SPECIAL ISSUE

CSIRO PUBLISHING

Australian Journal of Botany, 2021, **69**, 329–338
https://doi.org/10.1071/BT21102

Editorial

Australian advances in vegetation classification and the need for a national, science-based approach

Sarah Luxton [A], *Donna Lewis* [B], *Shane Chalwell* [C], *Eda Addicott* [D] *and John Hunter* [E]

[A]School of Molecular and Life Sciences, Curtin University, GPO Box U1987, Perth, WA 6845, Australia. Email: sarahjluxton@outlook.com
[B]Northern Territory Herbarium, Flora and Fauna Division, Department of Environment, Parks and Water Security (DEPWS), Northern Territory Government, PO Box 496, Palmerston, NT 0831, Australia. Email: donna.lewis@nt.gov.au
[C]Plantecology Consulting, 50 New Cross Road, Kingsley WA 6026, Australia. Email: shane@plantecology.com.au
[D]Queensland Herbarium, Mt Coot-tha Road, Toowong, Department of Environment and Science, Queensland Government, Qld 4066, Australia. Email: eda.addicott@des.qld.gov.au
[E]School of Environmental and Rural Science, Elm Avenue, University of New England, Armidale, NSW 2350, Australia. Email: jhunter8@bigpond.com

Abstract. This editorial introduces the *Australian Journal of Botany* special issue 'Vegetation science for decision-making'. Vegetation science and classification are crucial to understanding Australian landscapes. From the mulga shrublands of the arid interior to the monsoon rain forests of northern Australia, we have culturally and scientifically built upon the delineation of vegetation into recognisable and repeatable patterns. As remote sensing and database capacities increase, this improved capability to measure vegetation and share data also prompts collaboration and synthesis of complex, specialised datasets. Although the task faces significant challenges, the growing body of literature demonstrates a strong discipline. In Australia, purpose-driven products describe vegetation at broad scales (e.g. the National Vegetation Information System, the Terrestrial Ecosystem Research Network). At fine scales however (i.e. that of the vegetation community), no uniform framework or agreed protocols exist. Climate and landform dictate vegetation patterns at broad scales, but microtopography, microclimate and biotic processes act as filters at finer scales. This is the scale where climate-change impacts are most likely to be detected and effected; this is the scale at which a deeper understanding of evolutionary ecology will be achieved, and it is the scale at which species need to be protected. A common language and system for understanding Australian communities and impetus for collecting data at this scale is needed. In the face of ongoing climate and development pressures and an increasingly complex set of tools to manage these threats (e.g. offset policies, cumulative impact assessments), a nationally collaborative approach is needed. It is our hope that this special issue will help to achieve this.

Received 20 August 2021, accepted 1 September 2021, published online 6 October 2021

Introduction

The aim of this editorial is to introduce the *Australian Journal of Botany* special issue 'Vegetation science for decision-making', which evolved from a symposium of the same name at the Ecological Society of Australia's 2019 annual conference in Launceston, Tasmania. We provide broad, global and national contexts for vegetation classification, discuss the importance of the plant community and highlight the main findings of each contribution to the special issue. The main focus – vegetation classification – is a globally important issue in plant science and has been a major feature of Australian vegetation science for well over half a century. It is our hope that this special issue will contribute to a greater understanding of the language, data, methods and applications of vegetation classification, and, importantly, how cross-jurisdictional collaboration can be enhanced.

A global snapshot of vegetation classification

Classification is a fundamental scientific pursuit. From the spectral classification of stars in astronomy, to the morphological and genetic classification of living things into species, the observation of differences and repeating patterns is critical to understanding the processes underlying nature. Vegetation classification helps us to summarise and describe complex patterns of species co-occurrence and its typologies are useful for multiple purposes (Dengler *et al*. 2008; Austin 2013;

De Cáceres *et al*. 2015). These include: (1) communication about complex vegetation patterns; (2) formulation of hypotheses about the ecological and evolutionary processes shaping these patterns; (3) creation of maps to display the spatial variation of vegetation and related ecosystem properties and services; (4) surveying, monitoring and reporting plant and animal populations, communities and their habitats; and (5) development of coherent management and conservation strategies (De Cáceres *et al*. 2015).

Ideally, the purpose of a classification schema should inform the type of data collected (including sampling strategy and primary vegetation attributes) and the protocol ('class definition procedures') used for analysis (De Cáceres *et al*. 2015). For example, a forestry classification may focus on commercial tree species and attributes such as height (Sun *et al*. 1997). Alternatively, conservation decision-making requires an accurate assessment of understory and rare species (Tierney *et al*. 2018; Bell and Driscoll 2021), whereas vegetation mapping focuses on key indicator species in the dominant strata, and the inclusion of rare species may hinder rather than inform mapping (Addicott *et al*. 2018). Across all forms of classification, scale is an essential consideration for appropriate data collection and applications (Levin 1992; McKenzie *et al*. 2008; Bell and Driscoll 2021; Hunter and Growns 2021; Patykowski *et al*. 2021).

Vegetation classification has developed from descriptive into a numerically intensive discipline with an extensive literature and complex protocols and methods (Mucina 1997; De Cáceres *et al*. 2015). Data collection includes decisions regarding survey type (random, stratified, preferential (De Cáceres *et al*. 2015), data format (presence-absence, frequency, cover, cover-abundance) and plot size (Neldner and Butler 2008; Dengler *et al*. 2009; Patykowski *et al*. 2021). Analysis decisions extend from data transformation (Lewis *et al*. 2021*a*) and the type of association metric and clustering algorithm used (e.g. hierarchical *v*. non-hierarchical clustering; Wards *v*. UPGMA); to whether environmental data is integral or secondary to the classification (supervised *v*. unsupervised classification; see Wildi 2010, Borcard *et al*. 2011, Kent 2011 and Legendre and Legendre 2012 for full treatments of vegetation classification methods). A range of software tools are available to analyse data. The more commonly used include R (R Foundation for Statistical Computing, Vienna, Austria, see https://www.R-project.org/), which has well supported and up-to-date vegetation classification packages (e.g. vegan, ver. 2.5-6, J. Oksanen, F. G. Blanchet, M. Friendly, R. Kindt, P. Legendre, D. McGlinn, P. R. Minchin, R. B. O'Hara, G. L. Simpson, P. Solymos, M. H. H. Stevens, E. Szoecs, and H. Wagner, see https://cran.r-project.org/web/packages/vegan/index.html; labdsv, ver. 2.0-1, D. W. Roberts, see https://CRAN.R-project.org/package=labdsv; vegclust, ver. 1.6.5, M. De Cáceres and S. K. Wiser, see https://cran.r-project.org/web/packages/vegclust/index.html); JUICE, which handles large datasets (>100 000 plots) (Tichý 2002; Chytrý and Tichý 2018; Addicott *et al*. 2021); PRIMER-e (see https://www.primer-e.com/), which does not require use of a command line (Lewis *et al*. 2021*a*) and PATN (see https://patn.org/), which can also handle large datasets (>30 000 plots) (Belbin 1993; Luxton *et al*. 2021). This complexity has likely been a barrier to numerical methods being used to ascribe vegetation types in Australia, although intuitive approaches may have benefits over numerical when the purpose is to create broad map units in wooded systems. In this case, herbaceous species will influence classification results but have a low correlation with remotely sensed patterns (Neldner and Howitt 1991; Addicott *et al*. 2021). Complexity has also been a barrier to the use of numerical methods in policy and regulatory frameworks and can make the synthesis of historic with current datasets, and across jurisdictional boundaries difficult (Gellie and Hunter 2021; Luxton *et al*. 2021; Muldavin *et al*. 2021). These factors, together with the lack of a critical number of practitioners, have likely stymied vegetation classification collaboration efforts within Australia and internationally.

Despite the challenges however, global advances enable robust solutions and collaborations both within and between countries. For example, VegBank (the vegetation plot database of the Ecological Society of America's panel on vegetation classification) contains 115 246 plots and includes 10 695 vegetation types, which are recognised in the US National Vegetation Classification (USNVC, see http://vegbank.org/vegbank/index.jsp) (Peet *et al*. 2012). New vegetation types for the USNVC can be proposed and are reviewed by an expert panel (in a similar vein to the academic peer-review process) before being accepted as an official vegetation type (Peet *et al*. 2012). In Europe, the European Vegetation Archive (EVA), a centralised database of European plots, has over 1 million plot records (see http://euroveg.org/eva-database) (Chytrý *et al*. 2016) and the Botanical Information and Ecology Network (BIEN) currently holds 364 477 plots. BIEN also contains other bioinformatic data (e.g. plant traits) and has been working since 2008 to bring together managers of botanical survey data, computer scientists and ecologists interested in synthetic research across scales (see https://bien.nceas.ucsb.edu/bien/, accessed 25 July 2021) (Enquist *et al*. 2016). sPlot, a global vegetation-plot database initiated by an international working group at the German Centre for Integrative Biodiversity Research in 2013, contains almost two million georeferenced plots and provides a basis for global vegetation analyses (Bruelheide *et al*. 2019).

Ongoing research into analytical methods also underpins this global push towards synthesising vegetation data and types into comprehensive typologies. Work includes the development of semi-supervised classification, which incorporates new plot records while retaining 'old' classification units (Tichý *et al*. 2014) and fuzzy (noise) clustering. Noise clustering enabled plots to be placed in transition vegetation types or left unassigned until enough data are available to robustly define a vegetation type (De Cáceres *et al*. 2010; Wiser and De Cáceres 2018). Together, these international efforts to collaborate and overcome data and analysis issues provide a path forward for joint continent-wide efforts within and between jurisdictions – States, Territories and the Commonwealth – in Australia.

Australian vegetation science and classification

In the context of land management and ecology, Australian vegetation classification has been reviewed in several places. Most recently, Keith (2017) provides a comprehensive and up-to-date account of Australian vegetation ecology and science, from the evolutionary biogeography of the Australian flora in the Cenozoic era to in-depth chapters on Australia's 16 major vegetation types. It also includes a new high-level ecological typology of Australian vegetation, with an evaluation of how ecological processes and legacies shape and delineate the major vegetation types (Keith and Tozer 2017). In the forward to Keith (2017), Groves touches on the origins of vegetation description in Australia (see also Short 2003 for a detailed account), the history of structural and floristic typologies (e.g. Wood 1939; Beadle and Costin 1952; Specht 1970, 1981; Carnahan 1990; Specht and Specht 2000), the emergence of the link between vegetation functionality and type, and the importance of fire in determining vegetation distribution. Sun *et al*. (1997) provide a detailed summary of the major vegetation classification and mapping systems used by the management agencies with primary responsibilities for forested land in Australia. Gellie *et al*. (2018*a*) summarise the density and distribution of plot data and review local classifications by each State and Territory. They also make a case for cross jurisdictional co-operation, including the need for agreed nation-wide classification protocols and procedures, improved plot coverage in data-poor areas, higher standards of plot data curation and plant taxa nomenclature, and a scientifically defensible hierarchical classification that integrates with the International Vegetation Classification (IVC) (see also Table 1 for an updated summary of plot data by jurisdiction).

Australia has several nation-wide classifications of vegetation at broad scales, with each system having different purposes, advantages, and limitations. They include the Interim Biogeographic Regionalisation for Australia (IBRA) (Thackway and Cresswell 1995), the National Vegetation Information System (NVIS) (National Land and Water Resources Audit 2001) and the Terrestrial Ecosystem Research Network's Advanced Ecological Knowledge and Observation System (TERN AEKOS) (Sparrow *et al*. 2020) (which is to be superseded by TERN EcoPlots, see https://ecoplots.tern.org.au; Table 1). IBRA classifies Australia's landscapes into 89 bioregions and 419 subregions and forms the basis of a comprehensive, adequate and representative ('CAR') National Reserve System (Kukkala and Moilanen 2013; Margules and Pressey 2000; National Reserve System Task Group 2009) (see https://www.environment.gov.au/land/nrs/science/ibra). However, it is an ecoregional assessment rather than a vegetation classification typology *per se*. NVIS was formed in the early 2000s as a spatially explicit national repository for vegetation information and has consistent coverage at the Major Vegetation Groups (Fig. 1) and Subgroups levels, but is patchy at lower levels of the classification (Level V and VI, Association and Sub-association) (National Land and Water Resources Audit 2001; Keith and Tozer 2017; Scarth *et al*. 2019). Additionally, although lower level units incorporate floristic data (three and five species per strata respectively), they are not associations in the sense of European and North American definitions, which tend to be based on full-floristic data (Willner 2006; Peet and Roberts 2013; van der Maarel and Franklin 2013). TERN's EcoPlots may prove the forerunner for a nationally integrated plot database and classification. Currently it houses ~98 000 vegetation plots from Queensland, South Australia, Northern Territory, Western Australia, and New South Wales (Table 1). It overcome state-based idiosyncrasies to integrate data between different agencies using a semantic web approach (Guru *et al*. 2019).

Australian plant ecology provides a backbone for understanding the drivers of vegetation patterns. Australia is the 'flattest, driest, and geologically oldest vegetated continent' in the world, with the first European explorers marvelling at the strange plants encountered here (Short 2003; Orians and Milewski 2007). Although patterns of plant diversity are intermediate, our vegetation is highly endemic (>80% taxa) and botanical species discovery is ongoing (Keith and Tozer 2017; Gellie *et al*. 2018*a*; Taxonomy Decadal Plan Working Group 2018). For First Nations people, the sorting of plants (and animals) into groups is interwoven with religious and cultural beliefs (McHale 2018). In western science, scale is the key concept that organises our understanding of vegetation patterns and the processes driving them (Levin 1992; Chave 2013). Specifically, in Australia, climate and available energy operate broadly, whereas topography, soils and fire (and other disturbances, e.g. cyclones) act at intermediate scales (Havel 1975; Hunter 2021*a*). The role of nutrient poverty and fire (Milewski 1983; Orians and Milewski 2007); old *v*. young landscapes and climatic 'stability' (Hopper 2009; Mucina and Wardell-Johnson 2011; Hopper *et al*. 2021) and alternative stable states (Peterson 1984; Sousa and Connell 1985; Pausas and Dantas 2017) are important, as is the role of competition and top down effects (e.g. grazing) (Greenwood and McKenzie 2001; Trinder *et al*. 2013).

Fine scale effects are increasingly recognised as influencing species patterns within the broad-scale filters of climate and landform and are an important frontier for vegetation science (Keith and Tozer 2017). Factors include biotic interactions (e.g. pathogens, competition, mutualisms with mycorrhiza (Albornoz *et al*. 2017; Brundrett *et al*. 2017), microclimatic and microtopographic effects (e.g. cold air pooling, banded ironstones formations; Curtis *et al*. 2014; Robinson *et al*. 2019) and life history traits (Leishman and Westoby 1992; Schwarz *et al*. 2018). Explicitly modelling processes such as physiology, dispersal, demography and biotic interactions is believed to provide more robust predictions in species distribution models, particularly when extrapolating to novel conditions (Wisz *et al*. 2013; le Roux *et al*. 2014; Briscoe *et al*. 2019). Surveying at this scale enables species discovery, the identification of rare species (Patykowski *et al*. 2021) and mapping of rare and threatened plant communities (Tierney *et al*. 2018; Bell and Driscoll 2021). Subsequently, the lack of national standards for data collection, analysis and classification development at this scale has serious negative implications for conservation decision making.

Australia faces challenges due to its size and remoteness, but a national vegetation database and classification system (i.e. the 'Australian Vegetation Classification System

Table 1. An updated summary of full floristic vegetation plot databases in Australia by Federal and State jurisdictions (adapted from and reprinted with permission from (Gellie *et al.* 2018*a*)

Jurisdiction	Database name	Custodian	Number of floristic vegetation plots	Source or URL	Database details
Australia-wide	TERN EcoPlots	Supported by the Australian Government through the National Collaborative Research Infrastructure Strategy (NCRIS), hosted by the University of Queensland.	98 000[A]	https://ecoplots.tern.org.au	• TERN EcoPlots (previously AEKOS) aims to become an Australian-wide bio-data repository including vegetation and monitoring plot data. Success will depend on continued Commonwealth funding. • EcoPlots hosts data from Qld, SA, NT, WA and NSW. • The system includes TERN Surveillance monitoring plots spread across Australia and collected as per the TERN Ausplots Rangelands Survey Protocol (Sparrow *et al.* 2020).
ACT	None	ACT Parks and Conservation	1441	No external access	• 75% of plots are in a digital format. There is no central database, but most are included in the NSW plot database. • Plot data collected during individual research projects. • Each project has its own database structured to generate queries specific to that project.
NSW	BioNet Systematic Flora Survey	Department of Primary Industries and the Environment	116 312[A]	http://www.environment.nsw.gov.au/research/VISplot.htm	• 104 365 flora sites, with 116 312 replicates. • 87 845 of these plots are estimated to be full floristic. • Contains a data-export function for classification analysis.
NT	NT Vegetation Site Database (NTVSD)	Department of Environment Parks and Water Security	69 000[A]	http://www.ntlis.nt.gov.au/vsd/f?p=113 (with permissions) https://nrmaps.nt.gov.au/ https://ftp-dlrm.nt.gov.au/	• Data in NTVSD are collected for a range of purposes including land resource and vegetation community mapping, flora surveys, habitat assessment for fauna surveys, rare and threatened species surveys, development assessment and monitoring. • Data are of varying degrees of attribute detail including floristics, structure, strata and associated environmental information. • NTVSD includes 423 surveys, 13 300 point records and almost 900 000 flora records. • Survey manual is available at https://hdl.handle.net/10070/237908.
Qld	Queensland Biodiversity and Ecology Information System (QBEIS)	Queensland Herbarium, Department of Science, Information Technology and Innovation.'	~20 000 plots[B]	Accessible from an internal agency URL.	• QBEIS – Vegetation communities site survey database. • Supplies data to TERN EcoPlots on a monthly basis. • Plots of various sizes. • Additional plot data include woody species = 671; woody species and perennial herbs = 3226; Dominant characteristic spp.= 9014; other = 548.
SA	Biodiversity Database of South Australia (BDBSA)	Department of Environment, Water and Natural Resources	29 000[C] 89 877[A,D]	Meta data at: http://location.sa.gov.au/lms/Reports/ReportMetadata.aspx?p_no=994+&pa=dewnr	• SA plot data are forwarded to TERN EcoPlots.
Tas.	Natural Values Atlas (NVA)	Department of Primary Industries, Parks, Water and Environment	5000	http://dpipwe.tas.gov.au/conservation/development-planning-conservation-assessment/tools/natural-values-atlas#Species	• There is no central plot repository with the NVA database. Individual species records from plots and other observations are entered directly into NVA. • This estimate is likely too low, but not all survey data are discoverable and some are held privately.
Vic.	Two VIC databases: Victorian Biodiversity Atlas (VBA) and VIRIDANS	Department of Environment, Land, Water and Planning	60 205[A]	https://www.environment.vic.gov.au/biodiversity/victorian-biodiversity-atlas https://viridans.com/pagezero.html	• There are two VIC databases. VBA is maintained by the Victorian Government; the VIRIDANS database is run privately. • There may be issues with species nomenclature not being consistent within the database.
WA	Nature Map Database	Department of Biodiversity, Conservation and Attractions, private consultants	16 049	https://naturemap.dpaw.wa.gov.au/	• WA NatureMap database: 6634 records (Gibson 2018). • Data from older flora surveys and environmental consultancies are being coordinated by the Index of Biodiversity Surveys for Assessments (IBSA), but are not databased. • 9588 plots in privately maintained database(s) (Gellie *et al.* 2018*b*)
Total (estimate)			407 796[E]		

[A]Data not restricted to full floristic plots.
[B]Not all plots are verified and in the public domain.
[C]General vegetation survey records.
[D]Roadside vegetation survey.
[E]Excludes TERN EcoPlots plots.

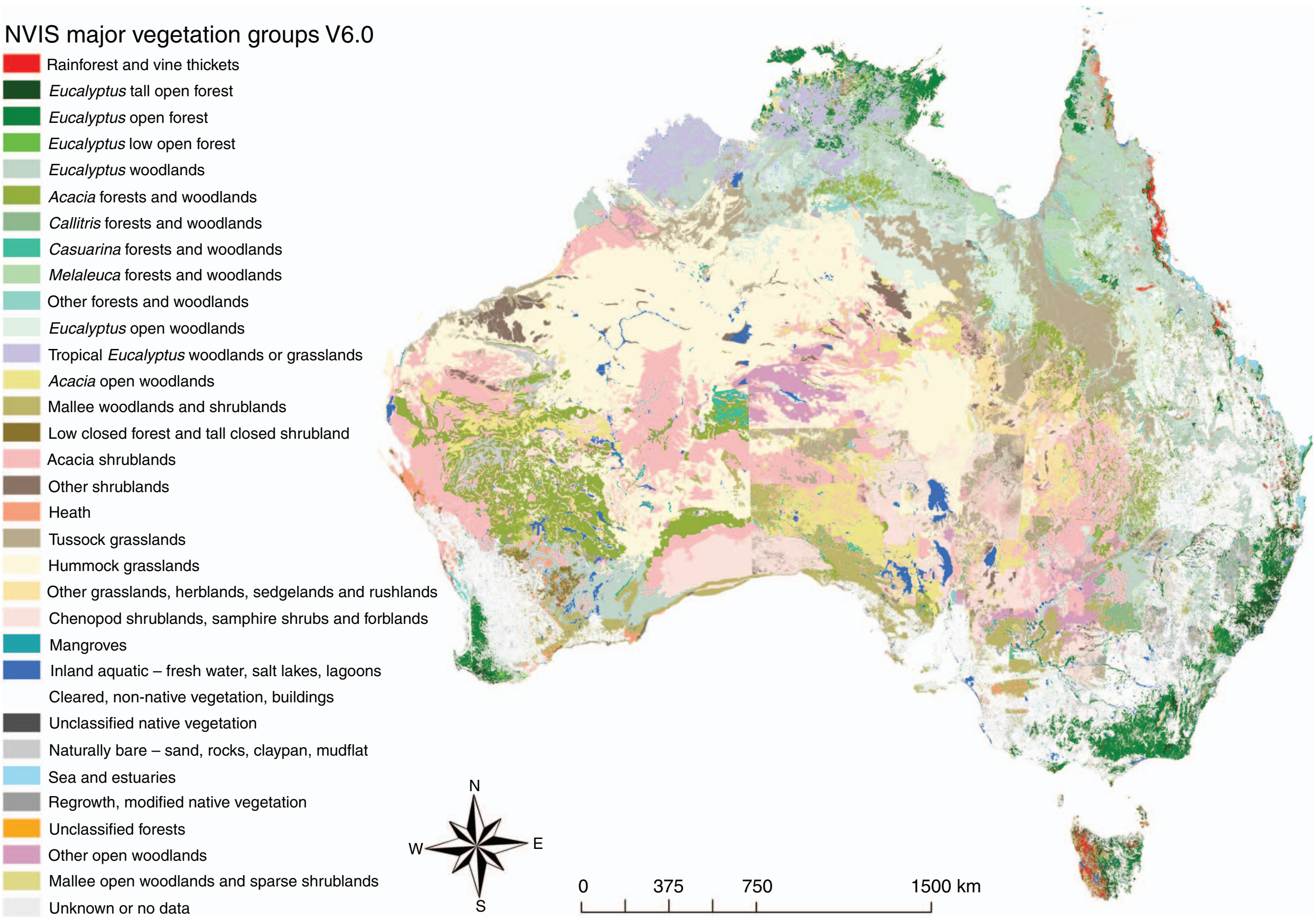

Fig. 1. The National Vegetation Information System (NVIS) Major Vegetation Groups (present) – Version 6.0 (Albers Equal Area projection, 100-m product). The Major Vegetation Groups are often dominated by a single genus and classify the type and distribution of Australia's native vegetation into 32 groups that reflect structurally similar mixes of plant species within the canopy, shrub or ground layers. Subdominant vegetation groups which may be present within map units are not shown (CAPAD, see https://www.environment.gov.au/land/nrs/science/capad/2020).

(AVCS)', Gellie *et al.* (2018*b*) will enable best-practice analysis, map products, reporting and decision-making. Applications include as a basis for monitoring programs, plant and animal survey stratification, and development assessments (including offsets and cumulative impacts) (Kent 2011; Neldner *et al.* 2019). Conservation planning and decision making would be better supported (e.g. assessments of representativeness, investment planning and mapping of threatened communities) (Keith and Pellow 2015; Luxton *et al.* 2021). It would also bring Australia in line with Northern Hemisphere methodology, for example, Europe, where the plant community is the unit of conservation targets (Bakker 2013). Consistency between jurisdictions would likely flow through to major national and international reporting obligations including the Paris agreement and Montreal Protocol (emissions reduction targets, national forest inventory time-series), the IUCN Red List of Ecosystems (Keith *et al.* 2015), State of the Environment Reporting (Cresswell and Murphy 2017), the National Reserve System (Commonwealth of Australia 1997; National Reserve System Task Group 2009) and the Collaborative Australian Protected Area Database (Collaborative Australian Protected Area Database (CAPAD, Department of Agriculture, Water and the Environment, see https://www.environment.gov.au/land/nrs/science/capad/2020).

National and international quantitative, plot-based classification systems

The AVCS could be built from existing frameworks (e.g. TERN AEKOS) and draw on other national and international frameworks for guidance. Countries that have overcome problems that Australia faces include the USA, the United Kingdom, Czech Republic and New Zealand. VegBank and the USNVC provide direction on both the database infrastructure required to support complex, inter-jurisdictional vegetation datasets and a framework for managing and reviewing new vegetation types (http://usnvc.org/) (Faber-Langendoen *et al.* 2018). The United Kingdom's national vegetation classification (UK NVC) contains over 33,000 georeferenced plots (Rodwell 2018). A clear classification approach has been consistently followed and the framework has become the standard for vegetation description among all statutory agencies, non-government organisations, industry, consultancies and academics in the UK (De Cáceres *et al*. 2015; Rodwell 2018). In the Czech Republic, the *Vegetation of the Czech Republic* was developed from 1997 to 2013 and based on the analyses of over 100 000 vegetation plot records from the Czech National Phytosociological Database (Chytrý and Tichý 2018). As plot sizes were variable (Otypková and Chytry 2006; Dengler *et al*. 2009), records from a broad range of plot sizes were still used to prevent data-loss, but were restricted to certain ranges per vegetation type (e.g. 50–1000 m^2 for forests; Chytrý and Tichý 2018). New Zealand has also classified its varied and unique vegetation based on plot data, using 5751 plot records from the New Zealand Land Cover Database and the National Vegetation Survey databank. The classification approach used two hierarchically nested levels to define vegetation types ('forests and shrublands', measured using cover abundance and 'herbaceous' measured using relative species ranks) (Wiser and De Cáceres 2018).

Even more broadly – systems like the European vegetation checklist (EuroVegChecklist, see https://www.synbiosys.alterra.nl/evc/) (Mucina *et al*. 2016) and the IVC provide a roadmap for consistent, hierarchical classification of vegetation within and between national jurisdictions (Gellie *et al*. 2018*a*). The EuroVegChecklist evaluated ~10 000 sources to create a comprehensive list of syntaxonomic units, that were evaluated by experts for 'floristic and ecological distinctness, clarity of geographic distribution and compliance with the nomenclature code' (Mucina *et al*. 2016). Accepted units were compiled into three systems (classes, orders and alliances) for vascular plants, bryophytes and lichens, and algae (Mucina *et al*. 2016). Alternatively, the IVC is based on the EcoVeg approach and has eight hierarchical levels (Faber-Langendoen *et al*. 2014, 2018). The six upper levels are based on physiognomy, climatic region and tree leaf morphology, whereas the two base levels incorporate floristics (L7: alliance and L8: association). Both approaches shine a light on ways forward for Australian vegetation classification. The goal: a unified, collaborative approach that allows for innovation, flexibility and growth and is attractive to new researchers.

This special issue

This special issue brings together a range of articles from vegetation scientists across Australia, highlighting classification systems, nuances in data collection and analysis methods, and the application to, and implications of, this work for land management and decision-making (Fig. 2). The articles presented here provide a snapshot of challenges faced in vegetation classification and science; from sampling methods (e.g. plot size, type of sampling effort) (Patykowski *et al*. 2021) through data-pre-treatment (Lewis *et al*. 2021*a*) to the use of historical remotely sensed imagery and vegetation data to develop map products (Gellie and Hunter 2021). An overview of how State-based plot-based vegetation data (the Northern Territory's in this case), together with an assessment of how well data can be utilised for attribution to the National Vegetation Classification System, is provided by Lewis *et al*. (2021*b*). Addicott *et al*. (2021) provides a review of the updated classification approach of the Regional Ecosystem (RE) mapping program used in Queensland. The RE's are placed in the context of classification systems globally, and an explanation given as to how expert *v*. quantitatively derived vegetation classes are incorporated in mapping (Addicott *et al*. 2021). The paper also provides an up-to-date review of classification and cluster evaluation methods in Australia and internationally. Hunter and Growns (2021) use generalised dissimilarity modelling (a semi-supervised form of classification), to identify riparian macrogroups at the landscape scale. Six macrogroups (ecoregions) were identified for NSW (802 000 km^2), providing a practical map product for conservation decision-making despite data-poor areas. Bell and Driscoll (2021) outline a new method (data-informed sampling and mapping: D-iSM) for vegetation mapping that ensures that plot-based classifications identify rare and restricted vegetation types. Hunter (2021*a*, 2021*b*) highlights the importance of the temporal dimension in defining communities sensitive to inter-annual variation, e.g. ephemeral montane marshes (lagoons) or ephemeral vegetation types associated with the aseasonal climates found in the arid and semi-arid zone. Luxton *et al*. (2021) use a large plot database (30 000 plots) to develop an updated classification in the northern jarrah forests of south-western Australia and explore how heterogeneity and representativeness are captured by the conservation reserve system.

It is our hope that this special issue will strengthen relationships between the Commonwealth, and the States and Territories, attract new students to vegetation classification and provide a basis and stimulation for further discussion. We also look to the future – for how Australian vegetation science may be improved with further collaboration nationally, and how we may work globally, for example, by incorporating our classifications into the IVC. Gellie and Hunter (2021) and Muldavin *et al*. (2021) provide case-studies for how this can be done, with their applications to the flora of eastern NSW and the *Eucalyptus tetrodonta* and *Triodia* spp. hummock grasslands and savanna systems across northern Australia (Fig. 2). Muldavin *et al*. (2021) also discusses how we can be informed by international experience and how our unique vegetation and experiences can also inform and improve international programs for the benefit of all. Nationally and internationally co-ordinated, science-based approaches to vegetation classification will aid communication across jurisdictional boundaries and help to provide consistency in national and international reporting requirements. It will also result in a stronger vegetation science community, which is better placed to face the challenges ahead.

Conflicts of interest

Sarah Luxton, Eda Addicott, John Hunter and Shane Chalwell were guest editors for the ESA Conference special issue for *Australian Journal of Botany*. Despite this relationship, they

Fig. 2. Vegetation communities included in the special issue: (*a*) *Acacia dunnii* and *Acacia* spp. tall sparse shrubland over *Triodia* spp. hummock grassland, Keep River National Park, Northern Territory (Patykowski *et al*. 2021); (*b*) *Triodia* hummock grassland, Queensland (Muldavin *et al*. 2021); (*c*) *Eucalyptus phoenicea* low open woodland, Northern Territory (Lewis *et al*. 2021*a*); (*d*) previously undetected and highly restricted *Corymbia eximia* heathy forest near Kurri, New South Wales (Bell and Driscoll 2021); (*e*) *Eucalyptus campanulata* (New England blackbutt) forest, Mummel Gulf National Park, New South Wales (Gellie and Hunter 2021); (*f*) intertidal communities, Yule Point, Queensland (Addicott *et al*. 2021); (*g*) *Corymbia dichromophloia* open woodland, Northern Territory (Lewis *et al*. 2021*b*); (*h*) river red gum (*Eucalyptus camaldulensis*) on the Barwon River, Barwon National Park (Hunter and Growns 2021); (*i*) *Eucalyptus tetrodonta* woodland, Hann River, Queensland (Muldavin *et al*. 2021); (*j*) *Eucalyptus marginata* and *Xanthorrhoea* spp., Northern Jarrah Forest, Western Australia (Luxton *et al*. 2021); (*k*) ephemeral montane marsh (Hunter 2021*a*, 2021*b*); (*l*) *Heteropogon triticeus* grassy headland and semi-evergreen vine thicket, Cape Weymouth, Queensland (Addicott *et al*. 2021). All photographs reproduced with written permission. Image credits: (*a*) Donna Lewis, (*b*) TERN Ecosystem Surveillance, (*c*) Donna Lewis, (*d*) Stephen Bell, (*e*) John Hunter, (*f*) Mark Newton, (*g*) Sarah Luxton, (*h*) John Hunter, (*i*) Mark Newton, (*j*) Sarah Luxton, (*k*) John Hunter, (*l*) Mark Newton.

did not at any stage have editor-level access to this manuscript while in peer review, as is the standard practice when handling manuscripts submitted by an editor to this journal. *Australian Journal of Botany* encourages its editors to publish in the journal and they are kept totally separate from the decision-making process for their manuscripts. The authors have no further conflicts of interest to declare.

Declaration of funding

This research did not receive any specific funding.

Acknowledgements

This special issue arose from the symposium ‘Vegetation Science for Decision-Making’ at the 2019 Ecological Society of Australia’s annual conference in Launceston, Tasmania. The symposium was convened after discussions by an informal group of ‘vegetation classificationists’ – consisting of several government employees, students and consultants – about the lack of cross jurisdictional collaboration within the field of vegetation classification. The group is now looking to formalise itself as an ‘Australian Vegetation Classification’ Research Chapter of the Ecological Society of Australia. As such, the group would like to say a hearty thank you to the Ecological Society of Australia, the participants of the symposium, and especially to the reviewers, guest editors and authors for all of your hard work in bringing this special issue together. Our thanks also to Grant Wardell-Johnson and Ashley Sparrow for comments on an earlier draft of the manuscript; and to Ron Avery and Philip Gleeson (NSW), David Storey (Tas.), Felicity Grant (ACT), Bev Yen (Vic.), and Ben Sparrow and Siddeswara Guru (TERN Ecosystem Surveillance) for supplying updated plot information for Table 1.

References

Addicott E, Laurance S, Lyons M, Butler D, Neldner J (2018) When rare species are not important: linking plot-based vegetation classifications and landscape-scale mapping in Australian savanna vegetation. *Community Ecology* **19**, 67–76. doi:10.1556/168.2018.19.1.7

Addicott E, Neldner VJ, Ryan T (2021) Aligning quantitative vegetation classification and landscape scale mapping: updating the classification approach of the Regional Ecosystem classification system used in Queensland. *Australian Journal of Botany* **69**(6–7), 400–413. doi:10.1071/BT20108

Albornoz FE, Burgess TI, Lambers H, Etchells H, Laliberté E (2017) Native soilborne pathogens equalize differences in competitive ability between plants of contrasting nutrient-acquisition strategies. *Journal of Ecology* **105**, 549–557. doi:10.1111/1365-2745.12638

Austin MP (2013) Vegetation and environment: discontinuities and continuities. In 'Vegetation Ecology'. pp. 71–106. (Wiley)

Bakker JP (2013) Vegetation conservation, management and restoration. In 'Vegetation Ecology'. pp. 425–454. (Wiley)

Beadle NCW, Costin AB (1952) Ecological classification and nomenclature. *Proceedings of the Linnean Society of New South Wales* **77**, 61–82.

Belbin L (1993) 'PATN Technical Reference.' (CSIRO Division of Wildlife and Ecology)

Bell SAJ, Driscoll C (2021) Data-informed sampling and mapping: an approach to ensure plot-based classifications locate, classify and map rare and restricted vegetation types. *Australian Journal of Botany* **69**(6–7), 357–374. doi:10.1071/BT20024

Borcard D, Gillet F, Legendre P (2011) 'Numerical Ecology with R.' (Springer Science & Business Media)

Briscoe NJ, Elith J, Salguero-Gómez R, Lahoz-Monfort JJ, Camac JS, Giljohann KM, Holden MH, Hradsky BA, Kearney MR, McMahon SM, Phillips BL, Regan TJ, Rhodes JR, Vesk PA, Wintle BA, Yen JD, Guillera-Arroita G (2019) Forecasting species range dynamics with process-explicit models: matching methods to applications. *Ecology Letters* **22**, 1940–1956. doi:10.1111/ele.13348

Bruelheide H, Dengler J, Jiménez-Alfaro B, Purschke O, Hennekens SM, Chytrý M, Pillar VD, Jansen F, Kattge J, Sandel B, Aubin I et al. (2019) sPlot – a new tool for global vegetation analyses. *Journal of Vegetation Science* **30**, 161–186. doi:10.1111/jvs.12710

Brundrett MC, Grierson PF, Bennett LT, Weston CJ (2017) Soils and the below-ground interactions that shape Australian vegetation. In 'Australian Vegetation'. (Ed. DA Keith) pp. 156–181. (Cambridge University Press: Cambridge, UK)

Carnahan JA (1990) Australia: present vegetation (map). In 'Atlas of Australian Resources'. (Department of Natural Resources: Canberra, ACT, Australia)

Chave J (2013) The problem of pattern and scale in ecology: what have we learned in 20 years? *Ecology Letters* **16**, 4–16. doi:10.1111/ele.12048

Chytrý M, Tichý L (2018) National vegetation classification of the Czech Republic: a summary of the approach. *Phytocoenologia* **48**, 121–131. doi:10.1127/phyto/2017/0184

Chytrý M, Hennekens SM, Jiménez-Alfaro B, Knollová I, Dengler J, Jansen F, Landucci F, Schaminée JH, Aćić S, Agrillo E, Ambarlı D, Angelini P, Apostolova I, Attorre F, Berg C, Bergmeier E, Biurrun I, Botta-Dukát Z, Brisse H, Campos JA, Carlón L, Čarni A, Casella L, Csiky J, Ćušterevska R, Dajić Stevanović Z, Danihelka J, De Bie E, de Ruffray P, De Sanctis M, Dickoré WB, Dimopoulos P, Dubyna D, Dziuba T, Ejrnæs R, Ermakov N, Ewald J, Fanelli G, Fernández-González F, FitzPatrick Ú, Font X, García-Mijangos I, Gavilán RG, Golub V, Guarino R, Haveman R, Indreica A, Işık Gürsoy D, Jandt U, Janssen JA, Jiroušek M, Kącki Z, Kavgacı A, Kleikamp M, Kolomiychuk V, Krstivojević Ćuk M, Krstonošić D, Kuzemko A, Lenoir J, Lysenko T, Marcenò C, Martynenko V, Michalcová D, Moeslund JE, Onyshchenko V, Pedashenko H, Pérez-Haase A, Peterka T, Prokhorov V, Rašomavičius V, Rodríguez-Rojo MP, Rodwell JS, Rogova T, Ruprecht E, Rūsiņa S, Seidler G, Šibík J, Šilc U, Škvorc Ž, Sopotlieva D, Stančić Z, Svenning J-C, Swacha G, Tsiripidis I, Turtureanu PD, Uğurlu E, Uogintas D, Valachovič M, Vashenyak Y, Vassilev K, Venanzoni R, Virtanen R, Weekes L, Willner W, Wohlgemuth T, Yamalov S (2016) European Vegetation Archive (EVA): an integrated database of European vegetation plots. *Applied Vegetation Science* **19**, 173–180. doi:10.1111/avsc.12191

Commonwealth of Australia (1997) Nationally agreed criteria for the establishment of a comprehensive, adequate and representative reserve system for forests in Australia. Report by Joint ANZECC/ MCFFA National Forest Policy Statement Implementation Sub-committee (JANIS). Available at https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/rfa/publications/nat_nac.pdf

Cresswell I, Murphy H (2017) Australia state of the environment 2016: biodiversity, independent report to the Australian Government Minister for the Environment and Energy. Australian Government Department of the Environment and Energy, Canberra, ACT, Australia.

Curtis JA, Flint LE, Flint AL, Lundquist JD, Hudgens B, Boydston EE, Young JK (2014) Incorporating cold-air pooling into downscaled climate models increases potential refugia for snow-dependent species within the Sierra Nevada Ecoregion, CA. *PLoS One* **9**, e106984. doi:10.1371/journal.pone.0106984

De Cáceres M, Font X, Oliva F (2010) The management of vegetation classifications with fuzzy clustering. *Journal of Vegetation Science* **21**, 1138–1151. doi:10.1111/j.1654-1103.2010.01211.x

De Cáceres M, Chytrý M, Agrillo E, Attorre F, Botta-Dukát Z, Capelo J, Czúcz B, Dengler J, Ewald J, Faber-Langendoen D, Feoli E, Franklin SB, Gavilán R, Gillet F, Jansen F, Jiménez-Alfaro B, Krestov P, Landucci F, Lengyel A, Loidi J, Mucina L, Peet RK, Roberts DW, Roleček J, Schaminée JH, Schmidtlein S, Theurillat J-P, Tichý L, Walker DA, Wildi O, Willner W, Wiser SK (2015) A comparative framework for broad-scale plot-based vegetation classification. *Applied Vegetation Science* **18**, 543–560. doi:10.1111/avsc.12179

Dengler J, Chytrý M, Ewald J (2008) Phytosociology. In 'Encyclopedia of Ecology. Vol. 4'. (Eds SE Jørgensen and BD Faith) pp. 2767–2779. (Elsevier: Oxford, UK)

Dengler J, Löbel S, Dolnik C (2009) Species constancy depends on plot size–a problem for vegetation classification and how it can be solved. *Journal of Vegetation Science* **20**, 754–766. doi:10.1111/j.1654-1103.2009.01073.x

Enquist BJ, Condit R, Peet RK, Schildhauer M, Thiers BM (2016) Cyberinfrastructure for an integrated botanical information network to investigate the ecological impacts of global climate change on plant biodiversity. *PeerJ Preprints* **4**, e2615v2. doi:10.7287/peerj.preprints.2615v2

Faber-Langendoen D, Keeler-Wolf T, Meidinger D, Tart D, Hoagland B, Josse C, Navarro G, Ponomarenko S, Saucier JP, Weakley A, Comer P (2014) EcoVeg: a new approach to vegetation description and classification. *Ecological Monographs* **84**, 533–561. doi:10.1890/13-2334.1

Faber-Langendoen D, Baldwin K, Peet RK, Meidinger D, Muldavin E, Keeler-Wolf T, Josse C (2018) The EcoVeg approach in the Americas: US, Canadian and international vegetation classifications. *Phytocoenologia* **48**, 215–237. doi:10.1127/phyto/2017/0165

Gellie N, Hunter J (2021) An alternative broad vegetation hierarchy for eastern New South Wales with application for environmental planning and management. *Australian Journal of Botany* **69**(6–7), 450–467. doi:10.1071/BT20072

Gellie NJ, Hunter JT, Benson JS, Kirkpatrick JB, Cheal DC, McCreery K, Brocklehurst P (2018*a*) Overview of plot-based vegetation classification approaches within Australia. *Phytocoenologia* **48**, 251–272. doi:10.1127/phyto/2017/0173

Gellie NJ, Hunter JT, Benson JS, McCreery K (2018*b*) A review of the state of vegetation plot data in Western Australia in response to comments by Neil Gibson. *Phytocoenologia* **48**, 325–330. doi:10.1127/phyto/2018/0283

Gibson N (2018) Availability of vegetation plot data in Western Australia-a reply to Gellie *et al*. *Phytocoenologia* **48**, 321–324. doi:10.1127/phyto/2018/0279

Greenwood K, McKenzie B (2001) Grazing effects on soil physical properties and the consequences for pastures: a review. *Australian Journal of Experimental Agriculture* **41**, 1231–1250. doi:10.1071/EA00102

Guru S, Cox S, Chuc E, Schroeder T, Eliyahu M, Sun Y, Mahuika J, Sebastian A (2019) Integration of plot-based ecology data: a semantic approach. In 'Proceedings of the ISWC 2019 Satellite Tracks (Posters & Demonstrations, Industry, and Outrageous Ideas) co-located with 18th International Semantic Web Conference (ISWC 2019)', 26 October 2019, Auckland, New Zealand. (Eds MC Suárez-Figueroa, G Cheng, AL Gentile, C Guéret, CM Keet, A Bernstein) CEUR Workshop Proceedings 2456, pp. 153–156. (CEUR-WS.org) Available at http://ceur-ws.org/Vol-2456/paper40.pdf

Havel J (1975) Site vegetation mapping in the northern jarrah forest (Darling Range): I. Definition of site-vegetation types. Forest Department Western Australia.

Hopper SD (2009) OCBIL theory: towards an integrated understanding of the evolution, ecology and conservation of biodiversity on old, climatically buffered, infertile landscapes. *Plant and Soil* **322**, 49–86. doi:10.1007/s11104-009-0068-0

Hopper SD, Lambers H, Silveira FA, Fiedler PL (2021) OCBIL theory examined: reassessing evolution, ecology and conservation in the world's ancient, climatically buffered and infertile landscapes. *Biological Journal of the Linnean Society. Linnean Society of London* **133**, 266–296. doi:10.1093/biolinnean/blaa213

Hunter JT (2021*a*) Vegetation change in semi-permanent or ephemeral montane marshes (lagoons) of the New England Tablelands Bioregion. *Australian Journal of Botany* **69**(6–7), 478–489. doi:10.1071/BT20028

Hunter JT (2021*b*) Temporal phytocoenosia and synusiae: should we consider temporal sampling in vegetation classification? *Australian Journal of Botany* **69**(6–7), 386–399. doi:10.1071/BT21008

Hunter JT, Growns I (2021) Semi-supervised delineation of riparian Macrogroups in plot deficient regions within eastern Australia using generalised dissimilarity modelling. *Australian Journal of Botany* **69**(6–7), 414–422. doi:10.1071/BT20029

Keith DA (2017) 'Australian Vegetation.' (Cambridge University Press)

Keith DA, Pellow BJ (2015) Review of Australia's major vegetation classification and descriptions. Centre for Ecosystem Science, UNSW, Sydney, NSW, Australia.

Keith DA, Tozer MG (2017) Girt: a continental synthesis of Australian vegetation. In 'Australian Vegetation'. (Ed. DA Keith) pp. 3–39. (Cambridge University Press)

Keith DA, Rodríguez JP, Brooks TM, Burgman MA, Barrow EG, Bland L, Comer PJ, Franklin J, Link J, McCarthy MA, Miller RM, Murray NJ, Nel J, Nicholson E, Oliveira-Miranda MA, Regan TJ, Rodríguez-Clark KM, Rouget M, Spalding MD (2015) The IUCN Red List of Ecosystems: Motivations, Challenges, and Applications. *Conservation Letters* **8**, 214–226. doi:10.1111/conl.12167

Kent M (2011) 'Vegetation Description and Data Analysis: a Practical Approach.' (Wiley)

Kukkala AS, Moilanen A (2013) Core concepts of spatial prioritisation in systematic conservation planning. *Biological Reviews of the Cambridge Philosophical Society* **88**, 443–464. doi:10.1111/brv.12008

le Roux PC, Pellissier L, Wisz MS, Luoto M (2014) Incorporating dominant species as proxies for biotic interactions strengthens plant community models. *Journal of Ecology* **102**, 767–775. doi:10.1111/1365-2745.12239

Legendre P, Legendre LF (2012) 'Numerical Ecology.' (Elsevier)

Leishman MR, Westoby M (1992) Classifying plants into groups on the basis of associations of individual traits – evidence from Australian semi-arid woodlands. *Journal of Ecology* **80**, 417–424. doi:10.2307/2260687

Levin SA (1992) The problem of pattern and scale in ecology: the Robert H. MacArthur award lecture. *Ecology* **73**, 1943–1967. doi:10.2307/1941447

Lewis D, Patykowski J, Nano C (2021*a*) Comparing data subsets and transformations for reproducing an expert-based vegetation classification of an Australian tropical savanna. *Australian Journal of Botany* **69**(6–7), 423–435. doi:10.1071/BT20164

Lewis D, Brocklehurst P, Milne D, Cowie IID, Cuff N (2021*b*) Overview and compatibility of Northern Territory plot-based vegetation data with the National Vegetation Classification System and future vegetation typologies. *Australian Journal of Botany* **69**(6–7), 468–477. doi:10.1071/BT20031

Luxton S, Wardell-Johnson G, Sparrow A, Robinson T, Trotter L, Grigg A (2021) Vegetation classification in south-western Australia's Mediterranean jarrah forest: new data, old units, and a conservation conundrum. *Australian Journal of Botany* **69**(6–7), 436–449. doi:10.1071/BT20172

Margules CR, Pressey RL (2000) Systematic conservation planning. *Nature* **405**, 243–253. doi:10.1038/35012251

McHale J (2018) Classification – an Aboriginal perspective. (Nalderun Education Aboriginal Corporation) Available at https://nalderun.net.au/curriculum/classification-an-aboriginal-perspective/ [Verified 16 September 2021]

McKenzie NJ, Grundy M, Webster R, Ringrose-Voase A (2008) 'Guidelines for Surveying Soil and Land Resources.' (CSIRO Publishing: Melbourne, Vic., Australia)

Milewski A (1983) A comparison of ecosystems in Mediterranean Australia and Southern Africa: nutrient-poor sites at the barrens and the Caledon coast. *Annual Review of Ecology and Systematics* **14**, 57–76. doi:10.1146/annurev.es.14.110183.000421

Mucina L (1997) Classification of vegetation: Past, present and future. *Journal of Vegetation Science* **8**, 751–760. doi:10.2307/3237019

Mucina L, Wardell-Johnson G (2011) Landscape age and soil fertility, climate stability, and fire regime predictability: beyond the OBCIL framework. *Plant and Soil* **341**, 1–23. doi:10.1007/s11104-011-0734-x

Mucina L, Bültmann H, Dierßen K, Theurillat J-P, Raus T, Čarni A, Šumberová K, Willner W, Dengler J, García RG, Chytrý M, Hájek M, Di Pietro R, Iakushenko D, Pallas J, Daniëls FJ, Bergmeier E, Santos Guerra A, Ermakov N, Valachovič M, Schaminée JH, Lysenko T, Didukh YP, Pignatti S, Rodwell JS, Capelo J, Weber HE, Solomeshch A, Dimopoulos P, Aguiar C, Hennekens SM, Tichý L (2016) Vegetation of Europe: hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. *Applied Vegetation Science* **19**, 3–264. doi:10.1111/avsc.12257

Muldavin EH, Addicott E, Hunter JT, Lewis D, Faber-Langendoen D (2021) Australian vegetation classification and the International Vegetation Classification framework: an overview with case studies. *Australian Journal of Botany* **69**(6–7), 339–356. doi:10.1071/BT20076

National Land and Water Resources Audit (2001) National Land & Water Resources Audit 2001. Theme six report. (NLWRA: Canberra, ACT, Australia) Available at http://lwa.gov.au/products/pr010286

National Reserve System Task Group (2009) Strategy for Australia's National Reserve System 2009–2030. (Australian Government: Canberra, ACT, Australia.) Available at https://www.environment.gov.au/land/nrs/publications/strategy-national-reserve-system
Neldner V, Butler D (2008) Is 500 m^2 an effective plot size to sample floristic diversity for Queensland's vegetation? *Cunninghamia* **10**, 513–519.
Neldner V, Howitt C (1991) Comparison of an intuitive mapping classification and numerical classifications of vegetation in south-east Queensland, Australia. *Vegetatio* **94**, 141–152. doi:10.1007/BF00032628
Neldner VJ, Dillewaard HA, Butler DW, Ryan TS, Wilson BA, Addicott E, Appelman CN, McDonald WJF (2019) Methodology for surveying and mapping regional ecosystems and vegetation communities in Queensland. Department of Environment and Science.
Orians GH, Milewski AV (2007) Ecology of Australia: the effects of nutrient-poor soils and intense fires. *Biological Reviews of the Cambridge Philosophical Society* **82**, 393–423. doi:10.1111/j.1469-185X.2007.00017.x
Otypková Z, Chytry M (2006) Effects of plot size on the ordination of vegetation samples. *Journal of Vegetation Science* **17**, 465–472. doi:10.1111/j.1654-1103.2006.tb02467.x
Patykowski J, Cowie I, Cuff N, Chong C, Nano C, Jobson P, Lewis D (2021) Can sampling for vegetation characterisation surrogate for species richness? Case studies from the wet–dry tropics of northern Australia. *Australian Journal of Botany* **69**(6–7), 375–385. doi:10.1071/BT20158
Pausas JG, Dantas VL (2017) Scale matters: fire–vegetation feedbacks are needed to explain tropical tree cover at the local scale. *Global Ecology and Biogeography* **26**, 395–399. doi:10.1111/geb.12562
Peet RK, Roberts DW (2013) Classification of natural and semi-natural vegetation. In 'Vegetation Ecology'. pp. 28–70. (Wiley)
Peet RK, Lee MT, Jennings MD, Faber-Langendoen D (2012) VegBank–a permanent, open-access archive for vegetation-plot data. *Biodiversity & Ecology* **4**, 233–241. doi:10.7809/b-e.00080
Peterson CH (1984) Does a rigorous criterion for environmental identity preclude the existence of multiple stable points? *American Naturalist* **124**, 127–133. doi:10.1086/284256
Robinson T, Di Virgilio G, Temple-Smith D, Hesford J, Wardell-Johnson G (2019) Characterisation of range restriction amongst the rare flora of Banded Ironstone Formation ranges in semiarid south-western Australia. *Australian Journal of Botany* **67**, 234–247. doi:10.1071/BT18111
Rodwell JS (2018) The UK national vegetation classification. *Phytocoenologia* **48**, 133–140. doi:10.1127/phyto/2017/0179
Scarth P, Armston J, Lucas R, Bunting P (2019) A structural classification of Australian vegetation using ICESat/GLAS, ALOS PALSAR, and Landsat sensor data. *Remote Sensing* **11**, 147. doi:10.3390/rs11020147
Schwarz C, Gourgue O, Van Belzen J, Zhu Z, Bouma TJ, Van De Koppel J, Ruessink G, Claude N, Temmerman S (2018) Self-organization of a biogeomorphic landscape controlled by plant life-history traits. *Nature Geoscience* **11**, 672–677. doi:10.1038/s41561-018-0180-y
Short P (2003) 'In Pursuit of Plants: Experiences of Nineteenth Century and Early Twentieth Century Plant Collectors.' (Timber Press: Portland, OR, USA)
Sousa WP, Connell JH (1985) Further comments on the evidence for multiple stable points in natural communities. *American Naturalist* **125**, 612–615. doi:10.1086/284366
Sparrow BD, Foulkes JN, Sparrow BD, Foulkes JN, Wardle GM, Leitch EJ, Caddy-Retalic S, van Leeuwen SJ, Tokmakoff A, Thurgate NY, Guerin GR, Lowe AJ (2020) A vegetation and soil survey method for surveillance monitoring of rangeland environments. *Frontiers in Ecology and Evolution* **8**, 157. doi:10.3389/fevo.2020.00157
Specht RL (1970) Vegetation. In 'Australian Environment'. (Ed. GW Leeper) pp. 44–67. (Melbourne University Press: Melbourne, Vic., Australia)
Specht RL (1981) Projective foliage cover and standing biomass. In 'Vegetation Classification in Australia'. pp. 10–21. (CSIRO: Canberra, ACT, Australia)
Specht RL, Specht A (2000) 'Australian Plant Communities: Dynamics of Structure, Growth and Biodiversity.' (Oxford University Press: Melbourne, Vic., Australia)
Sun D, Hnatiuk R, Neldner V (1997) Review of vegetation classification and mapping systems undertaken by major forested land management agencies in Australia. *Australian Journal of Botany* **45**, 929–948. doi:10.1071/BT96121
Taxonomy Decadal Plan Working Group (2018) Discovering biodiversity: a decadal plan for taxonomy and biosystematics in Australia and New Zealand 2018–2028. (Australian Academy of Science: Canberra, ACT, Australia; and Royal Society Te Apārangi: Wellington, New Zealand) Available at https://www.science.org.au/support/analysis/decadal-plans-science/discovering-biodiversity-decadal-plan-taxonomy
Thackway R, Cresswell I (1995) An interim biogeographic regionalisation for Australia: a framework for setting priorities in the National Reserve System Cooperative Program. Version 4.0. (Australian Nature Conservation Agency: Canberra, ACT, Australia) Available at https://www.environment.gov.au/land/nrs/publications/ibra-framework-setting-priorities-nrs-cooperative-program
Tichý L (2002) JUICE, software for vegetation classification. *Journal of Vegetation Science* **13**, 451–453. doi:10.1111/j.1654-1103.2002.tb02069.x
Tichý L, Chytrý M, Botta-Dukát Z (2014) Semi-supervised classification of vegetation: preserving the good old units and searching for new ones. *Journal of Vegetation Science* **25**, 1504–1512. doi:10.1111/jvs.12193
Tierney D, Wardle G, Erskine P (2018) The intersection of diversity metrics and spatial mapping: a case study of regional vegetation patterns for a complex community. *Plant Ecology* **219**, 1169–1183. doi:10.1007/s11258-018-0870-y
Trinder CJ, Brooker RW, Robinson D (2013) Plant ecology's guilty little secret: understanding the dynamics of plant competition. *Functional Ecology* **27**, 918–929. doi:10.1111/1365-2435.12078
van der Maarel E, Franklin J (2013) Vegetation ecology: historical notes and outline. In 'Vegetation Ecology'. pp. 1–27. (Wiley)
Wildi O (2010) 'Data Analysis in Vegetation Ecology.' (Wiley)
Willner W (2006) The association concept revisited. *Phytocoenologia* **36**, 67. doi:10.1127/0340-269X/2006/0036-0067
Wiser SK, De Cáceres M (2018) New Zealand's plot-based classification of vegetation. *Phytocoenologia* **48**, 153–161. doi:10.1127/phyto/2017/0180
Wisz MS, Pottier J, Kissling WD, Pellissier L, Lenoir J, Damgaard CF, Dormann CF, Forchhammer MC, Grytnes J-A, Guisan A (2013) The role of biotic interactions in shaping distributions and realised assemblages of species: implications for species distribution modelling. *Biological Reviews of the Cambridge Philosophical Society* **88**, 15–30. doi:10.1111/j.1469-185X.2012.00235.x
Wood JG (1939) Ecological concepts and nomenclature. *Transactions of the Royal Society of South Australia* **63**, 215–223.

Handling editor: Andrew Denham