Is 500m^2 an effective plot size to sample floristic diversity for Queensland's vegetation?

V.J. Neldner and D. W. Butler

Queensland Herbarium, Environmental Protection Agency, Mt Coot-tha Botanic Gardens, Mt Coot-tha Road, Toowong, QLD 4066, AUSTRALIA. Email: john.neldner@epa.qld.gov.au

Abstract: Species area curves from 37 sites spanning the diversity of native vegetation in Queensland were examined. For the majority of sites investigated a 500 m^2 plot captured about 80–90% of the vascular plant species present at the time of sampling. Floristic data collected for grassland, heathland, acacia shrublands and most eucalypt woodlands using a 500 m^2 plot is appropriate for floristic analysis and adequately represent the vascular plants present at the site at the time. Using a larger plot would only slightly increase the species capture at a site but it would generally be more efficient to increase the number of sites sampled to more adequately capture the diversity across the extent of the vegetation type. However for many Queensland rainforest communities, a much larger sample size is required to capture the full species richness of a site.

***Cunninghamia* (2008) 10(4): 513–519**

Introduction

Plot-based data on vegetation composition has a multitude of uses and is rightly considered primary descriptive data from vegetation surveys. Whether users are writing map-unit descriptions or undertaking more complex quantitative analyses or modelling, they need to have confidence that the plot size and methodology used was appropriate to capture the majority of species present at a site. This paper examines species area curves from a structurally and floristically diverse array of vegetation from across Queensland to assess the effectiveness of 500 m^2 plots as samples of local floristic richness.

Queensland's diverse vegetation

The state of Queensland has a diverse array of vegetation ranging from the moist mega-diverse rainforests of the Wet Tropics, to the arid hummock grasslands of the Simpson Desert in the south west. Currently 1383 regional ecosystems are recognised at the regional (1:100 000) scale for the state (Accad *et al*. 2006). On a state wide basis, the majority of the pre-clearing vegetation was dominated by eucalypt woodlands and open-forests (44.4%), with extensive areas formerly covered with *Acacia* dominated woodlands and shrublands (22.8%). There are also large areas of *Astrebla* and other genera dominated tussock grasslands (20.1%) and *Triodia* dominated hummock grasslands (3.1%). Rainforests (2.2%), wetlands (5.4%), mangroves (1.1%) and heathlands (0.9%) cover much less extensive areas (derived from Appendix 3 in Wilson *et al*. 2002).

The Queensland Herbarium has had a long term program of survey and mapping vegetation of the state (Neldner 1993) and in recent years this mapping has been utilised for the *Vegetation Management Act 1999* (*VMA 1999*), which regulates tree clearing. The collection of detailed structural and floristic data is a core component of vegetation survey and mapping. The Herbarium program is structured around the mapping of vegetation communities at the 1:100 000 scale, and the site sampling aims to typify vegetation communities and regional ecosystems which are recognised and classified at the 1:100 000 scale. The Herbarium's botanists use standardised data collection procedures to maximise comparability of data between different collectors and across the wide range of vegetation types in the state. Apart from ground truthing the mapping, the vegetation data collected are providing a comprehensive floristic and structural inventory of Queensland's vegetation. It has hence been important to choose a plot size appropriate for sampling local-scale plant species richness across the wide range of vegetation types in Queensland.

Aim of this study

The aim of this study was to assess the effectiveness of 500 m^2 plots used in the Herbarium's survey and mapping methodology (Neldner *et al*. 2005) by examining the effect of sample area on species richness across a diverse range of the types of vegetation found in Queensland. The results provide information on the relative value (in terms of percentage floristic diversity capture) and limits to use of data collected at different size plots in different vegetation.

Table 1. Details of the sites included in this study and some important characteristics of the pattern of vascular plant species accumulation therein.

Site	Vegetation	Location	Total sampled area (m^2)	Total species at site	% of total recorded species at 500 m^2	Minimal area (95% species)	Gradient @ 500 m^2	#
1	*Astrebla lappacea* tussock grassland	north of Longreach 23°13'S 144°21'E	500	34	100	65	0.0	A
2	*Astrebla lappacea* tussock grassland	north of Longreach 23°45'S 144°29'E	1000	35	100	65	0.0	A
3	*Imperata cylindrica* closed-tussock grassland	Lockhart River 12°49'S 143°18'E	500	13	100	15	0.0	B
4	*Neofabricia myrtifolia, Allocasuarina littoralis* open-heath	Heathlands 11°43'S 142°31'E	500	20	100	23	0.0	B
5	*Neofabricia myrtifolia, Thyrptomene oligandra* open-heath	Heathlands 11°44'S 142°32'E	500	18	100	25	0.0	B
6	Sandplain dwarf heath	Cape Flattery 14°59'S 145°18'E	1000	23	96	100		C
7	Quaternary dunefield heath	Cape Flattery 14°59'S 145°18'E	1000	30	97	100		C
8	Quaternary dunefield wet heath	Cape Flattery 15°01'S 145°18'E	1000	24	100	100	0.001	C
9	Frontal dune exposed heath	Cape Flattery 15°01'S 145°18'E	1000	20	95	100	0.001	C
10	*Banksia aemula* woodland with dense low heath understorey	North Stradbroke Island 27°38'S 153°26'E	2050	48	91	872	0.005	D
11	*Acacia cambagei tall* shrubland	Hughenden 21°12'S 144°28'E	980	26	96	340	0.002	E
12	*Acacia harpophylla* tall shrubland	Erringibba National Park 27°18'S 149°41'E	750	37	99	490	0.002	F
13	*Acacia aneura* tall shrubland	Culgoa Floodplains National Park 28°54'S 146°58'E	650	37	97	210	0.004	G
14	*Melaleuca viridiflora* low open-woodland	Lakefield 15°16'S 144°38'E	1200	39	94	590	0.004	H
15	*Eucalyptus chlorophylla* woodland	Lakefield 15°22'S 144°26'E	1450	47	80	1000	0.017	H
16	*Eucalyptus tetrodonta, Erythrophleum chlorostachyus* woodland	near Laura 15°27'S 144°26'E	2900	73	79	1600	0.011	H
17	*Eucalyptus tetrodonta, Corymbia setosa* woodland	Strathgordon 14°52'S 142°30'E	660	52	99	250	0.007	B
18	*Eucalyptus platyphylla, E. leptophleba* open-woodland	near Mareeba 16°51'S 145°23'E	1300	43	85	1000	0.008	B
19	*Eucalyptus persistens* low open-woodland	White Mountains 20°27'S 144°50'E	760	45	94	530	0.011	I
20	*Eucalyptus quadricostata, Corymbia brachycarpa* woodland	White Mountains 20°27'S 144°50'E	1150	45	90	760	0.001	I
21	*Eucalyptus similis* woodland	White Mountains 20°34'S 144°15'E	500	54	-	280	<0.01	J
22	*Eucalyptus coolabah* open-woodland	Hebel 28°52'S 147°40'E	730	35	96	450	0.008	G
23	*Callitris glaucophylla Eucalyptus caleyi, E. dealbata,* woodland	near Texas 28°32'S 151°05'E	2500	30	87	1750	0.002	K
24	*Callitris glaucophylla* woodland with emergent *Angophora leiocarpa*	near Texas 28°59'S 151°12'E	2500	40	78	2000	0.01	K
25	*Eucalyptus albens, E. dealbata* woodland	near Texas 28°56'S 151°21'E	2500	32	84	1300	0.008	K

Site	Vegetation	Location	Total sampled area (m²)	Total species at site	% of total recorded species at 500 m²	Minimal area (95% species)	Gradient @ 500 m²	#
26	*Eucalyptus caleyi, E. dealbata* woodland	near Texas 28°38'S 151°20'E	2500	35	86	900	0.01	K
27	*Eucalyptus dealbata, Callitris glaucophylla* woodland	near Texas 28°34'S 151°23'E	2500	29	69	970	0.01	K
28	*Eucalyptus dealbata, E.caleyi, Callitris endlicheri* woodland	near Texas 28°35'S 151°09'E	2500	30	86	1370	0.01	K
29	*Eucalyptus crebra, E. moluccana, Angophora leiocarpa* open-forest	near Texas 28°41'S 151°10'E	2500	60	77	1860	0.03	L
30	*Eucalyptus crebra, Allocasuarina luehmannii* woodland	near Texas 28°35'S 151°03'E	2500	17	82	850	0.01	K
31	*Eucalyptus fibrosa* woodland	near Texas 28°39'S 151°08'E	2500	58	81	2000	0.01	L
32	*Eucalyptus melanophloia, Callitris glaucophylla, E. dealbata* woodland	near Texas 28°59'S 151°09'E	2500	34	82	1700	0.02	K
33	*Eucalyptus pillagensis, E. molucanna* woodland	near Texas 28°37'S 151°19'E	2500	26	69	880	0.02	K
34	*Eucalyptus terrica, E.crebra, Callitris endlicheri* woodland	near Texas 28°30'S 151°14'E	2500	26	81	950	0.01	K
35	Low microphyll vine forest	Western Bunya Mountains 26°50'S 151°32'E	10000	59*	66	7000	0.01	M
36	Araucaurian notophyll vine forest	Eastern Bunya Mountains 26°52'S 151°36'E	10000	60*	57	6000	0.02	M
37	Regrowth complex notophyll vine forest	Mt Glorious 27°20'S 152°43'E	800	115*	86	695	0.07	N

 # Botanists: A = H. Cartan; B = V.J.Neldner; C = N.Cuff; D = K.M. Stephens; E = H. Cartan & C.Kahler; F = B.A.Wilson; G = M.Schmeider; H = V.J.Neldner & D. Milne; I = V.J.Neldner & R.J.Cumming; J = E.J.Thompson & R.J.Cumming; K = K.M.Sparshott & A.R.Bean; L = K.M.Sparshott & E.J.Thompson; M = D.W.Butler; N = D.W.Butler & A.J.Franks.

* = only trees and shrubs sampled at these sites

Methods

Plots from 37 sites across Queensland were included in this study (Fig.1, Table 1). The sites were from a range of native vegetation types (all classified as remnant under the *VMA 1999*) and were sampled over a period of years (1988–2000) by a number of Queensland Herbarium botanists. The plots were all located in contiguous areas of the same vegetation type and were generally sampled at a time when the maximum plant species diversity would be present, eg. sampling eucalypt woodlands in the tropical savannas in the late wet season yields more than 80% of the overall floristic diversity recorded in repeated samples (Neldner *et al*. 2005). All vascular plant taxa were recorded at most sites, the exceptions were the three sites from rainforests (35–37) in which only tree and shrub species were recorded. In rainforests the majority of the vascular plant diversity is captured by the woody plants as ground-dwelling grasses and forbs are relatively uncommon. Plant nomenclature follows Bostock and Holland (2007).

For 18 sites, the data were collected by sampling contingous quadrats arrayed on a continuous grid. The plot size generally started as a 0.5 m² quadrat, with contiguous 1.0 m² quadrats added out along a 50 metre transect line and any additional species recorded with each new quadrat. At the completion

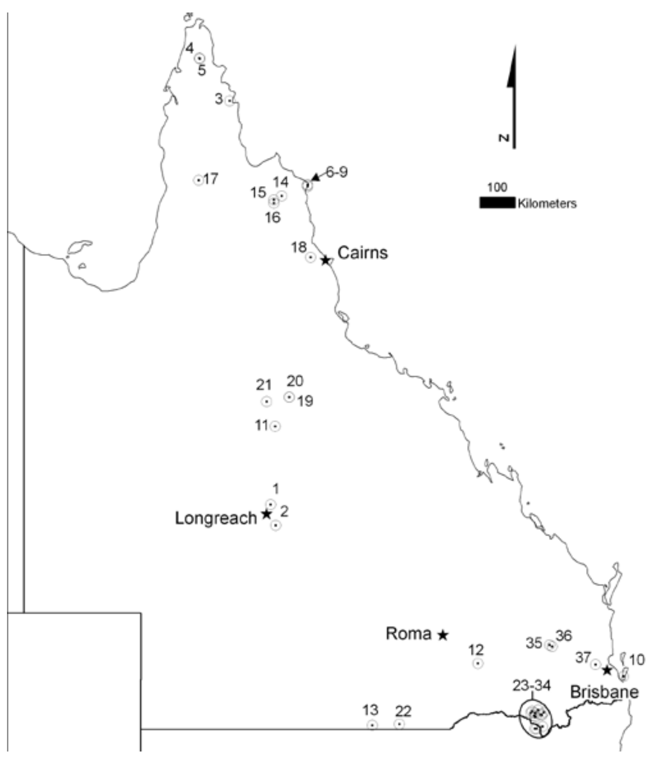

Fig. 1. Map of Queensland showing the locations of the 37 sites included in this study.

of the first 50 m, the transect line was moved up a metre and the quadrats sampled in the reverse direction. The sampling was terminated when the rate of recording new species was very low, such that the botanist assumed the total richness was captured. Graphs of the number of species encountered at the accumulated overall sample area for each site were generated. For the remaining 19 sites, data were collected in nested quadrats with incrementally pre-determined larger plot sizes added. The total accumulated species number for each plot size were then recorded. The rate at which new species were still being encountered at and beyond a plot size of 500 m^2 was estimated using a linear model based upon data points close to and beyond this threshold.

Results

Table 1 presents basic plot statistics as well as estimates of the percentage of the total species richness recorded at the site which was encountered in the first 500 m^2, and the rate at which previously unrecorded species were being encountered at 500 m^2 . The largest plot size at the sites ranged from 80 m^2 to 10 000 m^2 and the number of species encountered ranged from 13 to 115. Species area curves for each plot are presented in Figure 2. Only a few sites reached a plateau of no additional species being found with increasing area; three tropical heathlands (sites 4, 5 and 8) and three grasslands (sites 1–3). Most of the curves had passed the inflection point and commenced to plateau by the time plot area passed 500 m^2. Estimates of the rate of species accumulation at 500 m^2 (Table 1) varied between one species per 1000 m^2 (gradient = 0.001) to 2.6 species per 100 m^2, the average gradient was 0.01 suggesting one new species was being encountered for every 100 m^2 surveyed. On average, 88 percent of the total richness, as measured at the largest plot size at each site, was encountered when the plot area was 500 m^2.

The important factor in plot size selection is the inflection point at which the rate of species accumulation substantially declines, which for most of the sites in this study occurred between 50 and 500 m^2 (Fig. 2).

Discussion

There was significant variation between sites both in terms of the environmental conditions (landscape position, geology, climate) and the vegetation at the sites sampled but the pattern of species accumulation at each site followed the classic pattern well known to ecologists. It is very difficult to get a definitive number for the total vascular plant species at a site, as one moves further out frequently new environments and vegetation types are encountered. Indeed, there is significant debate on the relative impact of sampling design and ecological processes and environmental heterogeneity has on the type of curve produced (Hill *et al*. 1994, Scheiner 2003, 2004, Gray *et al*. 2004a, b).

In this investigation we are examining the local-scale richness within a vegetation community at a site. A 500 m^2 plot appears adequate for sampling the floristic richness at a given location (alpha diversity) for most types of vegetation in Queensland, recording about 88% of species present in the vicinity. Rainforests are an exception, this study included two rainforest sites in which the rate of new species being encountered did not decline until about 2000 m^2 had been sampled (sites 35 and 36). This may simply be explained by the high richness of large life-forms each requiring more space in rainforests.

Dense communities with relatively small predominant life-forms, such as heathlands and grasslands, showed little species accumulation after just 20 – 30 m^2. It could be argued that smaller plots, in the order of 100m^2, can be used in some less diverse vegetation types such as grasslands and heathlands of northern Queensland. This may be the case if only one vegetation type or structural formation were to be investigated, eg. a study of Queensland grasslands. However the advantages of a standard plot size in a Queensland wide methodology is that it allows comparisons of species richness across vegetation types. Operationally there are advantages in using a standard methodology by different botanists in different vegetation types across the State. Any cost savings by reducing the sample area of sites in simpler communities would be very limited, as the communities are easy to move through and few additional species will be encountered.

For eucalypt woodlands and open-forests, 500m^2 is often close to the break of slope in the species area curve and typically captures about 85% of species. Our data suggest that plot sizes of 1000m^2 or larger may be needed to capture over 90% of species in such communities.

These findings accord with other studies of species area relationships for vascular plants. Mueller-Dombois & Ellenberg (1974) estimated appropriate plot sizes of 200–500 m^2 for temperate zone forests, 50–100 m^2 for grassland and 10–25 m^2 for dwarf–shrub heath, while Kent and Coker (1994) recommend plot sizes of 400–2500 m^2 for woodlands, 100 m^2 for scrub/ shrub woodlands and 4–26 m^2 for heaths and grasslands. Ashton's data for tropical rainforest of Borneo (Ashton 1965 redrafted in Mueller-Dombois & Ellenberg 1974) included six species area curves only one of which showed a distinct levelling off within two hectares, suggesting a minimal area for these communities around five hectares.

The overall statistics on vascular plant richness recorded in this study are comparable with other Australian surveys, for example the total species recorded in grassy Eucalypt woodlands in northern Queensland range from 43 to 73 species from plots ranging from 450–2900 m^2 (sites 17–22), with 37–62 species being recorded from 1000 m^2 by Rice and Westoby (1983) and 42–61 species from 1600 m^2 plots by Taylor and Dunlop (1985) in similar vegetation in the Northern Territory. In 1000 m^2 plots in temperate New South Wales, 32–36 species were recorded in Eucalypt forests by Rice and Westoby (1983) and a

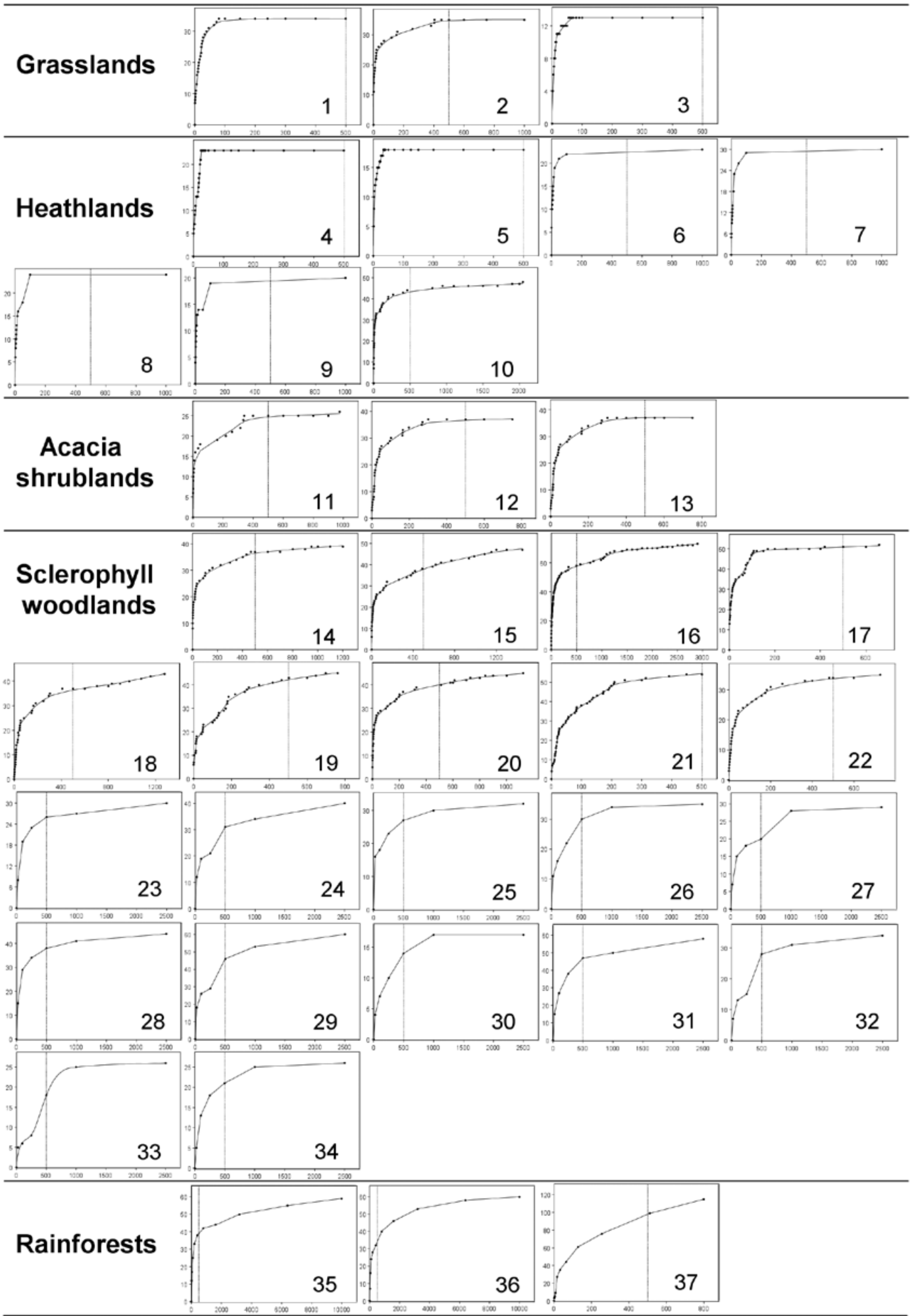

Fig. 2. Species area curves for vascular plant species at 37 sites across Queensland, the X-axis is cumulative area (m^2) and the Y-axis is cumulative number of plant species recorded. The numbers refer to site numbers in table 1 and figure 1. The 500 m^2 plot is indicated by the dotted vertical line. Lines were fitted using various smoothing algorithms in Splus 7.0.

mean number of 53 species in mallee by Whittaker *et al*. (1979) which compares favourably with the 30–59 species recorded in sites 23–34. In Australian tropical rainforests, Webb *et al*. (1967) recorded a mean of 140 species in 1000 m^2 plots in the wettest situations, while in the seasonally dry rainforests species diversity was down to 54 species. The subtropical rainforests sites reported in this study (35, 36 & 37) recorded 59 (trees and shrubs only) to 115 species, while Laidlaw *et al*. (2000) recorded 74 tree species (>5cm DBH) from a 10 000 m^2 plot, with a species area curve flattening above 3000 m^2.

While species area curves can be useful indicators of the plot size required to capture local-scale richness, similar curves are also required to examine the number of sites needed to adequately capture the beta diversity of a vegetation type, eg. total diversity in a vegetation type across its full extent. For Cape York Peninsula eucalypt woodlands, at least 30 sites are required before the curves tend to plateau, while for heathlands and grasslands 15 sites were adequate (Neldner *et al*. 1995; Neldner 1996). It is recommended that 500 m^2 plots are adequate sample units for capturing the species at a site for general vegetation survey in most Queensland vegetation types. Rather than record data from larger plots to capture the few species that may be missed from a site, resources are better allocated to increasing the number of locations sampled to adequately sample the biodiversity across the extent of the vegetation type.

Conclusions

For the majority of Queensland vegetation types investigated a 500 m^2 plot captured about 90% of the vascular plant species present at the time of sampling. This suggests that floristic data collected from 500m^2 plots is adequate for floristic analysis and appropriately represents the local-scale vascular plant composition of grasslands, heathlands, acacia shrublands, melaleuca woodlands and most eucalypt woodlands. However, in many rainforest communities, which cover less than 1.5% of Queensland's remnant vegetation, a much larger sample size would be required to adequately capture the full species complement. The advantages of a standard plot size are that cross vegetation community analyses can be conducted.

Acknowledgements

The authors wish to thank Tony Bean, Helen Cartan, Nick Cuff, Russell Cumming, Andrew Franks, Chris Kahler, Damian Milne, Miriam Schmeider, Kym Sparshott, Kathy Stephens, John Thompson and Bruce Wilson who assisted with the field data collection, and Queensland Herbarium management who facilitated the field work.

References

Accad, A., Neldner, V.J., Wilson, B. A. & Niehus, R.E. (2006) *Remnant Vegetation in Queensland: Analysis of Remnant Vegetation 1997–1999–2000–2001–2003, including Regional Ecosystem Information*. (Queensland Herbarium, Environmental Protection Agency: Brisbane).

Ashton, P.S. (1965) Some problems arising in the sampling of mixed rainforest communities for floristic studies. In *Symposium on Ecological Research in Humid Tropics vegetation*, pp. 235–240. (Government of Sarawak&UNESCO: Tokyo).

Austin, M.P. (1991) Vegetation: data collection and analysis. In *Nature Conservation: Cost Effective Biological Surveys and Data Analysis*. (Eds CR Margules, MP Austin) pp. 37-41. (CSIRO: Australia).

Austin M.P. & Heyligers P.C. (1991) New approach to vegetation survey design: gradsect sampling In *Nature Conservation: Cost Effective Biological Surveys and Data Analysis*. (Eds CR Margules, MP Austin) pp. 31–36. (CSIRO: Australia).

Bostock P.B. & Holland A.E. (eds) (2007) *Census of the Queensland Flora 2007*. (Queensland Herbarium, Environmental Protection Agency; Brisbane).

Gray, J.S., Ugland, K.I. & Lambshead, J. (2004a) Species accumulation and species–area curves – a comment on Scheiner (2003). *Global Ecology and Biogeography* 13: 469–476.

Gray, J.S., Ugland, K.I. & Lambshead, J. (2004b) On species accumulation and species-area curves *Global Ecology and Biogeography* 13: 567–68.

Hill J.L., Curran, P.J. & Foody, G.M. (1994) The effect of sampling on the species-area curve. *Global Ecology and Biogeography* 4: 97–106.

Kent M. & Coker P. (1994) *Vegetation Description and Analysis. A Practical Approach*. (John Wiley & Sons Ltd: Chinchester).

Laidlaw M., Olsen M., Kitching R.L. & Greenway, M. (2000) Tree floristic and structural characteristics of one hectare of subtropical rainforest in Lamington National Park, Queensland. *Proceedings of the Royal Society of Queensland* 109**:** 91–105.

Mueller-Dombois D. & Ellenberg H. (1974) *Aims and Methods of Vegetation Ecology*. (John Wiley & Sons: New York).

Neldner V.J. (1993) *Vegetation survey and mapping in Queensland*. Queensland Department of Environment Botany Bulletin No.12, Brisbane.

Neldner V.J. (1996) *Improving vegetation survey: integrating the use of Geographic Information Systems and Species modelling techniques in vegetation survey. A case study using the eucalypt dominated communities of Cape York Peninsula*. (Doctor of Philosophy thesis, Australian National University: Canberra).

Neldner V.J., Crossley D.C. & Cofinas M. (1995) Using Geographical Information Systems (GIS) to determine the adequacy of sampling in vegetation surveys. *Biological Conservation* 73:1–17.

Neldner V.J., Kirkwood A.B. & Collyer B.S. (2004) Optimum time for sampling floristic diversity in tropical eucalypt woodlands of northern Queensland. *The Rangeland Journal* 26:190–203.

Neldner V.J., Wilson B.A., Thompson E.J. & Dillewaard H.A. (2005) *Methodology for Survey And Mapping of Regional Ecosystems and Vegetation Communities in Queensland. Version 3.1*. Queensland Herbarium, Environmental Protection Agency, Brisbane.

Rice B. & Westoby M. (1983) Plant species richness at the 0.1 hectare scale in Australian vegetation compared to other continents. *Vegetatio* 52: 129–40.

Scheiner S.M. (2003) Six types of species-area curves. *Global Ecology and Biogeography* 12: 441–47.

Scheiner S.M. (2004) A mélange of curves – further dialogue about species-area relationships. *Global Ecology and Biogeography* 13: 479–84.

Taylor J.A. & Dunlop C.R. (1985) Plant communities of the wet-dry tropics of Australia: the Alligator Rivers region, Northern Territory. *Proceedings of the Ecological Society of Australia* 13: 83–127.

Thompson G.G., Withers P.C., Pianka E.R. & Thompson S.A. (2003) Assessing biodiversity with species accumulation curves; inventories of small reptiles by pit-trapping in Western Australia. *Austral Ecology* 28: 361–83.

Webb L.J., Tracey J.G., Williams W.T. & Lance G.N. (1967) Studies in numerical analysis of complex rainforest communities. I. Comparison of methods applicable to site-species data. *Journal of Ecology* 55: 171–191.

Whittaker, R.H., Niering, W.A. & Crisp, M.D. (1979) Structure, pattern and diversity of a mallee community in New South Wales. *Vegetatio* 39: 65–76.

Wilson B.A., Neldner V.J. & Accad A. (2002) The extent and status of remnant vegetation in Queensland and its implications for statewide vegetation management and legislation. *The Rangeland Journal* 24: 6–35.

Wilson J.B., White P.S., Bakker J.P. & Diaz S. (2002) Disentangling the environment and representing vegetation science. *Journal of Vegetation Science* 17: 1–3.

Manuscript accepted 11 June 2008