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# Poplar box woodlands of Eastern Australia: an assessment of a threatened ecological community within the IVC framework

John T. Hunter[1], Eda Addicott[2,3,4]

1 *School of Environmental and Rural Science, University of New England, Armidale, New South Wales, Australia*
2 *Queensland Herbarium, Department of Environmental Science, Brisbane Botanic Gardens Mount Coot-tha, Queensland, Australia*
3 *Australian Tropical Herbarium, James Cook University, Cairns, Queensland, Australia*
4 *Centre for Tropical Environmental & Sustainability Science (TESS) and College of Science & Engineering, James Cook University, Cairns, Queensland, Australia*

Corresponding author: John T. Hunter (jhunter8@bigpond.com)

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## Abstract

**Aims:** Ecosystems nationally at risk in Australia are listed under the Environmental Protection and Biodiversity Act (EPBC Act), and many cross State jurisdictional boundaries. The determination of these ecosystems across the State boundaries are based on expert knowledge. The International Vegetation Classification has the potential to be useful as a cross-jurisdictional hierarchy which also gives global perspective to ecosystems. **Study Area:** All bioregions that include *Eucalyptus populnea* as a dominant or major component of woodlands across the species known distribution. **Methods:** We use plot-based data (455 plots) from two states (Queensland and New South Wales) in eastern Australia and quantitative classification methods to assess the definition and description for the Poplar Box Woodland ecosystem type (hereafter "ecological community" or "community") that is listed as endangered under the EPBC Act. Analyses were conducted using kR-CLUSTER methods to generate alliances. Within these alliances, analyses were undertaken to define associations using agglomerative hierarchical clustering and similarity profile testing (SIMPROF). We then explore how assigning this community into the IVC hierarchy may provide a mechanism for linking Australian communities, defined at the association and alliance levels, to international communities at risk. **Results:** We define three alliances and 23 associations based on the results of floristic analysis. Using the standard rule-set of the IVC system, we found that the IVC hierarchy was a useful instrument in correlating ecological communities across jurisdictional boundaries where different classification systems are used. It is potentially important in giving a broader understanding of communities that may be at risk continentally and globally. **Conclusions:** We conclude that the IVC hierarchy can incorporate Australian communities at the association level into useful units at higher levels, and provides a useful classification tool for Australian ecosystems.

**Taxonomic reference:** PlantNET (http://plantnet/10rbgsyd.nsw.gov.au/) [accessed June 2019].

**Abbreviations:** EPBC Act = Environmental Protection and Biodiversity Act; IVC = International Vegetation Classification; NMDS = non-metric multidimensional scaling; NSW = New South Wales; PCT = Plant Community Type; QLD = Queensland; RE = Regional Vegetation Community; SIMPER = similarity percentage analysis; SIMPROF = Similarity profile analysis.

## Keywords

Australia, ecological community, International Vegetation Classification, New South Wales, Queensland, woodland

## Introduction

One of the core methods for tackling the loss of biodiversity is the listing of threatened ecological communities on international, national and regional lists (IPBES 2019). However, this necessarily requires that such communities are defined and are identifiable. Without clear definitions of inclusion or exclusion we risk conservation priorities being misdirected (Hunter 2021a; Saunders et al. 2021). One key impediment to the process of listing threatened ecological communities is a lack of jurisdictional conformity in typology (Gellie et al. 2018; Muldavin et al. 2021; Saunders et al. 2021). Only through the unification of terminology and procedure, at least with some critical components of survey and naming across jurisdictions, can a clearer understanding of the distribution and threats to communities occur (De Cáceres et al. 2015; Gellie et al. 2018; Luxton et al. 2021).

A lack of jurisdictional conformity is a global issue within many regions and concerted efforts are being made to unify classificatory procedures at all levels to allow greater regional, continental and global understandings (Faber-Langendoen et al. 2014; De Cáceres et al. 2018; Luxton et al. 2021; Muldavin et al. 2021). Though many early attempts at classifying vegetation within Australia were continental in focus (e.g. Carnahan 1976; Beadle 1981; Walker and Hopkins 1990; Specht et al. 1995), classification within Australia has become strongly State and Territory led, each with their own individualistic approaches (Gellie et al. 2018; Luxton et al. 2021). In most instances, intuitive qualitative supervised methodologies have been used to create typologies, often with minimal hierarchical structures that are used primarily for mapping (Gellie et al. 2018). As such, difficulty arises when a threatened ecological community is listed at the continental scale on the Federal Environmental Protection and Biodiversity Act 1999 (EPBC Act; https://www.environment.gov.au/epbc) and is known to occur across jurisdictional boundaries within Australia. An intent of threatened community listings is to channel and prioritise limited resources towards those systems that are in urgent need of immediate protection, however, listings are often constrained by limited knowledge, outdated taxonomy and jurisdictional differences (Wallace and Fluker 2015; Dovey and Walker 2018; Saunders et al. 2021). Currently the *EPBC* Act contains 92 threatened ecological communities (4 Nov 2021). Any organisation or community member can nominate a listing which goes to a scientific committee for discussion. Potential listings are then refined and placed on public exhibition for comment before finally being presented to the federal minister for acceptance or rejection. Although guidelines suggest that communities should be defined based on numerical classification this has not been applied to many currently listed, some of which are clearly defined based on geomorphological features with only a generalised concept of a floristic assemblage (see, e.g., Hunter and Hunter 2020; Hunter 2021a). Without a full comprehension of all floristic and ecological components and interrelationships with co-occurring types, a real understanding cannot be gained of threats and persistence (Franklin et al. 2016; Jansen et al. 2016).

Although adjacent to each other and sharing approximately 1,500 km of border the vegetation classification methodologies between New South Wales (NSW) and Queensland (QLD) (Gellie et al. 2018) are highly divergent. Within QLD communities are defined as regional ecosystems (RE) that are classified at a thematic level considered equivalent to association. Unlike traditional concepts of an association, which strongly emphasize floristics, REs in QLD are named based firstly on the bioregion (IBRA7; Thackway and Cresswell 1995) in which they occur, secondarily by geology, landform and soils and only thirdly by the most dominant stratum in terms of biomass (not height) and then dominant floristics within strata (Gellie et al. 2018; Addicott et al. 2021). The approach is mapping based and created predominantly through expert opinion, with more than 1300 types currently defined (Gellie et al. 2018), although recently quantitative classification approaches are being implemented (Addicott et al. 2018; Addicott et al. 2021). In NSW, the vegetation classification has three hierarchical levels, of which the Plant Community Type level (PCT) was derived under a separate process to the other thematic levels of class and formation (Keith 2004; Benson 2006; Gellie et al. 2018). PCTs are based on floristics, unlike REs, and thus are closer to the traditional concept of association *sensu* Braun-Blanquet (Benson 2006). Un-supervised, semi-supervised, and, more rarely, fully supervised methods were used to define PCTs, depending on the density of qualitative data (Benson 2006). In contrast to REs, the PCT approach was not mapping based. Currently, approximately 1500 PCTs are defined for NSW. Independently developed classes and formations have also been defined for NSW through largely supervised and semi-supervised methods, with the relationships between the thematic levels based on expert opinion (Gellie et al. 2018). Overall NSW and QLD typologies have been developed through expert opinion; rarely do plot-based analyses underpin the circumscription of units.

Plot-based techniques are needed to better circumscribe communities within and across jurisdictions for greater consistency. Several tests have been completed within select vegetation types (e.g. Hunter and Lechner 2017; Addicott et al. 2018; Hunter 2020; Hunter and Hunter 2021a; Muldavin et al. 2021). Here we introduce an additional test based on the Poplar Box Woodland dominated by *Eucalyptus populnea*. *Eucalyptus populnea* is a widespread species with a wide edaphic tolerance but is generally restricted to annual rainfalls between 300 and 500 mm (Beeston et al. 1980; Beadle 1981) with a distribution almost equally divided across NSW and QLD and is restricted to these two jurisdictions. Beeston et al. (1980) subjectively defined 31 *Eucalyptus populnea* communities based on structure primarily for mapping purposes. Beadle (1981) defined a *Eucalyptus populnea*

alliance with seven sub-alliances. These subjective cross jurisdictional works have been replaced by the Qld RE and the NSW PCT classifications. Within QLD, 34 REs have been circumscribed that are either dominated by, or have *Eucalyptus populnea*, as a characteristic canopy species, and they are found in 4 bioregions and a number of land zones (Suppl. material 1). Within NSW, 56 PCTs have *Eucalyptus populnea* as the dominant overstorey species or listed as a diagnostic element. These PCTs are placed within 23 Classes and 10 Formations (see Suppl. material 1).

In 2013, Poplar Box (*Eucalyptus populnea*) Grassy Woodland on Alluvial Plains was nominated as a nationally threatened ecological community within Australia and was accepted as such in 2019 under the Commonwealth EPBC Act 1999. At the time of listing no independent numerical classification was undertaken but existing state-based classifications were used as a guide for what should be included within listing advice for identification. Although there are 90 PCTs and REs types across both states that have *Eucalyptus populnea* as a defined diagnostic component, the current conservation listing advice for the endangered community only lists four PCTs and five REs as being characteristic of the endangered community. The listing advice was based on expert opinion and no cross jurisdictional analyses were performed to justify the conclusions made or to assess the interrelationships of the types incorporated. The differences between classification systems and methodologies in NSW and QLD and a lack of plot-based analysis limits our understanding of communities dominated by *Eucalyptus populnea* across its range. To address conservation priorities and to better place limited management resources, the interrelationships of these communities need to be better understood from a local, continental and global perspective. Hierarchical classification schema allow for a better understanding of interrelationships between communities and the conceptualisation of different ranks allows the scale of management to be applied at appropriate scales (Faber-Langendoen et al. 2018; Luxton et al. 2021).

One such hierarchical classification schema is the International Vegetation Classification (IVC) system, which is based on the EcoVeg approach (Faber-Langendoen et al. 2014) and was developed to characterise the world's vegetation. Due to its hierarchical structure, which includes eight thematic levels (indigenous and anthropogenic), the IVC enables vegetation types to be defined locally, regionally, and globally, without regard to jurisdictions (Gellie et al 2018; Muldavin et al. 2021). Here we propose to resolve the issues of differences between state-based classification schema and the lack of knowledge of their interrelationships by using plot based analytical techniques and defining types using the IVC criteria and structure across the full range of systems in which *Eucalyptus populnea* is a characteristic dominant. The results are used to assess the current circumscription of the listed endangered Poplar Box Grassy Woodlands on Alluvial Plains.

# Methods

## Study region

The study region incorporates the full range of environments across NSW and QLD in which *Eucalyptus populnea* is found to be a dominant or a characteristic species. This includes the eastern Australian bioregions of: Brigalow Belt North, Brigalow Belt South, Desert Uplands, Darling Riverine Plains, Nandewar, Mulga Lands, Cobar Peneplains, NSW South Western Slopes and the Murray Darling Basin (Figure 1) covering over 960,000 sq km and 14 degrees of latitude (Beeston et al. 1980).

## Data and statistical analysis

Different Australian jurisdictions (States and Territories) have different protocols for plot-based vegetation sampling, using different sized plots and scoring systems (Gellie et al. 2018). There currently is no Australian national vegetation database system, although data exchange protocols for incorporating data from individual databases are under development (TERN AEKOS). Thus, vegetation data from the different databases were used to cover the extent of *Eucalyptus populnea* dominated communities within eastern Australia. These databases included the QLD government 'CORVEG' database, which is the most comprehensive database covering QLD, and a private database curated by one of the authors (JTH; listed in GIVD as Au-Au-003 – https://www/givd.info/databses.xhtml), which primarily covered NSW but includes some parts of QLD. Use of the private database was considered appropriate as it contained much of the data already incorporated in state-based databases and had the additional benefit of having a single surveyor providing consistency in identification and scoring of species.

Floristic data was extracted from plots in which *Eucalyptus populnea* was a dominant or co-dominant from CORVEG and Au-Au-003. From each database, plots were extracted where *Eucalyptus populnea* had >10% canopy cover. Within the Australian context, woodlands are defined as having a canopy cover of between 10–30% and thus at minimum the plots chosen for analysis had to have *Eucalyptus populnea* occupying a third of the canopy cover. Plots where less than six taxa were recorded within plots were removed. Plots where a misidentification with the closely related *Eucalyptus brownii* was made were also removed. Misidentification was determined by knowledge of the distribution and habitat preferences of the two species. Taxa not identified to species level were removed. The final dataset incorporated 455 plots (151 from CORVEG) and 1326 species (native and introduced) (see Figure 1 for distribution). IVC protocols specify using percentage cover of all species in all strata for the description of types (Jennings et al. 2009).

Within the CORVEG protocol, species cover can be recorded differentially across strata and there is a standard

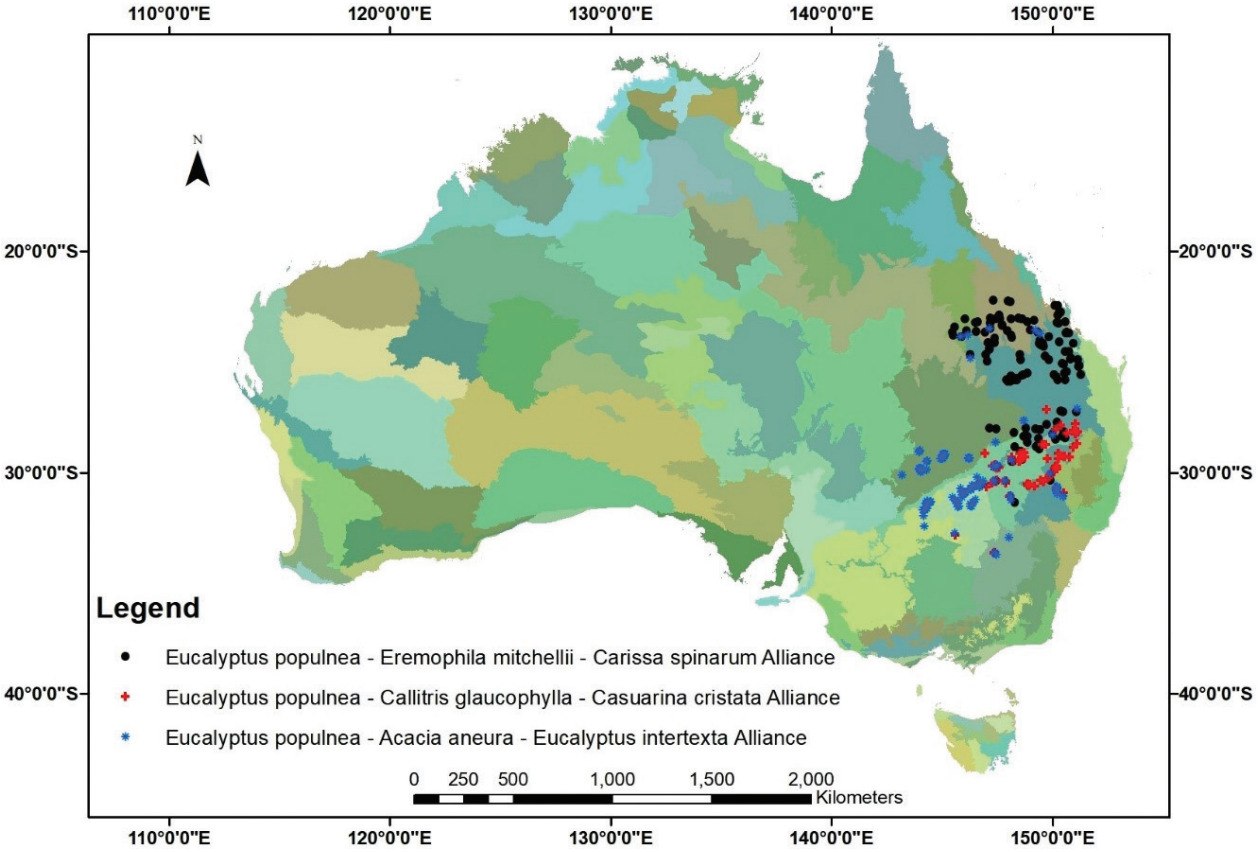


**Figure 1.** Location of plots from Poplar Box Woodlands in New South Wales and Queensland, Australia incorporated in analyses with proposed alliances. The boundaries of the bioregions of Australia from the IBRA version 7 (2012) are also shown.

plot size of 50 × 10 m. This plot size has been shown to adequately capture species richness in Eucalypt woodlands in Queensland (Neldner and Butler 2008). Within QLD plots, species were recorded using percent cover down to fractional percentages (0.1%). Plots surveyed within NSW most commonly were recorded using a modified six-point Braun-Blanquet cover abundance method (Westhoff and van der Maarel 1980) or percent cover and are of a 20 × 20 m dimension. Later protocols within NSW were changed to record percent cover down to 1%. Differences in recognised nomenclature were noted between jurisdictions. In order to assist compatibility across datasets, the following protocols were used; a) Braun-Blanquet scores were rescored to the mid-percent of each category, b) all fractional percentage scores were increased to a minimum of 1%, c) cover scores between strata of the same taxa were summed, d) nomenclature was standardised.

Primer E (ver. 7.0.11; Quest Research Limited; Ivybridge, Devon, UK) was used for data exploration, as commonly utilised within the target jurisdictions (e.g. Hunter and Lechner 2017; Addicott et al. 2018; Hunter and Hunter 2020; Muldavin et al. 2021). Due to the size of the dataset, an initial analysis was performed using kR-CLUSTER to generate major groups based on lowest stress (R = 0.77188). From this analysis three groups were defined, which were visually assessed secondarily via projection in 3-D using non-metric multidimensional scaling ordination (nMDS). The three groups were then separated for within group analysis. Removing sparse species from a dataset is also recommended (McCune and Grace 2002; Clarke et al. 2014). To avoid removing species which may occur infrequently but contribute a large component to the cover, species occurring only once and contributing 1% to the total cover across each of the major groups were removed.

Each of the major groups was analysed using the Bray-Curtis similarity co-efficient after square root transformation of cover values, and agglomerative hierarchical clustering was applied using group averaging. The similarity was profile tested using similarity profile analysis (SIMPROF) permutation tests (9999 iterations) in order to assess a relevant statistically significant cut-off dissimilarity for defining vegetation types at the association level. 3-D ordinations were generated using nMDS and defined groups were further assessed based on group projection and associated ordination stress. Where plots were found to be outliers within the group analyses, they were removed and placed within analyses of other groups to assess if the original analyses had caused a misallocation. Occasionally individual plots were reallocated to different proposed associations based on nMDS 3-D projection and visual assessment of species occurrence if they were deemed to have been misallocated during initial clustering. Once preliminary associations were

determined, all plots within each association were combined and their scores averaged to form a single sample. A further cluster, SIMPROF, and ordination was performed against all associations to determine higher level relatedness between groups.

Similarity percentage analysis (SIMPER) identifies the species that drive differences between selected types. SIMPER uses the Bray–Curtis similarity measure to identify positively and negatively diagnostic taxa across vegetation types. Taxa with combined high frequency and cover were also identified and listed for diagnostic purposes and type delineation.

### Alignment within the IVC hierarchy

The IVC schema is based on a hierarchy of natural physiognomic-ecological types at the upper levels, physiognomic-biogeographic-floristic characteristics at the middle levels and floristic-ecological characteristics at the lower level (Faber-Langendoen et al. 2016). For incorporation into the IVC hierarchy, expert knowledge and qualitative application of the criteria is often used at upper level, whereas quantitative analysis of plot-based data is used to distinguish vegetation types at the mid to lower levels (Faber-Langendoen et al. 2014). For the current study, allocation of proposed vegetation types into the IVC hierarchy was achieved by combining the key to IVC formation classes and brief definitions provided by Faber-Langendoen et al. (2016), the criteria of the IVC (Jennings et al. 2009; Faber-Langendoen et al. 2014) and expert knowledge with reference to environmental datasets and existing sub-continental scale vegetation classification systems. Sources of expert knowledge include publications by other authors, including Beadle (1981), Beeston (1980), Keith and Tozer (2017) and Neldner et al. (2019). In applying the key to IVC formation classes (Faber-Langendoen et al. 2016), we included scleromorphic trees in the mesomorphic tree concept, as the descriptions of Forest and Woodland (C01) and Shrub and Herb Vegetation (C02) formations include scleromorphic growth forms.

### Crosswalk of Plant Community Types and Regional Ecosystem types to associations

In order for the IVC to provide a link between classification systems used by different jurisdictions, we crosswalked existing PCTs from NSW and REs from QLD to the associations recognised in this study. To do this we did two things: (i) allocated REs to associations using the RE attribution in the metadata of CORVEG plots from QLD and allocated PCTs from NSW to associations based on the metadata held within BioNET (https://www.environment.nsw.gov.au/research/Visclassification.htm) (see Suppl. material 1), and (ii) listed REs and PCTs that would make up the *E. populnea* woodlands based on the descriptions given online (see Suppl. material 1). In addition to providing a cross-walk table between jurisdictional classifications, this enabled us to indicate REs and PCTs that are most likely to be part of the *E. populnea* woodlands. PCTs and REs are maintained on a searchable databases by the respective state governments (https://apps.des.QLD.gov.au/regional-ecosystems; https://www.environment.nsw.gov.au/research/Visclassification.htm; both accessed 27 June 2021). *Eucalyptus populnea* was used as a key search term to find all REs and PCTs where this species was used in describing types.

## Results

### Alignment with the IVC hierarchy

The *E. populnea* woodlands range in height from 8–16 metres and from 12–38% in cover and are dominated by scleromorphic trees. This puts it into the IVC formation class 1. Forest and Woodland. The *E. populnea* woodlands are referred to as occurring in the subtropical and sub-humid climate zones of Australia (Fensham et al. 2017; Keith and Tozer 2017) and both climate zones are included in the Warm Temperate climatic zone of the IVC (Faber-Langendoen et al. 2016). We therefore suggest they be placed within the formation 1.B.1 Warm Temperate Forest and Woodland of the IVC. This is supported by Eucalypt woodlands of Australia having been specifically identified as part of the Temperate Forest and Woodlands formation by Faber-Langendoen et al. (2016). This contrasts with Keith and Tozer (2017)'s placement of subtropical woodlands in Savanna, which they have aligned with 1.A.1 Tropical dry forest and/or woodland and 2.A.1 Tropical lowland, grassland and savanna IVC formations. Although the Eucalypt woodlands of Australia have been referred to in formation level descriptions of the IVC types (Faber-Langendoen et al. 2014), there is currently no formal recognition of the eucalypt dominated woodlands at the division and lower levels of the IVC hierarchy within the Warm Temperate Forest and Woodlands formation. There is, however, informal recognition of the woodlands suggesting an Australian division of 1.B.1.La.4 Australian Warm Temperate Subhumid Woodland which would accommodate the *E. populnea* woodlands (Faber-Langendoen pers comm 2020). Although the IVC protocols recommend quantitative analyses to determine the mid-levels of the hierarchy, based on the criteria and descriptions given for the mid-level IVC types (Faber-Langendoen et al. 2014) we suggest the "Brigalow Forests and Associated Eucalypt Woodlands of Subtropical Eastern Australia" (Fensham et al. 2017) would be placed as a 'macrogroup' within this division. This 'macrogroup' is identified by the diagnostic species of *Acacia harpophylla – Eucalyptus populnea – Eucalyptus crebra/melanophloia* occurring on deep soils formed predominantly on sedimentary rocks on the western side of the Great Dividing Range of eastern Australia. Within this the *E. populnea* woodlands match the criteria of a 'group', in having a limited set of diagnostic species

**Table 1.** Circumscription of Poplar Box Woodlands (*Eucalyptus populnea*) of New South Wales and Queensland within eastern Australia. Descriptions of the 3 alliances and 23 associations 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. Negative diagnostic taxa are those not found within plots and should not occur or only occasionally within the defined type.s Common taxa are listed in decreasing order of cumulative frequency and cover within each identified group. Non-native taxa are indicated by '*'.

| Hierarchy | Positive diagnostic (SIMPER) | Negative diagnostic (SIMPER) | Common taxa | Notes and distribution |
|---|---|---|---|---|
| **Alliance 1:** *Eucalyptus populnea – Eremophila mitchellii – Carissa spinarum / Heteropogon contortus – Eragrostis lacunaria* alliance | *Eremophila mitchellii*, *Cenchrus ciliaris**, *Panicum effusum*, *Carissa spinarum*, *Heteropogon contortus*, *Eragrostis lacunaria*, *Aristida calycina*, *Chrysopogon fallax*, *Bothriochloa decipiens*, *Fimbristylis dichotoma*, *Cyperus gracilis*, *Evolvulus alsinoides*. | *Austrostipa aristiglumis*, *Paspalidium jubiflorum*, *Sclerolaena muricata*, *Austrostipa scabra*, *Austrostipa verticillata*, *Callitris glaucophylla*, *Acacia aneura*, *Carex inversa*, | *Eremophila mitchellii*, *Cenchrus ciliaris*, *Heteropogon contortus*, *Eragrostis lacunaria*, *Themeda triandra*, *Carissa spinarum*, *Aristida calycina*, *Panicum effusum*, *Enneapogon lindleyanus*, *Bothriochloa decipiens*. | More common in the northern half of the distribution. Widespread from the Belyando Downs and northern Bowen Basin south to Castlereagh-Barwon region. Does not occur in the more western areas of NSW. |
| Association 1: *Eucalyptus populnea - E. tereticornis – E. crebra / Themeda triandra – Heteropogon contortus* | *Themeda triandra*, *Heteropogon contortus*, *Sida hackettiana*, *Eremophila debilis*, *Cyperus gracilis*, *Dichanthium sericeum*, *Dinebra decipiens*, *Eucalyptus tereticornis*, *Dichatnium foecundum*, *Eucalyptus cambageana*. | *Eremophila mitchellii*, *Cenchrus ciliaris**, *Chloris divaricata*, *Chloris ventricosa*, *Aristida calycina*, *Geijera parvifolia*, *Enteropogon acicularis*, *Enteropogon ramosus*, *Eucalyptus melanophloia*, *Thyridolepis xerophyila*. | *Themeda triandra*, *Heteropogon contortus*, *Aristida ramosa*, *Eucalyptus tereticornis*, *Eucalyptus crebra*, *Dinebra decipiens*, *Sporobolus creber*, *Dichanthium foecundum*, *Bothriochloa decipiens*, *Paspalum distans*. | Found on quaternary alluvial clay, sand, silt, and gravel. From Bloomsbury south of Proserpine south to Rockhampton west to Biloela in QLD. Brigalow Belt North, Brigalow Belt South and South East Queensland Bioregions. |
| Association 2: *Eucalyptus populnea – E. melanophloia – Corymbia dallachiana / Eremophila mitchellii – Archidendropsis basaltica* | *Eremophila mitchellii*, *Archidendropsis basaltica*, *Eragrostis leptocarpa*, *Chloris ventricosa*, *Eucalyptus melanophloia*, *Eragrostis tenella*, *Dodonaea viscosa*, *Corymbia dallachiana*, *Acacia leiocalyx*. | *Cenchrus ciliaris**, *Corymbia dallachyana*, *Heteropogon contortus*, *Bothriochloa decipiens*, *Chloris divaricata*, *Geijera parviflora*, *Eucalyptus crebra*, *Casuarina cristata*, *Paspalidium caespitosum*, *Eragrostis lacunaria*, *Enteropogon acicularis*. | *Eremophila mitchellii*, *Archidendropsis basaltica*, *Eragrostis leptocarpa*, *Chloris ventricosa*, *Eucalyptus melanophloia*, *Eragrostis tenellula*, *Bothriochloa ewartiana*, *Dodonaea viscosa*, *Aristida calycina*, *Corymbia dallachiana*. | Found on Quartzose to lithic sandstone, siltstone and shale. A restricted community with only a few characteristic sites located in the Rubyvale and Capella areas of eastern central QLD. Brigalow Belt North Bioregion. |
| Association 3: *Eucalyptus populnea / Eragrostis lacunaria – Aristida caput-medusae* | *Eragrostis lacunaria*, *Aristida caput-medusae*, *Eragrostis sororia*, *Cyanthillium cinereum*, *Dinebra decipiens*, *Enneapogon lindleyanus*, *Heteropogon contortus*, *Aristida queenslandica*, *Dodonaea viscosa*, *Eriochloa fatmensis*, *Enteropogon unispiceus*. | *Cenchrus ciliaris*, *Themeda triandra*, *Bothriochloa decipiens*, *Chloris ventricosa*, *Aristida calycina*, *Geijera parviflora*, *Casuarina cristata*, *Paspalidium caespitosum*. | *Eragrostis lacunaria*, *Aristida lignosa*, *Aristida caput-medusae*, *Dodonaea viscosa*, *Melinis repens**, *Eriochloa fatmensis*, *Enteropogon unispeceus*, *Eragrostis sororia*, *Aristida queenslandica*, *Enneapogon lindleyanus*. | Found on pebbly quart sandstone, conglomerate, shale, and siltstone. Restricted to the Brigalow Belt North within the Springsure and Fairburn State Forest area. Brigalow Belt North Bioregion. |
| Association 4: *Eucalyptus populnea – Casuarina cristata – E. largiflorens / Thyridolepis xerophila – Aristida jerichoensis* | *Eremophila mitchellii*, *Casuarina cristata*, *Aristida jerichoensis*, *Thyridolepis xerophila*, *Acacia aneura*, *Eucalyptus largiflorens*. | *Bothriochloa decipiens*, *Heteropogon contortus*, *Geijera parviflora*, *Aristida calycina*, *Chloris ventricosa*, *Enteropogon acicularis*, *Paspalidium caespitosum*, *Dichanthium sericeum*, *Cyperus gracilis*. | *Casuarina cristata*, *Thyridolepis xerophila*, *Acacia aneura*, *Eucalyptus largiflorens*, *Cenchrus ciliaris**, *Chloris divaricata*, *Eremophila mitchellii*, *Aristida jerichoensis*, *Eucalyptus melanophloia*, *Themeda triandra*. | Found on Tertiary-Quaternary and Cainozoic sands and weathered sandstones. Widespread occurrences from Mt Wyatt area to Alpha and south to Bollon, St George, Texas in QLD and south to the Walgett (Wilgavale) area of NSW. Brigalow Belt North, Brigalow Belt South, Desert Uplands and Mulga Lands Bioregions. |
| Association 5: *Eucalyptus populnea – Corymbia clarksoniana / Cassia brewsteri – Carissa spinarum* | *Cassia brewsteri*, *Evolvulus alsinoides*, *Stylosanthus scabra*, *Paspalidium gracile*, *Carissa spinarum*, *Chrysopogon fallax*, *Denhamia cunninghamii*, *Aristida calycina*, *Bothriochloa decipiens*, *Corymbia clarksoniana*, *Eragrostis sororia*. | *Chloris divaricata*, *Geijera parviflora*, *Paspalidium caespitosum*, *Casuarina cristata*, *Enteropogon acicularis*, *Eucaliptus melanophloia*, *Dichanthium sericeum*, *Thyridolepis xerophila*, *Cymbopogon refractus*, *Aristida ramosa*. | *Chloris ventricosa*, *Cenchrus ciliaris*, *Aristida calycina*, *Paspalidium gracile*, *Chrysopogon fallax*, *Stylosanthus scabra*, *Bothriochloa decipiens*, *Abutilon oxycarpum*, *Panicum effusum*, *Carissa spinarum*, *Cassia brewsteri*. | Found on soils from deep sands. In the Logan and Peak Downs area of the Bowen Basin of the Brigalow Belt North within QLD. |
| Association 6: *Eucalyptus populnea / Bothriochloa decipiens – Chloris divaricata* | *Cyperus gracilis*, *Bothriochloa decipiens*, *Aristida calycina*, *Brunoniella australis*, *Cymbopogon refractus*, *Eremophila mitchellii*, *Cenchrus ciliaris**, *Sida hackettiana*, *Chloris divaricata*, *Cyanthillium cinereum*, *Chloris ventricosa*, *Heteropogon contortus*. | *Geijera parviflora*, *Casuarina cristata*, *Aristida personata*, *Thyridolepis xerophila*, *Acacia aneura*, *Triodia pungens*. | *Cenchrus ciliaris**, *Chloris divaricata*, *Chloris ventricosa*, *Heteropogon contortus*, *Bothriochloa decipiens*, *Aristida calycina*, *Eremophila mitchellii*, *Dichanthium sericeum*, *Paspalidium caespitosum*, *Cymbopogon refractus*. | One of the most widespread associations occurring within QLD. From Rockhampton west to Barcaldine and Tambo and south to Taroom and Gayndah with a contracted occurrence around Dalby to Tara and south to Goondiwindi. Found on Quaternary sand, silt, clay, and gravel in floodplains and alluvial fans. Also known from granites and porphyrite. Brigalow Belt North, Brigalow Belt South and Desert Uplands. |

| Hierarchy | Positive diagnostic (SIMPER) | Negative diagnostic (SIMPER) | Common taxa | Notes and distribution |
|---|---|---|---|---|
| Association 7: *Eucalyptus populnea – Casuarina cristata – Acacia harpophylla / Eremophila mitchellii – Geijera parviflora* | *Eremophila mitchellii*, *Geijera parviflora*, *Enteropogon acicularis*, *Abutilon oxycarpum*, *Sporobolus caroli*, *Cenchrus ciliaris**, *Eragrostis lacunaria*, *Enchylaena tomentosa*, *Boerhavia dominii.* | *Themeda triandra*, *Heteropogon contortus*, *Carissa spinarum*, *Eucalyptus melanophloia*, *Melinis repens**, *Sida hackettiana.* | *Eremophila mitchellii*, *Geijera parviflora*, *Cenchrus ciliaris**, *Enteropogon acicularis*, *Bothriochloa decipiens*, *Acacia harpophylla*, *Paspalidium caespitosum*, *Sporobolus caroli*, *Casuarina cristata*, *Paspalidium constrictum*, *Ancistrachne uncinata.* | A common association from Clermont in QLD south in an arc from Taroom to Mitchell, Tara, Goondiwindi, St George in QLD and further south to Lightning Ridge, Narrabri and north of Gilgandra in NSW. Known from Quaternary alluvia of clay, sand, silt, and gravel and sandstones. Brigalow Belt North, Brigalow Belt South, Darling Riverine Plains, Mulga Lands. |
| Association 8: *Eucalyptus populnea – E. melanophloia / Triodia pungens – Triodia mitchellii* (*Cenchrus ciliaris**) | *Cenchrus ciliaris**, *Eremophila mitchellii*, *Eragrostis lacunaria*, *Archidendropsis basaltica*, *Enneapogon lindleyanus*, *Psydrax oleifolia*, *Geijera parviflora*, *Triodia pungens*, *Carissa lanceolata*, *Triodia mitchellii*, *Eriachne mucronata.* | *Bothriochloa decipiens*, *Chloris divaricata*, *Chloris ventricosa*, *Casuarina cristata*, *Paspalidium caespitosum*, *Cyperus gracilis*, *Aristida ramosa.* | *Cenchrus ciliaris**, *Melinis repens**, *Triodia pungens*, *Eucalyptus melanophloia*, *Thyridolepis xerophylla*, *Heteropogon contortus*, *Aristida calycina*, *Carissa lanceolata*, *Eremophila mitchellii*, *Aristida jerichoensis.* | Restricted to QLD and most common South of Mt Coolon to Blackwater, Springsure, Tambo, and west to Barcaldine with a disjunct occurrence near Nindgully and Thallon south to Engonia in NSW. Found on sand sheets, red hard setting sandy clay, aeolian sands and sandstone. Brigalow Belt North, Brigalow Belt South and Desert Uplands Bioregion. |
| Association 9: *Eucalyptus populnea – Eucalyptus crebra / Carissa spinarum – Alectryon diversifolius* | *Cenchrus ciliaris**, *Carissa spinarum*, *Bothriochloa decipiens*, *Eucalyptus crebra*, *Enneapogon lindleyanus*, *Erythroxylum australe*, *Alectryon diversifolius.* | *Heteropogon contortus*, *Chloris divaricata*, *Chloris ventricosa*, *Geijera parviflora*, *Paspalidium caespitosum*, *Casuarina cristata*, *Enteropogon acicularis*, *Cymbopogon refractus*, *Eucalyptus melanophloia*, *Dichanthium sericeum*, *Thyridolepis xerophila.* | *Cenchrus ciliaris**, *Carissa spinarum*, *Bothriochloa decipiens*, *Eremophila mitchellii*, *Themeda triandra*, *Enneapogon lindleyanus*, *Eucalyptus crebra*, *Erythroxylum australe*, *Alectryon diversifolius*, *Chloris truncata.* | Found primarily within the Yeppoon, Mirandbah, Clermont, and south to Moura region of QLD. Found on deeply weathered course grained sandstone, Quaternary and Tertiary alluvia and sediments. Brigalow Belt North and Brigalow Belt South Bioregions. |
| **Alliance 2:** *Eucalyptus populnea – Callitris glaucophylla – Casuarina cristata / Geijera parviflora – Eremophila mitchellii* alliance | *Geijera parviflora*, *Callitris glaucophylla*, *Cyperus gracilis*, *Austrostipa scabra*, *Eremophila mitchellii*, *Brunoniella australis*, *Einadia nutans*, *Casuarina cristata*, *Abutilon oxycarpum*, *Maireana microphylla*, *Enchylaena tomentosa*, *Cheilanthes sieberi.* | *Austrostipa aristiglumis*, *Paspalidium jubiflorum*, *Sclerolaena muricata*, *Acacia aneura.* | *Eremophila mitchellii*, *Callitris glaucophylla*, *Geijera parviflora*, *Austrostipa scabra*, *Einadia nutans*, *Sclerolaena birchii*, *Cyperus gracilis*, *Enteropogon acicularis*, *Casuarina cristata*, *Calotis lappulacea* *Eucalyptus largiflorens*, *Carissa spinarum.* | Primarily restricted to the central and eastern parts of the range. Most common from Carbelago region of the Cobar Peneplain to the Tara Downs and Inglewood Sandstone region. |
| Association 10: *Eucalyptus populnea – Acacia harpophylla – Casuarina cristata / Geijera parviflora – Eremophila glabra* | *Acacia harpophylla*, *Setaria paspalidioides*, *Abutilon oxycarpum*, *Apophyllum anomalum*, *Austrostipa setacea*, *Brachyscome dentata*, *Brunoniella australis*, *Einadia nutans*, *Enchylaena tomentosa*, *Eremophila mitchellii.* | *Eremophila mitchellii*, *Callitris glaucophylla*, *Austrostipa scabra*, *Sclerolaena birchii*, *Einadia nutans*, *Enteropogon acicularis*, *Calotis cuneifolia*, *Paspalidium constrictum*, *Eucalyptus largiflorens*, *Eremophila debilis.* | *Acacia harpophylla*, *Brachyscome ciliaris*, *Setaria paspalidioides*, *Geijera parviflora*, *Enchylaena tomentosa*, *Casuarina cristata*, *Sporobolus caroli*, *Rytidosperma longifolium*, *Eremophila glabra*, *Eremophila mitchellii.* | Found as disjunct distributions within the northern Pilliga Outwash south west to Culgoa in NSW and north to the Expedition and Carnarvon Ranges usually on gilgai clay soils. Brigalow Belt South, Darling Riverine Plains and Mulga Lands Bioregions. |
| Association 11: *Eucalyptus populnea – Callitris glaucophylla – E. melanophloia / Calotis cuneifolia - Pimelea trichostachya* | *Callitris glaucophylla*, *Calotis cuneifolia*, *Pimelea trichostachya*, *Einadia nutans*, *Calandrinia eremaea*, *Sida cunninghamii*, *Fimbristylis dichotoma*, *Austrostipa scabra*, *Chenopodium curvispicatum*, *Glossocardia bidens*, *Rhodanthe moschata*, *Euphorbia drummondii.* | *Eremophila mitchellii*, *Geijera parviflora*, *Sclerolaena birchii*, *Einadia nutans*, *Enteropogon acicularis*, *Casuarina cristata*, *Paspalidium constrictum*, *Eucalyptus largiflorens*, *Chenopodium desertorum.* | *Callitris glaucophylla*, *Dodonaea viscosa*, *Pimelea trichostachya*, *Calotis cuneifolia*, *Cheilanthes sieberi*, *Eucalyptus melanophloia*, *Centipeda cunninghamii*, *Aristida ramosa*, *Dysphania melanocarpa*, *Glycine canescens.* | Known from Collarenebri, the Narran Lakes region and Culgoa Floodplains. Occurring on low lying clay floodplains. Brigalow Belt South, Darling Riverine Plains and Mulga Lands Bioregions. |
| Association 12: *Eucalyptus populnea – Allocasuarina luehmannii – Callitris glaucophylla / Cymbopogon refractus – Aristida* spp. | *Allocasuarina luehmannii*, *Cymbopogon refractus*, *Callitris glaucophylla*, *Brunoniella australis*, *Aristida caput-medusae*, *Chloris divaricata*, *Aristida ramosa*, *Eucalyptus conica*, *Aristida jerichoensis*, *Paspalidium caespitosum.* | *Eremophila mitchellii*, *Sclerolaena birchii*, *Einadia nutans*, *Enteropogon acicularis*, *Paspalidium constrictum*, *Chenopodium desertorum.* | *Cymbopogon refractus*, *Allocasuarina luehmannii*, *Eucalyptus largiflorens*, *Callitris glaucophylla*, *Chloris divaricata*, *Aristida ramosa*, *Austrostipa scabra*, *Aristida caput-medusae*, *Geijera parviflora*, *Eucalyptus crebra.* | Found within southern QLD from Glenmorgan south to Texas. Known from Quaternary alluvia, sand sheets, clayey sandstone and aeolian sands. Primarily within the Brigalow Belt South but also within the Nandewar Bioregion. |
| Association 13: *Eucalyptus populnea – Casuarina cristata – Allocasuarina luehmannii / Aristida scabra – Cymbopogon refractus* | *Austrostipa scabra*, *Cyperus gracilis*, *Eremophila debilis*, *Dichanthium sericeum*, *Leptochloa ciliolata*, *Abutilon oxycarpum*, *Aristida caput-medusae*, *Cymbopogon refractus*, *Sporobolus creber*, *Casuarina cristata*, *Chloris truncata.* | *Sclerolaena birchii*, *Calotis cuneifolia*, *Eucalyptus largiflorens*, *Eucalyptus melanophloia*, *Paspalidium constrictum*, *Chenopodium desertorum.* | *Cymbopogon refractus*, *Aristida caput-medusae*, *Austrostipa scabra*, *Cyperus gracilis*, *Leptochloa ciliolata*, *Dichanthium sericeum*, *Callitris glaucophylla*, *Allocasuarina luehmannii*, *Eremophila debilis*, *Notelaea microcarpa.* | Found within NSW from Croppa Creek south to Terry Hie Hie. Generally, on sandy clays or within and surrounding small wetlands on sandy clay or loamy clay soils. Brigalow Belt South Bioregion. |

| Hierarchy | Positive diagnostic (SIMPER) | Negative diagnostic (SIMPER) | Common taxa | Notes and distribution |
|---|---|---|---|---|
| Association 14: *Eucalyptus populnea – Eucalyptus albens – Eucalyptus blakelyi / Eremophila mitchellii – Carisa spinarum* | *Carissa spinarum*, *Notelaea microcarpa*, *Cheilanthes distans*, *Eucalyptus albens*, *Acacia deanei*, *Chloris ventricosa*, *Psydrax odoratum*, *Eucalyptus blakelyi*, *Teucrium junceum*. | *Austrostipa scabra*, *Sclerolaena birchii*, *Enteropogon acicularis*, *Calotis cuneifolia*, *Eucalyptus largiflorens*, *Chenopodium desertorum*, *Calotis lappulacea*. | *Geijera parviflora*, *Eremophila mitchellii*, *Carissa spinarum*, *Casuarina cristata*, *Notelaea microcarpa*, *Cheilanthes distans*, *Callitris glaucophylla*, *Eucalyptus melanophloia*, *Eucalyptus albens*, *Chloris ventricosa*. | Known from north of Millmerran in QLD south to Narrabri and west to the western Pilliga outwash near Gwabegar in NSW. Known from sandy clays or loam clay outwash plains and around small wetlands within broader sandy soils landscapes. Brigalow Belt South Bioregion. |
| Association 15: *Eucalyptus populnea – Callitris glaucophylla – Casuarina cristata / Geijera parviflora – Eremophila mitchellii* | *Geijera parviflora*, *Eremophila mitchellii*, *Austrostipa scabra*, *Callitris glaucophylla*, *Sclerolaena birchii*, *Einadia nutans*, *Chenopodium desertorum*. | *Cyperus gracilis*, *Carissa spinarum*, *Cymbopogon refractus*, *Acacia harpophylla*, *Cadellia pentastylis*, *Notelaea microcarpa*, *Enchylaena tomentosa*, *Aristida ramosa*. | *Geijera parviflora*, *Eremophila mitchellii*, *Carissa spinarum*, *Casuarina cristata*, *Notelaea microcarpa*, *Cheilanthes distans*, *Callitris glaucophylla*, *Eucalyptus albens*, *Eucalyptus melanophloia*, *Chloris ventricosa*. | Known from south of Texas, Mungindi and Lightning Ridge to Gunnedah in the east and Brewarrina in the west and as far south as Mount Hope and Lake Cowal. Association with clay and cracking clay alluvial soils within floodplains Brigalow Belt South and Darling Riverine Plains Bioregions. |
| Association 16: *Eucalyptus populnea – Callitris glaucophylla – Cadellia pentastylis / Geijera parviflora – Carissa spinarum* | *Callitris glaucophylla*, *Cyperus gracilis*, *Brunoniella australis*, *Austrostipa scabra*, *Calotis lappulacea*, *Aristida personata*, *Geijera parviflora*, *Lomandra multflora*, *Sida corrugata*, *Evolvulus alsinoides*, *Austrostipa verticillata*, *Boerhavia dominii*, *Maireana microphylla*, *Notelaea microcarpa*, *Acacia deanei*. | *Eremophila mitchellii*, *Geijera parviflora*, *Einadia nutans*, *Enteropogon acicularis*, *Eucalyptus largiflorens*, *Chenopodium desertorum*. | *Callitris glaucophylla*, *Austrostipa scabra*, *Cyperus gracilis*, *Carissa spinarum*, *Cadellia pentastylis*, *Aristida personata*, *Eucalyptus pilligaensis*, *Acacia decora*, *Chloris truncata*, *Dichondra* sp. A. | A similar geographic distribution of association 15 but occurring on higher parts of the landscape on clay loam and sandy clay loam soils. Nandewar, Brigalow Belt South and Darling Riverine Plains Bioregions. |
| **Alliance 3:** *Eucalyptus populnea – Acacia aneura – Eucalyptus intertexta / Enteropogon acicularis – Austrostipa verticillata* alliance | *Acacia aneura*, *Enteropogon acicularis*, *Austrostipa verticillata*, *Dodonaea viscosa*, *Paspalidium jubiflorum*, *Senna zygophylla*, *Carex inversa*, *Eremophila sturtii*, *Austrostipa aristiglumis*, *Eucalyptus intertexta*. | *Eremophila mitchellii*, *Callitris glaucophylla*, *Cenchrus ciliaris**, *Austrostipa scabra*, *Sclerolaena birchii*, *Cyperus gracilis*, *Einadia nutans*, *Themeda triandra*, *Carissa spinarum*. | *Acacia aneura*, *Eremophila mitchellii*, *Geijera parviflora*, *Enteropogon acicularis*, *Austrostipa verticillata*, *Senna zygophylla*, *Carex inversa*, *Paspalidium jubiflorum*, *Austrostipa aristiglumis*, *Dodonaea viscosa*. | Occurring throughout the range but more common in more western regions. Occurring as far west as the Ursino Sandplains. |
| Association 17: *Eucalyptus populnea / Paspalidium jubiflorum – Sclerolaena muricata* | *Medicago polymorpha**, *Rapistrum rugosum**, *Hordeum glaucum*, *Paspalidium jubiflorum*, *Sclerolaena muricata*, *Austrostipa aristiglumis*. | *Acacia aneura*, *Eremophila mitchellii*, *Geijera parviflora*, *Senna zygophylla*, *Carex inversa*, *Dodonaea viscosa*, *Eremophila sturtii*, *Eucalyptus intertexta*, *Casuarina cristata*, *Callitris glaucophylla*. | *Austrostipa aristiglumis*, *Medicago polymorpha**, *Hordeum glaucum**, *Paspalidium jubiflorum*, *Lolium perenne**, *Rapistrum rugosum**, *Sclerolaena muricata*, *Enteropogon acicularis*, *Sisymbrium erysimoides**, *Malva parviflora**. | Found in the Gunnedah and Boggabri regions on alluvial clay loam and loamy clay soils. An association of heavily grazed and disturbed soils with many associated introduced species. |
| Association 18: *Eucalyptus populnea – Casuarina cristata – Eucalyptus camaldulensis / Austrostipa verticillata – Paspalidium jubiflorum* | *Carex inversa*, *Austrostipa verticillata*, *Paspalidium jubiflorum*, *Casuarina cristata*, *Cynodon dactylon*, *Austrostipa scabra*, *Paspalidium constrictum*, *Phyla canescens**, *Enteropogon acicularis*, *Sonchus oleraceus**, *Sisymbrium erysimoides**, *Sclerolaena muricata*. | *Acacia aneura*, *Eremophila mitchellii*, *Geijera parviflora*, *Dodonaea viscosa*, *Austrostipa aristiglumis*, *Eremophila sturtii*, *Eucalyptus intertexta*, *Senna filifolia*. | *Austrostipa verticillata*, *Carex inversa*, *Cynodon dactylon*, *Casuarina cristata*, *Paspalidium jubiflorum*, *Enteropogon acicularis*, *Austrostipa scabra*, *Paspalidium constrictum*, *Phyla canescens**, *Lolium perenne**, *Eucalyptus camaldulensis*, *Eucalyptus melliodora*. | Widespread from Dalby in QLD south as far west as Yantabulla and east to Gunnedah and as far south as Lake Cowal in NSW. generally found clay, clay loam and loamy clay soils but often higher parts of floodplains. Brigalow Belt South, Darling Riverine Plains, Mulga Lands and NSW South Western Slopes Bioregions. |
| Association 19: *Eucalyptus populnea – Eucalyptus crebra – Allocasuarina luehmannii / Austrostipa aristiglumis – Sporobolus mitchellii* | *Austrostipa aristiglumis*, *Centipeda thespidioides*, *Allocasuarina luehmannii*, *Eucalyptus crebra*, *Sporobolus mitchellii*, *Corymbia clarksoniana*, *Rorippa eustylis**, *Panicum laevinode*. | *Eremophila mitchellii*, *Geijera parviflora*, *Enteropogon acicularis*, *Austrostipa verticillata*, *Paspalidium jubiflorum*, *Dodonaea viscosa*, *Senna zygophylla*, *Eremophila sturtii*. | *Austrostipa aristiglumis*, *Centipeda thespidioides*, *Allocasuarina luehmannii*, *Eucalyptus crebra*, *Sporobolus mitchellii*, *Panicum laevinode*, *Corymbia clarksoniana*, *Rorippa eustylis**, *Austrostipa nitida*. | Widespread but disjunct occurrences from west of Duaringa to east of Alpha in QLD and from Gunnedah and Parkes in the east to Yantabulla and east of Wilcannia in NSW. Associated with and fringing ephemeral wetlands usually on clay soils. Brigalow Belt North, Brigalow Belt South, Mulga Lands, NSW South Western Slopes and Murray Darling Depression Bioregions. |

| Hierarchy | Positive diagnostic (SIMPER) | Negative diagnostic (SIMPER) | Common taxa | Notes and distribution |
|---|---|---|---|---|
| Association 20: *Eucalyptus populnea – Eucalyptus intertexta – Acacia aneura / Eremophila mitchellii – Geijera parviflora* | *Eremophila mitchellii*, *Geijera parviflora*, *Acacia aneura*, *Eucalyptus intertexta*, *Dodonaea viscosa*, *Cenchrus ciliaris**, *Senna sturtii.* | *Austrostipa verticillata*, *Paspalidium jubiflorum*, *Carex inversa*, *Austrostipa aristiglumis*, *Casuarina cristata*, *Senna filifolia*, *Acacia brachystachya.* | *Eremophila mitchellii*, *Geijera parviflora*, *Acacia aneura*, *Eucalyptus intertexta*, *Dodonaea viscosa*, *Callitris glaucophylla*, *Senna zygophylla*, *Enteropogon acicularis*, *Acacia excelsa*, *Senna sturtii.* | Most commonly restricted to the more western districts. Found from south of Barcaldine to Tambo and St George to Goondiwindi in QLD and within NSW from Ledknapper Carinda south to Cobar. Generally associated with low lying ephemerally wet areas within higher landscape elements. Desert Uplands, Brigalow Belt South, Mulga Lands, Darling Riverine Plains and Cobar Peneplain. |
| Association 21: *Eucalyptus populnea – Acacia aneura – Acacia brachystachya / Senna* spp. – *Eremophila gilesii* | *Acacia aneura*, *Cheilanthes sieberi*, *Tripogon loliiformis*, *Senna zygophylla*, *Acacia brachystachya*, *Eragrostis eriopoda*, *Eremophila gilesii*, *Fimbristylis dichotoma*, *Eragrostis laniflora.* | *Austrostipa verticillata*, *Paspalidium jubiflorum*, *Carex inversa*, *Austrostipa aristiglumis*, *Casuarina cristata*, *Cynodon dactylon*, *Sclerolaena birchii.* | *Acacia aneura*, *Senna zygophylla*, *Cheilanthes sieberi*, *Senna filifolia*, *eragrostis eriopoda*, *Geijera parviflora*, *Enteropogon acicularis*, *Eremophila sturtii*, *Acacia brachystachya*, *Eremophila gilesii.* | Restricted to far western areas of NSW from Narran Lake south to Cobar to west of Hungerford and Wannaring. This assemblage is generally found growing around small ephemeral semi-arid wetlands and small ephemeral creeklines. Often on clay soils. Brigalow Belt South, Mulga Lands, Cobar Peneplain and Murray Darling Depression Bioregions. |
| Association 22: *Eucalyptus populnea / Enchylaena tomentosa – Dissocarpus paradoxus* | *Enchylaena tomentosa*, *Dissocarpus paradoxus*, *Senna filifolia*, *Carractera annua**, *Duma florulenta*, *Roepera similis.* | *Acacia aneura*, *Eremophila mitchellii*, *Geijera parviflora*, *Austrostipa verticillata*, *Senna zygophylla*, *Carex inversa*, *Austrostipa aristiglumis*, *Eucalyptus intertexta*, *Callitris glaucophylla*, *Casuarina cristata.* | *Sisymbrium erysimoides**, *Medicago laciniata** *Enchylaena tomentosa*, *Dissocarpus paradoxus*, *Carrichtera annua**, *Senna filifolia*, *Eremophila sturtii*, *Duma florulenta*, *Dodonaea viscosa*, *Roepera similis*, *Sclerolaena birchii*, *Enteropogon acicularis*, *Salvia verbenaca*.* | Found only in the most western extent of *Eucalyptus populnea* distribution in NSW. From Yantabulla in the north, south to Wanaaring and the Paroo Darling wetlands to north of Ivanhoe. Restricted to shallow ephemeral semi-arid wetlands. Usually on clay soils. Mulga Lands and Murray Darling Depression Bioregions. |
| Association 23: *Eucalyptus populnea / Sclerolaena birchii – Eragrostis lacunaria* | *Sclerolaena birchii*, *Sida trichopoda*, *Eragrostis lacunaria*, *Nicotiana simulans*, *Teucrium racemosa*, *Centipeda thespidioides*, *Cyperus iria*, *Wahlenbergia gracilis*, *Stemodia florulenta*, *Marsilea costulifera*, *Sporobolus actinocladus*, *Tetragonia moorei.* | *Acacia aneura*, *Eremophila mitchellii*, *Geijera parviflora*, *Enteropogon acicularis*, *Austrostipa verticillata*, *Paspalidium jubiflorum*, *Senna zygophylla*, *Dodonaea viscosa*, *Carex inversa*, *Austrostipa aristiglumis.* | *Wahlenbergia gracilis*, *Cyperus iria*, *Sclerolaena birchii*, *Eragrostis lacunaria*, *Stemodia florulenta*, *Teucrium racemosum*, *Sporobolus actinocladus*, *Tetragonia moorei*, *Nicotiana simulans*, *Enchylaena tomentosa.* | Restricted to western NSW from Narran Lakes west to Yantabulla and Wanaaring and south to Yathong. Restricted to the margins of ephemeral semi-arid wetlands and small ephemeral semi-arid creeklines. Brigalow Belt South, Mulga Lands and Cobar Peneplains Bioregions. |

(*E. populnea*, *Callitris glaucophylla* and *Acacia aneura*), a diagnostic growth form (trees) with broadly similar composition, and a distribution that reflects a regional mesoclimate and soil characteristics (sub-humid / subtropical climate and largely on soils with sodic sub-soils; Fensham et al. 2017). We propose that the major vegetation types within this *E. populnea* woodlands group are alliances and describe the vegetation types within those alliances as associations. Confirming these proposed mid-levels of the hierarchy using plot-based data remains to be done.

## Vegetation types

Analysis of our data of 455 plots in which *Eucalyptus populnea* was a major component of the canopy enabled us to define three interim alliances and 23 associations. We propose the types as interim and refrain from adding proper formal and colloquial names that are generally provided for alliances and associations within the IVC as we would prefer standardised naming to be provided based on a wider decision-making process than the authors alone. Table 1 highlights for each community type the positive and negative diagnostic taxa, along with their most common taxa (i.e., those with high summed cover) (Suppl. material 2 and 3). The *Eucalyptus populnea – Eremophila mitchellii – Carissa spinarum / Heteropogon contortus – Eragrostis lacunaria* alliance (Figure 2), primarily of the Brigalow Belt (IBRA7; Thackway and Cresswell 1995), was prominent in QLD and incorporated most of the plots from this state. It was generally widespread

**Figure 2.** *Eucalyptus populnea – Eremophila mitchellii – Carissa spinarum / Heteropogon contortus – Eragrostis lacunaria* alliance.

**Figure 3.** *Eucalyptus populnea – Callitris glaucophylla – Casuarina* spp. */ Geijera parviflora – Eremophila mitchellii* alliance.

**Figure 4.** *Eucalyptus populnea – Acacia aneura – Eucalyptus intertexta / Enteropogon acicularis – Austrostipa verticillata* alliance.

across the whole geographic range of *Eucalyptus populnea* and contains nine associations. The *Eucalyptus populnea – Callitris glaucophylla – Casuarina* spp. */ Geijera parviflora – Eremophila mitchellii* alliance (Figure 3) contains seven associations, and it was primarily restricted to southern QLD, though also found in the most southern locations sampled within the range of *Eucalyptus populnea*. This alliance was commonly found within the Brigalow Belt South and the Darling Riverine Plains Bioregions and thus had general south easterly distribution (IBRA7; Thackway and Cresswell 1995). The *Eucalyptus populnea – Acacia aneura – Eucalyptus intertexta / Enteropogon acicularis – Austrostipa verticillata* alliance (Figure 4) also includes seven associations and while occurring across the entire geographic range sampled, was primarily found in the most western semi-arid districts of southwestern QLD and northwestern NSW and the only alliance distributed in these areas (Figure 4).

Although the listing advice for the endangered Poplar Box Grassy Woodlands on Alluvial Plains only includes the six REs 11.3.2, 11.3.17, 11.4.7, 11.4.12, 12.3.10, and the four PCTs 56, 87, 101, and 244 (https://www.environment.gov.au/cgi-bin/sprat/public/publicshowcommunity.pl?id=141&status=Endangered), there are fifteen PCTs and 34 REs that have *Eucalyptus populnea* as a diagnostic species within the title or detailed descriptions of the type (Suppl. material 1). All of these types were found to correspond to our associations directly or in part within our classification. Thus, all described *Eucalyptus populnea* dominant PCTs or REs were sampled and incorporated within our analyses (Table 2). However, a few of our defined associations had no direct correlates and thus could not be placed within the current state-based classifications (association 19, 22 and 23; Tables 1 and 2) and thus may require new RE and PCT designations. Many of the defined PCTs had a 1:1 or a 2:1 relationship with our defined types. Only association 20 appeared to incorporate multiple PCTs (6 in total) suggesting this PCT maybe overly split at the association level. There was less correlation found between the NSW classes and formations compared to that found for PCTs and there is little direct relationship between REs and our proposed types, with most associations having multiple REs (up to 13), as potentially synonymous. Additionally, REs were found to occur across multiple associations. RE 11.3.2 in particular was found to be attributed to nearly half of our associations (9 in total) and to all three alliances, and it is listed as an assemblage that typifies the listed endangered Poplar Box Grassy Woodlands on Alluvial Plains (Table 2). Thirteen of the associations defined here are synonymous with the nine REs and PCTs contained in the listing advice for the endangered Poplar Box Woodlands. Based on our analysis the listing of the endangered Poplar Box Grassy Woodland on Alluvial Plains does not correspond to any particular level of a classification hierarchy and incorporates multiple associations and crosses alliances but not in a consistently applicable way. We also found that at the RE and PCT diagnostic level some areas that could be included or excluded as part of the endangered community in one state would not in the other if based purely on the listed REs considered synonymous. Thus, from a floristic perspective there is a lack congruence within the current definition of the listed endangered community and plot-based analyses but also between jurisdictions if using PCTs and REs. Basing listed communities on plot-based classifications could present a better approach and allow for greater cross jurisdictional alignment when categorising what is and isn't included in the definition on ground.

## Discussion

Here we present one of the few examples of cross jurisdictional vegetation classification analyses that have been conducted within Australia. Our results highlight two issues; firstly, the difficulty in trying to align vegetation types across borders when such divergent systems are used (in this case between NSW and QLD), particularly when it involves the determination of an endangered ecological community, and secondly, the benefits of using a hierarchical quantitative plot-based classification system that identifies the relationships between ecological com-

**Table 2.** Legacy existing classification equivalents to plant associations proposed under the IVC hierarchy in this study. Plant Community Types (PCT), class and formation are part of the current New South Wales vegetation classification schema; Regional Ecosystems (RE) comprise the Queensland equivalent of associations.

| Hierarchy Level and Type | NSW (PCT/Class/Formation) Classification | QLD (RE) Classification |
|---|---|---|
| **Alliance 1:** *Eucalyptus populnea – Eremophila mitchellii – Carissa spinarum / Heteropogon contortus – Eragrostis lacunaria* alliance | | |
| Association 1: *Eucalyptus populnea – E. tereticornis – E. crebra / Themeda triandra – Heteropogon contortus* | NA | 11.3.2; 11.5.1; 11.8.15; 11.11.9; 12.3.10; 12.12.26 |
| Association 2: *Eucalyptus populnea – E. melanophloia – Corymbia dallachiana / Eremophila mitchellii – Archidendropsis basaltica* | NA | 11.10.7; 11.4.2 |
| Association 3: *Eucalyptus populnea / Eragrostis lacunaria – Aristida caput-medusae* | NA | 11.10.12. |
| Association 4: *Eucalyptus populnea – Casuarina cristata – E. largiflorens / Thyridolepis xerophila – Aristida jerichoensis* | PCT87; PCT 55. North west Floodplain - Woodlands Semi-arid Woodlands Grassy sub-formation. | 6.5.2; 10.5.12; 11.4.10; 11.5.3; 11.5.13 |
| Association 5: *Eucalyptus populnea – Corymbia clarksoniana / Cassia brewsteri – Carissa spinarum* | NA | 11.5.3; 11.10.12 |
| Association 6: *Eucalyptus populnea / Bothriochloa decipiens – Chloris divaricata* | NA | 10.3.27; 11.3.2; 11.10.7; 11.11.9; 11.12.17; 11.4.12; 11.5.1; 11.5.13; 11.9.7. |
| Association 7: *Eucalyptus populnea – Casuarina cristata – Acacia harpophylla / Eremophila mitchellii – Geijera parviflora* | PCT 35, Brigalow Clay Plain Woodlands - Semi-arid Woodlands Grassy sub-formation. | 6.3.24; 6.4.3; 6.5.1; 6.5.3; 11.3.2; 11.3.17; 11.4.2; 11.4.3; 11.4.7; 11.4.12; 11.5.1; 11.9.10; 11.9.7 |
| Association 8: *Eucalyptus populnea – E. melanophloia / Triodia pungens – Triodia mitchellii* (*Cenchrus ciliaris**) | PCT 117, Sub-tropical Semi-arid Woodlands – Semi-arid Woodlands Shrubby sub-formation. | 10.3.27; 10.5.12; 11.3.2; 11.3.17; 11.4.2; 11.4.12; 11.5.3;11.5.13; 11.9.2; 11.11.9 |
| Association 9: *Eucalyptus populnea – Eucalyptus crebra / Carissa spinarum – Alectryon diversifolius* | NA | 11.3.2; 11.3.36; 11.4.2; 11.5.3; 11.10.7; 11.10.12 |
| **Alliance 2:** *Eucalyptus populnea – Callitris glaucophylla – Casuarina cristata / Geijera parviflora – Eremophila mitchellii* alliance | | |
| Association 10: *Eucalyptus populnea – Acacia harpophylla – Casuarina cristata / Geijera parviflora – Eremophila glabra* | PCT 35, Brigalow Clay Plain Woodlands - Semi-arid Woodlands Grassy sub-formation. | No equivalent in QLD |
| Association 11: *Eucalyptus populnea – Callitris glaucophylla – E. melanophloia / Calotis cuneifolia - Pimelea trichostachya* | PCT 192, Subtropical Semi-arid Woodlands – Semi-arid Woodlands Shrubby sub-formation. | 6.5.17; 11.5.5 |
| Association 12: *Eucalyptus populnea – Allocasuarina luehmannii – Callitris glaucophylla / Cymbopogon refractus – Aristida* spp. | PCT 71, North-west Alluvial Sand Woodlands – Semi-arid Woodlands Shrubby sub-formation. | 11.3.2; 11.3.16; 11.3.18; 11.5.1 |
| Association 13: *Eucalyptus populnea – Casuarina cristata – Allocasuarina luehmannii / Aristida scabra – Cymbopogon refractus* | PCT 55, North west Floodplain - Woodlands Semi-arid Woodlands Grassy sub-formation; PCT 56, Floodplain Transitional Woodlands – Grassy Woodlands. | No equivalent in QLD |
| Association 14: *Eucalyptus populnea – Eucalyptus albens – Eucalyptus blakelyi / Eremophila mitchellii – Carisa spinarum* | no real equivalent in NSW but possibly close to PCT 710 Semi-arid Floodplain Grasslands – Grasslands. | 11.5.1 |
| Association 15: *Eucalyptus populnea – Callitris glaucophylla – Casuarina cristata / Geijera parviflora – Eremophila mitchellii* | Though widespread no clear match but similar to PCT 98; PCT 244 Floodplain Transitional Woodlands – Grassy Woodlands. | No clear equivalent in QLD, but possibly close to 11.5.3 |
| Association 16: *Eucalyptus populnea – Callitris glaucophylla – Cadellia pentastylis / Geijera parviflora – Carissa spinarum* | PCT 113 North-west Alluvial Sand Woodlands – Semi-arid Woodlands Shrubby sub-formation; PCT 98 North-west Alluvial Sand Woodlands – Semi-arid Woodlands Shrubby sub-formation. | No equivalent in QLD |
| **Alliance 3:** *Eucalyptus populnea – Acacia aneura – Eucalyptus intertexta / Enteropogon acicularis – Austrostipa verticillata* alliance | | |
| Association 17: *Eucalyptus populnea / Paspalidium jubiflorum – Sclerolaena muricata* | Possibly a derived form of PCT 101 Brigalow Clay Plain Woodlands – Semi-arid Woodlands Grassy sub-formation. | No equivalent in QLD |
| Association 18: *Eucalyptus populnea – Casuarina cristata – Eucalyptus camaldulensis / Austrostipa verticillata – Paspalidium jubiflorum* | PCT 36 Inland Riverine Forests – Freshwater Wetlands; PCT 74 Floodplain Transitional Woodlands – Grassy Woodlands. | 11.3.2 |
| Association 19: *Eucalyptus populnea – Eucalyptus crebra – Allocasuarina luehmannii / Austrostipa aristiglumis – Sporobolus mitchellii* | In part PCT 88 Pilliga Outwash Dry Sclerophyll Forests – Dry Sclerophyll Forests shrubby sub-formation. | 11.3.2; 11.5.3; 11.9.7 |
| Association 20: *Eucalyptus populnea – Eucalyptus intertexta – Acacia aneura / Eremophila mitchellii – Geijera parviflora* | PCT 72, PCT 103 North-west Alluvial Sand Woodlands – Semi-arid Woodlands shrubby sub-formation; PCT 82 Floodplain Transitional Woodlands – Grassy Woodlands; PCT 100 Desert Woodlands – Semi-arid Woodlands shrubby sub-formation; PCT 229 North West Plain Shrublands – Arid Shrublands Acacia sub-formation; PCT 258 Inland Rocky Hills – Semi-arid Woodlands shrubby sub-formation. | 6.3.18; 6.5.3; 6.5.5; 6.5.7; 10.5.12; 11.5.1; 11.9.7 |
| Association 21: *Eucalyptus populnea – Acacia aneura – Acacia brachystachya / Senna* spp. *– Eremophila gilesii* | PCT 105, PCT 109 North-west Alluvial Sand Woodlands – Semi-arid Woodlands shrubby sub-formation; PCT 207 North-west Floodplain Woodlands – Semi-arid Woodlands grassy sub-formation. | 6.5.15 |
| Association 22: *Eucalyptus populnea / Enchylaena tomentosa – Dissocarpus paradoxus* | Possibly PCT 25 Inland Floodplain Wetlands – Freshwater Wetlands or PCT 144 North West Plain Shrublands – Arid Shrublands Acacia sub-formation. | No equivalent in QLD |
| Association 23: *Eucalyptus populnea / Sclerolaena birchii – Eragrostis lacunaria* | No direct equivalents. | No direct equivalents. |

munities at local, continental and global levels as opposed to classification systems which rely on correlative environmental gradients or cross-walked map-based systems (ESCAVI 2003; Keith and Tozer 2017; Luxton et al. 2021).

The congruence between our associations and the types in existing classifications varied between the different jurisdictions. Most PCTs types (NSW) were found to form a closer relationship with our proposed associations than REs (QLD). This may not be surprising as the methods used to define PCTs were either based on previous published and unpublished un-supervised analyses or, where fully supervised means were used, types were defined based on floristic composition and dominance, whereas the REs in the bioregions included in this study have been derived by fully supervised means and incorporate historical units derived from disparate studies. There are some notable exceptions within the PCTs, in particular those generally listed for the Cobar Peneplain Bioregion, where association 20 was potentially synonymous with six PCTs suggesting these PCTs are over-split at the association level. The lack of correlation on the Cobar Peneplain may be due to previous limited plot data within this bioregion. A lack of congruence was more apparent between our types and the NSW class and formation types. The situation was much more complicated for REs, where we also found little congruence between our associations and REs. Under the RE classification system, similar plant associations are divided by geomorphological categories, reflecting the assumption that there will be different biodiversity values associated with different substrates which are not necessarily reflected in plant diversity (Sattler and Williams 1995). This means that ideally, there should not be plots from one RE occurring in multiple associations, such as found in this study; for example, all plots attributed to RE 11.3.2 should match only one association, rather than nine (Table 2). When this mismatch does occur, it is likely reflecting the qualitative nature of the current classification of REs within each bioregion of QLD. The lack of hierarchical quantitative delineation of the NSW classes and formations and their relationship to PCTs is also likely to be the reason for their lack of congruence between our alliances and associations. One use of the results of this study, and future associations recognised under the IVC hierarchy, is to provide feedback into the individual jurisdictional classification systems to improve the delineations of individual vegetation types. Conversely, in identifying a possible new division, macrogroup, group, alliances, and associations within the IVC, analysis such as in this study feed back into the flexible design of the IVC, modifying it to include new levels in the hierarchy which accurately reflect the diversity of vegetation globally.

Under the *EPBC* Act 1999 an ecological community is defined as "*The extent in nature in the Australian jurisdiction of an assemblage of native species that inhabits a particular area in nature*" and is defined by the co-occurrence and interactions of species with overlapping distributions (Threatened Species Scientific Committee 2017). Furthermore, listing guidelines state that threatened communities should be defined based on classification of (dis-) similarities between vegetation types preferably based on composition (Threatened Species Scientific Committee 2017). Thus, the intent is to include in the classification vegetation types that are defined by composition. Our analysis indicates that the endangered community listing is largely based on a landscape element with an emphasis on alluvial plains, excluding types that were not predominantly grassy, reflected in its title and the REs and PCTs characterising this landscape element and structural type, rather than plant associations, to which it bears little relationship. It thus cannot be placed directly within a hierarchical classification scheme. Although low lying floodplain landscapes are commonly the most highly impacted within the Australian landscape, the emphasis on this landscape element over floristic coherence raises a number of important questions regarding conservation targets, with consideration of the whole distribution of the plant association required rather than one particular element of its distribution. Concentration on one landscape element does not help to increase our understanding of these communities or their interrelationships. Furthermore, restriction to a predominantly grassy understorey can be complicated in systems where this is transitory in nature due to natural climatic variation, disturbances both natural and human induced (Hunter 2021b; Saunders et al. 2021). It is possible that consideration of the threatened community at the alliance level may provide a more useful level of protection for the Poplar Box Grassy Woodlands than disparate sections of numerous associations.

Our relationship of synonymous types (Table 2) with the associations in this study highlights an important function of using a consistent national classification system, such as one based on the EcoVeg approach and integrated with the IVC. Adherence to the rules and processes of quantitative classification systems such as the IVC provides a clear and repeatable process when defining vegetation units and also allows for interrelationships to be recognised across jurisdictions. This is obscured within both the current NSW and QLD systems from a purely floristic-ecological classification perspective, and compounded when comparing across jurisdictions. For instance, our comparison table shows that the RE types 11.3.2 and 11.3.17, which are included in the definition of the listed endangered community description, align in part with PCT 35 yet this PCT is not one listed as defining the endangered community. The strength of using a national classification system based on quantitative plot-based analysis is in showing the relationships between floristic assemblages across jurisdictions. These may not show up in classification systems that are mapping oriented and not quantitatively based, such as the National Vegetation Inventory System, which is the current Australian national classification system (ESCVAI 2003). The strength of the IVC is that it also puts the individual threatened ecological community in a global perspective. If many of the plant associations within any given level of the IVC are listed as threatened communities it helps pro-

vide a continental and global perspective for communities within any level of the hierarchy.

## Conclusion

This investigation highlights how a rigorous rule-based hierarchical classification system, where the lower schematic levels are based on plot-based vegetation analyses of floristic and ecological data, should underpin our understanding of Australian vegetation. Such processes allow for a better understanding of distribution, interrelatedness, rarity, and threat of ecological communities at lower levels and inform mid to broad levels of vegetation pattern. Our study also suggests that state-based systems should not, in and of themselves, be the only basis for the listing of endangered ecological communities. Lack of clear guidelines and a similar process applied across state and territory borders only adds further confusion leaving practitioners to rely on intuition and opinion. Using a classification system such as the IVC allows an understanding of the threats to, and status of, communities both at local and regional levels and within a continental and global perspective.

## Data availability

The NSW data is contained within Version 3 of sPlot (https://www.idiv.de/?id=176&L=0) (Bruelheide et al. 2019) and is listed on GIVD as AU-AU-003 (https://www.givd.info/databases.xhtml). The Queensland data is contained within the Queensland government QBEIS database and is publicly available on request.

## Author contributions

JTH collected all NSW plot data, entered all of NSW data, analysed the data and co-wrote the manuscript. EA contributed equally to writing of the manuscript and in particular the incorporation of the IVC hierarchy to the results presented.

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## E-mail and ORCID

**John T. Hunter** (Corresponding author, jhunter8@bigpond.com), ORCID: https://orcid.org/0000-0001-5112-0465
**Eda Addicott** (eda.addicott@des.qld.gov.au), ORCID: https://orcid.org/0000-0002-4806-9205

## Supplementary material

**Supplementary material 1**
**NSW PCTs and Qld REs that use *Eucalyptus populnea* as a diagnostic or community associated overstorey species**
Link: https://doi.org/10.3897/VCS/2021/71216.suppl1

**Supplementary material 2**
**Frequency table**
Link: https://doi.org/10.3897/VCS/2021/71216.suppl2

**Supplementary material 3**
**Images of *Eucalyptus populnea* plant associations**
Link: https://doi.org/10.3897/VCS/2021/71216.suppl3