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

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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 inter-relationships 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...
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/databases.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
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 (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
| Hierarchy | Positive diagnostic (SIMPER) | Negative diagnostic (SIMPER) | Common taxa | Notes and distribution |
|-----------|-----------------------------|-------------------------------|-------------|-----------------------|
| **Alliance 1: Eucalyptus populnea** - Eremophila michelii - Carissa spinarum - Heteropogon contortus - Eragrostis lacunaria alliance | Eremophila michelii, *Cenchrus ciliaris*, Panicus effusus, Carissa spinarum, Heteropogon contortus, Eragrostis lacunaria, Aristida calycina, *Corymbia dallachiana*, Bothriochloa decipiens, *Themeda triandra*, *Sporobolus creber*, *Callichneura glaucophylla*, Acacia aneura, Corex inversa | Austrostipa aristiglumis, *Paspalum jubiliflorum*, Sclerolaena muncata, Austrostipa scabra, Austrostipa verticaliata, Callichneura glaucophylla, Acacia aneura, Corex inversa | Eremophila michelii, *Cenchrus ciliaris*, Heteropogon contortus, Eragrostis lacunaria, *Themeda triandra*, Carissa spinarum, Aristida calycina, Panicum effusum, Enneapogon lindeyerianus, Bothriochloa decipiens | More common in the northern half of the distribution. Widespread from the Belyando Downs and northern Bowen Basin south to Castleleigh-Bowen 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 carolinianum*, Dinebra decipiens, *Eucalyptus cambagiana*, Eremophila michelii | Cenchrus ciliaris*, *Corymbia dallachiana*, Heteropogon contortus, Bothriochloa decipiens, Carissa spinarum, *Eragrostis lespedoides*, Eremophila mitchellii, *Eremophila mitchellii* | Themeda triandra, Heteropogon contortus, Aristida ramosa, Eucalyptus tereticornis, *Eragrostis lespedoides*, Dinebra decipiens, Sparabolus creber, Dichanthium acuminatum, Bothriochloa decipiens, Paspalum distichum | Found on Quaternary alluvial clay, sand, silt, and gravel. From Bloomsbury south of Proserpine south to Rockhampton west to Blilosa in QLD. Brigalow Belt North, Brigalow Belt South and South East Queensland Bioregions. |
| **Association 2:** Eucalyptus populnea - E. melanolophia - Corymbia dallachiana / Eremophila michelii - Archidendropsis basaltica | Eremophila michelii, Archidendropsis basaltica, *Eragrostis lespedoides*, *Eremophila mitchellii* | Eremophila michelii, *Cenchrus ciliaris*, *Chloris divaricata*, *Chloris ventricosa*, *Chloris diversicarinata*, *Aristida calycina*, Geigeria parviflora, *Eucalyptus melanolophia*, *Thyridolepis xerophila*, *Eremophila mitchellii* | Eremophila michelii, Archidendropsis basaltica, *Eragrostis lespedoides*, *Chloris ventricosa*, *Eucalyptus melanolophia*, *Eremophila mitchellii* | Found on Quaternary alluvial limestone, 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 - E. melanolophia - *Aristida caput-medusa* | *Eragrostis lacunaria*, *Aristida calycina*, *Corymbia dallachiana*, *Acacia leucophylla*, Eremophila michelii | *Cenchrus ciliaris*, *Corymbia dallachiana*, Heteropogon contortus, *Bothriochloa decipiens*, *Chloris divaricata*, *Aristida calycina*, Geigeria parviflora, *Eucalyptus melanolophia*, *Thyridolepis xerophila*, *Eremophila mitchellii* | *Eragrostis lacunaria*, *Aristida ignosa*, *Aristida caput-medusa*, *Diodonae viscosa*, *Melinis repens**, Eucalyptus fatensis*, *Enteropogon unispeciosus*, *Eragrostis sororia*, *Aristida queenslandica*, *Enneapogon lindeyerianus* | Found on pebbly quartz sandstone, conglomerate, shale, and siltstone. Restricted to the Brigalow Belt North within the Springhurst and Farburn State Forest area. Brigalow Belt North Bioregion. |
| **Association 4:** Eucalyptus populnea - *Casuarina cristata* - *E. largiflorae* / *Thyridolepis xerophila* - *Aristida jerichoensis* | *Eremophila michelii*, *Casuarina cristata*, *Aristida jerichoensis*, *Thyridolepis xerophila*, *Acacia aneura*, *Eucalyptus largiflorae* | *Casuarina cristata*, *Aristida calycina*, *Geigeria parviflora*, *Aristida calycina*, *Eucalyptus melanolophia*, *Dichanthium sericeum*, *Cyperus gracilis* | *Casuarina cristata*, *Thyridolepis xerophila*, *Acacia aneura*, *Eucalyptus largiflorae*, *Cenchrus ciliaris*, *Chloris divaricata*, *Eremophila michelii*, *Aristida jerichoensis*, *Eucalyptus melanolophia*, *Themeda triandra* | Found on Tertiary-Quaternary and Cainozoic sands and weathered sandstones. Widespread occurrences from Mt. Wyatt area to Alpha and south to Boolin, St. George, Texas in QLD and south to the Walgett (Wigawa) area of NSW. Brigalow Belt North, Brigalow Belt South, Desert Uplands and Mulga Lands Bioregions. |
| **Association 5:** Eucalyptus populnea - Corymbia clarksoniana / *Cassia brevisterni* - *Cassia spinarum* | *Cassia brevisterni*, *Evolvulus alsinoideus*, *Stylosanthes scabra*, *Paspalum gracile*, *Carissa spinarum*, *Chrysopegia fallax*, Denhamia cunninghamii, *Aristida calycina*, *Bothriochloa decipiens*, *Corymbia clarksoniana*, *Eragrostis soraria* | *Chloris divaricata*, Geigeria parviflora, *Paspalum caput-medusa*, *Casuarina cristata*, *Enteropogon unispeciosus*, *Eucalyptus melanolophia*, *Dichanthium sericeum*, *Thyridolepis xerophila*, *Cypselomorphus refractus*, *Aristida ramosa* | *Chloris ventricosa*, *Chloris divaricata*, *Aristida calycina*, *Paspalum caput-medusa*, *Casuarina cristata*, *Aristida ramosa* | 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*, *Brunoella australis*, *Cymobopogon refractus*, *Eremophila michelii*, *Chenopodium ciliaris*, *Sida hackettiana*, *Chloris divaricata*, *Cyanthillium cinereum*, *Chloris ventricosa*, *Heteropogon contortus* | Geigeria parviflora, *Casuarina cristata*, *Aristida calycina*, *Thyridolepis xerophila*, *Acacia aneura*, *Tridax pungens* | *Chenopodium ciliaris*, *Chloris divaricata*, *Chloris ventricosa*, *Heteropogon contortus*, *Bothriochloa decipiens*, *Aristida calycina*, *Eremophila michelii*, *Dichanthium sericeum*, *Paspalum caput-medusa*, *Cypselomorphus refractus* | One of the most widespread associations occurring within QLD. From Rockhampton west to Barcaldine and Tombo and south to Taroona and Gayndah with a contracted occurrence around Dalby to Tara and south to Goondiwindi. Found on Quaternary sands, silt, clay, and gravel in floodplains and alluvial fans. Also known from gravels and phryngea. Brigalow Belt North, Brigalow Belt South and Desert Uplands Bioregions. |
| Hierarchy | Positive diagnostic (SIMPER) | Negative diagnostic (SIMPER) | Common taxa | Notes and distribution |
|-----------|-----------------------------|-----------------------------|------------|-----------------------|
| Association 7: Eucalyptus pauciflora – Casuarina cristata – Acacia harpophylla – Eremophila mitchelli – Geijera parviflora | Eremophila mitchelli, Geijera parviflora, Enteropogon acicularis, Abutilon oxyacarpum, Sporobolus caroli, Chloris cristata, Eragrostis australis, Erythroxylum australis, Eremophila mitchelli, Aristida ramosa. | Themeda triandra, Heteropogon contortus, Casania spinarum, Eucalyptus malakophloia, Melinis repens*, Astrotia medusae. | Eremophila mitchelli, Geijera parviflora, Enneapogon acicularis, Eucalyptus largiflorens, Thrydonopsis xerophila, Heteropogon contortus, Aristida calyceola, Casania lanceolata, Eremophila mitchelli, Aristida enchoensis. | 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 pauciflora / Triodia pungens / Triodia mitchelli (Cenchrus ciliaris*) | Cenchrus ciliaris*, Eremophila mitchelli, Eragrostis laeucoria, Archaeopteris basaltica, Enneapogon lindleyanus, Psyllium aleuriticum, Geijera parviflora, Triodia pungens, Casania lanceolata, Triodia mitchelli, Enneapogon diversifolius. | Heteropogon contortus, Chloris ventricosa, Geijera parviflora, Enteropogon acicularis, Cymobopogon refractus, Eucalyptus malakophloia, Paraphialus squamosus, Cyperus gracilis, Aristida ramosa. | Cenchrus ciliaris*, Casania spinarum, Bathroichloa decipiens, Eucalyptus curvula, Eremophila mitchelli, Themeda triandra, Enneapogon lindleyanus, Eucalyptus curvula, Erythroxylum australis, Eremophila diversifolius, Chloris truncata. | Restricted to QLD and most common South of Mt Coolon to Blackwater, Springsure, Tambo, and west to Barcaldine with a discontinuous occurrence near Nindigully and Thallon south to Engonia in NSW. Found on sand sheets, red hard setting sandy clay, aestival sands and sandstone. Brigalow Belt North, Brigalow Belt South and Desert Uplands Bioregions. |
| Association 9: Eucalyptus pauciflora / Casrois curvula / Allocasuarina – Allocasuarina luehmannii – Eremophila mitchelli alliance | Cenchrus ciliaris*, Casania spinarum, Bathroichloa decipiens, Eucalyptus curvula, Eremophila mitchelli, Themeda triandra, Enneapogon lindleyanus, Erythroxylum australis, Allocasuarina luehmannii, Aristida ramosa. | Heteropogon contortus, Chloris ventricosa, Geijera parviflora, Enteropogon acicularis, Cymobopogon refractus, Eucalyptus malakophloia, Dichanthium acicularis, Thrydonopsis xerophila. | Cenchrus ciliaris*, Casania spinarum, Bathroichloa decipiens, Eremophila mitchelli, Themeda triandra, Enneapogon lindleyanus, Eucalyptus curvula, Erythroxylum australis, Allocasaurina luehmannii, Aristida enchoensis. | Found primarily within the Yappoon, Miranbahn, Clermont, and south to Moura region of QLD. Found on deeply weathered coarse grained sands, Quaternary and Tertiary alluvia and sediments. Brigalow Belt North and Brigalow Belt South Bioregions. |
| Alliance 2: Eucalyptus pauciflora – Callitris glaucophylla – Casuarina cristata / Geijera parviflora / Eremophila mitchelli alliance | Geijera parviflora, Callitris glaucophylla, Cyperus gracilis, Austrostipa scabra, Eremophila mitchelli, Brunoniae australis, Einadia nutans, Casaurina cristata, Abutilon oxyacarpum, Maiena microphylla, Enchylaena tomentosa, Chelintheae sieberi. | Austrostipa aristiglomus, Paraphialus jubiflorus, Scleroalaena munitica, Acacia aneura. | Eremophila mitchelli, Callitris glaucophylla, Geijera parviflora, Austrostipa scabra, Einadia nutans, Scleroalaena birchi, Cyperus gracilis, Alternanthera corticata, Thrydonopsis xerophila. | Primarily restricted to the central and eastern parts of the range. Most common from Carabelag region of the Coban Peneplein to the Tara Downs and Inglewood Sandstone region. |
| Association 10: Eucalyptus pauciflora – Acacia harpophylla – Casuarina cristata / Geijera parviflora / Eremophila glabra | Acacia harpophylla, Setaria parapaludoloides, Abutilon oxyacarpum, Aphyllum anamalum, Austrostipa setacea, Brachyschismu dentata, Brunoniae australis, Einadia nutans, Enchylaena tomentosa, Eremophila mitchelli. | Eremophila mitchelli, Callitris glaucophylla, Austrostipa scabra, Scleroalaena birchi, Einadia nutans, Enteropogon acicularis, Calotis cuneifolia, Paraphialus constrictum, Eucalyptus largiflorens, Eremophila glabra. | Acacia harpophylla, Brachyschismu ciliaris, Setaria parapaludoloides, Geijera parviflora, Enchylaena tomentosa, Casaurina cristata, Sporobolus caroli, Rytidosperma longifolium, Eremophila glabra, Eremophila mitchelli. | 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 gilgas clay soils. Brigalow Belt South, Darling Riverine Plains and Mulga Lands Bioregions. |
| Association 11: Eucalyptus pauciflora – Callitris glaucophylla – E. melanolophia / Calotis cuneifolia / Pimelea trichostachya | Callitris glaucophylla, Calotis cuneifolia, Pimelea trichostachya, Einadia nutans, Calotis cuneifolia, Astrotia medusae, Sida cunninghamii, Fimbriatyst dichotoma, Austrostipa scabra, Chenopodium curvispicatum, Glossocarca bidens, Rhodanthe moschatata, Euphorbia drummondi. | Eremophila mitchelli, Geijera parviflora, Scleroalaena birchi, Einadia nutans, Enteropogon acicularis, Casaurina cristata, Paraphialus constrictum, Eucalyptus largiflorens, Chenoaphyllum desertorum. | Callitris glaucophylla, Dodonaea viscosa, Pimelea trichostachya, Calotis cuneifolia, Calotis cuneifolia, Chelintheae sieberi, Eucalyptus malakophloia, Centepeda cunninghamii, Aristida ramosa, Dysphania melanolophia, Glycine canescens. | Known from Collarenebi, the Narran Lakes region and Culgoa Floodplains. Occurring on low lying clay Floodplains. Brigalow Belt North, Darling Riverine Plains and Mulga Lands Bioregions. |
| Association 12: Eucalyptus pauciflora – Allocasuarina luehmannii – Callitris glaucophylla / Cymobopogon refractus – Aristida spp | Allocasuarina luehmannii, Cymobopogon refractus, Callitris glaucophylla, Brunoniae australis, Aristida capituliflora, Chelintheae medusae, Chelintheae divaricata, Aristida ramosa, Eucalyptus cinerea, Aristida jenchoensis, Paraphialus squamosus. | Eremophila mitchelli, Scleroalaena birchi, Einadia nutans, Enteropogon acicularis, Casaurina cristata, Paraphialus constrictum, Chenoaphyllum desertorum. | Cymobopogon refractus, Allocasuarina luehmannii, Eucalyptus largiflorens, Callitris glaucophylla, Chelintheae divaricata, Aristida ramosa, Austrostipa scabra, Aristida capituliflora, Eucalyptus cinerea, Euphorbia drummondii. | Found within southern QLD from Glenmorgan south to Texas. Known from Quaternary alluvia, sand sheets, clayey sandstone and aestival sands. Primarily within the Bigalow Belt South but also within the Nandewar Bioregion. |
| Association 13: Eucalyptus pauciflora – Casuarina cristata – Allocasuarina luehmannii – Aristida scabra / Cymobopogon refractus | Austrostipa scabra, Cyperus gracilis, Eremophila debilis, Dichanthium seneceum, Leptochloa ciliata, Abutilon oxyacarpum, Aristida capituliflora, Chelintheae medusae, Cymobopogon refractus, Sporobolus creber, Casaurina cristata, Chelintheae medusae. | Scleroalaena birchi, Calotis cuneifolia, Eucalyptus largiflorens, Eremophila malakophloia, Paraphialus constrictum, Chenoaphyllum desertorum. | Cymobopogon refractus, Aristida capituliflora, Austrostipa scabra, Cyperus gracilis, Leptochloa ciliata, Dichanthium seneceum, Calotis cuneifolia, 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. |
| Association 14: | Positive diagnostic (SIMPER) | Negative diagnostic (SIMPER) | Common taxa | Notes and distribution |
|----------------|-------------------------------|-------------------------------|-------------|-----------------------|
| Eucalyptus populnea – Eucalyptus albens – Eucalyptus blakelyi – Eremophila michilli – Carissa spinarum | | | | Known from north of Millenner 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. |
| | Carissa spinarum, Notelaea microcarpa, Cheilanthes distans, Eucalyptus albens, Acacia deanei, Chloris ventricosa, Psathyrodactylon, Eucalyptus blakelyi, Tetraria junceum. | Austrostipa scabra, Scelarolena birchi, Enteropogon acuicularis, Calotos cuneiformis, Eucalyptus longiflorum, Chenopodium desertorum, Calotos lappulacea. | Geigeria parviflora, Eremophila michilli, Carissa spinarum, Casuarina cristata, Notelaea microcarpa, Cheilanthes distans, Calitoris glaucophylla, Eucalyptus melanoplophia, Eucalyptus albens, Chloris ventricosa. | |
| Association 15: | | | | 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. |
| Eucalyptus populnea – Callitris glaucophylla – Casuarina cristata / Geigeria parviflora – Eremophila michilli | | | | 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. |
| | | | | |
| Association 16: | | | | |
| Eucalyptus populnea – Callitris glaucophylla – Cadellia pentastylis / Geigeria parviflora – Carissa spinarum | Calitris glaucophylla, Cyperus gracilis, Brunonella australis, Austrostipa scabra, Calotis labiata, Arista personata, Geigeria parviflora, Lomandra multiflora, Sida cordata, Evolvulus alisoides, Austrostipa verticillata, Boenavia domini, Marena microphylla, Notelaea microcarpa, Acacia deanei. | Eremophila michilli, Geigeria parviflora, Eremophila mitchelli, Enteropogon acuicularis, Austrostipa verticillata, Chenopodium desertorum. | Calitris glaucophylla, Austrostipa scabra, Cyperus gracilis, Carissa spinarum, Cadellia pentastylis, Notelaea microcarpa, Callitris glaucophylla, Eremophila mitchelli, Arista personata, Eucalyptus piggieensis, Acacia decora, Chloris truncata, Dichandra sp. A. | |
| Association 17: | | | | 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. |
| Eucalyptus populnea – Paspalidium jubiflorum – Sclerolaena muncata | Acacia aneura, Enteropogon acicularis, Austrostipa verticillata, Dodonaea viscosa, Paspalidium jubiflorum, Senna zygophylla, Carex inversa, Eremophila sturtii, Austrostipa aristiglumis, Eucalyptus intertexta. | Eremophila michilli, Callitris glaucophylla, Cenchrus ciliaris*, Austrostipa scabra, Scelarolena birchi, Cyperus gracilis, Eucalia nutans, Themeda triandra, Carissa spinarum. | Acacia aneura, Eremophila michilli, Geigeria 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 Urruca Sandplains. |
| | | | | |
| Association 18: | | | | 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. |
| Eucalyptus populnea – Casuarina cristata – Eucalyptus camaldulensis / Austrostipa verticillata – Paspalidium jubiflorum | Carex inversa, Austrostipa verticillata, Paspalidium jubiflorum, Casuarina cristata, Cynodon dactylon, Austrostipa scabra, Paspalidium conjunctum, Phyla canescens*, Enteropogon acuicularis, Sorchus aleracea*, Sisymbrium erismoides*, Sclerolaena muncata. | Acacia aneura, Eremophila michilli, Geigeria 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 conjunctum, Phyla canescens*, Lomum perenne*, Rapsnium rugosum*, Sclerolaena muncata, Enteropogon acicularis, Sisymbrium erismoides*, Maloa parviflora*. | |
| | | | | |
| Association 19: | | | | Widespread but disjoint occurrences from west of Duaringa to east of Alpha in QLD and from Gunnedah and Parke 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. |
| Eucalyptus populnea – Eucalyptus crebra – Allocasuarina luehmannii – Austrostipa aristiglumis / Sporobolus michilli | Austrostipa aristiglumis, Centipeda thalpidoides, Allocasuarina luehmannii, Eucalyptus crebra, Sporobolus michilli, Corymbia clarksoniana, Roripa eustyla*, Panicum laevinode. | Eremophila michilli, Geigeria parviflora, Enteropogon acicularis, Austrostipa verticillata, Paspalidium jubiflorum, Dodonaea viscosa, Senna zygophylla, Eremophila sturtii. | Austrostipa aristiglumis, Centipeda thalpidoides, Allocasuarina luehmannii, Eucalyptus crebra, Sporobolus michilli, Panicum laevinode, Corymbia clarksoniana, Roripa eustyla*, Austrostipa nitida |
Vegetation Classification and Survey

| Hierarchy | Positive diagnostic (SIMPER) | Negative diagnostic (SIMPER) | Common taxa | Notes and distribution |
|-----------|-----------------------------|-----------------------------|-------------|-----------------------|
| Association 20: Eucalyptus populnea – Eucalyptus intertexta – Acacia aneura / Eremophila michellii – Geijera parviflora | Eremophila michellii, 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 michellii, Geijera parviflora, Acacia aneura, Eucalyptus intertexta, Dodonaea viscosa, Callicthus 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 Liddicoat Carinda south to Cobah. Generally associated with low lying ephemeral wet areas within higher landscape elements. Desert Uplands, Brigalow Belt South, Mulga Lands, Darling Riverine Plains and Cobah Penepalein. |
| Association 21: Eucalyptus populnea – Acacia aneura – Acacia brachystachya / Senna sp. – Eremophila gilesii | Acacia aneura, Chelanthes seberi, Triopogon multiflorus, Senna zygophylla, Acacia brachystachya, Eragrostis eriopoda, Eremophila gilesii, Fimbriystylis dichotoma, Eragrostis laniflora. | Austrostipa verticillata, Paspalidium jubiflorum, Carex inversa, Austrostipa aristiglumis, Casuarina cristata, Cynodon dactylon, Sclerolaena birchii. | Acacia aneura, Senna zygophylla, Chelanthes seberi, Senna filifolia, eragrostis eriopoda, Acacia parviflora, Enteropogon acicularis, Eremophila sturtii, Acacia brachystachya, Eremophila gilesii. | Restricted to far western areas of NSW from Narran Lake south to Cobah to west of Hungerford and Wanaaring. 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, Cobah Penepalein and Murray Darling Depression Bioregions. |
| Association 22: Eucalyptus populnea / Enchylaena tomentosa – Dissocarpus paradoxus | Enchylaena tomentosa, Dissocarpus paradoxus, Senna zygophylla, Corractea annua*, Duma florulenta, Roepaea similis. | Acacia aneura, Eremophila michellii, Geijera parviflora, Austrostipa verticillata, Senna zygophylla, Carex inversa, Austrostipa aristiglumis, Eucalyptus intertexta, Callicthus glaucophylla, Casuarina cristata. | Sisymbrium erisimoides*, Medicago lacinata*, Enchylaena tomentosa, Dissocarpus paradoxus, Carrichtera annua*, Senna filifolia, Eremophila sturtii, Duma florulenta, Dodonaea viscosa, Acacia parviflora, Eremophila gilesii. | 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 trichoides, Eragrostis lacunaria, Nicotiana simulans, Teucrium racemosum, Centropeda thespidioides, Cyperus iria, Wahlenbergia gracilis, Stenotaphrum clavatum, Myriocarpa costiflora, Sporobolus actinocladus, Tetragonia moorei. | Acacia aneura, Eremophila michellii, Geijera parviflora, Enteropogon acicularis, Austrostipa verticillata, Paspalidium jubiflorum, Senna zygophylla, Dodonaea viscosa, Carex inversa, Austrostipa aristiglumis. | Wahlenbergia gracilis, Cyperus iria, Sclerolaena birchii, Eragrostis lacunaria, Stenotaphrum fluitans, 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 Cobah Penepalein Bioregions. |

(E. populnea, Callitris glaucophylla and Acacia aneura), a diagnostic growth form (trees) with broadly similar composition, and a distribution that reflects a regional meso-climate 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 michellii – Carissa spinarum / Heteropogon contortus – Eragrostis lacunaria alliance (Figure 2), primarily of the Brugalow Belt (IBRA7; Thackway and Cresswell 1995), was prominent in QLD and incorporated most of the plots from this state. It was generally widespread...
Figure 3. Eucalyptus populnea – Callitris glaucaphylla – 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 glaucaphylla – 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 14.2.10, 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 micchelli – Carissa spinarum – Heteropogon contortus – Ergrostis lanacina 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. melanopila / Corymbia dallachana / Eremophila micchelli – Archaeandropogon basistaica NA | 11.10.7; 11.4.2 |
| | Association 3: Eucalyptus populnea / Ergrostis lanacina – Aristida caput-medusae NA | 11.10.12. |
| | Association 4: Eucalyptus populnea – Casuarina cristata – E. largiflorens / Thrydondeles xeraphila – Aristida jenkichensis PCT87, PCT 55. North west Floodplain – Woodlands Semi- and 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 brevisteri – Carissa spinarum NA | 11.5.3; 11.10.12 |
| Alliance 2: Eucalyptus populnea – Calitris glaucophiphylla – Allocasuarina luehmannii / Austrostipa verticillata – Eucalyptus blakelyi / Eremophila mitchellii alliance | Association 10: Eucalyptus populnea – Acacia harpophylla – Casuarina cristata / Geijera parviflora – Eremophila glabra NA PCT 35, Brigalow Clay Plain Woodlands – Semi-arid Woodlands Grassy sub-formation. 6.1.3.2; 6.1.3.3; 6.11.9; 11.12.17; 11.4.12; 11.5.1; 11.5.13; 11.9.7 |
| | Association 11: Eucalyptus populnea – Calitris glaucophiphylla – Allocasuarina luehmannii – Calotis cuneifolia – Pimelea trichostachya PCT 192, Subtropical Semi-arid Woodlands – Semi-arid Woodlands Shrubby sub-formation. 5.6.17; 11.5.5 |
| | Association 12: Eucalyptus populnea – Allocasuarina luehmannii – Calitris glaucophiphylla / Cymbopogon refractus – Aristida spp. PCT 71, North-west Alluvial Sand Woodlands – Semi-arid Woodlands Shrubby sub-formation. 11.3.2; 11.3.15; 11.5.3; 11.9.12; 11.9.9 |
| | Association 13: Eucalyptus populnea – Casuarina cristata – Allocasuarina luehmannii / Aristida scabra – Cymbopogon refractus NA 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 micchelli – Carissa spinarum | no real equivalent in NSW but possibly close to PCT 710 Semi-arid Floodplain Grasslands – Grasslands. 11.5.1 |
| | Association 15: Eucalyptus populnea – Calitris glaucophiphylla – Casuarina cristata / Geijera parviflora – Eremophila micchelli | 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 – Calitris glaucophiphylla / Casuarina scorpiodes / 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 occulans – Austrostipa verticillata alliance | Association 17: Eucalyptus populnea / Pastinacium jubiferanum – Sclerolaena irichi – Eremophila maculosa – Geijera parviflora | 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 crista / Eucalyptus camaldulensis / Austrostipa verticillata – Pastinacium jubiferanum PCT 36 Inland Riverine Forests – Freshwater Wetlands; PCT 74 Floodplain Transitional Woodlands – Grassy Woodlands. 11.3.2 |
| | Association 19: Eucalyptus populnea – Eucalyptus crebra / Allocasuarina lehmannii / Austrostipa aristiglumis – Sporabolus micchelli | 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 micchelli – 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 / Sena spp. – Eremophila glesii 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 / Enchyela tomentosa – Dissoporos 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 birchi – Ergrostis lanacina | 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 (ESCAVI 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=1768&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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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