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A new classification of savanna plant communities on the igneous rock lowlands and Tertiary sandy plain landscapes of Cape York Peninsula bioregion

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***Abstract*:** Classifying and mapping landscapes are tools to simplify complex systems into the discreet subsets widely used in landscape management. In 1999, the Queensland Government adopted a Regional Ecosystems approach as a state-wide landscape classification scheme. For the Cape York Peninsula bioregion in north-eastern Australia, Regional Ecosystems (RE) were initially recognised based on a pre-existing vegetation map and classification for the bioregion. The classification had been developed using expert-techniques based on extensive field plot data. Here, we use numerical analyses to classify the field plot data and identify savanna plant communities associated with two widespread landform groups in the bioregion (the old loamy and sandy plains (land zone 5) and the hills and lowlands on igneous rocks (land zone 12). Communities were identified at the plant association level, using species importance values calculated from foliage cover and vegetation height at each plot. We developed a descriptive-framework for each community using statistically based characterising species and biophysical attributes. We recognise 57 communities compared with 110 that had been previously identified using expert-techniques. This classification is used to recommend refined Regional Ecosystems under the government's regulations. The descriptive-framework supported consistent descriptions of communities and assignment of new sites to the classification. We conclude that incorporating quantitative methods in classifying and describing plant communities will improve the robustness and defensibility of Regional Ecosystems and their use in landscape management across Queensland.

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Introduction

Vegetation classification is a globally used tool for land management and for investigating ecological diversity at multiple scales. Consistent vegetation classification schemes which cross geographical and administrative boundaries are therefore highly desirable (ESCAVI 2003; Rodwell 2006; Jennings *et al.* 2009; De Cáceres *et al.* 2015). Recognising this, the Queensland government adopted the Regional Ecosystem (RE) approach as a state-wide classification scheme in 1999. This is a triple-tiered hierarchy with the first division being based on the Interim Biogeographical Regions of Australia (Thackway & Cresswell 1995). The second division of the hierarchy is 'land zone'; a concept that involves broad geological divisions with consideration of geomorphological processes and soils (Wilson & Taylor 2012). Examples of land zones include 'alluvial river and creek flats', 'coastal dunes' or 'hills and lowlands on granitic rocks'. The third level of the classification scheme is termed 'vegetation community' and is a plant community, recognised at the plant association level (Figure 1). A Regional Ecosystem is therefore defined as "a vegetation community, or communities, in a bioregion that are consistently associated with a particular combination of geology, landform and soil" (Sattler & Williams 1999). REs can therefore contain one or more vegetation communities. REs are mappable, with a distinctive signature recognisable from remote sensing imagery at the landscape scale of 1:100,000. REs are revised and updated when new data is supplied. To this end, each bioregion has a technical committee to review and implement proposed changes based on appropriate data. This technical review committee performs the same function as similar panels in other Australian and international jurisdictions (EVSWG 2017; OEH 2018; USNVC 2018).

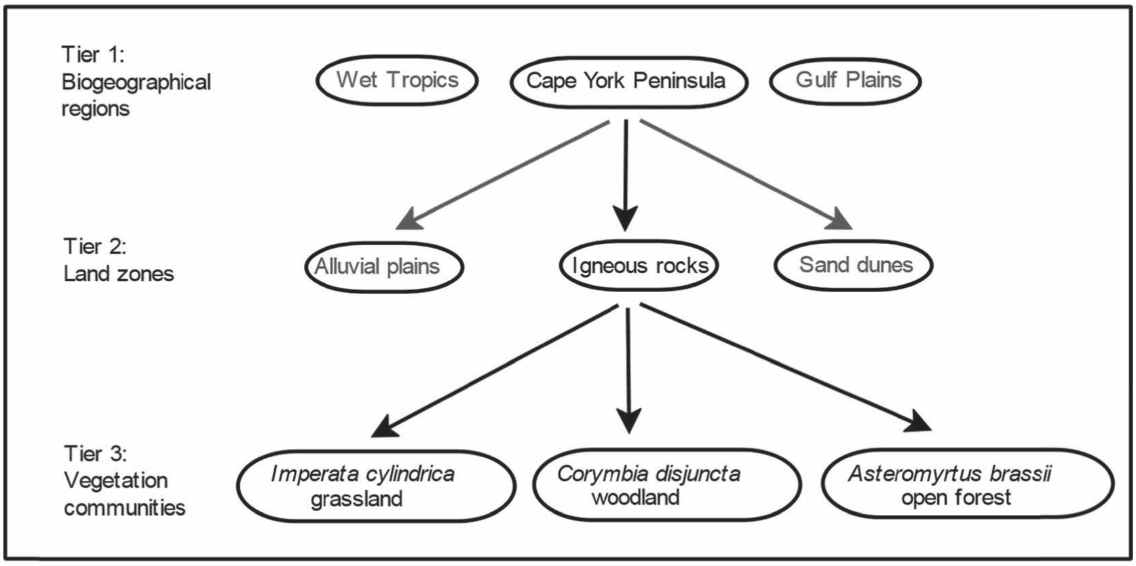

Figure 1: Regional Ecosystem classification scheme. Regional Ecosystems are a triple-tiered hierarchy. The first tier is biogeographical regions based on the Interim Biogeographical Regions of Australia. The second tier is broad geological / geomorphological groups (labelled land zones). The third tier are plant communities recognised at the association level (labelled vegetation communities)

For Cape York Peninsula (the Peninsula) a vegetation map and qualitatively-based classification at the plant association level was developed as part of the Cape York Peninsula Land Use Study (CYPLUS) carried out in the early 1990s (Neldner & Clarkson 1995). With the adoption of the RE framework, the CYPLUS vegetation classification was converted to a Regional Ecosystem classification using qualitative methods. The vegetation map was also revised in the context of a state-wide RE mapping program at a scale of 1:100,000, an exercise that ultimately necessitated a revision of the RE classification of the Peninsula.

A best-practice framework for vegetation classification is centred around standardised methods of data collection and classification techniques (De Cáceres *et al.* 2015). Following this best-practice, the RE classification framework has accompanying documentation describing a standardised survey and mapping methodology for Queensland (the methodology) (Neldner *et al.* 2017c). It outlines a consistent set of classification protocols for defining vegetation communities which align with both the Beadle (1981) definition of a plant association and the necessary emphasis on canopy species used in classifications for vegetation mapping. These protocols identify the pre-dominant layer within a vegetation's structure as that contributing most to the above-ground biomass (Neldner *et al.* 2017c). Communities are then defined using the height, cover and dominant species in the pre-dominant layer, with sub-ordinate consideration given to associated species in other layers (Neldner *et al.* 2017c). Plant associations are thus defined as a community where the pre-dominant layer has a uniform floristic composition and exhibits a uniform structure. This forms the basis for mapping and survey projects at all scales across the state and is embedded in legislation. Currently however, implementation of these classification protocols relies on qualitative techniques and subjective sorting of plot data into similar groups. The use of qualitative techniques is widespread and common in remote areas with limited researchers such as in Queensland, but they have acknowledged problems based primarily around their lack of transparency, repeatability and consistency between researchers (Mucina 1997; Kent 2012; Oliver *et al.* 2012). A good outcome from such processes is heavily dependent on a researcher's knowledge of the vegetation of the area and the biases introduced by their assumptions of the ecological and biophysical processes important to landscape function and biodiversity. Consequently, qualitative methods do not produce communities which are statistically comparable (Harris & Kitchener 2005; Kent 2012; Oliver *et al.* 2012). Using quantitative techniques in the classification process can help to overcome some of these problems allowing consistent, statistical information to be produced about community composition and structure.

A classification scheme has widest applicability if it can perform two major tasks: firstly, determine communities with transparent and repeatable techniques, and secondly provide consistent and reliable assignment of new sites to the classification scheme (De Cáceres & Wiser 2012). The aim of this study is to address these requirements by incorporating quantitative analyses into the classification of vegetation communities within the RE framework. Specifically, we aim to classify the savanna communities of two land zones on the Peninsula at the association level, assess the adequacy of the preferential sampling design used and develop a descriptive-framework which incorporates statistically derived characterising species for assigning new site data into these communities. We use this framework to describe REs suitable as distinct vegetation mapping units.

Methods

The Cape York Study area

Cape York Peninsula bioregion covers 120,000 km^2 in the monsoon tropics of north-eastern Australia and lies between 10 and 16 degrees south (Figure 2). Elevations range from sea level to approximately 800 m. The annual average rainfall varies between 1000–2000 mm with 80% falling in the wet season between December and March (Horn 1995). Temperatures range from an average annual monthly minimum of 14 °C in winter (July) to an average monthly maximum of 35 °C in summer (December) (BoM. 2016). Our study encompasses the savanna communities on two of the ten land zones on the Peninsula (Neldner 1999); the old loamy and sandy plains (land zone 5) and the hills and lowlands on igneous rocks (land zone 12). These communities on land zone 5 cover 45,000 km^2 (40% of the bioregion) and on land zone 12, 6,500 km^2 (5% of the bioregion). Land zone 5 is distributed across the full extent of the bioregion while land zone 12 occurs primarily along a north-south spine associated with the Great Dividing Range (Figure 2).

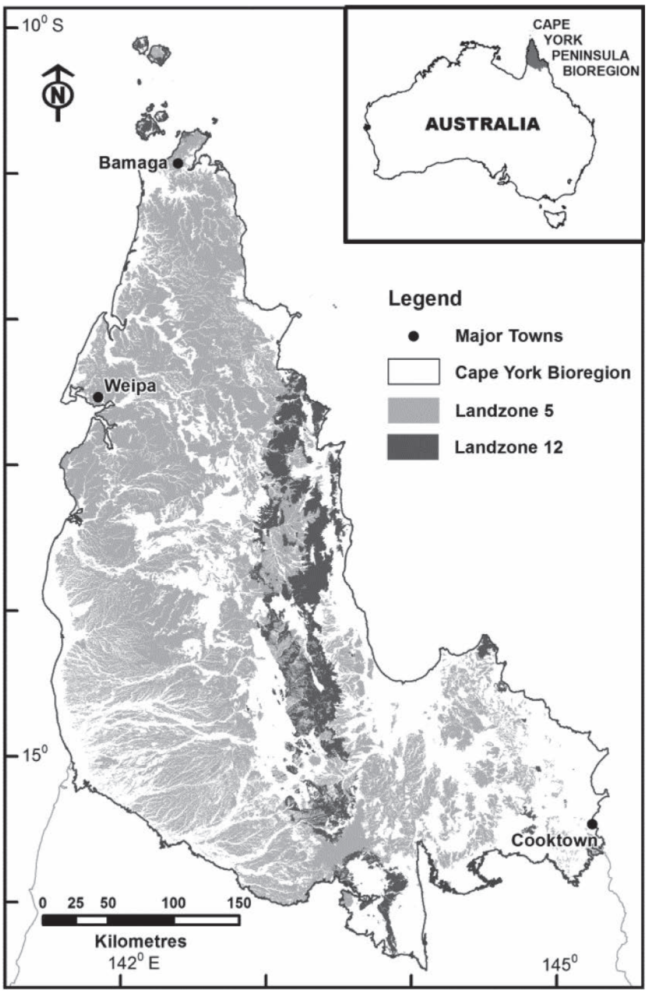

Figure 2: Distribution of the two land zones on Cape York Peninsula classified in this study.

Data Collation

During the mapping process two major types of vegetation data were collected; observational sites and vegetation plot data. These were sampled from 1990 to 2015, with the majority between 1992 and 1996 as part of the original mapping project (Neldner & Clarkson 1995). The observational sites were collected in large numbers as rapid records made during field traverses of the mapping area. They include records of geolocation, dominant species in the pre-dominant layer and vegetation structure. The survey design for locating vegetation plot data was preferential, with locations chosen based on either interpreted photo-patterns from air photos and ease of access, or on plant assemblages identified during the collection of observational sites. Observational site data were extracted from GIS coverages associated with the mapping project and vegetation plot data from the Queensland government 'CORVEG' database. The latter were categorised as either 'detailed' plots, containing data appropriate for use in determining the vegetation classification, or 'non-detailed' plots, containing incomplete data or data collected using different methods. Detailed plots contained data on percent foliage projected cover (%FPC) for each species in each woody vegetation layer recorded along a 50m transect using the line intercept method (Neldner *et al.* 2017c). The average height of each layer was also recorded. The ground layer had species abundance recorded as an estimate of %FPC in 1 m^2 quadrats at 10 m intervals along the 50 m transect (five quadrats in total) and averaged. There were 192 detailed, 38 non-detailed plots and 4,670 observational sites on land zone 5 and 96 detailed, 45 non-detailed sites and 1,424 observational sites on land zone 12. Vegetation communities in which the pre-dominant canopy was the ground layer we refer to collectively as grasslands, but this group includes sedgelands and rock pavements with scattered herbs and forbs as well as true grasslands (Neldner *et al.* 2017c).

It was necessary for our quantitative analysis to accord with the classification protocols and principles outlined in the methodology as they are embedded in all current regional ecosystem mapping relied upon for regulatory purposes. To this end, previous research identified transformations to detailed plot data suited to incorporating vegetation structure into the classification of plant associations (Addicott *et al.* 2018). As a result, %FPC for each species was multiplied by the height of the layer in which it occurred prior to data analysis. This generated a species importance value for every species in each plot. The protocols also specify using dominant species and removing species which have low occurrence or abundance (here termed 'sparse') from a dataset is recommended in general scientific practice when exploring ecological patterns in data. Sparse species may mask relationships of interest at the relevant scale, their occurrence and identification may be dependent on survey design or their distribution may be spatially and temporally inconsistent (Grime 1998; McCune & Grace 2002; Kent 2012). To standardise the removal of sparse species across plots we excluded those whose contribution to total foliage cover was never >1%. For example, if a species contributed <1% in one plot and >1% in others it was retained in **all** plots in which it occurred. A species whose contribution to total foliage cover was <1% in every plot was excluded. This resulted in removing 175 taxa from the land zone 12 and 254 taxa from the land zone 5 analyses. Standardising the removal of sparse species in this way provides a consistent method across the dataset which does not delete infrequent but dominant taxa (Field *et al.* 1982), eliminates most of the unidentified taxa in a site without affecting the identification of communities at the association level (Pos *et al.* 2014) and improves the recognition of communities identifiable at landscape mapping scales (Addicott *et al.* 2018). We acknowledge that sparse species and unidentified taxa may be new, rare and/or endangered species and hence of high conservation significance. However, for this study they are not critical to vegetation classification at landscape scales (Addicott *et al* 2018). Non-native species were also excluded, and any remaining taxa not reliably identified to species were amalgamated to genus level. The ground layer at wooded plots was excluded to identify communities suitable as mapping units (Neldner & Howitt 1991; Archibald & Scholes 2007; Mucina & Daniel 2013). In the final analyses there were 351 species with 241 occurring on land zone 5, 258 on land zone 12, and 148 shared between the two land zones. Plant nomenclature follows Bostock & Holland (2015).

Identifying plant communities

Plots were allocated to either land zone 5 or 12 based on field observations as well as geology, regolith and / or soils mapping available at plot each location. We analysed the detailed plots in each land zone to look for groups of co-occurring plant species using agglomerative hierarchical clustering and the software package PRIMER-E v6 (Clarke & Gorley 2006). We produced a similarity matrix (square-root transformation, Bray-Curtis coefficient) and ran the CLUSTER routine, using unweighted pair group mean averaging, to form clusters. To choose the level of cluster division for identifying plant communities we used a combination of three evaluation methods: 1) the SIMPROF routine which determines clusters significantly different to each other (Field *et al.* 1982), 2) Indicator Species Analysis (Dufrêne & Legendre 1997) (in the 'labdsv' R package (Roberts 2013)) which determines clusters maximising species occurrence and 3) generalised linear models (GLM) in a mulitvariate framework (Lyons *et al.* 2016) (available in the 'optimus' R package (Lyons 2018) to estimate the relative performance of differing cluster divisions in predicting species foliage cover. This last method uses GLMs and Akaike's Information Criteria (AIC). AIC is summed across individual species, and the final sum-of-AIC score is used as a measure of how well the cluster division predicts species cover. A lower sum-of-AIC score indicates a better prediction. In situations where the three evaluators produced differing results, we formed a subset of plots and tested cluster divisions within the subset.

Assigning plant communities to the Regional Ecosystem framework

Our final plant communities were evaluated by the *technical review committee for regional ecosystems of the Cape York Peninsula bioregion* whose role was to evaluate and give effect to proposals to modify Regional Ecosystems classifications. During this process the committee assigned plant communities to regional ecosystems based on expert-judgement of non-floristic variables as outlined by the methodology (Neldner et al 2017c), potentially producing REs containing communities with different dominant species and low floristic similarity to each other. For example, communities which did not have predictable or mappable occurrences or were <100 ha in total area of distribution were grouped with those on closely associated landforms and similar ecological niches. Communities recognised as successional temporal variants, or condition states, of a climax association were also grouped into one RE. Where the committee requested more evidence to support proposed changes, we used the classification protocols as a guide for conducting further analyses. Consequently, we tested for floristic differences between sites on different geomorphological areas and soil types (using the ANOSIM routine), for differences in canopy height (using an unpaired t-test) and investigated whether differences in the ground layers of sites were coincident with geomorphological areas or soil divisions (using *n*MDS ordination and GIS overlay). One additional role of the committee was to identify communities not represented in the analyses but recognisable from aerial photo interpretation, non-detailed plot data and observational sites. There were therefore two types of communities in the final classification scheme; those identified through quantitative analysis and those identified by expert-techniques. The latter communities will be reviewed when further detailed sampling data and quantitative analyses are available.

Creating community descriptions and assigning new sites

An important aspect of a vegetation classification scheme is to allow description and identification of its plant communities (De Cáceres & Wiser 2012). To this end we compiled a descriptive-framework based on characterising species, vegetation structure and landform, including geographical distribution when it aided identification. Characterising species were those used to describe the floristic and structural composition of a community (De Cáceres *et al.* 2015) and were identified for the quantitatively defined communities using each species' frequency, average cover and strength of association with a community. To determine the strength of each species' association with a community, we calculated a phi-coefficient of association (Chytrý *et al.* 2002) based on cover, using the JUICE software package (Tichý 2002). Each group was standardised to equal number of plots. A phi-coefficient of 100 means a species occurs only in that community, while values approaching zero indicate the species is equally abundant in several communities. The phi-coefficient values were also used to identify species with a significant association to a community using Fisher's exact test ($p<0.05$) (Chytrý & Tichý 2003). We listed species frequency and average cover using the technical-description routine within the CORVEG database, which also allowed identification of vegetation structure. We defined characterising species as those with a phi-coefficient of association >6 or occurring in >70% of sites. A phi-coefficient of >6 was chosen to ensure a minimum of one statistically associated species with each community. Landform and additional vegetation structure information was taken from plot sheets and observational data where available. Geographical distribution came from the final mapping. Where communities were represented by fewer than three sites in analyses we used non-detailed or observational sites for additional information. To describe qualitatively determined communities we used species, structure and landform information from non-detailed plots and observational sites, and, where it was diagnostic, mapped distribution. These community descriptions are necessarily less robust but allow indicative recognition in the field.

The ease and certainty with which new sites can be reliably allocated into a classification scheme outside of an analysis process is important (De Cáceres & Wiser 2012) and we expected our descriptive-framework to enable this. To test this, we used the 'non-detailed' plots previously excluded from analysis as 'new' sites. We matched the information available from each plot to that in the descriptive-framework, subjectively assigning it to a vegetation community and rating its level of fit-to-community as high or low. These non-detailed sites had a variety of vegetation information available ranging from a community label with or without a limited species list (and sometimes growth form) to complete species lists with alternative abundance measure such as classes, stem density or basal area and an indication of which layer species occurred in. In sites which had only a label (or label and a species list) we took the label as an indicator of dominance and structure. We also used landform information where it was provided on the site pro-forma.

Along with defining a classification via consistent analytical techniques, labelling communities using consistent naming conventions is important (De Cáceres & Wiser 2012). Neldner *et al.* (2017c) outlines these for the RE framework. In this, a limited number of characterising species are listed in order of dominance, with punctuation to indicate relative abundance and frequency, followed by the structural formation. Associated habitat characteristics, such as landform or soil descriptors are included in labels where they are diagnostic. We followed these conventions to develop community labels.

Assessing sampling adequacy

Knowledge of bias in a sampling design allows an understanding of the strength and weaknesses of results. We reduced bias by using plots with standardised plot size, collection methods, data attributes, data quality and season of survey. The standard plot size of 500 m^2 has been shown to adequately capture the species diversity at the plot level in savanna and woodland communities (Neldner & Butler 2008). Data collection methods follow the standard survey methods outlined in Neldner *et al.* (2017c). Seasonality is an issue in the ground layer as many species occur only in the wet and early dry season. In sites dominated by woody vegetation, excluding the ground layer removed this potential bias. Plots dominated by the ground layer were surveyed between May and August (the early dry season). Despite standardising these aspects of survey design however, we expected some bias due to preferential rather than random selection of plot locations. Therefore, we assessed how well the field sampling captures firstly the environmental variability across the landscape, and secondly the community and species richness.

To test how well the environmental variability was sampled, we followed the convention of testing those variables expected to limit plant species growth, dividing them into climate and soil themes. We used four climate variables, two temperature variables (average annual temperature, and the coefficient of variation of temperature seasonality) and two rainfall variables (annual average rainfall, and the mean moisture index of the lowest quarter), available as ANUCLIM datasets (Xu & Hutchinson 2013). The soils variables were grouped in to soil nutrients (organic carbon content, and phosphorus) and soil structure (available plant water capacity, permeability, drainage, and slope) (Lyons *et al.* 2017; Neldner *et al.* 2017a). All soil datasets came from Australian Soil and Resource Information System (McKenzie *et al.* 2012; ASRIS 2014), with the slope derived from the digital elevation model for the Peninsula

(GeoScience Australia *et al.* 2009). In addition to these climate and soil variables, we assessed how well the survey sampled variation in vegetation structure by using a maximum persistent greenness GIS coverage (JRSRP 2017). This coverage is derived from LANDSAT imagery classification and, on the Peninsula, equates to density of woody vegetation layers, with a higher greenness index indicating denser woody vegetation. While density of woody vegetation is significantly correlated with the climate variables ($r = 0.6, p < 0.0001$), the R^2 value of the 4-way multiple regression is 34% indicating the predictability of density of woody vegetation using these variables is relatively low (Appendix 6, Figures A6.1-A6.4). We are therefore confident that assessing woody vegetation density will provide useful additional information on bias in sampling of vegetation structure. All these datasets were accessed as raster coverages. Using the DOMAIN software program (Carpenter *et al.* 1993) we calculated the similarity of the environmental envelope at any grid point to that at any plot or observational site. DOMAIN uses the input variables to create an environmental envelope for each grid cell and then calculates the similarity between each grid cell and any site in a Euclidean p-dimensional space using the Gower metric. The similarity is bounded in one direction, with values close to 100% for maximum congruence, and can be displayed spatially. Because observational sites assist in identifying the assemblages recorded in the detailed plots we investigated the amount of environmental variability captured by both types of data.

To assess the community and species richness surveyed by the detailed plots we estimated total population richness, and calculated the proportion captured by our sampling. To assess the species richness surveyed we used the full species dataset (with weeds removed), as our classification analyses used only a subset of species surveyed. To estimate population richness from our samples we derived 1,000 model-populations using bootstrap techniques. We then calculated an unbiased population estimate of richness by 1) estimating the bias, by subtracting the sample richness from the mean richness of the model-populations, and 2) subtracting this bias from the sample richness. Using the bootstrap model-populations we also defined 90% confidence intervals (using the 0.05 and 0.95 quantiles around the mean of the 1,000 model-populations). All calculations were done in the R environment (R Development Core Team 2014) using the 'bootstrap' package (Efron & Tibshirani 1993).

Results

Assessing sampling adequacy-Environmental variability

The survey design comprehensively sampled the full environmental variability in each land zone. Between 99 and 100% of the total area of each land zone was >90%-similar to any observational site for all variables. Results were similar for detailed plots for climate, vegetation structure and soil nutrient variables. Between 99 and 100% of the total area of land zone 5 and 98% of land zone 12 was >90%-similar to any detailed plot (in the respective land zone). These results were slightly lower for soil structure, with 98.6% of land zone 5 and 95% of land zone 12 >90%-similar to any site. Appendices 3a and 3b have detailed tables and indicative maps of areas of lower similarity to sites. The detailed GIS coverages of these areas are available from the senior author if more detail is required.

Community Richness

We found the survey design reliably sampled the community richness of land zone 5 but not that of land zone 12. On land zone 5 it captured 95% of the estimated total community richness. Nineteen of an estimated 20 communities were sampled in detailed sites, within the 90% CI (19 - 21). On land zone 12 the survey captured 89% of the community richness (24 of an estimated 27 communities), outside the 90% CI of 25 – 29 (Table 1).

Species Richness

The survey did not reliably capture the full species richness on either land zone, with the number of species sampled lying outside of the 90% CIs (Table 1). There were 775 species sampled on land zone 5 and 673 on land zone 12, representing 86% of the estimated species richness on either land zone (Table 1).

Table 1: Sampled and expected community and species richness. The expected number of communities and species and the 90% confidence intervals (CI) are calculated from bias corrected estimates of 1,000 bootstrap model-populations.

	Number sampled	Number expected	90% CI
Community richness			
Land zone 5	19	20	19 - 21
Land zone 12	24	27	25 - 29
Species richness			
Land zone 5	775	904	889 - 920
Land zone 12	673	785	771 - 798

Plant Communities

There were 57 communities in our study's final classification, 27 on land zone 5 and 30 on land zone 12. Seventy-five percent of these were identified by quantitative methods and 25% by qualitative techniques and less detailed plot data (Table 2). Two communities were recognised after additional analyses requested by the technical review committee (Appendix 4). Incorporating quantitative analysis resulted in fewer communities on both land zones than the expert-based classification with an overall reduction of 49%. Individually, the reduction was higher on land zone 5 (54%) than land zone 12 (42%), driven by the larger decrease in the number of woodlands and shrublands identified (Table 2). Whilst most of the final REs consisted of one plant community, in 11 instances, the review committee assigned several communities to individual REs. The 27 communities on land zone 5 were assigned to 21 REs, and the 30 on land zone 12 to 23 forming some REs with more than one community (appendix 2). Because the detailed descriptions, conservation status and ecological notes for individual REs and their communities are available on-line we have not included it in this manuscript (http://www.qld.gov.au/environment/plants-animals/plants/ecosystems). However, to portray the communities and REs recognised, we have included the short label descriptions, mapped areas and notes for the REs in Appendix 2. To illustrate the floristic relationships between the communities and REs on each land zone we formed community dendrograms and ordination plots from the detailed plot data (Appendix 5).

Table 2: The number of communities in each formation on each land zone. The quantitative analysis resulted in a reduction in the number of vegetation communities. 'a priori' classification = vegetation communities in the pre-existing, qualitatively derived, classification.

	Grasslands	Shrublands	Woodlands
Land zone 5 (45,000 km^2)	806 ha	1,904 km^2	46,089 km^2
Quantitatively derived	1	1	17
Qualitatively derived	1	1	6
Total after review *(no. of REs)*	**2** *(1)*	**2** *(2)*	**23** *(18)*
a priori classification	4	7	48
Land zone 12 (5,500 km^2)	154 km^2	110 km^2	5,236 km^2
Quantitatively derived	5	3	16
Qualitatively derived	1	1	4
Total after review *(no. of REs)*	**6** ***(5)***	**4** ***(4)***	**20** ***(14)***
a priori classification	7	6	38

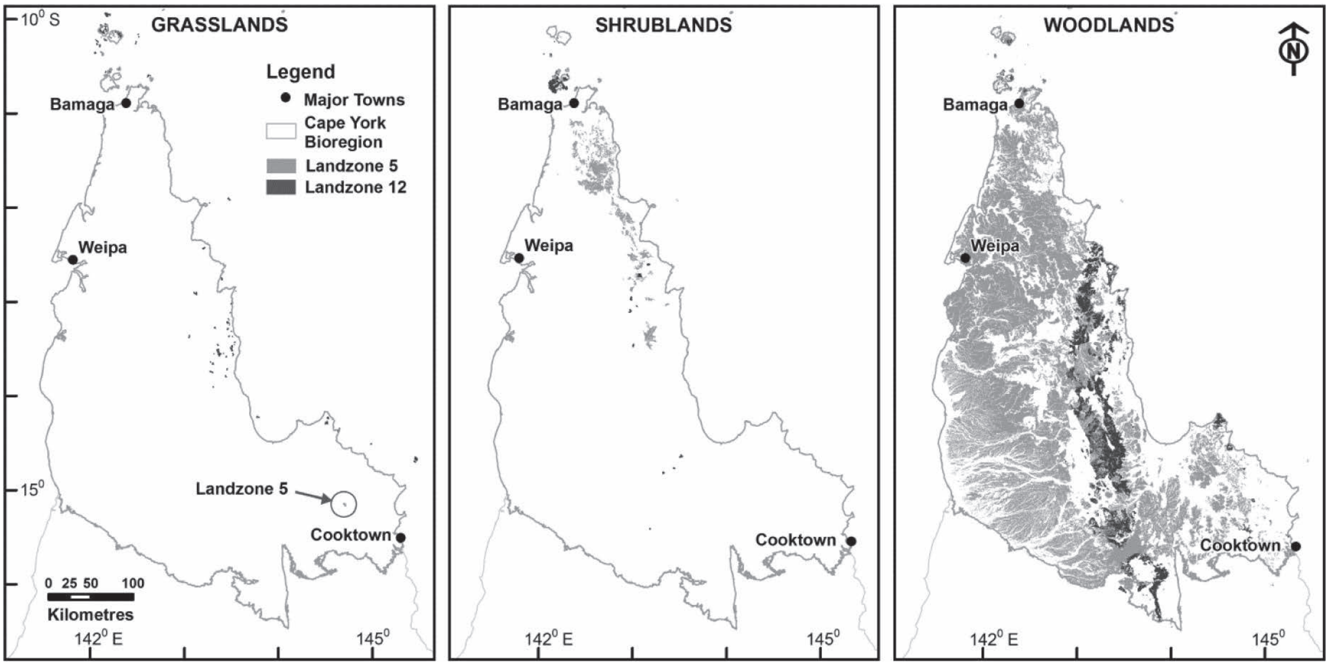

Figure 3: Distribution of the vegetation formations across Cape York Peninsula bioregion included in this study.

Summary of plant communities and formations of land zone 5 (old loamy and sandy plains)

Grasslands are of limited extent on land zone 5 (0.01% of the land zone) and contain two communities. One occurs only on islands in the Torres Strait and the other in southern Cape York Peninsula (Figure 3). Shrubland communities cover 4% of the land zone (Figure 3), the most extensive of which (1,900 km^2) occur on the deep sand plains in the north-east and east of the bioregion. The second occurs only on the Torres Strait islands. Woodlands dominate land zone 5 (95% of the area) (Figure 3) and can be broadly categorised into four groups; 1) *Eucalyptus tetrodonta* dominated woodlands, 2) other Eucalypt and *Corymbia* dominated woodlands, 3) *Melaleuca* dominated woodlands, and 4) *Asteromyrtus* dominated woodlands. The *Eucalyptus tetrodonta* woodlands dominate the landscape, covering 42,870 km^2. *Melaleuca* dominated woodlands cover the next largest area of 2,825 km^2, the *Asteromyrtus* dominated woodlands 1,044 km^2 and Eucalypts and *Corymbia* species other than *Eucalyptus tetrodonta* cover the smallest area (528 km^2).

Summary of plant communities and formations of land zone 12 (hills and lowlands on granitic rocks)

Grasslands are again of limited extent on land zone 12, covering 2% (Figure 3). The most widespread of these was the rock pavements with scattered herbs and forbs associated with the tops of the major mountain chains on the mainland and the Torres Strait islands (66 km^2). The remaining five are all dominated by Poaceae species. Shrublands cover 12% of the land zone (Figure 3), with three of the four communities dominated by *Melaleuca* species. The fourth, covering the largest area (57 km^2), is dominated by an endemic species, *Leptospermum purpurascens.* Despite having the largest area, its range is restricted to the hills and mountains associated with Iron Range in the centre of the bioregion. Woodlands are again the most widespread formation (75% of land zone) (Figure 3). These are dominated by *Eucalyptus tetrodonta* woodlands (41% of woodland area) and ironbark woodlands (*Eucalyptus cullenii* and *Eucalyptus crebra*) (28%). Other Eucalypt and *Corymbia* dominated woodlands cover 21%. *Melaleuca* woodlands cover 3% of the land zone, a much smaller area than on land zone 5. The remaining area is covered by one mixed species low woodland and two *Acacia* communities (both of which occur only in the Torres Strait islands).

Assigning new sites into the classification scheme

Using the descriptive-framework (Appendix 1) we were able to incorporate all 83 non-detailed sites into the classification scheme. The characterising species provide the most useful information; strength of association allowed us to rank characterising species in importance for a community. The species information in the non-detailed sites could then be matched to this, even when not all characterising species were recorded at a site. While the characterising species was the most useful individual piece of information, the most powerful tool for assigning sites in to the classification was the combination of characterising species plus vegetation structure information. Landform became diagnostic where the characterising species overlapped (particularly the *Eucalyptus tetrodonta* woodlands). We could assign 66% of sites (55) with a high level-of-fit to community. These were the sites that contained quantitative abundance and structure data collected using different methods. The sites assigned with a low level-of-fit to community were those with only a community label to indicate abundance and structure.

Inclusion of results in mapping

Vegetation mapping and classification are two separate processes often accompanying each other (Franklin 2013). In this survey the process was iterative, with the mapping (and accessibility) driving the choice of transects, and the outcomes feeding back to change the qualitative classification depicted in the mapping. Continuing this process, the results of our classification analyses were used to revise the Regional Ecosystem mapping to reflect the updated vegetation communities and REs. As part of the mapping, individual mapped areas (i.e. polygons) are also assigned levels of reliability for attributes and locational accuracy. Polygons which contained detailed plots were given a high reliability in the mapping, as were areas containing non-detailed plots assigned in to the classification with a high fit-to-community. Polygons containing non-detailed plots with low fit-to-community were mapped with a low reliability and identified as requiring further survey.

Figure 4: RE 3.5.19 *Asteromyrtus lysicephala* and *Neofabricia myrtifolia* open heath to shrubland on sand sheets.

Figure 5: RE3.5.36a *Eucalyptus tetrodonta* and *Corymbia nesophila* woodland on undulating plains.

Figure 6: RE 3.5.41b *Melaleuca viridiflora* low open woodland +/- *Petalostigma banksii* on plains.

Figure 7: RE 3.12.10a *Eucalyptus cullenii* +/- *Corymbia clarksoniana* woodland on granite hills and footslopes.

Figure 8: RE 3.12.28 *Leptospermum purpurascens* tall shrubland on igneous hills.

Figure 9: RE 3.12.48a *Heteropogon triticeus* dominated grasslands on igneous headlands and offshore islands.

Discussion

We present, for the first time, a bioregional scale classification of vegetation communities, within the Regional Ecosystem framework, incorporating quantitative analyses. After initial assignment of sites to land zones, we allocated sites to communities using 1) numerical classification based on floristic attributes, and 2) statistical analysis of vegetation structure and environmental factors. These communities were incorporated into the RE framework by an expert panel peer-review process. We developed a descriptive-framework to characterise the vegetation communities (using statistically derived floristic attributes and non-statistically derived abiotic variables), and used this to assign new sites to the classification. In so doing we addressed the two main tasks of a classification scheme (as outlined by De Cáceres & Wiser -2012) - to determine vegetation communities using transparent and repeatable techniques, and to provide a framework for consistent and reliable assignment of new sites into the classification scheme.

While our classification incorporates as much quantitative analysis as available data allows, 25% of communities were still identified using expert-based techniques. This was done using plots with different data collection methods, or observational data from helicopter flights over inaccessible areas of the bioregion, meaning the data could not be used in the analyses. Communities identified by expert-based techniques therefore represent ‘known unknowns’ and provide a targeted direction for future data collection.

A notable outcome of the quantitative analysis was the 49% reduction in the number of communities recognised, compared to the expert-driven process. Quantitative analysis allows experts to test their interpretation of the factors influencing landscape function; in this case, unquantified floristic and biophysical attributes. One question our analysis asks is, ‘Does the floristic composition of the landscape reflect the divisions chosen by experts, based on their assumptions about the importance of these attributes?’ The 49% reduction suggests that, in this case, it does not. Quantifying the differences between the expert and quantitatively derived communities is beyond the scope of this paper, but is the focus of ongoing work. However, one function of quantitative analysis is to help gain consensus among experts about the species driving vegetation community differences.

Preferential-sampling designs are biased in several ways compared to stratified random-sampling designs (Diekmann *et al.* 2007; Hédl 2007; Michalcová *et al.* 2011). It is well recognised that the statistical power of preferential-sampling designs is lower (Lájer 2007), but much of the aim of vegetation survey and mapping is to distinguish patterns using descriptive procedures rather than to produce inferential results from null hypothesis significance testing (De Cáceres *et al.* 2015). Roleček *et al.* (2007) found that preferential sampling designs cover a greater range of environmental extremes than random sampling designs for the same level of survey effort; our results appear to agree with this. Despite an initial perception that 51,500 km^2 would not be adequately sampled with 288 detailed plots, this survey covered the environmental variability and community richness comprehensively on land zone 5, and adequately on land zone 12. We suggest this is due to the two-tiered system of data collection, with large numbers of rapid observational sites augmented by detailed vegetation plots in representative locations. The small difference in the sampling adequacy between land zones is likely due to accessibility. Whilst the landscapes of the old loamy and sandy plains of land zone 5 are relatively well traversed by roads, allowing access for detailed plot collections, the landscapes of the igneous rocks of land zone 12 have mountainous terrain with few roads providing limited access.

Although our sample design adequately surveyed landscape variability and community richness, our analyses show this is not so for species richness. This differs from other studies that found preferential-sampling had a higher likelihood of sampling the full species richness than stratified-random sampling, as researchers tend to choose sample locations with higher species richness (Michalcová *et al.* 2011). In this survey, however, locations were chosen on a perception of representativeness of distinctive communities, rather than species richness, potentially explaining the difference to other studies. Our survey's design of detailed plot locations evidently captures the communities present, but not the full floristic variability within those communities. This result agrees with the intuitive assessment that sampling such a large area with so few sites would not provide comprehensive coverage; and with Lawson *et al.* (2010) who found high levels of floristic heterogeneity within regional ecosystems in south-east Queensland.

A major function of a classification scheme is to allow new site data to be assigned to it (De Cáceres & Wiser 2012). In the authors' experience, an important issue when using a qualitatively-derived classification for this task, is ambiguity in allocating new sites into the scheme. A descriptive-framework based on quantitative data helped overcome this by allowing us to allocate sites with different data collection methods to the classification scheme with a high level-of-fit to community, enhancing the repeatability of allocating new sites. This, in turn, increases the classification's applicability by allowing 1) easier recognition of community types, 2) greater confidence in identifying sites from communities new to the classification, and 3) the classification to become a dynamic scheme responsive to new information. Our descriptive-framework does not fit the definition of membership rules outlined by De Cáceres & Wiser (2012), (in that the same rules used to define communities are not used to allocate new sites into it) but it performs a similar function.

A potential benefit of incorporating quantitative analyses in the Regional Ecosystem framework is to allow a display of relationships between communities not obvious in a qualitative classification. An area with many similar REs, may have less diversity than an area with fewer dissimilar REs. For instance, a result of the committee process of allocating communities to REs, based on non-floristic variables, is that REs can contain communities dominated by different species with low similarity to each other. Dendrograms, scatter plots and similarity matrices produced by quantitative analyses provide a visualisation and measure of the similarities between REs and their vegetation communities (Appendix 5). For example RE 3.12.18 has two communities 'a' and 'b' (Appendix 5, figs 5.2 and 5.4). RE 3.12.18b is found in small patches scattered through larger areas of 3.12.18a, on the same landform, and not predictable enough to be reliably mapped at 1:100,000 scale. Displaying these relationships between communities may be useful in conservation planning, for example.

Incorporating quantitative analyses in the Regional Ecosystem framework will enhance its already wide use. As well as the current comparisons of spatial and temporal change of REs (Accad *et al.* 2017), statistical comparisons between vegetation communities at a cross-bioregion scale will become possible (Goodall 1973). We anticipate quantitatively-based vegetation communities will aid investigations into questions such as the assumptions behind their use as surrogates for biodiversity (Sattler & Williams 1999), the environmental drivers of the patterns of community distribution, and the phylogenetic diversity of communities. Importantly it will provide statistically-backed base-line data against which to measure the effects of future changes, such as climate and land use. REs are used by a wide cross-section of the public and form part of legislation at multiple tiers of government. With vegetation communities (the base-line level of the RE hierarchy) based on quantitative analyses, REs are more robust and readily defensible, providing legislators and users with greater confidence in the classification scheme.

Conclusion

To standardise classification procedures across large geographic areas and multiple administrative boundaries is one of the globally-recognised goals of vegetation science (Jennings *et al.* 2009; Walker *et al.* 2013; De Cáceres *et al.* 2015). These procedures are generally described as standardised data collection methods, classification schemes and quantitative classification techniques. In Australia, most state governments have adopted approaches which work towards achieving these goals (Sun *et al.* 1997; Gellie *et al.* 2017). In Queensland this is well advanced. As well as having state-wide Regional Ecosystem mapping at 1:100,000 scale, there is a standardised classification scheme, data collection methods and qualitative classification techniques. Extending our quantitative classification approach to the Regional Ecosystem framework across the remainder of Cape York Peninsula and other bioregions in Queensland, will further the achievement of these globally recognised goals.

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Appendix 1: Descriptive-framework for quantitatively derived vegetation communities on land zone 5 and 12 in Cape York Peninsula bioregion.

‘Frequently occurring spp.’ are produced using the technical-description routine in the QLD government database ‘CORVEG’. Frequency = % of total sites in which a species occurs; average %cover = mean of all cover values >0 for each species. Formatting is as outputted from this routine, with % after the frequency and no percent symbol associated with average %cover. For example, *Corymbia stockeri* (93%, 3) means this species occurs in 93% of sites and when it occurs has an average cover of 3%. Statistically **highly** associated species are those with a phi-coefficient of association >6 with a community. Statistically **significantly** associated are those significantly associated with a community (p<0.05) using Fisher’s exact test. A species may be highly associated with a community but not significantly associated if it also has a strong association with another community. For example, *Dodonaea polyandra* is highly associated with RE 3.5.5, but not significantly as it is also highly associated with RE 3.5.42. Communities recognised using qualitative techniques are not included.

Version 10 RE *(number of sites used in NA)*	**Short label description**	**Frequently occurring spp. (% frequency, average %cover)** *(Species not occurring in the canopy layer are labelled with their layer, E = emergent, T2 = Second tree layer, S1 = shrub layer)*	**Statistically significantly associated spp.** *(p<0.05) (phi association coefficient)*	**Statistically highly associated spp.** *(phi association coefficient)*	**Occasional spp with high average %cover (% frequency, average %cover)** *(Species not occurring in the canopy layer are labelled with their layer, E = emergent, T2 = Second tree layer, S1 = shrub layer)*	**Additional information**
Land Zone 5						
3.5.5 (6 sites)	*Corymbia novoguinensis* +/- *C. tessellaris* woodland on sand plains on northern Cape York Peninsula	*Corymbia novoguinensis* (100%, 16)	*Corymbia novoguinensis* (40.1) *Corymbia tessellaris* (22.8) *Gardenia* sp. (19.5) *Welchiodendron longivalve* (12.2) *Acacia polystachya* (12.1) *Acacia crassicarpa (10.3)* *Bridelia tomentosa* (8) *Tabernaemontana orientalis* (6.9) *Mallotus nesophilus* (6.9) *Terminalia muelleri* (6.2) *Syzygium suborbiculare* (6.1) *Livistona muelleri* (6)	*Corymbia novoguinensis* (40.1) *Corymbia tessellaris* (22.8) *Gardenia* sp. (19.5) *Dodonaea polyandra* (13.1) *Welchiodendron longivalve* (12.2) *Acacia polystachya* (12.1) *Acacia crassicarpa (10.3)* *Bridelia tomentosa* (8) *Tabernaemontana orientalis* (6.9) *Mallotus nesophilus* (6.9) *Terminalia muelleri* (6.2) *Syzygium suborbiculare* (6.1) *Livistona muelleri* (6)	*Welchiodendron longivalve* (17%, 12) *Corymbia tessellaris* (50%, 11) *Corymbia nesophila* (13%, 10)	Occurs in the northern Peninsula area and Torres Strait Islands.
3.5.6 (4 sites)	*Eucalyptus phoenicea* woodland on sandy outwash plains	*Eucalyptus phoenicea* (100%, 17)	*Eucalyptus phoenicea* (41.8) *Eucalyptus portuensis* (15.4) *Melaleuca nervosa* (7.3)	*Eucalyptus phoenicea* (41.8) *Eucalyptus portuensis* (15.4) *Xanthorrhoea johnsonii* (14.7) *Melaleuca nervosa* (7.3) *Acacia torulosa* (6.8)	*Eucalyptus portuensis* (25%, 10) *Grevillea glauca* (100%, 2) T2 *Xanthorrhoea johnsonii* (25%, 15) S1	On the Battlecamp sandstone plateau. *Eucalyptus portuensis* can be co-dominant

3.5.9 (11 sites)	*Eucalyptus tetrodonta*, *Corymbia stockeri* +/- *C. setosa* woodland on sand plains	*Erythrophleum chlorostachys* (100%, 6) *Eucalyptus tetrodonta* (100%, 4) *Corymbia stockeri* (93%, 3)	*Corymbia setosa* (17.8) *Neofabricia sericisepala* (12.8) *Erythrophleum chlorostachys* (10.2) *Melaleuca nervosa* (6.1)	*Corymbia setosa* (17.8) *Neofabricia sericisepala* (12.8) *Erythrophleum chlorostachys* (10.2) *Melaleuca nervosa* (6.1)	*Corymbia setosa* (64%, 4) *Corymbia novoguinensis* (9%, 9)	Widespread in the southern half of the bioregion and occurs predominantly on the Holroyd Plain in close association with 3.5.37a. At the northern extent of this community *Corymbia novoguinensis* can dominate the canopy and *C. setosa* is absent. *Corymbia setosa* is not always present but there is often a combination of mixed species, including heaths, in the community. *C. stockeri* is likely to be subsp. *peninsularis.*
3.5.15b (1 site)	*Dapsilanthus spathaceus* open sedgeland with emergent shrubs.	*Dapsilanthus spathaceus* (100%, 19) *Germainia capitata* (100%, 10) *Schoenus sparteus* (100%, 9) *Scleria* sp. (100%, 6) *Pandanus* sp. (100%, 6)	*Dapsilanthus spathaceus* (42.7) *Germainia capitata* (30.9) *Schoenus sparteus* (29.3) *Scleria* sp. (23.9) *Tricostularia undulata* (13.8) *Eriocaulaceae* (9.7) *Xyris* sp. (9.7)	*Dapsilanthus spathaceus (42.7)* *Germainia capitata (30.9)* *Schoenus sparteus (29.3)* *Scleria sp. (23.9)* *Pandanus (22.1)* *Poaceae (19.5)* *Tricostularia undulata (13.8)* *Eriocaulaceae (9.5)* *Xyris sp. (9.5)*		Occurs in mosaic patches with 3.5.15a on Torres Strait Islands
3.5.19 (14 sites)	*Asteromyrtus lysicephala* and/or *Neofabricia myrtifolia* and/or *Jacksonia thesioides* open heath to shrubland on sand sheets	*Asteromyrtus lysicephala* (86%, 8) *Jacksonia thesioides* (86%, 3) *Neofabricia myrtifolia* (86%, 5) *Choriceras tricorne* (71%, 3) *Hibbertia banksii* (71%, 1) *Allocasuarina littoralis* (79%, 3) E.	*Asteromyrtus lysicephala* (24.3) *Allocasuarina littoralis* (12.8) *Thryptomene oligandra* (11.5) *Neofabricia myrtifolia* (11.3) *Hibbertia banksii* (8.9) *Leucopogon ruscifolius* (8.8) *Choriceras tricorne* (8.4) *Gompholobium nitidum* (8.2) *Grevillea pteridifolia* (6.8)	*Asteromyrtus lysicephala* (24.3) *Allocasuarina littoralis* (12.8) *Thryptomene oligandra* (11.5) *Neofabricia myrtifolia* (11.3) *Hibbertia banksii* (8.9) *Leucopogon ruscifolius* (8.8) *Choriceras tricorne* (8.4) *Gompholobium nitidum* (8.2) *Grevillea pteridifolia* (6.8)	*Leucopogon ruscifolius* (29%, 4) *Thryptomene oligandra* (21%, 7)	Heath formation differentiates this from RE 3.5.42 which is a low woodland to open forest.
3.5.25 (1 site)	*Eucalyptus leptophleba* woodland on plains	*Eucalyptus leptophleba* (100%, 21) *Eucalyptus chlorophylla* (100%, 2) *Corymbia clarksoniana* (100%, 2)	*Eucalyptus chlorophylla* (6.3)	*Eucalyptus leptophleba* (42.4) *Eucalyptus chlorophylla* (6.3)		
3.5.34 (4 sites)	*Corymbia nesophila* open forest on sand rises in the Torres Strait	*Corymbia nesophila* (100%, 20)	*Corymbia nesophila* (22.5) *Acacia simsii* (9.7)	*Corymbia nesophila* (22.5) *Acacia simsii* (9.7)	*Corymbia clarksoniana* (50%, 13) *Corymbia stockeri* (50%, 6) *Jacksonia thesioides* (50%, 15) S1	Occurs on Torres Strait Islands. *Corymbia stockeri* is likely to be *Corymbia stockeri* subsp. *peninsularis.*

3.5.35 (13 sites)	*Eucalyptus tetrodonta, Corymbia nesophila* woodland with a heathy understory	*Eucalyptus tetrodonta* (100%, 8) *Corymbia nesophila* (92%, 5) *Asteromyrtus brassii* (77%, 4) T2. *Neofabricia myrtifolia* (69%, 4) T2 *Neoroepera banksii* (69%, 6) S1 *Acacia calyculata* (77%, 2) S1	*Neoroepera banksii* (14.1) S1 *Asteromyrtus brassii* (8) T2 *Acacia calyculata (6.7) S1* *Neofabricia myrtifolia (6.3)*	*Neoroepera banksii* (14.1) S1 *Lophostemon suaveolens* (10.3) *Asteromyrtus brassii* (8) T2 *Acacia calyculata* (6.7) S1 *Neofabricia myrtifolia* (6.3)	*Lophostemon suaveolens* (15%, 13)	Characterised by a dominance of heath species in the understory. The understory species mix of this community may change depending on fire history.
3.5.36	*Eucalyptus tetrodonta* and *Corymbia nesophila* woodland to open forest on undulating plains and remnant plateaus					
3.5.36a (40 sites)	*Eucalyptus tetrodonta* and *Corymbia nesophila* woodland on undulating plains	*Eucalyptus tetrodonta* (100% 11) *Corymbia nesophila* (100, 10) *Erythrophleum chlorostachys* (45%, 2)	*Corymbia nesophila* (13) *Eucalyptus tetrodonta* (7.6)	*Corymbia nesophila* (13) *Eucalyptus tetrodonta* (7.6)		Occurs on sandy and loamy plains off remnant bauxite plateaus.
3.5.36b (10sites)	*Eucalyptus tetrodonta* and *Corymbia nesophila* open forest on remnant plateaus	*Eucalyptus tetrodonta* (100%, 15) *Corymbia nesophila* (100%, 15) *Erythrophleum chlorostachys* (50%, 3)	*Corymbia nesophila* (19.7) *Planchonia careya* (6.5) T3, S1	*Corymbia nesophila* (19.7) *Eucalyptus tetrodonta* (12.3) *Parinari nonda* (6.8) *Planchonia careya* (6.5) T3, S1		Occurs on bauxite plateaus. May occur as a woodland.
3.5.37	*Eucalyptus tetrodonta +/- Corymbia stockeri* woodland to tall open forest on erosional plains and remnant plateaus					
3.5.37a (14 sites)	*Eucalyptus tetrodonta +/- Corymbia stockeri* woodland on erosional plains	*Eucalyptus tetrodonta* (100%, 12) *Corymbia stockeri* (93%, 7) *Erythrophleum chlorostachys* (43%, 2)	*Corymbia stockeri* (9.7) *Eucalyptus tetrodonta* (6.9)	*Corymbia stockeri* (9.7) *Eucalyptus brassiana* (7) *Eucalyptus tetrodonta* (6.9)	*Xanthorrhoea johnsonii* (21%, 5) S1	Occurs predominantly on erosional plains and rises but can occur on edges of bauxite plateaus. *Corymbia stockeri* is likely to be subsp. *peninsularis*.
3.5.37b (16 sites)	*Eucalyptus tetrodonta +/- Corymbia stockeri* tall woodland on tertiary remnant plateaus	*Eucalyptus tetrodonta* (100%, 18) *Corymbia stockeri* (81%, 9) *Erythrophleum chlorostachys* (69%, 7)	*Corymbia stockeri* (12.6) *Erythrophleum chlorostachys* (11.6)	*Eucalyptus tetrodonta* (14.2) *Corymbia stockeri* (12.6) *Erythrophleum chlorostachys* (11.6)		Occurs predominantly on the Kimba plateau and northern extensions. *Corymbia stockeri* is likely to be subsp. *peninsularis*.

3.5.38	*Eucalyptus tetrodonta* +/- *E. cullenii* or *E. tetrodonta* +/- *C. stockeri and Melaleuca* spp. woodland on remnant surfaces					
3.5.38a (7 sites)	*Eucalyptus tetrodonta, Corymbia stockeri* +/- *E. cullenii* woodland on remnant surfaces	*Eucalyptus tetrodonta* (100%, 9) *Corymbia stockeri* (100%, 4) *Eucalyptus cullenii* (86%, 6)	*Eucalyptus cullenii* (25)	*Eucalyptus cullenii* (25) *Corymbia disjuncta* (7.5)		Both subspecies of *Corymbia stockeri* may occur. Occurs on weathered remnant surfaces often with ironstone nodules to surface. *Melaleuca stenostachya* may occur but will have lower biomass than the *C. stockeri* and *Eucalyptus cullenii.*
3.5.38b (7 sites)	*E. tetrodonta* +/- *C. stockeri* woodland with a *Melaleuca* spp shrub layer on remnant surfaces	*Eucalyptus tetrodonta* (100%, 8) *Corymbia stockeri* (86%, 7) *Melaleuca viridiflora* (100%, 3) T2 *Melaleuca stenostachya* (43%, 4) *Corymbia clarksoniana* (43%, 2) *Melaleuca stenostachya* (57%, 4) T2	*Corymbia stockeri* (7.9) *Melaleuca stenostachya* (7.9)	*Corymbia stockeri* (7.9) *Melaleuca stenostachya* (7.9)	*Jacksonia thesioides* (14%, 5) S1	Occurs on weathered remnant surfaces often with ironstone nodules to surface.
3.5.39 (26 sites)	*Eucalyptus tetrodonta* +/- *Corymbia clarksoniana* woodland on sand plains	*Eucalyptus tetrodonta* (100%, 13) *Corymbia clarksoniana* (73%, 4) *Erythrophleum chlorostachys* (54%,*4)*	*Eucalyptus tetrodonta* (7.1)	*Eucalyptus tetrodonta* (7.1)	*Corymbia stockeri* (15%, 7) *Corymbia tessellaris* (12%, 7) *Eucalyptus leptophleba* (4%, 8)	
3.5.40 (5 sites)	*Melaleuca stenostachya* +/- *Eucalyptus chlorophylla woodland* +/- *M. viridiflora* shrub layer on outwash plains	*Melaleuca stenostachya* (100%, 9) *Eucalyptus chlorophylla* (60%, 8) *Melaleuca viridiflora* (60%, 3)	*Melaleuca stenostachya* (35.7) *Eucalyptus chlorophylla (*17.3) *Corymbia hylandii* (8.7)	*Melaleuca stenostachya* (35.7) *Eucalyptus chlorophylla* (17.3) *Corymbia hylandii* (8.7) *Acacia brassii* (7.2)		
3.5.41	*Melaleuca viridiflora* +/- *Corymbia clarksoniana* woodland to low open woodland on plains					

3.5.41a (14 sites)	*Melaleuca viridiflora* +/- *Corymbia clarksoniana* woodland on plains	*Corymbia clarksoniana* (86%, 12) *Melaleuca viridiflora* (50%, 9) *Melaleuca viridiflora* (79%, 2) T2	*Corymbia clarksoniana* (17.7) *Melaleuca viridiflora (8.7)*	*Corymbia clarksoniana* (17.7) *Melaleuca viridiflora (8.7)*	*Melaleuca viridiflora* (64%, 2) S1	
3.5.41b (1 site)	*Melaleuca viridiflora* +/- *Petalostigma banksii* low open woodland on plains	*Melaleuca viridiflora* (100%, 7) *Petalostigma banksii* (100%, 5) T2	None > 6	*Petalostigma banksii* (14.6) *Melaleuca viridiflora* (10.3) *Wrightia saligna* (6.1)		
3.5.42 (14 sites)	*Asteromyrtus brassii* and/or *Neofabricia myrtifolia* low open forest to woodland on sand plains	*Neofabricia myrtifolia* (93%, 9) *Asteromyrtus brassii* (93%, 6) *Allocasuarina littoralis* (71%, 3) T2	*Leucopogon yorkensis* (24.1) *Neofabricia myrtifolia* (20.3) *Asteromyrtus brassii* (19.4) *Callitris intratropica* (16.9) *Choriceras tricorne* (11.4) *Allocasuarina littoralis* (11.2) *Dodonaea polyandra* (10.6) *Welchiodendron longivalve* (10) *Alyxia spicata* (9.2) *Olax pendula* (6.8)	*Leucopogon yorkensis* (24.1) *Neofabricia myrtifolia* (20.3) *Asteromyrtus brassii* (19.4) *Callitris intratropica* (16.9) *Choriceras tricorne* (11.4) *Allocasuarina littoralis* (11.2) *Dodonaea polyandra* (10.6) *Welchiodendron longivalve* (10) *Alyxia spicata* (9.2) *Olax pendula* (6.8)	*Welchiodendron longivalve* (36%, 5) *Leucopogon yorkensis* (29%, 21) *Choriceras tricorne* (43%, 4) *Dodonaea polyandra* (36%, 4) *Callitris intratropica* (21%, 5) *Alyxia spicata* (71%, 2) S1 *Neoroepera banksii* (21%, 5) S1 *Melaleuca viridiflora* (50%, 5)	Woodland to open forest structure differentiates this from RE 3.5.19.
Land Zone 12						
3.12.7 (2 sites)	*Corymbia clarksoniana, Eucalyptus brassiana* open forest on granite ranges	*Corymbia clarksoniana* (100%, 20) *Eucalyptus brassiana* (100%, 12)	*Chionanthus ramiflorus* (29.4) *Eucalyptus brassiana* (29.1) *Calophyllum sil* (15.5) *Wikstroemia indica* (13.8) *Celtis paniculata* (12) *Polyscias elegans* (12) *Ganophyllum falcatum* (11.9) *Litsea glutinosa* (11.9) *Cupaniopsis anacardioides (6.9)*	*Corymbia clarksoniana* (35.5) *Chionanthus ramiflorus* (29.4) *Eucalyptus brassiana* (28.9) *Melaleuca nervosa* (21.8) *Calophyllum sil* (15.5) *Wikstroemia indica* (13.8) *Celtis paniculata* (12) *Polyscias elegans* (12) *Ganophyllum falcatum* (11.9) *Litsea glutinosa* (11.9) *Schefflera actinophylla* (11.9) *Buchanania arborescens* (10.9) *Wodyetia bifurcata* (9.8) *Cupaniopsis anacardioides* (6.9) *Alyxia spicata* (6.6)	*Corymbia stockeri* (50%,5) *Chionanthus ramiflorus* (50%, 20) T2 *Melaleuca nervosa* (50%, 12) T2	
3.12.9 (1 site)	*Corymbia tessellaris* +/- *Welchiodendron longivalve* +/- *Eucalyptus cullenii* open forest on footslopes of granite hills.	*Corymbia tessellaris* (100%, 30)	*Tabernaemontana pandacaqui* (6.9)	*Corymbia tessellaris* (51.1) *Tabernaemontana pandacaqui* (6.9)		

3.12.10	*Eucalyptus cullenii* +/- *Corymbia clarksoniana* woodland or *E. chlorophylla* woodland on granitic ranges					
3.12.10a (13 sites)	*Eucalyptus cullenii* +/- *Corymbia clarksoniana* woodland on granitic ranges	*Eucalyptus cullenii* (100%, 12) *Corymbia clarksoniana* (69%, 5)	*Eucalyptus cullenii* (28.8) *Dendrolobium umbellatum* (14.8)	*Eucalyptus cullenii* (28.8) *Dendrolobium umbellatum* (14.8) *Dolichandrone heterophylla* (8.1) *Acacia oraria* (6.1)	*Dendrolobium umbellatum* (38%, 8) T2 *Dendrolobium umbellatum* (38%, 7) S1	This vegetation community is unmappable at the RE mapping scale and interspersed with vegetation community 3.12.10b. These communities are mapped collectively as 3.12.10
3.12.10b (2 sites)	*Eucalyptus chlorophylla* woodlands on granitic ranges	*Eucalyptus chlorophylla* (100%, 4) *Corymbia dallachiana* (100%, 1)	*Eucalyptus chlorophylla* (19.6) *Corymbia confertiflora* (9.6)	*Eucalyptus chlorophylla* (19.6) *Corymbia confertiflora* (9.5)	*Corymbia confertiflora* (50%, 3)	This vegetation community is unmappable at the RE mapping scale and interspersed with vegetation community 3.12.10a. These communities are mapped collectively as 3.12.10.
3.12.11 (6 sites)	*Corymbia stockeri* +/- *Welchiodendron longivalve* woodland on steep to rolling granite hills	*Corymbia stockeri* (100%, 23)	*Corymbia stockeri* (46.2) *Dalbergia densa* (10.9) *Welchiodendron longivalve* (9.4)	*Corymbia stockeri* (45.9) *Dalbergia densa* (10.9) *Cryptocarya exfoliata* (9.8) *Welchiodendron longivalve* (9.2)	*Eucalyptus cullenii* (17%, 10) *Corymbia tessellaris* (17%, 8) *Welchiodendron longivalve* (17%, 8) *Dalbergia densa* (83%,2) S1	
3.12.18	*Eucalyptus leptophleba* and *Corymbia clarksoniana* woodland or *Corymbia disjuncta* woodland on steep to low igneous hills					
3.12.18a (7 sites)	*Eucalyptus leptophleba* +/- *Corymbia clarksoniana* woodland to open woodland on steep to low igneous hills	*Eucalyptus leptophleba* (100%, 13) *Corymbia clarksoniana* (86%, 3)	*Eucalyptus leptophleba* (35.2) *Dendrolobium umbellatum* (10) *Flueggea virosa* (6.7)	*Eucalyptus leptophleba* (35.1) *Dendrolobium umbellatum* (9.9) *Eucalyptus platyphylla* (8.4) *Flueggea virosa* (6.7)	*Eucalyptus platyphylla* (14%, 8) *Dendrolobium umbellatum* (43%, 7) T2 *Dendrolobium umbellatum* (43%, 3) S1	
3.12.18b (2 sites)	*Corymbia disjuncta* +/- *C. clarksoniana* woodland on steep igneous hillslopes	*Corymbia disjuncta* (100%, 8) *Corymbia clarksoniana* (100%, 1)	*Corymbia disjuncta* (29.4) *Piliostigma malabaricum* (6.9)	*Corymbia disjuncta* (29.4) *Piliostigma malabaricum* (6.9) *Alstonia* sp. (6.3)		Restricted to Orchid Creek area.

3.12.28 (5 sites)	*Leptospermum purpurascens* tall shrubland on igneous hills	*Leptospermum purpurascens* (100%, 19)	*Leptospermum purpurascens* (44.3) *Shonia tristigma* (10.7) *Hovea* sp. (7.7)	*Leptospermum purpurascens* (44.4) *Shonia tristigma* (10.7) *Acacia brassii* (10.2) *Hovea* sp.(7.7) *Lomandra banksii* (6.2)	*Shonia tristigma* (20%, 6) S2	
3.12.30 (1 site)	*Imperata cylindrica* +/- *Heteropogon contortus* +/- *Mnesithea rottboellioides* closed tussock grassland on steep slopes of igneous hills	*Imperata cylindrica* (100%, 52) *Heteropogon contortus* (100%, 18) *Mnesithea rottboellioides* (100%, 11)	*Imperata cylindrica* (71.3) *Heteropogon contortus* (41.6) *Mnesithea rottboellioides* (32.5) *Cymbopogon refractus* (19.6)	*Imperata cylindrica* (71.4) *Heteropogon contortus* (41.6) *Mnesithea rottboellioides* (32.5) *Cymbopogon refractus* (19.6)		
3.12.32 (2 sites)	*Schizachyrium* spp. +/- *Rhynchosia* spp. grasslands on granit hills and rck pavmet	*Schizachyrium* sp. (100%, 9) *Ectrosia* sp. (100%, 8) *Rhynchosia minima* (100%, 5) *Eriachne* sp. (100%, 4)	*Ectrosia leporina* (26.8) *Rhynchosia* sp. (19.8) *Eriachne* sp. (18.1) *Schizachyrium* sp. (13.8) *Polycarpaea spirostylis* (12.2) *Scleria* sp. (10.5) *Fimbristylis* sp. (9.4)	*Ectrosia leporina* (26.9) *Rhynchosia sp.* (19.7) *Eriachne sp.* (18.1) *Schizachyrium sp.* (13.6) *Polycarpaea spirostylis* (12.2) *Scleria* sp. (10.5) *Fimbristylis* sp.(9.4) *Pseudopogonatherum contortum* (6.9) *Ptilotus* sp. (6.9) *Indigofera* sp. (6.7)		Restricted to granite hills south of Coen.
3.12.34 (2 sites)	Igneous rock pavements associated with mountains and some offshore islands	*Rhynchosia* sp. (100%)	Rock pavement (99.5)	Rock pavement (99.5)		Occurs as a complex of rock pavements (rather than boulder piles) with shrubland that can include *Acacia umbellata*, *Canarium australianum*, *Psydrax* spp., *Terminalia* spp. and *Carissa ovata* growing in areas where soil accumulates
3.12.39	*Eucalyptus crebra* +/- *Corymbia hylandii* or *Lophostemon suaveolens* low woodland to low open forest on granite hills					

3.12.39a (2 sites)	*Eucalyptus crebra* +/- *Corymbia hylandii* low woodland to low open forest on skeletal soils on gullies and foothills of granite hills	*Eucalyptus crebra* (100%, 10)	*Eucalyptus crebra* (22.2) *Diospyros* sp.(19.1) *Acacia disparrima* (17.7) *Manilkara kauki* (16.9) *Terminalia subacroptera* (14.7) *Micromelum minutum* (10) *Alphitonia excelsa* (9.8) *Argophyllum verae* (9.8) *Bombax ceiba* (9.8) *Cupaniopsis fleckeri* (9.8) *Psychotria* sp. *(7.2)*	*Corymbia hylandii* (29.8) *Cochlospermum gillivraei* (27.4) *Eucalyptus crebra* (21.9) *Diospyros* sp. (19.1) *Acacia disparrima* (17.7) *Manilkara kauki* (16.9) *Terminalia subacroptera* (14.7) *Gardenia* sp. (12.8) *Erythrophleum chlorostachys* (11.2) *Micromelum minutum* (10) *Alphitonia excelsa* (9.8) *Argophyllum verae* (9.8) *Bombax ceiba* (9.8) *Cupaniopsis fleckeri* (9.8) *Psydrax* sp (8.8) *Sterculia quadrifida* (8) *Psychotria* sp. (7.2) *Euroschinus falcatus* (6.7)	*Corymbia hylandii* (50%, 19) *Cochlospermum gillivraei* (50%, 18)
3.12.39b (1 site)	*Lophostemon suaveolens* low open forest on upper slopes of granite ranges.	*Lophostemon suaveolens* (100%, 30) *Eucalyptus crebra* (100%, 8)	*Endiandra glauca* (53.2) *Myrsine variabilis* (21.9) *Litsea breviumbellata* (16.9) *Cyclophyllum coprosmoides* (13.8) *Rhodamnia* sp. (13.8) *Cryptocarya vulgaris (9.8)* *Guioa acutifolia (9.8)* *Mischocarpus* sp. *(9.8)*	*Endiandra glauca* (53.2) *Lophostemon suaveolens* (51.8) *Acacia flavescens* (30.3) *Myrsine variabilis* (21.9) *Litsea breviumbellata* (16.9) *Cyclophyllum coprosmoides* (13.8) *Muehlenbeckia zippelii* (13.9) *Rhodamnia sp. (13.9)* *Cryptocarya vulgaris* (9.8) *Guioa acutifolia* (9.8) *Mischocarpus* sp. *(9.8)*	*Endiandra glauca* (100%, 30) S1
3.12.40 (7 sites)	*Corymbia nesophila* +/- *Eucalyptus tetrodonta* woodlands on igneous hills and rises	*Corymbia nesophila* (100%, 27)	*Corymbia nesophila* (52) *Eucalyptus tetrodonta* (16.9) *Coelospermum reticulatum* (9.8)	*Corymbia nesophila* (51.7) *Eucalyptus tetrodonta* (16.6) *Neoroepera banksii* (10.6) *Coelospermum reticulatum* (9.8) *Antidesma ghaesembilla* (8.7) *Erythrophleum chlorostachys* (7.5) *Hibbertia* sp. (7)	*Eucalyptus tetrodonta* (57%, 12)
3.12.41 (6 sites)	*Eucalyptus tetrodonta* woodland +/- heath species on granite hills and rises	*Eucalyptus tetrodonta* (100%, 6) *Neofabricia myrtifolia* (83%, 3) T2 *Asteromyrtus brassii* (67%, 3) T2 *Acacia rothii* (67%, 5) T2 *Xanthorrhoea johnsonii* (83%, 3) S1	*Asteromyrtus brassii* (19.1) *Acacia rothii* (17.8) *Neofabricia myrtifolia* (12.4) *Eucalyptus tetrodonta* (10.2) *Grevillea glauca* (10) *Xanthorrhoea johnsonii* (9.8) *Hibbertia banksii* (8.9) *Allocasuarina littoralis* (8.4) *Corymbia nesophila* (7.6) *Banksia dentata* (6.3)	*Asteromyrtus brassii* (19) *Acacia rothii* (17.7) *Neofabricia myrtifolia* (12.2) *Eucalyptus tetrodonta* (10) *Grevillea glauca* (9.9) *Xanthorrhoea johnsonii (9.7)* *Hibbertia banksii (8.9)* *Allocasuarina littoralis (8.3)* *Corymbia nesophila (7.4)* *Banksia dentata (6.3)*	*Corymbia nesophila* (50%, 8) *Asteromyrtus brassii* (50%, 7) *Corymbia stockeri* (17%, 8)

3.12.42 (12 sites)	*Eucalyptus tetrodonta* woodland on low to undulating granite hills.	*Eucalyptus tetrodonta* (100%, 11) *Corymbia clarksoniana* (67%, 3)	*Eucalyptus tetrodonta* (20.7)	*Eucalyptus tetrodonta* (20.4) *Erythrophleum chlorostachys* (7.3)	*Eucalyptus brassiana* (8%, 17) *Corymbia stockeri (8%, 15)*	
3.12.43 (5 sites)	*Welchiodendron longivalve, Acacia brassii* low woodland on igneous hills					
3.12.43a (4 sites)	*Welchiodendron longivalve* and *Acacia brassi*i low woodland on undulating igneous rises to steep hills.	*Welchiodendron longivalve* (100%, 7) *Acacia brassii* (75%, 6)	*Welchiodendron longivalve* (24) *Acacia brassii* (17.4)	*Welchiodendron longivalve* (24) *Acacia brassii* (17.4) *Eucalyptus platyphylla* (13.5) *Bursaria incana* (8.3) *Petalostigma pubescens* (7.6) *Livistona muelleri (6.1)*	*Eucalyptus cullenii (25%, 13)* *Eucalyptus platyphylla* (25%, 10) *Neofabricia myrtifolia* (25%, 6)	
3.12.43b (1 site)	*Melaleuca viridiflora* and *Welchiodendron longivale* shrubland on rocky igneous headlands	*Corymbia tessellaris* (100%,10) *Jacksonia thesioides* (100%,6)	*Corymbia tessellaris* (20.4) *Jacksonia thesioides* (19.6)	*Corymbia tessellaris* (20.4) *Jacksonia thesioides* (19.6) *Acacia crassicarpa* (13.5) *Croton arnhemicus* (8.2) *Syzygium suborbiculare* (8.1)	*Corymbia tessellaris* (100%,6) E *Acacia crassicarpa* (100%,4) E	Restricted to continental Torres Strait islands.
3.12.44 (3 sites)	*Melaleuca citrolens* low open woodland on low granite hills and rolling rises	*Melaleuca citrolens* (100%, 3)	*Melaleuca citrolens* (24.7) *Melaleuca foliolosa* (11.3) *Petalostigma banksii* (8.9)	*Melaleuca citrolens* (24.7) *Melaleuca foliolosa* (11.3) *Petalostigma banksii* (8.8)	*Melaleuca foliolosa* (33% ,3) *Petalostigma banksii* (33%, 3)	
3.12.45 (5 sites)	*Melaleuca viridiflora* low woodland to low open woodland occurs on steep igneous hills and footslopes	*Melaleuca viridiflora* (100%, 13)	*Melaleuca viridiflora* (22.9)	*Melaleuca viridiflora* (22.9) *Choriceras tricorne* (8.1)	*Eucalyptus tetrodonta* (20%, 4) E *Choriceras tricorne* (20%, 13) S1	
3.12.47	Mixed heath species low woodland to wetter dwarf shrubland on igneous hills					
3.12.47a (4 sites)	Mixed heath species tall shrubland on igneous hills	*Asteromyrtus lysicephala* (100%, 3) S1 *Melaleuca viridiflora* (40%, 6) *Allocasuarina littoralis* (40%, 4) *Neofabricia myrtifolia* (40%, 4) *Melaleuca arcana* (40%, 4) *Asteromyrtus brassii* (40%, 3)	*Allocasuarina littoralis* (17) *Choriceras tricorne* (11.1) *Asteromyrtus lysicephala* (10.6) *Xanthorrhoea johnsonii* (9.9) *Melaleuca arcana* (9.8) *Jacksonia thesioides (8.9)* *Neofabricia myrtifolia* (7.3)	*Allocasuarina littoralis* (17) *Choriceras tricorne* (11.1) *Asteromyrtus lysicephala* (10.6) *Xanthorrhoea johnsonii* (9.9) *Melaleuca arcana* (9.8) *Jacksonia thesioides (8.9)* *Neofabricia myrtifolia (7.3)*		
3.12.47b (1 site)	*Asteromyrtus lysicephala, Choriceras tricorne, Jacksonia thesioides* dwarf shrubland on igneous slopes with impeded drainage	*Asteromyrtus lysicephala* (100%, 6) *Choriceras tricorne* (100%, 5) *Jacksonia thesioides* (100%, 4) *Melaleuca viridiflora* (100%, 3)	None	*Asteromyrtus lysicephala* (10.6) *Melaleuca viridiflora* (13.3) *Grevillea pteridifolia* (7)		

3.12.48	*Heteropogon triticeus* or *Themeda triandra* or *Schizachyrium fragile* tussock grassland on rocky igneous coastal headlands and islands				
3.12.48a (5 sites)	*Heteropogon triticeus* +/- *Sarga plumosum* grasslands on igneous headlands and offshore islands	*Heteropogon triticeus* (100%, 42) *Sarga plumosum* (80%, 14)	*Heteropogon triticeus* (63.4) *Sarga plumosum* (32.2) *Ipomoea* sp. (9.8) *Eragrostis* sp. (8.3)	*Heteropogon triticeus* (63.5) *Sarga plumosum* (32.2) *Lomandra* sp. (15.8) *Lepturus repens* (13.9) *Ipomoea* sp. (9.8) *Salsola australis* (9.8) *Sesuvium portulacastrum* (9.8) *Eulalia mackinlayi* (9.6) *Lithomyrtus obtusa* (9.5) *Bulbostylis barbata* (8.8) *Eragrostis* sp. (8.3)	*Lomandra* sp. (20%, 13) *Lepturus repens* (20%, 10) *Lithomyrtus obtusa* (20%,6) E
3.12.48c (1 site)	*Schizachyrium* spp., *Aristida* spp. grasslands on igneous headlands	*Aristida* sp. (100, 20) *Schizachyrium* sp. (100%, 20)	None	*Aristida* sp. (43.3) *Schizachyrium* sp. (35.7)	

Appendix 2. Regional Ecosystems and vegetation communities on land zone 5 and 12 in Cape York Peninsula bioregion

Short label descriptions only are included. For more detailed descriptions please visit the website https://environment.ehp.qld.gov.au/regional-ecosystems/. Communities are grouped by vegetation formation.

RE Label	Short Description	Area km^2) (areas <1 km^2 in Ha)	No. of Vegetation communities	Derivation	No. of Sites	Comments & Distribution
Land zone 5						
Grasslands (0.01% of land zone)						
3.5.15b	*Dapsilanthus spathaceu*s open sedgeland with emergent shrubs.	120 Ha		Quantitative	1	Occurs in mosaic patches with 3.5.15a only on Torres Strait Islands.
3.5.29	*Themeda triandra* and *Heteropogon contortus* closed tussock grasslands on erosional plains.	686 Ha	1	Qualitative	0	The grassland is a fire climax community, with scattered vine forest remnants clumped on low granite mounds which protrude above the undulating sand plain, offering some protection from fire. Moa Island in the Torres Strait and also on coastal areas and islands in the north-east of the bioregion.
Shrublands (4% of land zone)						
3.5.19	*Asteromyrtus lysicephala* and *Neofabricia myrtifolia* open heath to shrubland on sand sheets.	1,902	1	Quantitative	14	Heath formation differentiates this from RE 3.5.42 which is a low woodland to open forest. From Coen to the McHenry Uplands. Also occurs just north of Hopevale.
3.5.43	*Asteromyrtus brassii* + *Melaleuca saligna* tall shrubland on residual sand plains.	230 Ha	1	Qualitative	0	Restricted to Moa Island in the Torres Strait.
Woodlands (95% of land zone)						
3.5.5	*Corymbia novoguinensis* +/- *C. tessellaris* woodland on sand plains on northern Cape York Peninsula.	117	1	Quantitative	6	Occurs on northern Cape York Peninsula and Torres Strait islands.
3.5.6	*Eucalyptus phoenicea* +/- *E. tetrodonta* woodland on sandy outwash plains.	401	1	Quantitative	4	On the Battlecamp sandstone plateau.
3.5.9	*Eucalyptus tetrodonta* and *Corymbia stockeri* and/or *C. setosa* on sand plains.	5,346	1	Quantitative	11	Western side of Great Dividing Range and Kalpowar Plains. Widespread in the southern half of the bioregion and occurs predominantly on the Holroyd Plain in close association with 3.5.37a.
3.5.15	*Melaleuca viridiflora* and *Asteromyrtus symphyocarpa* low woodland on colluvial plains.	33	2			
Vegetation communities:						
3.5.15a	*Melaleuca viridiflora* +/- *M. saligna* +/- *Corymbia* spp. low woodland or tall shrubland on residual sands.	32		Qualitative	0	Occurs on depositional and erosional plains. Widespread throughout the bioregion.
3.5.15b (Included in grasslands)						
3.5.21	*Corymbia clarksoniana* +/- *C. tessellari*s open forest on coastal ranges and lowlands.	54	1	Qualitative	0	On east coast from Cooktown to Lockhart River.
3.5.24	*Eucalyptus chlorophylla* +/- *Corymbia clarksoniana* woodland on erosional plains.	290	1	Qualitative	0	Occurs in the south-east of the bioregion on the Laura Basin and south of Cooktown.

RE Label	Short Description	Area km^2) (areas <1 km^2 in Ha)	No. of Vegetation communities	Derivation	No. of Sites	Comments & Distribution
3.5.25	*Eucalyptus leptophleba* and *E. platyphylla* woodland on outwash plains.	45	1	Quantitative	1	South-east of bioregion.
3.5.26	*Eucalyptus platyphylla* +/- *Corymbia clarksoniana* woodland to open forest on flat wet plains.	22	1	Qualitative	0	Occurs in the south-east of the bioregion close to the Wet Tropics Bioregion boundary.
3.5.27	*Melaleuca citrolens* +/- *M. foliolosa* +/- *M. viridiflora* low open woodland on plains.	711 Ha	1	Qualitative	0	Restricted to Rinyirru (Lakefield) National Park (CYPAL) within the Laura Basin.
3.5.32	*Asteromyrtus brassii* +/- *Syzygium angophoroides* +/- *Acmena hemilampra* open forest on residual sand rises and sheets.	228 Ha	1	Qualitative	0	Restricted to Moa Island, Torres Strait.
3.5.34	*Corymbia nesophila* and *C. stockeri* open forest on sand rises in the Torres Strait	116 Ha	1	Quantitative	4	Restricted to Moa Island, Torres Strait.
3.5.35	*Eucalyptus tetrodonta* and *Corymbia nesophila* woodland with heathy understory on sand plains.	2,241	1	Quantitative	13	Areas dominated by *Corymbia nesophila* sometimes occur. The understory species mix of this community may change depending on fire history. Extensive on sandplains from the upper reaches of the Archer River and Temple Bay through the McHenry Uplands to Bamaga.
3.5.36	*Eucalyptus tetrodonta* and *Corymbia nesophila* woodland on undulating plains and remnant plateaus.	17,751	2			
Vegetation communities:						
3.5.36a	*Eucalyptus tetrodonta* and *Corymbia nesophila* woodland on undulating plains.	9,880		Quantitative	40	Occurs from Cape Melville, across to the Kimba plateau and throughout the north of the bioregion.
3.5.36b	*Eucalyptus tetrodonta* and *Corymbia nesophila* woodland to open forest on plateaus.	7,870		Quantitative	10	Small unmappable areas of 3.5.36a occur sporadically throughout the range of this community. Occurs on the Weipa Plateau and other remnant bauxite plateaus. 3.5.36b is generally taller than 3.5.36a. Occurs more often as an open forest in the north.
3.5.37	*Eucalyptus tetrodonta* and *Corymbia stockeri* +/- *Erythrophleum chlorostachys* woodland on erosional plains and deep massive sands.	5,587	2			
Vegetation communities:						
3.5.37a	*Eucalyptus tetrodonta* and *Corymbia stockeri* woodland.	4,585		Quantitative	15	Occurs on depositional and erosional plains. Widespread throughout the bioregion.
3.5.37b	*Eucalyptus tetrodonta* ± *Erythrophleum chlorostachys* ± *Corymbia stockeri* tall woodland.	998		Quantitative	13	Predominantly on the Kimba Plateau, but may occur on other tertiary remnant plateaus in small patches below the scale of mapping. Typical vegetation is on the Kimba Plateau in an area known as the Desert. Occurs on tertiary remnant plateaus whilst 3.5.37a does not. 3.5.37b is generally taller than 3.5.37a (above 22m).
3.5.38	*Eucalyptus tetrodonta* and *E. cullenii* woodland or *E. tetrodonta* and *C. stockeri* +/- *Melaleuca* spp. woodland on remnant surfaces.	275	2			

RE Label	Short Description	Area km^2) (areas <1 km^2 in Ha)	No. of Vegetation communities	Derivation	No. of Sites	Comments & Distribution
Vegetation communities:						
3.5.38a	*Eucalyptus tetrodonta* and *E. cullenii* +/- *Corymbia stockeri* woodland on remnant weathered surfaces.	269		Quantitative	6	Central plains on the Peninsula from Musgrave to the Torres Strait Islands.
3.5.38b	*Eucalyptus tetrodonta* and *Corymbia stockeri* often with *Melaleuca stenostachya*.	640 Ha		Quantitative	7	Occurs in the central Peninsula from Coen to Bramwell Junction.
3.5.39	*Eucalyptus tetrodonta* and *Corymbia clarksoniana* woodland on sand plains.	9,848	1	Quantitative	25	Mainly occurs on plains in the Laura basin, but also in the central west Peninsula and on some Torres Strait Islands.
3.5.40	*Melaleuca stenostachya* +/- *Eucalyptus chlorophylla* +/- *M. viridiflora* woodland on outwash plains.		1	Quantitative	5	Occurs throughout Cape York including the Torres Strait Islands.
3.5.41	*Melaleuca viridiflora* +/- *Corymbia clarksoniana* woodland on plains.	2,386	2			
Vegetation communities:						
3.5.41a	*Melaleuca viridiflora* +/- *Corymbia clarksoniana* woodland on plains	318 Ha		Quantitative	14	Central plains on the Peninsula from Musgrave to the Torres Strait Islands.
3.5.41b	*Melaleuca viridiflora* low open woodland +/- *Petalostigma banksii* on plains.	336 Ha		Quantitative	1	Occurs in the central Peninsula from Coen to Bramwell Junction.
3.5.42	*Asteromyrtus brassii* and/or *Neofabricia myrtifolia* low open forest to woodland on sand plains.	426	1	Quantitative	14	Occurs throughout Cape York including the Torres Strait Islands.
Land zone 12						
Grasslands (2% of land zone)						
3.12.30	*Imperata cylindrica* +/- *Mnesithea rottboellioides* closed tussock grassland on steep slopes of igneous hills.	37	1	Quantitative	1	Occurs mainly in the northern McIlwraith Range, but also near Temple Bay and on some Torres Strait Islands.
3.12.32	*Schizachyrium* spp. +/- *Rhynchosia* spp. grasslands on shallow soils on undulating granite hills.	10	1	Quantitative	2	Restricted to granite hills south of Coen.
3.12.34	Igneous rock pavements associated with mountains and some offshore islands.	66	1	Quantitative	2	McIlwraith Range, Iron Range and Altanmoui Range. Torres Strait Islands.
3.12.48	*Heteropogon triticeus* or *Themeda triandra* or *Schizachyrium fragile* tussock grassland on rocky igneous coastal headlands and islands.	20	3			
Vegetation communities:						
3.12.48a	*Heteropogon triticeus* dominated grasslands on igneous headlands and offshore islands.	11		Quantitative	5	Occurs on Torres Strait Islands
3.12.48b	*Themeda triandra* tussock grassland on igneous headlands and islands.	533 Ha		Qualitative	0	Occurs on Torres Strait Islands and other offshore islands and headlands along the east coast.
3.12.48c	*Schizachyrium* spp. +/- *Aristida* spp. grasslands on igneous headlands.	356 Ha		Quantitative	1	Restricted to headlands near the northern most extent of Cape York Peninsula and some east coast islands.
Shrublands (12% of land zone)						
3.12.28	*Leptospermum purpurascens* tall shrubland on igneous hills.	58	1	Quantitative	5	Occurs on the western edge of Iron Range.

RE Label	Short Description	Area km²) (areas <1 km^2 in Ha)	No. of Vegetation communities	Derivation	No. of Sites	Comments & Distribution
3.12.43b	*Melaleuca viridiflora* and *Welchiodendron longivalve* shrubland on rocky igneous headlands.	9a Ha		Quantitative	1	Occurs on most continental Torres Strait Islands.
3.12.46	*Melaleuca stenostachya* shrubland on exposed igneous headlands and hills.	52	1	Qualitative	0	Occurs on granite hills between Musgrave Roadhouse and Archer River crossing as well as on some Torres Strait Islands.
3.12.47b	*Asteromyrtus lysicephala, Choriceras tricorne, Jacksonia thesioides* dwarf shrubland on igneous slopes with impeded drainage			Quantitative	1	Occurs west of the Iron Range.
Woodlands (75% of land zone)						
3.12.7	*Eucalyptus brassiana* and *Corymbia clarksoniana* open forest on granite ranges.	103	1	Quantitative	2	Occurs on western McIlwraith Range and the Melville Range.
3.12.8	*Corymbia clarksoniana* +/- *C. tessellaris* open forest on coastal granite ranges and lowlands.	185	1	Qualitative	0	McIlwraith Range and Iron Range, with extensive patches on some Torres Strait islands.
3.12.9	*Corymbia tessellaris* +/- *Welchiodendron longivalve* +/- *E. cullenii* open forest on footslopes of granite hills.	49	1	Quantitative	1	East of McIlwraith Range and Torres Strait islands close to the Australian mainland.
3.12.10[#]	*Eucalyptus cullenii* +/- *Corymbia clarksoniana* woodland or *E. chlorophylla* woodland on granitic ranges.	1,677	2			
Vegetation communities:						[#]This RE is mapped as 3.12.10 as the vegetation communities are unmappable at the RE mapping scale.
3.12.10a	*Eucalyptus cullenii* +/- *Corymbia clarksoniana* woodland on granite hills and footslopes.	25		Quantitative	13	Occurs along the length of the Great Dividing Range. Also in small patches on ranges from Cooktown to the Altamoui Range.
3.12.10b	*Eucalyptus chlorophylla* woodlands on granite hills.	273 Ha		Quantitative	2	Occurs along the length of the Great Dividing Range. Also in small patches on ranges from Cooktown to the Altamoui Range.
3.12.11	*Corymbia stockeri* +/- *Welchiodendron longivalve* woodland on steep to rolling granite hills.	137	1	Quantitative	6	Southern Torres Strait islands and near Lockhart River.
3.12.18	*Eucalyptus leptophleba* and *Corymbia clarksoniana* woodland or *C. disjuncta* woodland on steep to low igneous hills.	483	2			
Vegetation communities:						
3.12.18a	*Eucalyptus leptophleba* and *Corymbia clarksoniana* woodland to open woodland on steep to low igneous hills.	481		Quantitative	7	Central Peninsula along the Great Dividing Range.
3.12.18b	*Corymbia disjuncta* woodland on steep igneous hillslopes.	153 Ha		Quantitative	2	Restricted to hills northeast of Archer River Roadhouse.
3.12.23	*Acacia brassii* low open forest on igneous hills.	18	1	Qualitative	0	Torres Strait islands.
3.12.37	*Eucalyptus platyphylla* +/- *Corymbia* spp. woodland to open forest on coastal igneous headlands and footslopes.	547 Ha	1	Qualitative	0	Restricted to Horn and Muralag Islands in the Torres Strait.
3.12.38	*Corymbia clarksoniana* and/or *C. nesophila* and/or *C. stockeri* low woodland on acid volcanic hills.	17	1	Qualitative	0	Torres Strait Islands.
3.12.39	*Eucalyptus crebra* +/- *Corymbia hylandii* or *Lophostemon suaveolens* low open forest to low woodland on skeletal soils on gullies and foothills of granite hills.	63	2			

RE Label	Short Description	Area km^2) (areas <1 km^2 in Ha)	No. of Vegetation communities	Derivation	No. of Sites	Comments & Distribution
Vegetation communities:						
3.12.39a	*Eucalyptus crebra* +/- *Corymbia hylandii* low open forest on skeletal soils on gullies and foothills of granite hills.	52		Quantitative	2	Occurs on Cape Melville
3.12.39b	*Lophostemon suaveolens, Eucalyptus crebra* low open forest on upper slopes of granite ranges.	11		Quantitative	1	Occurs on the Altanmoui Range north of Cooktown.
3.12.40	*Corymbia nesophila* +/- *Eucalyptus tetrodonta* woodlands on igneous hills and rises.	368	1	Quantitative	7	Occurs from Musgrave to Temple Bay on the Coen-Yambo Inlier. Small areas west of Cooktown and on some Torres Strait Islands.
3.12.41	*Eucalyptus tetrodonta* +/- *Corymbia nesophila* woodland on igneous hills and rises.	120	1	Quantitative	6	Occurs mainly around Iron Range but also found south of Coen and north of Bamaga.
3.12.42	*Eucalyptus tetrodonta* +/- *Corymbia clarksoniana* woodland on low to undulating granite hills.	2,445	1	Quantitative	12	Occurs along the length of the Coen -Yambo Inlier from Musgrave to Portlands Rds. Also on ranges from north-west of Cooktown.
3.12.43	*Welchiodendron longivalve* and *Acacia brassii* low woodland on undulating igneous rises to steep hills.	14	2			
Vegetation communities:						
3.12.43a	*Welchiodendron longivalve* and *Acacia brassii* low woodland on undulating igneous rises to steep hills.	13		Quantitative	4	Occurs near Wolverton and Temple Bay as well as on some Torres Strait Islands.
3.12.43b	(Included in shrublands)					
3.12.44	*Melaleuca citrolens* low open woodland on low granite hills and rolling rises.	61	1	Quantitative	3	Occurs on granite ranges from Coen to Palmerville.
3.12.45	*Melaleuca viridiflora* +/- *Eucalyptus* spp. low woodland to low open woodland on steep hills and footslopes.	141	1	Quantitative	5	Occurs along the length of the Great Dividing Range from the Hann River up to Portlands Rds.
3.12.47[#]	Mixed heath species low woodland to wetter dwarf shrubland on igneous hills	352	2	Quantitative		
Vegetation communities:						[#]This RE is mapped as 3.12.47 as the vegetation communities are unmappable at the RE mapping scale.
3.12.47a	Mixed heath species low woodland on igneous hills			Quantitative	4	
3.12.47b	(Included in shrublands)					

Appendix 3a. Assessment of the sampling adequacy of survey design on land zone 5 and 12, Cape York Peninsula bioregion

Sampling adequacy of landscape variability

Table 3.1: Total area of land zone 5 and 12 at different similarity levels to any site for each environmental variable. For example, 818 ha of land zone 5 is between 75 – 89% similar in climate to any observational site. This represents 0.01% of the total area of land zone 5. The minimum similarity in climate of any grid cell to any observational site is 81%. Figures are rounded to the nearest hectare or km^2.

LZ 5	Observational sites					Analysis Sites				
	% Similarity Class	ha	km^2	**% total area**	Minimum %similarity	% Similarity Class	ha	km^2	**% total area**	Minimum %similarity
Climate	<75%	0	0	**0%**	81	<75%	205	2	**0.003%**	70
	75 - 89%	818	8	**0.01%**		75 - 89%	26076	261	**0.41%**	
	90-95%	3283	33	**0.1%**		90-95%	400620	4006	**6.32%**	
	>95%	6333855	63339	**99.9%**		>95%	5911054	59111	**93.26%**	
Vegetation Density	<75%	241	2	**0.004%**	63	<75%	3657	37	**0.06%**	12
	75 - 89%	659	7	**0.01%**		75 - 89%	6360	64	**0.10%**	
	90-95%	673	7	**0.01%**		90-95%	40744	407	**0.64%**	
	>95%	6336315	63363	**99.98%**		>95%	6287275	62873	**99.2%**	
Soil Nutrient	<75%	76	1	**0.001%**	66	<75%	2229	22	**0.04%**	0
	75 - 89%	53	1	**0.001%**		75 - 89%	261	3	**0.004%**	
	90-95%	197	2	**0.003%**		90-95%	20946	209	**0.33%**	
	>95%	6331552	63316	**99.99%**		>95%	6278650	62787	**99.16%**	
Soil Structure	<75%	0	0	**0**	84	<75%	21888	219	**0.35%**	0
	75 - 89%	426	4	**0.01%**		75 - 89%	65998	660	**1.04%**	
	90-95%	6601	66	**0.10%**		90-95%	493978	4940	**7.80%**	
	>95%	6324721	63247	**99.89%**		>95%	5749884	57499	**90.81%**	

LZ 12	Observational sites					Analysis sites				
	% Similarity Class	ha	km^2	**% total area**	Minimum %similarity	% Similarity Class	ha	km^2	**% total area**	Minimum %similarity
Climate	<75%	0	0	**0.0%**	84	<75%	149	1	**0.02%**	60
	75 - 89%	2903	29	0.3%		75 - 89%	17770	178	**1.9%**	
	90-95%	19622	196	**2.1%**		90-95%	178764	1788	19.5%	
	>95%	894385	8944	**97.5%**		>95%	720226	7202	**78.5%**	
Vegetation density	<75%	64	1	**0.01%**	59	<75%	524	5	**0.06%**	5
	75 - 89%	167	2	**0.02%**		75 - 89%	12768	128	**1.4%**	
	90-95%	1147	11	**0.1%**		90-95%	14875	149	**1.6%**	
	>95%	915365	9154	**99.9%**		>95%	888575	8886	**96.9%**	
Soil nutrient	<75%	651	7	**0.1%**	35	<75%	6879	69	**0.8%**	27
	75 - 89%	2615	26	**0.3%**		75 - 89%	12865	129	**1.4%**	
	90-95%	14165	142	**1.6%**		90-95%	21919	219	**2.4%**	
	>95%	884381	8844	**98.1%**		>95%	860150	8602	**95.4%**	
Soil structure	<75%	20	0.2	**0.002%**	68	<75%	1773	18	**0.2%**	48
	75 - 89%	5135	51	**0.6%**		75 - 89%	42218	422	**4.7%**	
	90-95%	28428	284	**3.2%**		90-95%	116632	1166	**12.9%**	
	>95%	868186	8682	**96.3%**		>95%	741159	7412	**82.2%**	

Appendix 3b: Areas of low sampling adequacy by survey design on land zone 5 and 12, Cape York Peninsula bioregion

Figure 3.1: Distribution of areas of land zone 5 and land zone 12 which are <90%-similar to any site for each environmental variable. Because such large areas of both land zones were >90%-similar to any site, for display purposes we show only areas with <90%-similarity. Areas on land zone 12 correspond largely with areas of rainforest which are not included in this study. These maps are indicative only. GIS layers are available from the first author if more detail is required

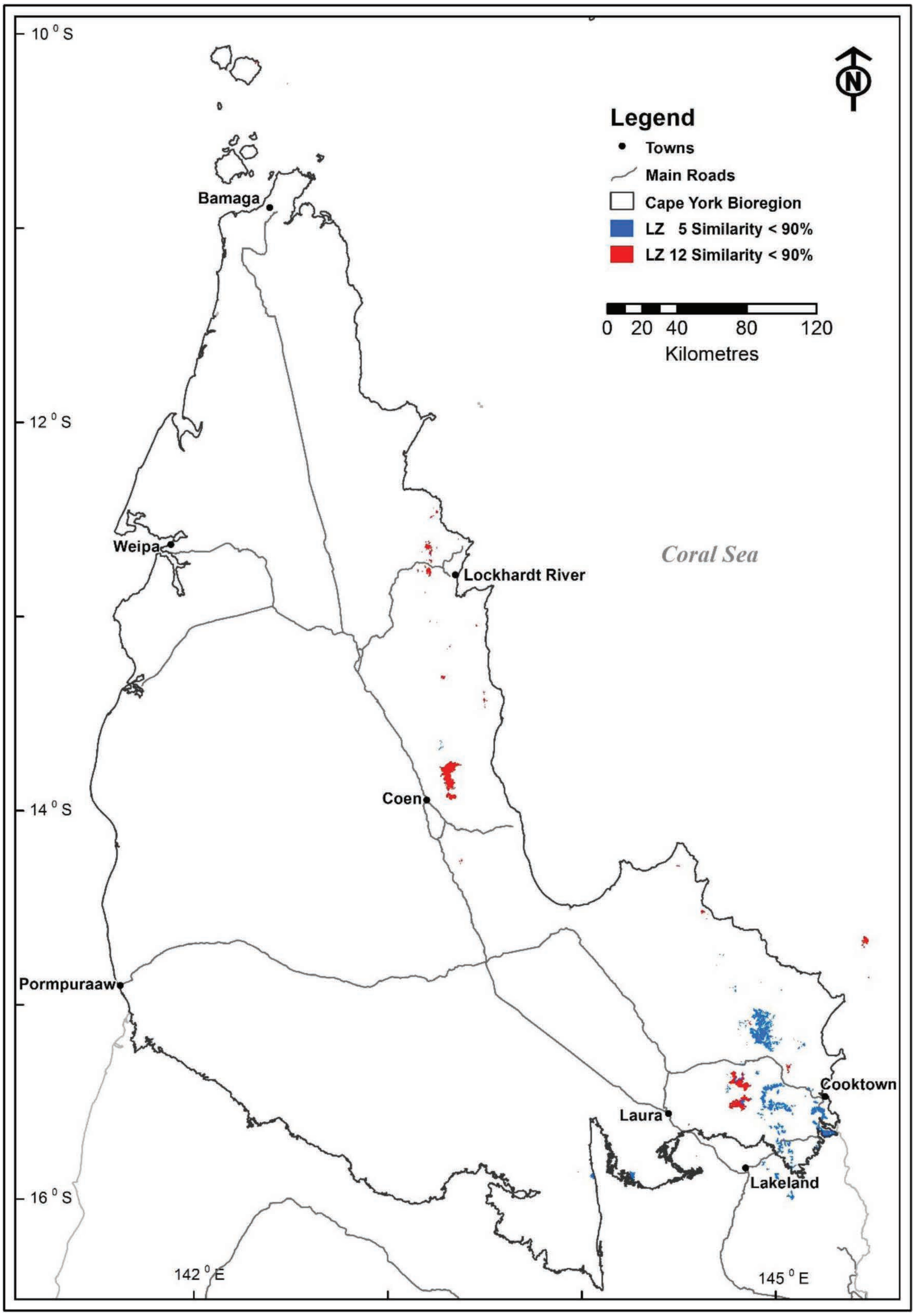

Figure 3.1a: Climate.

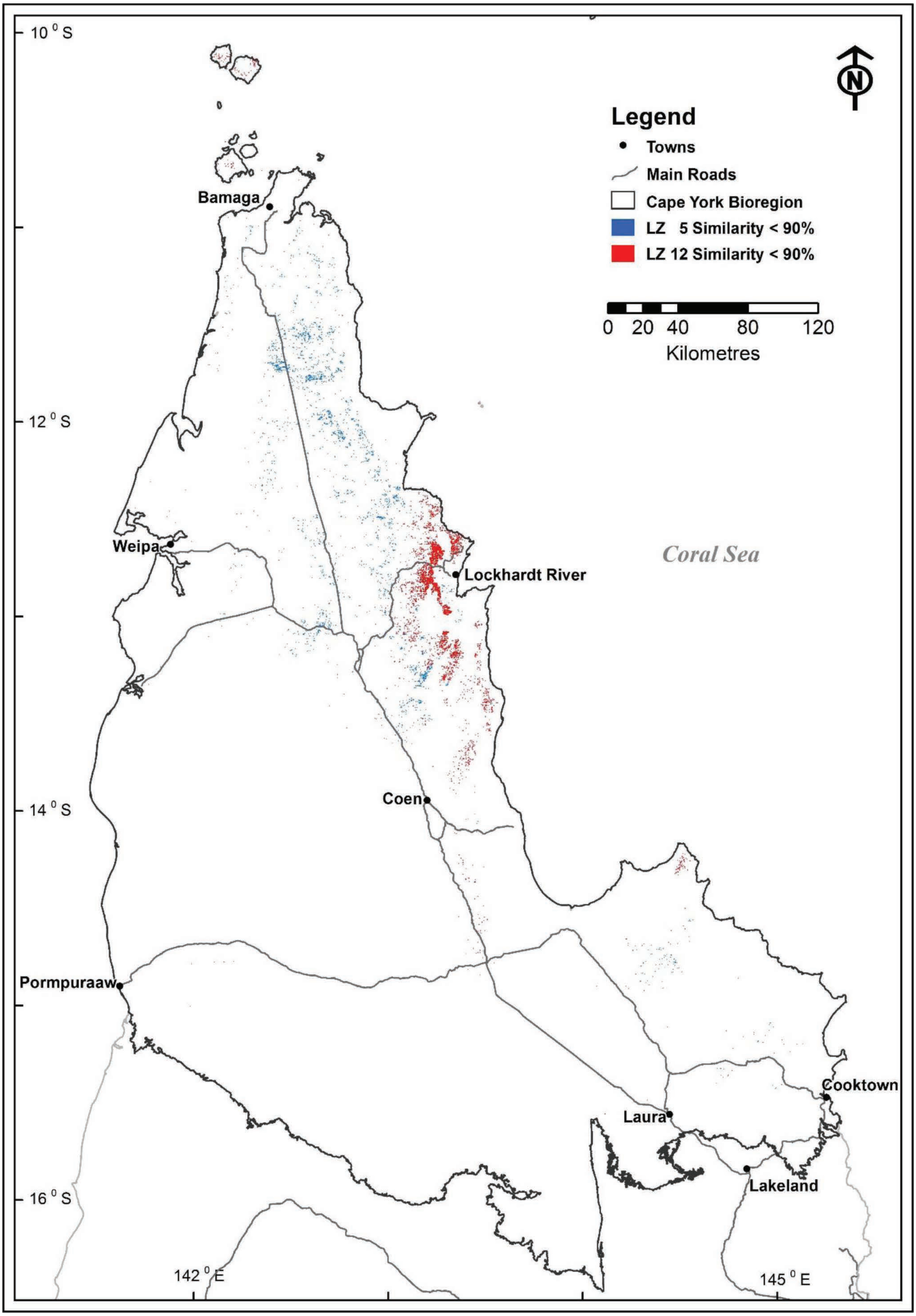

Figure 3.1b: Woody vegetation density (represented by maximum persistent greenness)

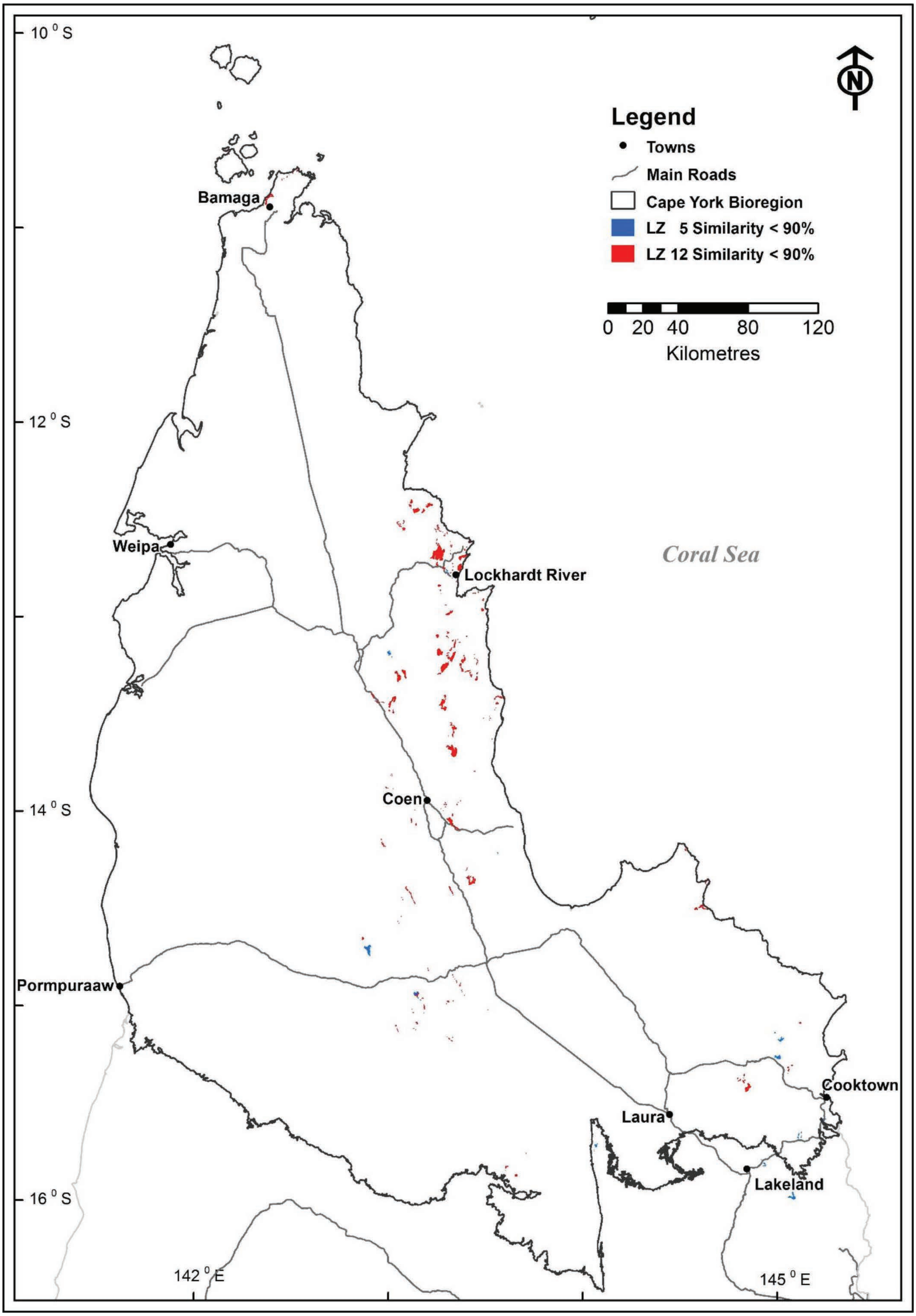

Figure 3.1c: Soil nutrient

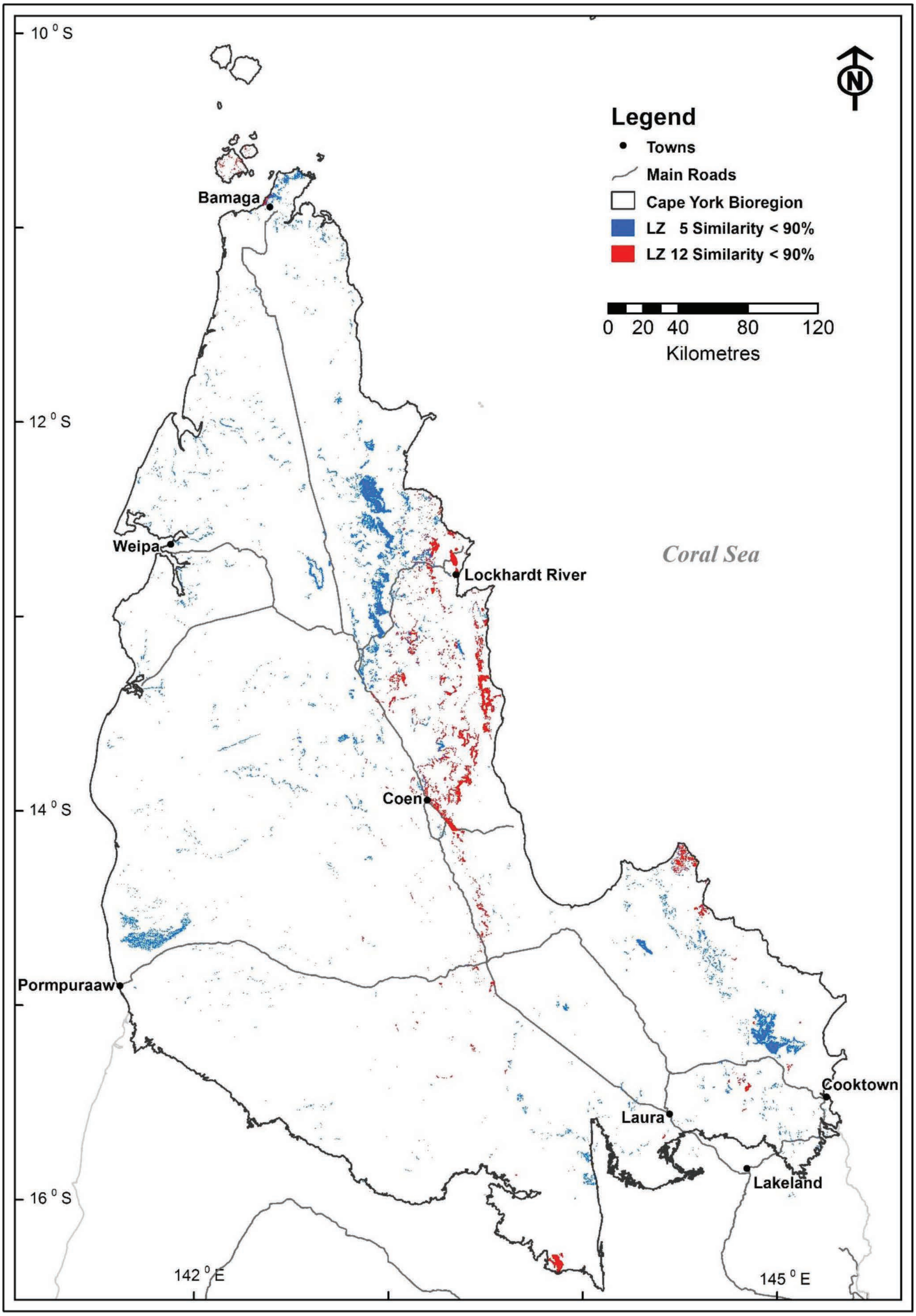

Figure 3.1d: Soil structure

Appendix 4: Additional analysis requested by the technical review committee and recommendations.

The expert panel queried two communities identified by the numerical analysis, requesting further analysis. These were the *Eucalyptus tetrodonta, Corymbia nesophila* woodlands and the *Eucalyptus tetrodonta, Corymbia stockeri* woodlands, both distributed across the extent of land zone 5. The final recommendations are discussed below.

Methods

We carried out the initial investigations with the *Eucalyptus tetrodonta, Corymbia nesophila* woodlands, testing for differences in three attributes; canopy heights of the tallest layer, and floristic differences in the woody and ground layer vegetation (separately). We tested each attribute for differences between landform (Tertiary remnant plateaus and sand plains), soil colour (red, yellow, brown) and soil texture (sand and earth) as recorded on site pro-formas. We used the ANOSIM routine (Clarke and Gorley 2006) which has two outputs; an R statistic and a significance value. The R statistic generally lies between 0 (there is no difference between the groups) and 1 (there is no similarity between the groups) but negative values indicate the within group variation is larger than the between group variation. In the ground layer we firstly looked for distinct species assemblages using *n*MDS and visually assessed whether these were coincident with different landform, soil colours or soil texture using GIS overlay. To test for differences in canopy height we also used an unpaired t-test as well as the ANOSIM routine. Due to the results of these investigations in the *Eucalyptus tetrodonta, Corymbia nesophila* woodlands, analysis requested by review panel for the *Eucalyptus tetrodonta, Corymbia stockeri* woodlands was limited to differences in canopy height between landform (again Tertiary remnant plateaus and sand plains) and soil colour (red earths versus all other colours).

Of the 50 sites in the *Eucalyptus tetrodonta, Corymbia nesophila* woodlands, 32 contained data useful for ground layer analysis and 49 for soil analysis. There were 3 additional sites not included in the original dataset which contained enough information for testing canopy heights. This resulted in 53 sites in the canopy height analysis. There were 31 sites in the *Eucalyptus tetrodonta, Corymbia stockeri* woodlands.

Results

Eucalyptus tetrodonta, Corymbia nesophila woodlands

Floristic differences in woody vegetation layers.

There was no floristic difference between soil textures (*$R = -0.05, p = 0.75$*), soil colours (*$R = 0.08, p = 0.14$*) or landform (*$R = 0.01, p = 0.44$*). The negative R value for soil texture indicates that the floristic differences individually on the sandy soils and on the earth soils is greater than the floristic differences between these two soil types.

Floristic differences in ground layer vegetation.

The two-dimensional *n*MDS ordination showed two ground layer species assemblages, one dominated by *Heteropogon triticeus* and the other by *Schizachyrium* species (figure 4.1), but with a lot of variability as evidenced by the high stress level (0.2). However, these assemblages were not significantly associated with either different soil textures *($R = 0.02, p = 0.40$)*, different soil colours *($R = -0.08, p = 0.71$)* or different landforms *($R = 0.04, p = 0.33$)*. This was also supported by the GIS overlay where there was no clear alignment of these assemblages with different soils or landforms.

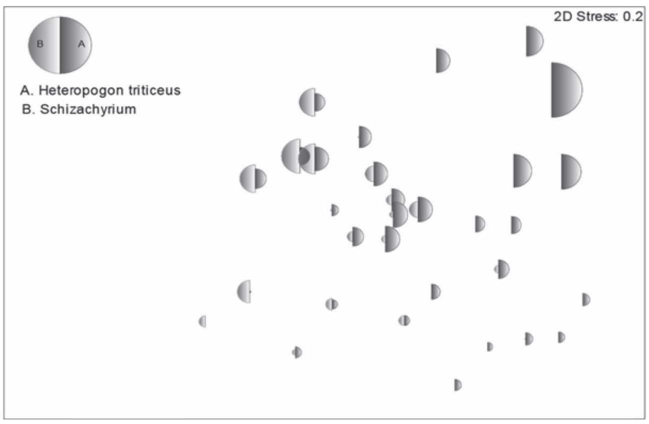

Figure 4.1: Bubble plot showing two species assemblages in the ground layer of the Eucalyptus tetrodonta, Corymbia nesophila woodlands – one dominated by Schizachyrium spp, the other by Heteropogon triticeus. Abundances are standardised.

Canopy height differences

There was no difference in the canopy heights on different soil textures (*t(47) = 1.1, p = 0.28)* and the ANOSIM results indicated the variability of heights within individual soil textures was greater than between the soil textures (*R = -0.04*). Differences in canopy height on different coloured soils was not straight forward. There was a distinct, but not significant difference between the heights of trees on red earths versus brown earths (*R = 0.86, p = 0.06*), and an indistinct, but significant difference between the heights of trees on red earths versus yellow earths (*R = 0.18, p = 0.03*). The differences in canopy heights between landforms, however, was highly significant *(t(51) = 5.7, p<0.0001)*, with the average height of trees on the Tertiary remnant plateaus being 5.2m taller than those on sand plains. We confirmed these results by running two different ANOSIM analysis. Firstly, we included all sites; 13 on the plateaus and 40 on the plains. These results showed a significant difference *(p = 0.01*), but a large overlap in height *(R = 0.25)*. We then ran ANOSIM with an equal number of sites (13) in both landforms (sites from the plains were chosen randomly). The difference in height was again significant *(p = 0.1)* however there was a small overlap in height *(R = 0.84)*.

Eucalyptus tetrodonta, Corymbia stockeri woodlands

There was a significant difference in the canopy heights of trees on both different landforms and different soil colours. The average height difference between trees on Tertiary remnant plateaus and on sand plains was 7.5m (*t(29) = 7.0, p<0.0001)* and on red earths versus all other coloured soil was 7.2m (*t(29) = 6.4, p<0.0001)*. The ANOSIM results show that there is overlap in tree height on both landform *(R = 0.63)* and soil colour *(R = 0.52)*.

Discussion

There are no differences in the floristics of the woody vegetation of the *Eucalyptus tetrodonta, Corymbia nesophila* woodlands across land zone 5. There is a difference in the floristics of the ground layer, but it is not relatable to differences in soil types or landform and it is possible that the different assemblages are due to disturbance history (Kutt and Woinarski 2007, Miller and Murphy 2017).

There were significant differences in the canopy height of both *Eucalyptus tetrodonta, Corymbia nesophila* woodlands and *Eucalyptus tetrodonta, Corymbia stockeri* woodlands on different landforms and soil colour. The red earths, which are most common on the remnant plateaus, grow significantly taller woodlands than other coloured soils, which are most common on the sand plains. From this it is not surprising that the woodlands on the Tertiary remnant plateaus are significantly taller, however, as our ANOSIM results indicate there are areas on sand plains and on yellow earths where woodlands are also tall. This leads us to conclude that the height of woodlands on sand plains is variable, but woodlands on the remnant plateaus are consistently taller.

Recommendation

The classification protocols used in Queensland (Neldner et al. 2017) specify that woodlands with the same dominant species, but with a consistent height difference of 5m, can be split into separate communities. Despite having no consistent floristic differences, the *Eucalyptus tetrodonta, Corymbia nesophila* woodlands and the *Eucalyptus tetrodonta, Corymbia stockeri* woodlands on the Tertiary remnant plateaus are consistently >=5m taller than those on sand plains. However, there is an overlap in height between the plateaus and the sand plains. We therefore recommend the woodlands on the remnant plateaus are recognised as vegetation communities within the appropriate floristically defined regional ecosystem.

References

Clarke, K.R. and R.N. Gorley. 2006. *PRIMER v6: User Manual/Tutorial*. PRIMER-E, Plymouth.

Kutt, A.S. and J.C.Z. Woinarski. 2007. The effects of grazing and fire on vegetation and the vertebrate assemblage in a tropical savanna woodland in north-eastern Australia. *Journal of Tropical Ecology* 23 (1): 95-106.

Miller, B.P. and B.P. Murphy. 2017. Fire and Australian Vegetation. In: D. Keith (eds), *Australian Vegetation*. Cambridge University Press, Cambridge. 113-134.

Neldner, V.J., B.A. Wilson, H.A. Dilleward, T.S. Ryan and D.W. Butler. 2017. Methodology for Survey and Mapping of Regional Ecosystems and Vegetation Communities in Queensland. version 4. Queensland Herbarium, Queensland Department of Science, Information Technology and Innovation, Brisbane. https://publications.qld.gov.au/dataset/redd/resource/6dee78ab-c12c-4692-9842-b7257c2511e4, accessed 1st June 2017.

Appendix 5: Floristic similarities between communities on land zone 5 and land zone 12 in Cape York Peninsula bioregion.

Plot data in each community was averaged. The dendrogram was formed using the CLUSTER routine and scatter plots using *n*MDS ordination in PRIMER v6 (Clarke & Gorley 2006).

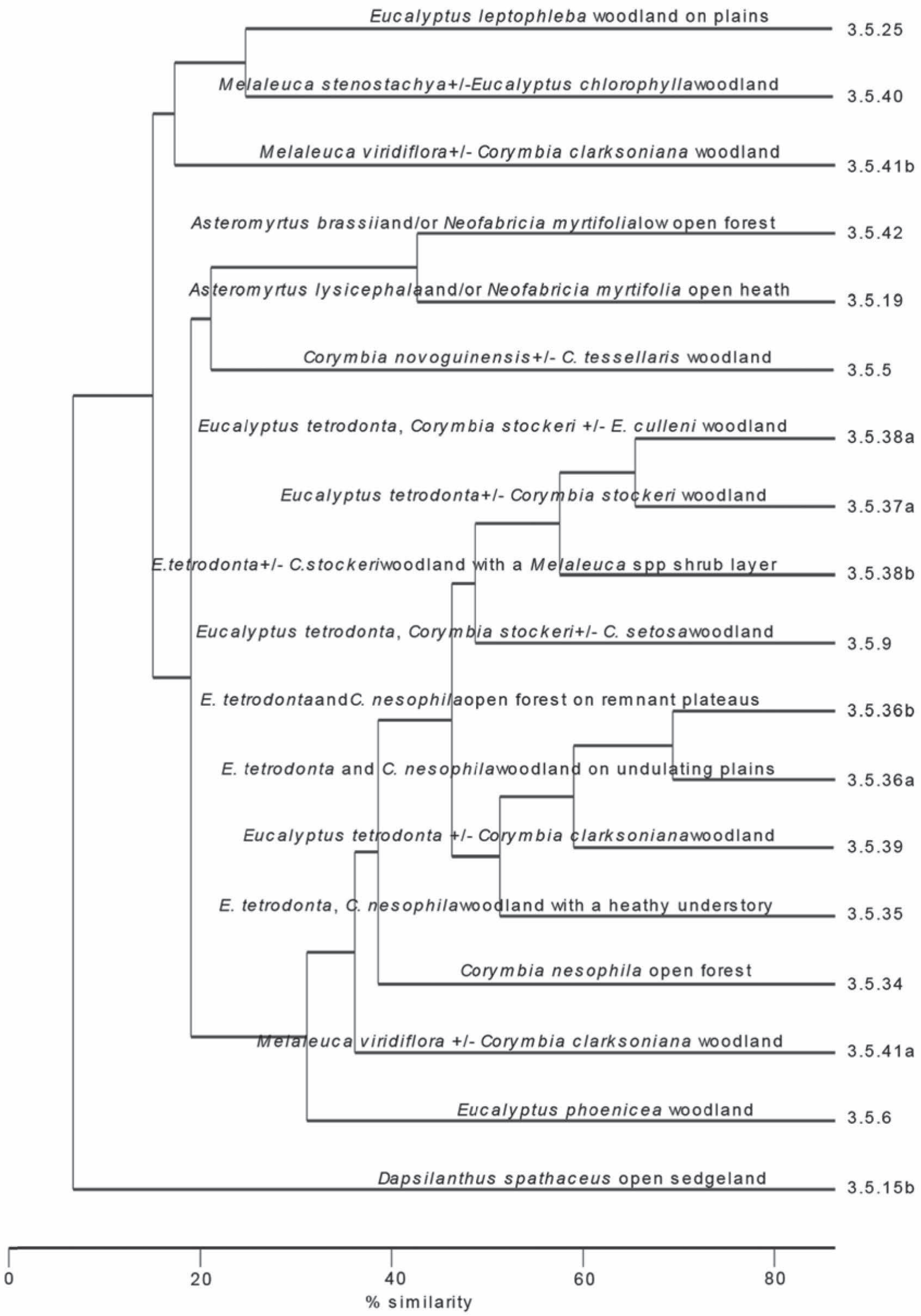

Figure 5.1: Dendrogram showing hierarchical relationships of communities on land zone 5 identified by quantitative analyses.

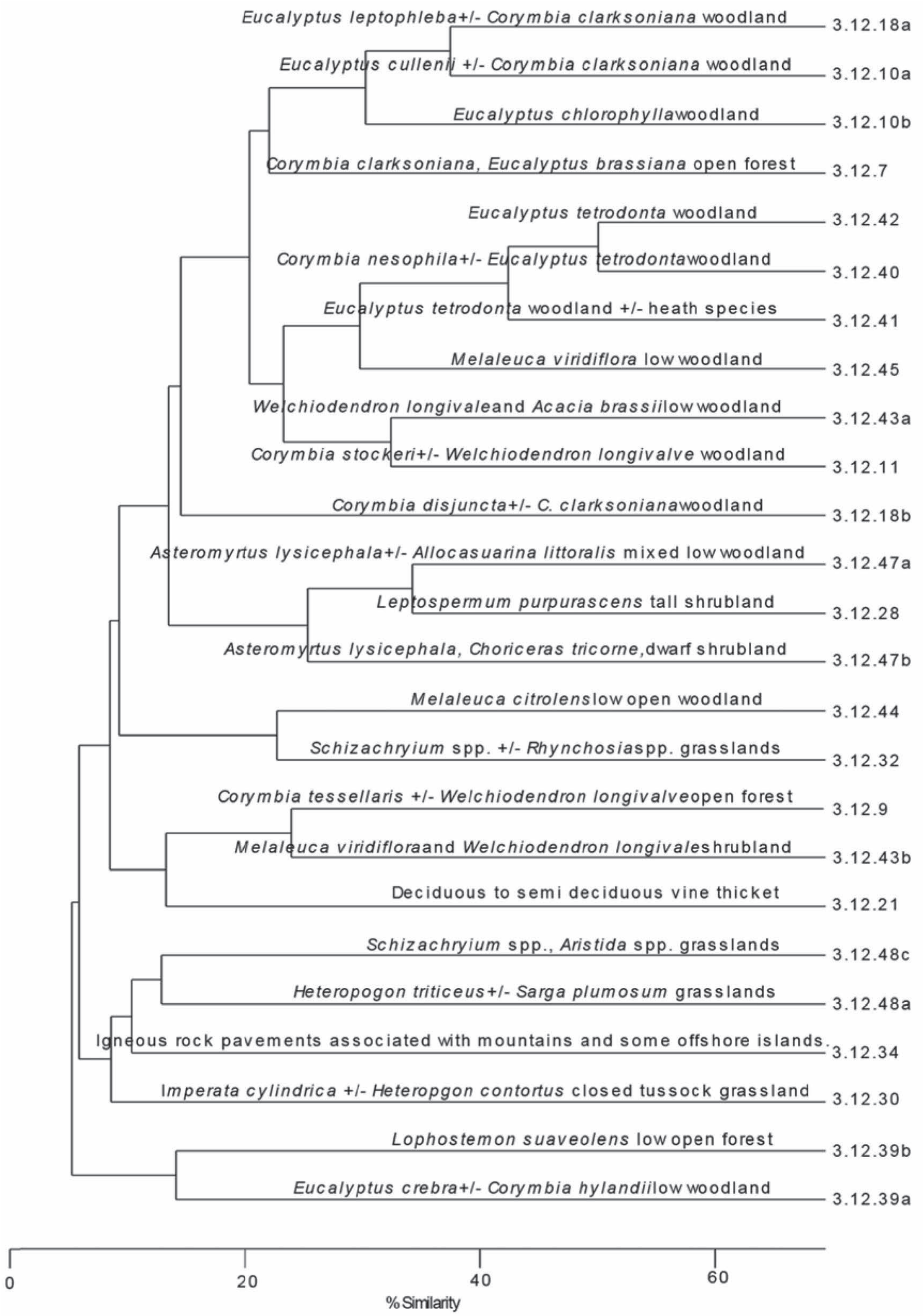

Figure 5.2: Dendrogram showing hierarchical relationships of communities identified by quantitative analyses on land zone 12.

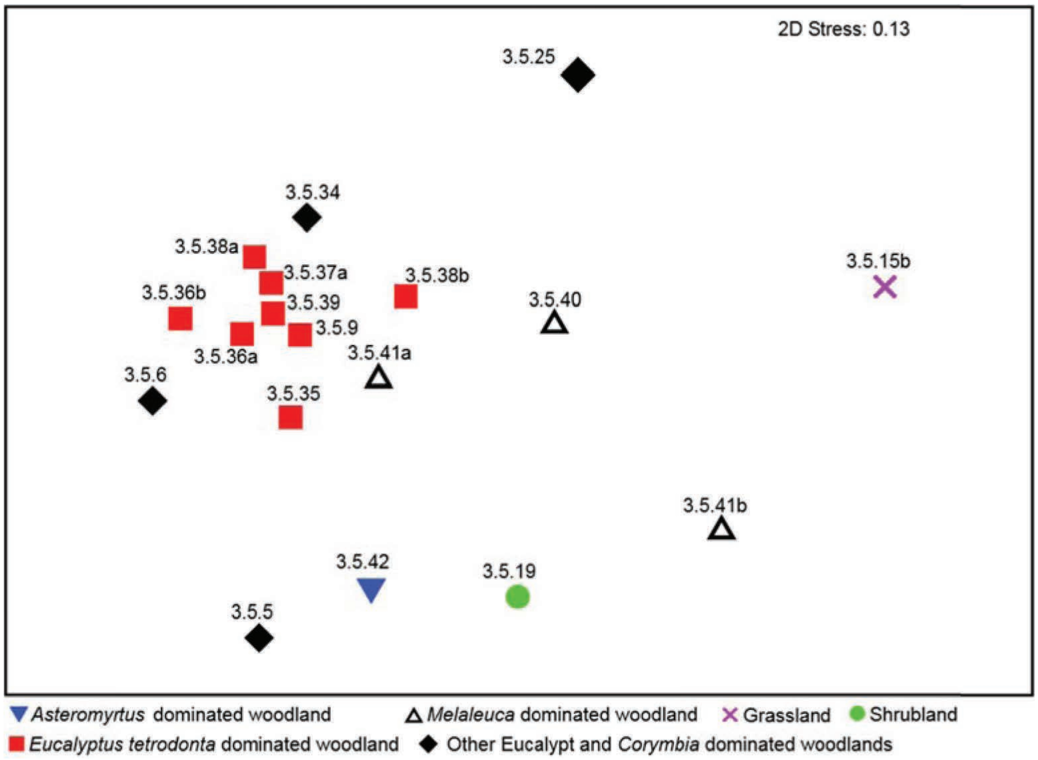

Figure 5.3: Land zone 5 scatter plot showing relative similarity of communities to each other in two-dimensions. Communities close together are more similar to each other. The greater clumping of communities than on land zone 12 scatter plot (Fig.5. 4) indicates a higher level of similarity of communities on land zone 5 than those on land zone 12.

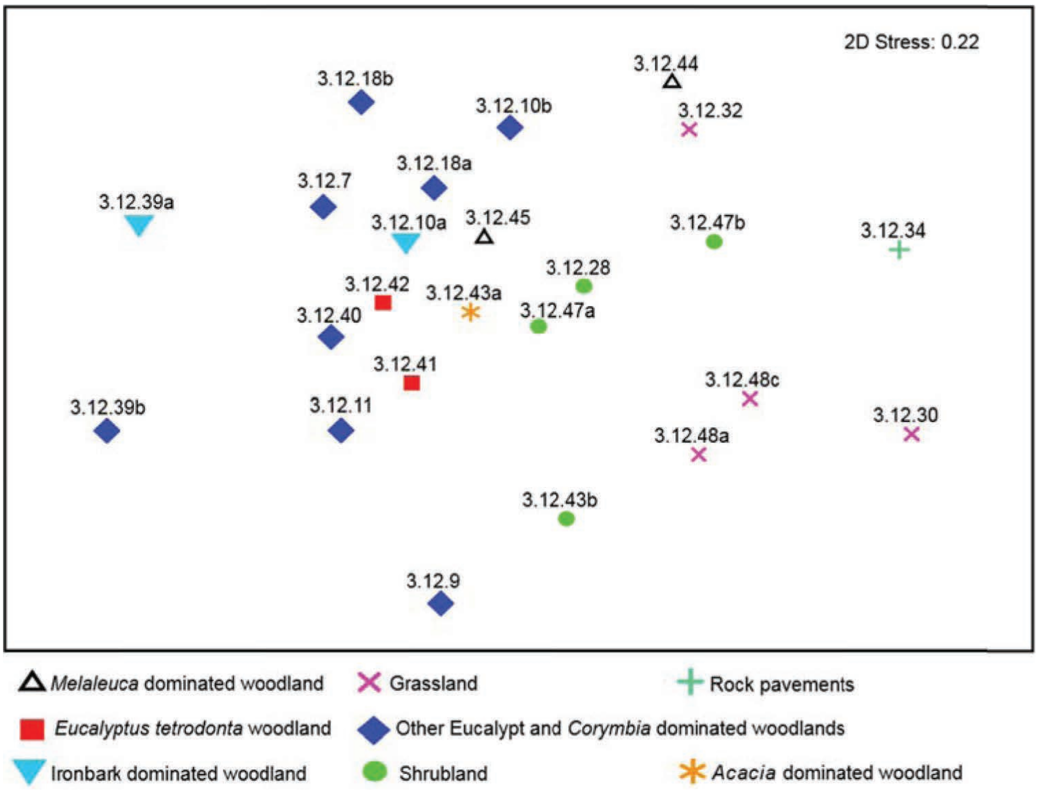

Figure 5.4: Land zone 12 scatter plot showing relative similarity of communities to each other. Communities close together are more similar to each other. The more scattered spread of communities on land zone 12 when compared to the land zone 5 (Fig. 5.3) indicates a lower level of similarity between communities than land zone 5.

Table 5.1: Percent similarity matrix of communities on land zone 5 (calculated with Bray-Curtis coefficient).

	3.5.15b	3.5.19	3.5.25	3.5.34	3.5.35	3.5.36a	3.5.36b	3.5.37a	3.5.38a	3.5.38b	3.5.39	3.5.40	3.5.41a	3.5.41b	3.5.42	3.5.5	3.5.6	3.5.9
3.5.15b																		
3.5.19	9.2																	
3.5.25	8.4	7.6																
3.5.34	6.8	13.6	16.1															
3.5.35	6.6	36.5	9.7	38.8														
3.5.36a	5.9	14.8	9.6	47.8	56.5													
3.5.36b	3.0	9.5	7.5	44.6	50.9	69.4												
3.5.37a	6.0	12.4	15.0	36.2	45.2	61.7	47.8											
3.5.38a	4.4	10.1	17.8	38.7	42.7	52.8	41.3	65.4										
3.5.38b	8.5	16.2	17.3	38.1	37.5	38.7	30.3	53.7	61.4									
3.5.39	4.9	9.5	19.3	33.7	46.5	61.0	57.0	56.0	56.3	40.7								
3.5.40	8.0	20.8	24.7	20.4	18.6	18.1	13.2	22.1	25.1	49.6	17.6							
3.5.41a	7.6	16.6	24.1	32.2	34.7	33.5	28.9	35.0	35.9	35.8	46.9	26.8						
3.5.41b	14.0	19.1	10.6	5.9	6.9	7.3	3.6	7.7	6.5	23.7	10.5	24.1	25.6					
3.5.42	5.5	42.7	4.9	19.4	41.3	24.0	18.3	20.2	15.7	20.2	20.8	18.1	28.5	13.9				
3.5.5	4.5	11.2	5.1	22.0	26.6	25.4	23.9	12.6	9.6	13.3	24.5	10.4	26.6	13.3	31.0			
3.5.6	4.7	13.2	9.1	23.0	33.7	31.5	30.0	35.2	31.2	24.5	35.2	12.3	32.0	4.1	22.3	15.1		
3.5.9	5.9	10.1	13.9	30.9	42.0	46.8	44.2	53.1	49.2	43.8	56.1	20.3	42.1	14.2	17.8	17.1	35.0	

Table 5.2: **Percent similarity matrix of communities on land zone 12 (calculated with Bray-Curtis coefficient).**

	3.12. 10a	3.12. 10b	3.12. 11	3.12. 18a	3.12. 18b	3.12. 21	3.12. 28	3.12 .30	3.12. 32	3.12. 34	3.12. 39a	3.12. 39b	3.12. 40	3.12. 41	3.12. 42	3.12. 43b	3.12. 43a	3.12. 44	3.12. 45	3.12. 47a	3.12. 47b	3.12. 48a	3.12 .48c	3.12. 7
3.12.10a																								
3.12.10b	31.8																							
3.12.11	23.2	12.1																						
3.12.18a	37.4	28.8	9.5																					
3.12.18b	21.5	14.0	11.1	24.8																				
3.12.21	8.8	7.1	13.0	7.2	4.3																			
3.12.28	13.3	13.3	8.9	8.5	4.0	12.4																		
3.12.30	2.9	4.6	2.0	3.9	4.6	4.3	3.1																	
3.12.32	18.8	14.0	3.7	10.0	9.0	3.0	7.0	6.6																
3.12.34	2.3	4.9	2.7	3.2	5.2	4.7	4.4	7.0	7.9															
3.12.39a	14.8	2.8	6.3	4.7	12.5	4.0	9.5	2.0	1.9	2.4														
3.12.39b	5.1	2.1	6.4	2.7	5.1	2.9	2.8	2.4	2.2	3.1	14.1													
3.12.40	24.5	8.5	26.2	15.8	15.6	11.2	11.2	2.2	5.6	2.4	17.7	13.6												
3.12.41	24.6	7.0	23.3	15.6	3.5	12.9	16.2	2.2	8.5	2.1	2.6	10.0	44.2											
3.12.42	44.8	15.7	31.6	32.1	18.4	11.7	11.8	2.8	7.5	2.3	11.1	10.5	50.1	40.6										
3.12.43b	9.4	5.7	13.1	12.2	4.7	9.4	10.2	4.7	4.0	8.1	2.1	3.5	10.7	8.9	12.2									
3.12.43a	33.8	18.3	32.4	19.1	4.9	14.5	28.9	3.1	12.9	2.5	11.9	2.1	17.3	31.3	23.8	6.5								
3.12.44	13.1	15.9	5.9	7.6	5.5	3.6	9.0	4.8	22.7	8.5	2.1	2.6	4.1	3.8	5.7	7.8	9.9							
3.12.45	32.2	22.2	9.2	28.0	16.7	7.2	18.6	3.8	9.6	4.5	4.0	7.1	21.9	32.2	35.3	7.0	23.4	11.8						
3.12.47a	19.6	11.1	8.3	9.9	4.1	16.2	34.2	3.0	6.8	4.2	3.8	4.7	14.7	40.7	22.0	11.0	28.3	9.7	33.1					
3.12.47b	10.6	12.4	2.4	9.8	4.8	8.2	21.3	6.3	15.8	14.5	2.4	2.9	6.0	11.1	10.2	7.2	14.0	15.1	17.1	29.4				
3.12.48a	7.8	6.1	5.8	6.5	6.0	11.5	8.7	10.1	9.5	9.5	3.1	3.8	9.0	6.1	7.2	11.1	7.5	4.7	9.2	10.1	8.4			
3.12.48c	5.8	3.7	8.2	6.4	3.9	7.3	6.6	8.6	18.6	11.2	5.1	2.6	9.2	5.6	8.5	7.4	7.6	5.5	8.7	5.4	12.8	12.9		
3.12.7	26.1	13.6	16.7	26.5	14.7	7.2	7.7	1.5	6.1	1.7	11.7	1.6	14.7	13.1	30.4	9.6	14.0	7.3	13.4	8.7	3.8	4.8	3.8	
3.12.9	6.4	3.5	24.7	7.7	7.3	17.1	2.8	2.9	2.6	3.8	2.3	1.9	6.4	7.6	10.2	23.9	12.2	3.1	6.1	3.0	3.6	4.2	7.4	10.7

References

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Neldner, V.J., Niehus, R.E., Wilson, B.A., McDonald, W.J.F., Ford, A.J. & Accad, A. (2017) Vegetation of Queensland. Descriptions of Broad Vegetation Groups. Queensland Herbarium, Department of Science, Information Technology and Innovation.

Appendix 6. Investigation into the correlations between persistent greenness index and climate variables.

We tested for correlations between climate variables and woody vegetation density using a 4-way ANOVA in the EXCEL stats package. Woody vegetation is represented by a maximum persistent greenness index (JRSRP 2017). The line-fit plots of woody vegetation density against each climate variable (Fig 6.1 – 6.4) provide a visualisation of the strength of correlation and the low predictability for woody vegetation. While there is a significant correlation between woody density and climate, the spread of actual woody vegetation values compared to expected values portrays the low predictability of woody vegetation density by climate ($R^2 = 0.34$)

Table A6.1: 4-way ANOVA of woody vegetation density against climate variables.

Regression Statistics	
Multiple R	0.58
R Square	0.34
Adjusted R Square	0.34
Standard Error	13.00
Observations	1000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	86136.3	21534.1	127.3	8.13988E-88
Residual	995	168254.7	169.1		
Total	999	254391			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	203.77	26.98	7.55	9.67745E-14	150.82	256.71
Temperature seasonality (C of V%)	-0.33	0.09	-3.51	0.0005	-0.51	-0.15
Mean moisture index of lowest quarter	1.75	0.39	4.50	7.63064E-06	0.99	2.52
Annual precipitation (mm)	0.02	0.01	3.23	0.0013	0.01	0.03
Annual mean temperature (^{0}C)	-2.76	0.88	-3.12	0.0018	-4.49	-1.02

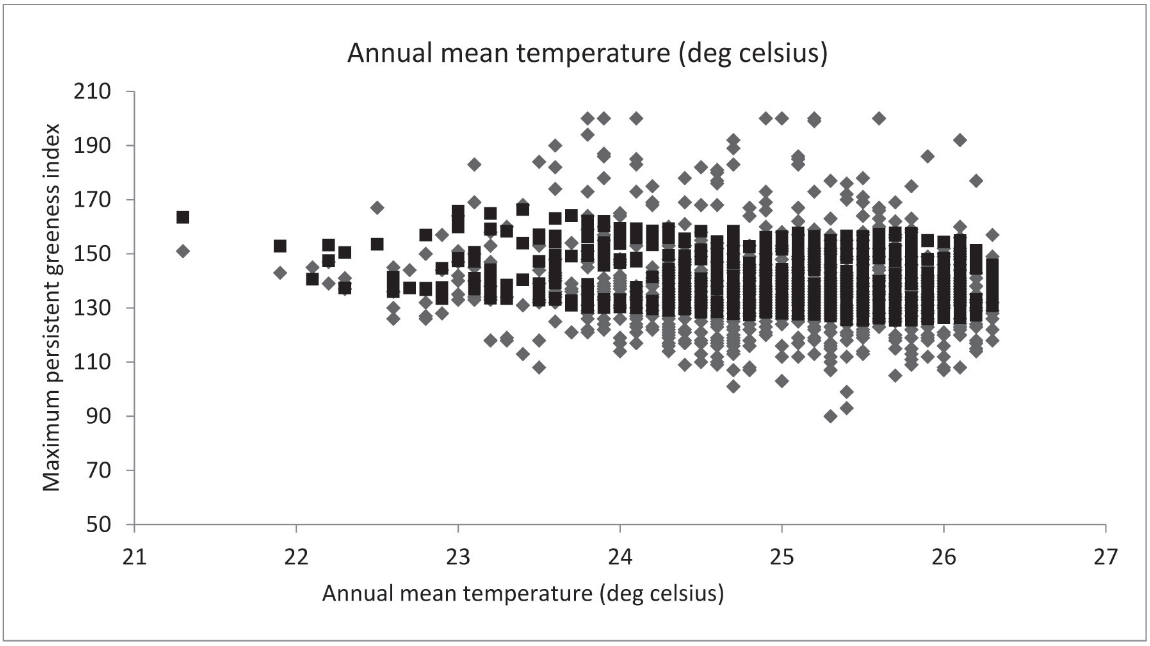

Figure A6.1: Line-fit plots of annual mean temperature against woody vegetation density (represented by maximum persistent greenness index). ◆ = actual maximum persistent greenness index at each observation point, ■ = predicted maximum persistent greenness index at each observation point

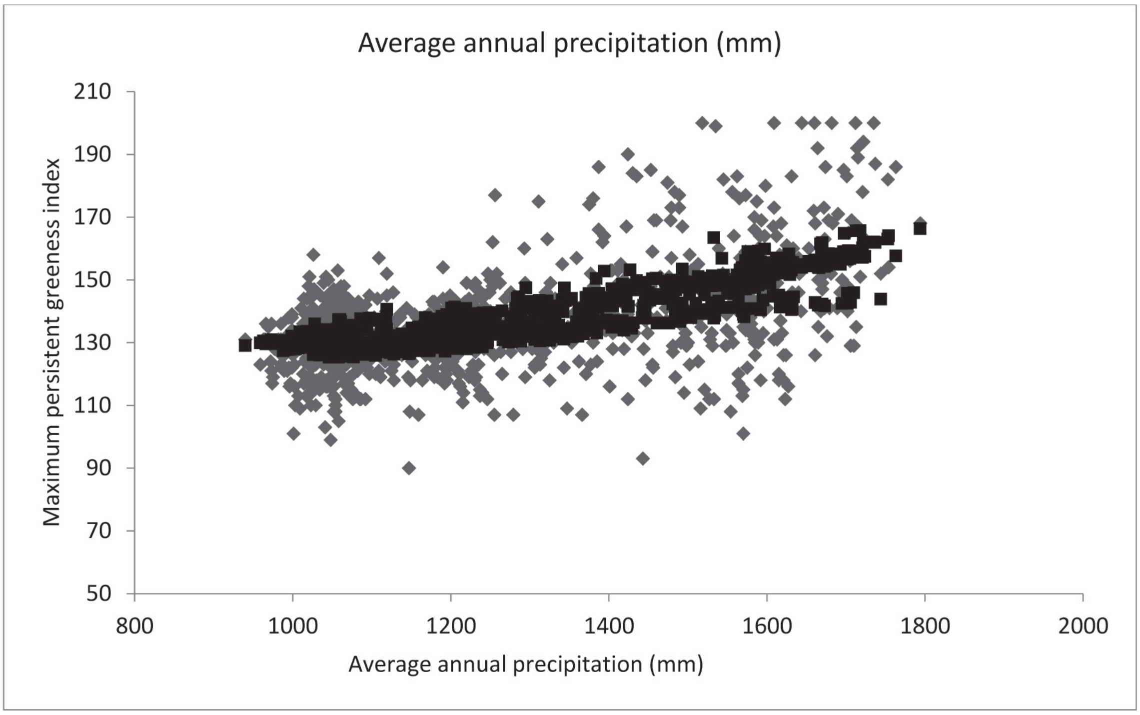

Figure A6.2: Line-fit plots of average annual precipitation against woody vegetation density (represented by maximum persistent greenness index). ◆ = actual maximum persistent greenness index at each observation point, ■ = predicted maximum persistent greenness index at each observation point

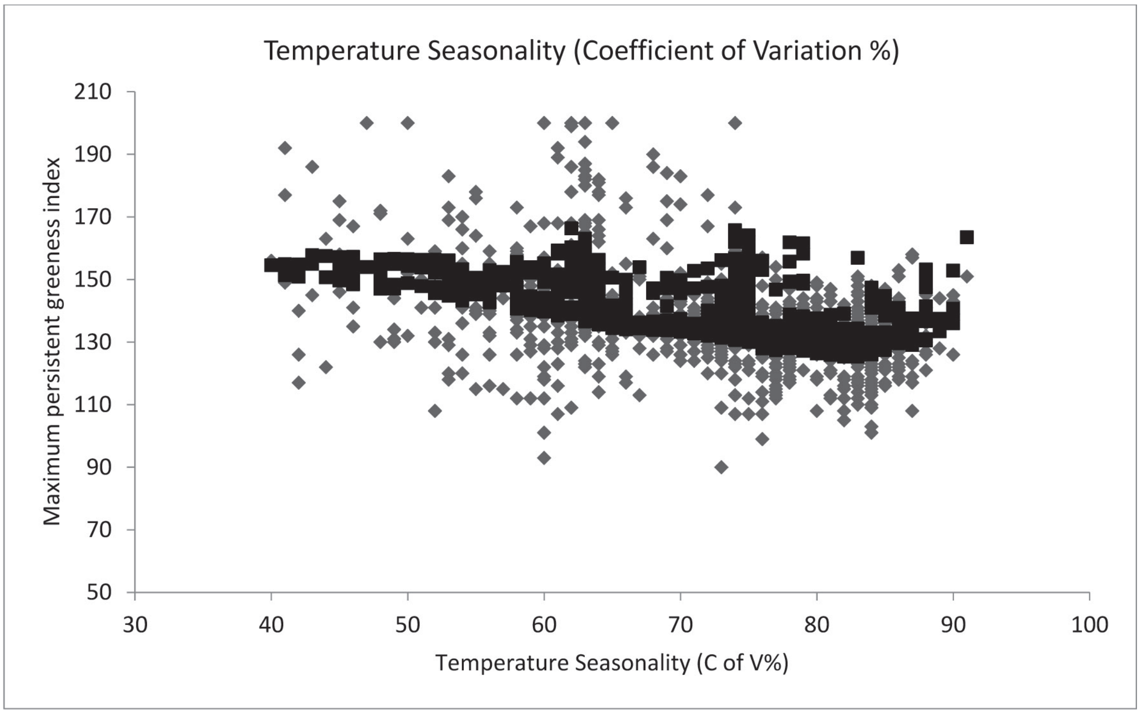

Figure A6.3: Line-fit plots of temperature seasonality against woody vegetation density (represented by maximum persistent greenness index). ◆ = actual maximum persistent greenness index at each observation point, ■ = predicted maximum persistent greenness index at each observation point

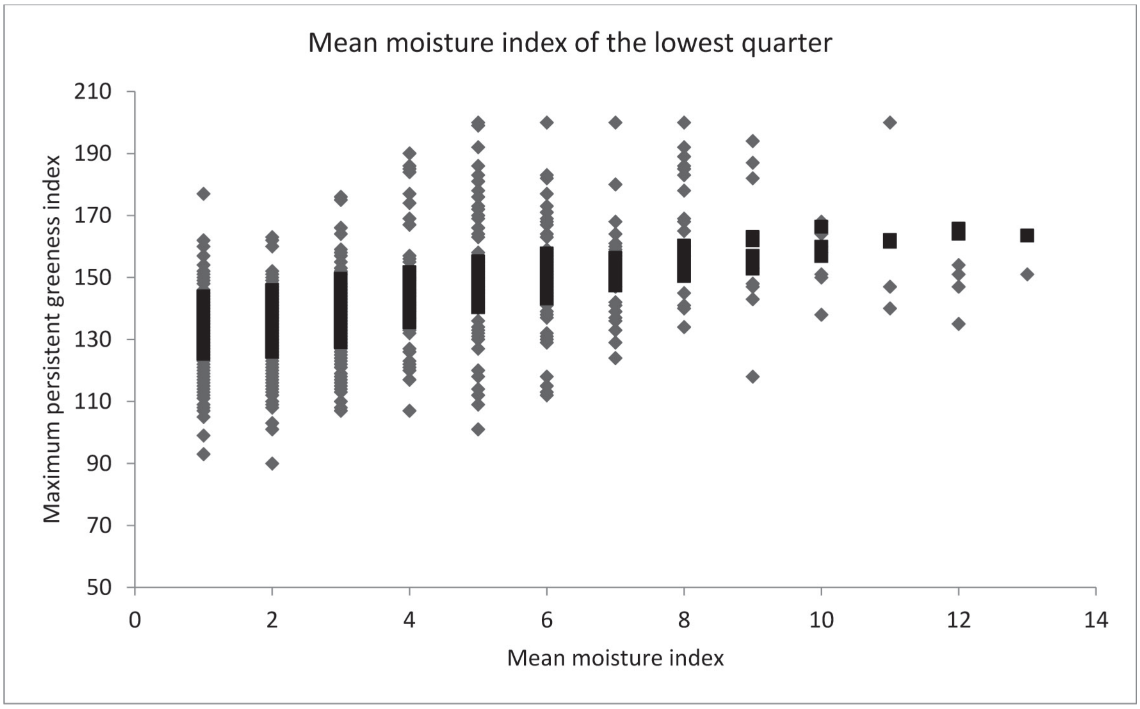

Figure A6.4: Line-fit plots of mean moisture index of the lowest quarter against woody vegetation density (represented by maximum persistent greenness index). ◆ = actual maximum persistent greenness index at each observation point, ■ = predicted maximum persistent greenness index at each observation point

References.

JRSRP. (2017) Seasonal fractional vegetation cover for Queensland derived from USGS Landsat images. Joint Remote Sensing Research Project. Department of Science, Information Technology and Innovation, Brisbane.