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RESEARCH PAPER

Grasslands on Coastal Headlands in New South Wales, south eastern Australia

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Abstract

Aims: To use unsupervised techniques to produce a hierarchical classification of grasslands on coastal headlands of New South Wales in eastern Australia. **Methods:** A dataset of 520 vegetation plots scored on cover and placed across grasslands on coastal headlands (ca. 2000 km of coastline). Vegetation assemblages were identified with the aid of a clustering method based on group averaging and tested using similarity profile analysis (SIMPROF) using Bray-Curtis similarity. A hierarchical schema was developed based on EcoVeg hierarchy and was circumscribed using positive and negative diagnostic taxa via similarity percentage analysis (SIMPER) and importance based on summed cover scores and frequency. Mapping the occurrences grasslands was initially constructed using remote sensing which was verified and modified with on ground observations. **Results:** One group *Themeda* – *Pultenaea* – *Zoysia* – *Cynodon* grasslands and heathy grasslands was defined to include all coastal headland grassland vegetation of the New South Wales, and within this, three alliances and ten associations. Only one of the circumscribed associations is represented within the current state classification schema. In total 107 ha were mapped of which 68 ha occurred within secure conservation tenure. **Conclusions:** A number of unique and rare grassland assemblages on coastal headlands have to date gone undescribed. The most common alliance constitutes approximately 87% of extant grassland occurrences but is currently the only type listed as endangered and afforded protection. Although *Poa* spp. are listed as a threat to *Themeda* dominated assemblages on headlands data from this study suggest that this is unlikely to be the case.

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

Abbreviations: BC Act = Biodiversity Conservation Act; NMDS = non-metric multidimensional scaling; NSW = New South Wales; PCT = Plant Community Type; SIMPER = similarity percentage analysis; SIMPROF = Similarity profile analysis.

Keywords

Australia, EcoVeg, Grassland, Headlands, New South Wales

Introduction

Natural temperate grasslands cover 7% of continental landmasses with approximately 4% within protected areas (Henwood 2010). In the Australian context and in particular in NSW temperate grasslands are a highly threatened and restricted vegetation type of which less than 3% remains in good condition with patches often under 10 ha in size (Baines and Dunford 2008; Hunter and Hunter 2016). Grasslands are some of the best studied vegetation types within Australia (Williams et al. 2015). Even so little is known about the dynamics of most species and well-known species are likely to have more nuanced responses to disturbance and competition that currently is portrayed (Moore et al. 2019; Price et al. 2019).

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Potentially the most restricted grassland type within Australia are those found on coastal headlands and sea cliffs. These closed tussock and sod tussock grasslands have been recognised as unique by a number of authors (Beadle 1981; Kirkpatrick 1981; Opie et al. 1984; Myerscough and Carolin 1986; Adam et al. 1990; Griffith et al. 2003; Keith 2004; Tozer et al. 2010; Hunter and Hunter 2017a). Generally, such grasslands occur on more nutrient rich soils with a higher proportion of clay content than comparable areas containing heaths in similar landscape positions (Kirkpatrick 1977; Beadle 1981; Adam et al. 1990).

Grasslands on headlands are thought by some authors to be a dis-climax community created by Aboriginal burning which were subsequently then kept open by European management (Morris et al. 1990). Others, however, have argued that the grasslands are natural and a product of nutrient rich soils, exposure and salt spray (Beadle 1981; Adam et al. 1990). Furthermore, the often-protected nature of headlands, steepness of slopes, prevailing onshore winds during summer months and salt spray are likely to retard fire spread suggesting areas of grassland would have occurred and persisted even without fire (Adam et al. 1990). The presence of long-lived obligate seeding prostrate shrubs endemic to these grasslands suggest that the community is not a dis-climax created by regular burning (Hunter and Hunter 2017b; Hunter 2018).

The most comprehensive survey and analysis of the vegetation of coastal headlands in south eastern Australia was conducted by Adam et al. (1990) who surveyed 613 plots (1×1, 2×2 or 4×4 m plots along transects). This survey was restricted to the southern half of the New South Wales (NSW) coastline and sampled all vegetation assemblages including rushlands and heaths. The subsequent analyses derived one purely grassland and two broadly 'grassland' like assemblages, one circumscribed by *Themeda triandra* (syn. *T. australis*), one by *Lomandra longifolia* and the other by *Ficinia nodosa* (syn. *Isolepis nodosa*) and the introduced grass *Stenotaphrum secundum*. The description of the *Themeda triandra* community by Adam et al. (1990) was used as a basis for the listing of the endangered ecological community *Themeda* grassland on sea cliffs and coastal headlands in the NSW North Coast, Sydney Basin and South East Corner Bioregions on the NSW *Biodiversity Conservation* Act 2016 (https://www.environment.nsw.gov.au/). The vegetation types of Adam et al. (1990) were considered to be provisional and were not given an official designation but are likely fall within the level of alliance or above. A subsequent floristic analysis was performed on 117 (2×2 m) plots placed only within grasslands on headlands in the northern half of the NSW coastline by Hunter and Hunter (2017b). This additional analysis described three *Themeda triandra* dominated assemblages and an additional four others. As Adam et al. (1990) and Hunter and Hunter (2017b) were describing northern and southern parts of the NSW coast some overlap between types occurs but geographical and thematic differences make direct comparison less clear. A further analysis of 352 (2×2 m) plots sampling only grassland on headlands was performed by Hunter (2018). These later analyses highlighted a number of factors that influenced composition and dominance such as distance from seaward edge, altitude, wind shear, grazing, fire and direct and indirect facilitation by adjacent taller shrubs (Hunter and Hunter 2017a, b, 2019; Hunter 2018).

A number of threats have been listed as potentially affecting the survival of these unique vegetation types which include; weed invasion, too frequent or infrequent fires, invasion from native shrubs, mowing, trampling, lack of tenure security, overgrazing by abundant macropods, competition from native *Poa* (particularly *Poa poiformis*), coastal development and pasture improvement. Many of these threats are still current in urban and semi-urban localities (e.g. weed invasion, trampling, coastal development, pasture improvement), however, others have been shown to be non-critical threats and even important to the diversity and persistence of these systems. For example, tall shrub occurrence and grazing by abundant macropods have been positively implicated for the maintenance and persistence of biodiversity (Hunter and Hunter 2017a, b, 2019) and low frequency fire may also not be a critical threat (Hunter and Hunter 2017b, Hunter 2018).

Thus far no fully comprehensive investigation across the entire range of these unique, and in part legally protected endangered grasslands, has occurred within NSW (Adam et al. 1990; Hunter and Hunter 2017a). Management decisions are currently being made without full comprehension of their full floristic components, distribution and natural variation across their range. It is essential, especially for communities considered threatened, that a fundamental understanding of their distribution, rarity and floristic interrelationships with co-occurring types be gained (Franklin et al. 2016; Jensen et al. 2016). Even within areas considered relatively well surveyed, many highly restricted systems are likely to be poorly sampled and incompletely treated within current classifications, leading to misunderstandings of their placement, function, importance and rarity (Hunter and Lechner 2017; Hunter and Hunter 2017a). Even though these grasslands occur in the most highly populated jurisdictions in Australia they have up until recently been very poorly sampled. Currently the NSW Plant Community Type (PCT) classification schema describes four coastal headland grasslands all collectively described as *Themeda australis* Sod Tussock Grasslands within the hierarchy of Maritime Grasslands (Class) and Temperate Grasslands (Formation) (https://www.environment.nsw.gov.au/). The designations of Class and Formation have been developed in isolation from that of association and no divisions occur between Class and Association thus the links between these hierarchical levels is not fully resolved (Gellie et al. 2017).

Within this investigation an attempt is made to provide a more comprehensive plot-based assessment of the

floristic relationships between grass dominated communities on coastal headlands along the entire NSW coastline. Hierarchical classification systems facilitate integrated understanding of relationships between vegetation assemblages and also allow conceptualisations at different ranks to match scales at which management and investigations may be applied, from local to global (Gellie et al. 2017; De Cáceres et al. 2018; Faber-Langendoen et al. 2018). Here I provide a hierarchical classification based on unsupervised analysis of plot data producing a consistent classification section (CCS) for a unified vegetation type (De Cáceres et al. 2015). Mapping of natural remnants is also undertaken using on ground and remote sensing techniques in order to better understand the distribution, area of occupancy and reservation status of these grasslands.

Methods

Study region

The study region encompasses the NSW coastal headlands and sea cliffs (ca. 2,000 km of coastline; Figure 1) in eastern Australia. Headlands occur as isolated island like rocky protrusions separated by long distances of beaches and dunal landscapes (Figure 2). Field investigations were carried out from northern and eastern Tasmania to south eastern Queensland. Although headlands also occur within south eastern Queensland, eastern Victoria and north and eastern Tasmania no sampling was undertaken in these areas due to the comparative paucity of grassland assemblages. Though largely rainfall is aseasonal the region has slightly higher rainfall in summer in the northern locations becoming more winter dominant in the southern parts of the study area. Rainfall varies from 816 to 1711 mm per year with average annual temperatures from 14 to 21°C. Winds tend to be offshore during winter months and onshore during summer (Adam et al. 1990).

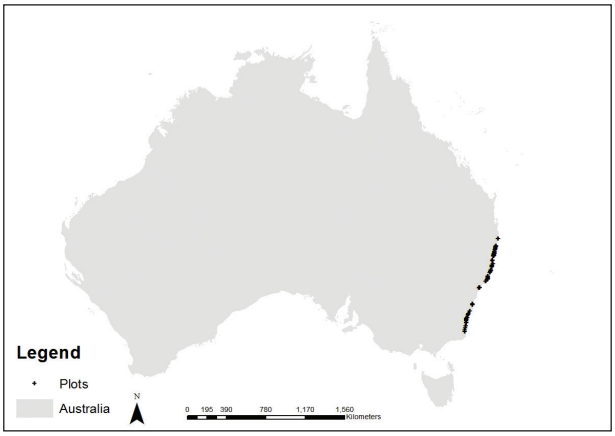

Figure 1. Location of 520 plots placed on coastal headlands in New South Wales, Australia.

Field sampling

Survey plots of a 2 × 2 m dimension were placed randomly within vegetation in which Poaceae taxa was visually assessed to cover a minimum of 50% of the patch to be surveyed. Where possible a minimum of three plots were placed in a random stratified way (to ensure coverage of aspect and distance from seaward edge) on each headland with a minimum distance of 10 m between plots. Larger headlands with larger grass dominated patches received more plots. All plots were surveyed by the author. The survey was conducted over a period of four years from 2015–2019 during Spring to Summer (November and February) of each year. Most accessible headlands were visited at least once. Species nomenclature follows that of PlantNET (http://plantnet.rbgsyd.nsw.gov.au/; accessed January 2019). Vascular plant taxa were scored using overlapping percent cover and frequency. Frequency was determined by dividing the plot into 16 subplots (50 cm × 50 cm) where the rooted presence and absence of each species was scored in each subplot. The majority of plot data has been submitted for hosting in 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).

Mapping

Imagery including ADS40 (Coffs Harbour 2009 – 50 cm resolution) and World Imagery (WGS84 1 m resolution supplied by ESRI) was used within ArcGIS 10.6 (ESRI Inc) to map potential grasslands on headlands on the mainland and nearby off shore islands. The majority of accessible headlands were visited between 2015 and 2019 and mapping re-adjusted based on on-ground observations of extent. In some cases, exact boundaries of grasslands were mapped with a hand held GPS. Mapping was conducted over all land tenures but restricted to within the NSW jurisdiction. Mapping was conducted for the purpose of understanding how much grassland in total occurs within protected lands. Based on the resolution of the imagery available it is not possible to map to individual community type.

Statistical analysis

Primer E (ver. 7.0.11; Quest Research Limited; Ivybridge, Devon, UK) was used for data exploration, whereby an initial triangular resemblance matrix using Bray-Curtis similarity co-efficient was created after dispersion weighting and square root transformation. Clustering was achieved through group averaging and the similarity profile tested using similarity profile analysis (SIMPROF) permutation tests (9999 iterations). SIMPROF tests the statistical significance of every node within a dendrogram starting from the top and (all points within a single group) and high-

Figure 2. Bare Bluff, an example of the island like headlands and grassland sampling plot locations from the North Coast Bioregion of NSW.

lighting only those groups which show within group multivariate structure. The EcoVeg (Faber-Langendoen et al. 2014) approach was used to define hierarchical levels and guide nomenclature. The type and density of data available allowed for the circumscription of vegetation types from medial Group down to alliance and associations.

Similarity percentage analysis (SIMPER) identifies the species driving differences between selected types. SIMPER uses the Bray-Curtis similarity measure (Primer E ver. 7.0.11; Quest Research Limited; Ivybridge, Devon, UK) to identify positively and negatively diagnostic taxa across vegetation types. Taxa with combined high fidelity and cover were also identified and listed for diagnostic purposes and type delineation. Attempts to place current eastern Australian state based noncultural units was derived by comparing diagnostic and non-diagnostic taxa from SIMPER results. The results of the analyses were used to define mid to lower level classification levels (Macrogroup, Group and Alliance) based on EcoVeg terminology. It should be noted that although EcoVeg uses the alliance and association as does the Braun-Blanquet approach, the nomenclatural and procedural roles are distinct.

Results

A total of 520 plots were placed with approximately across 90 headlands. 326 vascular plant taxa from within 75 families were found within plots. An average of 15 and a maximum of 27 taxa were recorded per plot. The current survey is the first to encompass the entirety of the NSW coastline and also the first unified hierarchical classification for this vegetation type. Association was defined at a Bray-Curtis similarity of 23% (Figure 3). Splicing the dendrogram at 23% similarity allowed all associations to be delineated at a level which shows statistical evidence of multivariate structure and enabled the circumscription of ten associations within three alliances (Figures 4–6) and a single group (Table 1). The Alliances separate assemblages found in areas with a higher water table, with Alliances 2 and 3 largely separating northern and southern floristic elements with the dominant grasses in general possessing different photosynthetic pathways (Table 1). All described vegetation units would be included within the defined Class – Maritime Grasslands. Three associations appear to have no equivalent in any published resources (Tables 2, 3). The other seven associations have broadly or more directly synonymous types described from disparate literature sources (Table 2). Association 3.5 constitutes the most widely distributed vegetation type found along much of the NSW coastline and is the type most commonly described within previous analyses and literature (Tables 1–3).

A total of 604 'grassland' mapping polygons were created constituting 107 ha of which 72 ha were within the National Reserve system or other forms of registered con-

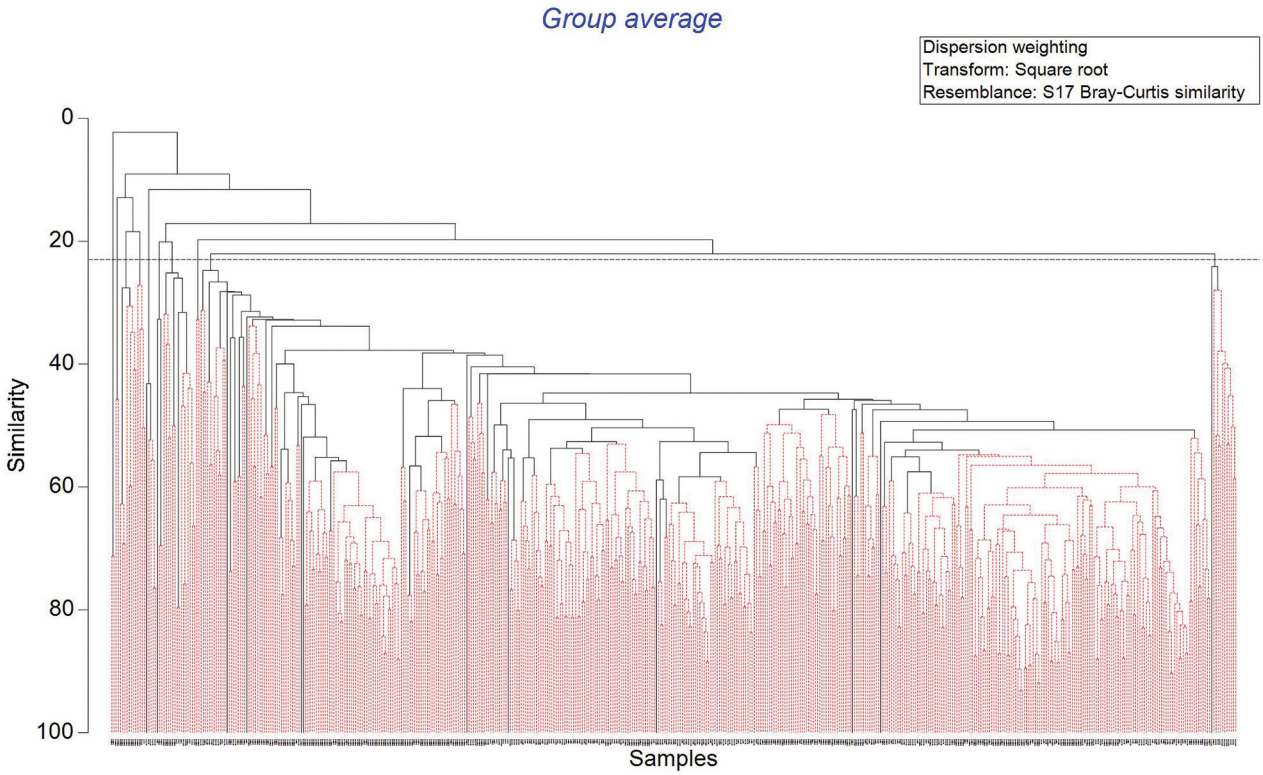

Figure 3. SIMPROF cluster analysis of the full dataset from grasslands of coastal headlands NSW in south eastern Australia showing association level recognition.

Figure 4. Alliance 1 *Hemarthria uncinata – Pteridium esculentum* NSW North Coast Bioregion Sod Tussock Grasslands (Broughton Island National Park).

Table 1. Circumscription of grasslands on coastal headlands of New South Wales within south eastern Australia. Descriptions include positive and negative diagnostic and negatively associated species, common dominant taxa (based on cumulative frequency and cover) and notes for each unit. Positive diagnostic species are listed in order of decreasing contribution to group identity. Common taxa are listed in decreasing order of cumulative frequency and cover within each identified group.

Hierarchy	Positive diagnostic (SIMPER)	Negative diagnostic (SIMPER)	Common taxa	Notes and distribution
Group: Scientific Name: *Themeda – Pultenaea – Zoysia - Cynodon* grasslands & heathy grasslands Colloquial: Grasslands of South East Australian Coastal Headlands	NA	NA	*Themeda triandra, Pultenaea maritima, Hibbertia vestita, Zoysia macrantha, Polymeria calycina, Cynodon dactylon, Viola banksii, Pimelea linifolia, Gonocarpus humilis, Goodenia rotundifolia, Entolasia stricta, Imperata cylindrica, Ficinia nodosa, Hydrocotyle hirta, Lobelia anceps.*	Restricted to the south east Australian coastal headlands commonly south from Noosa in Qld to near Bega of the south coast of NSW, though minor occurrences may occur as far south as Tasmania and north of Noosa.
Alliance 1: Scientific Name: *Hemarthria uncinata – Pteridium esculentum* NSW North Coast Bioregion Sod Tussock Grasslands **Association 1–1:** Scientific Name: *Hemarthria uncinata – Pteridium esculentum* Sod Tussock Grasslands	*Hemarthria uncinata, Pteridium esculentum, Imperata cylindrica, Ficinia nodosa, Parsonsia lanceolata.*	*Themeda triandra, Hibbertia vestita, Zoysia macrantha, Pultenaea maritima, Polymeria calycina, Viola banksii, Cynodon dactylon, Pimelea linifolia, Zieria prostrata, Lobelia anceps, Goodenia rotundifolia. Gonocarpus humilus.*	*Hemarthria uncinata, Pteridium esculentum, Imperata cylindrica, Ficinia nodosa, Parsonsia lanceolata, Stephania japonica, Hydrocotyle hirta.*	Sample plots restricted to Broughton Island within the NSW North Coast Bioregion. Likely also to occur on sands with a high-water table on the mainland within the same bioregion.
Alliance 2: Scientific Name: *Cynodon dactylon – Microlaena stipoides* North Coast and South East Coast Bioregion Grassy Shrublands & Grasslands	*Microlaena stipoides, Cynodon dactylon, Poa poiformis, Eragrostis leptostachya, Ficinia nodosa, Schoenus nitens, Glycine clandestina, Hydrocotyle sibthorpioides, Sporobolus creber, Crassula sieberiana.*	*Themeda triandra, Hibbertia vestita, Pultenaea maritima, Polymeria calycina, Zieria prostrata, Goodenia rotundifolia, Gonocarpus humilis.*	*Cynodon dactylon, Microlaena stipoides, Poa poiformis, Eragrostis leptostachya, Viola banksii, Zoysia macrantha, Ficinia nodosa, Micromyrtus ciliata, Lobelia anceps, Glycine clandestina, Schoenus nitens.*	Often dominated by the C_3 *Microlaena stipoides.* Found most commonly as grasslands in the open south of Narooma within the South East Corner Bioregion. Found as far north as Coffs Harbour within sheltered sites adjacent shrublands.
Association 2–1: Scientific Name: *Cynodon dactylon – Viola banksii* Grassland	*Cynodon dactylon, Viola banksii, Schoenus nitens, Bothriochloa decipiens, Schoenus apogon, Lobelia anceps, Centipeda minima*	*Themeda triandra, Hibbertia vestita, Pultenaea maritima, Zieria prostrata, Goodenia rotundifolia, Gonocarpus humilus, Imperata cylindrica, Poa poiformis.*	*Cynodon dactylon, Viola banksii, Schoenus nitens, Bothriochloa decipiens, Zoysia macrantha, Schoenus apogon, Lobelia anceps, Pimelea linifolia, Themeda triandra, Hydrocotyle hirta.*	Constituting the disjunct northern occurrence of this Group. Generally found in more frequently disturbed sheltered sites where *Themeda triandra* has been excluded and/or on sites where sand deposition has occurred.
Association 2–2: Scientific Name: *Zoysia macrantha – Ficinia nodosa* Grassy Shrublands and Grassland	*Zoysia macrantha, Ficinia nodosa, Zieria cytisoides, Westringia fruticosa, Crassula sieberiana, Sporobolus creber.*	*Themeda triandra, Hibbertia vestita, Pultenaea maritima, Polymeria calycina, Viola banksii, Cynodon dactylon, Pimelea linifolia, Zieria prostrata, Goodenia rotundifolia, Schoenus apogon.*	*Zoysia macrantha, Ficinia nodosa, Lobelia anceps, Zieria cytisoides, Westringia fruticosa, Sporobolus creber, Crassula sieberiana, Themeda triandra.*	Generally restricted to South East Corner Bioregion in the Eden area but may occur further north in favourable areas. *Zoysia macrantha* is a common species along the entire coast that is a highly salt tolerant species. Generally occurring closer to the seaward edge. The combination with *Ficinia nodosa* indicates a generally higher moisture availability of sites.
Association 2–3: Scientific Name: *– Poa poiformis - Microlaena stipoides* Grassland	*Poa poiformis, Microlaena stipoides, Eragrostis leptostachya, Cynodon dactylon, Ficinia nodosa, Glycine clandestina, Hydrocotyle sibthorpioides, Dichondra repens, Oxalis perennans, Lobelia anceps, Rytidosperma racemosum, Cheilanthes sieberi.*	*Themeda triandra, Hibbertia vestita, Zoysia macrantha, Pultenaea maritima, Polymeria calycina, Viola banksii, Pimelea linifolia, Zieria prostrata, Goodenia rotundifolia, Gonocarpus humilis.*	*Microlaena stipoides, Poa poiformis, Eragrostis leptostachya, Cynodon dactylon, Ficinia nodosa, Glycine cladestina, Lobelia anceps, Hydrocotyle sibthorpioides, Oxalis perennans, Entolasia stricta, Dichondra repens.*	Generally restricted to the South East Corner Bioregion. Dominated by C_3 grasses and in particular *Poa poiformis* which is largely confined to the most southern parts of the continent. Generally found where rainfall is higher and more aseasonal or winter dominant.

Hierarchy	Positive diagnostic (SIMPER)	Negative diagnostic (SIMPER)	Common taxa	Notes and distribution
Alliance 3: Scientific Name: *Themeda – Hibbertia – Pultenaea* South East Qld to South East Coast Bioregions Shrubby Grassland, Prostrate Heathy Grasslands & Sod Tussock Grasslands	*Themeda triandra, Hibbertia vestita, Pultenaea maritima, Polymeria calycina, Pimelea linifolia, Zieria prostrata, Goodenia rotundifolia, Hydrocotyle hirta, Gonocarpus humilis, Poranthera microphylla, Podolobium scandens, Pultenaea myrtoides, Senecio spathulatus.*	*Microlaena stipoides, Poa poiformis, Hemarthria uncinata, Eragrostis leptostachya, Pteridium esculentum, Schoenus nitens, Hydrocoytle sibthorpioides, Bothriochloa decipiens, Sporobolus creber.*	*Themeda triandra, Hibbertia vestita, Pultenaea marítima, Zoysia macrantha, Polymeria calycina, Viola banksii, Cynodon dactylon, Pimelea linifolia, Zieria prostrata, Gonocarpus humilis, Goodenia rotundifolia, Lobelia anceps.*	Found across the entire study area from the South East Queensland Bioregion to the South East Corner Bioregion.
Association 3–1: Scientific Name: *Cynodon dactylon – Viola banksii – Micromyrtus ciliata* Shrubby Grassland & Grassland	*Cynodon dactylon, Viola banksii, Hydrocotyle hirta, Micromyrtus ciliata, Parsonsia straminea, Hydrocotyle laxiflora, Dichondra repens, Lobelia purpurascens, Crassula sieberiana.*	*Themeda triandra, Hibbertia vestita, Zoysia macrantha, Pultenaea maritima, Pimelea linifolia, Zieria prostrata, Lobelia anceps, Goodenia rotundifolia, Gonocarpus humilis, Schoenus apogon, Ficinia nodosa, Imperata cylindrica, Poa poiformis, Lomandra longifolia, Microlaena stipoides, Carex breviculmis, Entolasia stricta.*	*Cynodon dactylon, Viola banksii, Hydrocotyle hirta, Micromyrtus ciliata, Polymeria calycina, Parsonsia straminea, Hydrocotyle laxiflora, Lobelia purpurascens, Dichondra repens, Hibbertia vestita, Themeda triandra.*	Found from the North Coast Bioregion (Coffs Harbour) to the Sydney Basin (Ulladulla). Often occurring in disturbed sites or heavily disturbed in the past.
Association 3–2: Scientific Name: *Zoysia macrantha – Aotus ericoides* Grassland	*Zoysia macrantha, Aotus ericoides, Imperata cylindrica, Centella asiatica, Commelina cyanea, Actinotus helianthi, Dianella congesta, Einadia hastata, Baumea juncea, Wahlenbergia littoricola.*	*Themeda triandra, Hibbertia vestita, Pultenaea maritima, Polymeria calycina, Viola banksii, Cynodon dactylon, Zieria prostrata, Lobelia anceps, Goodenia rotundifolia, Gonocarpus humilis, Ficinia nodosa.*	*Zoysia macrantha, Aotus ericoides, Imperata cylindrica, Themeda triandra, Centella asiatica, Dianella congesta, Actinotus helianthi, Commelina cyanea, Pimelea linifolia, Baumea juncea, Einadia hastata.*	Restricted to the NSW North Coast Bioregion occurring north of Coffs Harbour. Occurring in higher salt deposition areas. *Aotus ericoides* and *Actinotus helianthi* become prominent associated species in these northern locales but are largely absent further south.
Association 3–3: Scientific Name: *Zoysia macrantha – Themeda triandra* Shrubby Grassland & Sod Tussock Grassland	*Zoysia macrantha, Wollastonia uniflora, Viola banksii, Zieria prostrata, Poa poiformis, Lomandra longifolia, Podolobium scandens, Plectranthus cremnus, Senecio spathulatus, Atriplex cinereas.*	*Pultenaea marítima, Cynodon dactylon, Hydrocoytle hirtus, Pultenaea myrtoides, Aotus ericoides. Westringia fruticosa.*	*Zoysia macrantha, Themeda triandra, Wollastonia uniflora, Hibbertia vestita, Viola banksii, Plectranthus cremnus, Poa poiformis, Zieria prostrata, Podolobium scandens, Lomandra longifolia, Senecio spathulatus, Pimelea linifolia.*	More common assemblage than Assemblage 3.2 found within the NSW North Coast Bioregion (Coffs Harbour) to the South East Coast Bioregion (Bega). In higher salt deposition areas closer to seaward edge. Prostrate shrubs generally less prominent in this assemblage. *Atriplex cinereas* found only in the southern locales.
Association 3–4: Scientific Name: *Themeda triandra – Microlaena stipoides* Shrubby Grassland & Sod Tussock Grassland	*Microlaena stipoides, Cynodon dactylon, Commelina cyanea, Melaleuca armillaris, Bulbine bulbosa, Goodenia bellidifolia, Westringia fruticosa, Crassula sieberiana.*	*Hibbertia vestita, Zoysia macrantha, Pultenaea maritima, Polymeria calycina, Pimelea linifolia, Zieria prostrata, Lobelia anceps, Goodenia rotundifolia, Gonocarpus humilis, Ficinia nodosa, Imperata cylindrica.*	*Themeda triandra, Microlaena stipoides, Cynodon dactylon, Commelina cyanea, Schoenus apogon, Melaleuca armillaris, Goodenia bellidifolia, Bulbine bulbosa.*	Found within the South East Corner Bioregion. Small occurrences within the Moruya area. This assemblage occurs at the cross over of *Themeda* dominated assemblages to the north and *Microlaena* dominated assemblages to the south.
Association 3–5: Scientific Name: *Themeda triandra – Pultenaea maritima* Prostrate Heathy Grassland & Sod Tussock Grassland	*Themeda triandra, Polymeria calycina, Pultenaea maritima, Goodenia rotundifolia, Lobelia anceps, Pultenaea myrtoides.*	*Zoysia macrantha, Microlaena stipoides, Zieria prostrata, Poa poiformis, Hemarthria uncinata, Eragrostis leptostachya, Aotus ericoides, Micromyrtus ciliatus.*	*Themeda triandra, Pulteanea marítima, Hibbertia vestita, Polymeria calycina, Zoysia macrantha, Viola banksii, Cynodon dactylon, Pimelea linifolia, Zieria prostrata, Goodenia rotundifolia, Gonocarpus humilis, Lobelia anceps.*	The most common assemblage found from South East Qld to the South East Corner Bioregion. Largely dominated by *Themeda triandra* throughout its range this community type has a wide ecological amplitude but primarily found on higher nutrient soils e.g. basalt derived.
Association 3–6: Scientific Name: *Themeda triandra – Zieria prostrata* Prostrate Heathy Grassland, Shrubby Grassland & Sod Tussock Grassland	*Zieria prostrata, Hibbertia vestita, Viola banksii, Acacia sophorae, Schoenus apogon, Kunzea capitata, Gonocarpus humilis, Entolasia stricta, Leptospermum* sp., *Lomandra multiflora, Baumea juncea, Cynodon dactylon.*	*Lobelia anceps, Imperata cylindrica, Lomandra longifolia, Ficinia nodosa, Pultenaea myrtoides.*	*Themeda triandra, Zieria prostrata, Hibbertia vestita, Acacia sophorae, Viola banksii, Polymeria calycina, Zoysia macrantha, Pultenaea maritima, Pimelea linifolia, Schoenus apogon, Cynodon dactylon, Gonocarpus humilis.*	Restricted to the NSW North Coast Bioregion occurring north of Diamond Head. Generally distinguished by the presence of *Zieria prostrata* this assemblage often occurs closer to and is protected by dense taller shrub patches.

Figure 5. Alliance 2 *Cynodon dactylon – Microlaena stipoides* North Coast and South East Coast Bioregion Grassy Shrublands & Grasslands (Eurobodalla National Park).

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

Hierarchy	Previous published classification units
Group: Scientific Name: *Themeda – Pultenaea – Zoysia - Cynodon* grasslands & heathy grasslands Colloquial: Grasslands of South East Australian Coastal Headlands	Contained within Class - Maritime Grasslands (Keith 2004).
Association 1–1: *Hemarthria uncinata – Pteridium esculentum* Sod Tussock Grasslands	Not previously circumscribed.
Association 2–1: Scientific Name: *Cynodon dactylon – Viola banksii* Grassland	Not previously circumscribed.
Association 2–2: Scientific Name: *Zoysia macrantha – Ficinia nodosa* Grassy Shrublands and Grassland	Contained within 3: *Isolepis nodosa – Stenotaphrum subsecundum* Community (Adam et al. 1990).
Association 2–3: Scientific Name: *– Poa poiformis - Microlaena stipoides* Grassland	Contained within *Poa poiformis* Alliance (Beadle 1981); 3: *Isolepis nodosa – Stenotaphrum subsecundum* Community (Adam et al. 1990).
Association 3–1: Scientific Name: *Cynodon dactylon – Viola banksii – Micromyrtus ciliata* Shrubby Grassland & Grassland	In part Assemblage 5: *Cynodon dactylon – Viola banksii – Zoysia macrantha* and 6: *Viola banksii – Schoenus apogon – Zoysia macrantha* (Hunter and Hunter 2017a).
Association 3–2: Scientific Name: *Zoysia macrantha – Aotus ericoides* Grassland	Not previously circumscribed.
Association 3–3: Scientific Name: *Zoysia macrantha – Themeda triandra* Shrubby Grassland & Sod Tussock Grassland	Equivalent to Assemblage 4: *Zoysia macrantha – Melanthera biflora – Viola banksii* (Hunter and Hunter 2017a).
Association 3–4: Scientific Name: *Themeda triandra – Microlaena stipoides* Shrubby Grassland & Sod Tussock Grassland	Equivalent to 5.1.5 *Themeda australis* on Headlands Alliance (Beadle 1981); Possibly contained within 5: *Monotoca elliptica – Banksia integrifolia* Community (Adam et al. 1990).
Association 3–5: Scientific Name: *Themeda triandra – Pultenaea maritima* Prostrate Heathy Grassland & Sod Tussock Grassland	Equivalent to 5.1.5 *Themeda australis* on Headlands Alliance (Beadle 1981); Headland Thicket (Myerscough and Carolin 1986); 2: *Themeda australis* Community and in part 7: *Westringia fruticosa* Community (Adam et al. 1990); Community No. 14: *Themeda australis* Sod Grassland (Griffith et al. 2003); PCT 897 & 898: Kangaroo Grass Sod Tussock Grassland of Coastal areas of the Sydney Basin, PCT 1272: *Themeda australis* Sod Tussock Grassland of the NSW North Coast Bioregion, PCT 1513: Kangaroo Grass Sod Tussock Grassland of Coastal Areas of the North Coast (Benson 2006); GL: Headland Grassland of South East NSW (Tozer et al. 2010); Assemblage 1–3: 1 *Themeda triandra – Polymeria calycina – Pultenaea maritima*, 2 *Themeda triandra – Viola banksii – Cynodon dactylon*, 3 *Themeda triandra – Viola banksii – Cynodon dactylon* (Hunter and Hunter 2017).
Association 3–6: Scientific Name: *Themeda triandra – Zieria prostrata* Prostrate Heathy Grassland, Shrubby Grassland & Sod Tussock Grassland	Equivalent to 5.1.5 *Themeda australis* on Headlands Alliance (Beadle 1981); Assemblage 1–3: 1 *Themeda triandra – Polymeria calycina – Pultenaea maritima* (Hunter and Hunter 2017).

Figure 6. Alliance 3 *Themeda – Hibbertia – Pultenaea* South East Qld to South East Coast Bioregions Shrubby Grassland, Prostrate Heathy Grasslands & Sod Tussock Grasslands (Moonee Beach Nature Reserve).

Table 3. Comparison of species density and general environmental data and average percent cover synoptic table of Grasslands of South East Australian Coastal Headlands. 1–1 *Hemarthria uncinata – Pteridium esculentum*, 2–1 *Cynodon dactylon – Viola banksii*, 2–2 *Zoysia macrantha – Ficinia nodosa*, 2–3 *Poa poiformis – Microlaena stipoides*, 3–1 *Cynodon dactylon – Viola banksii – Micromyrtus ciliata*, 3–2 *Zoysia macrantha – Aotus ericoides*, 3–3 *Zoysia macrantha – Themeda triandra*, 3–4 *Themeda triandra – Microlaena stipoides*, 3–5 *Themeda triandra – Pultenaea maritima*, 3–6 *Themeda triandra – Zieria prostrata*. Climatic data was derived from ANUCLIM 6.1.1 (Xu and Hutchinson 2011) modelled using the variables easting, northing and altitude.

Association	1–1	2–1	2–2	2–3	3–1	3–2	3–3	3–4	3–5	3–6
Number of plots	2	2	2	8	7	7	3	15	463	12
Species density (4 m²)	5–6 (6)	5–17 (12)	11–11 (11)	13–21 (16)	4–20 (13)	9–12 (11)	4–19 (13)	13–19 (16)	2–27 (11)	13–25 (18)
Average sward height	55	11	34	24	30	30	17	40	23	15
Mean Annual Temperature (°C)	18.1	20.8–21.2	14.4	17.5–19.3	19.1–20.6	21.1–21.4	17.9–21.4	18.4–18.9	17.8–22.1	20.4–21.7
Annual Precipitation (mm)	1488–1490	1583–1711	862–863	817–1074	1179–1671	1390–1646	988–1711	891–978	941–1875	1559–1730
Association 1–1										
Hemarthria uncinata	100	0	0	0	0	0	0.5	0	0	0
Pteridium esculentum	29	0	0	0	0	0	0.2	0	0.1	0
Imperata cylindrica	16	0	0	0.1	0	14.3	0.5	0	0.9	0
Association 2–1										
Cynodon dactylon	0	85	0	15.4	29.1	0	0	15	2.3	4
Viola banksii	0	30	0	0.8	7.9	0	6	1.5	3.4	8.2
Schoenus nitens	0	12.5	0	0	0	0	0	0	0.3	0
Bothriochloa decipiens	0	7.5	0	0	0	0	0	0	0	0
Association 2–2										
Westringia fruticosa	0	0	35	0	0	0	0	1	0.5	0
Zieria cytisoides	0	0	15	0	0	0	0	0	0	0
Paspalum dilatatum	0	0	8.5	0.1	0	0	0.1	1	0.2	0.8
Association 2–3										
Microlaena stipoides	0	0	0	40.9	0	0	0.5	25	0.1	1.8
Poa poiformis	0	0	0	31	0	0	4.9	0	0.4	0
Eragrostis leptostachya	0	0	0	20.6	0	0	0.1	0.5	0	0

Association	1–1	2–1	2–2	2–3	3–1	3–2	3–3	3–4	3–5	3–6
Association 3–1										
Stenotaphrum secundatum	0	0	5	0.8	71.7	0	0.1	0	0.4	0
Hydrocotyle hirta	0.5	1.5	0	0	7.9	0	0.1	0	1	0.2
Micromyrtus ciliata	0	0	0	0	7.1	0	0	0	0	0
Association 3–2										
Zoysia macrantha	0	4	25	0	0	86.7	56.3	0	4.6	7.3
Aotus ericoides	0	0	0	0	0	50	0	0	0.3	0
Centella asiatica	0	0	0	0	0	4.7	0	0	0.1	0
Dianella congesta	0	0	0	0.1	0	4	0	0.5	0.3	0
Actinotus helianthi	0	0	0	0	0	4	0	0	0.3	0
Association 3–3										
Wollastonia uniflora	0	0	0	0	0	0	15	0	0.1	0
Plectranthus cremnus	0	0	0	0	0	0	8	0	0	0
Podolobium scandens	0	0	0	0	0	0	4.5	0	0.6	1.6
Lomandra longifolia	0	0.5	0	0.5	0	0	4.3	0	0.9	0
Senecio spathulatus	0	0	0	0	0	0	3.6	0	0.4	0
Association 3–4										
Commelina cyanea	0	0	0	0.3	0.4	3.3	0	25	0.3	0
Sporobolus fertilis	0	0	0	0	0	0	0	25	0	0
Plantago lanceolata	0	0	0.5	0.1	0	0	0	2	0	0.1
Bulbine bulbosa	0	0	0	0	0	0	0	2	0	0
Goodenia bellidifolia	0	0	0	0	0	0	0	2	0	0
Melaleuca armillaris	0	0	0	0	0	0	0	2	0	0
Association 3–5										
Themeda triandra	0	1.5	0.5	0	0.6	8.3	22.8	29	88.5	29.1
Pultenaea maritima	0	0	0	0	0	0	0.7	0	7.9	4.8
Hibbertia vestita	0	0.5	0	0	1	0	7.9	0	7.8	16.6
Lobelia anceps	0	3	2	2.5	0	0	0.5	0	1.3	0.4
Association 3–6										
Zieria prostrata	0	0	0	0	0	0	4.8	0	1.4	26
Acacia sophorae	0	0	0	0.3	0	0	0	0	0.2	8.8
Banksia integrifolia	0	0	0	0.1	0	0	0.1	0	0.1	8.3
Polymeria calycina	0	1	0	0	3.7	1.3	2.1	0	6	7.8
Hypochaeris radicata	0	2.5	2.5	1.5	0.1	0	1.6	0	0.5	5.2
Pimelea linifolia	0	2	0	0	0.1	2.7	3.5	0	2.5	4.8
Schoenus apogon	0	3	0	0.1	0	0	1.3	2	1	4.4
Gonocarpus humilis	0	0	0	0	0	0	0.5	0	1.3	3.8
Entolasia stricta	0	0	0	1.5	0	0	1.1	0	0.9	3.5
Dichondra repens	0	0	0	1.5	1.6	0	1.1	1.5	0.8	2.8
Leptospermum liversidgei	0	0	0	0	0	0	0	0	0	2.5
Goodenia rotundifolia	0	0	0	0	0	0	0.1	0	1.3	2.4
Lomandra multiflora	0	0	0	0	0	0	0.3	0	0.1	2.4
Baumea juncea	0	0	0	0	0	2	0	0	0.1	2.1
Viola betonicifolia	0	0	0	0.3	0	0	0	0	0.1	2.1

servation tenure. Ninety-three (87%) mapped hectares (68 ha within reserves) was found to conform to the listed endangered ecological community based on plot data and on-ground assessment. Inclusion within the endangered community was easily assessed as the main criterion is a dominance of *Themeda triandra*. Only 24 mapped stands were over one hectare in size with the largest being 5.3 ha.

Discussion

Previously, no comprehensive vegetation survey and classification has been attempted on coastal grassland vegetation on coastal headlands along their whole range of occurrence in NSW. This study has derived ten distinct associations. At least three of the assemblages have no synonymous descriptions one of these is considered to be at the group level within this analysis (Table 2). A further three assemblages were only recently circumscribed during an earlier analysis of a subset of this same dataset (Hunter and Hunter 2017b). Although four Plant Community Types (PCT) are currently recognised on coastal headlands within the NSW classification system, all of these types would fall within a single association in the analysis presented here (Association 3.5; Table 2). Thus, currently only one of the associations described here is included within the state-based classification schema. Association 3.5 *Themeda triandra – Pultenaea maritima* Prostrate Heathy Grassland and Sod Tussock Grassland is the most widespread, has been described by numerous authors (Table 2) and constitutes what is circumscribed by the endangered community listing. The other nine associations herewith are more restricted and rarer but have no protection under current legislation (Table 1).

The ten associations were found to fall within three distinct alliances. Alliance 1 was only found as isolated examples where the water table was found close to the surface and was found to have no shrubby elements distinguishing it from the other two alliances. Alliance 2 and 3 though they overlap in distribution likely due to exposure and local site conditions largely represent northern and southern floristic elements. Within Alliance 2 the dominant grasses were largely of the C_3 photosynthetic pathway (Table 1). The diversity of shrubs was lower within Alliance 2 with *Micromyrtus ciliata* being the most common associated low shrub (Table 1). Alliance 3 in contrast is largely dominated by C_4 grasses and a high diversity of associated prostrate or low growing shrubs.

Collectively these grasslands on headlands are highly restricted with the extant distribution being approximately 107 ha along more than 2,000 km of coastline. Though they are restricted they appear to be well reserved with at least 64% (73% of the listed endangered *Themeda* type) of the known area of occurrence falling with public reserves. Although these grasslands are highly disjunct and small in area, they are better reserved than almost any other vegetation type within NSW. Despite previous suggestions, lack of tenure security is likely not a threat for the *Themeda* dominated grasslands.

Currently invasion and competition by native *Poa* spp., in particular *Poa poiformis*, is listed as threat to the more common *Themeda triandra* dominated assemblages. Management actions have been enacted to counteract the threat of *Poa* invasion. *Poa* spp. were rare on coastal headlands and *Poa poiformis* was only sampled in 26 plots (0.05%) and only dominated four and is described here within its own association *Poa poiformis – Microlaena stipoides* Grassland which is highly restricted in southern NSW. Observations made during this survey would suggest that *Poa* spp. are not a threat to *Themeda triandra* assemblages. In context *Poa poiformis* assemblages are significantly rarer and more threatened in NSW and have a general distribution along the cooler and more temperate southern coasts of Australia. *Themeda triandra* is more common and dominant in northern locales. *Themeda triandra* has a C_4 and *Poa poiformis* a C_3 photosynthetic pathway and it is suggested that *Themeda triandra* is naturally less dominant in southern locations with *Poa poiformis* becoming more naturally abundant further south. Southern NSW is the expected location for floristic turnover between *Poa poiformis* and *Themeda triandra* dominated assemblages which has been misinterpreted as invasion. It is suggested here that *Poa poiformis* is therefore not a threat to the endangered listed *Themeda triandra*-dominated assemblages and is more likely a rare occurrence that warrants protection within NSW rather than eradication from headlands within the state.

Conclusion

This comprehensive analysis of the full distribution of grassland occurrences on headlands within NSW has highlighted significant gaps in our knowledge. Three associations have not previously been described but more importantly nine associations have no corresponding type within the NSW state-wide classification. All of these nine previously uncharacterised types are much more restricted and threatened than the more common *Themeda triandra*-dominated association and remain unprotected. This fuller survey has also allowed a better interpretation of floristic distribution and dominance and cast doubt on *Poa* spp. invasion as a listed threatening process. Even areas considered to be generally well surveyed may have undervalued and under protected vegetation types.

Data availability

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).

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Supplementary material

Supplementary material 1

Mapped hectares of and tenure of mapped occurrences.
Link: https://doi.org/10.3897/VCS/2020/48228.suppl1