Vegetation survey in Western Australia

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Ludwig Diels (1906), Charles Gardner (1928, 1956) and John Beard (1980, 1981) in turn produced increasingly more detailed biogeographical classifications and vegetation maps for Western Australia. These three men are largely responsible for our current understanding of the broad-scale patterning of vegetation across the State and, while John Beard's contribution to vegetation mapping has long been recognised, Gardner's earlier state-wide vegetation map has generally been attributed to other authors. Since Beard's final map was produced in 1981 there has been no consistent program to map the vegetation of Western Australia at a higher resolution. What such a program might entail and what impediments need to be overcome are reviewed.

KEYWORDS: Beard, biogeography, Diels, Gardner, mapping, survey, vegetation.

INTRODUCTION

The task of basic inventory of the plant species of Western Australia from a European perspective had begun in the late 1600s by Vlamingh (in 1696/97) and Dampier (in 1699) and was continued by Brown (visited 1802), Drummond (active mid 1830–1851), Preiss (visited 1838–1842), Diels and Pritzel (visited 1900–1901), Gardner (active 1920–1969) and continues to this day with the State collection now numbering over 730 000 specimens (Hopper 2003, 2004; Underwood 2011). In contrast, the broad-scale survey of vegetation of Western Australia only began in earnest in the opening years of the 20th century (Diels 1906) and culminated toward the end of that century as a series of detailed vegetation maps covering the whole State with a second more detailed series covering the southwest (Beard 1981). It was in essence the work of three remarkable men: Ludwig Diels, Charles Gardner and John Beard. Since that time further mapping at a variety of scales and for a variety of purposes has been undertaken (Havel & Mattiske 1999; van Vreeswyk *et al*. 2004; Craig *et al*. 2008; Sandiford & Barrett 2010) as have quadrat-based biological surveys (Keighery *et al*. 2007). All of this later work builds to a greater or lesser degree on Beard's broad-scale vegetation mapping.

Diels, Gardner and Beard all had strong connections with the Royal Society of Western Australia and its precursors with Gardner and Beard serving terms as President of the Society (1941-42 and 1986-87) and as recipients of the Society's Medal in 1949 and 1983, respectively. While the history of Beard's *Vegetation Survey of Western Australia* project and his collaboration with the Geography Department of the University of Western Australia is well documented (Beard & Webb 1974; Beard 1979; Beard *et al*. 2013) less is known of the contributions of Diels and Gardner.

LUDWIG DIELS

Ludwig Diels was just 26 years old when he came to Western Australia with his friend Ernst Pritzel to study the flora and vegetation of Western Australia in October 1900. After their arrival in Albany they quickly made their way to Perth where they rented premises at 194 Roe Street which they retained for their 14 month stay. Diels had various letters of introduction to the Premier Sir John Forrest including one from Edward Wittenoom the Agent General in London urging Forrest to facilitate Diels' work and to introduce him to Mr Bickford then President of the Mueller Botanical Society (SROWA 1900). Diels wasted little time on his arrival in Perth writing to Forrest on the 6 November 1900 requesting permission to '*collect wild plants everywhere right over the colony*' and to be issued two 12 month tickets for the Government Railway Lines. In return Diels offered to present duplicate specimens of all their collections to the Government along with copies of their subsequent publications (SROWA 1900). These requests were received favourably and rail passes were subsequently issued and utilised on most of their collection trips (Diels 1906; Beard 2001a figure 2; Beard & Kilian 2003).

As well as undertaking an exhaustive field program, they also were quite active in the Mueller Botanical Society attending meetings and flower shows throughout the year (West Australian 1901c). In November 1901, close to the end of their stay, Diels gave a lecture to the Society on *Plant forms and climate in Western Australia* (Diels 1902) and both young men were heartily complimented on their endeavours at the last meeting they attended in December 1901 just prior to their departure (West Australian 1901d).

Their expedition to Western Australia must rank as one of the most productive and timely undertaken in Western Australia. Diels collected some 4660 specimens while Pritzel collected multiple sheets of some 1016 collections (Diels & Pritzel 1904-05) as well as jointly collecting a set that was donated to the Perth Museum during their stay (West Australian 1901a, b). These collections formed the basis of their taxonomic and biogeographical studies. By 1906 two significant volumes had been published. The first was a taxonomic treatise *Fragmenta Phytographiae Australiae occidentalis* (Diels & Pritzel 1904-05) naming ~300 new taxa of which just over half are currently accepted. The second volume published in 1906 was the first detailed biogeographic

treatment of the Western Australian flora and vegetation. It was titled *Die Pflanzenwelt von West-Australien südlich des Wendekreises* (Diels 1906) and in this 400 page tome Diels defined two botanical provinces in southern Western Australia: the Eremaean Province covering the arid interior, which he subdivided into two botanical districts; and the Southwest Province, which he subdivided into six botanical districts.

Diels' concepts of the major biogeographical patterns (Diels & Pritzel 1904-05; Diels 1906) although later modified by Gardner & Bennetts (1956), Beard (1980) and others (Thackway & Cresswell 1995) formed the foundation for our current understanding of the biogeography of the flora of southern Western Australia. The 1906 treatise also included the first vegetation map of Australia as a coloured plate at 1: 27 000 000 scale and, as Beard (2001b) pointed out, the map and the associated table appears to be incongruent with the detailed description of the Western Australian vegetation in the later chapters. Nonetheless it is a remarkably accurate representation of broad vegetation patterns considering the scale and time it was produced.

Until recently there has been little direct information as to the sources used to compile this map. Diels' diaries have not been located and were probably lost when the Berlin herbarium was bombed toward the end of the Second World War. The recent rediscovery of two albums of Pritzel's photographs in Berlin from which their itinerary after leaving Western Australia can be deduced (Beard & Kilian 2003) and the acknowledgements in the *Fragmenta* suggests several possible sources. Diels and Pritzel travelled extensively in eastern Australia in the first half of 1902, they are likely to have met L Rodway in Hobart (January 1902), G Luehmann in Melbourne (March), J H Maiden in Sydney (April) and F M Bailey in Brisbane (May) on their way back to Europe. These people or others they met at the State Herbaria of Victoria, New South Wales and Queensland are likely to have been his primary sources.

CHARLES GARDNER

Charles Gardner held the position as Government Botanist and head of the herbarium from 1929 until 1960 having worked previously in the Forest Department (1920–1924) (Green 1990). He is primarily remembered as a taxonomist (having described 10 genera and over 260 taxa, and provided new combinations for a further 57 taxa) and plant collector (with over 20000 specimens in the Western Australian Herbarium –PERTH) but he also made a significant contribution to biogeography and vegetation mapping.

It is seldom recognised that Gardner produced the first vegetation map of the State at 1:3 125 000 scale in 1928 (Gardner 1928 appended to Kesssell 1928). This map shows nine major vegetation types (seven forests/ woodlands and two treeless types) and alludes to two further units too small to map. This map is usually ascribed to Jutson (1914) but in fact only appeared in the second and third editions of that work (Jutson 1934, 1950). The 1928 map gives 'Compiled by C.A. Gardner' and 'S.L. Kessell, Conservator of Forests. January, 1928' separately; indicating it was published with Kessell's report on forest resources in Western Australia. Contemporary newspaper reports confirm that this was Gardner's map (West Australian 1928; Daily News 1928): interestingly Kessell gives no acknowledgement to Gardner despite using the map as a basis for discussion in his report. Gardner's map was republished in 1952 and 1967 on less-detailed base maps. The 1952 edition attributes the map to Gardner in association with T N Stoate, and separately acknowledges Gardner for providing the added information on eucalypt distributions (absent on the 1928 map) (Gardner & Stoate 1952). The authorship of the 1967 map is attributed to A C Harris but again acknowledges Gardner for additional eucalypt information (Harris 1967). Both Stoate and Harris were the Conservator of Forests (i.e. head of the Forest Department of Western Australia) at the time the maps were produced. All three versions of the map were published by the Forest Department.

Gardner appears to have largely relied on his own knowledge of the vegetation of Western Australia in the compilation of this map. The newspaper report that marked the release of the map stated '*That it has been prepared with such accuracy is due to the extensive local travels of the compiler, who has personal knowledge of all the areas marked, with the exception of the deserts*' and '*In defining the limits of this desert, it was necessary to rely for the most part upon the journals and diaries of explorers*' (West Australian 1928). As Gardner never collected across the eastern half of the State, except for the Kimberley (Figure 1), this appears to be somewhat of an exaggeration. The 1928 base map certainly showed many of the explorer's routes and Gardner must have made more use of their journals than the article suggested. In addition the depiction of the extent of the southwest forest on Gardner's map appears to be based, in part, on contemporary and earlier Forest Department mapping of these areas (Kessell 1928; Moore 1902).

Gardner had been working on a vegetation map for some years and he produced his first State-wide map in 1921 (Daily News 1928) but no extant copy of that earlier map is known. An interesting aspect of Gardner's map, which shows parallels with Diels' map, is the depiction of a narrow belt of '*Savannah forest and woodlands*' to the east of the '*Sclerophyll forest*' (jarrah) occurring in a mosaic with his other temperate woodland type. On Gardner's larger scale map this unit also becomes the dominant vegetation unit on the Swan Coastal Plain to the west of the jarrah forest, and along the south coast. His legend defines the savannah woodland as eucalypt-dominated forests and woodlands with a herbaceous undergrowth, primarily grasses. This map unit also covers extensive areas of the tropical north.

On Diels' map there is a savannah woodland/forest unit ('*savannen-wald*') in a similar location to the east of the jarrah forest in a mosaic with a mallee scrub and sand heath unit. Diels also used this mapping unit to encompass the widespread temperate grassy woodlands of eastern Australia and the tropical savannahs of the north.

Currently true savannah woodlands (i.e. woodlands with grass-dominated understorey) are very rare in southwest Western Australia and Beard (2001b) considered Diels' use of the term encompassed young green herbage which could consist of annuals of all kinds

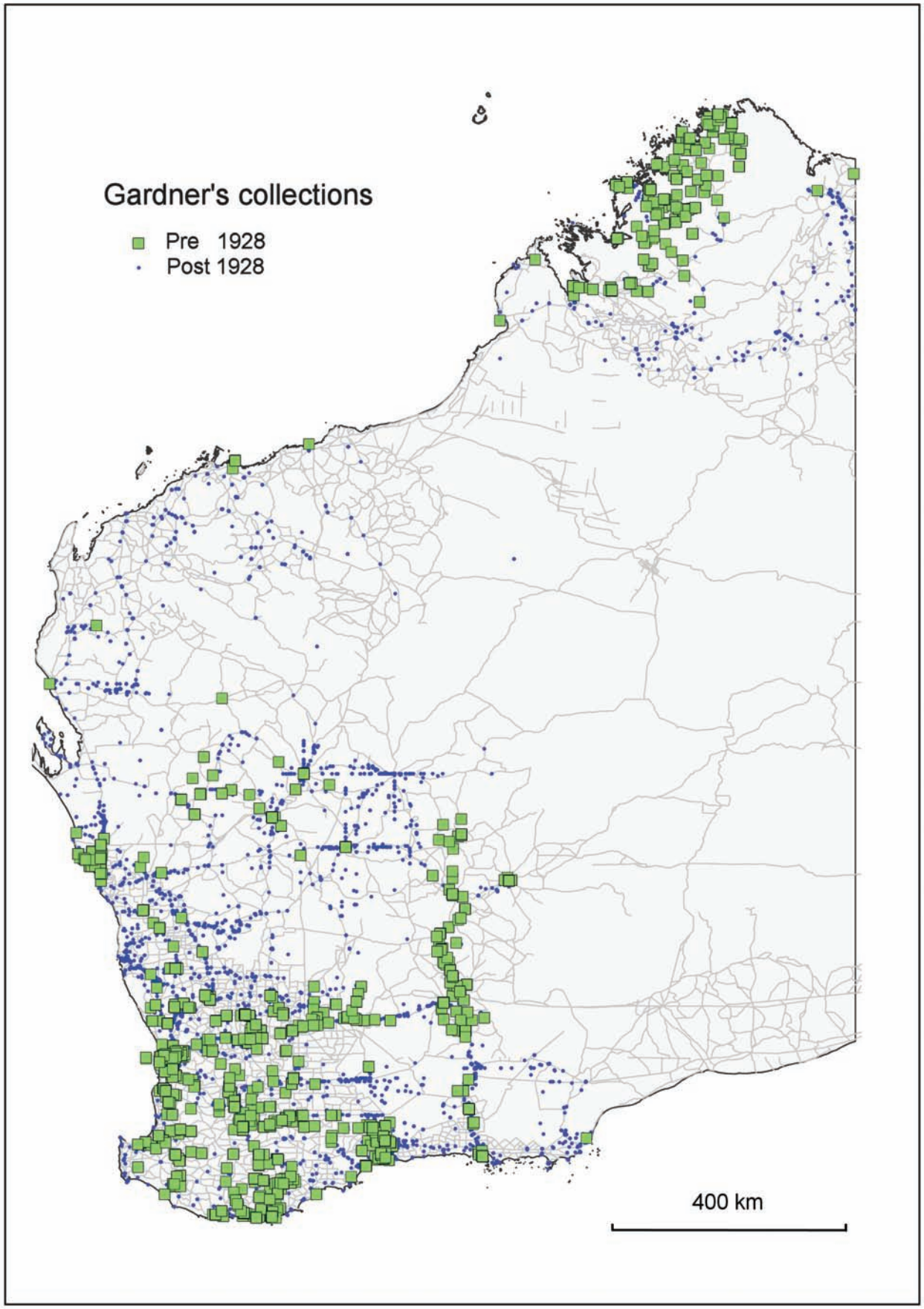

Figure 1 Gardner's Western Australian collections held in PERTH: squares indicate collections made before the publication of his vegetation map in 1928, circles indicate subsequent collections.

and the new shoots of perennials such as sedges, rushes as well as grasses. This interpretation is supported by Diels' (1906) comment on the vegetation of the southwest where he states that: '*The rarity of occurrence of members of the Graminaceae and Compositae in the southwest Australia is very difficult to understand. Climatically similar areas .... are rich in members of both these families. Moreover introduced species of both, particularly annuals, do remarkably well in south-west Australia.* Briza maxima, *for example, is at present more common than any of the indigenous grasses.*'

Gardner's (1928) use of the term 'savannah' in southwestern Australia must also be considered to be somewhat imprecise. In a very small-scale vegetation map of the State included in his Presidential Address (Gardner 1944) he separated this southwestern savannah unit which he calls '*Savannah (temperate) Woodland*' and somewhat modifies its boundaries. In his discussion of this formation he describes woodlands of *Eucalyptus wandoo* (*sensus lat*.), *Acacia acuminata* and *Eucalyptus loxophleba* with a low shrubby or herbaceous undergrowth, '*forming open savannah like country*'.

Similarly on the Coastal Plain he describes the Tuart forest '*as a type of savannah forest ....with an understory of* Agonis *and* Banksia, Melaleuca *and* Hakea, *with a herbaceous ground layer where shrubs are comparatively few*'. Given Diels comments it seems unlikely that either of these vegetation types had understorey dominated by grasses, except perhaps for short periods immediately after fire or in very specific habitats. Gardner (and Diels before him) appear to be using the term savannah to describe the open nature of the canopy species and the lack of a dense shrub layer in the understory. No unequivocal evidence such as a painting or early photograph that depict communities dominated by grasses are known from these areas.

Gardner did not include any biogeographical information on his 1928 map or the later reprints. His notion of the biogeographic regions developed over a number of decades. He would have had the opportunity of discussing them with Diels as he visited Berlin (where Diels was Director) during the time he spent as the first Australian Botanical Liaison Officer based in Kew (1937-39: Marchant 1996). About this time he was collaborating with Teakle to publish a map (1: 9 580 000) showing soil zones subdivided into soil and ecological regions (Teakle 1938). This map depicts several soils/ecological regions in northern and eastern Western Australia (Hann, Fitzroy, Ashburton, Carnegie) that Gardner would go on formally to describe as botanical districts (with amended boundaries) in his 1956 publication (Gardner & Bennetts 1956). In his 1942 Presidential address to the Royal Society of Western Australia he provided a detailed analysis of the vegetation across the State in relation to climate and soils (Gardner 1944). Here he extended Diels' biogeographical classification to include a third botanical province covering the Kimberley and Pilbara and described three major formations occurring there (his plates IX and X). The small map (1:15 840 000) showing the boundaries of all three provinces clearly demonstrates the connection with broad-scale climatic factors (plate IX). His boundary between the Southwest and Eremaean Provinces appears significantly further inland than Diels' boundary.

In the south of the State the boundaries of the major vegetation formations are largely the same as his 1928 map except that the boundary between '*Mulga bush*' and '*Sclerophyll woodland*' was moved to the southwest in the section from Shark Bay to Lake Moore. In the north the boundaries of the '*Tropical sclerophyll woodland*', '*Monsoon woodland, savannah woodland and riverine forest'* and '*Desert*' formations remain essentially the same, however the classification and boundaries of the '*Savannah and open savannah woodland'* and '*Triodia steppe'* have changed considerably. Gardner collected in the Pilbara after 1928 but what further information he gathered to inform these changes in the eastern Eremaean is not clear (Figure 1).

Gardner formally described his botanical provinces and districts and provided a map (1:13 400 000) as an appendix in Gardner & Bennetts' (1956) *The Toxic Plants of Western Australia*. The boundary of the Southwest Province move slightly further inland while the boundary of the Northern Province was largely consistent with his 1942 boundary except for northeast contraction between the Ashburton and Fortescue Rivers. He described five districts in the Northern Province, five in the Eremaean and six in the Southwest Province. In both the Eremaean and Southwest Provinces he retained the districts described by Diels but redefined their boundaries. This classification was to stand for almost 40 years until the completion of Beard's seminal mapping program (Beard 1980).

While Gardner's classification was the most widely applied, further research into biogeographic patterns in Western Australia continued, notably the work of Nathanial Speck (Gibson *et al*. 1997) and Nancy Burbidge (1960). As part of his PhD work Speck (1958) mapped structural vegetation units across the southwest and undertook a biogeographical analysis of the species distributions patterns in the Proteaceae. From the mapping he recognised 62 vegetation communities in 26 vegetation systems. Based on both these datasets he proposed modifications to Diels' phytogeographic districts including the addition of a Lesueur botanical district and the splitting the southern sandplains into two districts to better reflect centres of species richness. Unfortunately this work was never formally published, and has largely been ignored (but see Lamont & Connell 1996).

The other major contribution during this period was the continental-scale phytogeographic analysis published by Burbidge (1960). In this classification the intermediate nature of the flora and vegetation of the southwest interzone, occurring between the species rich southwest and the more arid interior, was identified for the first time.

JOHN BEARD

Beard has outlined the general methods he use in the *Vegetation Survey of Western Australia* to produce the twenty 1:250 000 maps of the southwest and the seven 1:1 000 000 sheets mapping the vegetation across the whole state (Beard & Webb 1974; Beard 1979, 1981; Beard *et al*. 2013). This monumental undertaking was supported by the Geography Department at the University of Western Australia with some initial assistance from

Kings Park Board with Australian Biological Resources Study (Beard 1979) as well as considerable assistance from the Western Australian Herbarium and from Pauline Fairall, an honorary botanist based at Kings Park. The level of available resources profoundly affected both the scale of the mapping and the classification system adopted (Beard & Webb 1974; Beard 1979). What made the project feasible was the availability of aerial photography mosaics across the much of the State for the first time (Beard 1979).

The first field work began in August 1963 and ran until April 1978 with the final map being produced in 1981. Beard kept a series of collection books, field log books and a 1:3 168 000 scale map of the routes he traversed throughout the survey; he donated these to the Western Australian Herbarium library in December 2002 (Figure 2). For each trip his log books provide a record of running observations tied to the distance from known positions; these were subsequently used in the revision of the initial air photo interpretation (Beard & Webb 1974).

Beard normally collected extensively on each of his trips. His collection numbers for the survey ran from 2556 (August 1963) to 8212 (14 April 1978), some 72% (4072) of which are currently lodged in PERTH. Significant assistance was provided by the Western Australian Herbarium and by Fairall in the identification of these collections. Three field trips were undertaken with a botanist from the herbarium (two by Alex George and one by Paul Wilson) who undertook the bulk of the collecting on these trips (Figure 2). According to his log books regular field assistance was also provided by Fred Lullfitz, Pamela Beard, Ernie and Magada Wittwer, Arthur and Pauline Fairall and Herbert Demarz, amongst others.

In addition to publishing the two series of vegetation maps, Beard (1980) also published a new phytogeographic map of Western Australia at 1:2 500 000 and a coloured vegetation map of the whole State at 1:3 000 000 (Beard 1981). This map was further reduced and simplified and has appeared (at 1:10 000 000 scale) in a number of publications including Beard's *Plant Life in Western Australia* (Beard 1990).

Table 1 List of Beard's trip log books showing the period and distance covered.

Book	Period	Distance (km)
1	Aug 1963–Jan 1965	19 062
2	Sept 1963–Oct 1966	18 323
3	May 1965–Sept 1967	17 848
4	July 1967–Sept 1968	23 630
5	Aug 1968–Sept 1970	15 097
6	Sept 1973–Nov 1974	15 414
7	May 1974–Sept 1976	17 512
8	Sept 1976–April 1978	8 635
Total		135 523

Books are held in the library archive of the Western Australian Herbarium.

Beard's vegetation maps, based on 17 years of field work using the available air photo mosaics, provide much more detail information on vegetation patterning compared to the earlier work. At the larger 1:1 000 000 scale Beard recognised 130 vegetation units (Beard & Sprenger 1984) which were amalgamated into 50 units at the smaller 1:3 000 000 scale: this can be compared to the nine units recognised by Gardner at a similar scale.

Beard's original 1:250 000 base maps have recently been digitised and updated and a new digital 1:3 000 000 scale vegetation map has been published (Beard *et al*. 2013). The new edition recognises 70 map units (50 vegetation units and 20 mosaic units), compared with the 50 map units in the first edition. This more detailed classification is based on almost 900 mapped associations covering close to 30 000 polygons: for details of the methodology see Beard *et al*. (2013).

Beard's mapping provided for the first time the ability to accurately locate major changes in vegetation associations. This led to the publication of Beard's phytogeographic map which provided a far more detailed biogeographic classification than the earlier classifications of Diels and Gardner. For the first time the boundaries of the three botanical provinces, the twenty botanical districts and the interzone (which had been previously recognised by Burbidge) were available at a useable scale (Beard 1980). Beard's Northern Province and its four botanical districts had radically different boundaries to those of Gardner, most notably in excluding the Pilbara region. His Eremaean Province encompassed 11 botanical districts (cf. five of Gardner) and the Coolgardie Interzone, while the Southwest Province was made up of four botanical districts with the forested district (Darling) being subdivided into four subdistricts. A small-scale map of this classification was later published with slightly revised nomenclature (Beard & Sprenger 1984; Beard 1990).

At about the same time as Beard published his phytogeographic map Takhtajan published a review of the classification of the floristic regions of the world largely based on occurrence of endemic taxa at different taxonomic levels. He recognised six plant kingdoms containing 35 regions which were further subdivided into a series of one or more botanical provinces. This classification first appeared in Russian in 1978 followed by an English translation (Takhtajan 1986).

Takhtajan considered that the three provinces recognised by Beard should be classified as regions indicating a higher level of floristically significance than previously recognised in a global context. Cox (2001) in a worldwide review of biogeographical regions supported Takhtajan's decision. Following on from earlier work (Hopper 1979) Hopper & Gioia (2004) published a map of the Southwest Australian Floristic Region based on species richness and endemism subdivided into three provinces and 11 districts which incorporated some of the elements of Speck's (1958) classification. Subsequently there has been wide general acceptance of the recognition of the southwest as a botanical region and in the utility of their provinces in analysis in both phylogenetic (Cooper *et al*. 2011; Cardillo & Pratt 2013) and ecological studies (Gibson *et al*. 2012; Merwin *et al*. 2012). Their concepts of botanical districts are yet to be rigorously tested.

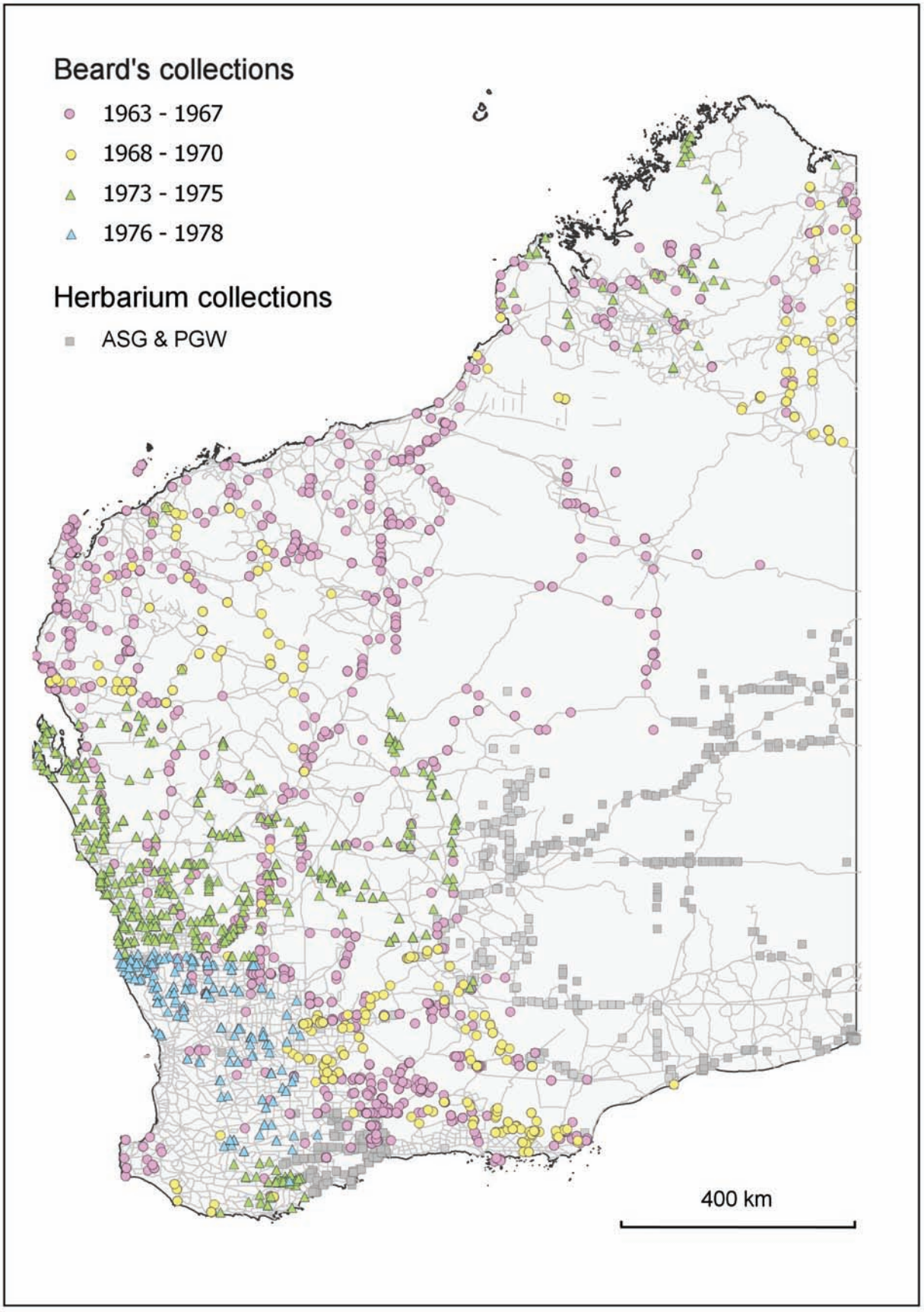

Figure 2 Beard's collections 1963–1978 held in PERTH made during the Vegetation Survey of Western Australia and the collections made by two PERTH botanists (Alex George and Paul Wilson) who accompanied him on three of his expeditions.

Notwithstanding this more recent work Beard's (1980) classification still forms the basis of current biogeographic regionalisation used by the State and Federal governments as a conservation planning tool [Thackway & Cresswell 1995: an Interim Biogeographic Regionalisation for Australia (IBRA)]. The latest IBRA version recognises an additional interzone to the northwest of the Coolgardie Interzone running up to Shark Bay, a further two bioregions (equalivent to Beard's districts) in the Eremaean Province and the seven bioregions in the Southwest Province modifying Beard's original hierarchical scheme.

A recent survey of the terrestrial biota across the southwest covering six IBRA bioregions provided little support for the utility of this classification either in terms of species composition of the vegetation (Gibson *et al*. 2004) or the biota as a whole (McKenzie *et al*. 2004). In addition IBRA does not recognise the hierarchal nature of Beard and later classifications and this can lead to highly inaccurate assessments of the regional and global significance of individual bioregions. A serious reappraisal of the effectiveness of the IBRA as a conservation planning tool is overdue.

STATE-WIDE MAPPING POST-BEARD

The major uses of vegetation mapping are to: (i) document the diversity of plant cover across a region; (ii) reflect the current knowledge of the structure and biogeographic patterns of the vegetation; and (iii) determine a baseline for land managers (Mucina *et al*. 2006). In land management vegetation mapping is used in both the assessment of conservation status and in the assessment of environment impacts. It is also used in the identification of potential land uses and as a surrogate for fuel loads in fire-management planning, and as planning units in local and regional management plans. A vegetation map is nonetheless a model of vegetation patterning and the success of a vegetation map to fulfill these various roles is dependent on the scale and classification used in the mapping.

Broad-scale mapping such as Beard's can be considered a 'coarse-filter approach' (Noss 1987, 1990) and has been used as a surrogate for biodiversity patterning at the Commonwealth level (Thackway & Creswell 1995) and for initial conservation assessments at the State level (Brandis & Mitchell 2000; May & McKenzie 2003). However it appears to be, at best, only moderately accurate in predicting patterns in floristic composition in the Southwest and the ranges of the Eremaean (Hnantiuk & Hopkins 1981; Burgman 1988; Gibson *et al*. 1994, 2004, 2012). Accurate identification of these patterns requires a more 'fine-filter approach'.

Beard (1979, 1981) clearly realised the implications of scale and classification method he chose and he deliberately used a 'coarse-filter approach' to enable him to map the vast area of Western Australia in 15 year period with limited resources. The mapping was therefore at the plant association (defined dominant species or group of closely related species) or plant formation (structural) level. He did not have time to use quantitative floristic analyses or phytosociological approaches (i.e. quadrat/révélée-based methods capturing compositional data) but expected more detailed mapping/classification work would be undertaken at a later stage using his *Vegetation Survey of Western Australia* as a framework (Beard 1981). This is exemplified by Muir's (1977) subsequent fine-scale mapping of wheatbelt reserves where he modified Beard's classification to better reflect both vegetation pattern and animal habitats. Muir's classification has subsequently been widely used in the southwest.

However, many other projects that have mapped smaller regions of the State for specific purposes show little correspondence to Beard's classification framework. Such mapping includes: land systems mapping of the pastoral region (van Vreeswyk *et al*. 2004 and earlier surveys at 1:250 000); vegetation complexes in the southern forests (Havel & Mattiske 1999 at 1:500 000); vegetation types in regional planning areas (Sandiford & Barrett 2010 at 1:25 000); or specific locations (Craig *et al*. 2008 at 1:10 000) and other ongoing large-scale mapping related to resource development proposals. Because of the different methods and/or scales used they depict quite different facets of the vegetation pattern.

The question arises could the Beard's *Vegetation Survey of Western Australia* be extended to provide consistent high-resolution vegetation mapping across the whole State that could be used for a variety of land planning and land management purposes? Or, alternatively, is the future the continuation of the multitude of smaller projects each designed to answer specific questions but contributing little in the development of a consistent State-wide perspective.

There are several issues involved with developing a high-resolution State-wide vegetation coverage and these are discussed below.

Questions of scale

Since the production of Beard's maps there has been an increasing requirement for higher resolution coverage to aid in land-management decisions (Salt *et al*. 2008). Current mapping for land planning and environmental impact is generally undertaken at scales of between 1:10 000 and 1:50 000. For example, recent mapping of 10 200 ha in the Ravensthorpe Range at scale of 1:10 000 identified 70 vegetation units with a mean polygons size of 1.4 ha (Craig *et al*. 2008). In contrast Beard mapped six vegetation units in the same area.

Clearly it would not be possible to undertake mapping at this level of detail across the whole State, even mapping the State at 1:100 000 would require over 1000 map sheets. It could be argued however that given the geographic information systems (GIS) now available it is not necessary to work to a single map scale. In large sections of the Eremaean where there is high degree of both geomorphological and vegetation uniformity such high-resolution mapping would not be required to aid land-planning decisions. High-resolution mapping could be concentrated in areas where it is most need for conservation or other type of land-use planning.

Types of classification

The classification used to denote vegetation units also has a profound effect on the final vegetation map no matter what the scale. In southwestern Western Australia

as in southern Africa there is often little or no relationship between units based on vegetation structural and units based on species composition (Hnantiuk & Hopkins 1981; Burgman 1988; Gibson *et al*. 1994, 2004, 2012; Rebelo *et al*. 2006). This is a major issue in areas of high species turnover but relatively uniform vegetation structure. As most mapping relies on interpretation of air photo or satellite imagery to identify the initial mapping units there is a strong structural bias in these classifications. In southern Africa a workable classification (at 1:250 000) has been developed incorporating addition information on substrate and geographical area but a method that directly includes detailed compositional information is still lacking (Rebelo *et al*. 2006).

In recent years more sophisticated approaches to vegetation mapping have been used that incorporate modelling vegetation units using plot data and ancillary environmental information (Ferrier *et al*. 2002; Keith 2004; Accad & Neil 2006). In addition the launch of hyperspectral satellites in the near future will fundamentally change the way vegetation mapping is undertaken, opening the possibility of incorporating compositional information (based on spectral reflectance) for the first time in areas of continuous vegetation cover (Schmidtlein & Sassin 2004). In more arid areas with low vegetation cover this technology will be able to map substrate chemistry in considerable detail (van der Meer *et al*.2012) that could then be incorporated into the vegetation mapping. In addition the increasing availability of LIDAR data allows detailed structural information to be captured (Hall *et al*. 2009). If such techniques can be fully developed and integrated, then high-resolution vegetation mapping of large areas could be undertaken at reasonable cost.

Consistency of methods

Most current vegetation mapping is being undertaken for the resource industry for development applications. This mapping is generally very detailed but over relatively small areas. There is currently no consistent methodology used in the mapping and published details of method used are generally scant. If a State-wide mapping program was to be implemented to gather data from all available sources then a detail standard methodology would need to be developed along with quality assurance protocols to ensure consistent data quality that would allow high-resolution map products to be produced.

Mapping as a model

All vegetation mapping is a model of the change of vegetation units across the landscape. What is often lacking in vegetation mapping is some measure of the homogeneity of the mapped units. This could be particularly important if vegetation in different areas is mapped by different groups. Such mapping should also be subject to strict accuracy assessment that is published with the maps. This will require both the collection of sufficient plot-based data to allow the level of heterogeneity within mapping units to be determined, and the lodgement of voucher specimens to ensure the continued utility of these data through time. This implies that an ongoing vegetation mapping program would need to be supported by vegetation information system to capture both plot and voucher data in a consistent, transparent and repeatable way (Salt *et al*. 2008).

While Beard did not have the resources to establish permanent plots in his mapping units he did recognise the need to have a consistent taxonomy and collected over 4000 voucher specimens, a practice rarely seen in current vegetation mapping programs.

Possible future directions

A number of resources would need to available to develop integrated high-resolution vegetation coverage across the State, these include:

(1) Commitment of Government, Government Agencies and Resource Industry to the development of such a map.

(2) Identification of priority areas for mapping. This will be areas where there is the most pressing need for high-resolution mapping: these are likely to include the Swan Coastal Plain, and mining areas of the Midwest, Goldfields and Pilbara.

(3) A core mapping group to be established with ongoing funding. This group would: (i) develop the mapping standards; (ii) established the infrastructure for a vegetation information system, (iii) be responsible for the ongoing maintenance of the vegetation information system including databases, GIS capacity, and web-based applications for easy access to data; (iv) provide the quality assurance oversight of data being contributed to the system including accuracy assessments of contributed mapping products; (v) provide access to all contributed mapping products both in digital and hard copy forms; and (vi) develop the capacity for modelling of remote sensing data for use in vegetation mapping.

The next generation of vegetation maps will not be able to be provided by a single person as the task is now far too complex at the scale required across an area as vast as Western Australia. It will nonetheless be built on the foundations established across the 20 century by Diels, Gardner and Beard.

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