				
5. Swamp forest						✓	✓	
6. Open swamp forest				✓?	✓?			
7. Swamp woodland							✓	
8. Low sedgeland								✓
9. Swamp woodland							✓	

3.1.6 Vegetation group descriptions

Examples of vegetation groups and their species composition are in Appendix 2.

Group 1. *Phragmites australis* Reedland

EVC: Tall Marsh (EVC 821).

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, C. fascicularis* or *C. gaudichaudiana*. *Baumea rubiginosa*, *Juncus sarophorus* and *Glyceria australis* may be present, and *Glyceria maxima* occurs in some quadrats. The ground layer is species-poor and dominated by introduced species, particularly *Holcus lanatus* and *Lotus corniculatus*. Minor native species recorded are *Blechnum* spp., *Epilobium* spp. and *Juncus* spp. *Eucalyptus camphora*, *Leptospermum lanigerum* and *Dicksonia antarctica* are occasional emergents. Mean native species richness (7) in this group is half or less than that recorded in other groups and is significantly lower than in all other groups except group 2 ($P < 0.005$).

A horizon soils are neutral to mildly alkaline (pH 6.63–7.41) organic loams and peat reaching depths of 10–20 cm. Overall depth to the impermeable layer was usually more than 1 m. Most sites had been fenced for at least a year.

This community is distributed across the study area at a range of altitudes (380–590 m), mainly at sites with relatively low mean annual rainfall (830 mm). It is confined to saturated, topogenous sites with standing water in the central zone of vales or gullies (mean moisture = 80%).

Group 2. *Juncus sarophorus – Carex appressa* Sedgeland

EVC: Wet Verge Sedgeland (EVC 932).

Dominated by *Juncus sarophorus* and *Carex appressa* (30–70% combined cover) and a moderately dense to dense ground layer (30–80% cover) consisting mainly of introduced pasture species such as *Holcus lanatus*, *Anthoxanthum odoratum* and *Lotus corniculatus*. Minor species are *Cyperus lucidus*, *Isolepis* spp., *Eleocharis gracilis*, *Poa helmsii* and *Baumea rubiginosa*. *Eucalyptus camphora*, *Acacia melanoxylon* and *Leptospermum lanigerum* are occasional emergents.

The A horizon is shallow (< 5 cm) organic loam or peat that is acidic to mildly alkaline (pH 5.93–7.48) and damp to wet (mean moisture = 60%). Depth to the impermeable layer was generally at least 1 m. Sites were unfenced or only recently fenced, except one that had been fenced for five years.

Juncus sarophorus – Carex appressa Sedgeland is common on both topogenous vales and soligenous slopes across a range of elevations (390–500 m) at sites with relatively low mean annual rainfall (790 mm). It occurred on drier sites than group 1 and is a common remnant wetland vegetation in paddocks (‘paddock remnant’) along shallow drainage lines and at the margins of wetlands.

Group 3. *Baeckea utilis* Shrubland

EVC: Perched Boggy Shrubland (EVC 185).

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

The A horizon is generally 10–25 cm deep and consists of acidic to mildly acidic organic loam, with a higher organic content on wetter sites. However, while these soils appear quite wet, soil moisture values are the lowest recorded in the survey (mean moisture = 50%). This reflects the low water holding capacity of loams compared to soils with higher organic content in other groups. Depth to the impermeable layer is 25–50 cm, indicating close proximity to bedrock and relatively shallow soils.

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.

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

EVC: Swamp Scrub (EVC 53)/Perched Boggy Shrubland (EVC 185).

This community occurs on wet sites dominated by *Leptospermum lanigerum* (10–30% cover) to 1.5 m (occasionally taller) and *Baumea rubiginosa* with a high diversity of graminoid and herbaceous species in the ground layer. These include *Holcus lanatus*, *Eleocharis gracilis*, *Juncus planifolius*, *Phragmites australis*, *Schoenus* spp., *Isolepis* spp., *Triglochin striata*, *Utricularia dichotoma* and *Hypericum japonicum*. The rare species *Eriocaulon scariosum* was recorded at three sites.

The A horizon consists of pH neutral saturated peat (mean moisture = 90%), 20–50 cm deep but occasionally around 5 cm. Depth to the impermeable layer is variable (0.4 to > 1 m).

This community is found at significantly lower mean elevation (380 m, $P < 0.001$) than any other group except 1 and 2. It occurs in soligenous settings around spring outlets within vales as well as on gentle or steeper slopes in the Highlands and Caveat areas. Disturbance was also significantly higher than in any other group except 1, 2 and 3 ($P < 0.001$). 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.

Group 5. *Acacia melanoxylon* Swamp Forest

EVC: Swampy Woodland (EVC 937) / Fern Swamp (EVC 721).

This group contains three related swamp forest communities distributed over a soil moisture gradient and distinguished by their understorey composition. Different disturbance histories are also likely to have determined the current floristic composition of the understoreys. Most sites appeared to be drying out.

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

Dominated by *A. melanoxylon* with occasional *E. globulus* to 25 m with >25% cover. 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 codominant.

The A horizon consists of wet (mean moisture = 50%), acidic, organic loams or peat with low organic content, less than about 5–10 cm deep. Depth to the impermeable layer varies from 0.25 m on slopes to over 1 m in gullies.

Open Swamp Forest is confined to steeper slopes and gullies at higher elevations (around 600 m) in the northern Strathbogies. Sites are on gully slopes or drainage lines and are topo-soligenous. One site had been fenced for 10 years. This community is likely to be a remnant vegetation type formerly more widespread in drainage lines.

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

Dominated by *Acacia melonoxylon* and *Eucalyptus camphora* to 25 m high (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*. Distinguished from groups 5a and 5c by a higher cover of bracken and lower cover of native herbs and small sedges.

This community was recorded in a single quadrat on a soligenous gentle slope in one of the most elevated parts of the study area (595 m) on deep (> 1m) soils. The A horizon consists of wet, neutral organic loam, 25 cm deep and similar moisture content to soils in the previous group.

The quadrat is a rare example of *E. 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% vs 40%) than in group 5a, and bracken cover higher (10% vs < 1%).

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. Canopy cover is generally over 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*.

Soil depth is over 1 m, with charcoal throughout the cores. The A horizon is wetter (mean moisture = 80%) and more alkaline, with a higher organic content than sites in groups 5a and 5b and situated in areas with lower mean annual rainfall, although the differences were not significant ($P > 0.5$).

Open Swamp Forest occurs 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.

At one site in State Forest (DSE2), this community occurred within a broad gully and is considered a variant of the broader vegetation type. It consisted of intact *E. camphora* forest on deep organic loam (30 cm) with lower soil moisture. The area had evidently been used for the cultivation of potatoes some 100 years earlier (J. Linkins pers. comm.) but was otherwise undisturbed and in good condition.

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

EVC: closest to Swamp Scrub (EVC 53) / Riparian Scrub (EVC 191).

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. The understorey is generally quite open and consists mainly of a sparse cover of younger *L. lanigerum*, 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 such as *Hypochaeris radicata*, *Lotus corniculatus* and *Holcus lanatus*.

Most sites had developed on wet or waterlogged (mean moisture = 75%), neutral to mildly acidic peat (with one exception). Soil depth was variable (0.4 – > 1 m) but with a well-developed organic A horizon (20–60 cm). The community appears to be confined to cooler, high-rainfall areas (500–570 m) on slopes in the northern Strathbogies.

Group 7. *Eucalyptus camphora* Swamp Woodland

EVC: closest to Swampy Woodland (EVC 937).

Nearly a third of quadrats (22) were allocated to this group. Although there is some floristic and structural variation among quadrats, all are characterised by a moderately dense to dense cover (> 50%) of *Baumea rubiginosa* or, less frequently, *B. planifolia*. Community structure ranged from woodland (7a) to closed sedgeland (7b).

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

This vegetation community is characterised by a sparse to moderate cover (5–50%) of trees and/or tall shrubs (5 20 m) consisting of *Eucalyptus camphora*, *Leptospermum lanigerum*, and occasionally *Baekea utilis* at drier sites. The second stratum consists of a sparse cover (< 25%) of smaller shrubs (< 2 m high), typically *Leptospermum continentale* and/or *B. 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 *Elaeocharis gracilis*. Introduced exotics include *Lotus corniculatus*, *Holcus lanatus* and *Anthoxanthum odoratum*. However, these were generally less abundant than in group 7b.

Included in this group are two sites having particular significance in the Highlands area, which may warrant allocation to a unique group. One site (D. and P. Lade property) supports the only known occurrence of button grass (*Gymnoschoenus sphaerocephalus*) in the study area, co-dominant with *Baumea rubiginosa*. *Leptospermum lanigerum* co-dominates in the central wetland zone. The button grass tussocks have become very dense since grazing stock were excluded about 6 months prior to sampling, suggesting that some kind of disturbance will be needed in the future to maintain species reliant on inter-tussock spaces.

Euaclyptus camphora woodland with well-developed *Sphagnum* hummocks and herb components was recorded nearby (S. McAlpin property). The site had been recently fenced, and in spite of having been grazed in the past is in very good condition. It may represent the only remaining example of this vegetation type on the southern Strathbogie plateau and is of high conservation significance. Of additional interest are apparent floristic similarities with the Buxton Gum Reserve, which was burnt in 2009.

Euaclyptus camphora – Baumea rubiginosa Swamp Woodland was recorded in the central wetland zone at higher elevations (440–590 m). Quadrats were higher in native species richness than group 7b (17 vs 10 species), with lower mean cover of weeds (7% vs 20%). Almost all sites were recorded on soligenous slopes on acidic to neutral, saturated peat (mean moisture = 80%). The A horizon was generally well developed (mean = 25 cm) and depth to the impermeable layer varied from shallow to deep (0.3 to > 1 m).

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

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

Baumea rubiginosa / *Baumea planifolia* Closed Sedgeland is found at higher elevations (420– 590 m) in the central, mid and outer wetland zones. All sites are protected from stock grazing. The community occurs on mildly acidic to neutral, saturated peat (mean moisture = 80%). Compared to 7a, the A horizon is less well developed (mean depth = 12 cm) but overall soil depth is comparable (0.2 – > 1 m). Sites are mostly on soligenous slopes including mounds, but occasionally in gullies or vales.

Group 8. *Elaeocharis gracilis* Low Sedgeland

EVC: undescribed.

Dominated by *Eleocharis gracilis* and a suite of small sedges and herbs (60–80% combined cover) forming a low (< 0.3 m) turf. Associated species typically included *Hydrocotyle sibthorpioides*, *Epilobium* spp., *Drosera peltata*, *Schoenus maschalinus*, *S. apogon*, *Isolepis subtillissima*, *I. inundata*, *Juncus articulatus*, *J. planifolius* and *Lotus corniculatus*. *Holcus lanatus* was locally dominant at the spring vent.

Sites are on waterlogged (mean moisture = 85%), mildly acidic to neutral peat on soligenous mound springs. Depth to the impermeable layer is over 1 m, with a well-developed organic A horizon (mean = 15 cm).

The community is distributed mainly in cooler, high rainfall areas but is occasionally found at lower altitudes (350–570 m). Sites are within forest, or are fenced or unfenced in open paddocks. Reasonably high species richness (mean = 16) was recorded in both fenced and unfenced quadrats.

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

EVC: Swampy Woodland (EVC 937).

This group consists of species rich sites with an understorey characterised by a dense cover of *Gleichenia microphylla* (40–80%) and minor species *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 middle storey. 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 on slopes in cool, elevated areas (520 – 620 m), on neutral, waterlogged organic loams and peat soils (mean organic = 40%; mean moisture = 70%). All sites are on soligenous slopes but show signs of deterioration, as evidenced by large areas of *Gleichenia* either dead or dying as result of drying.

One anomalous site consisting of *Baumea rubiginosa – B. planifolia – G. microphylla* is tentatively placed within this group, although it may be better placed within group 7b. Soils at this site have higher than average organic content (80%) and soil moisture (90%), which may limit tree growth.

3.1.7 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 *Gleichenia* (coral fern) (> 25%) 4
3. Swamp woodland with groundlayer of sedges and/or other ferns 5

4. Swamp woodland with ground layer dominated by (*Gleichenia*) 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 7**b

When all pairs of vegetation groups were compared, *Leptospermum lanigerum – Baumea rubiginosa* Open Shrubland (Group 4) occurred at significantly lower altitudes ($P < 0.05$) and had higher levels of disturbance ($P < 0.05$) than most other groups (Figures 12, 13). There were some significant differences between various groups for rainfall, temperature, native species richness, weed species richness, weed cover, buffer width and length and years fenced. However, no group was consistently different from any other. There were no significant differences between groups for any of the measured soil variables (pH, %moisture, %organic, %carbonate, peat depth).

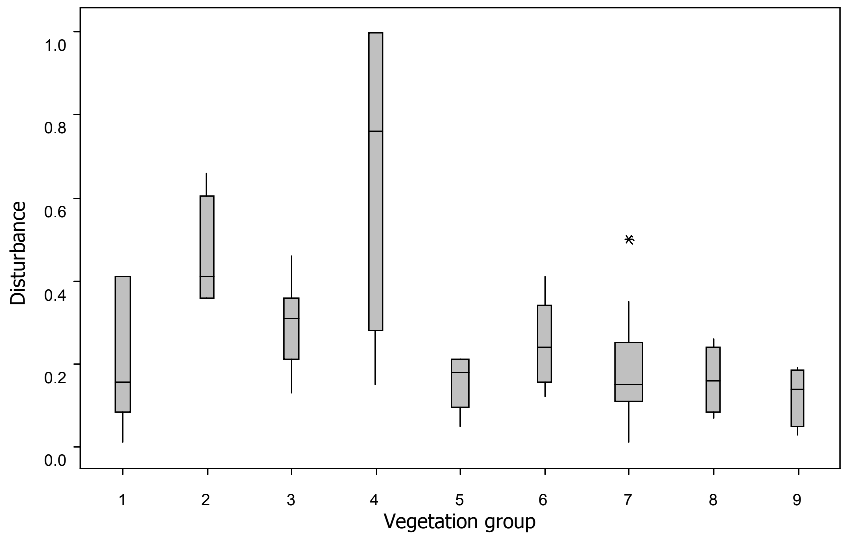

Figure 12. Boxplot of altitude according to floristic group. Median (horizontal line in boxes) and quartiles are shown; asterisk indicates outlier. Box width is proportional to sample size (*n*): Group 1 (6), Group 2 (5), Group 3 (7), Group 4 (5), Group 5 (8), Group 6 (6), Group 7 (22), Group 8 (5), Group 9 (4).

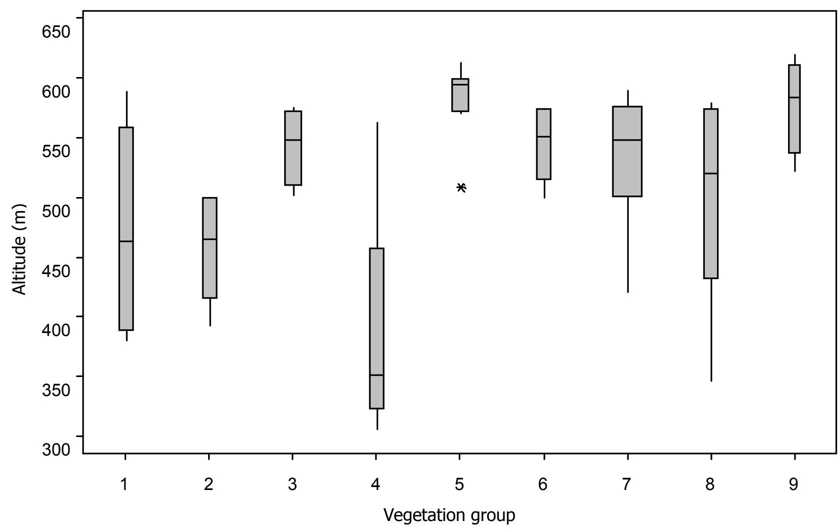

Figure 13. Boxplot of disturbance according to floristic group. Median (horizontal line in boxes) and quartiles are shown; asterisk indicates outlier. Box width is proportional to sample size (*n*): Group 1 (6), Group 2 (5), Group 3 (7), Group 4 (5), Group 5 (8), Group 6 (6), Group 7 (22), Group 8 (5), Group 9 (4). Disturbance was calculated from the combined cover of weeds, pugging and tracks (see section 2.2).

3.2 Mapping

All groundwater-influenced vegetation that was surveyed or otherwise visible in aerial photographs was mapped across the modified study area (e.g. Figure 14a). Where detailed field notes and quadrat data were available, the sites were mapped at a site (quadrat) scale as one of 16 vegetation groups (e.g. Figure 14b). Study sites and all other systems were then mapped at a study area scale as one of four broad vegetation types (e.g. Figure 14c).

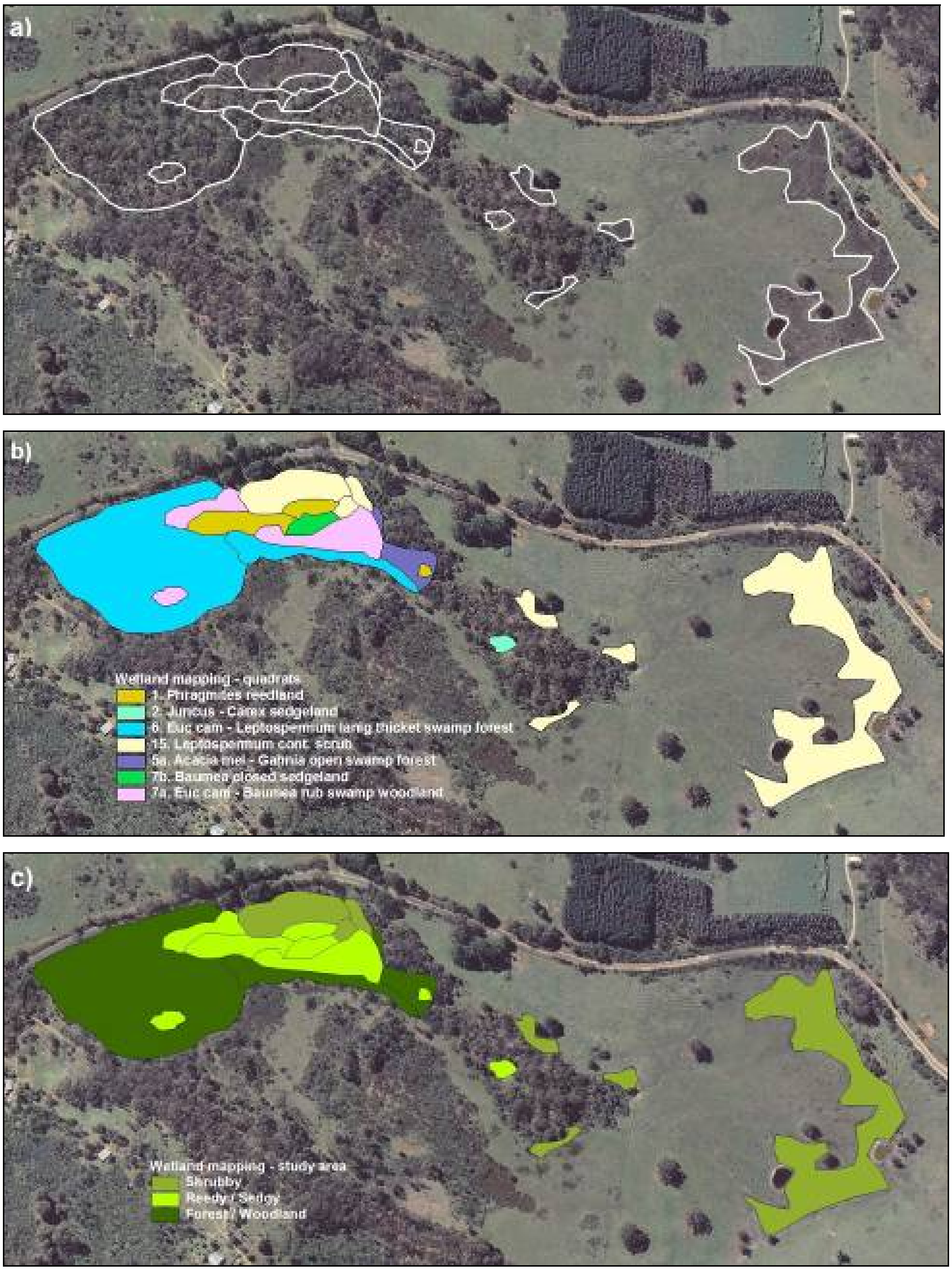

Figure 14. Example of wetland mapping. a – polygon outlines; b – mapping at higher-detail site scale (7 of 16 vegetation groups shown); c – mapping at study area scale (3 of 4 broad vegetation types shown).

3.2.1 Site scale

A total area of 145 hectares was mapped at a fine scale using quadrat data and comprehensive field notes. The resultant mapping polygons were allocated to one of the 12 formal vegetation groups identified in the classification (groups 1 to 9), or to an appropriate informal category (groups 15, 20, 25 or 30) if allocation proved difficult (Table 2, Figure 15).

Table 2. Vegetation groups (by area) from detailed site mapping.

Vegetation group		Polygons mapped	Area (ha)	Area (%)
1	*Phragmites australis* Reedland	14	3.8	2.6
2	*Juncus sarophorus – Carex appressa* Sedgeland	53	26.1	18.0
3	*Baeckea utilis* shrubland	38	21.0	14.5
4	*Leptospermum lanigerum – Baumea rubiginosa* Open Shrubland	7	1.8	1.2
5a	*Acacia melanoxylon – Gahnia sieberiana* Open Swamp Forest	12	6.4	4.4
5b	*Acacia melanoxylon – Eucalyptus camphora* Swamp Woodland	3	2.2	1.5
5c	*Acacia melanoxylon – Carex appressa* Open Swamp Forest	9	2.8	1.9
6	*Eucalyptus camphora – Leptospermum lanigerum* Thicket Swamp Forest	17	10.3	7.1
7a	*E. camphora – Baumea rubiginosa* Swamp Woodland	24	15.5	10.7
7b	*Baumea rubiginosa / Baumea planifolia* Closed Sedgeland	46	9.8	6.7
8	*Elaeocharis gracilis* Low Sedgeland	7	2.1	1.4
9	*Eucalyptus camphora – Acacia melanoxylon – Gleichenia* Swamp Woodland	7	3.7	2.5
15	*Leptospermum continentale* Scrub	15	6.5	4.5
20	Paddock Remnant with *Juncus*	44	23.2	16.0
25	*Glyceria* Reedland	8	5.9	4.1
30	*Typha* Reedland	2	4.2	2.9

Group 2 (*Juncus sarophorus – Carex appressa* Sedgeland) and Group 3 (*Baeckea utilis* Shrubland) together accounted for almost half of the 105 ha that was able to be allocated to a formal group (Figure 15). Further, the informal Group 20 (Paddock Remnant with *Juncus*) was the major contributor to the 40 ha that could not be allocated to a formal group (Table 2). This appears to reflect the marginal nature of many wetlands in the study area, as these vegetation types tended to occur on drier sites. Shrubby areas around wetlands might be natural, or partly an artefact of land use. However, the presence of remnant *Juncus* in cleared paddocks suggests vegetation change and wetland contraction as a result of long-term disturbance.

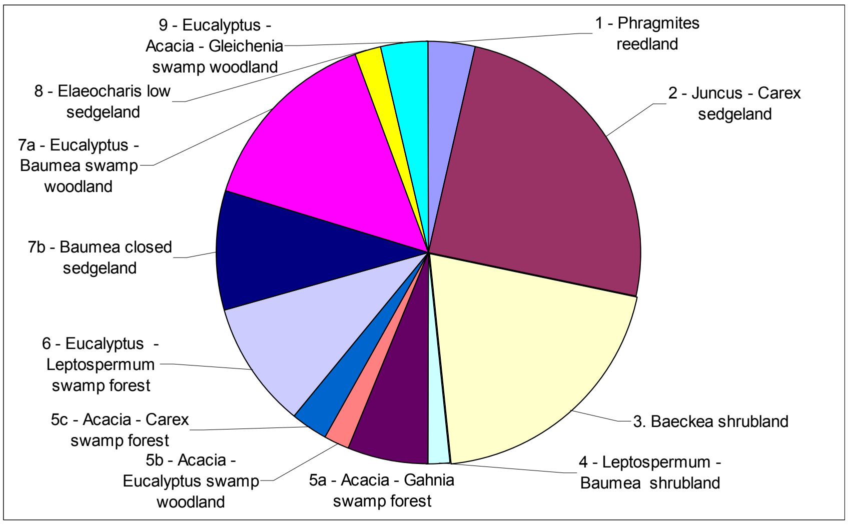

Figure 15. Vegetation groups 1 to 9, by area, from detailed site surveys. Total area is 105 ha.

3.2.2 Study area scale

A total area of 1646 hectares of soaks, wetlands and remnants was mapped from aerial photos across the adjusted study area, representing 0.65% of the total area (Table 3, Figure 16).

Table 3. Broad wetland vegetation types in the adjusted study area; 251 992 ha were mapped across this area.

Broad vegetation type	Polygons mapped	Mapped area (hectares)	% of mapped wetlands
Forest/woodland	65	41.8	2.5
Shrub-dominated	303	247.7	15.1
Sedgy/reedy	572	398.2	24.2
Paddock remnant	805	958.6	58.2

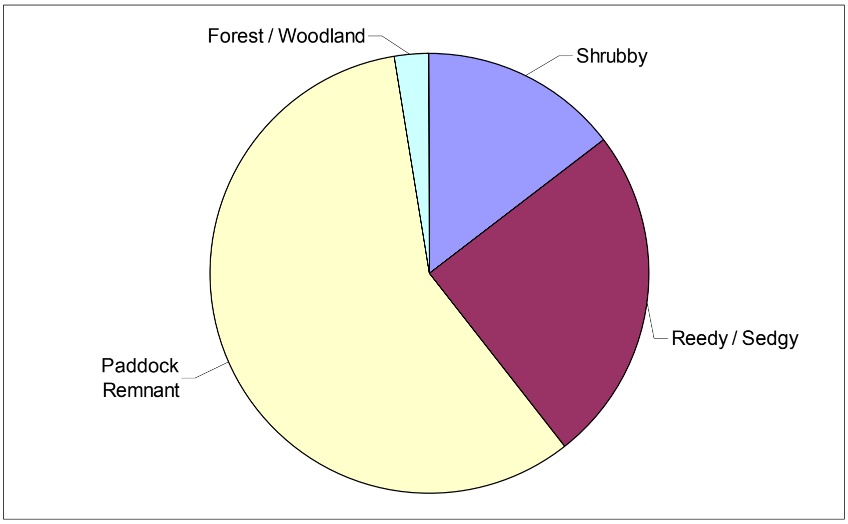

Figure 16. Broad vegetation types by area. Total area is 251 992 ha.

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.

Paddock remnant largely devoid of trees or shrubs accounted for 58% of all mapped wetland vegetation, a larger proportion than that suggested from the detailed site mapping. Given that the study area was forested prior to European settlement (Carr et al. 2006), this is a strong indication that more than half of the original wetland vegetation in the study area has been lost as a result of land clearing and altered land use. However, the true amount lost is likely to be substantially higher. In many parts of the study area, particularly in the south, the groundwater-influenced vegetation that would be expected to occur around the numerous dams and drainage lines was not discernible in aerial photos and so could not be mapped.

Most mapped wetlands were found at elevations of around 400 m to 600 m, with the greatest numbers in the 450–500 m and 500–550 m ranges (Figure 17). The largest total areas were in the 500–550 m and 550–600 m ranges, suggesting that the mean size of wetlands was slightly larger at higher altitudes.

Aerial photography, in conjunction with field observations, also highlighted the variable condition of wetlands, or portions of wetlands. For example, some wetland systems contained large areas that were 80% intact, as well as other large areas that were completely saturated yet highly disturbed and only 10% intact (Figure 18).

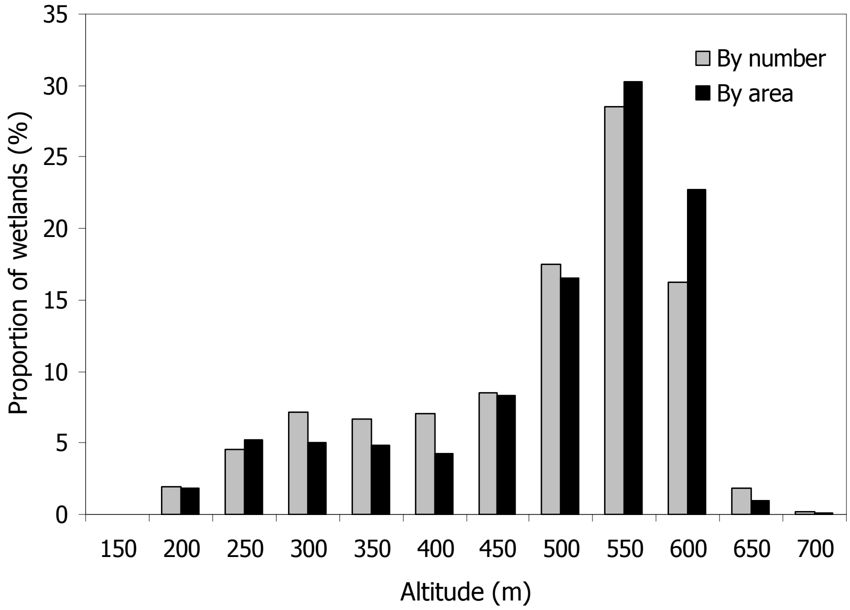

Figure 17. The distribution of mapped wetland vegetation in relation to altitude.

Figure 18. Example of variation in condition and extent of wetland vegetation.
a – Remnant soak that is presently in poor condition (10% intact), yet it remains saturated and has vegetation features that suggest fencing would be a worthwhile option. Species include *Poa helmsii*, *Baumea rubiginosa*, *Leptospermum continentale*, *Hydrocotyle* spp., *Leptospermum lanigerum*, *Gonocarpus micranthus* and occasionally *Sphagnum cristatum*.
b – Also saturated, with *Carex appressa*, *Juncus sarophorus*, *Isolepis* spp., *Elaeocharis gracilis*, *Poa helmsii*.
c – Very wet area, with high cover of *Baumea rubiginosa*, and flanked by *Eucalyptus camphora*; 80% intact.

3.3 Condition

NMDS attained a minimum stress of 0.17 in three dimensions, and while a lower stress value would have been preferred, the resultant ordination should still produce a usable picture (Clarke 1993). Vector fitting showed that floristic composition was correlated with variables related to climate and disturbance, and this relationship was best seen in the plane bounded by dimensions 1 and 2 (Figure 19).

The least disturbed sites, with fewer tracks, less pugging and lower weed cover, consisted of forest and woodland. 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). These were situated in cooler, wetter, more elevated locations. Vegetation belonging to these groups was also likely to be better buffered by native vegetation than disturbed sites.

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).

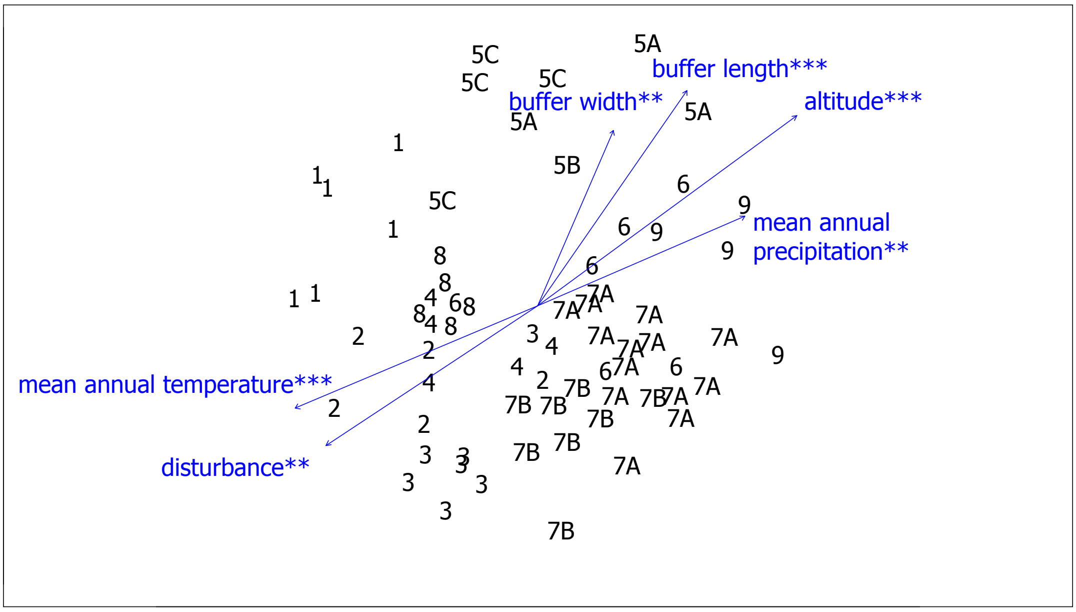

Figure 19. Distribution of quadrats within the 3-dimensional ordination space, dimensions 1 and 2. Points are labelled by cluster group membership and vectors of maximum correlation; fitted vectors correlation coefficients (*r^2*) and statistical significance. * < 0.05; ** <0.01; * < 0.001. Vector lengths are proportional to strength of correlation.**

A third compositional trend, best seen in the plane bounded by dimensions 1 and 3, was correlated with the vector for native species richness (Figure 20). Quadrats with high species richness mainly belonged to Group 6 (*E. camphora – L. lanigerum* Open Swamp Forest) and Group 9 (*E. camphora – A. melanoxylon – G. microphylla* Swamp Woodland). However, while the vector was highly significant in relation to site positions on the ordination, the relationship between richness and vegetation groups was weaker (Figure 20). There was also a weak correlation between floristic composition and the number of years that some of these sites had been fenced.

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

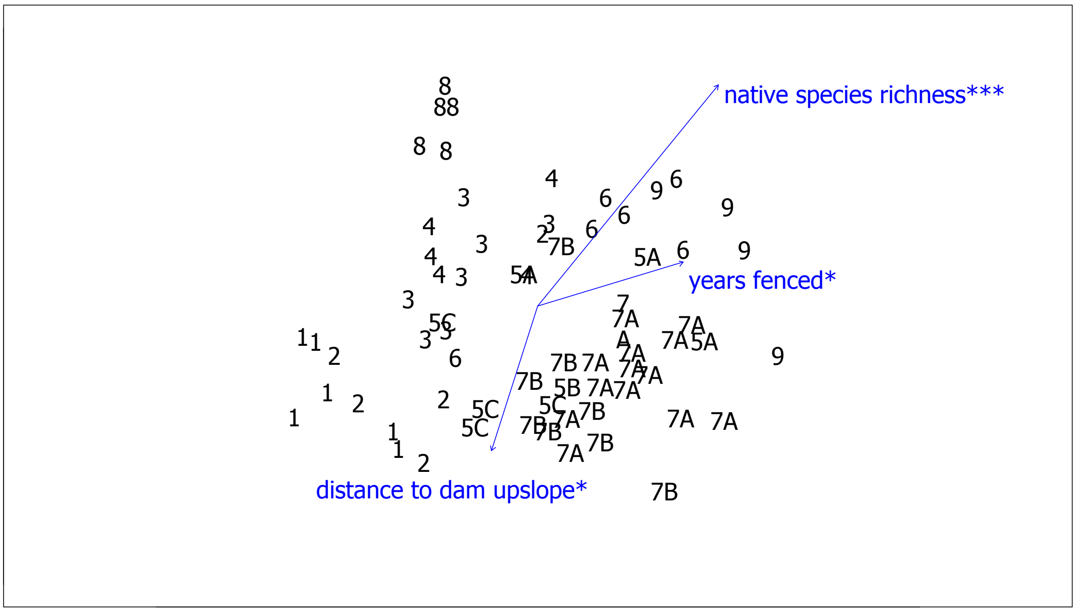

Figure 20. Distribution of quadrats within the 3-dimensional ordination space, dimensions 1 and 3. Points are labelled by cluster group membership and vectors of maximum correlation; fitted vectors correlation co-efficients (r^2) and statistical significance. * < 0.05; ** <0.01; * < 0.001. Vector lengths are proportional to strength of correlation.**

The overall results of the ordination indicated that the composition of vegetation in the study area is related to a combination of 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. Some of these sites were also associated with higher native species richness, had been fenced for a longer period of time and were closer to upslope dams, although vectors for these last two factors were relatively weak.

The observed patterns may reflect past settlement and land use patterns. The results imply that properties at higher elevations are less likely to have been as extensively cleared, fertilised or sown to annual grasses, and have had historically lower stocking rates than properties at lower elevations. However, this requires further investigation. Higher shrub cover may also have acted to deter grazing animals from entering the wetland area, thus affording a degree of protection during seasons when the ground was drier. This is in direct contrast to cleared mound areas, where the ground was pugged and the vegetation had been grazed down to a short turf.

There was no evidence in the data that water extraction via dams and known bores was a significant driver of vegetation composition at the quadrat scale at present; indeed there were few bores mapped within 100 m of any study site. Soil properties or moisture content were not related to vegetation composition and were not correlated with the disturbance index ($P > 0.05$). However, sampling was focused in the wetter, central wetland areas, where the effects of drying are less likely to be detectable than in the outer wetland zones. 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 (and additional data from outer wetland zones) may provide more information. For example, we observed obvious signs of drying out at forest and 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 thickets of *Gleichenia microphylla* or by dense stands of *Gahnia sieberiana*. One presently dry site even had some remnant *Sphagnum*, but it is difficult to determine to what extent the drying and wetland contraction was attributable to the dam above or to longer-term changes. However, these drying trends were indicated at the scale of overall site condition (see below). 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 'paddock remnant' vegetation (Table 3).

3.4 Current and potential threats

3.4.1 Habitat destruction and degradation

Changes in land cover: trends in land use change include an increase in the area of land converted to hardwood (Figure 21) or softwood plantations, viticulture and horticulture (10% of sites visited).

Figure 21. Southern Blue Gum plantations at the periphery of *Baumea rubiginosa* Closed Sedgeland.

Grazing: only seven quadrats were currently grazed. Two sites which were formerly grazed were excluded from stock (<10%). The major consequences of grazing are eutrophication resulting from pollution by urine and faeces, destruction of some native vegetation, soil disturbance leading to weed invasion and a reduction in the area available for survival and reproduction of native species. 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 (e.g. Figure 22) Grazing was also the most common land use within 250 m of wetlands (82%).

Figure 22. Severe pugging and trampling by cattle. This vegetation is likely to have once been *Leptospermum lanigerum – Baumea rubiginosa* Open Shrubland or *Eucalyptus camphora – L. lanigerum* Thicket Swamp Forest.

Weed invasion: high levels of weed cover were recorded throughout the wetland systems. 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 and cattle faeces. *Holcus lanatus*, *Lotus corniculatus* and *Hypochaeris radicata* were the three most frequently recorded weeds, occurring in more than 80% of quadrats. *Rubus* spp. (blackberry)(Figure 23) were recorded in approximately 50% of wetlands but was rarely abundant, probably because of high investment in control measures by landowners.

Figure 23. Severe blackberry invasion of *Baeckea utilis* Shrubland.

Earthworks and extraction: excavation in the form of dams or channels or water extraction via pipes (e.g. Figure 24) 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). Additional risks to wetland vegetation also include drying, local erosion, ponding, loss of wetland vegetation and flora, contraction of wetland area and an increased likelihood of weed invasion on disturbed soils.

Figure 24. Pipe draining Closed Sedgeland.

3.4.2 Dysfunction of physical and biological processes

Reduction in wetland area: almost all landowners consulted during the survey commented that drying out posed the most immediate threat to wetlands. A large proportion of wetlands (60%) 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). 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.

Wetlands have contracted and reduced in area as a result of historical clearing and grazing (and possibly interruptions to hydrology). Mapping suggested that wetlands within the study area are likely to have decreased by nearly two thirds of their original extent, as indicated by the conservative area of paddock remnant identified (Table 3). At least some vegetation zonation (> 25% intact) was detected at one third of wetlands (Figure 25). 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.

Figure 25. Cross-section of wetland system showing zonation of vegetation communities. *Phragmites* Reedland occurs in the central zone, adjacent to *E. camphora* Swamp Woodland.

Fragmentation: loss of connectivity as defined by a lack of continuous native vegetation was observed in 40% of wetland systems (with reduced area available to plants and animals), as a result of general land clearing (Figure 26). Connectivity of wetland vegetation may be difficult to re-establish, depending on the extent of ground compaction and changes to subsurface drainage.

Figure 26. Loss of connectivity of wetland vegetation along a slope break. Remnant patches of *B. utilis* Shrubland occur discontinuously across the slope.

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. This reflects the amount of clearing since European settlement, which is ongoing at some sites (e.g. Figure 27). However, as discussed previously, wetlands in areas with forest cover are likely to have been under-represented in the sampling because they are difficult to discern in aerial photos and information about their location requires good local knowledge.

Figure 27. Slashing of wetland vegetation in preparation for dam excavation.

Loss of species diversity: the replacement of species-diverse vegetation with monocultures is likely to disrupt biological interactions (Figure 28). We speculate that this might include a loss of pollinators, an increase in predators and herbivores, or loss of resilience to disease and pathogens (Auld and Keith 2008).

Figure 28. Species-rich Low Sedgeland. The site is currently grazed by sheep but is likely to become invaded by *Phragmites australis* or sedges in the absence of disturbance.

3.4.3 Changes to disturbance regimes

Increased interspecific competition: an over-abundance of some taxa (e.g. *Phragmites*, *Baumea, Gymnoschoenus*) may be in some instances a consequence of changed land use. The risk from this includes increased interspecific competition leading to exclusion of other species and reduction in species diversity, particularly minor inter-tussock species (Figure 29). However, dominance in low-lying areas by reedy vegetation such as *Phragmites* or *Typha* may also be a natural consequence of succession or a transition to seasonally inundated swamp. These sites are also highly likely to provide habitat for fauna such as bandicoots.

Frequency and degree of inundation: 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 (Figure 30), which characterises wetland systems and which has already occurred at most sites. This may result from a long-term decrease in precipitation, or from human-induced changes in the surrounding landscape.

Figure 29. Dominance of large sedge species in the absence of disturbance.

Figure 30. *E. camphora* – *A. melanoxylon* – *G. microphylla* Swamp Woodland deteriorating in response to lack of soil moisture.

Fire: the presence of charcoal throughout soil stratigraphies suggests that fire is likely to have occurred historically throughout the Strathbogie Ranges. Fire may increase on the Strathbogie plateau in some forested areas as a result of climate change, but it is unlikely to have any significant impact in the foreseeable future on cleared agricultural land.

3.5 Current management

Fencing, stock removal and weed control are the main methods used to manage sites for conservation of the wetland vegetation and to provide habitat for native fauna. Some wetlands were fenced in their entirety but it was more common for landowners to fence a portion of a wetland area, notably the wetter, central portion. Trees or shrubs have been planted in more elevated areas at some sites, either by direct seeding or tubestock (J. Hagen pers. comm.).

Forty-four quadrats (62%) were within fenced wetlands. Some sites that were fenced to exclude stock had developed a dense cover of vegetation compared to unfenced sites, notably *Baumea rubiginosa* and *Holcus lanatus*, to the exclusion of smaller, less competitive indigenous species. This suggests that the positive effects of protection from stock are being overwhelmed in some instances by the negative effects of dominance by individual (usually larger) species. Species richness is likely to have declined at these sites, suggesting a need to evaluate current management practices. Conversely, some highly disturbed sites were relatively species-rich and had a lower cover of introduced grasses, because ongoing grazing has prevented dominance by species such as *Baumea* or *Gymnoschoenus*.

Species richness ranged from 5 to 30 species per quadrat. There was no relationship between the number of species per plot and total vegetation cover, regardless of the number of years a site had been fenced (Figure 31). Many sites with higher species richness were unfenced, with a couple of exceptions. One site that had been fenced for 30 years was in good condition with high species richness (26 species per quadrat on average), although species richness was equally high in some unfenced quadrats (Figure 31).

There was some indication that fencing may reduce weed cover over a long period of time (> 5 years) at some sites but there were too few sites that had been fenced for more than a few years to make any firm conclusions (Figure 32). Some sites had low weed cover despite not being fenced at all. Furthermore, the weed cover of sites prior to fencing was unknown.

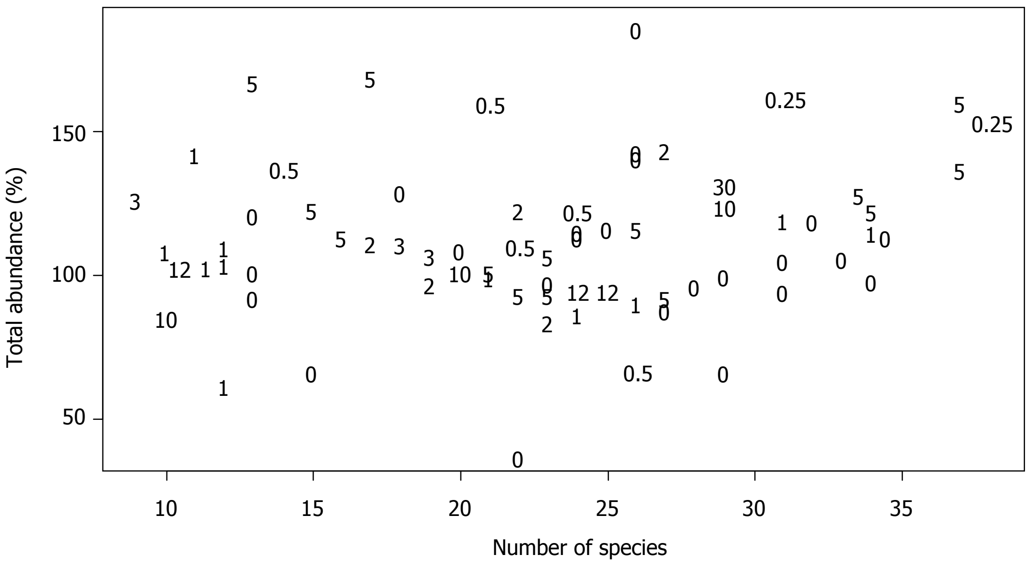

Figure 31. Plot of total species richness against total abundance. Quadrats are labelled according to years fenced. Total abundance is the sum of vegetation % cover in all strata.

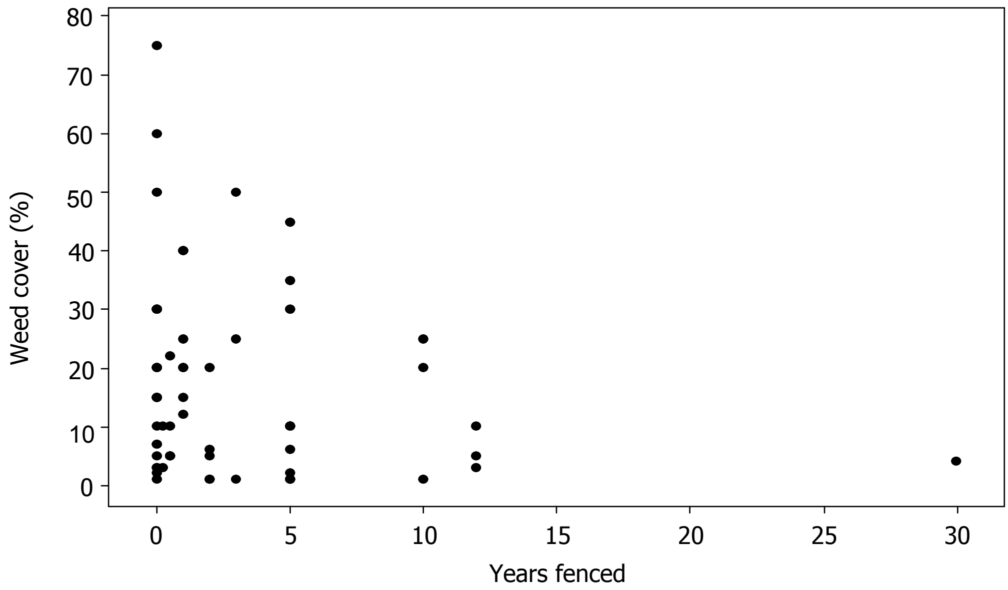

Figure 32. Plot of the number of years since a site had been fenced against total percent weed cover.

There was no clear relationship between weed cover and vegetation abundance (Figure 33), lending further support to the notion that fencing may not improve either species richness or reduce the cover of weeds. Weed cover is therefore likely to be a consequence of other site factors, including initial vegetation type, extent of clearing and pasture sowing, soil and moisture parameters, site history and other management practices.

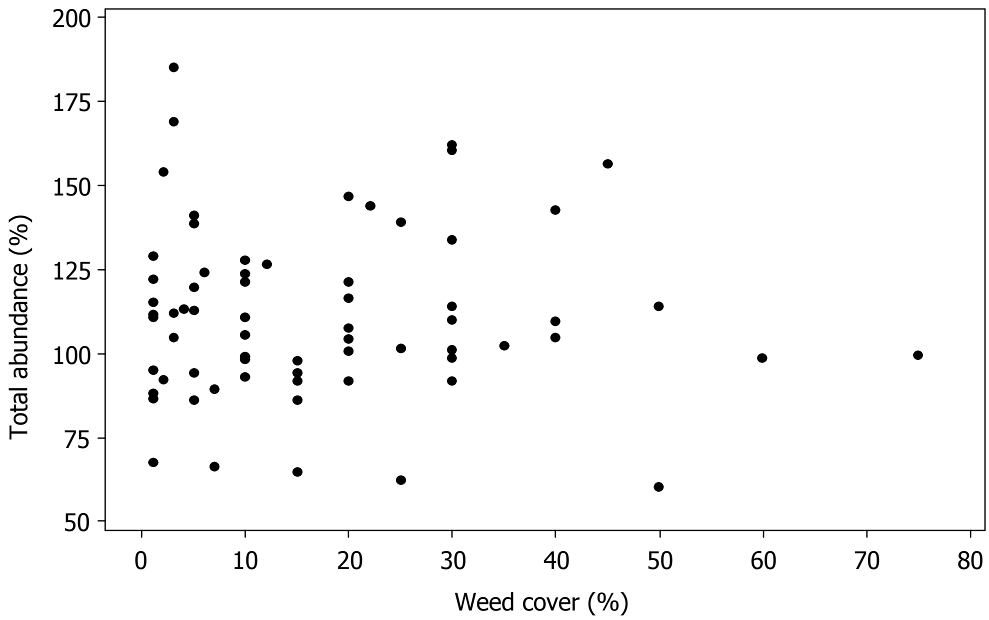

Figure 33. Plot of weed cover against total vegetation abundance. Total abundance is the sum of vegetation cover (%) in all strata.

The results are hampered by a dearth of sites fenced for more than five years, and clearer patterns may emerge in the future with longer-term data. We predict that the response of vegetation to fencing will vary according to initial floristic composition. Sedgeland communities may become rapidly overgrown following grazing exclusion, particularly some wetter sites that are vulnerable to invasion by *Phragmites* or eventual domination by taller sedges. In these cases some form of biomass removal is likely to be needed. Other communites such as *Leptospermum lanigerum – Baumea rubiginosa* Open Shrubland (Group 4) may benefit from fencing, particularly with respect to restoration of shrub cover.

However, there will be limits on what can realistically be achieved in terms of reverting wetland vegetation to some putative 'original' form. The study area was originally forested (Carr et al. 2006), and some study sites appear to provide a glimpse at what the original wetlands may have once looked like. We speculate that these are likely to have been forest or woodland (similar to Groups 5a & b, 7a or 9) with a scattered overstorey of *Eucalyptus camphora* over a midstorey of shrubs and *Acacia melanoxylon* (possibly with tree-ferns), and a mixed, sometimes sparse, ground layer (perhaps with *Sphagnum*). Vegetation structure and composition would have been influenced strongly by an intrinsic (and complex) regime of sunlight and shade, water, plant competition, disturbance by native animals, tree fall and occasional fire. The effects of management intervention on wetlands as they exist today are likely to be highly varied, and strongly influenced by current condition and vegetation composition.

4. Management recommendations

Management recommendations for specific sites will depend heavily on the present vegetation structure and composition, particularly the extent to which it has been modified from a putative 'original' condition and the present water regime. Water availability, present vegetation structure, floristic composition and the availability of plant propagules (either native or introduced), will dictate both the direction and limit of 'natural' change and the intensity of management required to bring about additional change.

A decision matrix based on hydrological state and vegetation structure under two management scenarios (fenced or unfenced) was designed to provide guidance for on-ground actions (Figures 34, 35). The matrix applies to local catchment and site-specific management actions. Catchment level issues relating to hydrological function will be addressed in a separate report (Stewardson and Western in prep.).

4.1 Principal recommendations

4.1.1 Stock and fencing

Unfenced (may have high species richness)

Outcomes if fenced in future: directional trends in vegetation composition and structure, should a wetland be fenced off from stock, will depend on two main factors. Firstly, the wetness (and reliability of water) at a site will determine to what extent the site can continue to be a wetland (Figure 34). If sites become drier, with permanent declines in water availability, it will become increasingly difficult to manage them in a way that will promote any form of wetland vegetation. Secondly, the intactness of the vegetation in and around a site will determine what form the wetland vegetation is likely to take (Figure 34). As the 'original' canopy and shrub layers are lost, the microclimate changes, the availability of propagules reduces, and the risk of individual species dominance increases. If a site is weedy there is the additional risk that the competitive 'winner' will be a weed, rather than a native species.

A broad zone of native vegetation around the wetland may also be an important factor, as this can help buffer the wetland from nutrient and sediment input (from surface water flows), provide some protection from weed invasion, and provide propagules for native species in drier areas of the wetland.

Sites that are a high priority for protection and which should respond positively are those with features that position them toward the top left of the management diagram (Figure 34). With good water availability and structural complexity of the overstorey, such sites should require little management to remain in good condition, other than perhaps weed control. Sites to the top right corner of the management diagram are wet, but lacking in structural complexity. They retain high potential as wetlands, but must be managed in a manner that does not promote a monoculture. Active management is required, which may include tree and shrub planting (in raised areas in the wetland and within the buffer zone), application of disturbance (e.g. pulse grazing, fire) and weed control.

At the bottom left of the management diagram, sites have retained structural complexity, but have dried out, altering the species composition. These sites are unlikely to revert back to a wetland type unless water availability can be substantially improved. However, these sites have value as remnant forest, and could be managed as such. Towards the bottom right of the management diagram, sites are dry, with little vegetation complexity, and it will be difficult to illicit a positive response by wetland species to any practical management action. Alternative uses should be found for these sites.

Before managers consider fencing (or other options), various parameters should be assessed.

- Wetland vegetation community. Is it dominated by sedges, shrubs or trees? What layers are missing? Are there tree or shrub propagules on-site? What weeds are present? Are any extant species likely to assume dominance? Is species dominance already occurring?
- Buffer zone. How wide is the buffer zone? What proportion of the wetland perimeter is buffered? What species are present there? What condition is the buffer zone in?
- Water reliability. Is the site consistently wet? Is soil moisture highly seasonal? Is the soil deep enough to resist drying? Is the soil predominantly peaty or gravelly? Are there interruptions to water flow? Can water availability be changed?
- Topographic position. To what extent does its position affect water-holding capacity (valley or slope, steep or flat, etc.)? Does water come predominantly from groundwater or surface flow? Are soils peaty or mineral, deep or shallow?
- Current condition. Is the soil compacted or eroded? Are there drainage lines or tracks? What weeds are present? Does the vegetation appear healthy? Is the overstorey senescent? What management actions have already occurred? Were management actions successful?

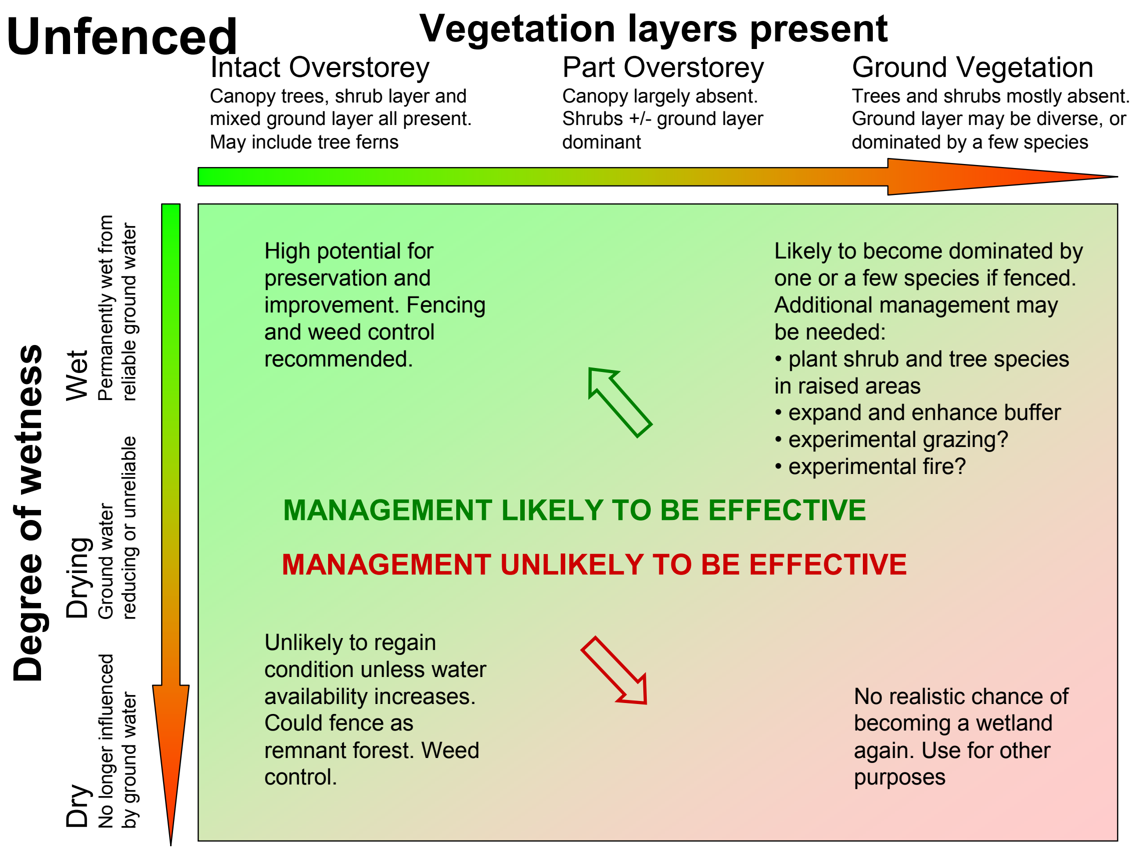

Figure 34. Decision matrix to determine management actions at unfenced sites.

Already fenced

Management issues are similar to those described above, except in this instance the site is already fenced, and vegetation structure and composition may already have changed as a result. These changes, whether positive or negative, can aid management decisions, because they partially remove the estimation otherwise involved. If, for example, fencing has led to a virtual species monoculture, then an alternative approach is clearly needed.

Changes from basic (past and future) management actions, are likely to be dependent on current wetness and structure (Figure 35). Fencing may need to be extended to protect a large enough area to include a range of water regimes to facilitate zonation, either through natural regeneration or via revegetation. The buffer zone around the wetland will also be important.

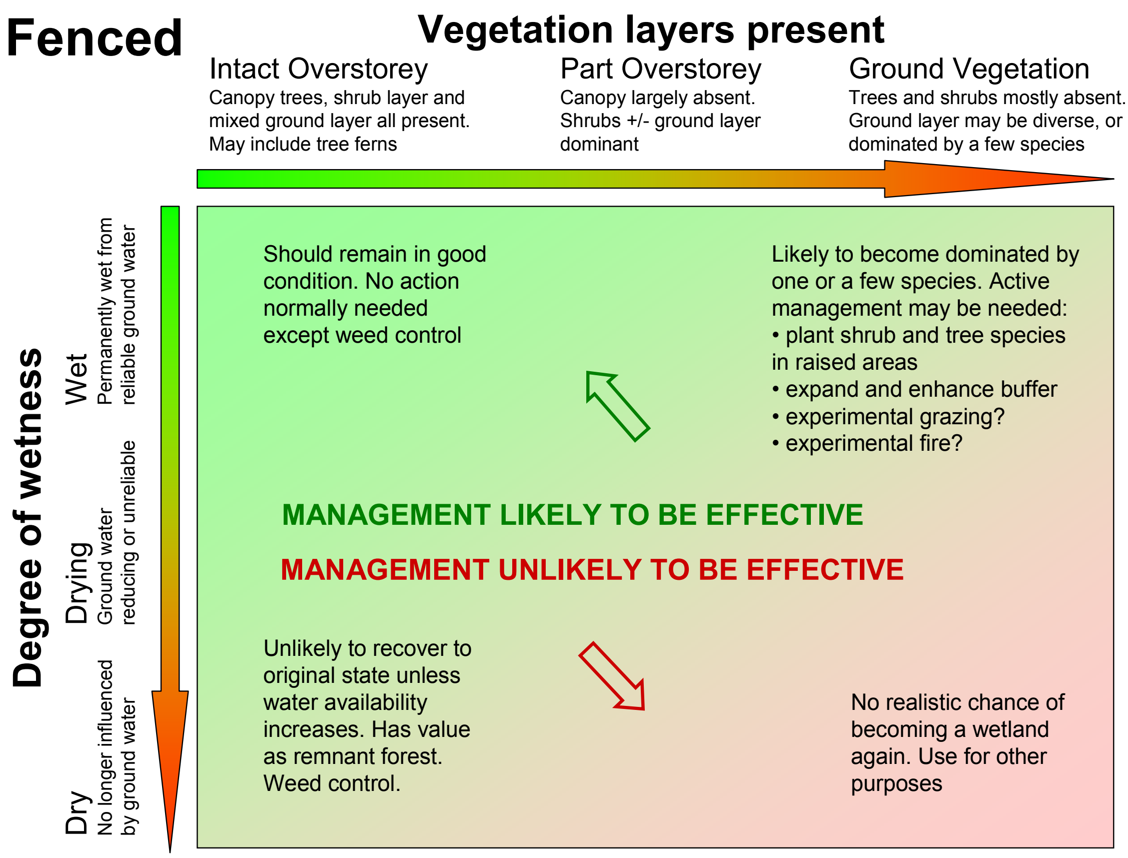

Figure 35. Decision matrix to determine management actions at fenced sites.

4.2 Secondary management recommendations

4.2.1 Loss of species diversity or richness

To reduce the effects of interspecific competition resulting in dominance of some species over others, reduce biomass at some sites — particularly *Baumea* and *Gynoschoenus* sedgelands — by manipulating grazing regimes, slashing or burning. Prevent encroachment of *Phragmites* at some sites, particularly mound springs, by manipulating or maintaining grazing regimes.

4.2.2 Weeds

Weed eradication may be more important in sites subject to higher levels of disturbance and weed cover (which were often at lower altitude in this study), and/or where structural complexity is low. Weed management will not be successful in all cases and it is recommended that priority is given to weeds considered 'high threat' and controlled using known management techniques (e.g. spraying, hand pulling). These are typically blackberry, willow, honeysuckle, thistles and bedstraw. Difficult-to-control weeds typically include pasture species such as *Holcus lanatus*, Sweet Vernal-grass, *Hypochaeris*, *Lotus*, etc. In these cases, manipulating grazing regimes and extending vegetation buffers may help.

4.2.3 Earthworks

Prevent loss of soil moisture through drainage or re-direction of flows, tracks, dams, drains, embankments. Management considerations include depth and extent of excavation and positioning of excavations. Earthworks should be prevented in particular at high-value sites with reliable water. Where earthworks exist, consider restoring site morphology and revegetation.

4.2.4 Reduction in wetland area resulting in fragmentation

To restore connectivity, increase the extent of buffers between remnant wetlands to maximise dispersal and pollination opportunities and the availability of potential habitat for native fauna.

4.2.5 Degradation or clearing of buffers:

Increase buffer perimeter and width by erecting fencing or excluding stock in areas adjacent to wetlands where indigenous species are likely to dominate, with/without supplementary planting where necessary.

4.2.6 Frequency and degree of inundation

It is unlikely that this threat can be effectively managed by landowners. However, reducing excessive extraction from wetlands and managing grazing to prevent soil drying may be of assistance. Some forested sites (particularly those supporting *E. camphora* – A. *melanoxylon* – *Gleichenia microphylla* Swamp Woodland, Group 9) are clearly deteriorating because of a lack of soil water and are in urgent need of rehydration. In these cases, some irrigation or engineering solution may be in order; however, these types of recommendations are beyond the scope of the vegetation study and may be better addressed in the hydrological component of the project (Stewardson and Western in prep).

4.3 Future investigations and knowledge gaps

The results of this study have highlighted a number of management issues that remain to be solved. Foremost among these is the need to develop methods to manage or restore hydrological function and maintain or improve biodiversity in the wetlands in the broader area of the Strathbogie Ranges. We propose that the most effective approach is to adopt an adaptive environmental management framework combining research and action, to (i) define conservation goals and measure progress toward achieving these goals, (ii) develop effective actions, and (iii) implement and test these actions (Salafsky et al. 2002).

This study provides an ideal foundation for the implementation of an adaptive environmental management strategy that could test conservation management actions using a site-based experimental approach (Salafsky et al. 2002). Firstly, the project has identified biodiversity assets, components of ecosystem function, threats and other factors that influence conservation outcomes. Secondly, it has also consulted with individuals, networks and organisations that form a core group of conservation practitioners in the Goulburn Broken catchment. Thirdly, it has developed a decision matrix that can provide a starting point for the further development of conservations actions (approaches, strategies and tools).

We recommend the following further work to address the following management issues, and identification of wetland sites for management trials:

1. Develop methods to replace natural disturbance regimes which have historically prevented over abundance of dominant species, and maintain or increase native species richness. Specifically, the use of fire and manipulated grazing regimes.
2. Develop methods to restore or prevent further loss of groundwater or soil moisture from wetlands.
3. Develop methods to reduce weed cover.
4. Prepare revegetation prescriptions to restore buffers and wetland zonation.
5. Implement experimental fencing and planting trials to measure the structural and compositional response at a range of sites with different morphologies. For example, the extent to which tea-tree regenerates on fenced mound springs compared to slope break communities; reductions in weediness and/or improvements in structural complexity with an increase in buffer quality and extent.

Further research is also required to address the following knowledge gaps and questions:

6. What is the impact on hydrological function or water yield of reinstating the canopy or shrub layers?
7. How do farmers perceive the wetlands and how important to them is ecological integrity?
8. What is the impact of increasing buffer extent on soil water?
9. What is the role of wetlands in filtering water, and does stock exclusion improve water quality?
10. Reconstruction of environmental histories of selected sites to determine fire frequency and the pre-European vegetation of the area as a reference point for site management. Investigations should evaluate to what degree the present systems are likely to be natural or human-induced and what evidence exists to describe past climates.
11. Additional survey work to describe more comprehensively the floristic composition and vegetation zonation at wetland sites and remnant wetland vegetation, and their environmental correlates.
12. Additional survey work to expand and improve the wetland vegetation classification to better understand the distribution and environmental correlates of wetlands on the Strathbogie Plateau and their relationship to Ecological Vegetation Classes.
13. Surveys to determine the importance of the wetlands as habitat for native fauna.
14. Evaluation of buffer quality and value of paddock vegetation surrounding wetlands (improved *vs* unimproved).

15. More detailed investigations to evaluate the role of bores and farm dams in reducing water supply at the site level.
16. Investigation of soil-stored seed banks to better understand the capacity of species to regenerate at a site.

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Appendix 1. Species recorded from spring soak wetlands 2009.

Key: * = introduced species; v = vulnerable in Victoria; r = rare in Victoria but otherwise not considered threatened; k = poorly known but suspected to be threatened

BRYOPHYTES

Sphagnaceae
Sphagnum cristatum
Sphagnum novo–zelandicum
Sphagnum sp.

FERNS
Adiantaceae
Adiantum aethiopicum

Blechnaceae
Blechnum minus
Blechnum nudum

Dennstadiaceae
Histiopteris incisa
Hypolepis amaurorachis
Pteridium esculentum

Dicksoniaceae
Dicksonia antarctica

Dryopteridaceae
Polystichum proliferum

Gleicheniaceae
Gleichenia microphylla

MONOCOTYLEDONS

Centrolepidaceae
Centrolepis aristata

Cyperaceae
Baumea planifolia k
Baumea rubiginosa
Carex appressa
Carex fascicularis
Carex gaudichaudiana
Carex inversa
Cyperus lucidus
Cyperus sanguinolentus
Eleocharis gracilis
Eleocharis sphacelata
Gahnia sieberiana
Gymnoschoenus sphaerocephalus
Isolepis cernua var. *cernua*
Isolepis fluitans
Isolepis habra
Isolepis inundata
Isolepis levynsiana
Isolepis sp.
Isolepis subtilissima
Schoenus apogon
Schoenus maschalinus

Eriocaulaceae
Eriocaulon scariosum r

Iridaceae
Romulea rosea

Juncaceae
**Juncus articulatus*
**Juncus bufonius*
Juncus holoschoenus
Juncus planifolius
Juncus procerus
Juncus sarophorus
Juncus sp.
Luzula meridionalis var. *flaccida*

Juncaginaceae
Triglochin striata

Liliaceae
Arthropodium milleflorum
Burchardia umbellata
Dianella tasmanica
Hypoxis vaginata var. *brevistigma* k
Hypoxis vaginata var. *vaginata*

Lemnaceae
Lemna disperma

Orchidaceae
Chiloglottis vallida
Spiranthes australis
Prasophyllum sp.
Pterostylis falcata
Pterostylis sp.
Thelymitra arenaria
Thelymitra sp.

Poaceae
**Agrostis capillaris* var. *capillaris*
**Anthoxanthum odoratum*
**Briza minor*
**Bromus diandrus*
Austrodanthonia duttoniana
Austrodanthonia sp.
**Cynosurus echinatus*
**Dactylis glomeratus*
Deyeuxia brachyanthera
Deyeuxia quadriseta
Elymus scaber
**Festuca arundinacea*
Glyceria australis
**Glyceria maxima*
Hemarthria uncinata
**Holcus lanatus*
**Lolium perenne*
**Lolium rigidum*
Microlaena stipoides
Notodanthonia semiannularis
Pentapogon quadrifidus
**Phalaris aquatica*
Phragmites australis
**Poa annua*
Poa helmsii
Poa labillardieri var. *labillardieri*
Poa sieberiana
Poa sp.
Poa tenera
Poaceae sp.
Themeda triandra
**Vulpia bromoides*
**Vulpia muralis*

Restionaceae
Lepyrodia anarthria r

Typhaceae
Typha domingensis

Xanthorrhoeaceae
Lomandra longifolia

DICOTYLEDONS

Apiaceae
Centella cordifolia
Hydrocotyle hirta
Hydrocotyle pterocarpa
Hydrocotyle sibthorpioides
Hydrocotyle sp.
Lilaeopsis polyantha

Asteraceae
**Arctotheca calendula*
Brachyscome cardiocarpa
**Carduus tenuiflorus*
Cassinia longifolia
**Cirsium vulgare*
Craspedia paludosa
Euchiton involucratus
**Hypochaeris radicata*
Lagenifera stipitata
Microseris scapigera
Senecio glomeratus subsp.*longifructis*
Senecio minimus
Senecio sp.
**Sonchus asper*
**Soncus oleraceus*
**Taraxacum* sp.

Brassicaceae
Cardamine microthrix v
**Nasturtium officinale*

Callitrichaceae
**Callitriche stagnalis*

Campanulaceae
Isotoma fluviatilis subsp. *australis*
Lobelia surrepens

Caprifoliaceae
**Lonicera japonica*

Caryophyllaceae
**Cerastium glomeratum*
**Moenchia erecta*
Stellaria angustifolia
**Stellaria media*
**Stellaria pallida*

Clusiaceae
Hypericum japonicum

Convolvulaceae
Dichondra repens

Crassulaceae
Crassula decumbens var. *decumbens*

Droseraceae
Drosera peltata subsp. *peltata*

Epacridaceae
Epacris breviflora
Epacris impressa
Epacris paludosa

Euphorbiaceae
Poranthera microphylla

Fabaceae
Almaleea subcapitata
Bossiaea cordigera r
Dillwynia glaberrima
Hovea heterophylla
Mirbelia oxylobioides
**Lotus corniculatus*
**Trifolium dubium*
**Trifolium repens* var. *repens*
**Trifolium* sp.

Gentianaceae
**Centaurium erythraea*

Geraniaceae
Geranium potentilloides var. *potentilloides*

Goodeniaceae
Goodenia elongata

Haloragaceae
Gonocarpus micranthus
Gonocarpus montanus
Gonocarpus tetragynus

Lamiaceae
Ajuga australis
Mentha laxiflora
**Prunella vulgaris*

Lauraceae
Cassytha melantha

Lentibulariaceae
Utricularia dichotoma

Loranthaceae
Amyema pendula subsp. *pendula*
Amyema quandang var. *quandang*

Lythraceae
Lythrum hyssopifolium

Mimosaceae
Acacia dealbata
Acacia melanoxylon
Acacia pravissima

Myrtaceae
Baeckea utilis
Eucalyptus camphora subsp. *humeana*
Eucalyptus globulus
Eucalyptus radiata
Leptospermum continentale
Leptospermum lanigerum

Onagraceae
Epilobium billardierianum subsp. *billardierianum*
Epilobium billardierianum subsp. *hydrophilum*
Epilobium billardierianum subsp. *cinereum*
Epilobium gunnianum
Epilobium pallidiflorum
Epilobium sp.
**Ludwigia palustris*

Oxalidaceae
Oxalis perennans
Oxalis sp.

Polygalaceae
Comesperma retusum

Polygonaceae
**Acetosella vulgaris*
Persicaria praetermissa
**Rumex crispus*

Portulaceae
Montia fontana subsp. *amporitana* k

Primulaceae
**Anagallis arvense*

Ranunculaceae
Ranunculus amphitrichus
Ranunculus glabrifolius
**Ranunculus repens*

Rosaceae
Acaena agnipila
Acaena novae–zelandiae
**Aphanes arvensis*
**Rosa rubiginosa*
**Rubus laciniatus*
Rubus parviflorus
**Rubus fruticosus* spp. agg.

Rubiaceae
Asperula gunnii
Asperula sp.
Asperula subsimplex
Coprosma quadrifida
**Galium aparine*
Galium australe
Galium binifolium
Galium propinquum
Galium sp.

Appendix 2. Examples of vegetation groups and floristic composition

Group 1. *Phragmites australis* Reedland

Site: Read property, Caveat area.

Site: Leunig property, Strathbogie area.

Group 1. Distribution of the most 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%.

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

Site: Habbie's Howe, Highlands area.

Site: Puden property, Terip area.

Group 2. Distribution of the most 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%.

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 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

Site: Chandon property, Strathbogie area.

Site: Rouget property, Strathbogie area.

Group 3. Distribution of the most 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%.

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

Site: Strong property, Dropmore area.

Site: Renfree property, Terip area.

Group 4. Distribution of the most 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%.

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

Site: Vasselet property, Strathbogie area.

Site: Brook property, Strathbogie area.

Group 5a. Distribution of the most 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%.

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

Site: State forest, Strathbogie area.

Group 5b. Distribution of the most 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%.

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

Site: N. Lade property, Highlands area.

Site: State forest, Strathbogie area.

Group 5c. Distribution of the most 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%.

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 billardieri*anum	1000
Epilobium hydrophilum	1000
Eucalyptus camphora	0500
Galium australe	0121
Geranium potentilloides	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
Epilobium sp.	0011

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

Site: Law property, Strathbogie area.

Site: Law property, Strathbogie area.

Group 6. Distribution of the most 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%.

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 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 novo-zelandicum	000100

Group 7a. *Eucalyptus camphora* Swamp Woodland

Site: S. McAlpin property, Highlands area.

Site: Leunig property, Strathbogie area.

Group 7a. Distribution of the most 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%.

Eucalyptus camphora	44001223205020
Acacia melanoxylon	01000200001110
Leptospermum continentale	22001000111110
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	00001100010100
Epilobium 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

Site: Crittendon property, dominated by *Baumea rubiginosa*, Highlands area.

Site: Hagen property, dominated by *Baumea planifolia*, Ruffy.

Group 7b. Distribution of the most 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%.

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	02100001
Epilobium 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

Site: D. and P. Lade property, Highlands.

Site: Strong property, Dropmore.

Group 8. Distribution of the most 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%.

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	00001
Epilobium 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 microphylla* Swamp Woodland

Site: R. McAlpin property, Highlands area.

Site: Hagen property, Ruffy.

Group 9. Distribution of the most 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%.

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

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