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RESEARCH PAPER

Montane mire vegetation of the New England Tablelands Bioregion of Eastern Australia

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Abstract

Aims: To use unsupervised techniques to produce a hierarchical classification of montane mires of the study region. **Study area:** New England Tablelands Bioregion (NETB) of eastern Australia. **Methods:** A dataset of 280 vascular floristic survey plots placed across the variation in montane mires of the NETB was collated. Vegetation types were identified with the aid of a clustering method based on group averaging and tested using similarity profile analysis (SIMPROF) and through ordinations using Bray-Curtis similarity and non-metric multidimensional scaling (NMDS). A hierarchical schema was developed based on EcoVeg hierarchy and was circumscribed using positive and negative diagnostic taxa via similarity percentage analysis (SIMPER) and importance based on summed cover scores and frequency. **Results:** We defined one macrogroup to include all montane mire vegetation of the NETB and within these two groups and twelve alliances. **Conclusions:** Our study re-enforced the separation of bogs from other montane mire systems and confirmed the separation of fens and wet meadows, a distinction that previously had not been independently tested. Based on our results many existing montane mire communities of the NETB have been ill-defined at multiple hierarchical levels, leading to confusion in threat status and mapping. Additionally, nearly half of the alliances we recognise were found to have no correlates within current classification systems, which necessarily has implications for the effectiveness of current conservation planning.

Taxonomic reference: PlantNET (http://plantnet.rbgsyd.nsw.gov.au/, accessed June 2016).

Abbreviations: BC Act = Biodiversity Conservation Act; EPBC Act = Environmental Protection and Biodiversity Act; NETB = New England Tablelands Bioregion; NMDS = non-metric multidimensional scaling; PCT = plant community type; RE = regional ecosystem; SIMPER = similarity percentage analysis; SIMPROF = similarity profile analysis.

Keywords

Australia, bog, EcoVeg, fen, marsh, New England Tableland Bioregion, similarity percentage analysis (SIMPER), wet meadow, unsupervised classification

Introduction

The first step in understanding the distribution, rarity and interrelationships of vegetated systems is description and classification (Franklin et al. 2016; Jensen et al. 2016). This is particularly true for systems that are under greatest threat and impact from human activities and which provide significant ecosystem services. Unfortunately, vegetation within many areas of the globe have poor survey coverage and/or inconsistent survey protocols, leading to insufficient or poor data hampering classification (Gellie et al. 2017; De Cáceres et al. 2018). Even within areas considered relatively well surveyed, many highly restricted and/or ephemeral systems are likely to be poorly sampled and incompletely treated within current classification systems, leading to misunderstandings of their placement, function, importance and rarity (Hunter and Hunter 2017; Hunter and Lechner 2017). Not all classification systems are hierarchical in nature, and many have no clear analytical proof of conceptual links (De Cáceres et al. 2018; Gellie et al. 2017). Ideally, hierarchical classification systems facilitate integrated understanding of relationships between vegetation assemblages and also allow conceptualisations at different ranks to match scales at which management and investigations may be applied, from local to global (Faber-Langendoen et al. 2018).

Australia is a dry continent, and thus, the more common and widely distributed wetlands are those that are impermanent in nature; that is, they may 'wet-up' once a year, multiple times a year or once within several decades, often not associated with seasonal patterns, but are dry more often than they are wet (Paijmans et al. 1985; Bell et al. 2008; Bell et al. 2012; Hunter and Lechner 2017). Such wetlands may contain shallow water less than 2 m depth, but more commonly only have saturated soils or seasonally standing water a few centimetres depth. Montane areas within Australia are limited and thus montane wetlands, in particular, are sparsely distributed and rare within the continent and poorly sampled across their range (Wahren et al. 1999; Whinam and Hope 2005).

The montane region bordering northern New South Wales and south east Queensland has been defined as the New England Tableland Bioregion (NETB) based on its unique biological and environmental elements (Thackwell and Creswell 1995). The Hunter Valley to the south of the NETB creates a break in the Great Dividing Range and separates the NETB from more southern montane environments in south eastern Australia. Within the NETB a number of semi-permanent and ephemeral mire systems locally known as bogs, fens, lagoons (marshes) and sod tussock grasslands (wet meadows) occur (Hunter and Bell 2007; 2009; Bell et al. 2008; Hunter and Hunter 2016a). Whinam and Chilcott (2002) showed through unsupervised analyses of floristic plots that the NETB bogs were dissimilar floristically from other montane bogs further south in eastern Australia. Hunter and Hunter (2016) also highlighted the distinct floristic differences between montane sod tussock grasslands (wet meadows) and those of other south eastern Australian montane districts. Lechner et al. (2016), in an analysis of environmental data associated with montane wetlands, found the NETB was largely encompassed by a unique montane wetland ecoregion.

Bogs of the NETB are characterised by altitudes above 850 m a.s.l, commonly on nutrient poor sites with low pH, saturation occurring seasonally or sporadically, and shallow standing water infrequent (Hunter and Bell 2007) (Suppl. material 1: Plate 1). Peat often forms but is largely created by sedge debris and at times *Sphagnum* (Hunter and Bell 2007; Hunter and Bell 2013; Hunter 2016a). Due to frequent fires, peat accumulation is often thin but can develop to depth where fires are excluded for long periods of time (Hunter and Bell 2007). These systems are largely dominated by cyperaceous taxa with a distinct component of woody shrubs species usually 0.5–1.5 m in height (*Myrtaceae*, *Fabaceae*, *Proteaceae* and *Ericaceae*) (Hunter and Bell 2007).

Fens within the NETB are found along watercourses and flat to concave valley floors generally associated with mineral rich substrates (Hunter and Bell 2009) (Suppl. material 1: Plate 1). Fens are dominated by softer leaved sedges, grasses and herbs and do not have a woody shrub component within the NETB (Hunter and Bell 2009). Peat accumulation can occur but is largely based on cyperaceous materials and soil pH is slightly acidic to neutral. Overall fens are far more common within the NETB but are much less common within the national reserve system (Hunter 2013).

Lagoons within the NETB may be best described as semi-permanent or ephemeral marshes (Bell et al. 2008) (Suppl. material 1: Plate 1). Unlike the other wetlands they are generally oval in shape and are distinguished by having a well-defined bank with a sandy lunette on their downwind shores formed under previous climatic conditions (Bell et al. 2008). Only 58 of these ephemeral marshes are known within the NETB and these are restricted to the top of the Great Dividing Range almost exclusively on basalt soils (Bell et al. 2008). Ephemeral marshes differ in depth and duration of inundation but water, when present, is less than 1.5 m deep and never persistent. The lagoons have very localised catchments often only a few hundred hectares in size or less and thus inundation is often unpredictable and reliant on very localised rainfall often unrelated to regional rainfall averages or season. Due to longer and deeper inundation, the ephemeral marshes, unlike the other wetland systems on the NETB, can support free floating and aquatic vegetation usually >20% vegetation cover (Bell et al. 2008; Hunter 2016a).

The sod tussock grasslands would likely be classed as spring fed and floodplain wet meadows within the mire classification (van Diggelen et al. 2006; Hunter and Hunter 2016) (Suppl. material 1: Plate 1). Wet meadows of the NETB occur within lower physiographic positions and frost hollows generally on higher nutrient soils which are seasonally damp or inundated with a few centimetres of water (Hunter and Hunter 2016).

Within the state of New South Wales, vegetation has been described into units called plant community types (PCTs), which are considered an equivalent to an association level of nomenclature (Benson et al. 2010) and used to assign conservation significance and threat. PCTs are based on a mixture of supervised and semi-supervised techniques (Gellie et al. 2017), and they have been subsequently placed within an independently derived hierarchical system of classes and formations (Keith 2004). As these classes and formations are circumscribed largely by supervised methods, and independently from PCTs, the interrelationships between the two systems and thus the placement of PCTs within formations and classes has been achieved by expert opinion without independent statistical testing (Gellie et al. 2017). The circumscription of associations within mires of the NETB have been either poor, misinterpreted, inconsistent or missed entirely within state-based vegetation classifications (Hunter and Bell 2007; 2009; Hunter and Hunter 2016). For instance, though Groves (1981) described a *Glyceria australis* wet grassland, no such PCT has been formally included in summaries of vegetation types for the NETB by Benson et al. (2010), nor wet meadows been included within state wide classes and formations (Keith 2004). Only four PCTs currently circumscribe the range of fens, bogs and lagoons found within the NETB (Benson et al. 2010).

Currently within certain Australian jurisdictions the development of vegetation community types is based almost solely on floristic classification techniques with little or no influence of environmental factors, although types may contain environmental terms as descriptors secondarily to floristics (Sivertsen 2009; Environmental Protection Authority 2016; Gillie et al. 2018). Although this has not always been the case due to poor plot data coverage within New South Wales, any new proposed associations need proof of floristic distinctiveness via unsupervised analyses. Floristic distinctiveness via unsupervised analysis is now a requirement that also applies for listings of threatened ecological communities on both the Federal *Environmental Protection and Biodiversity Act* and the New South Wales *Biodiversity Conservation Act*. Thus, currently for both general classification purposes and for endangered community listings floristic distinctiveness by analysis is removed from ecological distinctiveness and is generally the only method of recognition of types.

A concerted and comprehensive effort has been placed on plot-based sampling of the montane wetlands of the NETB in order to describe phytosociological units through unsupervised means (Bell et al. 2008; Hunter and Bell 2007; 2009; Hunter and Hunter 2016). Using the plot-based data and unsupervised floristic analyses, these studies describe 28 phytosociological assemblages equivalent to associations (Hunter and Bell 2007; Bell et al. 2008; Hunter and Bell 2009; Hunter and Hunter 2016). The majority of these associations are not encompassed within formal PCTs (Benson et al. 2010) and many are difficult to place within current published classes and formations (Keith 2004). However, these recent investigations into NETB mires have been conducted in isolation of each other and there is a need to provide an understanding of their interrelationships and to formally place them within an unsupervised hierarchy. Here we provide a plot-based analysis of mire assemblages within the NETB, to provide a formal understanding of the floristic relationships between the types and derive from analysis a hierarchical classification above that of association for the mires within the NETB.

Methods

Study area

The study region encompasses the New England Tablelands Bioregion (NETB; 30,000 km^2; Figure 1) which lie on the Great Dividing Range in eastern Australia. The NETB is largely restricted to north-east New South Wales but extends into south eastern Queensland with altitudes ranging from 700 to 1500 m a.s.l. The region has a strong west-east rainfall gradient (600–2500 mm) with easterly airflows from the Pacific Ocean causing orographic influences in the east (Resource and Conservation Assessment Council 1996).

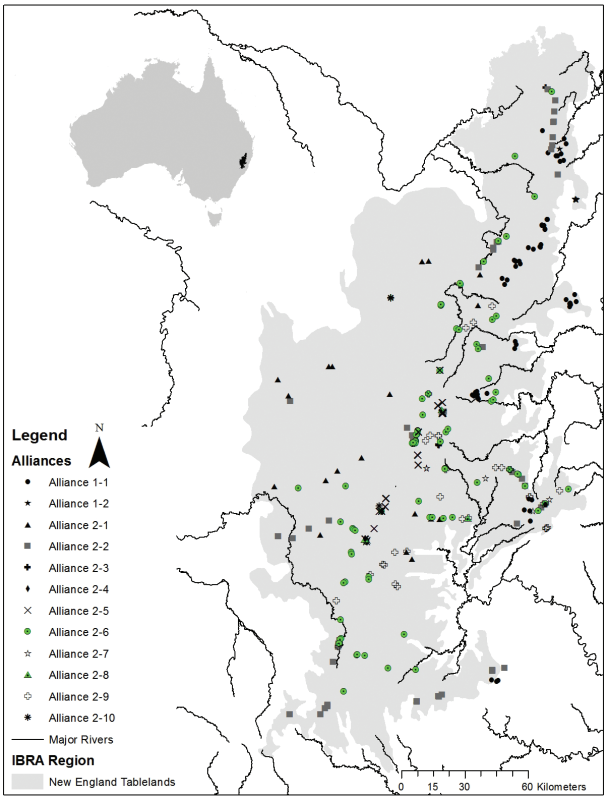

Figure 1. Location of the New England Tablelands Bioregion within Australia and location of 280 full vascular floristic survey plots.

Field sampling

Data from 280 full vascular floristic survey plots were collated from wetlands within the NETB. The plots were sampled on public lands, where possible first preference was to occurrences within state conservation reserves and secondarily within private reserves or travelling stock reserves. Conservation reserves are un-grazed by non-native animals while travelling stock reserves are only periodically grazed by non-native animals with grazing regulated by state government authorities. Thus non-native animal grazing was absent or minimal and tightly controlled. Standard plot sizes were 20 m × 20 m. Species were scored using a six-point modified Braun-Blanquet system based on percentage foliage cover (Westhoff and van der Maarel 1980): 1= 1–5% cover, uncommon; 2 = 1–5% cover, common; 3 = 6–25%; 4 = 26–50%; 5 = 51–75% and 6 = >75%. Plots where placed across the study area over a ten-year period between 2008 and 2018 within spring and summer. All plots were scored for general wetland type (bog, fen, sod grassland, lagoon), and location and altitude were based on global positioning system (GPS). All plot data has been submitted for hosting in version 3 of sPlot (Bruelheide et al. 2019; https://www.idiv.de/?id=176&L=0) and is listed on GIVD as AU-AU-003 (https://www.givd.info/databases.xhtml). No new data has been collected for this research with only existing data collected by the authors and previously published separately being used (see Hunter and Bell 2007; Bell et al. 2008; Hunter and Bell 2009; Hunter and Hunter 2016; Hunter 2018). Further details of the wetland types investigated, stratification and how data was collected for each survey is contained within these previous publications including information on species richness, elevation, vegetation cover and height, synoptic tables and photographs for each defined association.

Statistical analysis

Primer E (ver. 7.0.11; Quest Research Limited; Ivybridge, Devon, UK) was used for data exploration, whereby an initial triangular resemblance matrix using Bray-Curtis similarity co-efficient was created without transformation, as the Braun-Blanquet scoring was considered a pre-treatment. Non-metric multidimensional scaling (NMDS) in two and three dimensions was also created. Clustering was achieved through group averaging and the similarity profile tested using similarity profile analysis (SIMPROF) permutation tests (999 iterations). SIMPROF tests the statistical significance of every node within a dendrogram starting from the top of the dendrogram and (all points within a single group) and highlighting only those groups which show within group multivariate structure. The EcoVeg approach (Faber-Langendoen et al. 2014) was used to define hierarchical levels and guide the nomenclatural of the types. The type and density of data available allowed for the circumscription of vegetation types at the medial scales of group and alliance with associations derived from previous published analyses of the same data.

Similarity percentage analysis (SIMPER) identifies the species driving differences between selected types. SIMPER uses the Bray–Curtis similarity measure (Primer E ver. 7.0.11; Quest Research Limited; Ivybridge, Devon, UK) to identify positively and negatively diagnostic taxa across vegetation types. Taxa with combined high fidelity and cover were also identified and listed for diagnostic purposes and type delineation. Attempts to place current eastern Australian state based noncultural units was derived by comparing diagnostic and non-diagnostic taxa from SIMPER results.

The results of our analyses were used to define mid to lower level classification levels (macrogroup, group and alliance) based on EcoVeg terminology. It should be noted that although EcoVeg uses the alliance and association as does the Braun-Blanquet approach, the nomenclatural and procedural roles are distinct. Previous unsupervised cluster analyses using Kulzynski similarity measure have been performed and published on subsets of these datasets defining vegetation units at approximately the association level (see Hunter and Bell 2007; Bell et al. 2008; Hunter and Bell 2009; Hunter and Hunter 2016; Hunter 2018). It is the intention of this analysis to define hierarchical levels above association using the combined datasets from these previous investigations.

Results

Collectively, all mires within the NETB were defined as NETB montane mires (Level 5 – macrogroup) (Table 1). Our analyses support the separation of bogs, fens and wet meadows as broadly distinct units (Figures 2–4). Plots sampled within ephemeral marshes did not form a consistent group in either 2 or 3 axis results and were distributed throughout the non-bog plots (Figures 2–4). Both SIMPROF cluster analysis and NMDS ordination highlight a clear separation of bogs from that of the other types of mires within the NETB (Figures 2, 3). Bogs are floristically and often structurally distinct, being the only mire type on the NETB with a prominent shrub layer (Figure 5, Table 1). This high-level separation is considered appropriate for delineating at Level 6 – Group and thus two groups have been delineated; *Baeckea omissa – Lepidosperma limicola* NETB montane bog mires and *Glyceria australis – Carex gaudichaudiana* NETB fen, wet meadow and ephemeral marsh mires (Table 1).

Splicing the dendrogram at a similarity of 16, we further defined 12 alliances all of which are delineated at a level which shows statistical evidence of multivariate structure via SIMPROF (Figure 2; Suppl. material 1), two within the *Baeckea omissa – Lepidosperma limicola* NETB montane bogs and 10 within the *Glyceria australis – Carex gaudichaudiana* NETB fen, wet meadow and ephemeral marsh mires (Table 2). General environmental data and average species richness is given in Table 3 while the percent frequency of occurrence synoptic results of the most frequent taxa are presented in Table 4 (full table in Suppl. material 2).

A comparison of the placement of NETB montane mires with the currently published classification systems (PCT, class, formation, RE) shows only some congruence with our results (Table 2). The NETB montane mires would be placed within two formations and at least three class categories with some types unable to be clearly assigned. Seven of our 12 Alliances are not adequately circumscribed by current PCTs within New South Wales. Only one Queensland Regional Ecosystem (RE) describes montane mires within the NETB and this unit may cover three of our alliances, leaving three that are known to occur in this jurisdiction but uncategorized.

Discussion

We have successfully applied a consistent classification section to montane mire vegetation within the NETB using unsupervised techniques which have highlighted a number of differences with the current classifications used within eastern Australia. Although the EcoVeg approach

Table 1. Circumscription of mires of the New England Tableland Bioregion (NETB) of eastern Australia. Descriptions include positive and negative diagnostic and negatively associated species, common dominant taxa (based on cumulative frequency and cover) and notes for each unit. Positive diagnostic species are listed in order of decreasing contribution to group identity. Common taxa are listed in decreasing order of cumulative frequency and cover within each identified group.

Hierarchy	Positive diagnostic (SIMPER)	Negative diagnostic (SIMPER)	Common taxa	Notes and distribution
Macrogroup: Scientific Name: *Baeckea – Carex - Glyceria* mires. Colloquial: New England Tableland montane mires	*Baeckea omissa*, *Glyceria australis*, *Leptospermum gregarium*, *Carex gaudichaudiana*	NA	NA	Restricted to the NETB commonly at altitudes above 800 m and rainfall above 700 mm per annum
Group 1: Scientific Name: *Baeckea omissa – Lepidosperma limicola* New England Tableland montane bog mires	*Baeckea omissa*, *Epacris microphylla*, *Leptospermum gregarium*, *Gonocarpus micranthus*, *Goodenia bellidifolia*, *Baloskion stenocoleum*, *Lepidosperma limicola*, *Callistemon pityoides*, *Hakea microcarpa*, *Entolasia stricta*	*Glyceria australis*, *Carex gaudichaudiana*, *Carex appressa*, *Poa sieberiana*, *Pennisetum alopecuroides*, *Epilobium billardierianum*, *Stellaria angustifolia*	*Baeckea omissa*, *Epacris microphylla*, *Baloskion stenocoleum*, *Lepidosperma limicola*, *Goodenia bellidifolia*, *Leptospermum gregarium*, *Gonocarpus micranthus*, *Lepyrodia scariosa*, *Leptospermum arachnoides*, *Callistemon pityoides*	Commonly found on nutrient poor sites with low pH. Often with a prominent shrub layer and forming a peat layer. Often on granite, acid volcanic and metasedimentary rock types
Alliance 1-1: Scientific Name: *Baeckea omissa – Epacris microphylla* shrubby bog	*Baeckea omissa*, *Epacris microphylla*, *Leptospermum gregarium*, *Gonocarpus micranthus*, *Goodenia bellidifolia*, *Baloskion stenocoleum*, *Lepidosperma limicola*, *Callistemon pityoides*, *Hakea microcarpa*, *Entolasia stricta*	*Aristida jerichoensis*, *Comesperma retusum*, *Schoenus brevifolius*, *Caustis flexuosa*, *Tricostularia pauciflora*, *Eragrostis elongata*, *Melichrus procumbens*	*Lepidosperma limicola*, *Baeckea omissa*, *Thelionema caespitosa*, *Drosera binata*, *Caustis flexuosa*, *Tricostularia pauciflora*, *Schoenus brevifolius*, *Geranium solanderi*	Commonly found along the entire eastern half of NETB in higher rainfall areas. Structurally a shrubby sedgeland or sedgeland
Alliance 1-2: Scientific Name: *Lepidosperma gunnii – Lepidosperma limicola* herbaceous bog	*Lepidosperma gunnii*, *Comesperma retusum*, *Aristida jerichoensis*, *Caustis flexuosa*, *Dampiera stricta*, *Thelionema caespitosa*, *Austrostipa pubescens*	*Callistemon pityoides*, *Baloskion stenocoleum*, *Hakea microcarpa*	*Lepidosperma limicola*, *Xyris operculata*, *Lepyrodia scariosa*, *Drosera binata*, *Drosera spatulata*, *Baloskion fimbriatum*, *Amphibpogon strictus*, *Thelionema caespitosum*, *Caustis flexuosa*	Generally restricted to the higher rainfall extreme north east of the NETB. Sometimes with a dominant shrub layer. Structurally a sedgeland or shrubby sedgeland
Group 2: Scientific Name: *Glyceria australis – Carex gaudichaudiana* New England Tableland fen, wet meadow and ephemeral marsh mires	*Glyceria australis*, *Carex gaudichaudiana*, *Juncus australis*, *Carex appressa*, *Poa sieberiana*, *Geranium solanderi*, *Pennisetum alopecuroides*	*Baeckea omissa*, *Lepidosperma limicola*, *Leptospermum gregarium*, *Gonocarpus micranthus*, *Goodenia bellidifolia*, *Lepyrodia scariosa*, *Callistemon pityoides*, *Entolasia stricta*, *Xyris complanata*, *Banksia spinuolsa*, *Epacris obtusifolia*, *Xyris operculata*	*Glyceria australis*, *Carex gaudichaudiana*, *Carex appressa*, *Poa sieberiana*, *Geranium solanderi*, *Pennisetum alopecuroides*, *Juncus australis*, *Carex disticha*, *Epilobium billardiarianum*, *Isachne globosa*, *Stellaria angustifolia*, *Themeda triandra*	Commonly found nutrient rich sites with moderate to high pH. Shrubs rarely present and dominated by sedges, grasses and forbs. Usually restricted to basalt or higher nutrient metasediment rock types. Often forming a peat layer
Alliance 2-1: Scientific Name: *Carex appressa* herbaceous fen	*Carex appressa*	*Myriophyllum variifolium*, *Lachnagrostis filiformis*, *Eleocharis acuta*, *Paspalum distichum*, *Amphibromus sinuatus*, *Ottelia ovalifolia*, *Potamogeton tricarinatus*, *Amphibromus pithogastrus*, *Isolepis fluitans*	*Carex appressa*, *Carex gaudichaudiana*, *Eleocharis acuta*, *Geranium solanderi*, *Stellaria angustifolia*, *Pennisetum alopecuroides*, *Juncus australis*, *Haloragis heterophylla*, *Epilobium billardiarianum*	Commonly found on medial to lower rainfall areas of the NETB within central and western areas. A sedgeland
Alliance 2-2: Scientific Name: *Carex gaudichaudiana – Isachne globosa* herbaceous fen	*Carex gaudichaudiana*, *Isachne globosa*, *Epilobium billardierianum*, *Stellaria angustifolia*, *Geranium solanderi*, *Cyperus sphaeroideus*	*Isachne globosa*, *Scrirpus polystachyus*, *Viola caleyana*, *Lycopus australis*, *Baloskion stenocoleum*, *Lythrum salicaria*	*Carex gaudichaudiana*, *Isachne globosa*, *Epilobium billardierianum*, *Stellaria angustifolia*, *Geranium solanderi*, *Carex appressa*, *Scripus polystachyus*, *Carex disticha*, *Lythrum salicaria*, *Cyperus sphaeroideus*, *Baumea planifolia*	More commonly found within higher rainfall areas of the NETB, particularly in the eastern half. A sedgeland

Hierarchy	Positive diagnostic (SIMPER)	Negative diagnostic (SIMPER)	Common taxa	Notes and distribution
Alliance 2-3: Scientific Name: *Philydrum lanuginosum – Potamogeton tricarinatus* herbaceous ephemeral marsh and fen	*Philydrum lanuginosum – Potamogeton tricarinatus, Cynodon dactylon, Cardamine paucijuga, Persicaria elatior, Lythrum salicaria*	*Lachnagrostis filiformis, Eleocharis acuta, Eleocharis gracilis, Paspalum distichum, Hydrocotyle tripartita, Glyceria australis.*	*Eleocharis pusilla, Cynodon dactylon, Myriophyllum variifolium, Philydrum lanuginosum, Potamogeton tricarinatus, Lythrum salicaria.*	Found often on wet mud and retreating lagoon margins and around the margins of more permanent sedgeland on the edge of lagoons.
Alliance 2-4: Scientific Name: *Lachnagrostis filiformis* herbaceous wet meadow or marsh	*Lachnagrostis filiformis*	*Myriophyllum variifolium, Eleocharis acuta, Eleocharis gracilis, Paspalum distichum, Hydrocotyle tripartita, Glyceria australis, Ranunculus inundatus*	*Lachnagrostis filiformis, Cyperus gunnii, Geranium solanderi, Rumex brownii*	Found on wet mud associated with retreating lagoon margins. Often very weedy. A sedgeland or herbfield
Alliance 2-5: Scientific Name: *Myriophyllum variifolium – Eleocharis acuta* herbaceous ephemeral marsh	*Myriophyllum variifolium, Eleocharis acuta, Lachnagrostis filiformis, Hydrocotyle tripartita, Eleocharis gracilis, Ranunculus inundatus, Paspalum distichum, Glyceria australis, Juncus australis, Eleocharis sphacelata, Isotoma fluviatilis*	*Carex appressa, Isachne globosa, Carex gaudichaudiana, Carex disticha, Lythrum salicaria*	*Myriophyllum variifolium, Glyceria australis, Eleocharis dietrichiana, Eleocharis sphacelata, Eleocharis acuta, Eleocharis gracilis, Potamogeton tricarinatus, Panicum obseptum, Nymphoides geminata, Eleocharis pusilla, Lachnagrostis filiformis, Amphibromus nervosus, Ranunculus inundatus, Nymphoides montana*	Almost exclusively found on basalt substrates at the top of the Great Dividing Range within the central areas of the NETB. Primarily restricted to ephemeral lagoons. A herbfield or sedgeland
Alliance 2-6: Scientific Name: *Glyceria australis* grassy wet meadow	*Glyceria australis*	*Gonocarpus micranthus, Hypericum japonicum, Themeda triandra*	*Glyceria australis, Pennisetum alopecuroides, Geranium solanderi, Carex disticha, Carex gaudichaudiana, Poa sieberiana, Lachnagrostis filiformis*	Found throughout but more common within central areas of the NETB. A wet tussock grassland
Alliance 2-7: Scientific Name: *Juncus australis – Cenchrus purpurascens* herbaceous wet meadow	*Juncus australis*	*Carex tereticaulis, Dianella longifolia, Veronica gracilis, Hydrocotyle laxiflora*	*Juncus australis, Carex disticha, Pennisetum alopecuroides, Ranunculus lappaceus, Lotus uliginosus, Gonocarpus micranthus, Carex gaudichaudiana, Glyceria australis, Poa sieberiana*	Found in open cold air drainage areas often on the margins of damper wet meadows and on the upper margins of lagoons. A rushland, herbfield or wet tussock grassland
Alliance 2-8: Scientific Name: *Carex tereticaulis – Asperula conferta* herbaceous wet meadow and fen	*Asperula conferta, Carex tereticaulis, Hydrocotyle laxiflora*	*Themeda triandra, Schoenus apogon, Glyceria australis, Haloragis heterophylla, Carex appressa*	*Carex tereticaulis, Asperula conferta, Hydrocotyle laxiflora, Geranium solanderi, Dianella longifolia, Veronica gracilis, Ranunculus lappaceus, Poa sieberiana, Pennisetum alopecuroides, Carex gaudichaudiana*	Found on sandy soils sometimes associated with the drier margins of lagoons or around drier margins of wetter meadows. A wet tussock grassland or fen
Alliance 2-9: Scientific Name: *Poa sieberiana – Themeda triandra* grassy wet meadow	*Poa sieberiana, Themeda triandra, Pennisetum alopecuroides, Schoenus apogon, Haloragis heterophylla*	*Carex gaudichaudiana, Cyperus gunnii, Glyceria australis, Carex tereticaulis, Daucus glochidiatus, Viola hederacea, Caesia calliantha*	*Eleocharis atricha, Leptorhynchos squamatus, Juncus subsecundus, Hydrocotyle tripartita, Sporobolus creber, Calotis scapigera, Pennisetum alopecuroides, Schoenus apogon, Dichelachne macrantha, Carex inversa*	Found in cold frost drainage valley floors that are periodically damp and around the margins of wetter meadows such as Alliance 2-6 and lagoon margins. A wet tussock grassland
Alliance 2-10: Scientific Name: *Leptorhynchos squamatus – Schoenus apogon* herbfield	*Leptorhynchos squamatus, Schoenus apogon*	*Carex tereticaulis, Asperula conferta, Hydrocotyle laxiflora, Dianella longifolia, Geranium solanderi, Carex gaudichaudii. Veronica gracilis*	*Eleocharis atricha, Leptorhynchos squamatus, Juncus subsecundus, Hydrocotyle tripartita, Sporobolus creber, Calotis scapigera, Pennisetum alopecuroides, Schoenus apogon, Dichelachne macrantha, Carex inversa*	Found restricted to lagoons that are largely dry for extended periods and often only become damp rather than inundated. A herbfield or wet tussock grassland

Table 2. Comparison with existing hierarchical classifications within eastern Australia. Plant Community Types (PCT), class and formation are part of the current New South Wales vegetation classification schema and Regional Ecosystems are what are the Queensland equivalent of association.

Hierarchy	PCT (Benson et al. 2010)	Class (Keith 2004)	Formation (Keith 2004)	Regional Ecosystem (Sattler and Williams (1999)
Macrogroup: New England Tableland montane mires	NA	Temperate Montane Grasslands; Montane Bogs and Fens; Montane Lakes	Grasslands; Freshwater Wetlands	NA
Group 1: *Baeckea omissa – Lepidosperma limicola* New England Tableland montane bog mires	NA	Montane Bogs & Fens	Freshwater Wetlands	Regional ecosystem 13.12.7 – Sedgeland along small drainage lines and soaks at high altitude
Alliance 1-1: *Baeckea omissa – Epacris microphylla* shrubby bog	PCT 607: Montane bogs (in part); 518: Heath swamps wetland on leucogranite and granite (not in Benson et al. 2010)	Montane Bogs & Fens	Freshwater Wetlands	Regional ecosystem 13.12.7 – Sedgeland along small drainage lines and soaks at high altitude
Alliance 1-2: *Lepidosperma gunnii – Lepidosperma limicola* herbaceous bog	PCT 582: Sedgeland fens wetland of impeded drainage	Montane Bogs and Fens	Freshwater Wetlands	NA
Group 2: *Glyceria australis – Carex gaudichaudiana* NETB fen, wet meadow and ephemeral marsh mires	No equivalent	Temperate Montane Grasslands	Grasslands	No equivalent
Alliance 2-1: *Carex appressa* herbaceous fen	PCT: 574 Tea-tree riparian shrubland/heathland wetland	Montane Bogs and Fens	Freshwater Wetlands	Regional ecosystem 13.12.7 Sedgeland along small drainage lines and soaks at high altitude
Alliance 2-2: *Carex gaudichaudiana – Isachne globosa* herbaceous fen	PCT 582: Sedgeland fens wetland of impeded drainage	Montane Bogs and Fens	Freshwater Wetlands	NA
Alliance 2-3: *Philydrum lanuginosum – Potamogeton tricarinatus* herbaceous ephemeral marsh and fen	No equivalent	Montane Lakes	Freshwater Wetlands	NA
Alliance 2-4: *Lachnagrostis filiformis* herbaceous wet meadow or marsh	No equivalent	Montane Lakes	Freshwater Wetlands	NA
Alliance 2-5: *Myriophyllum variifolium – Eleocharis acuta* herbaceous ephemeral marsh.	PCT 500: Upland wetlands	Montane Lakes	Freshwater Wetlands	NA
Alliance 2-6: *Glyceria australis* grassy wet meadow	No equivalent	Temperate Montane Grassland	Grassland	No equivalent
Alliance 2-7: *Juncus australis – Cenchrus purpurascens* herbacous wet meadow	No equivalent	No equivalent	?Grassland	NA
Alliance 2-8: *Carex tereticaulis – Asperula conferta* fen and wet meadow	No equivalent	No equivalent	No equivalent	NA
Alliance 2-9: *Poa sieberiana – Themeda triandra* grassy wet meadow	PCT 586: Snow Grass – Swamp Foxtail tussock grassland sedgeland	Temperate Montane Grassland	Grassland	No equivalent
Alliance 2-10: *Leptorhynchos squamatus – Schoenus apogon* herbfield	No equivalent	No equivalent	No equivalent	NA

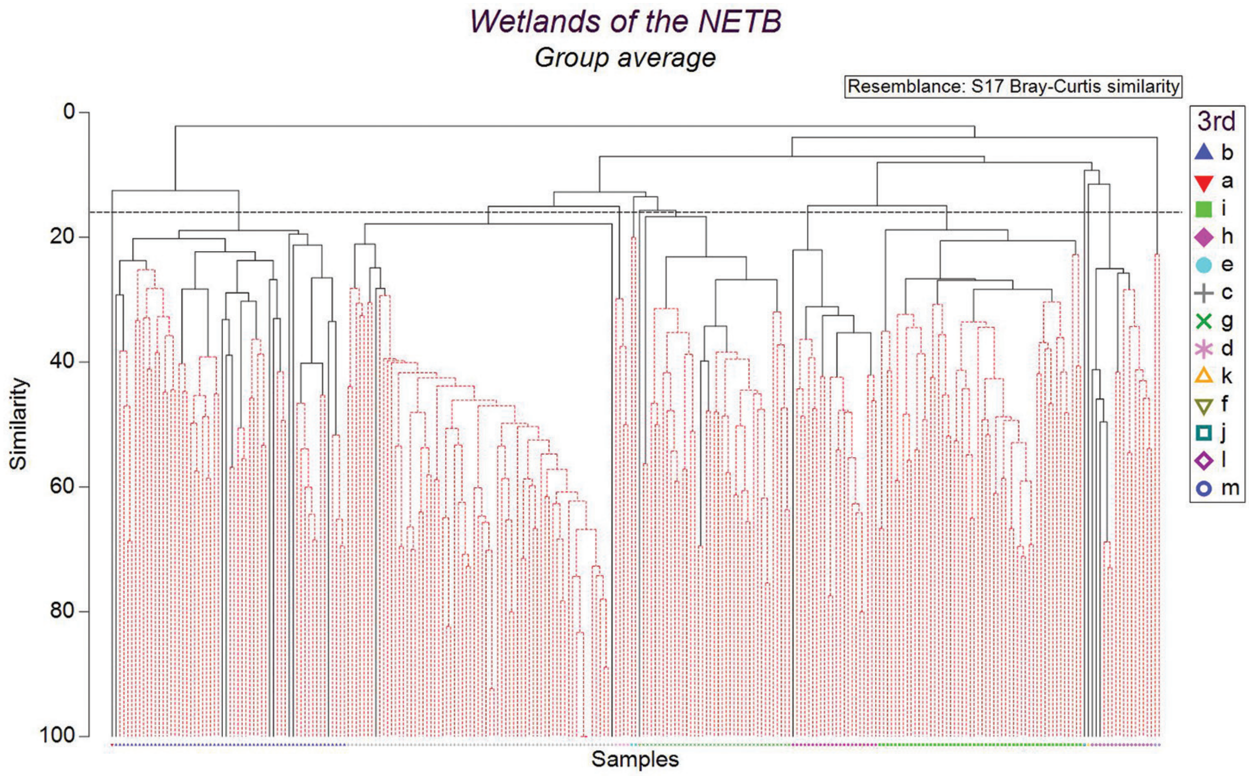

Figure 2. SIMPROF cluster analysis of the full dataset from mires of the New England Tablelands Bioregion of eastern Australia showing alliances recognised at similarity of 16.

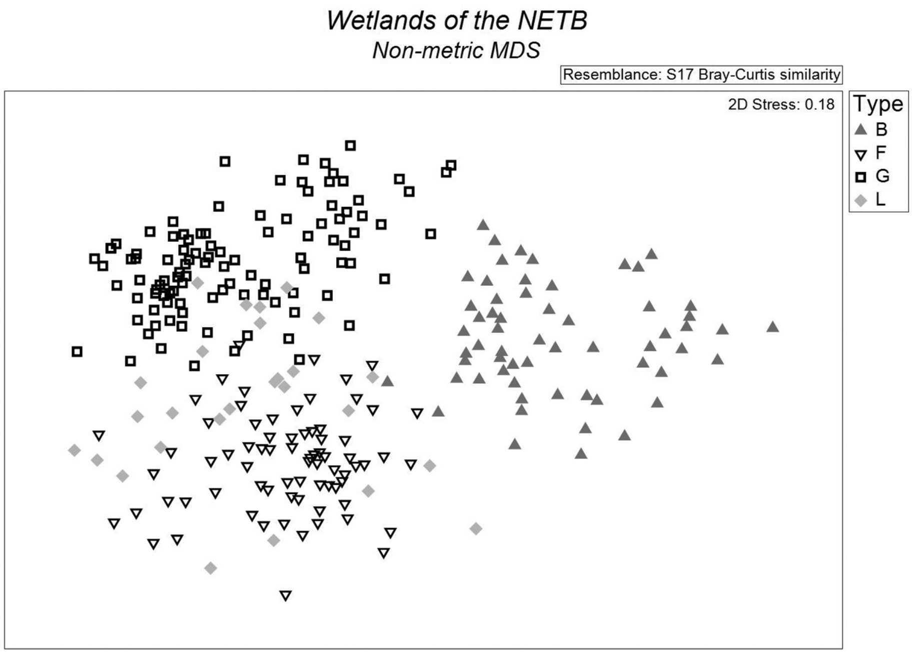

Figure 3. Ordination of full dataset of plots placed within mires of the New England Tablelands Bioregion of eastern Australia. Bogs (B), Fens (F), Sod Tussock Grasslands (G) and Lagoons (L).

typically considers ecological criteria, this is currently not the accepted general practice used in defining vegetation types within New South Wales or for state and federal listings of threatened communities. We believe our classification allows a better and more consistent understanding of the floristic relationships between these montane wetland types that co-occur within the NETB. The current New South Wales classification schema includes bogs and fens within the same class separate from wet meadows (Keith 2004). Our results and those of Hunter (2016a) show

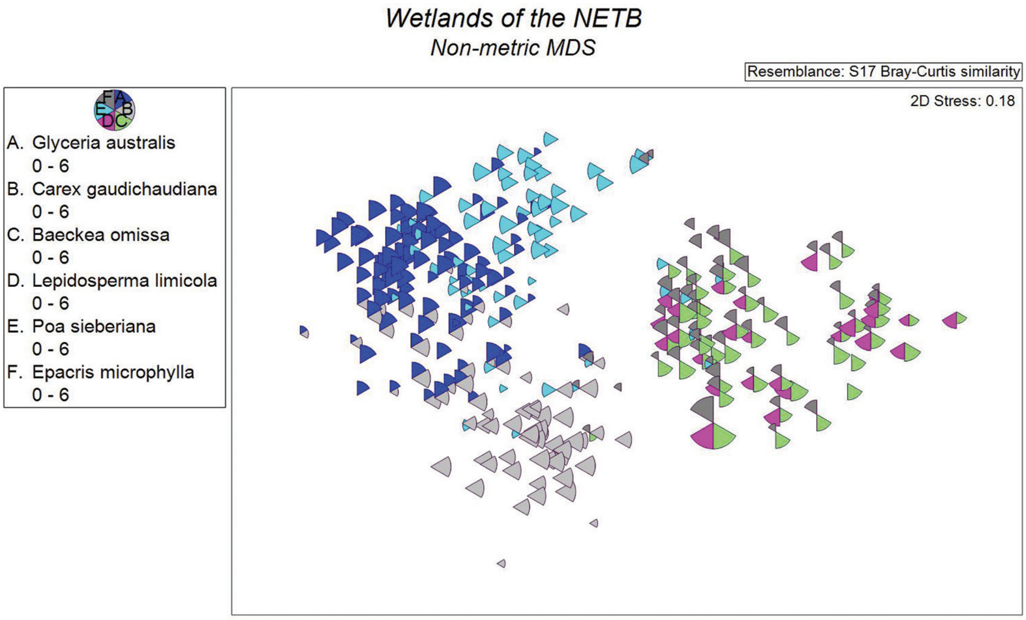

Figure 4. NMDS ordination Segmented bubble plot of the six species with a Pearson correlation greater than 0.5. Segment sizes are proportional to the Braun-Blanquet score given to each species within plots (0–6).

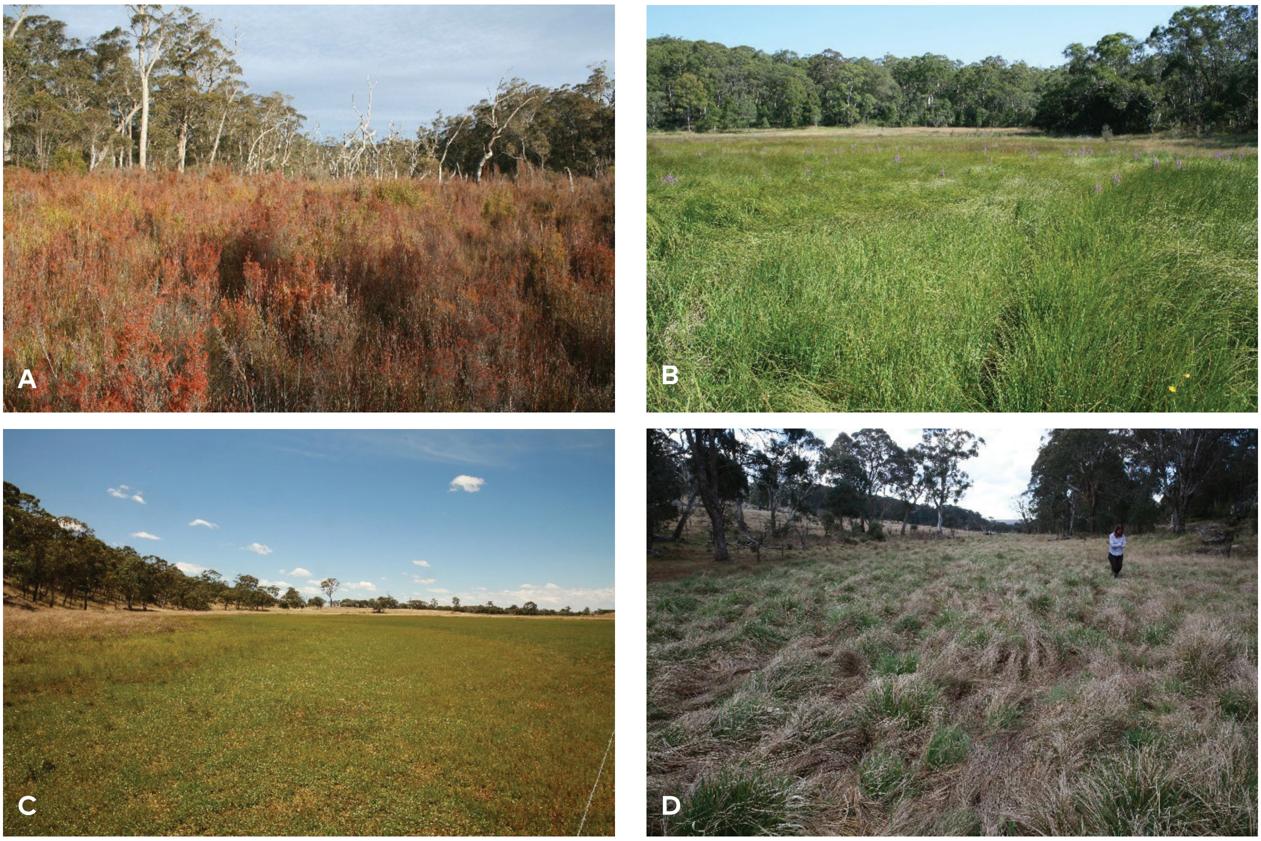

Figure 5. Broad wetland types found within the New England Tablelands Bioregion. A) Bog, B) Fen, C) Lagoon in its more common dry phase, D) Sod Tussock Grasslands.

a clear differentiation between bogs and other wetland types within the NETB.

Previous research has shown that bogs within the NETB are ecologically and functionally distinct dominated by taxa with traits dissimilar to those of the sympatric other wetland types such as fens and wet meadows (Hunter 2016a). Bogs form generally on low nutrient and acid soils with fire as a more frequent disturbance due to the dominance of oil-bearing resprouting shrub species. Bogs are the only wetland types to more consistently allow de-

Table 3. Comparison of species density and general environmental data for each alliance.

Hierarchy	Mean species density per 400 m²	Elevation (m a.s.l.)	Mean vegetation height (m)	Water depth (m)	Rock type
Alliance 1-1: Scientific Name: *Baeckea omissa – Epacris microphylla* shrubby bog	27	940–1372	0.2–6	0–0.2	Granite, acid volcanic, basalt
Alliance 1-2: Scientific Name: *Lepidosperma gunnii – Lepidosperma limicola* herbaceous bog	22	920–1040	0.2–3	0–0.2	Granite
Alliance 2-1: Scientific Name: *Carex appressa* herbaceous fen	18	446–1120	0.3–1.2	0–0.2	Granite, metasediment, acid volcanic, basalt
Alliance 2-2: Scientific Name: *Carex gaudichaudiana – Isachne globosa* herbaceous fen	18	780–1400	0.3–1	0–0.2	Granite, metasediment, basalt, sediment
Alliance 2-3: Scientific Name: *Philydrum lanuginosum – Potamogeton tricarinatus* herbaceous ephemeral marsh and fen	14	800–1000	0.1–1	0–0.5	Granite
Alliance 2-4: Scientific Name: *Lachnagrostis filiformis* herbaceous wet meadow or marsh	10	800–1300	0.1–1	0	Basalt, granite
Alliance 2-5: Scientific Name: *Myriophyllum variifolium – Eleocharis acuta* herbaceous ephemeral marsh	13	1040–1400	0.1–1	0–1.5	Basalt, granite
Alliance 2-6: Scientific Name: *Glyceria australis* grassy wet meadow	11	700–1400	0.2–1.2	0–0.2	Granite, metasediment, acid volcanic, basalt, shale, sediment
Alliance 2-7: Scientific Name: *Juncus australis – Cenchrus purpurascens* herbaceous wet meadow	8	1200–1350	0.2–1	0–0.1	Basalt, Metasediment
Alliance 2-8: Scientific Name: *Carex tereticaulis – Asperula conferta* herbaceous wet meadow and fen	22	1000–1350	0.5–1.5	0	Metasediment, sediment
Alliance 2-9: Scientific Name: *Poa sieberiana – Themeda triandra* grassy wet meadow	17	980–1350	0.15–1.2	0	Granite, metasediment, basalt, mudstone, acid volcanic
Alliance 2-10: Scientific Name: *Leptorhynchos squamatus – Schoenus apogon* herbfield	11	930–1100	0.15–0.3	0	Basalt

velopment of *Sphagnum* and it forms a major component of peat in patches less frequently burnt or more generally by restionaceous materials. The other mire types identified all predominantly occur on higher nutrient soils, do not generally burn and almost never contain *Sphagnum* as a component, with peat largely derived from cyperaceous and grass root and above ground materials.

Our numerical analysis approach has highlighted a deficiency in previous supervised or semi-supervised techniques to describe the variation within mires within the NETB. Nearly half of the alliances we have circumscribed are not represented within published state PCTs and even less of the 28 previously published associations are currently recognised as accepted PCTs (Hunter and Bell 2007; Hunter and Bell 2009; Hunter and Hunter 2016). A similar result was also found when comparing an unsupervised analysis of arid and semi-arid ephemeral wetlands within New South Wales to accepted PCTs, classes and formations (Hunter and Lechner 2017). More concerning is the Regional Ecosystem (RE) approach of Queensland, in which half of our circumscribed assemblages do not have an equivalent type and the remainder would all be placed within a single RE in spite of this classification being attributed to the association level (Addicott et al. 2018). This RE appears to be more aligned with our macrogroup level rather than association or alliance (Table 2) and thus we would suggest that the RE system may be operating at a different thematic scale and may not be closely aligned to association as the authors suggest.

What we consider as a single macrogroup is distributed across three classes and two formations within the New South Wales system which calls for the need to review the clarity and consistency of those accepted higher hierarchical levels (Hunter and Lechner 2017). We consider a more appropriate conceptualisation is that all the wetlands within our analysis be considered as types of mires and contained within a single hierarchical level. Thus, our macrogroup is floristically and biogeographically distinct, i.e. a New England Tableland Montane Mires (Table 1). This conceptualisation is supported both floristically and geographically. Floristically, Whinam and Chilcott (2002), Hunter and Bell (2013) and Hunter and Hunter (2016) have shown this region is floristically distinctive in terms of bog and wet meadow floristics. Lechner et al.

Table 4. Synoptic table of the most important species (≥ 5% mean constancy or ≥ 50% constancy in at least one alliance) of mire alliances of the New England Tableland Bioregion. Values in the columns are percentage constancies. Species with 50% or more in at least one alliance are listed under the alliance where they reach the highest constancy. Those species that did not reach 50% constancy in any of the alliances are listed under "Companion species" according to decreasing mean constancy. See Suppl. material 2 for full synoptic table. 1-1 *Baeckea omissa* – *Epacris microphylla* shrubby bog, 1-2 *Lepidosperma gunnii* – *Lepidosperma limicola* herbaceous bog, 2-1 *Carex appressa* herbaceous fen, 2-2 *Carex gaudichaudiana* – *Isachne globosa* herbaceous fen, 2-3 *Philydrum lanuginosum* – *Potamogeton tricarinatus* herbaceous ephemeral marsh and fen, 2-4 *Lachnagrostis filiformis* herbaceous wet meadow or marsh, 2-5 *Myriophyllum variifolium* – *Eleocharis acuta* herbaceous ephemeral marsh, 2-6 *Glyceria australis* grassy wet meadow, 2-7 *Juncus australis* – *Cenchrus purpurascens* herbaceous wet meadow, 2-8 *Carex tereticaulis* – *Asperula conferta* herbaceous wet meadow and fen, 2-9 *Poa sieberiana* – *Themeda triandra* grassy wet meadow, 2-10 *Leptorhynchos squamatus* – *Schoenus apogon* herbfield.

Alliance	**Mean**	1-1	1-2	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10
Number of plots		59	5	22	77	4	14	57	87	5	7	36	4
Alliance 1-1													
Baeckea omissa	13.5	100	60	–	2	–	–	–	–	–	–	–	–
Epacris microphylla	16.1	100	80	–	7	–	–	–	–	–	–	6	–
Gonocarpus micranthus	11.3	76	40	5	4	–	–	–	–	2	–	9	–
Leptospermum gregarium	5.9	71	–	–	–	–	–	–	–	–	–	–	–
Baloskion stenocoleum	11.9	63	60	–	20	–	–	–	–	–	–	–	–
Callistemon pityoides	4.9	59	–	–	–	–	–	–	–	–	–	–	–
Hakea microcarpa	6.0	55	–	–	11	–	–	–	–	–	–	6	–
Alliance 1-2													
Austrostipa pubescens	8.3	–	100	–	–	–	–	–	–	–	–	–	–
Dampiera stricta	9.0	8	100	–	–	–	–	–	–	–	–	–	–
Goodenia bellidifolia	14.7	73	100	–	–	–	–	–	–	–	–	3	–
Persoonia oleoides	8.7	4	100	–	–	–	–	–	–	–	–	–	–
Pteridium esculentum	9.8	10	100	–	2	–	–	–	–	–	–	6	–
Dillwynia phylicoides	7.0	4	80	–	–	–	–	–	–	–	–	–	–
Entolasia stricta	11.1	53	80	–	–	–	–	–	–	–	–	–	–
Hovea heterophylla	6.7	–	80	–	–	–	–	–	–	–	–	–	–
Leptospermum arachnoides	10.6	47	80	–	–	–	–	–	–	–	–	–	–
Petrophile canescens	7.3	8	80	–	–	–	–	–	–	–	–	–	–
Aristida jerichoensis	5.0	–	60	–	–	–	–	–	–	–	–	–	–
Banksia spinulosa	7.6	31	60	–	–	–	–	–	–	–	–	–	–
Dianella caerulea	5.5	6	60	–	–	–	–	–	–	–	–	–	–
Lepidosperma gunnii	5.8	10	60	–	–	–	–	–	–	–	–	–	–
Lepidosperma limicola	9.3	51	60	–	–	–	–	–	–	–	–	–	–
Lepidosperma tortuosum	5.5	6	60	–	–	–	–	–	–	–	–	–	–
Leptospermum minutifolium	6.3	10	60	5	–	–	–	–	–	–	–	–	–
Lepyrodia scariosa	7.9	35	60	–	–	–	–	–	–	–	–	–	–
Lindsaea linearis	6.5	18	60	–	–	–	–	–	–	–	–	–	–
Lomandra multiflora	7.0	14	60	–	–	–	–	–	4	–	–	6	–
Melichrus procumbens	5.2	2	60	–	–	–	–	–	–	–	–	–	–
Pimelea linifolia	6.2	14	60	–	–	–	–	–	–	–	–	–	–
Rytidosperma indutum	5.0	–	60	–	–	–	–	–	–	–	–	–	–
Selaginella uliginosa	5.3	4	60	–	–	–	–	–	–	–	–	–	–
Stylidium graminifolium	6.0	12	60	–	–	–	–	–	–	–	–	–	–
Alliance 2-1													
Carex appressa	14.9	2	–	100	37	–	–	4	10	–	–	26	–
Rubus anglocandicans	17.4	2	–	64	37	–	–	6	27	20	50	3	–
Rumex crispus	15.6	–	–	64	46	–	31	21	8	–	17	–	–
Verbena bonariensis	19.0	–	–	64	26	33	31	6	26	–	33	9	–
Alliance 2-2													
Holcus lanatus	41.8	4	–	41	100	33	8	45	64	80	67	59	–
Carex gaudichaudiana	19.9	2	–	23	98	33	–	26	17	20	17	3	–
Epilobium billardierianum	15.1	6	–	41	78	–	–	28	16	–	–	12	–
Stellaria angustifolia	14.3	2	–	27	76	–	–	17	9	–	–	15	25
Isachne globosa	7.7	24	–	–	65	–	–	2	1	–	–	–	–
Geranium solanderi	24.7	37	40	45	63	–	8	6	32	20	33	12	–
Cyperus sphaeroideus	7.3	2	–	27	50	–	–	9	–	–	–	–	–
Alliance 2-3													
Philydrum lanuginosum	8.8	2	–	–	4	100	–	–	–	–	–	–	–
Asperula conferta	14.0	–	–	9	–	67	–	4	14	–	33	41	–
Brachyscome tenuiscapa	8.4	2	–	–	–	67	–	–	8	–	–	24	–
Carex breviculmis	10.2	–	–	–	–	67	–	–	9	–	17	29	–

Alliance	**Mean**	1-1	1-2	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10
Number of plots		59	5	22	77	4	14	57	87	5	7	36	4
Plantago lanceolata	24.8	2	–	41	7	67	–	6	30	40	33	47	25
Alliance 2-4													
Lachnagrostis filiformis	25.5	4	–	23	17	–	100	74	18	–	17	3	50
Conyza bonariensis	17.0	–	–	27	11	–	77	17	26	40	–	6	–
Trifolium repens	24.3	–	–	32	26	33	54	17	42	40	–	47	–
Alliance 2-5													
Myriophyllum variifolium	12.1	2	–	–	7	33	–	100	3	–	–	–	–
Alliance 2-6													
Glyceria australis	22.8	–	–	9	11	67	–	26	100	20	–	41	–
Cirsium vulgare	32.8	6	–	50	52	–	31	23	79	60	33	35	25
Alliance 2-7													
Juncus australis	29.3	–	–	41	26	33	–	38	49	100	17	47	–
Cenchrus purpurascens	26.8	10	–	36	17	33	–	19	31	80	17	53	25
Carex disticha	10.8	–	–	5	35	–	–	–	18	60	–	12	–
Alliance 2-8													
Carex tereticaulis	8.5	–	–	–	–	–	–	2	–	–	100	–	–
Anthoxanthum odoratum	23.5	2	–	9	43	33	15	15	32	–	83	50	–
Carex inversa	11.0	2	–	14	28	–	–	4	3	–	50	6	25
Alliance 2-9													
Poa sieberiana	23.3	14	–	9	4	67	–	2	30	20	33	100	–
Hypochaeris radicata	31.9	22	–	50	30	–	69	17	26	40	33	71	25
Themeda triandra	14.6	35	–	–	–	67	–	–	5	–	–	68	–
Schoenus apogon	14.3	29	–	9	4	–	–	15	12	–	–	53	50
Haloragis heterophylla	14.3	8	–	36	28	33	–	9	8	–	–	50	–
Alliance 2-10													
Leptorhynchos squamatus	8.8	–	–	–	–	–	–	2	3	–	–	–	100
Paspalum dilatatum	35.3	–	–	73	20	33	31	34	25	60	33	15	100
Eleocharis atricha	6.3	–	–	–	–	–	–	–	–	–	–	–	75
Hydrocotyle tripartita	15.6	–	–	23	22	–	8	47	6	–	–	6	75
Juncus subsecundus	8.7	16	–	5	4	–	–	4	–	–	–	–	75
Eragrostis curvula	5.5	–	–	5	–	–	–	2	9	–	–	–	50
Phleum pratense	4.5	–	–	–	–	–	–	4	–	–	–	–	50
Sporobolus creber	5.6	2	–	–	–	–	–	–	–	–	–	15	50
Companion species													
Ranunculus lappaceus	15.3	18	–	14	39	33	–	4	12	20	17	26	–
Taraxacum officinale	15.3	2	–	14	22	33	8	13	43	–	33	15	–
Euchiton sphaericus	11.2	14	–	9	–	33	15	6	13	20	–	24	–
Ammi majus	10.5	–	–	–	–	–	46	–	26	–	33	21	–
Rumex brownii	10.3	–	–	18	2	33	8	2	16	20	–	24	–
Ranunculus inundatus	9.5	–	–	9	24	33	–	36	6	–	–	6	–
Persicaria prostrata	8.5	–	–	18	–	–	38	4	–	–	17	–	25
Eleocharis acuta	8.4	–	–	36	9	–	–	47	6	–	0	3	–
Festuca elatior	8.4	–	–	32	48	–	–	–	4	–	17	–	–
Persicaria hydropiper	8.3	–	–	23	30	–	–	19	8	20	–	–	–
Hypericum gramineum	8.1	29	20	5	7	–	–	2	3	–	–	6	25
Lythrum salicaria	8.0	4	–	5	48	33	–	–	3	–	–	3	–
Lomandra longifolia	7.9	29	20	–	4	33	–	–	–	–	–	9	–
Hemarthria uncinata	7.3	2	–	9	9	–	8	28	6	–	17	9	–
Poa labillardieri	7.3	–	40	5	9	33	–	–	1	–	–	–	–
Juncus usitatus	7.3	2	–	18	9	33	–	0	4	–	–	21	–
Phalaris aquatica	6.8	12	–	14	–	–	–	–	27	–	17	12	–
Rumex conglomeratus	6.8	–	–	23	13	–	–	–	23	20	–	3	–
Hypericum japonicum	6.7	16	–	5	20	–	–	6	1	20	–	12	–
Cynodon dactylon	6.6	–	–	9	–	33	–	11	3	20	–	3	–
Eleocharis sphacelata	6.2	4	–	5	24	–	–	38	3	–	–	–	–
Setaria pumila	6.0	6	–	–	7	–	–	4	4	–	17	9	25
Eleocharis pusilla	5.9	–	–	–	11	33	–	15	6	–	–	6	–
Prunella vulgaris	5.8	6	–	14	17	–	–	2	4	20	–	6	–
Viola hederacea	5.8	22	20	–	4	–	–	–	–	–	17	6	–
Geranium neglectum	5.7	–	–	–	2	–	38	2	3	–	17	6	–
Eleocharis gracilis	5.4	–	–	5	17	–	–	40	3	–	–	–	–
Juncus fockei	5.4	–	–	5	11	–	8	34	1	–	–	6	–
Oxalis perennans	5.3	4	–	5	–	–	–	–	3	–	17	35	–
Rorippa palustris	5.2	–	–	–	–	–	38	6	1	–	17	–	–
Sorghum leiocladum	5.2	4	–	–	–	33	–	–	1	–	–	24	–

(2016) showed the New England Region formed distinct ecoregions in terms of the occurrence of mapped mires of all types. Furthermore, the highland region of the New England Tablelands Bioregion is disconnected from more southern highland areas by the Hunter Valley.

Most of the NETB mires are currently listed as endangered communities on state and national acts (Hunter and Bell 2007; Bell et al. 2008; Hunter and Bell 2009; Hunter and Hunter 2016) and thus an understanding of the natural variation and interrelationships between these systems is important. Clear distinction of vegetation units is a necessity for conservation and management. Indistinct or ill-defined systems can lead to inappropriate management actions (Hunter and Hunter 2016; Hunter 2018). For example, semi-permanent or ephemeral marshes of the NETB are considered a distinct floristic association, class and formation within current New South Wales classification schema (Keith 2004; Benson et al. 2010). In addition, semi-permanent or ephemeral marshes are currently listed as an endangered ecological community both under the state *Biodiversity Conservation* (BC) *Act* 2017 (*Upland Wetlands of the Drainage Divide of the New England Tableland Bioregion*), and the federal *Environment Protection and Biodiversity Conservation* (EPBC) *Act* 1999 (*Upland wetlands of the New England Tablelands and the Monaro Plateau*).

Upland wetlands (lagoons) are a geomorphologically defined landscape element that contains a number of vegetation types within it (Bell et al. 2008; Hunter and Bell 2009; Hunter and Hunter 2016; Hunter 2018). However, only the floristics and not the geomorphological features are the dominant criteria used to distinguish this threatened community legislatively, but the system contains a number of distinct floristic types (fens, marshes, wet meadows). In practice this means that 'lagoons' are classed as an endangered vegetation community but this same community may also contain within it other endangered vegetation communities including *Carex* fens dominated by *Carex appressa*, which has its own listing, and bogs dominated by *Carex gaudichaudiana*, which also has its own listing and wet meadows which is under threat and may warrant listing in the near future (Hunter and Hunter 2016). Thus, within the one location two endangered communities can occur within another yet they are all supposed to be based on distinct floristic composition. This is further exacerbated by the fact that most of these 'lagoons' may only wet a few times a century and thus cannot be defined easily by floristics alone. The confusion of listing a geomorphological feature as an endangered system but defining it based on floristics has led to a distortion in understanding. We believe defining clear and distinct floristic units clarifies the relationships between wetland types and would avoid this nestedness of endangered community listings.

The most distinctive alliance, largely restricted to lagoons (2-5 *Myriophyllum variifolium – Eleocharis acuta* ephemeral marsh), is the least likely to be temporally present and often within only a proportion of the lagoon area and yet it is used to define the wetland. A more detail temporal understanding of the dynamics of this system is required (Bell et al. 2008; Hunter 2016a; Hunter 2018). As the majority of lagoons within the NETB cycle sporadically between mainly drier and often rare wet phases, that may or may not include inundation but almost always include zonation, samples taken within them were found to occur within various alliances within our analyses. We believe that by creating and defining vegetation types based on floristic analysis allows a better understanding of temporal changes and the effects of these wetting and drying cycles. Lumping several distinct floristic assemblages into a single geomorphic unit obscures our ability to conceptualise and study plant competition, establishment and changes due to fluctuating resources (Hunter 2016a, 2018). Based on our analysis, lagoons are likely to contain two formations, three classes and four PCTs rather than a single PCT, class and formation based on the works of Keith (2004) and Benson et al. (2010).

Supervised techniques have also led to the confusion in the determination of other state listed threatened montane mires within the NETB. Threatened community listings within state and federal acts are meant to be based on floristic distinctiveness. Fens dominated by either *Carex gaudichaudiana* or *Carex appressa* are peat forming and, closely aligned within our analyses but they are distinct from bogs, and do not occur within the same threatened community listings. Montane bogs are listed as endangered on the state BC Act as "*Montane peatlands and swamps of the New England Tableland*, *New South Wales North Coast*, *Sydney Basin. South East Corner*, *South Eastern Highlands and the Australian Alps bioregions*". This determination includes what we have circumscribed as bogs and fens, including fens that are dominated by *Carex gaudichaudiana* but not other fen types (Hunter and Bell 2007). Our analyses clearly indicate bogs and fens are very distinct systems (Figures 2–4). Fens dominated by *Carex appressa* (but excluding those dominated by *Carex gaudichaudiana*) are also listed as a separate endangered ecological community on the state BC Act as "*Carex sedgelands of the New England Tableland*, *Nandewar*, *Brigalow Belt South and New South Wales North Coast bioregions*". Thus, the same fen type is listed under two different ecological community listings and is also separated from other closer related fen types (Hunter and Bell 2009). This is in spite of the fact that such determinations are meant to be based on floristic uniqueness and determined by largely by species composition.

Classification within Australia has largely been driven by the need to manage natural resources from both conservation and production perspectives and is linked to mapping outputs with a recent emphasis on unsupervised modelling techniques such as segmentation (Hunter 2016b; Gellie et al. 2017). However, undescribed vegetation types cannot be modelled and poorly circumscribed entities are likely to be inaccurately modelled and mapped (Hunter 2016b; Hunter and Lechner 2017). This is particularly a problem with wetland types, especially semi-permanent or ephemeral wetlands. Recent vegetation modelling within part of the NETB provided only a 10% accuracy of wetland extent and types (Hunter 2013; Hunter 2018). Similar inaccuracy rates for modelled wetlands have been found with other recent state mapping programs (Hunter and Hawes 2013; Hunter 2016b). The lack of clear delineation of wetland vegetation types and the poor accuracy of modelled maps severely hampers our ability to understand and conserve these highly threatened systems.

Our results and those of other recent work (Hunter and Lechner 2017) has highlighted that wetlands within eastern Australia have been generally poorly sampled, at times ill-defined and often contain significant undescribed variation whose interrelationships have not been properly understood. This has led to poor circumscription of listed threatened ecological communities and difficulty in modelling for mapping and conservation purposes. While we have attempted to provide some clarity within a new proposed hierarchical classification schema for the NETB, there is a need to better circumscribe all Australian terrestrial wetland systems. There is significant utility in the creation of a well-defined hierarchical schema of vegetation types that is non-jurisdiction based and scalable to enable better understanding and management, and increase our ability to protect and conserve them.

Author contributions

J.T.H. and V.H.H. conceived and undertook all field work. J.T.H. completed all analyses and J.T.H. wrote the majority of the manuscript with V.H.H. providing comment and additional text.

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Supplementary material

Supplementary material 1
Images of the circumscribed NETB montane mire alliances
Link: https://doi.org/10.3897/VCS/2020/48765.suppl1

Supplementary material 2
Full synoptic table of the 12 distinguished alliances
Link: https://doi.org/10.3897/VCS/2020/48765.suppl2