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Regional variability in Salmon Gum (*Eucalyptus salmonophloia*) woodlands of south-western Australia, with particular focus on the Great Western Woodlands

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“To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university”.

Signed: Judith Harvey

Date: 11th December 2014

Dedicated to my mother Margret Brown for her encouragement and father Ross Brown (dec) who showed me that it is never too late in life to take on a big project.

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Abstract

Salmon gum woodlands, dominated by *Eucalyptus salmonophloia,* were originally widespread across south-western Australia, in areas with red loamy soils, and average annual rainfall of between 200 - 450 mm. These woodlands have been largely cleared from the Western Australian Wheatbelt, which forms part of the biodiversity hot spot known as the Southwest Australian Floristic Region. However, the woodlands are largely intact in the adjacent semi-arid region, known as the Great Western Woodlands (GWW). The GWW are globally unique; being the largest intact temperate woodland in Earth. Despite this uniqueness, little is known about the plant communities of this region or how they relate to their environment and how distinct they are to remnant communities in the Wheatbelt.

This study characterises patterns of floristic variation in salmon gum woodlands across their range to determine if they were made up of regionally distinct communities and to identify the main climatic and edaphic drivers of floristic patterns. First a floristic survey and analysis of salmon gum communities in the GWW was undertaken. Second, these novel data were combined with an existing data set for salmon gum communities in the WA Wheatbelt to obtain a range-wide overview. This resulting analysis represents the first major study of woodland understorey plant composition in the GWW and the range-wide analysis is one of the few vegetation studies to traverse the Wheatbelt and the GWW regions.

One hundred 400 m^2 plots in patches of mature salmon gum woodlands, were surveyed in 2011 and 2012, stratified to capture the range of variability in climatic, geology/soils, tenure and land use in the GWW. Floristic composition and structure was surveyed, and soil chemical and physical characterised. Patterns in the floristic data were explored using clustering classification techniques chosen by OptimClass, and Correspondence Analysis (CA), Principal Component Analysis (PCA) and Non-metric Multidimensional scaling (NMDS) ordinations. To interpret the influences of the environmental variables,

unconstrained PCA and constrained Canonical Correspondence Analysis (CCA) were undertaken.

Two distinct salmon gum woodlands communities were identified in the GWW: one community occurred predominately in the south west of the region, and was characterised by a mixed understorey with many *Eremophila* and *Acacia* species. The other community extended across the northern part of the GWW with a low open understorey dominated by species of the Chenopodiaceae family.

The main drivers precipitation, monthly precipitation variability and temperature, and to a lesser extent soil phosphorous pH, silt content, and cover of organic crust influenced the patterns in floristic composition and differentiated between the two main communities. Surface geological composition and distance to the nearest landform also characterised the groups and there was a relationship with grazing levels but not historical timber cutting.

The range-wide analysis of salmon gum woodlands incorporated 48 previously surveyed 100 m^2 plots from the Wheatbelt, with a reduced data set of GWW data from 100 m^2 quadrats nested within the 400 m^2 quadrats. Five communities were identified with the two previously recognised communities evident in the GWW only analysis evident in the range-wide analysis. Two further communities were largely confined to the Wheatbelt and there was one cross-regional community. The influence of the annual precipitation gradient present in the GWW continued across the whole region. Ratio of summer to winter precipitation and a modified influence of temperature were also significant drivers. The regional factors contributed 23% of the floristic variation while local soil variables only contributed 10%.

The recognition of communities within salmon gum woodlands contrasts with earlier studies that suggest it is difficult to define clear communities associated with different eucalypt dominants in the WA Wheatbelt. This may have resulted from the focus, in this study, on sites where salmon gum is dominant. However, the indicator species, for each of

the identified salmon gum communities, are not necessarily restricted to salmon gum woodlands, and salmon gum often occurs with other eucalypt tree and mallee species. A wider analysis across all available sites with salmon gum could thus result in a broader qualification of the influence of the overstorey component.

The findings of this study contribute to the assessment of the conservation status of these woodlands, and have implications for management strategies, future surveys and distribution modelling. The delineation of the Wheatbelt communities from the GWW communities confirms the threatened status of the highly cleared Wheatbelt woodlands. However, due to the differences in data quality and limited number of Wheatbelt sites available, these differences would benefit from confirmation through additional surveys. The permanently marked plots are available for assessing the adequacy of Vacant Crown Land for inclusion in the conservation estate, monitoring subsequent disturbances (such as fire and flood), changes in grazing activity and long-term changes due to climate change. Plot based cover data and the community classification provide essential input into modelling community distributions.

Key words

Semi-arid eucalypt woodlands, understorey vegetation, floristic community classification, Canonical Correspondence Analysis, fidelity, JUICE, OptimClass, Principal Correspondence Analysis, Unweighted Pair Group Method with Arithmetic Mean UPGMA.

Australian and New Zealand Standard Research Classifications (ANZSRC)
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Acronyms

ALA	Atlas of Living Australia
BOM	Bureau of Meteorology
DEC	Department of Environment and Conservation (to 2013)
DEM	Digital Elevation Model
DPaW	Department of Parks and Wildlife
EPBC	Environmental Protection and Biodiversity Conservation [Act]
GIS	Geographic Information System
GPS	Global Positioning System
IBRA	Interim Biogeographic Regionalisation of Australia
NP	National Park
NR	Nature Reserve
NVIS	National Vegetation Information Dedicate to Mum n System
SAP	Salinity Action Plan
SWAFR	Southwest Australia Floristic Region
TR	Timber reserve
VCL	Vacant Crown land
WWF	Worldwide Fund for Nature

1 BACKGROUND

1.1 Introduction

Woodlands dominated by *Eucalyptus salmonophloia* (salmon gum) extend over 800km across a broad area of south-western Australia. In the extensive agricultural area known as the Wheatbelt they have been largely cleared, and most that remain are in poor condition. This limited and disturbed extent, along with poor regeneration, threatens their long-term survival. By contrast, salmon gum woodlands remain largely intact in the semi-arid area to the east, known as the Great Western Woodlands (GWW,Watson *et al.* 2008). The GWW region is globally unique, arguably being the largest remaining intact area of temperate woodlands on Earth (Judd *et al.* 2008). However, very little is known about the floristic patterning in these woodlands in the GWW, and how these patterns relates to climatic, edaphic and other environmental factors. Further, it is not known whether floristic communities in the GWW are distinct from floristic communities in the Wheatbelt. This thesis aimed to address these knowledge gaps with regard to salmon gum woodlands. Chapter 1 places the salmon gum woodlands in their broader Australian context, summarizes current knowledge of the ecology of salmon gum, and considers methods for multivariate analysis of survey data.

1.1.1 Unique semi-arid woodlands

Woodlands are defined as having a tree canopy cover of between 10 % and 30 % and a height of 10 – 30 m. Open woodlands have 2 – 10 % tree cover, low woodlands < 10 m height and open low woodlands, < 10 % cover and < 10 m height (Specht 1970; Clarke 2000). In Western Australia (WA) five formations are described; tall woodland (ht >30m, cover 10 – 30%), medium woodland (ht 10 – 30m, cover 10 – 30 %), open woodland (ht 10 – 30 m, cover < 10 %), low woodland (< 10m, cover < 10 %) and thickly wooded succulent steppe (Beard 1981a).

On a national level woodlands have been subdivided into those which have an understorey of low trees and tall shrubs, low shrubs or hummock grasses and tussock grasses (Moore

1973). Woodlands generally cover approximately 25% of the Australian continent (Gillison 1994) extending across the tropical north as grassy savannas, through subtropical woodlands to the temperate woodlands inland in the southern part of the continent. Eucalypt dominated woodlands occur across the tropical and sub-tropical north, in temperate climates in south-western WA and in inland south-east Queensland, NSW, Victoria, South Australia and Tasmania.

The large, intact area of mixed open eucalypt temperate woodland occurring in the Great Western Woodlands region of south-western Australia is globally unique (Judd *et al.* 2008). These medium woodlands (10 m – 30 m) sclerophyllous (with small, leathery, evergreen leaves) eucalypt woodlands exist in an area that only receives between 200mm – 350mm annual rainfall, making it the driest place in the world where medium height woodlands occur (Prober *et al.* 2012). They defy the generally held belief that the tallest communities correlate with the highest rainfall areas, which lie near the wetter ranges and coastal zones of vegetation on the Australian (Groves 1981). They are overlooked in a review of Australian woodlands (Gillison 1994), and a discussion on the evolutionary biology and contemporary distribution of eucalypts (Wardell-Johnson *et al.* 1997). The semi-evergreen woodlands of northern Australia, the grassy savanna-woodlands of eastern Australia and the mallee of southern WA are all included in a list of globally distinctive vegetation (Box 2001), but the woodlands of SW Australia’s GWW/Wheatbelt are not mentioned, highlighting the poor recognition and paucity of information on woodlands of this region.

The GWW woodlands remain largely uncleared with substantial areas never used for livestock grazing, owing to the low rainfall and lack of suitable ground water, lack of grasses and poor palatability of some of the characteristic shrub understoreys. In contrast, due to the mostly wetter climate, the eucalypt woodlands of the south-western Australian Wheatbelt have been over 90% cleared for cropping and grazing, resulting in their being considered amongst the most poorly conserved ecological communities in Australia (Beadle 1981; Beard 1990; Yates & Hobbs 1997a; Yates, Hobbs*, et al.* 2000).

The temperate eucalypt woodlands of inland south-eastern Australia, such as the box woodlands (dominated by eucalypts such as *Eucalyptus populnea, E. microcarpa, E*.

melliodora and *E. albens* (Beeston *et al.* 1980; Prober 1996; Sivertsen & Clarke 2000; Prober & Thiele 2004)), are the most comparable to the WA salmon gum woodlands, although they extend into wetter climates. In the wetter part of their range (500-800 mm), the box woodlands have been largely modified by grazing (Moore 1973; Prober 1996; Sivertsen & Clarke 2000; McIntyre *et al.* 2004), as the understorey is predominantly grassy. Grasses are less common in the WA Wheatbelt so vast areas of woodlands have been completely cleared and replaced by pasture grasses and crops. In terms of understanding patterns in widespread communities, there is a trend for understoreys to become more shrubby with increasing aridity (Prober & Thiele 2004). This is evident in the variation between different communities of poplar or bimble box (*E. populnea*) and grey box (*E. microcarpa*) temperate woodlands on the semi-arid plains and ranges of NSW and in central Queensland (Moore 1973; Gillison 1994; Howling 1996; Prober 1996).

Eight poplar box communities have been mapped from available reports, papers and maps over a wide area of Queensland and New South Wales (Beeston *et al.* 1980). Often other dominant trees are present and there are relatively small areas of pure poplar box. These occur over grasses in the east and over shrubs in central New South Wales (NSW), where the understorey includes *Eremophila sturtii*, *E. longifolia, Cassia nemophila* (syn. *Senna artemisioides*) *Dodonaea viscosa* as well as *Sclerolaena diacantha*, *Chenopodium* spp., *Sida cunninghamii*, *Calotis cuneifolia*, *Vittadinia triloba* and *Boerhavia diffusa* (Beeston *et al.* 1980). The western bimble - grey box communities are characterised by an abundance of species in the Goodeniacea, Crassulaceae, Malvaceae, Chenopodiaceae, Myoporaceae Amaranthaceae and Asteraceae families including *Sida* spp., *Maireana microphylla*, *M. enchylaenoides*, *Chenopodium desertorum* and *Atriplex semibaccata*, *Ptilotus spathulatus* and *Vittadinia cervicularis, Calotis cuneifolia* and *Minuria leptophylla* (Prober 1996).

1.1.2 Survival in a semi-arid environment

With their sclerophyllous leaves and low evapotranspiration, eucalypts are very efficient in harvesting and retaining water (Bell & Williams 1997). A variety of factors may explain how the eucalypts of the GWW survive in areas of low (< 300 mm) rainfall. First, although there is no obvious tap root (as revealed by fallen trees), *E. salmonophloia* has a very extensive surface root systems in the top 20 – 30 cm of soil (Ladd *et al.* 1997). The roots may also descend vertically at some distance away from the tree (Williamson 1983). Second, where rainfall is low in the GWW, it tends to fall throughout the year. Summer rainfall, often resulting from the remnants of tropical low pressure systems, creates conditions that allow for the establishment and persistence of these tall trees in such dry environments (Milewski 1981). Third, it is proposed that the high clay content in the soil and their position in the landscape (in broad valleys and near drainage lines) optimises water capture and retention (Yates, Hobbs*, et al.* 2000). For example, *Eucalyptus salmonophloia* transpires most at the hottest time of the year (late spring and summer) suggesting they effectively extract water from clay subsoils (Farrington *et al.* 1994).

It seems reasonable to speculate that they influence understorey density through their influence on soil nutrients and shading. In the GWW, it is evident that the understorey is more concentrated beneath salmon gums than in gaps - possibly due to positive effects of nutrients and or shading.

1.1.3 Previous surveys in salmon gum woodlands

Great Western Woodlands

The GWW was previously known, and is still referred to, as the Goldfields. There has been only one regional-scale survey in the GWW; the biological survey of the Eastern Goldfields (27°S – 33°S and 188°33'E – 123°45'), by the Biological Surveys Committee involving WA Museum, Fisheries & Wildlife (now Department of Parks and Wildlife (DPaW)), Western Australian Herbarium, and National Parks Authority. The survey was undertaken between 1977 and 1983, and sampled a broad range of plant and animal communities at over 290 locations (Newbey & Hnatiuk 1984; Newbey & Hnatiuk 1985; Newbey & Hnatiuk 1988; Keighery *et al.* 1993; Newbey *et al.* 1995) No numerical analyses to elucidate patterns in floristic or faunal composition were carried out on the data collected. Despite woodlands with salmon gum being a dominant formation across the region, this survey only included eleven relevés described as salmon gum woodland with other eucalypts.

A number of more targeted surveys have also been undertaken in woodlands of the GWW. In response to the growing mining interest in the Banded Ironstone Formations (BIF) and greenstone ranges that are scattered through parts of the GWW, localised surveys in and adjacent to the ranges of the Eastern Goldfields have captured some woodland vegetation (Gibson & Lyons 1988; Gibson *et al.* 1997; Gibson & Lyons 1998, 2001a; Gibson & Lyons 2001b; Meissner & Coppen 2013, 2014; Thompson & Allen 2014). The BIF surveys of over 370 permanently marked plots included 41 plots with salmon gum, most of which were on the foot-slopes rather than the characteristic plains, and contained other *Eucalyptus* tree species. Floristic data was related to soils and at the scale of individual ranges, and to climate across a series of ranges (Gibson *et al.* 2012). Native vegetation maps prepared as part of various mining proposals have a limited foot print in the GWW (Bishop *et al.* 2013) and focus on the BIF and greenstone ranges rather than expanses of salmon gum.

Several million hectares of GWW were subject to logging during the gold rush and later periods (1890-1964; Kealley 1991). A study of the effects of timber cutting on the understorey composition surveyed paired cut and uncut plots in salmon gum woodland in and near the Kambalda Timber Reserve (Williamson 1983). The resulting classification revealed only slight floristic differences between cut and uncut woodland, and suggested these could also be due to the impact of grazing.

More recently, a detailed survey of 76 plots in, closely related *Eucalyptus salubris* (gimlet) woodlands in the western GWW used satellite imagery, growth rings and allometric relationships to establish a 400+-year fire-age gradient. Floristic and structural surveys showed a 'U'-shaped relationship of floristic diversity with age since fire (Gosper, Yates*, et al.* 2013). and characterized changes in fuel availability (Gosper, Prober & Yates 2013). Similar patterns in floristic composition in relation to fire age might be expected for salmon gum woodlands.

WA Wheatbelt

In contrast to the GWW, a comprehensive regional survey and analysis has been undertaken of the WA Wheatbelt vegetation, funded by the Salinity Action Plan (SAP). This survey revealed 25 vegetation units, three of which contained (but were not exclusive to) salmon gum (Gibson *et al.* 2004). These were herb-rich woodlands of the northern Wheatbelt, central and southern woodlands on duplex soils with chenopod understorey, and widespread woodlands with non-chenopod understorey. In total 55 plots contained *E. salmonophloia.*

Another Wheatbelt survey over eight years of mainly private remnants funded by the World Wide Fund for Nature (WWF 2001 – 2008) included many salmon gum woodlands but the plots often contained other eucalypts. The WWF data and a selection of data from SAP survey were incorporated into a floristic classification that focused on woodlands in the Wheatbelt (Griffin 2008). This classification identified only one salmon gum community; however, a further 10 of the 25 groups included *E. salmonophloia* in their composition. Common species present in the salmon gum community included *Acacia erinacea*, *Templetonia sulcata*, *Rhagodia preissii* and *Olearia dampieri* s. *eremicola. Eucalyptus salmonophloia* also formed communities with *E. salubris, E. loxophleba, E. wandoo, E. astringens* and *E. capillosa* as well as being present in two *Rhagodia drummondii* and one *Allocasuarina campestris* communities. *Eucalyptus salmonophloia* commonly occurs with other species of tree and/or mallee as evident by 195 SAP plots from the Wheatbelt where it occurs with other *Eucalyptus* species.

Eleven sub-communities of salmon gum woodlands were identified following a more subjective assessment of Wheatbelt eucalypt woodland communities and sub-communities (Harvey & Keighery 2012; Harvey 2013). This assessment was based on previous numerical classifications from the surveys above (Gibson *et al.* 2004; Griffin 2008), available plot data, mapped polygon attributes, vegetation descriptions, photographs and expert opinion.

Fox (2001b) surveyed species composition salmon gum woodlands at five locations in the Wheatbelt and one in the GWW and compared them to York gum (*E. loxophleba*) and wandoo (*E. wandoo*) communities. She found significant differences between Wheatbelt and Mt Jackson (in the GWW) floristics that were largely governed by temperature and soil chemistry. A survey of 3 sites in the eastern Wheatbelt at Sandford Rocks north of

Westonia (Keenan 1993) provided a detailed description of relatively undisturbed salmon gum woodlands.

A survey of 43 reserves in the Wheatbelt (Mattiske 1992) produced maps site descriptions (with dominant species) and reserve species lists recommended that 35 reserved be vested for the conservation of flora and fauna.

Cross-regional surveys

No broad-scale floristic surveys have spanned the GWW and Wheatbelt. While a general turnover of species (or beta diversity) has been observed across the Wheatbelt (Brown 1989; Gibson *et al.* 2004), it is not yet understood if this continues into the GWW. Further, it is unclear whether the biogeographic boundary between the two regions is due to natural differences or anthropogenic impacts (clearing for agriculture).

1.1.4 Conservation significance

Internationally, less than 3% of Mediterranean temperate woodlands are formally protected (Underwood *et al.* 2009). Temperate woodlands are poorly conserved worldwide and in eastern and western Australia as much as 85% of the woodlands have been cleared (Moore 1973). Across the whole range of salmon gum woodlands, the remaining extent ranges from about 10% of the pre-European coverage in the Wheatbelt to being largely intact in the GWW. A wide range of threats has affected, and continues to impact on their condition.

While the GWW vegetation remains largely intact, only 10% is in nature reserves or national parks (DEC 2010) and only 3.6% of this is preserved in ‘A’ class nature reserves, that require parliamentary approval for change or cancellation (Watson *et al.* 2008). Recent additions of the ex-pastoral leases (Credo and Jaurdi) to the conservation estate, managed by the DPaW, are degraded in parts due to grazing and logging and they will take some time to recover. Over 60% of the GWW is unallocated Crown land, which is potentially available for reservation.

The GWW woodlands generally face a range of threats including rapidly growing mining and tourism interests and land use diversification by pastoralists. In addition, the potential effects of human-induced climate change on the woodlands and associated fire regimes are unknown (Prober *et al.* 2012).

DPaW has recognised the importance of the GWW and has prepared a Biodiversity and Cultural Conservation Strategy (DEC 2010a). This document provides a framework to integrate the ideas and activities of stakeholders and members of the public in developing, resourcing and implementing agreed approaches to management in order to ensure the identification and long-term conservation of its natural and cultural values. Both the conservation strategy and report (Watson *et al.* 2008) have identified the need for an inventory of species and communities, and a better understanding of the fundamental ecosystem processes, with the specific intention of informing land managers to enable a better fire response and improved restoration activities, and identifying potential for indigenous collaborations and the impact of tourism activities.

Pre-European vegetation of the Wheatbelt included vast areas of mixed woodlands (Beard 1981b), but these have now largely been cleared with only 16% remaining (Government of Western Australia 2011). The once extensive salmon gum woodlands in the Wheatbelt are considered threatened because of extensive clearing and poor regeneration. Approximately 10 % of woodlands dominated by the four trees, *Eucalyptus salmonophloia*, *E. wandoo* (wandoo), *E. salubris* (gimlet), and *E. loxophleba* (York gum) remain (Beard & Sprenger 1984). Up to 97% of York gum-salmon gum-wandoo woodlands and 78% of the salmon gum – gimlet woodlands have been cleared for agriculture. The presence of *E. salmonophloia* signified productive soil, leading to it being selectively cleared over the past 120 years, with only about 9.5% of the original extent of all salmon gum woodlands now remaining in the Avon-Wheatbelt IBRA Region (Thackway & Cresswell 1995; Government of Western Australia 2011). Although widely distributed, and across the whole range 55.8% remain, the woodlands are not well protected with only 7% of the current extent occurring in conservation reserves (Government of Western Australia 2011). The rest occurs on private property, roadsides and various crown, town site and water catchment reserves (Pigott 1998; Saunders *et al.* 2003).

The persistence of remaining woodlands in the Wheatbelt is threatened due to fragmentation, poor recruitment, altered fire regimes, drought, weed invasion, rising water table, increased soil salinity, compaction and road widening (Yates & Hobbs 1997a; Yates, Hobbs*, et al.* 2000). This limited extend and poor condition, also reinforced by the results from previous surveys and analyses, has led to a nomination to the Australian Federal Government to list the Wheatbelt Eucalypt Woodlands as a Threatened Ecological Community (TEC) under the Environmental Protection and Biodiversity Conservation (EPBC) ACT (Kennedy 2011). This nomination identifies the need to compare salmon gum communities across the whole distribution to determine whether the communities in the intact GWW are different from, or an extension of, the communities present in the Wheatbelt.

1.2 *Eucalyptus salmonophloia* (salmon gum)

1.2.1 Characteristics

Eucalyptus salmonophloia is a tall tree (growing to 25 metres) with smooth bark, silver-grey in winter-spring, becoming salmon pink to coppery in summer-autumn.

The white flowers have been recorded in January, February, May and from August to October. Fruit is hemispherical and 3–5 mm long (see also Western Australian Herbarium 1998 – 2013; Brooker & Kleinig 2001; Centre for Plant Biodiversity Research 2006; French 2012).

Figure 1-1 Eucalyptus salmonophloia north of Helena Aurora Range (photo by Judith Harvey)

Eucalyptus salmonophloia occurs across the Mediterranean climatic zone in south-western Australia into the semi-arid zone, (Western Australian Herbarium 1998 – 2013) traversing a rainfall gradient from 500 mm average annual rainfall in the west near York, to 200 mm in the east north of Zanthus. Locations of collections (Figure 1-2) are from the PERTH Herbarium collections (Western Australian Herbarium 1998 – 2013), Wheatbelt surveys (WWF 2001 – 2008; Gibson *et al.* 2004; Lyons *et al.* 2004) and the surveys of the eastern goldfields ranges in the GWW (Gibson & Lyons 1988; Gibson *et al.* 1997; Gibson & Lyons 1998, 2001a; Gibson & Lyons 2001b; Gibson 2004a, 2004b).

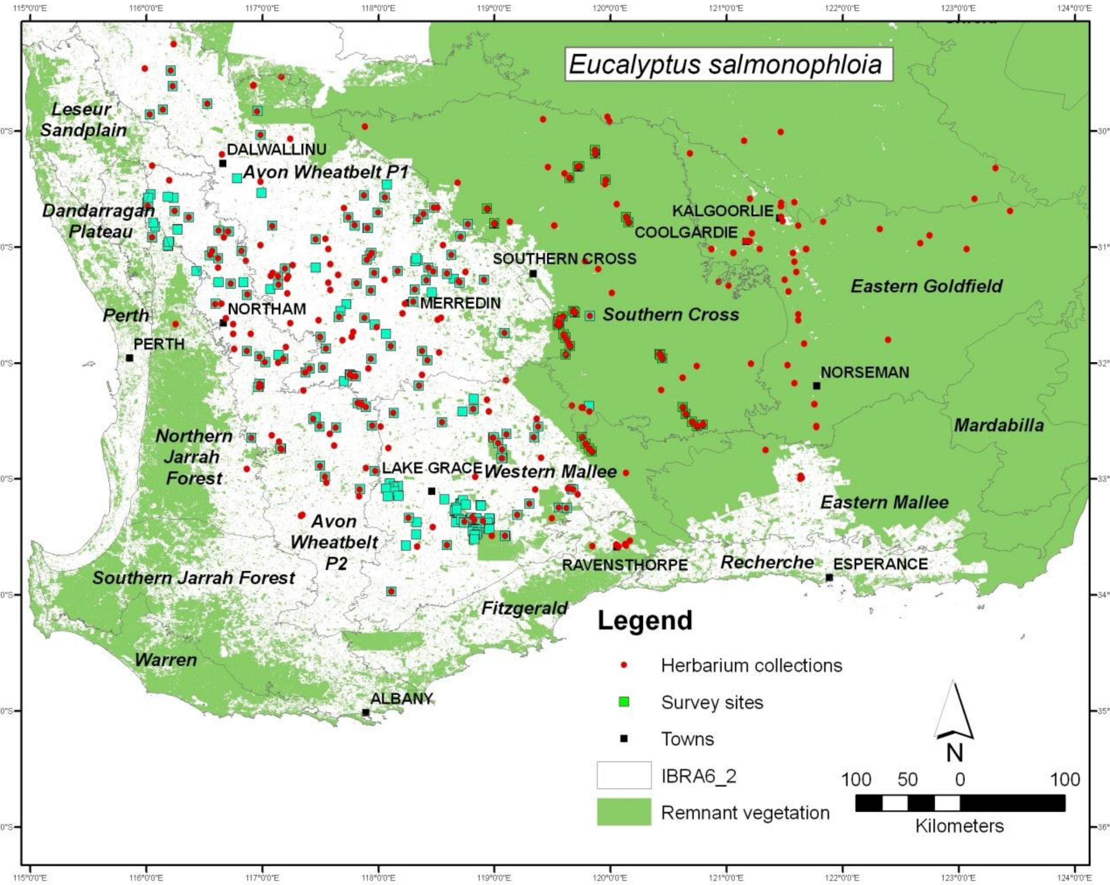


Figure 1-2 Distribution of records of *Eucalyptus salmonophloia* from herbarium collections and surveys data, in relation to the IBRA biogeographic subregions and remnant vegetation.

It occurs as pure stands, mixed with other Eucalypts such as *E. salubris, E. longicornis* and *E. transcontinentalis* or as a scattered emergents through lower woodland and mallee communities (Beard 1975, 1981b).

1.2.2 Ecology

Eucalyptus salmonophloia has probably received the most scientific attention amongst the eucalypts in the south-west woodlands with studies focusing on factors limiting recruitment (Yates *et al.* 1994a; Yates *et al.* 1994b; Yates 1995; Yates *et al.* 1995; Yates *et al.* 1996) restoration in the central Wheatbelt (e.g. Hobbs & Mooney 1993; Yates & Hobbs 1997b; Yates & Hobbs 1997a; Saunders *et al.* 2003), impact of grazing (e.g.Yates, Norton*, et al.* 2000; Fox 2001b) and aesthetics (Fox 2001a; Fox 2001b).

Regeneration occurs from seed, and occasionally epicormic shoots after mild disturbances (for example, fire). Flowering occurs about every three years with the tree able to retain fruit containing-seed for up to two flowering events (Yates *et al.* 1994a). These may be released when a branch is damaged by insect or birds, or falls to the ground (Yates *et al.* 1994a). These seeds are usually viable but once on the ground there is considerable predation and destruction by ants (Yates 1995). Viable seed (observed in the laboratory) can withstand wetting and drying cycles, but seed wet at sub-optimal temperatures for prolonged periods, while still able to germinate, rarely survive (Yates *et al.* 1996). Low levels of competition from parent trees and shrubs and good follow-up rainfall is necessary for successful seedling establishment. They are in a group of Eucalypts, including mallets, which appear to require a catastrophic event to trigger abundant seed fall and germination. Successful seedling establishment depends on follow up rainfall, mild temperatures and lack of disturbance such as grazing. Successful regeneration has been observed after fire, short term flooding, storm damage, clear-felling or the death of a mature adult (Yates *et al.* 1994b). In the Wheatbelt remnants, evidence of recruitment is rare as the incidence of disturbance events is infrequent and degradation from grazing and weed invasion is common (Yates, Norton*, et al.* 2000). In the GWW, regeneration occurred following timber cutting and clear felling (Kealley 1991; Yates *et al.* 1994b). All of the above have a significant impact on the long-term survival of salmon gum woodlands.

1.3 Vegetation science methods

The description of vegetation is important for basic and applied research. As a product of community classification, it provides a framework for modelling distributions, assessing the biodiversity values and monitoring impacts of management actions and threats. Methodologies can be applied at a local scale (e.g. Hoare *et al.* 2000; Tsiripidis *et al.* 2007; Chytrý *et al.* 2010; De Sanctis *et al.* 2013; Meissner & Coppen 2013), through to regional (e.g. Ermakov *et al.* 2002; Boublik & Zelený 2007; Bergmeier & Dimopoulos 2008; Krestov *et al.* 2009; Stevens *et al.* 2011), national (Chytrý 1997; Kočí *et al.* 2003; Corney *et al.* 2004; Bölöni *et al.* 2011; Li *et al.* 2013), continental (Mucina *et al.* 1993) and up to a global scale

(Mucina & Maarel 1989). Essential to these broader agglomerations is the need for compatible, widely available databases (Dengler et al. 2011).

1.3.1 Historical overview

Describing plant communities is complex and since the early 1900's there have been many approaches (Whittaker 1973). Very early use of vegetation classification focused on growth form and the acceptance that plants formed distinct communities (Grisebach 1838, Humbolt 1907). In Finland Cajander (1909) used composition of understorey species as the basis for forest classification, while Warming (1909) defined the plant formation as a community of associated species that have adapted to the climatic or edaphic character of their environment. Clements (1928), an American, considered plant succession as an important consideration when describing vegetation. Early formalized studies of vegetation occurred in England, with work by Tansley and others who developed a nation-wide system of classification and survey methods, also acknowledging successional states (Tansley 1920; Tansley & Chipp 1926). At the same time, a system was developed by Braun-Blanquet, a Swiss biologist who published his first text in 1921 (translated 1932). The Braun-Blanquet phytosociological approach (Westhoff & van der Maarel 1973, republished in 1978) incorporates the full floristic composition and identifies characteristic species which are used to describe and organise communities into a hierarchical classification (Westhoff & van der Maarel 1973). It is now commonly used across a wide variety of European ecosystems (e.g. Mucina *et al.* 1993; Chytrý 1997; Mucina 1997; Ermakov *et al.* 2002; Grabherr *et al.* 2003; Kočí *et al.* 2003) and forms the basis of the European typology and habitat network classification (Natura2000; Gégout & Coudun 2012).

Statistical methodology based on quantitative, site-based data is now essential as a sound basis for the description of vegetation units. There are two main approaches used in the quantitative study of vegetation: classification and ordination.

1.3.2 Classification

Vegetation classification is used widely to help understand ecological systems (e.g. Qian *et al.* 2003) and describe patterns and anomalies (Griffin 1994; Gibson *et al.* 2004; Griffin 2008). It is valuable for producing modelled distributions of similar communities as maps that underpin land use decisions, including managing conservation estate (Mucina & Daniel 2013) and assessing the conservation significance of a community (Fox 2001b; Gibson *et al.* 2012; Attorre *et al.* 2013).

Classification or clustering is the clustering of site-based species composition into groups based on pair-wise comparisons. It can be an effective tool to search for major similarities and discontinuities in a data set due to natural distributions or the impact of different treatments. Today there is a wide choice available of data analysis combinations (DAC) of data transformations, resemblance or distance matrices, and clustering methods (Goodall 1973; Legendre & Legendre 1998; Podani 2001; McCune & Mefford 2011). The choice of methods appears to be largely based on researcher preference and local tradition.

The choice of a coefficient to measure ecological resemblance can be assisted by a binary choice table (Legendre & Legendre 1998). These are mainly similarity coefficients (e.g. Jaccard (1900,1901,1908) (Sørensen 1948) and Bray Curtis or distance measures such as Euclidean (Legendre & Legendre 1998).

One of the oldest and best known occurrence measures is the Jaccard measure, also known as the Coefficient of Community, an asymmetrical binary coefficient, in which all terms are equal. The measure has seen extensive use, largely due to its simplicity and intuitiveness (Magurran 2004). A similar measure also in common use is the Sorenson measure (also known as Dice, Czekanowski or Coincidence Index), which places more emphasis on the shared species present rather than the unshared, and gives double weight to double presences. Again, the calculation is relatively simple and intuitive, and both indices have been shown to provide useful results (Wolda 1981). Possibly the most widely used abundance based measure is the Bray-Curtis measure, due to its strong relationship to ecological distance under varying conditions (Bray & Curtis 1957; Minchin 1987; Clarke

1993). This measure used with raw abundances compares pairs of sites in terms of the minimum abundance of each species and is equivalent to the Sorenson coefficient when used as a similarity measure with occurrence data. This coefficient is commonly used for ordination by principal coordinate analysis (Legendre & Legendre 1998).

Commonly used methods include Unweighted Pair Group Method with Arithmetic Mean (UPGMA, Sneath & Sokal 1973) which is an average linkage method where the dissimilarity is the average dissimilarly of each plot in each cluster in relation to all the other plots on the other cluster. Wards (1963) flexible beta algorithm attempts to minimize the sum of squared distances from each plot to the centroid of its cluster (Legendre & Legendre 1998) and is most appropriately applied to an Euclidean distance matrix of plot dissimilarities (Legendre & Legendre 1998). By assigning -0.25 flexible beta value the algorithm can be used with other dissimilarity matrices e.g. Sorenson.

One approach to deciding which classification method to use is to compare how a number of DACs treat each data set. OptimClass in JUICE, a program for management, analysis and classification of ecological data (Tichý 2002), is a technique that graphically assesses a set of DACs to formally choose the ‘best’ combinations of methods and the ‘optimum’ number of groups. The choice is based on a statistically identified number of faithful or diagnostic species according to Fisher’s exact test (Tichý *et al.* 2010). Once chosen and run, the resulting clusters can be assessed for statistical significance, integrated into an ordination analysis, and then used as a basis on which to develop a hypothesis. A high number of diagnostic species indicates a well-defined community.

Alternatively SIMPROF, a similarity profile test in the PRIMER package (Plymouth Routines In Multivariate Ecological Research, Clarke & Gorley 2006), tests for evidence of structure in an unstructured set of samples and helps determine the level at which splitting is valid. The use of SIMPROF in combination with clustering, and an additional facility to condense specific substructures within dendrograms, generates ‘trees’ that are pruned to statistically-defined groups. This overcomes the inadequacies of a simplistic straight-line analysis typically used in dendrograms. The program automatically assigns a factor defining these groups to the plots for display on dendrograms and ordinations.

Plot-or species-based clusters can be used to order plots and species in a two way phytosociological table to visualize the classification and indicate sets of diagnostic species (Westhoff & van der Maarel 1973). Plots can be ordered according to a classification dendrogram, however there is some degree of flexibility in the order, or according to an order based on a vector such as distance inland, mean annual temperature (or precipitation) or land use (Prober & Thiele 1995). Historically experts who know the taxa and region sort species in these tables intuitively based on comparison of differences in species frequencies among plant communities. A semi-automatic procedure available in JUICE (Tichý 2002) uses a synoptic table which can display fidelity, absolute frequencies, percentage constancy or categories and select diagnostic, constant and dominant species for each community (Tichý 2002). The fidelity of the species (the occurrence concentration of species compared to the group of other quadrats in the table) can be calculated using the phi coefficient, which is independent of the number of quadrats in the data set .and is minimally affected by the relative size of the vegetation unit (Sokal & Rohlf 1995; Tichý & Chytrý 2006). Alternatively indicator values (INDVAL) calculated in PC-ORD (McCune & Mefford 2011) can be used. The final arrangement of the phytosociological table still requires expert understanding of species traits, distributions, associated species and environmental characteristics as input into the final community descriptions.

1.3.3 Ordination

Ordination is a tool for analysing and visualising complex data sets with a high number of sampling units and many attributes (Wildi 2010) and can be used to complement cluster analysis or present a trend not influenced by preconceived groups. The term ordination was coined by Goodall (1954) and in general it orders objects along axes according to their resemblances (McCune & Mefford 2011). It is widely used to monitor the impact of disturbances such as fire (e.g. Gosper *et al.* 2012) or to assess changes over environmental gradients (e.g. Stevens *et al.* 2011).

Whittaker (1973) reports that the method was developed as early as 1926 (Ramensky 1926) in eastern Europe but gained popularity in the 1950’s with works by Curtis & McIntosh (1951), Goodall (1954), Whittaker (1956) and Bray & Curtis (1957) . The techniques advanced in these papers recognised that species turnover is potentially continuous and that stands can be arranged in a continuous order to reflect ecological information (Legendre & Legendre 1998).

Vegetation scientists use a wide range of ordination methods (Ter Braak 1987; McCune & Mefford 2011; Austin 2013). These can be based on relating independent ordinations of floristic and environmental data (indirect gradient analysis or unconstrained ordination (Legendre & Legendre 1998)), or by incorporating environmental variables into the floristic ordination (known as constrained ordination, direct gradient analysis or canonical analysis (Whittaker 1967)).

Commonly used unconstrained methods include non-metric multidimensional scaling (NMDS, cf Minchin 1987); a linear response principal components analysis (PCA, Ter Braak 1987) suited for data with a linear response and correspondence analysis (CA, Hill 1973) and its detrended derivative detrended correspondence analysis (DCA, Hill & Gauch 1980) which are more suited to data with a unimodal response (Ter Braak 1987). DCA can be used to obtain a gradient length along the first axis which then determines whether linear or unimodal ordination methods are best suited to the data (Leps & Smilauer 1999). NMDS is based on and reflects a pair-wise distance of similarity between plots and is commonly used with the Bray Curtis resemblance measure (Minchin 1987; Clarke & Warwick 2001; Austin 2013).

Direct gradient analysis or constrained analysis incorporates environmental variables (climate, soils and land use) within axes of the ordination to define and describe the patterns presented by classifications. This correlation can be determined through the use of a range of approaches such as detrended canonical correspondence analysis (DCCA, derived from DCA (Gauch 1982)), redundancy analysis (RDA canonical form of PCA (Rao 1964 in Ter Braak 1987)), and canonical correlation analysis (CCA) which incorporates an additional multiple regression step to CA (Ter Braak 1986; Palmer 1993; Legendre & Legendre 1998). CCA has become widely used as there is a growing awareness of the defects in indirect ordination methods (e.g. Minchin 1987), it intuitively relates environmental variables to vegetation patterns, and is easily applied using the CANOCO package and the associated plotting program, CANODRAW (Ter Braak & Šmilauer 2002). Examples of its use are evident across the field of ecology (Leps & Smilauer 1999; Qian *et al.* 2003; Mwavu *et al.* 2008; Sieben *et al.* 2009; Chytrý *et al.* 2010; Ohmann *et al.* 2011; Sander & Wardell-Johnson 2011). However CCA (for unimodal data) is based on CA and may inherit shortcomings of the indirect ordination method (Økland 1996) along with other limitations and assumptions (Ter Braak 1985; Ter Braak & Prentice 2004; Austin 2013). It also discards compositional variation that is not explained by the chosen variables and hence may overlook a potentially more significant compositional gradients (Palmer 1993). To overcome disadvantages of unconstrained and constrained ordinations, Økland (1996) recommends running parallel applications.

CCA variance partitioning is now an accepted method for separating the effects of sets of explanatory variables based on scale, geographic position, temporal status and management impacts (Borcard *et al.* 1992; Økland & Eilertsen 1994; Anderson & Cribble 1998; Økland 2003; Arbeláez & Duivenvoorden 2004; Sieben *et al.* 2009; Wiser *et al.* 2010). The analysis works on the variation that remains after the effects of particular environmental, spatial or temporal co-variables have been removed (Ter Braak & Prentice 2004).

1.3.4 Vegetation databases

Integral to all numerical analysis of vegetation is adequate data storage facility. This study utilized TURBOVEG (Hennekens & Schaminée 2001), a computer software package, compatible with Microsoft® Windows® (TvWin), (Schaminée *et al.* 2009). TURBOVEG has the benefits of easily importing data manually or from free formatted files into standard format features enabling the amalgamation and exchange of data. Data exported into various file formats provides input into a number of classification and ordination programs. It is utilised by or compatible with 97 of the 197 databases (as of 20/13/2013) collated in the Global Index of Vegetation-Plot database (Dengler *et al.* 2011 http://www.givd.info), but not yet widely used in Australia.

1.3.5 Extrapolation of classification analysis into vegetation maps

Practitioners use many different approaches, at a variety of spatial scales, to map and classify vegetation in Western Australia. The State-wide vegetation maps, at the 1:250,000 scale, involved extensive traverses documenting vegetation units and mapping their extent but did not involve plot based data (Beard & Webb 1974). Generally, large scale vegetation maps are based on aerial photography interpretation supplemented by site descriptions (e.g. Muir 1977; Mattiske 1992; Sandiford & Barrett 2010; Craig *et al.* 2008) . Plot-based surveys are numerous (Lyons & Gibson 1994) and classifications (e.g. Brown 1989; Gibson *et al.* 1997; Gibson & Lyons 1998, 2001a; Gibson 2004a; Gibson *et al.* 2004; Griffin 2008; Markey & Dillon 2011; Rick 2012) are not commonly extrapolated into modelled distributions as the focus was on the classification and it is a considerable undertaking to develop maps. This is partly due to the specific purpose of these surveys and the lack of requirement for maps. These analyses have typically been based on presence or absence of species which may have led to an over emphasis on rare taxa in classifying floristic patterns. Data incorporating cover values, and hence identifying dominant species, are needed to effectively contribute to the description and modelling of vegetation distribution (e.g. Neldner *et al.* 2005; Mucina & Rutherford 2006; Mucina & Daniel 2013). To obtain cover data marked (preferably permanently) plots need to be surveyed using standard methodology. Some of the Regional vegetation mapping project in south-western Australia have estimated cover ranges despite not having measured quadrats (Sandiford & Barrett 2010; Craig *et al.* 2008).

Current methods of modelling vegetation patterns involve a process of relating plot data to spatial layers in a GIS environment. The structure and composition of plots in each community is extrapolated using available digital maps of topography (digital terrain models), geology, remotely sensed satellite imagery (including radiometrics), soil, hydrology (including moisture balance) and site energy (solar radiation). The choice of layer(s) will depend on availability at a suitable scale and adequate level of detail (Franklin 1995).

A protocol recently applied in the Kimberley region (north-western Australia) involved modelling plot based data over simplified geological layers of geology and Normalised Differential Vegetation Index (NDVI, derived from Landsat imagery) using classification and regression trees (CART) and e-Cognition assisted segmentation of Landsat imagery (Mucina & Daniel 2013). This protocol could be applied to other areas such as the GWW.

1.4 Aims and Objectives

The aim of the project is to gain a better understanding of the patterns and processes governing the distribution, composition and structure of salmon gum communities across south-western Australia.

Given the paucity of information on salmon gum woodlands in Great Western Woodlands (GWW) prerequisite to the above aim is to survey and analyse the floristic patterns in the salmon gum woodlands and relate them to climate, soils and land use.

More specifically, the objectives were to:

- Review Australian temperate woodland extent, structure and composition in relation to salmon gum woodlands and its uncommon occurrence in a semi-arid area (Chapter 1).
- Describe salmon gum distribution, ecology and conservation status (Chapter 1).
- Review aspects of vegetation classification and ordination relevant to this project (Chapter 1)
- Describe the physical, biological and social characteristics of south-western Australia, in particular the GWW, relevant to a study of salmon gum woodlands; including the collation of existing literature, data, and GIS layers needed to stratify the GWW to implement a representative distribution of sampling plots (Chapter 2).
- Select and sample a representative selection of one hundred 400m^2 plots in pure salmon gum woodland patches (Chapter 2).

- Produce a classification of salmon gum woodland communities and determine the regional and local environmental variables that characterise those communities (Chapter 3).
- Incorporate available survey and environmental data from the Wheatbelt and modify GWW data accordingly to apply the methods chosen above to a classification of salmon gum woodlands throughout their range (Chapter 4).
- Compare salmon gum woodlands with other woodlands in WA and the eastern states in terms of floristic composition, climatic preferences and distribution (Chapter 5).
- Conclude from the findings of Chapter 3 and Chapter 4 potential floristic communities and relate these to other WA, eastern states and Australia-wide studies and descriptions (Chapter 5).
- Discuss the application of the findings to modelling the distribution of these woodlands and implications on community conservation status, biogeographic boundaries and conservation land management planning and actions (Chapter 5).

It is expected that there may be a gradual turnover of species along a rainfall gradient with the possibility of several dominant communities based on past observations (Beard 1975; Beadle 1981; Beard 1981b). The detailed findings will contribute to mapping the vegetation of the GWW and future research and monitoring activities. It also will provide additional information about a poorly known region adjacent to the globally recognised Southwest Australian biodiversity hot spot.

2 MATERIALS AND METHODS

2.1 Study area

2.1.1 Location and biogeography

This study focuses on a survey which was conducted in salmon gum woodlands within the Great Western Woodlands (GWW), also known as the WA Goldfields, in south-western Australia. Then, together with existing data from the WA Wheatbelt, the range-wide patterns in salmon gum woodlands were analysed. Together the two regions cover nearly 30 million ha and extend from Northam in the west to 100 km east of Kalgoorlie, Moora in the NW to near Ravensthorpe in the south (Figure 2-1).

The GWW, so named because of its position in the western part of the Australian continent (Watson *et al.* 2008), corresponds with the Coolgardie Interim Biogeographic Region of Australia (IBRA, Thackway & Cresswell 1995) and the northeast uncleared part of the Western Mallee sub-IBRA (Figure 2.1, Thackway & Cresswell 1995; Environment Australia 2000). The Wheatbelt is defined here as the Avon Wheatbelt IBRA region together with the Western Mallee sub-IBRA region. The IBRA regions have been further subdivided into sub regions; Coolgardie into Southern Cross, Eastern Goldfields and Mardabilla (to the south-east), the Mallee into Eastern and Western subregions, and the Avon Wheatbelt IBRA into P1-Ancient Drainage and P2-Rejuvenated Drainage. Each subregion has distinctive flora fauna and vegetation (May & McKenzie 2002).

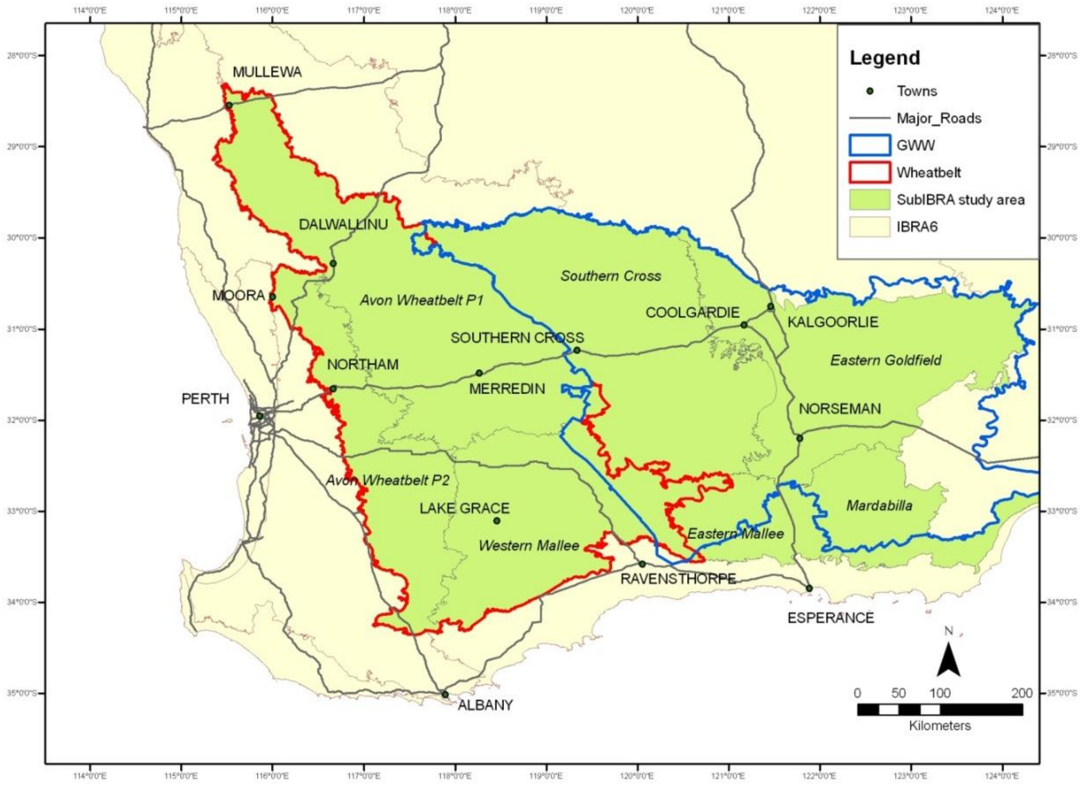


Figure 2-1 Location of area in relation to main and defining towns, and the IBRA biogeographic subregions (in italics)

The Coolgardie IBRA is also known as South-western Interzone as it lies between the South West Botanical Province and the arid interior or Eremaean Botanical Province (Burbidge 1960; Beard 1980a, 1990). The Avon Wheatbelt region and eastern Mallee subregion within the South-western Botanical Province, which is also referred to as the Southwest Australian Floristic Region (SWAFR: Hopper & Gioia 2004), is recognised globally as a biodiversity hot spot (Hopper & Gioia 2004) with well over 8,500 taxa of native plants (Western Australian Herbarium 1998 – 2013). The boundary between the Avon Wheatbelt region/eastern Mallee subregion and the Coolgardie Region is largely based on regional vegetation mapping but the latter also corresponds to an area where climate and land is not suitable for crops so the boundary could be considered anthropogenic.

2.1.2 Climate

An understanding of climatic history is important for the interpretation of current vegetation patterns as climate has influenced the evolution, distribution and abundance of species (Beard 1981b). Since 5,000 BP there has been decreasing precipitation to the present levels (Bowler 1977). This decline is predicted to continue, exacerbated by the impact of human induced climate change (Hughes 2002; Parry *et al.* 2007).

The study area lies between the 500 - 200 mm mean annual rainfall isohyets (Figure 2-2). The climate of the Wheatbelt is widely accepted as mediterranean but, the climate of the GWW, is less clearly defined and is considered an interzone between the South west and the dry Eremaean (Beard 1981b, 1990). The climate of the GWW has been described as semi-arid mediterranean (Judd *et al.* 2008; Prober *et al.* 2012), semi-desert mediterranean to desert non seasonal (Beard 1981b; Beard 1984 after Bagnouls and Gaussen (1957)) and xerothermomediterranean and sub-desert (UNESCO-FAO 1963)).

Mediterranean is defined in the Oxford dictionary as being “distinguished by warm, wet winters under prevailing westerly winds and calm, hot, dry summers, as is characteristic of the Mediterranean region and parts of California, Chile, South Africa, and SW Australia”. However, rainfall is not just the defining feature: it is rainfall patterns and certain characteristics of the vegetation (e.g. life forms and leaf traits). Blumler (2005) describes mediterranean as favouring, annuals when the winters are wet and there is a severe summer drought and/or favouring evergreen sclerophylls under semi-arid conditions with relatively short hot dry spells. However, in south-western Australia evergreen sclerophyllous shrubs are common in winter wet areas and annuals are abundant after rain in semi-arid areas where summer rainfall events result in relatively short hot dry spells. Le Houerou (2004) extends the definition to include desert areas with mean annual rainfall of less than 100 mm and stresses the importance of the ratio of winter to summer rainfall. ‘Semi-arid’ in eastern Australia has been defined as being between the 200 – 500 mm isohyets by Gillison (1994) or between 250– 500 mm by Keith (2004). The climatic definition of temperate is non-tropical (Burbidge 1960) with annual rainfall ranging from 250 – 1200 mm (Beadle 1981).

The delineation of climatic zones based on the 1936 classification of world climatic zones by Köppen (Dick 1975; Kriticos *et al.* 2012; CliMond 2013) shows only a relatively small area of Mediterranean dry summer (hot) with a smaller area in Mediterranean dry summer (cold) in the south west corner of the Wheatbelt. The rest of the Region is mainly classed as semi-arid: cold Arid Steppe to the south and hot Arid Steppe to the north. Both these zones extend well into the GWW, which also grades onto the cold Arid Desert and hot Arid Desert to the north east (Figure 2-2, (Dick 1975). Beard describes the GWW as semi-desert mediterranean, being dry for 9-11 months but in fact, summer rainfall is an important feature of this region. Here the term semi-arid mediterranean is preferred for the GWW but with the acknowledgment that summer rainfall is characteristic and it is the semi-arid characteristic that is distinctive especially in relation to the unique tall woodland that occur there.

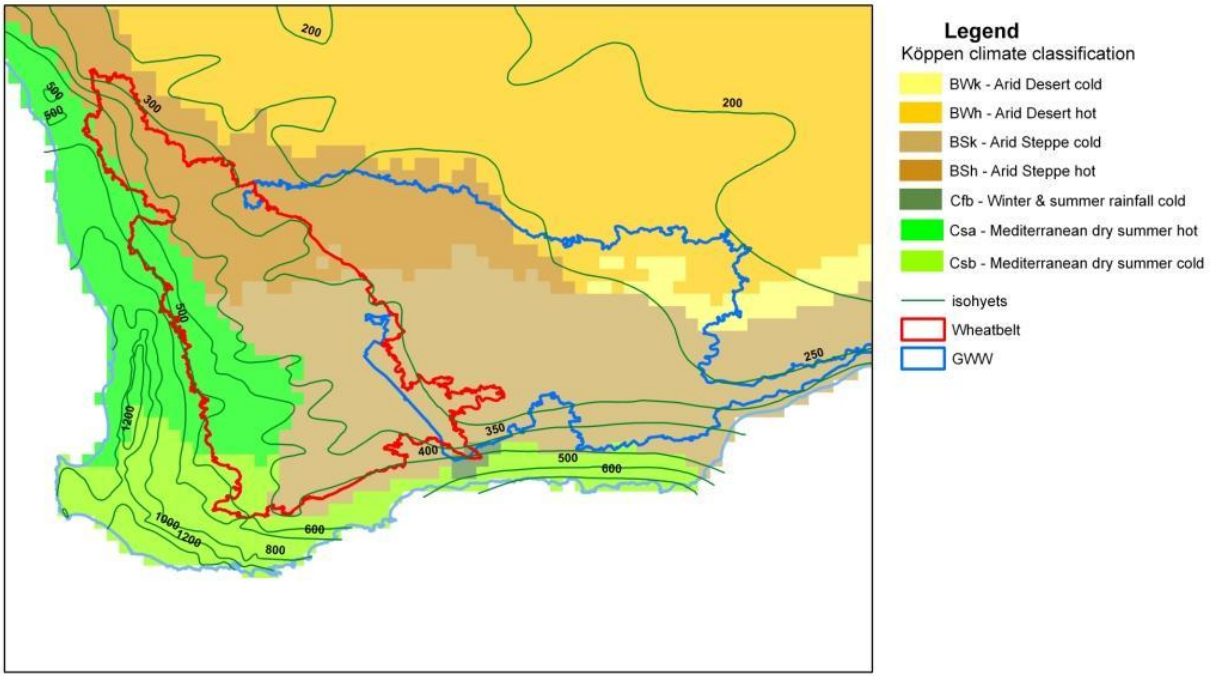


Figure 2-2 Climatic zones across the study area extracted from the CliMond data set (Kriticos *et al.* 2012) and isohyelts . The boundary between S (semi-arid) and W (arid) approximates 220mm where the rainfall is evenly distributed and 180mm where rainfall is chiefly in the winter. The difference between k=mean annual temp <18°C, h annual mean temp >18°C (Rick 1975)

A classification of Mediterranean regions by UNESCO-FAO (1963), shows the GWW traversed by series of bands (Figure 2-3). These bands run from a narrow belt of thermomediterranean on the western edge and in an area in the south near Salmon Gums townsite, through a broad area of xerothermomediterranean in the south west, then identified bands of sub-desert (attenuated) and sub-desert (accentuated) to desert in the north-east.

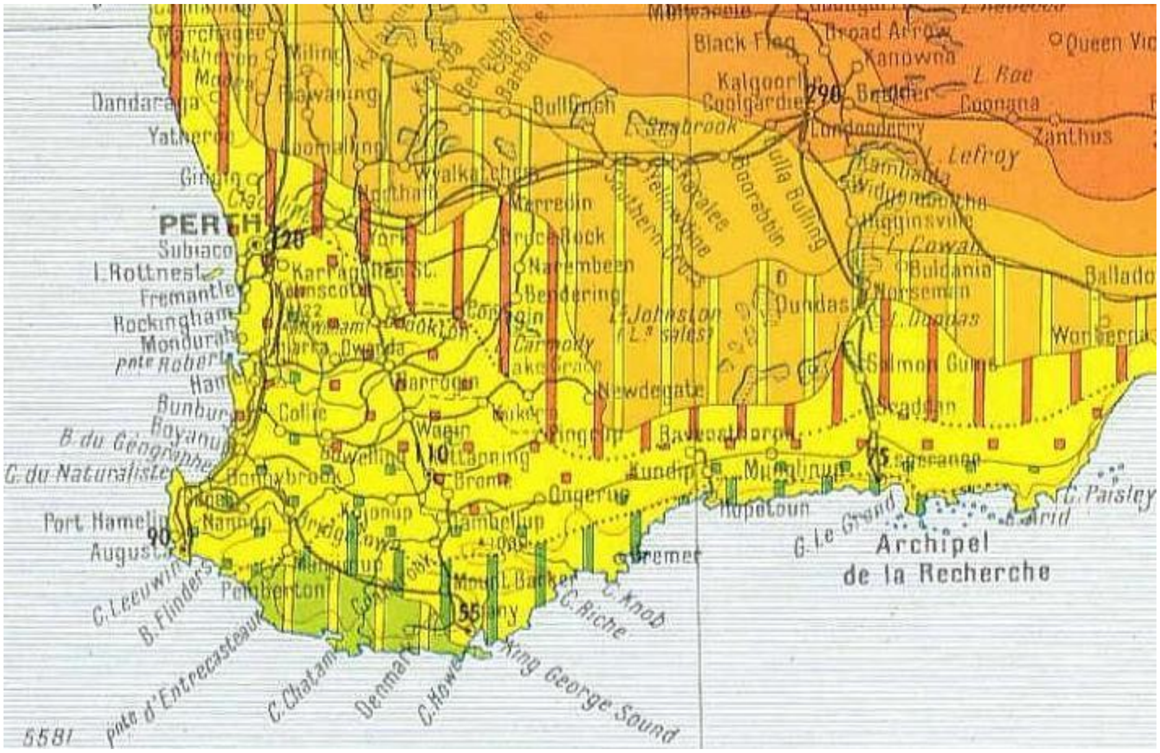


Figure 2-3 Climatic zones (UNESCO-FOA 1963)

Orange – sub-desert, mediterranean – yellow, green-sub- mediterranean, desert – red. Alternate bars and small blocks of colour are used to reflect the intensity and duration of the dry and wet seasons e.g. thermomediterranean – (yellow with orange stripes) long dry season=, xerothermomediterranean (orange with yellow stripes) very long dry season , sub-desert (attenuated) –orange, sub-desert (accentuated) – dark orange.

The rainfall of the GWW is generally low, intermittent and unpredictable with considerable range between highest and lowest annual falls (BOM 2013). There are two rainfall gradients over the region (Figure 2-2) a gentle one from the west and a steeper one from the south (Beard 1981b). In the west and south, the mean annual rainfall is 300 mm and 350 mm respectively with slightly more rain in winter (BOM 2013). In the east, the mean annual rainfall, of about 200 mm, is more evenly distributed throughout the year. Throughout the GWW, rainfall may occur in the warmer months (highest in February (Table 2-1) due to unpredictable thunderstorms and tropical cyclone remnants. The rainfall pattern is highly variable with bimodal summer and winter peaks. Precipitation seasonality index (calculated as the ratio of warm (Oct–Mar) to cool (Apr–Sep) season log-rainfall totals), available from Atlas of Living Australia (2013), of ranges in the shows only four sites, where *Eucalyptus salmonophloia* specimens have been collected (see Figure 1-2), receiving more summer than winter rainfall (ALA 2013).

Table 2-1 Rainfall statistics for major towns in the GWW (BOM 2013)

Station	Mean Annual Rainfall	Mean Annual Rainfall range	Years	Highest Monthly rainfall	Means in 1984
Southern Cross	292	118 - 577	1961 - 2012	136.7 (Feb)	284
Coolgardie	271	84 - 633	1893 - 2012	237 (Feb)	263
Kalgoorlie *	252	108 - 531	1899 – 2012*	314.5 (Feb)	256
Norseman	289	138 - 634	1897 - 2012	202.6 (Feb)	292
Salmon Gums	353	162 - 626	1932 - 2012	148.6 (Jan)	325

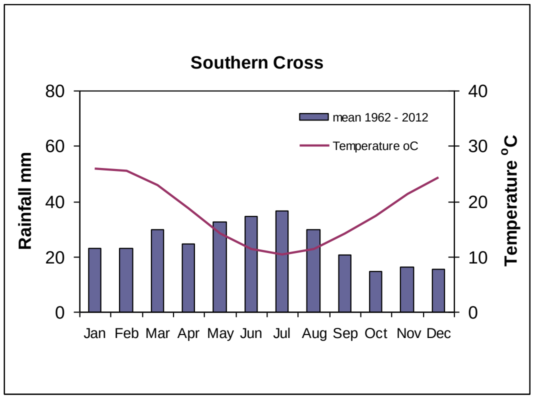
***Kalgoorlie data is from Post Office 1896 – 1953 and Kalgoorlie Boulder Aerodrome 1939 – 2012. This table also includes mean values cited in the Biological Survey of the Eastern Goldfields** (Newbey 1984, 1985, 1988; Hall & Newbey 1993; Milewski 1993)**.**

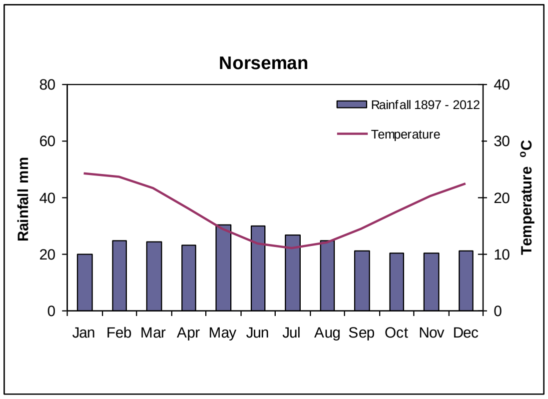
Temperatures for towns across the region range from a mean 24.8 °C maximum to a mean 10.6 °C minimum (BOM 2013). Hottest months tend to be February in the north, west and December in the south (Table 2-2).

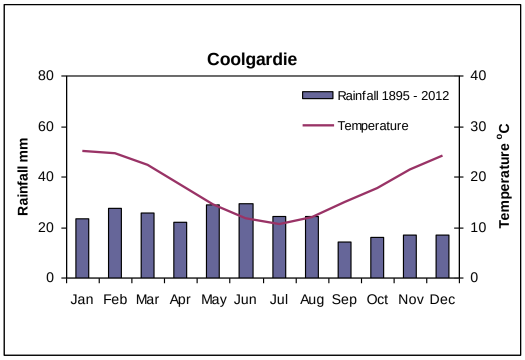
Table 2-2 Temperature statistics for major towns in the GWW (BOM 2013).

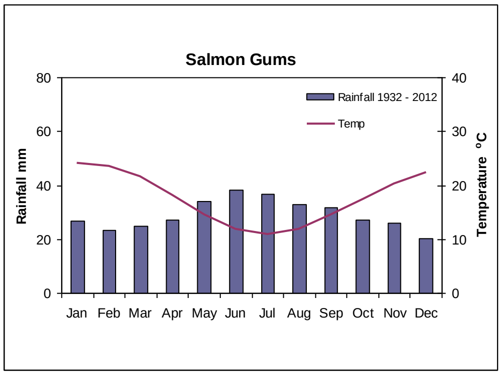
Station	Mean max °C	Mean min °C	Years	Highest monthly mean	Lowest monthly mean
Southern Cross	25.5	10.7	1895 - 2007	39 (Feb)	1 (Jul)
Coolgardie	25	11.2	1893 - 2007	36.9 (Feb)	3.2 (Jul)
Kalgoorlie	25.3	11.7	1896 - 2012	37 (Feb)	1.7 (Jul)
Norseman	24.7	10.5	1951 - 2012	35.6 (Dec)	1.6 (Aug)
Salmon Gums	23.4	9	1932 - 2012	33.8 (Dec)	1.3 (Aug)

Current weather patterns (Figure 2-4) were compared with ones produced in the early 1980s (Newbey 1984, 1985, 1988; Hall & Newbey 1993; Milewski 1993) and show how summer rainfall has increased. Overall rainfall has generally declined in the east and central region, and increased in the west and south, of the study area (Table 2-1).









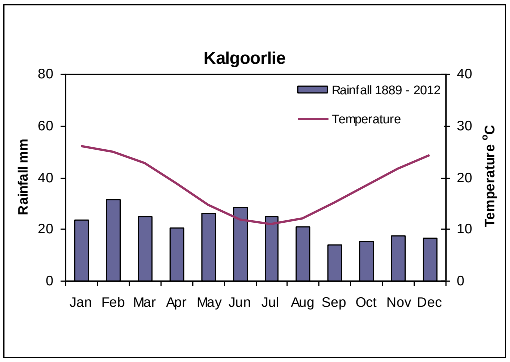


Figure 2-4 Comparison of rainfall and temperature for 5 stations in the GWW prepared (BOM 2013). See Figure 2.1 for town locations.

Climate change predictions for the region predict significant temperature changes are “likely”. Scenarios to 2070 predict increases in temperature of plus 2 - 5°C and annual rainfall probably decreasing between 10% and 40%. Summer rainfall changes are predicted to range from +40% to -60% (CSIRO & BOM 2007; Prober *et al.* 2012) however with such a low annual rainfall these represent minimal changes. If summer rainfall increases by a possible 40%, caused by the remnants of more intense ex-cyclonic, rain bearing depressions, the health and persistence of the salmon gum woodlands may benefit. However, as the frequency of these extreme events is predicted to decrease and temperature increase, the survival of these woodlands could be threatened. The increase in cover of shrubs is predicted in arid areas (Hughes 2003) which may also alter the structure and possibly the floristics of these woodlands. At different scales, the ecological communities, populations and individual species respond to changes in climate. Climate change also influences environmental conditions and ecological processes. This is recognised in the ‘change resilience’ framework for addressing climate change presented by Prober *et al* (2012). More research is needed to understand about how these factors impact on the long-term health and extent of salmon gum woodlands, especially those occurring at the climatic extremes of their range.

2.1.3 Geology and soils

Geologically the study area occurs entirely on the ancient Achaean Yilgarn Plateau, one of the largest, oldest and most stable land masses on earth (GSWA 1975; McArthur 1991; Fig 3 in Watson *et al.* 2008). It has been tectonically stable since the Proterozoic age (2500 - 600 Myr) with no icesheets, oceans, or mountain building episodes occurring since the Permo-Carboniferous Glaciation 300 Myr (Anand & Paine 2002). Only low hills and ranges composed of banded iron formations (BIF) and greenstone, and outcrops of granite, protrude from the heavily eroded land surface.

There is a drainage divide between the west flowing systems and the interior flowing palaeodrainage systems (Beard 1973). This divide approximately falls up to 150 km east of the main biogeographic boundary (see Figure 1-2).

Salmon gum woodlands generally occurred on alkaline red and yellow mottled duplex soils in the west, and red clays and red brown earths, grading to brown and grey-brown calcareous gradational soils occupy the valleys and crusty loamy duplex soils are associated with flatter ground in the east (Northcote *et al.* 1967; Beard 1975, 1981b; McArthur 1991). Gibson (2004) categorised the Wheatbelt soils into granite (derived from granites), duplex (occurring on valley floor and erosional slopes below the duricrust) laterite and deep sands, and stated that woodlands are usually found on the duplex soils.

Most of the salmon gum woodlands occur on soils overlaying the geological formations (colluvial and alluvial units) and are not directly associated with geological outcrops (as the woodlands associated with greenstone ranges).

The great age of the landscape and the extended period of weathering and leaching under humid climates has resulted in highly nutrient-deficient old soils with low levels of phosphorous in the parent rock, and considerable salt content in the form of sodium chloride (Hopper *et al.* 1996).

2.1.4 Landforms

Since the last glacial event, covering the region in the Permian age, the climate has played a significant role in moulding the landscape. Millions of years of wind and water erosion have resulted in the subdued landscape with relief ranging from 470 m asl in north-west 150 m asl in the south-east. Broad shallow river valleys flow into interior salt lake basins in the west but are reduced to strings of flat-floored lakes in the east (Van der Graaff et al 1977 in Hall & Newbey 1993). Salmon gums have been described as occurring on broad valleys, undulating plains and occasionally on dunes near salt lakes (Newbey & Hnatiuk 1984; Newbey & Hnatiuk 1985; Newbey & Hnatiuk 1988; Newbey *et al.* 1995).

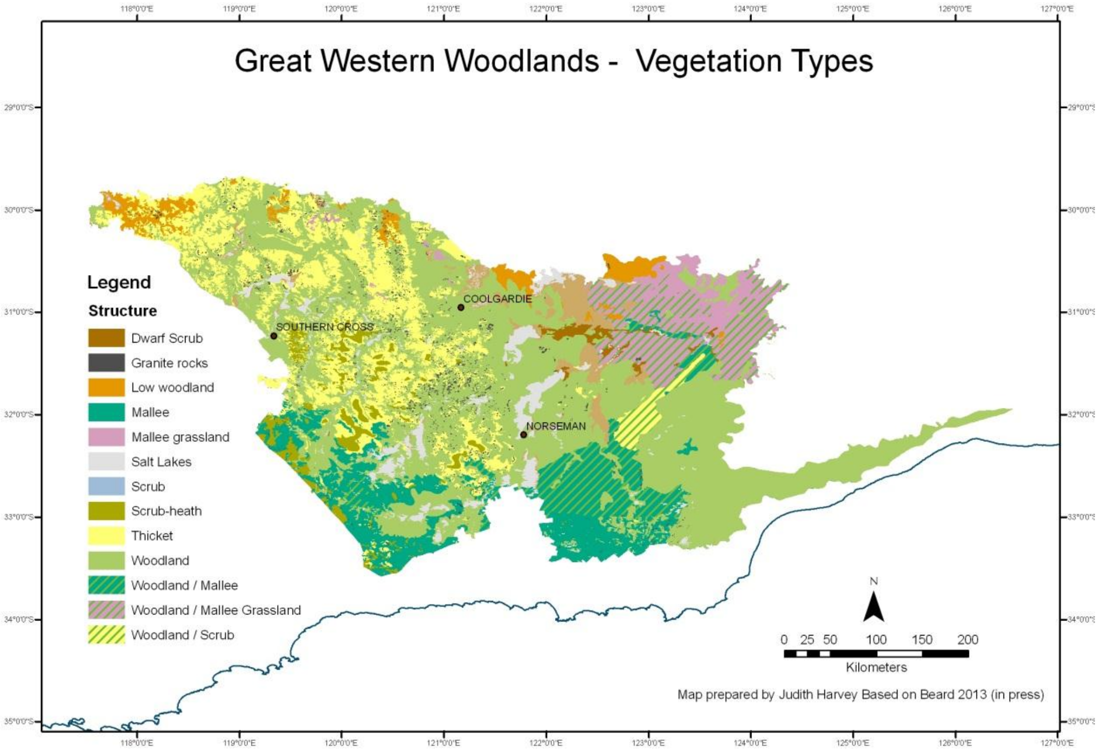
2.1.5 Flora

The Wheatbelt is part of a globally recognised Biodiversity Hot spot with a total of 5546 native species and subspecies recorded (NatureMap 2014 accessed March 2014) compared to 3336 recorded for the GWW. The GWW list includes 248 Eucalyptus taxa:

173 species, 62 sub species, nine undescribed taxa, one variety and two hybrids. Earlier estimates of *Eucalyptus* taxa range between 160 (DEC 2010) and 351 (Watson *et al.* 2008). Nowhere else in the world does the diversity of tree and mallee species exist, with some of the former reaching over 25 m, in a relatively subdued landscape with such low rainfall.

2.1.6 Vegetation

The Wheatbelt and GWW are characterised by a complex pattern of woodland, mallee and heath. This pattern is influenced by climate, topographic position and substrates (Beard 1981b, 1990). Vast areas of mixed scrub-heath (a diverse mix of tall and low shrubs occurring mainly on sandplain), thickets (*Allocasuarina, Melaleuca* and *Acacia*), mallee (tall eucalypt shrubland) and mixed woodland dominate the region (Figure 2-5) (Beard 1975, 1981b; Beard *et al.* 2013).



Map prepared by Judith Harvey Based on Beard 2013 (in press)

Figure 2-5 Pre-European Vegetation Types in the Great Western Woodlands, 1:250 000 (Beard *et al.* 2013)

In the GWW the wide variety of woodland vegetation associations have been identified in regional vegetation mapping (Beard's 1:250,000 scale mapping compiled into regional 1:1,000,000 scale (Beard 1975, 1981b)). Quadrat-based data did not inform the descriptions of the 28 woodland vegetation associations so descriptions of the understorey composition are limited to only a few species. Common woodland associations include *Eucalyptus salmonophloia* and *E. salubris* woodlands occurring on red loams and clays low in the landscape; *E. torquata, E. clelandii, E. campaspe* and *E. dundasii* woodlands occurring on greenstone; *E. oleosa, E. flocktoniae* and some *E. lesouefii* on pink calcareous soils east of Lake Cowan; *E. oleosa* woodlands on bottom land soils associated with salt lakes and *E. loxophleba* subsp. *loxophleba* also on granitic soils in the north-west GWW (Beard 1969, 1972a, 1972b, 1972c, 1972d; Beard & Webb 1974; Beard 1975, 1981b).

A set of vegetation systems based on the geology, soil and dominant species were derived for the Coolgardie botanic region (Jackson, Highclere Hills, Bungalbin Ranges, Boorabbin Plateau, Parker Hills, Yilgarn Hills, Bremer Ranges, Coolgardie Plains and Cave Hill Systems) (Beard 1981b). The part of the Roe Region, which occurs in the GWW, comprises Forrestiana Tableland, Lake Hope upland and the Clear Streak vegetation system, together with part of the Ridley system.

2.1.7 Salmon gum woodlands

In general, *Eucalyptus salmonophloia* is strongly associated with *E. salubris* (gimlet) (Gardner 1944; Beadle 1981; Beard 1981b, 1990; Yates, Hobbs*, et al.* 2000). Individually these two eucalypts have similar distributions with the former extending a little more in a south west direction and the latter extending a little more to the east (Western Australian Herbarium 1998 – 2013). This alliance is recognised in the overview of the vegetation of Australia by Beadle (1981), who identified four distinct types of understorey (Table 2-3).

Table 2-3 Summary of salmon gum - gimlet woodlands understorey (from Beadle 1981)

Dominant species	Associated species	Soils	Comments
Acacia acuminata	*Santalum spicatum** *Acacia* spp. *Grevillea* spp. *Dampiera* spp. *Daviesia* spp. *Neurachne alopecuroides* *Austrostipa elegantissima*	Sandy loam surface horizon on wetter part of the range	Discontinuous shrub layer
Melaleuca lateriflora & *M. pauperiflora*	*Daviesia* spp. *Dodonaea* spp. *Eremophila* spp.	Compact soils sometimes saline	Annuals, mainly Asteraceae after rain.
Mallee *Eucalyptus* spp.	*Melaleuca uncinata* very little ground flora		Wet and dry areas
Atriplex hymenotheca # *A. nummularia* & *Cratystylis conocephala*	*Eremophila scoparia* *Pittosporum phillyreoides* *Santalum acuminatum* * *Sclerolaena* spp. *Helipterum* spp. *Ptilotus* spp. *Zygophyllum* spp.		on flats In drier north eastern parts or in saline areas

[Updated names] *There appears to be an error with *Santalum acuminata* as it is more commonly collected and in the Wheatbelt and *A. spicatum* occurs well into arid areas. #*Atriplex hymenotheca* is very uncommon in the GWW and generally not well completion. I may have been confused with *A. vesicaria* (Western Australian Herbarium 1998 – 2013).

In the Avon Wheatbelt Beard (1990) summarised the salmon gum – gimlet woodland association as occurring on in valleys brown to re-brown sandy loam increasing in texture to clay within 7.5 cm, overlaying pallid zone at > 90cm, sometime with *kunkar* (lime concretions) in the profile. In the Coolgardie region, the salmon gum woodlands are described as being on lower slopes and flats on calcareous soils associated with a surface coating of moss and lichen and gimlet usually occurs separately on heavier clays in drainage lines.

In the GWW *Eucalyptus salmonophloia* (e_8) occurs in 23 vegetation associations (Beard 1969, 1972d, 1972b, 1972c, 1972a, 1975, 1981b); Figure 2-6). These comprise over 60% of the GWW but details about understorey patterning are limited and accuracy is variable. Beard mapped pure salmon gum over only 4% of the GWW; however, patches of pure stands in other salmon gum vegetation associations also occur at the local scale (personal observations). Good examples of original woodland are found in the Kambalda, Majestic and Randall’s timber reserves and there are large trees throughout the region. Of the vegetation associations containing salmon gum, only three occur without other eucalypts; pure salmon gum (central in the GWW) and salmon gum with saltbush in the north and salmon gum with bluebush to the north-east.

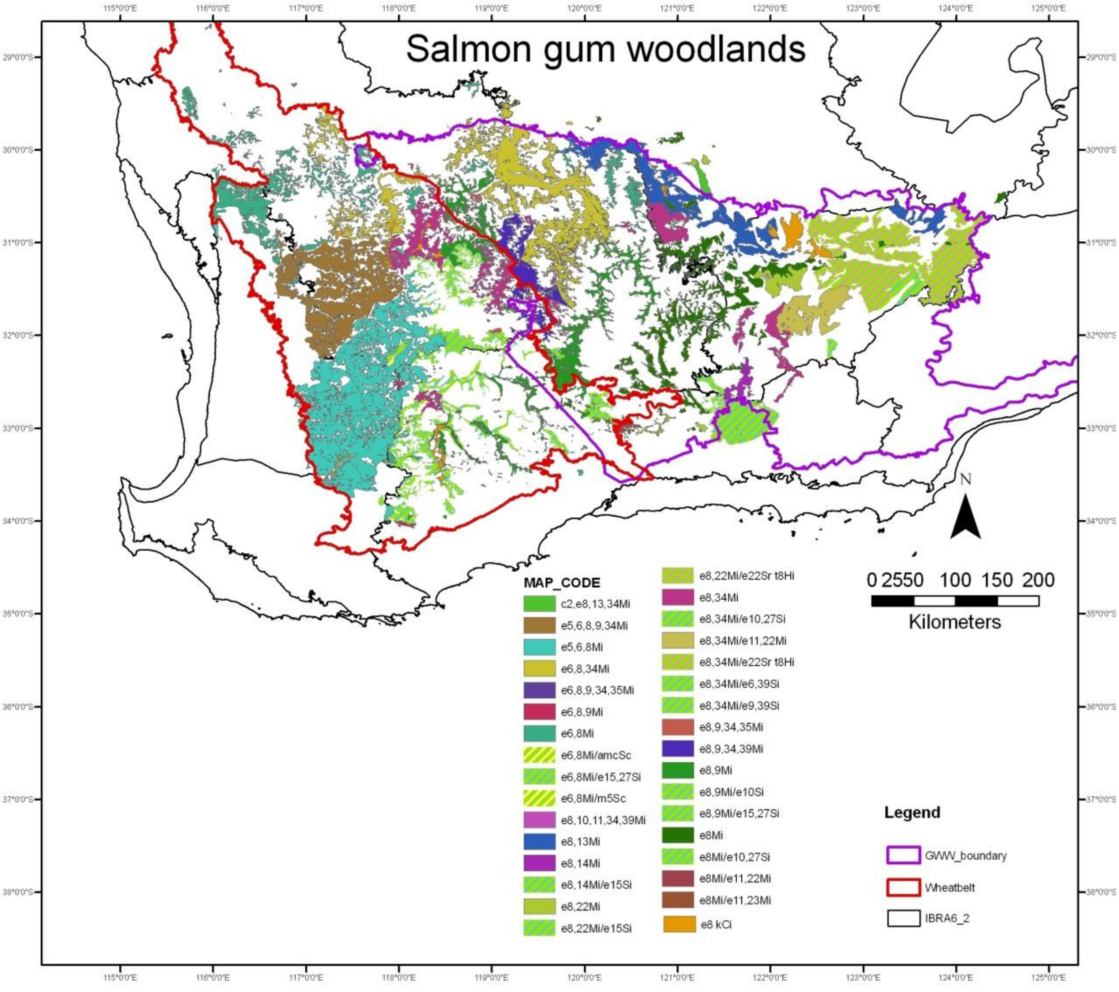


Figure 2-6 Beard pre-European vegetation associations, containing salmon gum (e8).

Codes c2-*Casuarina pauper*(black oak), e5 *Eucalyptus wan*doo, e6 *E. loxophleba* (York gum), *e8 E. salmonophloia* (salmon gum), e9 *E. longicornis* (red morrel), e10 *E. transcontinentalis*(redwood), e11 *E. flocktoniae* (merrit), e12 *Eucalyptus torquata* (coral gum), e13 *E. lesouefii* (goldfields blackbutt), *e14 E. dundasii* (Dundas blackbutt), e15 *E. eremophila* (horned mallee), e22 *E. oleosa* (giant mallee), e27 *E. redunca* (black marlock), e34 *E. salubris* (gimlet), e35 *E. corrugata* (rough fuited mallee), e39 *E. sheathiana* (ribbon-barked gum), k chenopod, k1 *Atriplex vesicaria* (bladder saltbush), k3 *Tecticornia halocnemoides* (shrubby samphire), t8* *Triodia scariosa*

Two of the communities dominated by *E. salmonophloia* in the Coolgardie Botanic region or GWW, are described by Beard: One has an understorey of broombush, *Acacia* spp. and *Eremophila* spp. and is typical in western parts of the Coolgardie Botanical district (GWW) (Beard 1972b, 1972a). The other occurs in the north and north east and the has the understorey, dominated by saltbush (*Atriplex* spp.) (Beard 1972c, 1975). He describes the salmon gum being restricted to isolated valley flats and deep valleys where it occurs with *E. salubris* usually over bluebush (*Maireana sedifolia*). These community compositions are likely controlled by the alkalinity of the soil with broombush preferring less alkaline soils on higher ground and saltbush and associated species preferring more alkaline soils on lower ground (Beard 1975).

Large expanses of mixed woodland, usually including salmon gum, are mapped across the Wheatbelt and GWW. It is evident from (Figure 2-6) that the GWW mapping is more accurate as it was based on extant vegetation whereas in the Wheatbelt broad generalisations had to be made across cleared areas. However, at a finer scale the individual woodlands are typical of certain parts of the landscape. For example in the Wheatbelt woodlands with salmon gum and gimlet occur on heavy loam low in the landscape, wandoo woodlands occur on loams mid slope and York gum occurs on sandy loams higher in the landscape [and in drainage lines] (Beard 1990; Bamford 1995).

2.1.8 Land use

Although none of the GWW has been cleared for agriculture, it has been subject to the impact of various human activities with large areas of woodlands logged, mined, and grazed since European settlement. Human ignited wild fires have contributed to an increased occurrence and impact of fire (Daniel 2006). Generally, the vegetation appears to have recovered once the immediate pressures are relieved but it will take the regenerating woodlands 100s of years to reach a fully mature state (Kealley 1991).

Pastoral activities: Domestic stock grazing has only affected limited areas owing to lack of suitable ground water and forage. However, pastoral interests in the region date back to 1860's and currently 43 leases cover about 17% of the GWW. Recently three leases transferred to DPaW to be managed for conservation, namely Jaurdi (1996), Credo (2007), Mt Elvire (mainly outside GWW), and a further is proposed (Mt Jackson). The remaining pastoral leases in the GWW are due for renewal in 2015.

Today, mining companies hold many of the pastoral leases resulting in a wide variety of land use practices and variable stocking rates. Pastoralists are supplementing or replacing their income with income from mining activities, sandalwood pulling and a limited tourism market, resulting in impacts of grazing being difficult to determine. Generally, grazing appears to be heavier around homesteads and water points (mainly dams) and the extremities of some stations have not been grazed as much. Locations of water points and homesteads are available from topographic 1:250,000 layers produced by Geoscience Australia (GEODATA 2009).

Some work on palatability of plants to stock, and how to assess rangeland condition in terms of favoured forage species has been published (Mitchell & Wilcox 1994; Russell & Fletcher 2003; Addinson 2012). Grazing is likely to impact on the composition, structure and cover of species in the salmon gum understorey (Graetz & Tongway 1986; Yates, Norton*, et al.* 2000; Pringle & Landsberg 2002; Clarke 2003).

The Wheatbelt is predominantly cropped (wheat and canola) and grazed (introduced pastures on cleared land. Remnant vegetation on private property may be grazed but grasses, palatable species are uncommon, and poison native species (*Gastrolobium* spp.) deter this practise.

Timber Cutting: It is estimated that between 1890 and 1964, over 30 million tons of timber were cut from an area of about 3.4 million ha in the GWW, (Kealley 1991). Harvested timber supplied fuel for power generation (steam trains and water pumping), mine infrastructure, railway sleepers and domestic fires to support a booming gold mining industry.

An intricate system of temporary railway lines, known as the woodlines, radiated out from large camps to the west and south east of Kalgoorlie. A map of the train lines and coups compiled by Ian Kealley from historical records and ground reconnaissance determined the areas that had been intensively logged. Individual operators, clearfelled blocks measuring approximately 5 yards (41 metres) frontage and extending 1 mile (1.6 km) back from the rail line.

Trees considered unsuitable for harvesting included those under 12 cm in diameter and over-mature trees, with burnt out trunks and hollows (Kealley 1991). Photographs from the woodline era confirm the stark nature of the landscape left post harvest (Bunbury 2002; Bianchi & Trovey 2007). The introduction of trucks in the 1940's resulted in coups that were larger and further from the tramlines and camps than in previous years. The clear felling activity left many stumps, some of which (depending on the species) have coppiced into multi stem trees while termites have consumed others. At one location south, just south east of Boulder, stumps were blasted out of the ground (Kealley pers. com), with a single-aged, seedling regeneration event similar to those after wildfire of flood (Yates *et al.* 1994b).

Much of the cut woodlands have recovered in the form of regrowth and coppiced trees however, insufficient time has passed to determine whether this regrowth will attain the structure present before European settlement (Williamson 1983; Kealley 1991).

Regeneration of trees was dependent on there being good seed stores, favourable weather conditions and limited grazing. The disturbance associated with harvesting activities generally promoted seed germination (Kealley 1991). It was normal practice that the residue of tree harvesting (leaves, bark, small branches etc), was left unburnt and scattered across the harvest area. There are many areas where regeneration has been prolific: some salmon gum trees between Burra Rock and Cave Hill have been observed to grow to diameters of 4½ inches (11.5 cm) in 17 years (Bunbury 2002).

A study of the effects of timber cutting on the understorey composition (Williamson 1983) revealed only slight floristic differences between cut and uncut woodland, however that study was not designed to assess the possible impact of grazing and further studies were recommended. One of the two paired plots in the Williamson study was in uncut salmon gum woodland in and near the Kambalda Timber Reserve, which prompted the location of several plots in this current study.

Mining: The impact of mining across the GWW has been significant from the early gold rush days in the 1890's in Kalgoorlie, Boulder, Coolgardie and nearby areas, through to the large scale gold extraction activities widely practiced in the 21st century. Nickel discoveries in the late 20th century has resulted in localised impacts, and in the last decade, the banded ironstone formations, which represent the highest and only significant topographic features in the landscape to the north and west of Kalgoorlie are being mined. In recent years environmental impact statement have required flora, fauna and vegetation surveys but these generally have not included the broad salmon gum flats although these are impacted by roads and infrastructure (Bishop *et al.* 2013). These extensive maze of exploration tracks, mining roads, haul roads, tailings dumps and other mining infrastructure often go through salmon gum woodlands. All have impacted on the salmon gum woodlands either directly, or indirectly though spread of weeds, changes to surface water flow, and introduction of hazards such as pits, drill holes and soil compaction (Keren Raiter pers. com.). The prolific and widespread nature of this mining activity has the potential to create significant and long-term ecological impact on the vegetation flora and fauna.

Very little work has been published regarding the revegetation of salmon gum woodlands after disturbance from mining. Restoration efforts are currently meeting with varying success (J Williams pers. comm.) and the re-establishment of salmon gum woodlands is known to be a difficult and long-term undertaking (Yates *et al.* 1994b; Yates & Hobbs 1997b; Hobbs & O'Connor 1999).

2.1.9 Fire

Fire has had a major influence on biodiversity across almost all Australian landscapes (Gill *et al.* 1981), including the GWW. The GIS section in DPaW compiled the fire history from early aerial photographs, field maps and satellite imagery (since 1972). Fires caused by lightning strikes during summer storms or by humans, are increasingly present in the GWW, leave scars obvious from aerial and satellite imagery for several decades (O'Donnell *et al.* 2010; Parsons & Gosper 2011; Gosper, Prober, Yates*, et al.* 2013). The sandplain vegetation (thickets and scrub-heath) and mallee vegetation, mainly in the west and south of the region, burns regularly at approximately 15-30 year intervals (Bell 1985; Newbey *et al.* 1995). The woodland areas do not readily burn with the exception of severe wildfire, and have considerable intervals between events. Very large wildfires have had significant and lasting impact in some areas, some exceeding 100 000 ha in size (McCaw & Hanstrum 2003). Studies of fire patterns and vegetation near Lake Johnston found that the fire intervals that will be exceeded 37% of the time, were 46 years for shrublands, 100 years for thickets and 405 years for woodlands (O'Donnell *et al.* 2010). The first major fires fully mapped for the woodlands were the extensive fires in the 1974/5 season which burnt large areas of woodland extending north into the mulga (Kealley 1991). Corridors of salmon gums growing along drainage lines, dissecting the sandplains in the west of the GWW, are in danger of being destroyed by repeated fires as the flush of regrowth easily burns in subsequent fires. This impact is also characteristic of edges of woodlands where fires have burnt in from the sandplain shrublands. In contrast the areas in the north around Kalgoorlie burn infrequently and there are large areas with no recently mapped fires (apart from an extensive fire in 1974/75) north-east of Kalgoorlie.

Recent studies along the western edge of the GWW, of *Eucalyptus salubris* (also killed by fire), attempted to estimate the time since fire of long unburnt stands and predicted a ‘U’ shaped response of the species diversity index (species density, species and Plant Functional Trait (PFT) evenness) to time since fire (Gosper, Yates*, et al.* 2013). They concur with O’Donnell that these and similar woodlands need > 200 year fire intervals to reach maturity (Gosper, Prober & Yates 2013; Gosper, Yates*, et al.* 2013).

2.1.10 Indigenous knowledge

Aboriginal history and presence in the GGW is significant and current land management by DPaW recognises the importance of incorporating Aboriginal traditional knowledge and practises. Prior to European settlement Indigenous people sustainably managed the land using fire as a means to hunt, encourage food stock and clear access (Hallam 1975).

The Ngadju people in the GWW call salmon gum marrlinja. A report (O’Connor & Prober 2010) incorporates local indigenous knowledge centred on the events and indicators of the Ngadju seasonal calendar. Their intricate knowledge of the land is still present today with active claims to native title covering a large portion of the GWW (NNTT 2007; Watson *et al.* 2008). Important are ‘water trees’ where a bowl is encouraged within the base of a multi-stemmed tree, usually a marrlinja. Some of the multi-stemmed coppices formed following timber harvesting may look similar to ‘water trees’ but these will be less than 120 years old. The salmon gum woodlands provide easy access on foot and many opportunities for hunter-gatherers to conceal themselves behind trees when hunting (Dorothy Dimer and Betty Logan pers. comm. via Richard Thackway).

Salmon gum is also known as Woonert by the Nyungar people of south-western Australia who regard it as significant in spiritual, social and practical ways. The tall trees guided the Nyungar people along their dreaming trails. They used as meeting places as ancestral spirits rested there and could provide guidance. The timber is used for weapons and food carrying implements (Fox 2001a).

2.2 Great Western Woodlands salmon gum survey

2.2.1 Field sampling design

A stratified preferential sampling design (Roleček *et al.* 2007) was implemented to get representative samples of relatively pure stands of salmon gum woodland over the vast area, within time and funding limitations. A comparison between preferential sampling and random sampling design indicated that preferential sites contained more endangered species, less weed cover and had a higher beta diversity (Michalcová et al. 2011). However, the alpha species richness and representation of alien species did not differ between the two sampling types. Although salmon gums often occur with other *Eucalyptus* species, it was possible to find stands of pure salmon gum stands, thus eliminating the influence of other trees on the understorey composition.

A set of available spatial layers (Appendix 7-1) was stratified using overlay and intersect operations in an ESRI® ArcGIS™9.2 environment. Amongst other things, this importantly identified time since last fire and the age of regeneration from timber cuttings activities. The neighbourhood-buffering tools incorporated the proximity to timber cutting rail lines, water points, homesteads and roads into the stratification. Major climatic zones were an important layer in the stratification and geology, regolith and soils provided useful reference layers both in the GIS and once on the ground. Locating plots in each of the biogeographic sub regions and vegetation systems were also selection criteria. Knowing the tenure was important; to ascertain possible influences of land management practises, for example those on pastoral leases, ex pastoral leases and reserves, and to direct access permission applications.

The age since fire was obtained from Landsat satellite imagery going back to 1970 available from the DPaW GIS corporate data and from early aerial photography dating back to 1945 (O'Donnell *et al.* 2010). Although mature woodlands are considered to be those over 200 years old it is difficult to age these without counting growth rings (Gosper, Prober, Yates*, et al.* 2013).

A digital elevation modelled surface was not used due to the coarse interval available for the whole area and the subdued topography. It was inherent in some of the topographic environmental variables obtained for each site (see Section 2.4)

The above spatial layers and stratification provided rudimentary guidance to suitable plot locations. Once on the ground, final selection required incorporation of local knowledge and considerable reconnaissance.

Previous surveys, by WA Museum and the predecessors of DPaW also provided an indication of potential sites in salmon gum woodlands (Newbey & Hnatiuk 1985; Gibson & Lyons 1988; Keighery *et al.* 1993; Newbey *et al.* 1995; Gibson *et al.* 1997; Gibson & Lyons 1998, 2001a; Gibson & Lyons 2001b). Six Museum sites were re-visited in the current survey; four were resampled and two were sampled nearby as the original sites had been disturbed (by fire and a storm). Of the possible Gibson sites for inclusion in this study, only three locations were suitable to be-resampled. Plots were also placed in the vicinity of Williamson’s (1983) plots in and near Kambalda Timber Reserve. Four plots were located outside and to the north of the GWW where there were patches of unlogged woodland. The field plot selection criteria included being more than 100 m from a road or track and within a patch of homogeneous woodland dominated by salmon gum that was >1 ha (most were >10 ha). A tree was intentionally included as the woodland was open (<30% cover) in many locations and random selection of the plot may not have captured a tree and its associated ‘sheltering’ plants. There was no evidence of fire (charcoal, burnt trunks or trees) at any of the sites.

A total of 100 plots were established (Appendix 7-2). These were spread across the climatic zones in rough proportion to the area of the GWW covered by each zone; BSk (Arid Steppe cold) 49 plots, BSh (Arid Steppe hot) 36 plots, BWh (Arid desert hot) 13 plots and BWk (Arid steppe cold) 2 plots. Within these zones an attempt was made to locate plots within the range of regolith units available (e.g. alluvium, colluvium and eolian). Prior knowledge influenced this attempt as colluvium was the preferred substrate for salmon gum and there were larger areas of sandplain in BSk zone. A good representation of tenure was achieved with 36 plots on Vacant Crown Land (VCL), 26 on current pastoral leases, 19 in DPaW conservation estate, 16 on ex-pastoral leases now under the management of DPaW, and 3 on town or road reserves.

2.2.2 Field data collection

Plots were sampled spring 2011 (33 plots) and 2012 (53 plots) and in autumn 2012 (14 plots). Each plot measured 20 m x 20 m, as this size has been previously used to survey woodlands and shrublands in this region (e.g. Gibson *et al.* 1997; Meissner & Coppen 2013). Plots were aligned N/S, E/W and marked with one labelled picket in one corner (usually the NW corner), as used in previous surveys in the region (e.g. Gibson *et al.* 1997; Meissner & Coppen 2013), and 1-3 fence droppers or pickets in the other corner(s). Vegetation was recorded in layers conforming to those in the TURBOVEG database (Hennekens & Schaminée 2001) with heights defined for this project according to the National Information Vegetation System (NVIS, ESCAVI 2003); tree layer high (> 10 m, t1), tree layer low (< 10 m, t2), shrub layer high(> 2 m, s1), shrub layer low (0.5 - 2 m, s2), and herb layer (0-0.5 m, h1). Each species, assigned to one or more layers, had its identity, percentage projection cover and height range recorded. Within the 400 m^2 plots, the total plant cover in each layer and cover of litter, organic crust (algae and micro-cryptophytes) and bare ground was also estimated. Growth forms, according to the NVIS, obtained from the (Western Australian Herbarium 1998 – 2013) were assigned to each species. For each plot, altitude (GPS), aspect (zero = flat, north = 360^{o}) and an estimation of slope were recorded. Any signs of grazing, timber cutting, mining, fire or storm damage were also noted. The number of coppicing trees and number of stems per coppicing tree were counted.

Soil was sampled to a depth of 10 cm from 30 points within the plot (a grid of 25 points plus 5 random points). These were analysed at the WA Government Chemistry Laboratory for particle size (% sand, silt and clay), pH (CaCl2), EC, total N (%), total P and K (mg/kg), available K and P (HCO3), organic carbon (W/B) and exchangeable cations (Ca, Mg, Na; cmol(+)/kg) according to standard methods (Appendix 7-3).

Voucher specimens were collected for all species in each plot and species identified at the Western Australian Herbarium (PERTH), Department of Parks and Wildlife. A representative voucher for each species and vouchers that filled gaps in the Herbarium collections were lodged with the Herbarium. Three taxa with insufficient reproductive material to allow positive identification were discarded from the data set, and species that could not be distinguished consistently were grouped together. Nomenclature followed FloraBase (Western Australian Herbarium 1998 – 2013) as of November 2012.

Plate 2.1 Data collection east of Kalgoorlie (Photo by Nina McLaren)

2.3 Incorporation of Wheatbelt floristic data for range-wide analysis

Previous plot based vegetation surveys (that included salmon gum woodlands) in the Wheatbelt collected presence/absence (P/A) data from 10 m x 10 m quadrats. P/A data from 10 m x 10 m plots (within the 20 m x 20 m plots) in the GWW were combined with existing suitable Wheatbelt data. Data from only 43 pure salmon gum plots were extracted from several sources (Table 2-4): the regional SAP survey (Gibson *et al.* 2004; Lyons *et al.* 2004), a survey over eight years of mainly private remnants (WWF 2001 – 2008) and a survey of the northern sandplains between Perth and Geraldton (Griffin 1994). Five SAP plots were re-surveyed for this study in the Wheatbelt, in the same seasons as the GWW survey, to check for operator and seasonal errors that might cause the Wheatbelt data set to be artificially distinguished from GWW set.

Table 2-4 Data sources, number of plots, date sampled and availability of soil data

(GWW = Great Western Woodlands, WB = Wheatbelt)

Project	No. of plots	Date sampled	Soil data
GWW J.Harvey	100	Spring 2011, 2012	yes
WB SAP	24	Spring Oct 1997 to Sept 2000 (often 2 visits)	all but 2
WB WWF	15	Spring 2001 to spring 2008	no
WB J.Harvey	5	Spring 2011	yes
WB E.A. Griffin	4	unknown	no

The aim of the SAP survey was to sample the range of plant communities across the WA agricultural zone (Gibson *et al.* 2004; Lyons *et al.* 2004). The surveyors deliberately placed the plots in the least disturbed sites available and generally visited them twice, once in spring and a follow up in autumn. The limited remaining extent of salmon gum woodlands meant they were not typical or pristine sites. The WWF sites focused on getting a representative sample from a woodland remnant rather than sampling particular woodland community. Twenty-six of the 48 Wheatbelt sites had associated soil data.

Taxonomic updates of species names present a major challenge when databases of different dates are combined (Jansen & Dengler 2010). Where possible, taxonomy was updated, otherwise original names were used consistently across the data sets. Presence/absence records were used as cover scores were not available for Wheatbelt plots.

2.4 Environmental variables

Regional variables were derived from spatial layers many made available through the Atlas of Living Australia (ALA 2013. accessed September 2012) and DPaW corporate GIS database. Latitude and longitude co-ordinates of all the plots (Appendix 7-2), used to extract the values, were not included as they are inherent in the spatial data. The set of data variables compiled for the GWW were slightly different from those for the range-wide analyses due to the different coverage of specific data (see Table 2-5, Appendix 7-5 and Appendix 7-6). All variables were quantitative except for categorical (nominal) values for geology, nearest landforms, grazing and timber cutting. The range-wide environmental data set differed in that it did not have management indices, distances to landforms and was simplified to just regional and local sets of variables. Some of the more complex variables are defined below.

Table 2-5 Environmental variables and codes. Exceptions g= GWW analysis only, h = range-wide analysis only

code	Environmental variables	Unit	Data type	Source	Except-ions
	REGIONAL / CLIMATE (RC)		**r**		
Tann	Temperature - annual mean (Bio01)	°C	r	BIOCLIM	
Tseas	Temperature - seasonality (Bio04)	ratio	r	BIOCLIM	
TannMnx	Temperature–annual mean maximum	°C	r	BIOCLIM	
TannMnn	Temperature–annual mean minimum	°C	r	BIOCLIM	
TCPMn	Temperature - coldest period min (Bio06)	°C	r	BIOCLIM	
TAR	Temperature - annual range (Bio07)	°C	r	BIOCLIM	
TDQ	Temperature driest quarter (Bio09)	°C	r	BIOCLIM	
TWrQ	Temperature warmest quarter (Bio10)	°C	r	BIOCLIM	
TClQ	Temperature coldest quarter (Bio11)	°C	r	BIOCLIM	
TIso	Temperature Isothermality	%	r	BIOCLIM	
Pann	Precipitation - annual mean (Bio12)	mm	r	BIOCLIM	
PWetP	Precipitation - wettest period (Bio13)	mm	r	BIOCLIM	
Pseas	Precipitation - seasonality (Bio15)	%	r	BIOCLIM	
PWrQ	Precipitation warmest quarter (Bio18)	mm	r	BIOCLIM	
RAD	Radiation - annual mean (Bio20)	MJ/m2/day	r	BIOCLIM	
PAnnSeas	Precipitation - annual seasonality	mm	r	CSIRO	
AI	Aridity index - annual mean	-	r	CSIRO	
	REGIONAL / SUBSTRATE (RS)				
				ALA	
WS	Water stress index - annual mean	-		CSIRO	
MIH	Moisture Index - highest quarter mean (Bio32)	-		BIOCLIM	
SD	Soil depth	m		ALA	
	Geology/soil/regolith variable				
ALL	Alluvium		n	GIS	
COL	Colluvium		n	GIS	
EOL	Eolian		n	GIS	
SND	Sand		n	GIS	g
OTH	Other		n	GIS	g
LAT	Lateritic		n	GIS	
GRT	Granite		n	GIS	
GNE	Gneiss		n	GIS	h
	REGIONAL / GEOGRAPHIC (RG)				
VB	Valley bottom	%		ALA	
TWI	Topographic wetness index	-		ALA	
ALT	Altitude	m (a.s.l.)		GPS	
Aspect	Aspect	degrees		site data	g
Slope	Slope	degrees		site data	g
NLV	*Neighbouring landform variable*			GIS	
SL	near salt lake		n		g
DL	near drainage line		n		g
GR	near granite rock		n		g
PL	more that 3 km from SL, DL or GR		n		g
	REGIONAL / MANAGEMENT (RM)				
	Timber cutting activity			GIS	
TCI1	No evidence of timber cutting		n	own calc.	g

code	Environmental variables	Unit	Data type	Source	Except-ions
TCI2	Possible timber cutting		n	own calc.	g
TCI3	Cut for timber		n	own calc.	g
TCI4	Clear felled		n	own calc.	g
	Grazing Pressure			GIS	
GI1	Very low grazing		n	own calc.	g
GI2	Low grazing		n	own calc.	g
GI3	Moderate grazing		n	own calc.	g
GI4	High level of grazing		n	own calc.	g
GI5	Very high level of grazing		n	own calc.	g
	LOCAL / SUBSTRATE (RM)				
EC	Electrical conductivity (1:5)	mS/m	r	site data	
pH	Acidity (CaCl2)		r	site data	
OrgC	Organic carbon (W/B)	%	r	site data	
Ntot	Nitrogen (total)	%	r	site data	
Ptot	Phosphorus (total)	mg/kg	r	site data	
Pav	Available phosphorus (HCO3)	mg/kg	r	site data	
Kav	Available potassium (HCO3)	mg/kg	r	site data	
Ca	calcium (exchangeable) cmol(+)/kg	cmol(+)/kg	r	site data	
K	potassium (exchangeable) cmol(+)/kg	cmol(+)/kg	r	site data	
Mg	magnesium (exchangeable) cmol(+)/kg	cmol(+)/kg	r	site data	
Na	sodium (exchangeable) cmol(+)/kg	cmol(+)/kg	r	site data	
Sand	<0.002mm fraction	%	r	site data	
Silt	0.002 - 0.02 mm fraction	%	r	site data	
Clay	>0.02mm fraction	%	r	site data	
	LOCAL / BIOLOGICAL				
tree	Cover tree layer	%		site data	g
shrub	Cover shrub layer	%		site data	g
herb	Cover herb layer	%		site data	g
litter	Cover litter layer	%		site data	g
BG	Cover bare ground	%		site data	g
OC	Cover organic crust	%		site data	g

Climate: Data from weather stations (Table 2-1, Table 2-2, Figure 2-4) feed into climatic surfaces which are combined with digital elevation surfaces and other available independent variable grids to form the bioclimatic model, BIOCLIM, which is a component of ANUCLIM (Hutchinson *et al.* 2009; Kriticos *et al.* 2012). A wide range of climatic variables can be extracted from these models for any specific location via the Atlas of Living Australia (ALA 2013).

Explaining some of the less obvious variables: Precipitation-annual seasonality is calculated as the ratio of warm (Oct-Nov-Dec-Jan-Feb-Mar) to cool (Apr-May-Jun-Jul-Aug-Sep) season log-rainfall totals (Hutchinson *et al.* 2009)). Precipitation seasonality coefficient of variation is the standard deviation of the monthly precipitation estimates expressed as a percentage of the mean of those estimates. Aridity index (annual mean) is the average monthly ratio of precipitation to potential evaporation (pan, free-water surface). Temperature Isothermality incorporates diurnal range.

Substrate: A combined geological/soil unit derived for each plot resulted in the final categories being alluvium, colluvium, eolian, shallow sands and laterite. Alluvium is fine, water transported soils associated with drainage line, colluvium usually flanks alluvium in broad sheets and can occur over gneiss, basalt or granitic bedrock, eolian dunes are associated with salt lakes and sands are created in situ usually derived from granite. These units were derived from available 1:1 000,000 and 1:250,000 geological GIS layers checked manually in a GIS environment against 1:100,000 geology images originally mapped by the Geological Survey of WA (where available), the regolith layer (1:500 000) and the soil of WA layer (1:2 000 000). Some of the GWW units were further generalised when amalgamated with the Wheatbelt data. Map codes assigned to alluvium, colluvium, dunes and sandplain were inconsistent between 1:250,000 maps (as these are not of prime importance to geologists) were resolved using the Surface Geology of WA at the 1:1,000,000 Scale, 2010 (Stewart *et al.* 2008). The coarse regolith layer is comprised of colluvial, alluvial eolian soils formed in the Tertiary Period (<65 Myr) through the erosion of ancient mountains, that support the woodlands and sandplains (Hopper *et al.* 1996) interspersed with exposed and laustrisine (salt lake) features.

The ‘Other’ geology/soil category in the GWW analysis referred to ‘sedimentary non-carbonate and sandstone’ which and was re-classed as colluvium in the range-wide analysis as the regolith layer overlays these geological units. Soil depth, from an Australian-wide spatial layer, refers to Solum depth (surface and subsoil layers).

The atlas of soils for Australian Soils for WA (CSIRO 1967) is very general for the GWW but much more detailed for the Wheatbelt. It is not known whether this actually refers to the complexity of the soils or the level of survey. Gibson’s (2004) categories were too general for differentiating woodland types. Site collected soils data, considered to better relate to the floristic patterns, was used in preference to map-derived soil values.

Geography: The valley bottom index (VB), in ALA, was derived from a digital elevation model (DEM) as the proportion of the 9 second grid cells classed as valley bottoms according to the values of valley bottom flatness (mrVBF) and ridge top flatness (mrRTF). The topographic wetness index (TWI) was calculated from the upslope area per unit contour length and the local slope. The slope estimated at each site was near flat hence aspect was not considered influential variable. Elevation was based on broad regional levels rather that local topographic differences.

The distance from the GWW survey plots to prominent landform features in the study area include granite rocks, salt lakes and drainage lines was considered a potential influence on the soils and species occurrences. Plots more than 3 km away from a feature were classed as being on the plain.

Management: Indices pertaining to disturbances due to selected land management activities calculated specifically for this project included grazing and timber cutting (Appendix 7-4).

The grazing impact levels were assigned to each plot: GI1 - Native/feral animal grazing, plot > 5 km from water; GI2 - Native/feral grazing, plot within 5 km water; GI3 - low stock grazing on lease. not near water, low to moderate historic grazing; GI4 - medium stock grazing on lease near water, high historic grazing and GI5 - high stock grazing on lease near homestead and water, high historic grazing.

The timber cutting impact levels were assigned to each plot: TC1 - no timber cutting for commercial purposes or in a Timber Reserve or Nature Reserve and no multiple stems at the site; TC2 - near road or track near timber cutting areas or with 1-2 multiple stemmed trees; TC3 - contained within a timber cutting area (but not 4) usually with 2-3 multiple stems and TC4 - within a cutting block and within 2 km of tramline and 3 km of track, and usually more than 3 multiple stems.

2.5 Analysis

2.5.1 Data collation

Plot vegetation data were entered into TURBOVEG 2.98 (Hennekens & Schaminée 2001) which incorporated the current flora list from the Western Australian Herbarium (PERTH) November 2012. The amalgamation of the Wheatbelt data was also carried out in TURBOVEG. *Eucalyptus salmonophloia* was present in all quadrats (by design) and had much higher cover values than any other species (the values). It was removed from the analysis and its cover values incorporated as the tree cover variable. Annuals were also removed, as their dependence on recent rainfall and time of sampling, would probably make them inconsistent across years and locations.

Other studies in south-western WA discounted singletons from their analysis after preliminary investigation revealed they were of limited significance (Gibson & Lyons 1988; Markey & Dillon 2008; Meissner & Caruso 2008). When occurrences of less than five were removed prior to analysis of the large, 682 plot Wheatbelt SAP survey, there was still a 99% correlation with the similarity matrix of the complete data set. The current study retained singleton data as only one vegetation type was under analysis and they were considered as potentially informative.

Separate species and environmental data matrices constructed for the GWW analysis and the range-wide analysis were explored using clustering and ordinations methods, determination of diagnostic species and production of a two-way phytosociological table (Table 2-6).

Table 2-6 Sequential summary data analyses (g for GWW only and h for range-wide survey only).

* DAC = Data Analysis Combination of transformation, resemblance matrix and classification methods. UPGMA = Unweighted Pair Group Method with Arithmetic Mean.

Method (data)	Software	Motivation (see text for more detail)	Data set
Data collation			
Vegetation and species data entry	TvWin		
Environmental data entry	MS-Excel		
Construction of matrices (TvWin data base, excel spreadsheet)	MS-Excel (xls)		
Removal of annual species and E. salmonophloia	MS-Excel	Reduce impact of rain events and cover dominance of tree.	
Draftsman plot of environmental variables, removal of highly correlated variables and transformation if necessary	PRIMER	To obtain comparable variables	
Choosing best DAC for this data	OptimClass in JUICE	Based on commonly used DACs.	
RELATE the resemblance matrices using the Mantle Test	PRIMER	compare data from 100m^2 plots with data from 400m^2 plots	h
Classification			
UPGMA (square-root transf., Bray-Curtis) - plots for GWW data	PC-ORD 5 linked to JUICE	To classify the plots onto optimum groups and to visualise classification hierarchy	g
UPGAM (Jaccard on P/A data) for range-wide data			h
UPGMA (square-root transf., Bray-Curtis) - plots including SIMPROF	PRIMER	To compare with PC-ORD and get recommendation of number of groups from SIMPROF and to pair with the classification of species groups (see next)	g
UPGMA (square-root transf., Bray-Curtis) - species (removed single occurrences)	PRIMER	To compare patterns in species composition based on similarities in species occurrence groupings and indicator species. Only species occurrences >1 were considered useful and to reduce the list	g
Phytosociological table sorting based on classification of plots	JUICE	To visualise the classification in tabular format	
Identification of diagnostic species using fidelity (phi coeff.)	JUICE	Phi recommended by (Chytrý et al. 2002) as it is independent of the number of quadrats in the data groups	
Geographical location of communities in relation to climate & vegetation systems	GIS		
Ordination			
Detrended Correspondence Analysis, DCA on raw and Sq Rt transformed data	PC-ORD 6	To find out the length of the gradients (axis 1) to choose appropriate ordination method.	
Correspondence Analysis, CA of plots	CANOCO 4.5	Data exploration & validation of the classification.	
Principal component analysis, PCA (variance/covariance; centered matrix)	CANOCO	Data exploration & validation of the classification.	
PCA ordination with overlay of important species & classification	PC-ORD 6	Facilitation of the interpretation of the ordination plots.	

NMDS; Sq Rt transformation, Bray-Curtis resemblance	PC-ORD 6	Validation of classification.
Principal component analysis - of environmental variables	PC-ORD	determine highly correlated varables
Principal component analysis of plots with overlay of environmental vectors	PC-ORD	Facilitation of the interpretation of the drivers of the communities and ordination cloud.
Canonical correspondence analysis CCA (otlying plots removed) biplots showing the classification of plots	CANOCO	To get a better spread 2 main communities and directly relate species patterns to environmental variables
Variation Partitioning		
Partial CCA (pCCA) using grouped variables Regional and Local, RClimate, RGeogrpahic RSubstate LSubstrate and LBiotic	CANOCO	To determine the amount of variation in species data that can be explained by regional vs. local groups of environmental variables.

In preparation for the multivariate analysis, the correlations between the environmental variables were assessed for normal distribution using draftsman plots which graphed the relationships between all the variables across plots and produced an associated matrix of all pair-wise correlations (Clarke & Gorley 2006). Skewed plots of EC, P(tot) and Na suggested that they needed transforming, and log(x+1) was used (Palmer 1993). One member of each pair-wise correlation > 0.8 was removed prior to subsequent analysis.

The optimal combination of data transformation, resemblance matrix and classification method best suited to this data set was established using OptimClass (Tichý et al. 2010), a component of the JUICE package, which uses species-to-cluster fidelity to determine the optimal partition in classification of ecological communities. Cluster analyses, using PC-Ord (McCune & Mefford 2011) were derived from commonly used data-analysis combinations (DAC; Table 2-7). Twenty 20 valid combinations were tested for the GWW analysis (Appendix 7-7). An extract of combinations, applicable to P/A data (DAC 6-10), were tested for the range wide data. These were all assessed by Lotter *et al*. (2013) when they tested 322 DACs on their complex forest data set . The number of fidelity values (Fisher's Exact Test) was set at higher than 5. The ‘best’, is the DAC that produces the smallest number of groups with the highest number of diagnostic species.

Table 2-7 Options of data analysis combinations tested in OptimClass.

Transformation	Resemblance measures	Classification methods
none,	Sorenson (Bray Curtis)	Unweighted Pair Group Method with Arithmetic Mean (UPGMA)
square root (Sq Rt),	relative Sorenson	Flexible beta (-0.25)
presence absence (P/A)	Euclidean (only used with Ward's)	Ward's (only used with Euclidean measure)
log (x+1)		

To determine the hierarchical similarity between plots and whether distinct groups or a gradient pattern are present, both classification (using the method determine by OptimClass) and ordination methods were applied to the data.

2.5.2 Classification of GWW survey data

Classification of cover data was a focus of the GWW analysis as it provides a meaningful input into defining plant communities. A Bray Curtis resemblance matrix (Sørensen 1948 ; Bray & Curtis 1957) was applied to square root transformed cover data and classified using UPGMA method (Sneath & Sokal 1973), as recommended by OptimClass. A dendrogram, produced in PC-ORD, was cut off at the 6-group level (also recommended by OptimClass). Optimum groups were also suggested by similarity profile permutation test (SIMPROF, Clarke & Gorley 2006) which looks for statistically significant evidence of genuine clusters at each node in the dendrogram. This test overcomes the inadequacies of just drawing a straight line through the dendrogram.

A classification to reveal species groups (rather that plot communities) conducted on the species plot matrix gave an indication of what species were co-occurring. Single occurrences were removed and a UPGMA clustering of square root cover values on a Bray Curtis similarity resemblance (Clarke & Gorley 2006) applied. A 7% resemblance cut off on the dendrogram was the lowest to break up a single large group of species.

A two-way phytosociological table compiled in the JUICE program used a synoptic table to display fidelity, absolute frequencies, percentage constancy or categories (Tichý 2002). Diagnostic species with a fidelity >10 were colour coded to aid sorting of the table. Fidelity was calculated using phi coefficient (Tichý & Chytrý 2006) with thresholds for fidelity, frequency and cover were set at 10%, 10% and 30% respectively. Average fidelity and sharpness values were produced and used to compare the ‘tightness’ of the communities identified by the classification As the cover estimates in this survey were consistently collected it was appropriate to use cover values in the measure. In large data sets with temporal fluctuations and observer bias a fidelity measure based on presence/absence may be more appropriate (Chytrý et al. 2002). All groups were standardised as equal sized and the size of the target group was 16.67% (default) of the total data set. The Fisher’s test gave zero fidelity to species with a significance of <0.05. The species composition of the resulting communities was compared with, and informed by, the species group classification and the PCA ordinations (below). The final table incorporated the precipitation gradient as the plot order within each community and weighted averages of precipitation in the species order.

2.5.3 Classification of range-wide data

OptimClass (Tichý et al. 2010) was applied to P/A data from 100m^2 plots to determine which combination of data analysis suited each of the following data sets :

- the GWW 10 x 10 m salmon gum woodlands only (to compare with the results (Section 2.5.2) from the 400 m^2 cover data),
- Range-wide salmon gum woodlands.

Mapping the resulting communities demonstrated their geographical relationships. Diagnostic species selected as above and a two-way phytosociological table highlight the species composition of each community and the gradient of species turnover across the two regions.

Further information pertaining to the diagnostic species obtained from the Herbarium database enhanced the floristic descriptions of the identified communities and determined how distinct these communities were in a broader sense. FloraBase (Western Australian Herbarium 1998 – 2013) contains a comprehensive collection of specimens from the WWF woodlands survey (WWF 2001 – 2008) together with a good representation from the SAP survey (Gibson *et al.* 2004; Lyons *et al.* 2004). Both of these include details regarding vegetation structure, soils and co-occurring species. However, descriptions of early collections predominately describe structure of associated vegetation (not associated species) and collection locations may be biased towards collections along roads or from localised surveys, such as those focussing on BIF and greenstone ranges. There are relatively few collections from the sandplain shrublands in the GWW and areas away from roads.

2.5.4 Ordinations

Indirect and direct gradient multivariate analyses performed and compared gave an in-depth understanding of the relationship between the floristic patterns and the environmental variables. Indirect analysis (Whittaker 1967) involves a two-step approach of firstly preparing an ordination of the species data, then relating the pattern about the first few ordination axes, to an ordination of the environmental variables. Direct gradient analysis incorporates the environmental variables into the ordination axes.

To determine the appropriate ordination method, a detrended (by segments) correspondence analysis (DCA, Hill & Gauch 1980) and was carried out on a matrix of raw cover (un-transformed) data and square root transformed cover data for the GWW and P/A data for range-wide data set, to determine the length of the gradients. The square root transformation suited the GWW data, as it was not highly skewed with cover ranging from 0.5 % – 30 %. If the length of gradient along the first axis is larger than 4 then the data is deemed homogeneous and unimodal ordination methods such as Correspondence Analysis (CA) or Canonical Correspondence Analysis (CCA) are considered appropriate, if it is shorter than 3 then a linear method such as Principle Components Analysis (PCA) or Redundancy Analysis (RCA) are suggested (Leps & Smilauer 1999; Ter Braak & Šmilauer 2002; Ter Braak & Prentice 2004).

Gradient length was intermediate in both analyses so CA, CCA ordinations carried out in CANOCO version 4.5 for Microsoft® for Windows® (Ter Braak & Šmilauer 2002) and PCA ordinations carried out in PC-Ord 6 (McCune & Mefford 2011), were used to explore gradient patterns in the data. Overlaying the community groupings on the ordinations further interpreted the associations present in the classification.

CA analysis using biplot scaling, focused on interspecies distances on square root transformed data. If the focus is on interspecies distances/correlations rather that inter sample distances then the scatter plot (prepared in the CanoDraw option of the

CANOCO 4.5 software package) optimally presents the inter sample distances due the scaling adjustment made by the program (Ter Braak & Šmilauer 2002).

Due to the strong distortion from outlying plots in the CA analysis, a PCA analysis carried out on square root transformed cover data. The PCA analysis focused scaling on inter-sample distances, with biplot sampling where species scores were divided by standard deviation and there was no centering of samples.

To include representation of an alternative (to CA) indirect ordination method, and due to ongoing debate about the “best” ordination method (Kenkel & Orlóci 1986; Minchin 1987; Økland 1996; Austin 2013), a NMDS ordination was also carried out for comparison with the CA and PCA ordinations. This is a non-parametric approach not based on assumptions of linearity or presumption of any underlying model of species response gradients (Clarke & Gorley 2006). A medium auto-pilot mode and Sorenson (Bray Curtis) distance measure on square root transformation of the data was used (McCune & Mefford 2011).

The selectively transformed environmental data matrices were normalised and subjected to a PCA that highlighted correlated variables. Variables with a correlation of >0.5 were superimposed on the 2D ordination of the floristics to reveal the strongest correlates (McCune & Mefford 2011). The percent variation and eigenvalues of each axes revealed their contribution to the overall variation.

Direct gradient analysis, Canonical Correspondence Analysis (CCA), was used due to the species would showing a unimodal rather than a linear response along environmental gradients (Ter Braak & Šmilauer 2002). This technique directly relates the species occurrences to the environmental gradient using the power of both ordination (such as DCA, PCA and CA) and multiple linear least-squares regression. The ordination axes chosen in the light of known environmental variables impose the extra restriction that the axes be linear combinations of environmental variables. In this way community variation can be directly related to environmental variation (Ter Braak 1986; Ter Braak & Prentice 2004).

A CCA analysis performed on GWW species data was carried out in PC-ORD6 (McCune & Mefford 2011) and CANOCO (Ter Braak & Šmilauer 2002). No transformation of the cover values are needed, however two outlying groups were removed to provide a more interpretable view of the 2 main communities. The environmental variables (Table 2-5) minus correlates were selectively transformed as above. For the range-wide analysis one outlying plot on laterite was removed and a set of 35 (no regional management variables) environmental variables (with correlates removed) were used. Removal of correlated variables improved the power of constrained ordinations and ensured that the number of environmental variables is considerably less than the number of plots (Ter Braak & Prentice 2004). Both biplot and Hills scaling were trialled and as there was no obvious difference, biplots scaling was using in all CCA ordinations. Biplot scaling and focusing on interspecies distances was used, with or without forward selection of environmental variables (Ter Braak & Šmilauer 2002). Forward selection of all the variables minimised over-fitting (Wiser *et al.* 2010) and was used to rank the most important environmental variables (out of the whole set). Variables were selected manually in sequence on the basis of maximum extra fit and the statistical significance of each selected variable judged by a Monte-Carlo test with 499 permutations (Ter Braak & Šmilauer 2002).

The ordinations, classified according to the defined communities displayed in CanoDraw (Ter Braak & Šmilauer 2002), were clarified by suppressing variables, displaying nominal variable as points and enclosing each community with convex hulls, in the range-wide analysis. The larger the spread of the nominal variables (i.e. greater distance between points), and area enclosed by joining them, indicates that they exert a significant influence on the floristic patterning compared to those variables located close to each other. The distance between the symbols approximates the average dissimilarity of species composition between the two sample classes being compared, measured by their Chi-square distance (Ter Braak & Šmilauer 2002; Mucina & Daniel 2013). CANOCO also indicates co-linearity, detected when fitting variables, meaning that a variable may be collinear with another earlier in the list. Individual Variance Inflations Factors (VIF) that are over 20 revealed further correlations with other variables and therefore no unique contribution to the regression equations (Ter Braak & Šmilauer 2002). Consequently, its canonical coefficient in the ordination is unstable and does not merit interpretation. Variables with high VIF (or their correlated pair) were removed and the analysis repeated.

As the range wide data only had 126 sites with soil texture and chemical data two separate CCA were run on:

- the whole 148 plots with regional environmental variables, and
- the 126 plots with regional and local soil variables.

Partitioning the environmental variables gave a more detailed indication of the role of scale in explaining the floristic variability. A variance partitioning procedure (pCCA), carried out in CANOCO, was applied to quantify variability in the species composition provided by selected sub-sets of regional and local variables for the GWW data (Legendre & Legendre 1998; Økland 2003). This procedure was used to calculate overlapping influences (for example between climate and soil) and the proportion of the variance that was not accounted for by the full set of selected variables (Leps & Smilauer 1999). For 100 plots in the GWW, four sets of regional environmental variables and two sets of local variables were compiled. This was simplified for the range-wide data set as regional data was limited by the lack of topographic and management variables obtainable for the Wheatbelt and soil data were only available for 126 plots.

The extent to which the GWW floristic and environmental similarity matrices matched was determined using a non-parametric form of the Mantel test (using RELATE in PRIMER (Clarke & Gorley 2006) performed on Euclidean distance matrix on normalised environmental variables, with EC, shrub cover and herb cover natural log transformed, and Bray Curtis species matrix of square root transformed cover. The respective similarity matrices from the original GWW 400 m^2 plots (cover) and the in 100 m^2 plots (P/A) were compared using 2Stage in PRIMER using a Spearman rank correlation.

Also for GWW only, an unconstrained analysis, involving rank similarities, determined the individual environmental variables that ‘best’ explained the community pattern.

3 CHARACTERISING PATTERNS WITHIN SALMON GUM WOODLANDS IN THE GREAT WESTERN WOODLANDS

3.1 Introduction

This is the first regional survey focusing on woodlands of the Great Western Woodlands (GWW) in particular those dominated by *Eucalyptus salmonophloia*. Previous surveys (detailed in Chapter 1) have been general over the whole region or focused on ranges (e.g. banded ironstone and greenstone) where *E. salmonophloia* often occurs with other *Eucalyptus* species on the foot-slopes of the ranges. The extensive colluvial and alluvial flats between the ranges have not been well surveyed, apart from occasional Museum survey sites. Chapter 2 provided details about the physical and biological characteristics of the GWW in relation to the distribution and ecology of salmon gum, as well as outlining the sampling design and general analytical methods.

This chapter presents the results of an analysis of a floristic survey of salmon gum communities across the GWW. Classification and ordinations methods determine if a floristic gradient or distinct communities exist and how they relate to environmental drivers. Identifying whether there is a single entity or a set of relatively unique communities will assist land managers to conserve and manage these woodlands.

3.2 Results

3.2.1 *Floristic composition*

The family and life form composition of all species encountered when compared with other studies determines how unique the salmon gum woodlands of the GWW are. Two hundred and three taxa in 36 families were recorded with most common being in the Chenopodiaceae (37 spp.), Fabaceae (27 spp.), Asteraceae (23 spp.), Scrophulariaceae (19 spp.), Myrtaceae (13 spp.), and Poaceae, (13 spp.) families. These consisted of 128 species (63%) of shrubs, 39 (19.2 %), forbs (annual and perennial), 21 (10.4%) of grass like species which include sedges. Nine exotic species were recorded. Eighteen daisies (Asteraceae spp.) dominated the composition of the 30 annual species and eight of the nine exotic species were annuals. The 30 annuals and *Eucalyptus salmonophloia* were removed prior to analysis leaving 171 perennial taxa in 32 families recorded from the 100 plots. Common genera were *Eremophila* (17 spp.), *Acacia* (16 spp.) and *Maireana* (13 spp.).

Fifty-four perennial (and a further 15 annual) taxa occurred in only one quadrat and only eight species occurred in more than 50% of the plots (with none found in more than 75%). Common species were: *Senna artemisioides* subsp. *filifolia* (74 plots), *Scaevola spinescens* (68) *Austrostipa elegantissima* (67), *Olearia muelleri* (67), *Eremophila scoparia* (63), *Sclerolaena diacantha* (60) and *Exocarpos aphyllus* (60). The many species that only occurred in one plot contributed to the high diversity in the flora sampled. Higher numbers of uncommon taxa occurred in plots at the edge of the survey area especially to the west and south-west. Average species richness was 18.6 (per 20 x 20 m plot) for all species and 17.5 without annuals. There was no clear relationship of species richness to rainfall (Appendix 7-8) to compare with Gibson *et al.* (2004).

3.2.2 Classification of plots based on floristics

When dealing with a homogeneous community it is advantageous to have objective recommendations (via OptimClass) of the number of communities that may be present. OptimClass identified the flowing combination as the most efficient to classify the 100 GWW plots (Figure 3-1): square root transformed cover data using a Sørensen (Bray-Curtis) similarity matrix and group average (UPGMA) classification method. This data analysis combination achieved the lowest number of groups (n=6) and the highest number of diagnostic species (n=9) and is widely used in vegetation analysis internationally (Clarke & Gorley 2006; IAVS 2013). Similar studies in WA have also used these measures applied to presence/absence data (Gibson *et al.* 2004; Meissner & Caruso 2008).

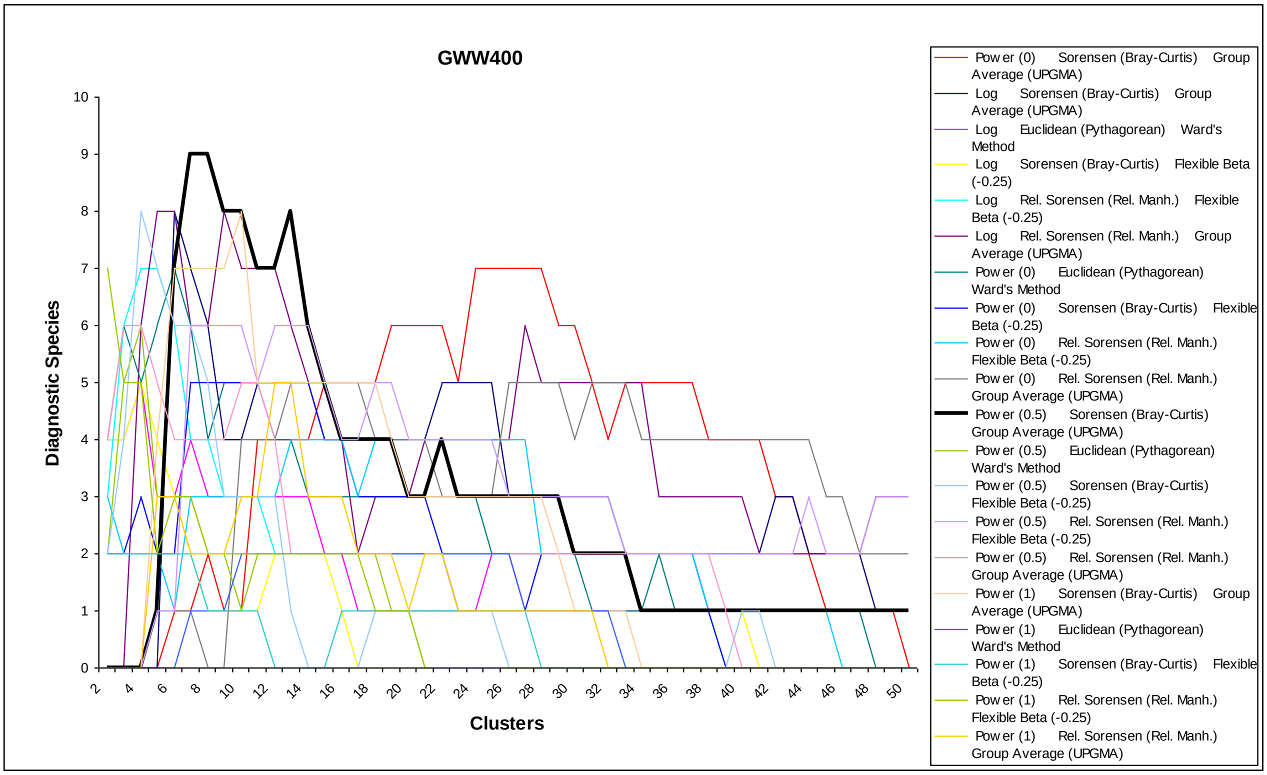


Figure 3-1 OptimClass comparison of data analysis combinations (DAC)

(see Appendix 7-7 for full list) showing that square root transformed cover data using a Sorensen (Bray-Curtis) resemblance matrix and Group Average (UPGMA) was the classification method best suited to this data set.

The six salmon gum communities identified by the 6 group cut-off on the dendrogram, (Appendix 7-9) were dominated by two substantial communities with 53 and 39 plots, and four much smaller outliers that were isolated before the main two groups were defined (Figure 3-2).

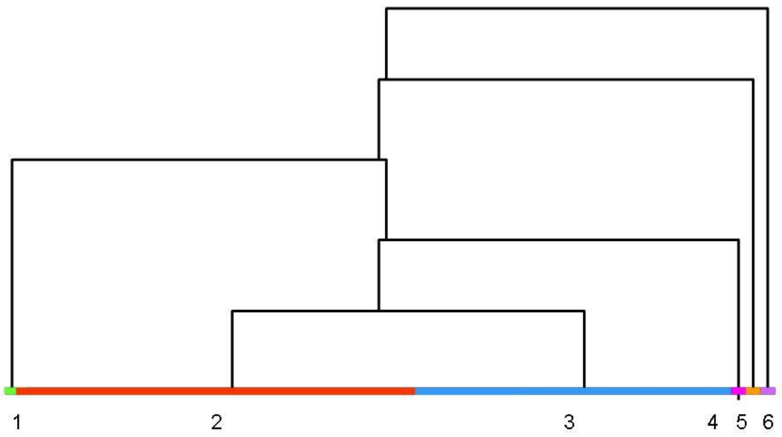


Figure 3-2 Simplified dendrogram cut off at six communities. Community 1 n=3, C2 n=53, C3 n=39, C4 n=2, C5 n=2, C6 n=1.

The same classification method applied to the data using the SIMPROF function in PRIMER determined that there were 20 communities. This result indicated a complexity in the data that may mean a larger data set is needed to clarify and describe a more complex subset of the communities. Of these 20 clusters, four had only one plot, five had two plots and two had three plots. However, a slice drawn through the PRIMER dendrogram at 23% resemblance reproduced the 6-group classification recommended by OptimClass.

The reasonable and distinct geographic distribution of the two large communities, also relates well to the climatic zones. The south-west community (2) occurs mainly in the BSk zone and the northern community spread across the BWk, BSh and BWk zones (Figure 3-3). Outlying communities 1 (plots 1, 2 and 82) and 6 (plot 60) are located on the western and the south–western margins of the survey area, both in BSk zone. These outliers were the wettest plots in the survey. Community 4 (plots 21 and 33) is located between community 2 and 3 and community 5 (plots 41 and 44) occurs within community 3.

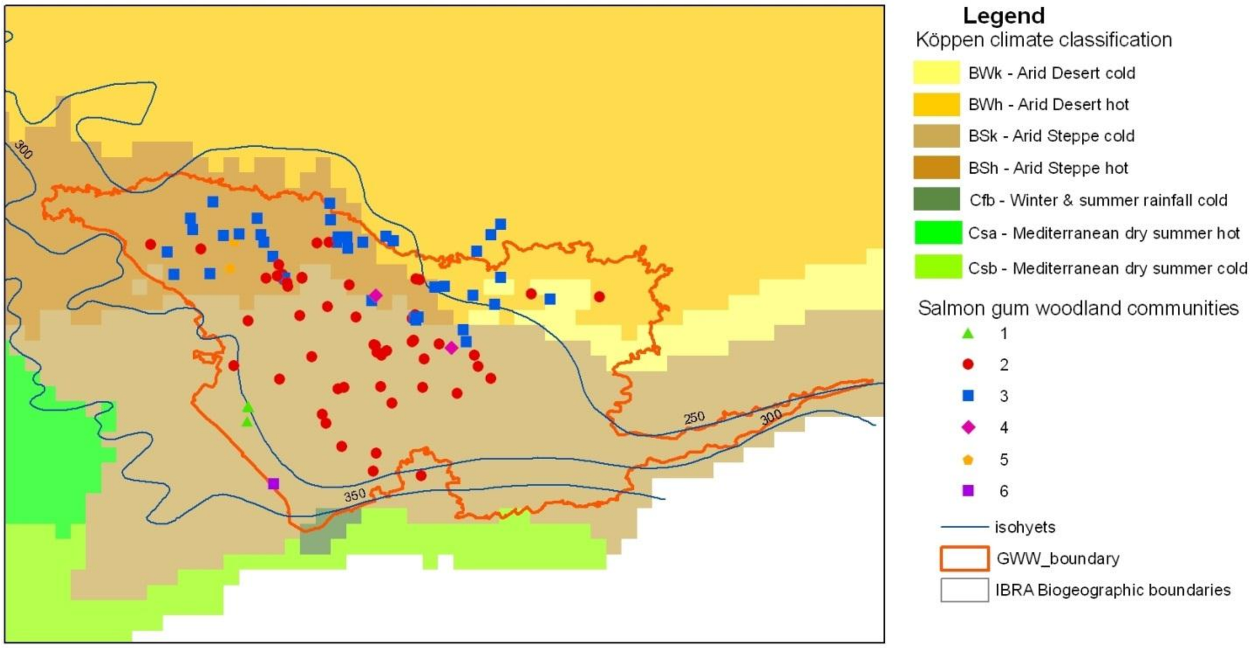


Figure 3-3 Geographic distribution of the communities in relation to climatic zones rainfall isohyets.

This north and south distribution pattern, when projected on the vegetation systems derived by Beard (Beard 1975, 1981b) as a result of his vegetation mapping, (Figure 3-4) indicated an east west sub-IBRA Boundary might be more logical than the current north-south boundary. Of the other smaller communities the western green community was confined to and the only occurrence in, the Forrestiana system and the south-west mauve plot was the only occurrence in the Hyden system that extends well into the Wheatbelt. This further suggests an alliance between this community and communities to the west. Community 4 occurred in two systems, and the fifth (orange) community is confined to the Jackson System.

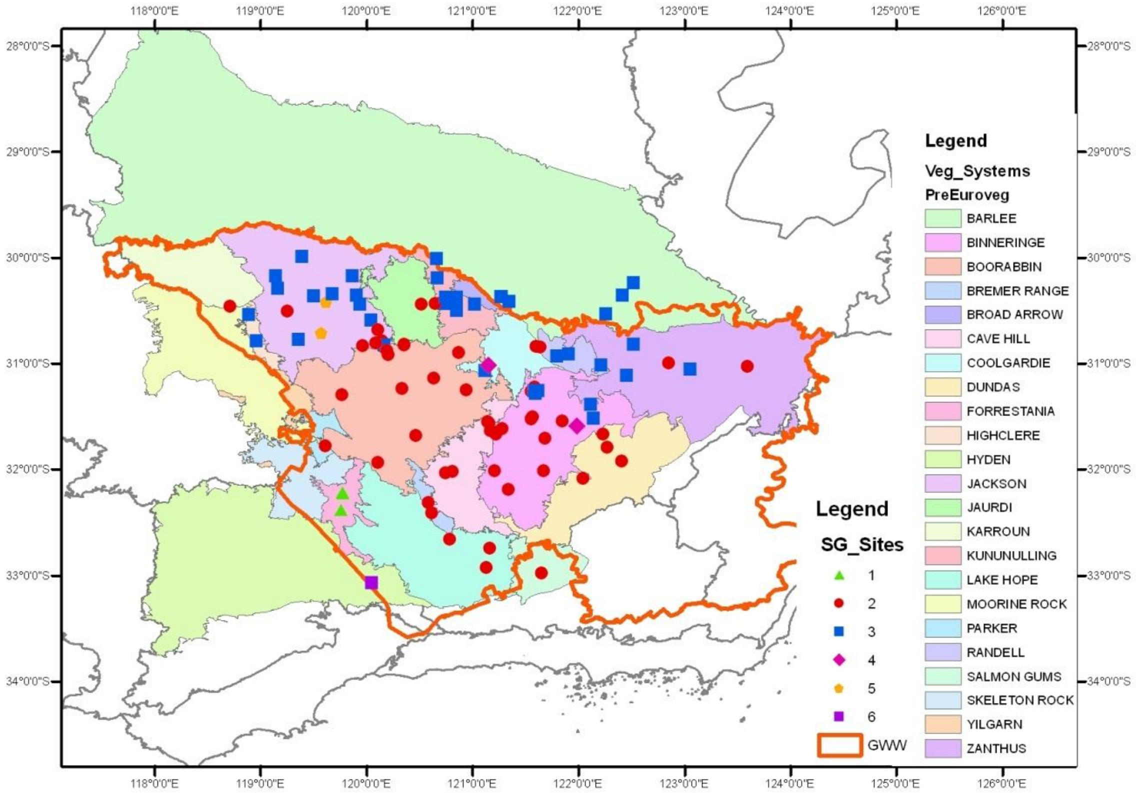


Figure 3-4 Distribution of GWW communities with respect to Beard's vegetation systems and IBRA subregions.

The floristic description of the communities based on a variety of sources includes a classification of species, consideration of fidelity and frequency of species occurrences and preference of common species in relation to the Principle Component Analysis.

3.2.3 *Classification of species*

A classification using UPGMA methods on a Bray Curtis dissimilarity matrix reveal species groups (rather that plot communities), conducted on the species plot x matrix, indicated which species were co-occurring. The homogeneous nature of the data set, all being pure salmon gum woodlands, meant that there were no easily distinguishable or explainable species groupings. A very large group of 53 species dominated fourteen groups identified. There was one group of 13 species, two of 9 spp., 1 of 6 spp. and the rest had 5 spp. or under. No species groups correlated well with any of the plot groups.

3.2.4 Descriptions of communities

The floristic composition of the communities based on the diagnostic species and the comparative sharpness values (Table 3-1) revealed the dominance of chenopods in the *E. salmonophloia-Maireana sedifolia* community and the mixed nature of the *E. salmonophloia-Eremophila ionantha* community. However, the diagnostic species were not always faithful to one community and many species occurred across the region as demonstrated by the phytosociological table (Appendix 7-10). Species frequency within a community is only one of the components of fidelity. Some species with low frequency confined to a community were indicative of that community. The species listed for communities 4 and 5 are widespread rather than restricted to those groups as no true diagnostic species are available. Average species richness is per 400m^2 plot.

Table 3-1 GWW salmon gum community descriptions (* unique occurrences)

ID	Community	No. of plots	Sharpness *	Average richness	Indicator species	Frequency
1 green	*Eucalyptus salmonophloia-Daviesia scoparia*	3	96.7	14.7	*Daviesia scoparia*	3
					Westringia cephalantha s. *caterva*	1*
					Platysace maxwellii	1
					Acacia dissona s. *dissona*	1
					Thelymitra petrophila	1
					Bentley diminuta	1
					Lomandra microphylla	1
2 red	*Eucalyptus salmonophloia-Eremophila ionantha*	53	114	17.4	*Eremophila ionantha*	
					Grevillea acuaria	12
					Alyxia buxifolia	30
					Scaevola spinescens	48
					Senna artemisioides s. *filifolia*	47
					Olearia muelleri	47
					Exocarpos aphyllus	46
					Acacia hemiteles	19
					Acacia nyssophylla	18
3 blue	*Eucalyptus salmonophloia-Maireana sedifolia*	39	98.1	17.1	*Maireana sedifolia*	
					Atriplex vesicaria	23
					Tecticornia disarticulata	4
					Atriplex nummularia	27
					Maireana triptera	16
					Paspalidium gracile	6
					Maireana radiata	7
					Sclerolaena diacantha	34

ID	Community	No. of plots	Sharpness *	Average richness	Indicator species	Frequency
4 pink	Modified form of *Eucalyptus salmonophloia-Maireana sedifolia*	2	56.2	12.5	*Eremophila scoparia*	20
					Ptilotus divaricatus	5
					Ptilotus obovatus	22
					Maireana pyramidata	2
					Sclerolaena obliquicuspis	2
					Mesembryanthemum nodiflorum	2
5 orange	Undetermined	2	61.6	16	*Austrostipa platychaeta*	2
					Solanum orbiculatum	2
					Eriochiton sclerolaenoides	2
					Zygophyllum eremaeum	2
					Chenopodium gaudichaudianum	1
6 purple	*Eucalyptus salmonophloia-Dodonaea bursariifolia*	1	171	14	*Eremophila psilocalyx*	
					Dodonaea glandulosa	
					Leucopogon brevicuspis	
					Gahnia ancistrophylla	
					Dodonaea bursariifolia	
					Coopernookia strophiolata	

Species with high fidelity, frequency and similar geographic distribution to the community (in the case of the large communities) are used to name the communities. It is premature to name a community with only one to three plots but this was convenient and consistent.

The two main communities are described fully in terms of their environmental characteristics in section 3.2.6. Of the four smaller communities identified by the classification, the *Eucalyptus salmonophloia – Daviesia scoparia* community and the *Eucalyptus salmonophloia-Dodonaea bursariifolia* community are located in the west and south west of the study area, respectively, and thus receive higher rainfall. The lower DCA gradient length achieved when these plots were removed confirms these outliers. The *E. salmonophloia-Dodonaea bursariifolia* community, based on only one plot, has five unique species: *Coopernookia strophiolata* (which extends into arid areas), *Dodonaea bursariifolia* and *Gahnia ancistrophylla* (general SWAFR species), *D. glandulosa,* (a much localised SWAFR species) and *Leocopogon brevicuspis* (a northern outlier of a south coast species)

(Western Australian Herbarium 1998 -2013). In Chapter 4, it is shown that this community is more closely aligned to Wheatbelt salmon gum woodland communities.

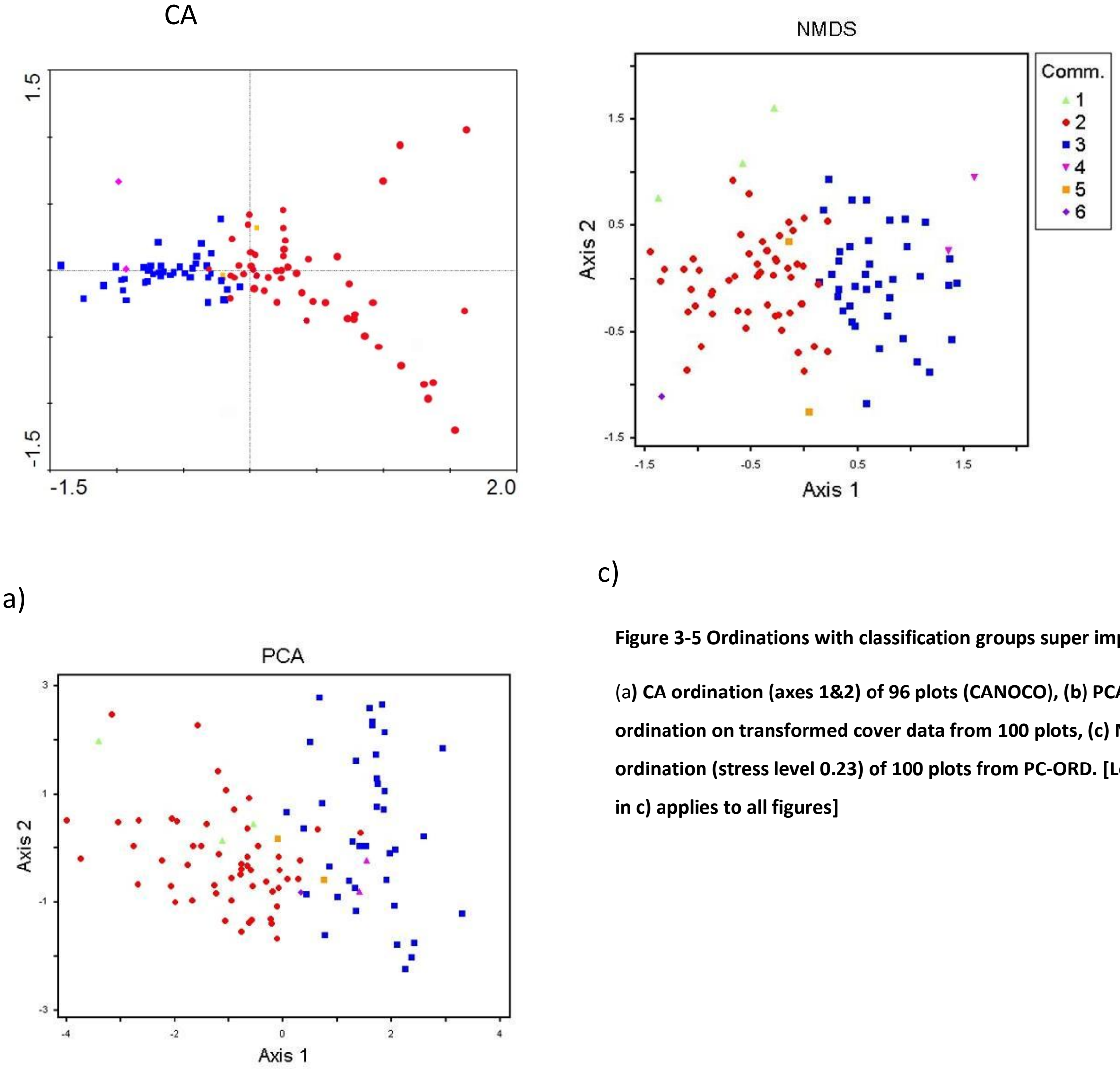
Several sources of evidence suggest that the distinction of the fourth community was associated with the *E. salmonophloia-Maireana sedifolia* community and that grazing pressure influenced the floristic composition. First the plots were located in paddocks in close vicinity to water points, second these were two of six plots with high (5) grazing level (the other three occurred in the *E. salmonophloia-Maireana sedifolia* community) and third the characteristic species tended to be unpalatable and hence remain or increase in grazed areas. Spiny *Sclerolaena obliquicuspis* and sour tasting *Atriplex stipitata* are unpalatable as are young plants of *Dissocarpus paradoxus* and *Maireana pyramidata* (Mitchell & Wilcox 1994). *Atriplex nummularia* and *Maireana sedifolia* increase in cover in grazed areas and are not grazed unless no other palatable species remain (Russell & Fletcher 2003; Addinson 2012). There were however, several palatable species present in the two plots. These included *Rhagodia drummondii*, *Maireana georgei* and three grass species. *Mesembryanthemum nodiflorum* (the only perennial exotic species recorded in the survey), occurred in one of these plots, is not preferred by stock and indicates disturbance. The high dissimilarity between the two plots comprising this community implied that this was probably a poor grouping, possibly due to the much lower average species richness compared to the other communities.

The characteristics of the fifth community were difficult to explain. Geographically the two plots were located within the *E. salmonophloia-Maireana sedifolia* community (Figure 3-3). They were not species poor and were not highly similar to each other (see dendrogram Appendix 7-9). They had not been grazed or cut for timber and had no distinct diagnostic species. Possibly replicate plots nearby may clarify this anomaly.

3.2.5 Ordination of plots

The DCA analysis on square root transformed cover data from 100 plots revealed a gradient length of 5.7. When the four most distant outliers were removed (plots 1, 2, 82 and 60 from *E. salmonophloia-Daviesia scoparia* and *E. salmonophloia-Dodonaea bursariifolia* communities) and the analysis repeated on 96 plots, the gradient length was reduced to 3.8 indicating that either unimodal ordination methods or linear methods (e.g. PCA) were appropriate. This shorter length also confirmed the status of these outliers. Un-transformed data had values of 6.3 for 100 plots and 4.9 for 96 plots. The reduced gradient length of the transformed data reinforces the advantages of using square root transformation over no transformation for this data set.

The CA ordination, performed on 100 plots was highly skewed (Appendix 7-11) but clearer when the outliers were removed (Figure 3-5a). This reiterated the influence of the outliers and their removal better highlighted the pattern in the remaining four communities. PCA and NMDS analyses carried out on 100 plots (Figure 3-5b & c) were not as strongly influence by the outliers, as for example in the case of NMDS the pattern relates to the similarity distance between plots. Plots from PCA Axes 1&3 and 2&3 further illustrated the relationships between the communities especially the outliers (Appendix 7-12).



a)

c)

b)

Figure 3-5 Ordinations with classification groups super imposed

(a**) CA ordination (axes 1&2) of 96 plots (CANOCO), (b) PCA ordination on transformed cover data from 100 plots, (c) NMDS ordination (stress level 0.23) of 100 plots from PC-ORD. [Legend in c) applies to all figures]**

All the ordinations showed a well-spaced pattern of the plots indicating gradients rather than distinct clusters (Figure 3-5). Nevertheless, a consistent separation of the two main communities was evident when the community classification overlaid the plots. The outlying plots were either intermediate (the *E. salmonophloia-Daviesia scoparia* community) or showed affinity with the two main communities (the modified *E. salmonophloia Maireana sedifolia* community), with the exception of the *E. salmonophloia-Dodonaea bursariifolia* community, which shifted around depending on the pair of axis (Appendix 7-12).

A stress level of 0.23 for the 2D NMDS was high but decreased to 0.18 for a 3 dimensions. The PCA and NMDS ordinations were similar to each other, but they showed the plots identified as outliers in the CA analysis to be more associated with the main 'cloud' of plots. Given the similarities between the PCA and MND ordinations, it was decided to proceed further with PCA ordinations to describe the communities, as clear presentation options were available in PC-Ord and CANOCO.

The PCA biplots of species and plots (Figure 3-6) highlighted the association between *Scaevola spinescens, Olearia muelleri* and *Alyxia buxifolia* and the *E. salmonophloia-Eremophila ionantha* community, and *Atriplex vesicaria, Maireana triptera, Ptilotus obovata, Marsdenia australis* and *Solanum nummularia* with the *E. salmonophloia-Maireana sedifolia* community. Plexus lines as an overlay on the ordination connect species that have strong positive associations (Goodall 1973; Mueller-Dombois & Ellenberg 1974).

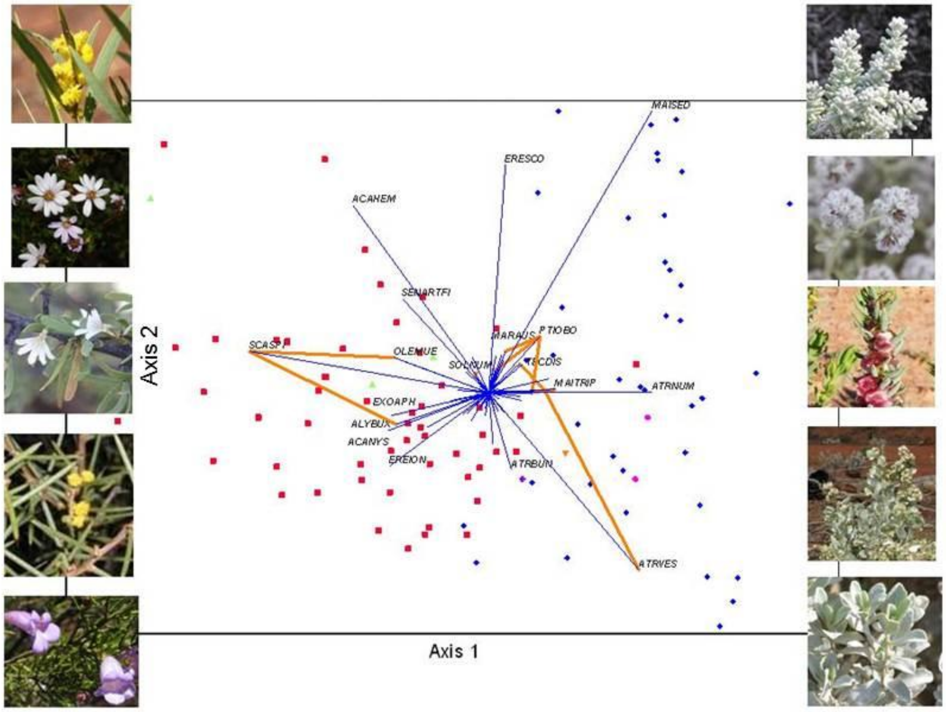


Figure 3-6 A PCA ordination (axis 1&2) for all plots with groups and important species linked by Plexus species association lines (0.4) in (orange).
Species photographs anticlockwise from lower left hand corner *Eremophila ionantha* (EREION), *Acacia nyssophylla* (ACANYS), *Scaevola spinescens* (SCASPI), *Olearia muelleri* (OLEMUE), *Acacia hemiteles* (ACAHEM), *Maireana sedifolia* (MAR SED*), Ptilotus obovatus* (PTIOBO), *Maireana trichoptera* (MAITRIP) *Atriplex nummularia* (ATRNUM and *Atriplex vesicaria* (ATRVES). Other species coded are *Eremophila scoparia* (ERESCO), *Tecticornia disarticulata* (TECDIS), *Marsdenia australis* (MARAUS), *Senna artemisioides* (SENART), *Solanum nummularia* (SOLNUM), *Exocarpos aphyllus* (EXOAPH), *Alyxia buxifolia* (ALYBUX), and *Atriplex bunburyana* (ATRBUN).

3.2.6 Correlation between environmental variables

Prior to further investigation of what environmental drivers are influencing the floristic patterns, the environmental variables were explored independently for correlations, internal patterns and how they characterised the two main communities. There were several highly correlated variables, revealed by the Draftsman plot and pair-wise correlation matrix (Table 3-2). Removing these from further analysis reduced the Variance Inflations Factors (VIF) in the CCA analysis to follow.

Table 3-2. Highly correlated variables revealed by the pair-wise correlation matrix

Code descriptions; Pann = Precipitation - annual mean, AI = Aridity index - annual mean, TannMnx = Temperature–annual mean maximum, TannMnn = Temperature–annual mean minimum, RAD = Radiation - annual mean, Tseas = Temperature - seasonality TWrQ = Temperature warmest quarter, MIH = Moisture Index - highest quarter mean, WS = Water stress index, PAnSeas = Precipitation - annual seasonality, EC = Electrical conductivity, pH Acidity, OrgC = Organic carbon , Ntot = Nitrogen (total), Ptot Phosphorus (total), Pav = Available phosphorus, Kav Available potassium, Ca calcium (exchangeable), K = potassium (exchangeable), Mg = magnesium (exchangeable), Na = sodium (exchangeable) Silt 0.002 - 0.02 mm fraction. (+) = variable retained, (-) = variable removed.

Correlation variable	Variable A	Variable B
>0.95	Pann (+)	AI (-), WS (-), TannMnx (-), TannMnn(-),
	TSeas	RAD(-), TAR(-), TWrQ(-),
	K (+)	Kav (-)
0.9 -0.94	Pann (+)	MIH (-)
	WS (-)	MIH (-)
0.85 – 0.89	PSeas (+)	MIH (-)
	OrgC (+)	Ntot (-)
0.8 -0.84	Silt (+)	K (+)
	Ptot (+)	Pav(-)
0.75 – 0.79	PSeas	TClQ (-)
	Silt	Mg (-)
	pH	Ca (-)
	EC	Na (-)

A PCA of the environmental data showed Axes 1 and 2 accounted for 13.8 % and 9.6% of the variation respectively and demonstrated correlation among the remaining variables. The variables that correlated most strongly with the PCA axes were rainfall and temperature (Table 3-3) but there is not a strong correlation between soil chemistry and the second axis an might be expected (Fox 2001b).

Table 3-3 Variables highly correlated with the PCA axes.

Code	Description	1st axis	2nd axis
Tann	Temperature - annual mean	0.805	
TCPMn	Temperature-coldest period min		-0.601
TDQ	Temperature coldest quarter		0.394
Tseas	Temperature - seasonality	0.637	
Pann	Precipitation - annual mean	-0.624	
Pseas	Precipitation - seasonality monthly avaiability	0.533	
PWrmQ	Precipitation Warmest Quarter		-0.641
PWtP	Precipitation - Wettest Quarter		0.616
pH	Acidity	0.705	
sand	<0.002 mm fraction	-0.703	
silt	0.002 - 0.02 mm fraction	0.615	
clay	>0.02 mm fraction	0.642	
Ptot	Phosphorus (total)	0.58	
Ocarbon	Organic carbon	-0.57	

The *E. salmonophloia-Eremophila ionantha* and *E. salmonophloia-Maireana sedifolia* communities had significantly different climatic preferences and soil composition characteristics (Table 3-4) calculated using a T test. The *E. salmonophloia-Maireana sedifolia* community occurred in areas with significantly higher average temperature, more specifically higher mean temperature in the coldest quarter, and lower and more variable annual rainfall. Its soils had a higher silt and clay content and were significantly higher in phosphorous, and more alkaline than the *E. salmonophloia-Eremophila ionantha* community was. Magnesium and Calcium levels, correlated with silt and pH levels respectively (Table 3-2) and were also higher in the *E. salmonophloia-Maireana sedifolia* community.

Table 3-4. Environmental characters differentiating the two main communities. EsEi = *E. salmonophloia-Eremophila ionantha*, EsMs = *E. salmonophloia-Maireana sedifolia* (See Table 3-2, Table 3-3 and Table 2-5 for descriptions of codes).

	EsEi Community n=53		EsMs Community n=39		
	average	SE	average	SE	*p* value
Tann	17.95	0.085	18.77	0.051	<0.001
Pann	261.47	2.527	239.38	2.149	<0.001
Ptot	108.51	6.971	161.03	5.308	<0.001
Pseas	24.66	0.614	29.44	0.597	<0.001
MTClQ	11.35	0.040	11.73	0.053	<0.001
pH	6.78	0.100	7.49	0.082	<0.001
Silt	12.81	0.740	19.21	1.119	<0.001
Sand	0.04	0.026	0.08	0.043	<0.001
Tseas	1.77	0.019	1.87	0.018	<0.001
OC	19.94	2.711	7.97	1.771	<0.001
PWetP	8.13	0.080	8.67	0.118	<0.001
K	1.22	0.063	1.56	0.072	<0.001
Clay	14.5	0.577	17.88	0.886	<0.01
Ntot	0.08	0.004	0.1	0.005	<0.01
EC	13.53	1.165	29.13	5.126	<0.01
TDQ	18.33	0.209	19.04	0.154	<0.01
herb	3.66	0.872	7.41	1.174	<0.05
SDth	0.91	0.038	1.05	0.045	<0.05
PAnSeas	0.41	0.030	0.29	0.043	<0.05

3.2.7 Correlation of environmental variables with the floristic pattern

Superimposing environmental variables over the PCA ordination of the floristics (Figure 3-7) showed the important variables explaining the north-south split in the floristic pattern along axis one were annual mean precipitation, % sand and organic crust increased to the left and annual mean temperature, phosphorous , pH, temperature seasonality and precipitation seasonality increased in a positive direction. Fewer environmental variables appeared to explain the apparent floristic separation along axis 2, although the strongest correlates were mean temperature in the coldest period and precipitation in the warmest quarter. The cover of herb layer and shrub layer did not show affiliation with either axis (or the 3rd Axis) but were included as they had $r^2 > 0.1$. These may be considered a product of the floristic pattern rather than an influence.

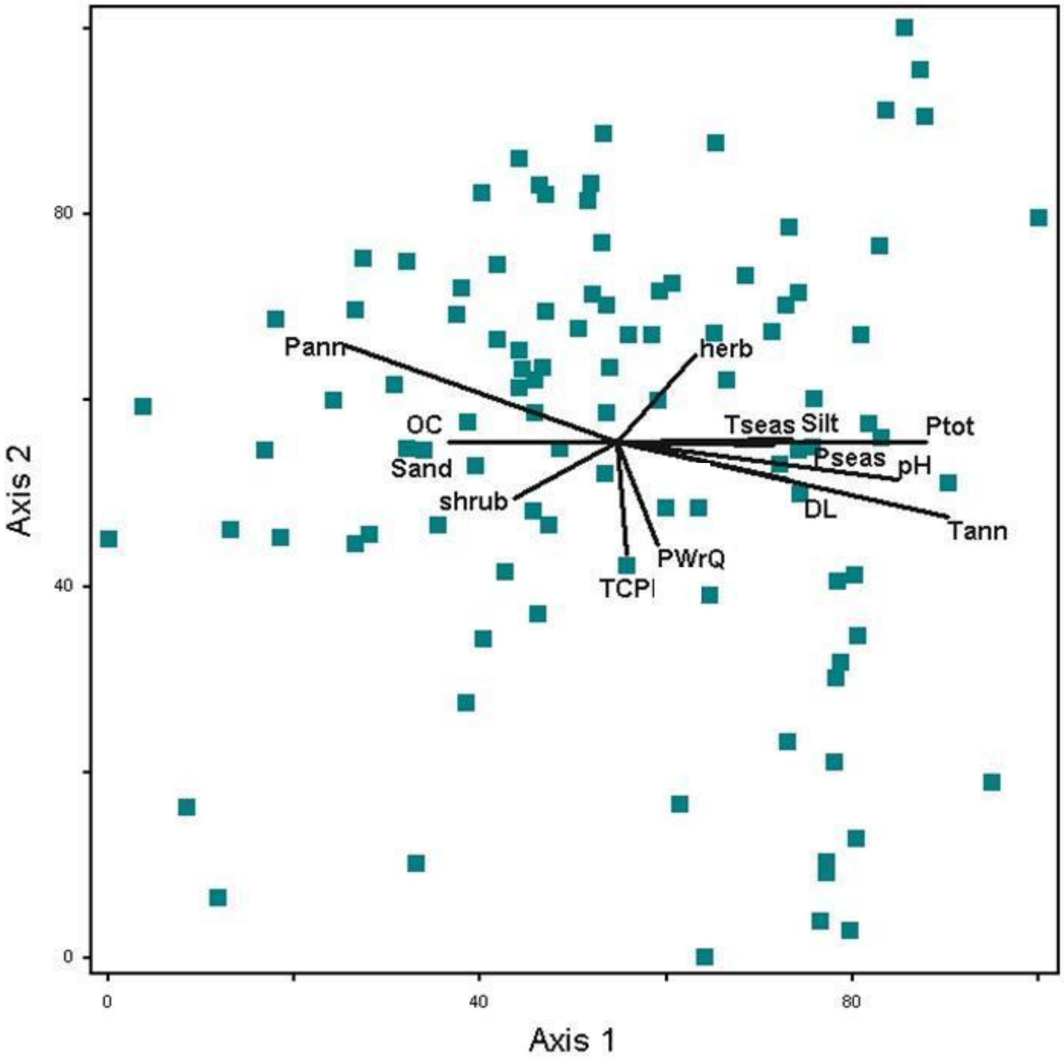


Figure 3-7 PCA ordination (PC-ORD) with superimposition of environmental vectors which have a cut off r^2 value of >0.1. Vector scaling is 150%. Communities are not included here to emphasize the pattern in the ordination. Codes; Pann = Precipitation - annual mean, Pseas = Precipitation – seasonality monthly variation, PWrQ = Precipitation Warmest Quarter, Tann = Temperature - annual mean, TCP = Temperature-coldest period, Tseas = Temperature – seasonality, pH Acidity, Ptot Phosphorus (total) Sand= <0.002 mm fraction, Silt = 0.002 - 0.02 mm fraction, fraction, herb = cover of herb layer, Shrub = Cover of shrub layer, OC = Organic Crust, DL = proximity to drainage lines.

The direct gradient or constrained canonical correspondence (CCA) analysis, incorporating the influence of the environmental variables, also indicated the importance (shown by the length of the vectors) of annual mean precipitation, annual mean temperature and the seasonality (monthly variability) of precipitation in defining the community patterns (Figure 3-8). Other important variables at the local level were the phosphorus levels, and pH of the soil samples with EC not useful in separating the two communities, as it is perpendicular to the main separation.

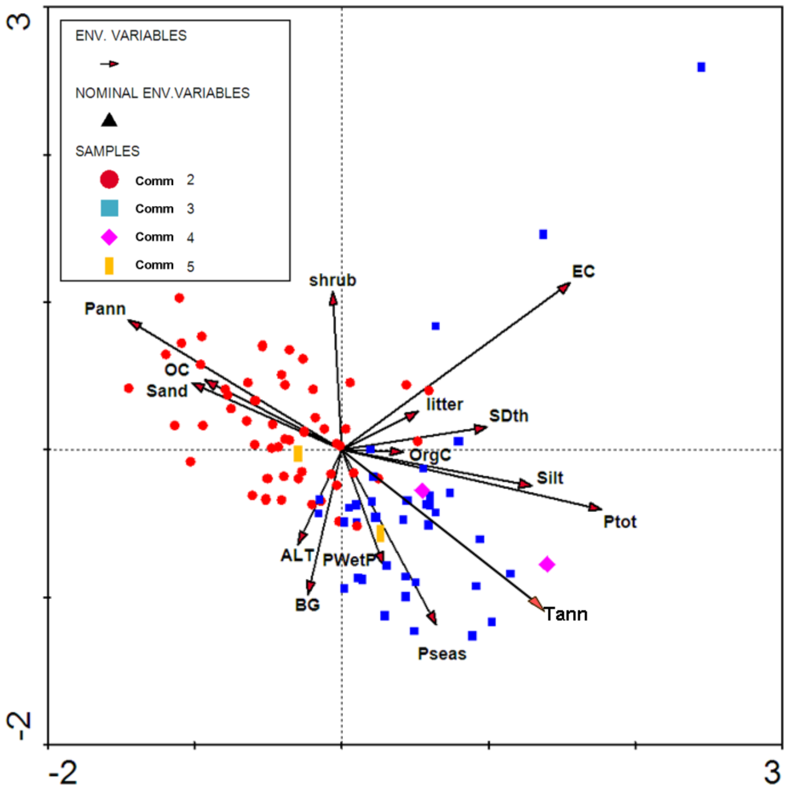


Figure 3-8 CCA of 96 plots with most relevant environmental variables (nominal variables suppressed) (See Table 2-5 for descriptions of codes).

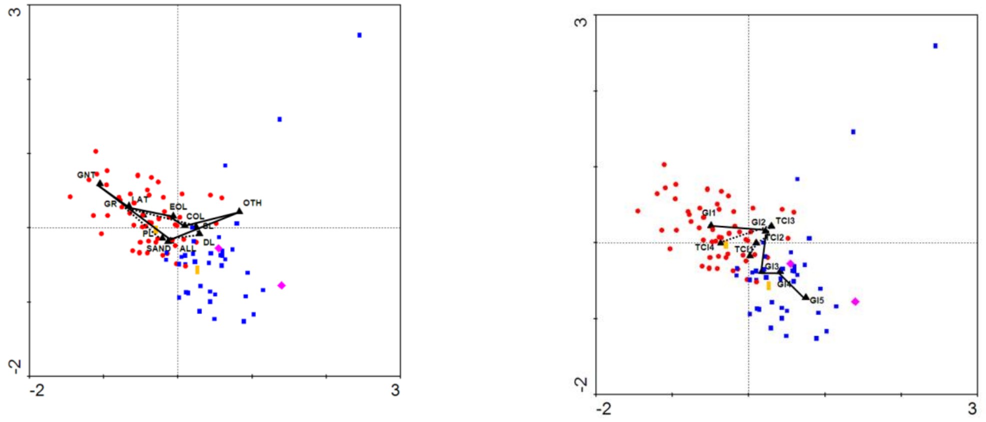


Figure 3-9 CCA of 96 plots with nominal variables a) geology and nearest landform and b) management (grazing and timber cutting) (see Figure 3-8 for legend Table 2-5 for descriptions of codes).

The influence of the nominal (categorical) variables showed the importance of geological granite and proximity to granite outcrops common to the *Eucalyptus salmonophloia-Eremophila ionantha* community (Figure 3-9a).

Geology appeared to have more influence on the floristic pattern than distance to nearest landform as shown by the greater the area enclosed by the lines joining the geological nominal variables (Figure 3-9a). The lines drawn from the lowest to the highest level of grazing go in one general direction. This indicates a gradient in floristic composition between the plots with low levels of grazing in the *E. salmonophloia-Eremophila ionantha* community, to those with high levels in the *E. salmonophloia-Maireana sedifolia* community and the modified *Eucalyptus salmonophloia-Maireana sedifolia* community (Figure 3-9b).

Associations between geology, substrate and distance from nearest landforms were evident. Substrate associated with salt lakes was associated with higher electrical conductivity (Figure 3-8). The variable for plain (away from granite rocks, salt lakes or drainage lines) was in the vicinity to the variable for sand (geology); the drainage line variable was close to those for alluvial and colluvial geology which had higher proportion of silt and clay (Figure 3-8); and as expected granitic geology was in close proximity to the variable for granite rocks to the (Figure 3-9a).

The most influential variables selected by the forward selection option in CCA were mean annual temperature, annual mean precipitation, precipitation seasonality (monthly variability), Phosphorus and silt content. These results concur with those produced by the unconstrained ordination. Cover of shrubs, bare ground and organic crust also showed a similar response but were suppressed from the CAA plot as they were considered responsive variables rather than potential drivers. Slope, shade, levels of litter cover and bare ground also appear to have little correlation with the differentiation between the two main communities.

To summarize the environmental patterns, the partial CCA showed that regional variables, accounted for 38.4% of the patterns in floristic composition and local variables accounted for 21.3% (Table 3-5, Figure 3-10). The subsets of regional climate and local substrate (soils) appeared to have similar amount of considerable influence (13.5 and 13.64% respectively), and a low level of overlap i.e. they are independent of each other There was also considerable variance unaccounted for, although this is not uncommon (e.g. Sieben *et al.* 2009). The results ultimately depend on the selection of explanatory variables (Økland & Eilertsen 1994).

Table 3-5 Percentage contributions of subsets of environmental variables explaining patterns in floristic composition.

Group	%	Group subset	No. of plots	%
ALL	53.14			
REGIONAL	38.39			
		climate	8	13
		substrate (geol)	8	9.74
		geographic	9	10.8
		management	9	10.31
			34	43.85
LOCAL	21.32			
		substrate	8	13.64
		biotic	6	9.72
			14	23.36
REGIONAL + LOCAL	59.7			
unaccounted	46.86			
overlap	6.57			
TOTAL	100			

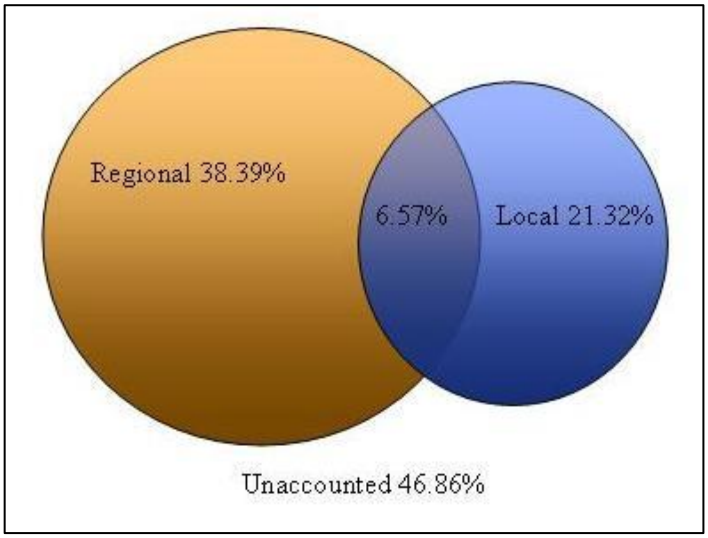


Figure 3-10 Contribution of GWW regional and local environmental canonical eigenvectors variables as calculated using partial CCA in CANOCO.

The influence of individual variables was also assessed using forward selection in the CCA. The 10 strongest variables accounted for 35% of the explained variation and were (in order) EC, mean annual temperature, mean annual precipitation, precipitation seasonality (ratio of summer the winter rainfall), phosphorus, organic carbon, organic crust, shrub cover, litter and alluvial geology .

3.3 Summary

Two clear communities were recognised by the classification of 100 plots from pure salmon gum woodlands in the GWW. The *E. salmonophloia-Eremophila ionantha* community occurred on sandy soils often mid-slope and received rainfall that is more reliable and cooler average temperatures than the *E. salmonophloia-Maireana sedifolia* community receive. The latter occurred on soils high in silt and with higher levels of phosphorous and more alkaline pH associated with drainage lines.

These communities were clearly delineated on the PCA, NMDS and CCA ordinations and in geographical space however, the communities presented in the phytosociological table were not highly distinct as, like salmon gum, many species were common across all sites.

The composition of the two small communities to the west and south of the GWW appeared to be influenced by their proximity to the Wheatbelt region to the west. The final two communities were associated geographically with *E. salmonophloia-Maireana sedifolia* community: one appeared to be influenced by high levels of grazing and the other was unexplainable (an outlier to the current data).

Over this large study area, the regional factors have such as rainfall and temperature had a somewhat stronger effect on the overall floristic gradient than the local factors such as soils. However, a high proportion of unaccounted variance indicates other, unmeasured factors may also be influential.

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4 FLORISTIC VARAITION IN SALMON GUM WOODLANDS IN SOUTH-WESTERN AUSTRALIA

4.1 Introduction

The improved understanding of the salmon gum communities in the Great Western Woodlands (GWW) (Chapter 3) allows a range-wide evaluation of the floristic variability in the understorey across the natural distribution of *Eucalyptus salmonophloia*. Knowing the differences or similarities between the Wheatbelt and GWW communities will confirm the conservation status of the woodlands. All sites will provide a benchmark against which to assess condition and measure the impact of management activities.

Salmon gum woodlands extend across the GWW and the Wheatbelt regions in south-western Australia (See Section 2.1.7). The biophysical environment, pertaining to salmon gum woodlands, is described for the two regions in Chapter 2. Less than 10% of the pre-European extent of vegetation associations containing salmon gum exist in the Avon Wheatbelt IBRA Region (Government of Western Australia 2011). Although largely intact in the GWW, the remaining populations in the Wheatbelt are in remnants and along road verges and are becoming degraded (see Section 1.1.4). Previous surveys and analyses (see Section 1.1.3) confirmed that salmon gums are a dominant component of the eucalypt woodlands of the Wheatbelt, which have been nominated as a Threatened Ecological Community under the Federal EPBC Act (Kennedy 2011) (see Section 1.1.4). This nomination identified a need to determine how different these threatened, fragmented communities are from the intact ones in the intact GWW.

The comprehensive, purpose collected data from the GWW survey, modified so that it could be supplemented with data from pre-existing surveys in the Wheatbelt, was analysed in a similar manner to the GWW survey data (Chapter 2). Combing data sets or adding sites to an existing analysis is becoming a widespread practise, as increasing amounts of data become available (Chytrý 1997; Chytrý *et al.* 2003; Illyés *et al.* 2007; Li *et al.* 2013; Wiser &

De Cáceres 2013). However, the available data in WA (not uniquely) is fragmented and inconsistent in methodology and there is a need for an integrated database storage facility to assist in the amalgamation and subsequent analysis of data sets.

The aim of this chapter was to explore the floristic variation in salmon gum woodlands over their entire range across south-western Australia and determine whether a floristic gradient or distinct regional communities exist and how environmental variables influence the patterns.

4.2 Results

4.2.1 Comparison of data sets

The resemblance matrix from the GWW 400 m^2 plots using cover data was 94% similar to 400 m^2 using presence/absence (P/A) data but this reduced to only a 74% similarity when the data were reduced to P/A in 100 m^2. To ascertain the differences between the GWW data sets, a classification, using methods recommended by OptimClass, was carried out on the GWW modified P/A data from 100 m^2 quadrats. Jaccard similarity measure and Group Average (UPGMA) method recommended 7 or 8 groups. These seven communities, especially the two major communities, showed considerable similarity, in terms of plot composition, with the six communities produced from the 400 m^2 cover data (Chapter 3). The 170 perennial taxa in the GWW 400m^2 data set was reduced to 131 recorded from the 100m^2 plots.

4.2.2 Floristic composition

Relevant floristic characteristics allow the comparison the GWW and the Wheatbelt communities and place the salmon gum woodlands in context of other western and eastern Australian woodlands.

The 200 taxa that occurred in the 48 Wheatbelt plots came from 37 families major ones being: Fabaceae (29 spp.), Chenopodiaceae (23 spp.), Myrtaceae (22 spp.), Poaceae (23 spp.), Asteraceae (16 spp.), Proteaceae (11 spp.) and Scrophulariaceae (9 spp.).

The combined data set from 100m^2 plots, with annuals, totalled 296 taxa with 84 species common to both areas, 94 taxa were unique to the GWW and 115 unique to the Wheatbelt. These belonged to 40 families, the most common being Fabaceae (44 spp.), Chenopodiaceae (36 spp.), Myrtaceae (30 spp.), Poaceae (27 spp.), Asteraceae (24spp.), Scrophulariaceae (24 spp.), Proteaceae (11 spp.) and Cyperaceae (10 spp.).

With 24 annuals (including four weeds) removed from the wheatbelt data, the remaining 178 taxa were amalgamated with the GWW data (19 annuals removed) resulting in a data set of 257 perennial taxa. Family composition was the same as above less 2 families and 16 annual Asteraceae species. Associated common genera were *Acacia* (30 spp.), *Eremophila* (22 spp.), *Austrostipa* (13 spp.) and Maireana (10 spp.). Only two species *Austrostipa elegantissima* (79) and *Olearia muelleri* (74) occurred in more than 50% of the plots spread across both the GWW, and Wheatbelt. Other common species, *Sclerolaena diacantha* and *Enchylaena tomentosa* had similar broad distributions. Chenopods such as *Rhagodia drummondii* and *R. preissii* were also common mainly in the Wheatbelt. One hundred and eight species only occurred once.

Species richness of all perennial species in the 100m^2 quadrats averaged 12.1 (range 5 to 24). Separate averages for the Wheatbelt plots were 14.1 and the GWW plots were 11.5 (17.5 in 400m^2 plots). If annuals are included, the species richness of the plots increased modestly to 14.9 for the Wheatbelt and 12.9 for the (reduced) GWW plots. There were 81 single occurrences in the Wheatbelt data set compared to 52 in the GWW 10mm^2 dataset.

4.2.3 Classification of plots

The optimal classification method for the range-wide data set, evaluated by OptimClass, was the Euclidian distance measure and Ward's method that produced 5 (or 6) Groups with up to 19 diagnostic species (Appendix 7-13). This classification of all the data produced 5 communities ranging from 15 to 52 plots. The highest similarity is between community 2 and 3, and communities 4 and 5 are the next most similar (Figure 4-1).

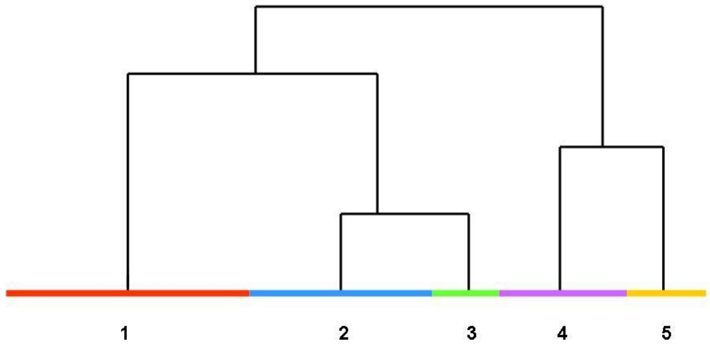


Figure 4-1 A simplified dendrogram showing relationship of the 5 communities

The primary division was essentially between the GWW and Wheatbelt sites. The green community (3) was most similar to the GWW plots (Figure 4-1) but geographically spread across the two regions (Figure 4-2).

The striking feature about this is the similarity with the communities identified in the analysis of the GWW survey data (Chapter 3). The plot composition of community 1 corresponded well with the *E. salmonophloia-Eremophila ionantha* community and that of community 2 matched the *E. salmonophloia-Maireana sedifolia* community. More specifically a high level (82%) of plots remained faithful to the communities identified in the GWW classification (8% swapped community and 10% showed greater similarity to Wheatbelt plots). The single plot in the GWW from community 4 is one of the outliers (possibly grazed) from the previous analysis (Chapter 3).

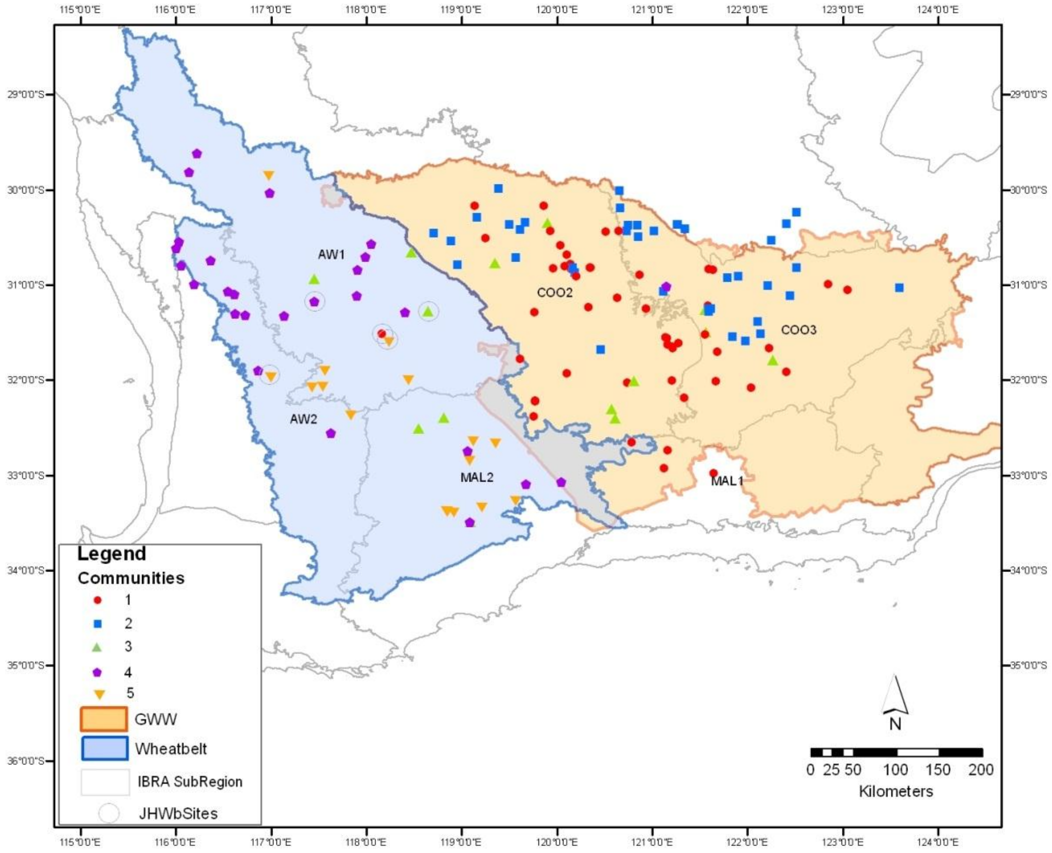


Figure 4-2 Geographic distribution of the 5 classified salmon gum woodland communities across the Wheatbelt and the GWW. (The locations of the five Wheatbelt sites sampled by author in 2011 circled).

Of the Wheatbelt plots sampled by the author in 2011, two belonged to the prominent Wheatbelt communities, one was in the inter-regional group, but one grouped with the GWW red (1) community. This indicates that observer bias was unlikely to be a major problem, but there may be a small degree of observer or temporal differences between the current and historical data sets.

There appeared to be some correlation with climatic zones (Figure 4-3). The north-eastern (2) community mainly occurs in the hot Arid Steppe and into the hot Arid Desert, the south-eastern (1) and south-western communities (5) are most common in the cold Arid Steppe but restricted to the east and west respectively. The north-western (4) community occurs in the hot dry summer Mediterranean zone in the west but extends into the western part of the hot Arid Steppe.

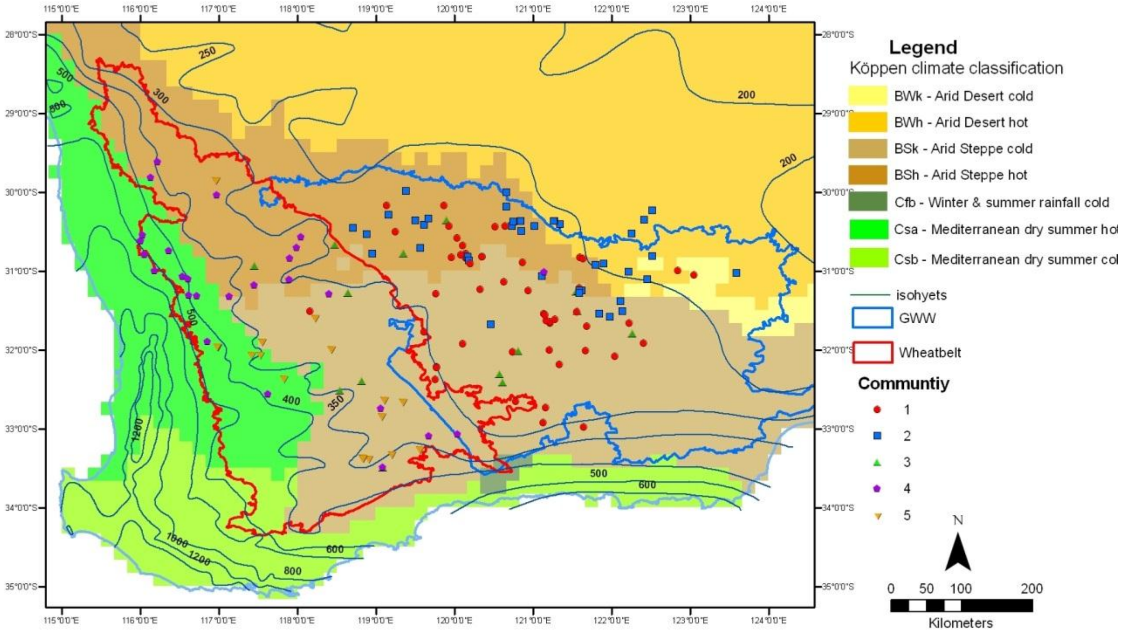


Figure 4-3 Distribution of all salmon gum communities over climatic zones

4.2.4 Descriptions of communities

The phytosociological table presents the communities identified in the classification and annual rainfall for each plot (Appendix 7-14). Indicator species for each community (Table 4-1) were also influenced by an understanding of the species' distributions and ecological preferences obtained from herbarium(Western Australian Herbarium 1998 – 2013) which also informed which indicator species to use in the naming of each community They are not necessarily the dominant component of the understorey and mainly used as a distinguishing label.

Table 4-1 Range-wide community descriptions in terms of characteristics of indicator species, distribution and associated vegetation.

ID	Community	No of plots	Av richness	Sharpness*	Indicator species	Characteristics (see key below)
1 red	*Eucalyptus salmonophloia-Eremophila ionantha* (Es-Ei)	52	11	92	*Eremophila ionantha*	#,a,d,ii
					Senna artemisioides s. *filifolia*	e,ii
					Scaevola spinescens	e
					Acacia hemiteles	c,d,ii
					Acacia nyssophylla	c,d,ii
					Eremophila caerulea s. *caerulea*	#,c ,ii,x
					Grevillea acuaria	a,d,iii
2 blue	*Eucalyptus salmonophloia-Maireana sedifolia* (Es-Ms)	36	12	81	*Maireana sedifolia*	#,c ,iii
					Maireana triptera	#,c,f, iii
					Atriplex vesicaria	a,d,iii
					Ptilotus obovatus	#,a f,iii
					Ptilotus nobilis	#, c,d,f,iii
					Eremophila scoparia	a,ii
					Tecticornia disarticulata	#,c,iii,x
3 green	*Eucalyptus salmonophloia-Melaleuca pauperiflora s. fastigiata* (Es-Mp)	15	15	65	*Melaleuca pauperiflora* s. *fastigiata*	#,c,d,i
					Atriplex bunburyana	c,d,x,iii
					Atriplex nummularia	c,ii
					Cratystylis conocephala	c,ii
					Acacia merrallii	a,c,ii
					Eremophila decipiens	e,ii
					Olearia muelleri	e,ii
4 purple	*Eucalyptus salmonophloia-Atriplex semibaccata* (Es-As)	26	10	57	*Atriplex semibaccata*	#,d,i
					Acacia bidentata	d,iii
					Daviesia hakeoides	d,ii
					Maireana marginata	#,d,ii
					Acacia erinacea	a,b,ii
5 orange	*Eucalyptus salmonophloia-Templetonia sulcata (*Es-Ts)	17	17	100	*Templetonia sulcata*	#,c,ii,x
					Lomandra effusa	b,iii
					Olearia dampieri s. *eremicola*	b,ii
					Neurachne alopecuroidea	b,iii
					Austrostipa hemipogon	b,iii
					Austrostipa trichophylla	b,iii
					Westringia rigida	e,ii
					Melaleuca lateriflora	b,ii
					Rhagodia preissii	b,ii

*** Sharpness values calculated in the analysis of constancy columns in the JUICE synoptic table gives an indication of the 'tightness' of the community. Characteristics key: #-Species distribution (in study area) is similar to community distribution, a-widespread in GWW, b-widespread in Wheatbelt, c-localised in GWW, d-localised in Wheatbelt, e-widespread across both regions, f-widespread outside study area, i-occurs mainly under *E. salmonophloia*, ii-also occurs with *Eucalyptus* spp. (woodlands & mallee), iii-also occurs under other vegetation types (in study area), x-uncommon**.

Eremophila ionantha confirmed as a suitable character species of the community (*E. salmonophloia-Eremophila ionantha*) with its own distribution localised to the GWW and the eastern edge of the Wheatbelt, where it occurs on red sandy, loamy & clayey soils. It has also has been collected from under *Eucalyptus clelandii, E. salubris E. yilgarnensis E. longicornis, E. corrugata* and several mallees (Western Australian Herbarium 1998 – 2013).

The main indicator for the *E. salmonophloia-Maireana sedifolia* community, *Maireana sedifolia*, also occurs under *Eucalyptus celastroides s. celastroides, E. lesouefii, Acacia aneura* (*sens lat*) and *Allocasuarina* low woodlands to the north and in more arid shrublands, to the east of the GWW. It often occurs on calcareous red loams but has been recorded on limestone ridges and red sands.

The *Eucalyptus salmonophloia-Melaleuca pauperiflora* s*. fastigiata* community is widespread across the whole study area but, as the low sharpness indicates, it is a diverse transitional group, with common species *Acacia merrallii, Eremophila decipiens* and *Olearia muelleri* in western plots and *Cratystylis conocephala* and *Atriplex nummularia* typical of the eastern plots. *Melaleuca lateriflora* s. *fastigiata* is associated with a mixture of soils and geological units. Saline loams associated with Eolian dunes indicate a preference for salt lake environments but many sites (50%) found on colluvial surfaces were associated with a range of soil types, in particular granitic soils. This melaleuca is commonly collected under salmon gum and gimlet (*E. salubris)*, and occasionally under *E. myriadena, E. longicornis* and *E. transcontinentalis* as well as occurring as thickets on clay loam and calcareous loam on undulating plains and valleys (Western Australian Herbarium 1998 – 2013).

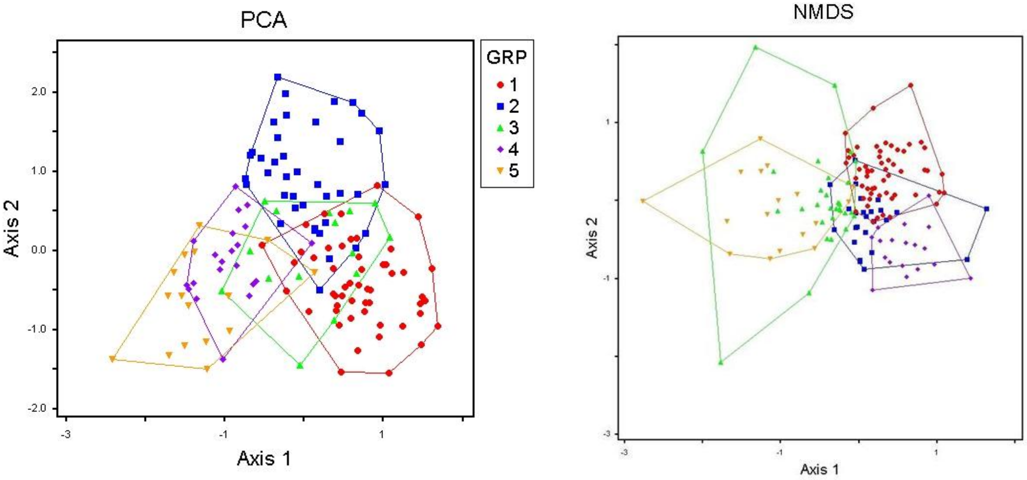
Templetonia sulcata is very often collected under salmon gums (and occasionally in *E. wandoo* woodlands) and its distribution closely matches that of the *E. salmonophloia-Templetonia sulcata* community (Western Australian Herbarium 1998 – 2013) over the wetter south-western part of the Wheatbelt.

Atriplex semibaccata appears to be a reasonable indicator of the north-western Wheatbelt *E. salmonophloia-Atriplex semibaccata* community as it is often collected under *E.*

salmonophloia (and only occasionally from under *E loxophleba, E. longicornis, E. wandoo* and *E. salubris)*. It is not like the semi-arid chenopods as occurs mainly in the western Avon Wheatbelt IBRA region on clay, sand, loam, laterite, on saline flats & lakes. Some sites in this community did not contain any of the diagnostic species but their similarity was based on other species, hence the low sharpness value. The single plot *E. salmonophloia-Dodonaea bursariifolia* community in the southwest GWW (from the GWW only analysis, Chapter 3) joined this EsAs community confirming its alignment to the Wheatbelt salmon gum woodland communities.

4.2.5 Ordinations of plots

Length of the first axis as determined by the DCA analysis is 7.9 indicating homogeneous data and that unimodal ordination methods such as Correspondence Analysis (CA) or Canonical Correspondence Analysis (CCA) are appropriate. However, the CA analysis (CANAOCO) produced a very concentrated cluster of plots and characteristically highlighted the influence of outliers. Conversely, the PCA and the NMDS ordinations of the range-wide data showed a more open spread of plots. Convex hulls enclosing each community clarified the relationships between the communities (Figure 4-4 a) and b)).



a) b)

Figure 4-4 a) PCA and b) NMDS Ordinations (PC-ORD) of range-wide plots. Community 1 red dots, 2 blue squares, 3 green triangles, 4 purple diamonds and 5 orange inverted triangles.

In the NMDS the minimum stress in real data, 50 runs, for 2D was 0.38 but reduced to 0.16 and for three dimensions, indicating that the 3-dimensional solution is preferable. The *E. salmonophloia-Atriplex semibaccata* community was consistently distinct from the *E. salmonophloia-Eremophila ionantha* and *E. salmonophloia-Maireana sedifolia* communities as demonstrated by the plots of axis 1 &3 and 2 & 3 (Appendix 7-15).

4.2.6 Correlations with environmental variables

Highly correlated environmental variables (>0.8 similarity) identified in a pair wise comparison in PRIMER resulted in total potassium (K), available potassium (Kav), (both correlated with Silt), available phosphorous (Pav) (correlated with total prosperous (Ptot)) and Organic carbon (correlated with total nitrogen (Ntot)) being removed from further analysis.

Trends on the PCA strongly correlated with precipitation and annual seasonality (proportion of winter to summer rainfall) along the first axis, and mean annual temperature and temperature isothermality along the second axis (Figure 4-5). The noticeable arch effect (in which the second axis is in an arched function of the first) could be flattened by aligning precipitation with the first axis. This action would reveal the gradient from the western Wheatbelt communities (*E. salmonophloia-Templetonia sulcata* and *E. salmonophloia-Atriplex semibaccata*) through the central community (*E. salmonophloia-Melaleuca pauperiflora*) to the eastern communities (*E. salmonophloia-Eremophila ionantha* and *E. salmonophloia-Maireana sedifolia*).

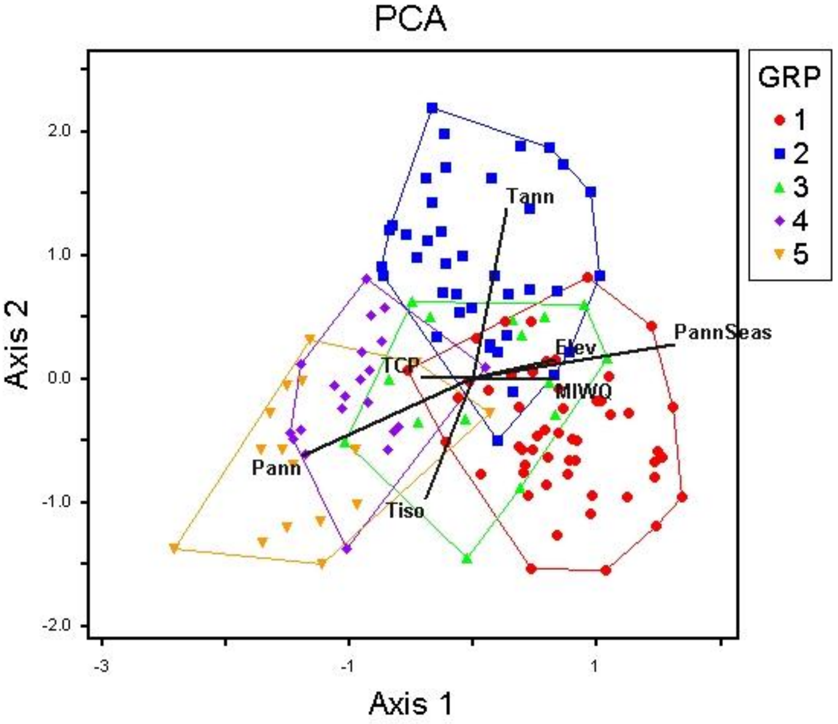


Figure 4-5 PCA biplot of all plots with regional variables overlaid chosen cut off r^2 value of 0.2.

(Code descriptions: Pann = Precipitation - annual mean, Tann = Temperature–annual mean, Pannseas = Precipitation – seasonality (ratio summer to winter), MIWQ = Moisture Index – wettest quarter), Elevation = altitude, Tiso Temperature isothermality, TCP temperature coldest period.

CCA constrained ordination clearly showed the higher similarity amongst the GWW plots and their distinctiveness from the two Wheatbelt communities (Figure 4-6) especially discounting the outlying *E. salmonophloia-Atriplex semibaccata* plot. The graph clearly confirms the cross-regional nature of the *E. salmonophloia-Melaleuca pauperiflora* community. Increasing annual mean temperature to be a strong driver of the *E.*

salmonophloia-Maireana sedifolia community composition, whereas the seasonality of the precipitation, increase in moisture index in the wettest quarter, elevation, topographic wetness index and valley bottom index all influence the floristics of the *E. salmonophloia-Eremophila ionantha* community. In the west, higher rainfall, warmer temperature in the wettest period, and the isothermality appear to drive the more open distribution of the Wheatbelt plots.

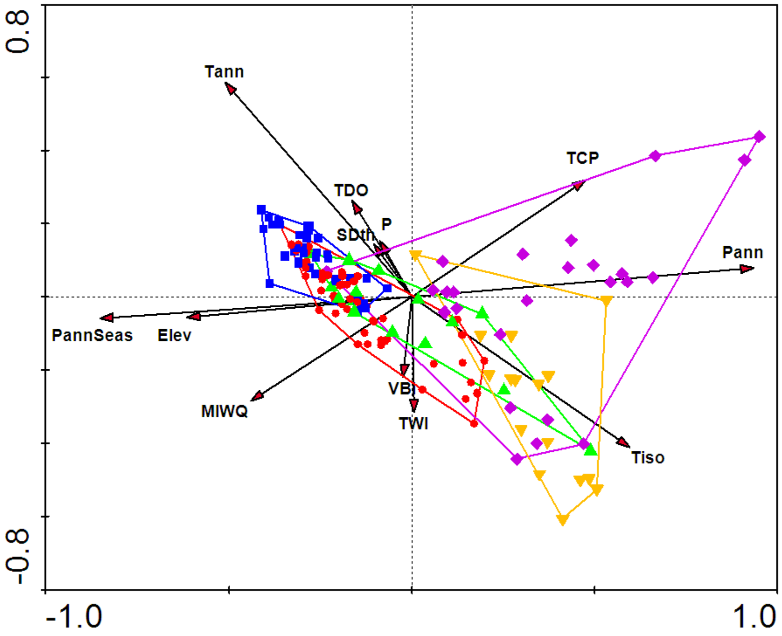


Figure 4-6 CCA (CANOCO) Ordination of all plots with regional variables. Variables with short vectors and some outlying plots were suppressed to enhance the interpretation of the graph.

Codes additional to Figure 4-5: TDO = temperature diurnal range, VB = valley bottom index, P = phosphorous, SDth = soil depth, TWI = topographic wetness index.

The associated statistics also confirmed the most significant variables were annual precipitation, annual temperature, precipitation seasonality, temperature of the driest quarter and isothermality (Table 4-2).

Table 4-2 Significance and level of variance of regional environmental variables calculated using automatic forward selection CCA (CANOCO)

Variable		variance		p-value
Pann	Precipitation - annual mean	0.55	**	0.002
Tann	Temperature - annual mean	0.35	**	0.002
PannSeas	Precipitation - annual seasonality (ratio Summer to winter)	0.25	**	0.002
TDQ	Temperature driest quarter	0.18	**	0.002
Tiso	Temperature Isothermality	0.18	**	0.002
TCP	Temperature - coldest period	0.17	*	0.01
Gnt	Granitic substate	0.19		0.012
Elev	Altitude	0.17		0.024
Eol	Eolian substrate	0.16		0.076
MIH	Moisture Index - highest quarter mean	0.14		0.084
TWI	Topographic wetness index	0.14		0.202
All	Alluvium	0.13		0.236
Ptot	Phosphorus (total)	0.13		0.264
SD	Soil depth	0.14		0.276
VB	Valley bottom index	0.12		0.378

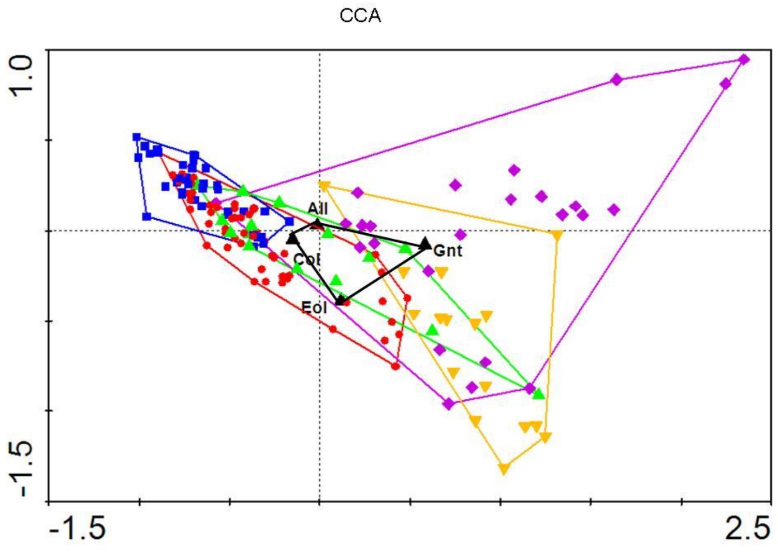


Figure 4-7 CCA showing regional geology/soil nominal variables.

Code descriptions All = alluvium, Col = colluvium, Eol= Eolian, Gnt = Granite (laterite plot suppressed as an outlier)

Plots surrounding each nominal substrate geology/soils/regolith variables indicate an affinity with that variable. These variables are located relatively close to each other, creating a small area when joined, indicating that they are not highly significant in driving the floristic pattern (Figure 4-7). The spread of different groups around each substrate variable also indicates a poor correlation.

Characteristically salmon gum in the GWW occurs on colluvial and alluvial geology. Over 80% of the *E. salmonophloia-Maireana sedifolia* community and nearly 70% of the *E. salmonophloia-Eremophila ionantha* community occurred on these substrates (Figure 4-7. Soils derived from granite appear to be characteristic of the wheatbelt communities although many plots are on alluvium and colluvium. The western *E. salmonophloia-Atriplex semibaccata* community composition correlated with the presence of gneiss and alluvial substrates as well as laterite and granite. The south-western community, *E. salmonophloia-Templetonia sulcata*, was influenced by laterite and granite. The cross–regional *E. salmonophloia-Melaleuca pauperiflora* community was associated with granite, laterite and sandplain colluvium in the Wheatbelt communities and is on basalt with the GWW.

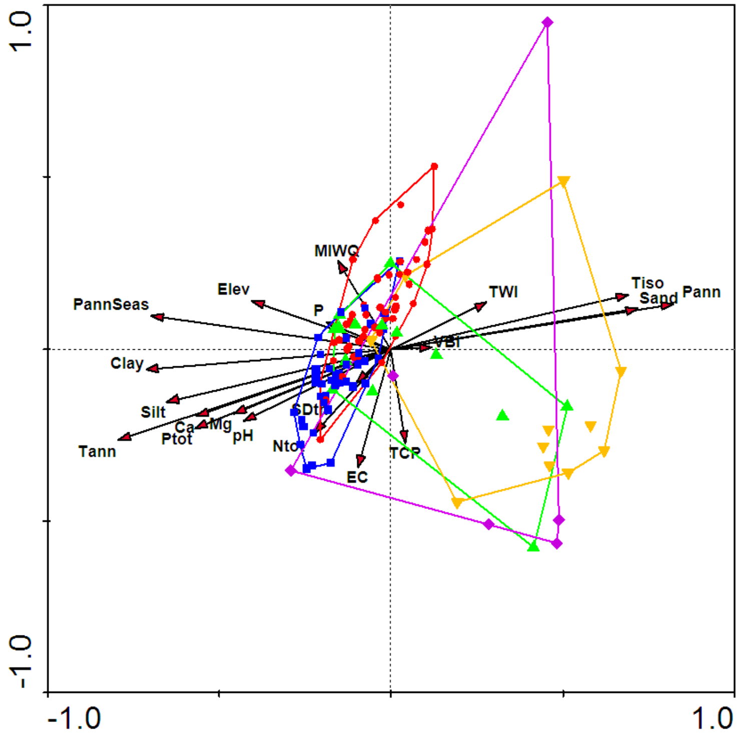


Figure 4-8 CCA inter sample ordination (Axis 1 & 2, CANOCO) the 121 plots with regional climate and local soil (geology and soil nominal variables suppressed. Plots 104, 147 &148 suppressed to get better spread of the remaining plots

Available site soil data incorporated into the CCA reduced the number of plots to 126. However, the graph still showed a similar pattern to the 148-plot analysis, with the plots in the eastern communities more clumped (Figure 4-8). The patterns reiterated the findings of the GWW survey with the eastern plots having high clay content correlating with higher level of nutrients (P, Ca, Mg and N) and pH. Western communities influenced by higher rainfall, sandier soils and higher isothermality.

The partial CCA revealed that the total set of environmental variables accounted for only 23.19% of the variation in species composition with the regional variables (climate, geology/soil/regolith unit) accounting for 16% and only 10.3% influenced by the plot based soil variables, with a 4.1% overlap (Table 4-3 and Figure 4-9). The best 10 variables (accounting for 14.4% of the total variation or 61.9% of the explained variation) in order of importance are annual average rainfall, laterite, annual average temperature, precipitation seasonality (monthly variation), sand, total phosphorous, granite, temperature in the driest quarter, isothermality , temperature in the coolest period and elevation.

Table 4-3 Contribution of environmental variables to the floristic variation 124 plots (all, regional and local.

Variables	Variance explained	%
Total inertia	19.49	100
Total explained	4.52	23.19
Regional	3.31	16.98
Climate	2.44	12.52
Geol/soil	0.99	5.08
Local soil	2.01	10.31
Regional local overlap		4.10
unaccounted		76.81

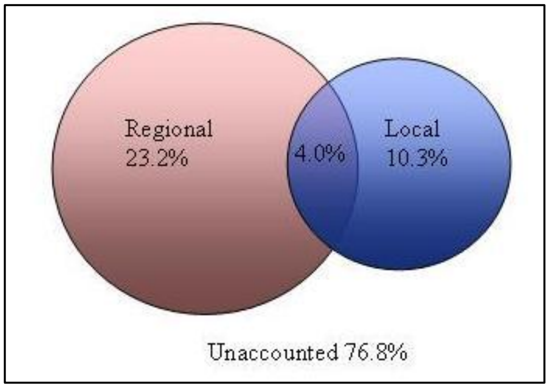


Figure 4-9 Contribution of range-wide regional and local environmental canonical eigenvectors variables as calculated using partial CCA in CANOCO.

4.3 Summary

There are potentially six communities of pure salmon gum woodlands with strong regional characteristics. The two communities in this range-wide analysis concur with those recognised in the GWW analysis (Chapter 3). The Wheatbelt communities are more tenuous reflecting the paucity of suitable sites and the different focus of the surveys. Regional climate in particular temperature, precipitation and the ratio of summer to winter rain are important drivers of this pattern however there is considerable unexplained variation.

5 DISCUSSION

The inaugural survey of salmon gum understorey of the Great Western Woodlands (GWW), undertaken in this study, contributes to the first floristic analysis of pure salmon gum woodlands across their range. It is also the first cross-regional plot based analysis to have been conducted for any vegetation type spanning the Wheatbelt and the GWW regions of south-western Australia. The results enhance the understanding of the gradational and community floristics patterns and show how they relate to regional and local environmental factors. Comparisons of floristics (family, genera and species) and life forms (annuals, perennials), origins (native or exotic), species richness and community composition made with other temperate woodlands in western and eastern Australia, reveal similarities and contrasts. The limitations of studying pure woodlands of a species, *Eucalyptus salmonophloia*, which commonly co-occurs with other *Eucalyptus* species, became apparent.

The results indicate regional distinctiveness in salmon gum woodlands, in particular establishing compositional differences between Wheatbelt salmon gum woodlands and those found in the GWW. This result has important implications for the assessment of the conservation status of threatened Wheatbelt eucalypt woodland communities. Moreover, the results suggest changes to sub-regional boundaries within the GWW. In addition, there is potential for using the data to model community distributions and monitor changes resulting from man-made activities.

The only previous consideration of salmon gum across its entire range is the state-wide vegetation survey (Beard 1975; Beard 1981a). Although this produced detailed maps with many vegetation associations containing salmon gum, few descriptions incorporated quantitative understorey composition. Beard’s maps, based on ground traverses, did not include plot-based data or numerical analyses. Of the many plot-based surveys conducted either in the Wheatbelt or in the GWW, only three surveys (SAP, kwongan and salmon gum) have crossed the regional boundary: Five of the 813 wetland SAP survey plots east of the clearing line appeared to be similar to other Wheatbelt plots (Lyons *et al.* 2004) and a kwongan plot in the GWW (east of Forrestiana crossroads) was found to be similar to 3 eastern Wheatbelt plots in a regional survey of 20 lateritic kwongan plots (Brown 1989). Conversely; the GWW salmon gum woodland plots surveyed near Mt Jackson were significantly different from Wheatbelt plots (Fox 2001b).

5.1 Regional variability in relation to other Australian studies

A gradation in floristic composition in this sample of salmon gum woodlands is consistent with findings in other woodlands studies in south-western and eastern Australia with similar widespread and continuous distributions (Beadle 1981; Gillison 1994; Howling 1996; Prober 1996; Yates & Hobbs 2000). This gradient of species turnover relates strongly to rainfall, concurring with other studies (e.g. Brown 1989; Prober & Thiele 2004). There is some similarity between the floristic composition between the wetter Western Australian communities and the drier parts of the temperate woodlands in central New South Wales and Queensland.

5.1.1 Floristic composition

Within salmon gum woodlands, more species in Poaceae, Myrtaceae, Proteaceae and Cyperaceae families occurred in the wetter western part and more Chenopodiaceae species occurred in the drier eastern end of the rainfall gradient. Fabaceae and Scrophulariaceae species were common across the whole range. Fox (2001b) also noted the importance of Fabaceae and Chenopodiaceae in salmon gum understorey in the central Wheatbelt and western GWW. The common genera follow similar patterns to the family composition, with more species of *Acacia* and *Austrostipa* recorded for the Wheatbelt than the GWW and a similar number of *Eremophila* species in each area. The low proportion of grasses in the GWW could be a natural characteristic or influenced by the lack of short-lived grasses and good flowering material found during the 2011/12 survey.

The dominance of Chenopodiaceae and Fabaceae families in the GWW was consistent with other surveys of woodlands containing salmon gum in the region (Newbey & Hnatiuk 1984;

Newbey & Hnatiuk 1985; Newbey & Hnatiuk 1988; Keighery *et al.* 1992; Keighery *et al.* 1993; Newbey *et al.* 1995; Fox 2001b) and woodlands in general (e.g. Meissner & Coppen 2013; Meissner & Coppen 2014). The current study recorded fewer species in the Asteraceae family than the studies mentioned above, as these are mainly annuals and the dry seasons prior to sampling meant there were few annuals. There were similar numbers of Scrophulariaceae species (including Myoporaceae; Mabberley 2008).

Despite this is survey having extended well into a semi-arid region, comparisons can be made with surveys and reviews in eastern Australia (Howling 1996; Prober 1996; Sivertsen & Clarke 2000), in particular the slightly wetter temperate eucalypt woodlands (e.g. poplar box and ironbark woodlands). A survey over a similarly large area of temperate eucalypt woodlands, between Queensland and Victoria in eastern Australia, revealed that changes in the main genera of grasses, shrubs and daisies also occurred across an east-west (400 mm rainfall) gradient. However, the floristic composition was more uniform over a 400 km north-south transect with a turnover of approximately half of the understorey species (Prober 1996; Prober & Thiele 2004). Understorey genera recorded in the current study, *Eremophila, Senna, Dodonaea, Schoenolaena, Vittadinia* and *Sida,* were also present in the shrubby poplar box (*E. populnea*) community in New South Wales (Beeston *et al.* 1980). Similarly, *Maireana, Atriplex, Chenopodium, Ptilotus, Vittadinia* and *Minuria* species also occurred in the western box communities (Prober 1996). Some of the species, *Atriplex semibaccata, Dodonaea viscosa, Senna artemisioides* and *Chenopodium desertorum* common in the wetter central western plots in WA were also recorded for the drier western plots in the grassy box woodlands of the eastern states (Prober & Thiele 2004). However *Alectryon oleifolium,* only found in some of the drier plots in WA, is widespread in the wetter temperate woodlands (Beeston *et al.* 1980).

5.1.2 Life form and introduced species -predominance of annual weeds

The presence of more grasses in the wetter parts of the salmon gum woodland range shows minor similarities with the composition of grassy box woodlands in the eastern states where cover of grasses dominate wetter plots and shrubs dominate drier plots (Moore 1973; Prober & Thiele 2004). However, historically, grassy woodlands may have been more common in WA according to records of early settlers and more frequent fire regimes prior to European settlement (Mattiske 1995). Grazing in the 26 GWW plots located on pastoral leases may account for a lower cover of grasses in the eastern part of the study area.

Annuals are an integral component of temperate woodlands across the country and were recorded in all the surveys of salmon gum woodland used in this study, although they were removed from the analyses due to their sporadic spatial and temporal nature. Rainfall governs their distribution at a regional level and triggers germination at the local scale. The marked seasons of the winter-wet climate prompts spring flushes of annuals in woodlands and adjacent semi-arid regions. Native annuals are not very common in the grassy box woodlands but also show some increase in diversity and abundance in relation to increasing aridity (Prober & Thiele 2004).

Salmon gum woodlands in the GWW appeared to have fewer (15%) annual species than other woodlands in the GWW, in the Wheatbelt and in temperate woodlands generally. A larger component of the understorey in other mixed woodlands, on Credo ranges and Kangaroo Hills in the GWW were annuals (33%, Meissner & Coppen 2013) and (27%, Meissner & Coppen 2014). Over 36% or 119 annuals removed from the Wheatbelt salmon gum data set prior to analysis (Chapter 4). Gibson *et al.* (2004) stated that for the Wheatbelt “richness in the eucalypt woodland quadrats was largely composed of annuals”. The 33 % annuals he recorded from duplex soils that commonly support woodlands verified this. Studies in York gum woodlands show that these have a very high proportion of annuals (Prober & Wiehl 2012). The paucity of annuals in the GWW salmon gum woodlands could be a natural occurrence due to infrequent, unpredictable and a-seasonal rainfall pattern or a survey specific phenomenon because of the dry pre-season sampling periods and single sites visits in the current study. Below average rainfall was received in Coolgardie, Kalgoorlie and Norseman in the month prior to each of the 2011 and 2012 sampling periods. Other factors contributing to poor diversity of annuals in salmon gum woodlands may include high litter levels or in drier areas competition for moisture by the trees and shrubs. Understanding regional patterns in the annuals in salmon gum woodlands would need further focused surveys carried out after considerable rainfall events (see 5.5.6 Future Research).

A large proportion of exotic species in woodlands was annuals and hence is subject to similar rainfall patterns mentioned above. The 3% exotics (all annuals except one) encountered in the GWW is less than the 7.5% percent found in woodland sites containing salmon gum (and often other *Eucalyptus* species) on the foot slopes of the eastern goldfields ranges (Gibson & Lyons 1988; Gibson *et al.* 1997; Gibson & Lyons 1998, 2001a; Gibson & Lyons 2001b; Gibson 2004a, 2004b; Gibson *et al.* 2012). This higher level of weeds is probably due to suitable protection (from grazing), moist microhabitats available in rocky and stony soils, and differences in pre-sampling rainfall. The high proportion (16%) of weeds in the 48 Wheatbelt salmon gum sites is an indication of the poor condition and fragmented nature compared to the intact GWW, but differs from the 1% recorded by Fox (2001) from ungrazed salmon gum woodlands.

The high proportion weeds that are annuals are a similar feature in temperate woodlands across the country, for example (Lunt 1990) found a high proportion of weeds (90%) under herbaceous grassy woodlands in western Victoria. Prober (1996) similarly recorded a significant proportion of weeds, the abundance of which was related to different landuse histories. Therefore the interrelation ships between annuals, exotic species, grazing and climate is pertinent to the condition and continuing viability of salmon gum woodlands.

5.1.3 Species richness

The higher average species richness and the greater number of unique species in the Wheatbelt plots (14.1, 81 spp/100 m^2) compared to the GWW (11.5, 52 spp/100 m^2) could be due to most of the Wheatbelt plots being visited twice at different times of the year and the WWF plots may have been placed on ecotones rather than within an identifiable community. As well, higher rainfall in the Wheatbelt could increase the species density of annuals, making it more likely for them to be recorded in small plots. However, there was no significant relationship between rainfall and species richness in this data set.

The average species richness recorded for of salmon gum woodlands at the 100 m^2 scale across the GWW and the Wheatbelt (12.1 spp./100m^2) is considerably less that that recorded for other woodlands in the Wheatbelt. For example Gibson *et* al. (2004) recorded an average of 34.8 spp. per 100 m^2 from woodlands on duplex soils. These woodlands also would have included wandoo (*E. wandoo*), York gum (E. *loxophleba*) and morel *E. longicornis* and *E. kondininensis*. Similarly a the higher level of species richness was recorded for York gum communities including an average of 28.23 spp. per 100 m^2 for reference sites and 18.3 spp. in grazed plots (Prober *et al.* 2011). Fox (2001b) also recorded an average of 36 spp. (including annuals) per 125 m^2 recorded from 13 plots in salmon gum, York gum (*Eucalyptus loxophleba*) and wandoo (*E. wandoo*) woodlands of good condition in the Wheatbelt. The species richness of the salmon gum woodlands in south-western Australia is well below the richness of Lunt (1990) up to 45 spp. in 1 square meter or 93 spp. from 128m^2 in temperate woodlands of southwest Victoria.

Species richness of the GWW salmon gum woodlands (17.5 spp./400 m2) was slightly lower compared to other surveys (18.4 spp./400 m^2 plots with annuals removed) containing salmon gum in the Eastern Goldfields Ranges (Gibson & Lyons 1988; Gibson *et al.* 1997; Gibson & Lyons 1998, 2001a; Gibson 2004b). These other plots were located on the lower slopes of the ranges (rather than on the wide-open valley flats sampled in the current survey) and adjacent vegetation types such as mallee or shrublands may have influenced their species composition. The species richness in plots near Mt Jackson averaged 15.4

native annual and perennial species per 125m^2 (Fox 2001b), but sampling is not directly comparable due to the bigger sized plots.

This study does not support the trend of decreasing species richness with decreasing rainfall reported by Gibson *et al.* (2004) and O'Brien (1993). There is also no indication that plots adjacent to areas of high species richness, to the north-west and south-east of the Wheatbelt, have relatively higher species richness. The areas have sharp climatic gradients which are thought promote species richness (Gardner 1944).

Many perennial and annual species recorded in salmon gum plots were single occurrences (30% of GWW species and 40% of the range-wide species). This supported the findings of Fox who reported 50% single occurrences (perennial and annual species) from 13 salmon gum plots. Fewer single occurrences (31 % all species) recorded from the more comprehensive Wheatbelt SAP survey of 682 plots is likely due to the large sample size. High number of rare species sampled here may be 'somewhere abundant or everywhere sparse' (Murray *et al.* 1999). This theory which considers the size and dispersal mechanism of plants (Murray & Westoby 2000) could be explored further using this data set.

In conclusion, despite salmon gum woodlands being relatively poor in species, there is a considerable species turnover from west to east with annuals and weeds are more common in the western wetter part of the range. Overall, they are more species poor than other woodlands in WA and the eastern states. This low species richness may be in part due to sampling time and local weather so a concentrated survey following significant rainfall events, particularly in the GWW is still needed.

5.2 Salmon gum woodland communities in south-western Australia.

5.2.1 The five communities

Five communities of pure salmon gum woodlands were recognised from this analysis. Two distinctive communities were largely confined to the GWW, two less distinct communities (in terms of distribution, characteristic environmental variables and dispersed pattern in ordination space) were occurred in the Wheatbelt and one community bridged the two regions. The substantial number of plots in each community, the adequate number of diagnostic species characterising these communities, and the lack of small outlying groups indicated that sampling across was sufficient to provide an overview of floristic structuring across the range of salmon gum woodlands.

The higher level of variation amongst the plots in the Wheatbelt communities, indicated on the NMDS and CCA ordinations by the greater spread of points, could be due to the stronger rainfall gradient, more dissected landscape (due to external drainage patterns), greater diversity in species, possible observer differences and differences in survey purpose. The slightly steeper rainfall gradient (300 – 600 mm) in the Wheatbelt, compared with 200 – 300 mm over the GWW, produced a more dissected landscape (Jutson 1950) and results in salmon gum occurring on different topographic positions. This is evident by the mix of substrate units occupied by the Wheatbelt plots. Collection records (NatureMap 2014) show that the Wheatbelt has a higher number of species (5546) than the GWW (3336, but this could partly be an artefact of collecting effort) and it is part of the globally recognised, floristically diverse Southwest Australian Floristic Region. This location could contribute to the greater diversity and more open spread of plots on ordination space. The higher plot density in the GWW communities also, reflects the narrow focus of the GWW survey.

Both the GWW analysis (Chapter 3) and the range-wide analysis (Chapter 4) recognised the two main GWW communities: *Eucalyptus salmonophloia-Eremophila ionantha* and *Eucalyptus salmonophloia –Maireana sedifolia* but with minor differences in plot composition. The *Eucalyptus salmonophloia-Atriplex semibaccata* community occurred in the western and northern Wheatbelt, the *Eucalyptus salmonophloia-Templetonia sulcata* community occurred in the in the cooler, wetter south-west and the *Eucalyptus salmonophloia-Melaleuca pauperiflora* s. *fastigiata* community spanned both regions.

Slight differences in plot membership and floristic composition between the two main GWW communities arising from the two analyses, may be due to the reduction the GWW data to presence/absence in 100 m^2 quadrats (to be consistent with surveys in the Wheatbelt). Therefore, some members in the sets of indicator species are different due to the influence of their distributions on the broader analysis.

Although the Wheatbelt communities appear dispersed, some general characteristics emerge. The higher rainfall appears to co-occur with higher sand content of the soils salmon gum were found on, with this trend extending from the GWW to the south west where the *Eucalyptus salmonophloia- Templetonia sulcata* community predominated. The distribution of the *E. salmonophloia-Atriplex semibaccata* community appears to be driven by higher temperatures and features many chenopods, although not nearly as many as the *E. salmonophloia-Maireana sedifolia* community.

The description of cross-regional community characterised by *Melaleuca pauperiflora* s. *fastigiata* corresponds with the descriptions of salmon gun over boree, (*M. lateriflora* and *M. pauperiflora*) in hilly areas associated with the Parker Ranges (Beard 1972a, 1972d). The five eastern sites, in this community, that occurred on broad valley colluvial soils appear to be similar to the boree community described on broad valleys in the Jackson Kalgoorlie area (Newbey & Hnatiuk 1985) and thus reinforce the cross-regional nature of this community. In the western GWW, *Melaleuca pauperiflora* was found to be most abundant in gimlet (*Eucalyptus salubris*) woodlands of intermediate age since fire (35-120 years) (Gosper, Yates*, et al.* 2013). This confirms that it was necessary to focus on long unburnt salmon gum sites to capture this indicative species.

The range-wide salmon gum woodland analysis showed that the small western GWW communities were not robust with the *Eucalyptus salmonophloia-Dodonaea bursariifolia* community more closely aligned with the Wheatbelt *Eucalyptus salmonophloia-Atriplex semibaccata* community and the *Eucalyptus salmonophloia – Daviesia scoparia* community absorbed into the *Eucalyptus salmonophloia-Eremophila ionantha* community. The movement of these western GWW plots could be partly due to the change in species composition with the reduced data set, as well as the influence of the boarder data set.

5.2.2 *Indicator species or generalists*

Most of the indicator species for the five communities, are not restricted to salmon gum woodlands, rather, they are typically more widespread in other woodlands and occasionally shrublands. However, the individual distributions and the association of main indicator species (used in naming the community) showed similarities with the geographic distributions of their community and occurred commonly with *E. salmonophloia.*

Many of the diagnostic species for the *E. salmonophloia-Eremophila ionantha* community occur in other woodlands. For example *Senna artemisioides* s. *filifolia*, *Olearia muelleri*, *Alyxia buxifolia, Grevillea acuaria* and *Scaevola spinescens* were found in woodlands of *Eucalyptus oleosa, E. clelandii, E. dundasii* or *E. griffithsii* associated with the greenstone ranges in the northern central part of the GWW (Meissner & Coppen 2013, 2014).

The characteristics of common species contribute to the understanding of the regional variability. *Olearia muelleri* and *Acacia erinacea* are noted as commonly occurring under *E. salmonophloia* in the Kellerberrin, Bencubbin and Hyden areas (Beard 1972a, 1980c, 1980b). *Acacia erinacea* is very common under *E. salmonophloia* but also found under other eucalypts*. Sclerolaena diacantha* is widespread and grows in a wide variety of soils and vegetation types (Mitchell & Wilcox 1994) and its high frequency (36% of the plots) is not unexpected. Another widespread species *Austrostipa elegantissima* (and similar species *A. platychaeta* in the GWW) also grows on a wider variety of soils in many vegetation types and is often is protected from grazing by growing amongst shrubs.

Alyxia buxifolia, considered a characteristic species in the *E. salmonophloia-Eremophila ionantha* community (in the GWW only analysis), actually occurs throughout the eastern Wheatbelt extending north to Shark Bay and also on the Swan Coastal Plain (see Western Australian Herbarium 1998 – 2013). As well as being common in eucalypt woodlands, it also has been recorded from woodlands of *Allocasuarina* spp., *Casuarina obesa* and *Acacia aneura* and occasional shrublands (including BIF ranges). *Exocarpos aphyllus* extends into the Wheatbelt and is common across-three of the salmon gum communities. It is a hemiparasite nearly always occurring in woodland and or mallee (except in the arid regions) on rocky loam, clay-loam, calcareous soils. In the GWW survey common shrub species, *Scaevola spinescens, Alyxia buxifolia* and *Exocarpos aphyllus,* often occurred beneath the salmon gum trees. The sticky, juicy fruits deposited on branches by birds fall to the ground to germinate. These shrubs were also found to be common in other woodlands (Newbey & Hnatiuk 1985; Newbey & Hnatiuk 1988; Newbey *et al.* 1995) so are not typical of salmon gum woodlands. It would be interesting in the future to compare the seed dispersal modes of the generalist versus the indicator species.

Understorey species do not appear to be specific to salmon gum woodlands. Fox (2001b) supports this assertion: "There was no such thing as a typical salmon gum woodland in the wheatbelt and that salmon gum woodlands are characterised more by the dominant tree height, litter cover and generally low cover on understorey [than by floristics]".

5.2.3 Comparisons with previous community classifications

The Wheatbelt communities identified here corresponded in part to those quadrat groups containing salmon gum identified in previous community classifications of all Wheatbelt vegetation (Gibson *et al.* 2004) and woodlands (Griffin 2008) but the differences due to the presence of other Eucalypts were evident. Gibson's analysis demonstrated that the understorey of salmon gum woodlands was similar to that of *E. longicornis* and *E. kondininensis* on duplex soils with high calcium and pH levels, with chenopods such as *Sclerolaena diacantha* and *Atriplex vesicaria* often present. Although Chenopods were present in the *E. salmonophloia – Atriplex semibaccata* community they were not as prominent as in the Gibson's analysis due to his 'central and southern woodlands on duplex soils with chenopod understorey' group being co-dominated by morrel (*E. longicornis*) and Kondinin blackbutt (*E. kondininensis*). Both these trees are associated with saline soils and lake margins that are habitat for many species of Chenopods. Similarly, morrel, flat-topped yate (*E. occidentalis*) and powderbark wandoo (*E. astringens*) with an understorey typical of soils with less calcium, available phosphorus and potassium dominated Gibson's 'widespread woodlands with non-chenopod understorey' group.

There was no community in the current study that corresponded with Gibson's 'herb rich woodland' group as it also contained York Gum (*E. loxophleba*) which is known to have a diverse herbaceous ground layer (Prober *et al.* 2011; Prober & Wiehl 2012). Common species identified in this current study were similar to those (*Acacia erinacea*, *Templetonia sulcata*, *Rhagodia preissii* and *Olearia dampieri* s. *eremicola*) in Griffin's single salmon gum-dominated community (Griffin 2008).

Atriplex vesicaria was indicative of the *E. salmonophloia-Maireana sedifolia* community and *S. diacantha* was widespread in the GWW thus supporting Fox's (2001b) conclusion, when these species were found in her Wheatbelt plots, that the salmon gum woodland understorey in the Wheatbelt was typified by semi-arid species. The presence of these semi-arid species even in the wetter environments of the Wheatbelt maybe due to the extensive surface root system of salmon gums absorbing moisture and creating dry conditions near the trees relative to the surroundings.

The three communities recognised in the Wheatbelt by the current study, showed varying correlations with the three of the sub-communities of Wheatbelt salmon gum woodlands that were recognised in the qualitative assessment by Harvey and Keighery (2012). These were the 'chenopod scrub', 'scrub (mixed shrubs)' and 'melaleuca' sub-communities. The locations of plots in the *E. salmonophloia-Atriplex semibaccata* community, which included *Atriplex* spp., *Rhagodia* spp. and *Maireana* spp (all chenopods), are very similar to those of the 'salmon gum over chenopod' sub-community (Harvey 2013). Many of the plots in the *E. salmonophloia-Templetonia sulcata* community occur where the more general 'salmon gum over scrub' plots occur although this sub-community extends well into the north of the Wheatbelt. Of the five Wheatbelt sites in the *E. salmonophloia-Melaleuca pauperiflora* community, three correlate with the sub-community described as 'salmon gum over Melaleuca'. The salmon gum on dune sub-community has not been recognised as distinctive by the current study as floristically these plots grouped with either the *E. salmonophloia-Atriplex semibaccata* or *E. salmonophloia-Templetonia sulcata* communities. The seven other salmon gum sub-communities identified by Harvey and

Keighery contained a co-dominant eucalypt or were over mallee so are not relevant to the current study.

There is a striking agreement between the communities identified in the current study with those recognised in a national context by Beadle(1981) who recognised four descriptions of salmon gum – gimlet woodland communities with a clear correspondence with the split between the Wheatbelt and the GWW. At a finer level, the classifications only partly matched. In the Wheatbelt a combination of the *E. salmonophloia-Atriplex semibaccata* and *E. salmonophloia-Templetonia sulcata* communities, showed some allegiance with Beadle's wetter, sandy loam community which contained *Acacia acuminata* (which was only present in four Wheatbelt plots) and *Daviesia hakeoides* (an indicator of the *E. salmonophloia-Atriplex semibaccata* community), *Daviesia pachyloma* (only in 2 plots) and *D. scoparia* (on the western edge of the GWW). However, Grevillea and Dampiera were uncommon in the current study with *Grevillea huegelii, G. hakeoides* and *G. paniculata* rare but mostly in the wheatbelt and *Dampiera lavandulacea* only in two plots. *Eucarya spicatum,* (now *Santalum spicatum*), in Beadle's description, is probably meant to be *S. acuminatum* as it is more common in the Wheatbelt than *S. spicatum*. The distinctive *E. salmonophloia-Maireana sedifolia* and *E. salmonophloia-Eremophila ionantha* communities in the drier eastern portion of the range clearly, subdivide Beadle's description of an eastern community: a taller shrub component featuring *Eremophila scoparia*, *Pittosporum phillyreoides* (now *P. angustifolia*) and *Eucarya acuminata* (now *Santalum acuminatum* but probably meant to be *S. spicatum*), and a lower saltbush (*Atriplex* spp.) dominated community on the flats. However, he includes *Cratystylis conocephalus* with this latter community, which reinforces its inclusion in the *E. salmonophloia-Eremophila ionantha* community in current GWW classification and questions its allegiance with the cross-regional *E. salmonophloia-Melaleuca pauperiflora* community in the range-wide analysis. This latter community showed a strong correlation with Beadle's melaleuca understorey where he listed *M. pauperiflora* as one of the common species. Beadle's other salmon gum-gimlet understorey had a mallee component so was not relevant here.

5.2.4 Comparisons with Beard's vegetation mapping

Useful comparisons can be made with the regional maps and available descriptions of some of the many salmon gum woodland vegetation associations (Beard 1981b, 1990). The descriptions of the two main communities in the GWW resulting from the current survey were in accordance with Beard's accounts. Concurring with Beadle (1981), Beard also recognises the association between *E. salmonophloia* and *E salubris* common to both the Wheatbelt and GWW. The distributions of all the communities showed some degree of correlation with Beard's regional mapping which encompassed salmon gum woodlands with co-dominant eucalypts (see Figure 2-6). The limited area mapped as pure salmon gum in central GWW contained many of the plots in the *E. salmonophloia-Eremophila ionantha* community and the two small areas where Beards mapped the understorey as saltbush (*Atriplex* spp.) or bluebush (*Maireana* spp.) are contained within the distribution of the *E. salmonophloia-Maireana sedifolia* community. Beard also recognized, in the western parts GWW, an association of *E. salmonophloia* over *Melaleuca* spp. which he termed boree and another community distinguished by the presence of *Acacia* and *Eremophila* species or broombush (Beard 1972d, 1972a).

In the Wheatbelt, some of the plots are not located within areas mapped by Beard as salmon gum indicating that these small or marginal patches of woodland that were sampled may be all that was available. Plots in the *E. salmonophloia-Templetonia sulcata* community often occurred in the 'salmon gum woodland over samphire' vegetation association along the saline drainage lines. Other plots occur within Beard's large mixed woodlands associations (see Figure 2-6) so they could be used , in conjunction with soil and terrain modelling, to more accurately differentiate salmon gum woodland from the mix of wandoo, York gum and morrel woodlands.

A broader analysis of all salmon gum communities would confirm the validity and accuracy of Beard's regional mapping as it is often a significant reference in other studies in WA. In a general sense, the current findings still provide a preliminary comparison with Beard's mapping in the GWW as other studies have been more localized or not analysed. The descriptions resulting from the current survey enhance previous work by providing a more comprehensive plot-based list of understorey species and characteristic environmental variables.

5.2.5 Comparisons with eastern states studies

The presence of five communities in salmon gum woodlands is comparable with the eight poplar box communities have been mapped over a wide area of Queensland and New South Wales (Beeston et al. 1980). However, these communities spanned over 1500km and only included two pure poplar box communities.

Communities identified in the survey of grassy box woodlands along an east-west gradient in central New South Wales (Prober & Thiele 2004) related strongly to the overstorey *Eucalyptus* species. In the more detailed survey of just grassy white box (*Eucalyptus albens)* woodlands, Prober (1996) identifies more of a gradient relating to latitude and possibly climate. This situation highlights that gradients rather than distinct communities present in woodlands may be a more accurate interpretation of the floristic patters and could also apply to the salmon gum woodlands.

5.2.6 Concept of a plant community

The outcomes of vegetation survey and classification are dependent on their purpose and comprehensiveness. The focus of the current survey was relatively narrow, involving samples with salmon gum as a dominant. This narrow focus allowed clear assessment of communities within this scope, but makes it more difficult to place those communities within the broader vegetation mosaic of the Wheatbelt and GWW. In particular, salmon gum also occurs with other eucalypts, and the status of these communities with mixed dominance is not clear. Similarly, it is possible that understorey communities identified here extend beneath different eucalypt dominants. Nevertheless, a number of studies have shown correlations between understorey composition and overstorey eucalypts in the Wheatbelt (Fox 2001b; Gibson *et al.* 2004) and in the south-east (Prober & Thiele 2004) indicating that the concept of community is dependent on the focus and comprehensiveness of the survey and understanding the characteristics of the component species. Ultimately, communities need to be distinguishable from neighbouring communities on the ground.

5.3 Relationships with environmental gradients

5.3.1 Overall

At this broad scale the understorey structure and floristic composition of the south-western Australian eucalypt woodlands varies with climate, topography, land forms soil type and hydrology (Gardner 1944; Moore 1973; Beard & Webb 1974; Beadle 1981; Beard 1981b, 1990). Survey results indicated a significant role of climate in determining the floristic patterns of salmon gum understorey. Mean annual rainfall and temperature were the strongest drivers in both analyses. However, over the larger area, the annual rainfall seasonality (the ratio between winter and summer rainfall) became a strong influence and supported arguments regarding the important contribution of the summer rainfall events enabling *E. salmonophloia* to exist in the drier interior (Milewski 1981). Temperature and isothermality (incorporating diurnal range) influenced south-north patterns in the Wheatbelt and the rainfall gradient acted more in a west-east direction. However this trend differs in the GWW where both the rainfall and temperature gradients were in more south to north direction (Beard 1981b) and rainfall seasonality (monthly variability) is more inconsistent in the east. The pattern of climatic zones, being more east west in the Wheatbelt and more north south in the GWW (Figure 2-3) also explain the differences between the regions.

The variables derived from geology, regolith and soils information exerted a secondary influence on the floristic patterns. Alluvial and colluvial units were common in all communities but most prominent in the GWW. The CCA ordination indicated granitic units were influential in the southern Wheatbelt and interregional communities where granite exposures are common.

The descriptions of vegetation associations (Beard 1975, 1981b) that contained salmon gum with notes pertaining to soil preferences, were largely substantiated and elaborated by this current study. Correlation between the calcareous nature of the red loamy soil in broad drainage lines (alluvium and colluvium units) and chenopod dominated understorey was recognised by Beard (1975). This alkaline nature of the soil appears to have a stronger influence of the species composition that the salinity.

Soil chemical and physical characteristics showed similar correlations in both analyses with the drier warmer plots associated with higher levels of calcium, magnesium, phosphorous, nitrogen, pH, silt and clay evident. Trends in soil chemical and physical characteristics were consistent with Fox (2001b) who also reported that drier Mt Jackson plots had higher levels of potassium, pH, phosphorous and iron than her cooler wetter Wheatbelt plots. She also noted that there was no significant difference in organic carbon and electrical conductivity, also observed in the current study. The subsets of regional climate and local substrate (soils) appeared to have similar amount of considerable influence (13.5 and 13.64% respectively), and a low level of overlap i.e. they are independent of each other.

5.3.2 Regional vs. local influences

The greater contribution of regional than local factors in contributing to floristic patterns across the distribution of salmon gum is consistent with other surveys around the world that covered a large spatial scale (e.g. Borcard *et al.* 1992; Sieben *et al.* 2009). In contrast, other more localised studies (Fox 2001b) concluded a more similar contribution of regional climatic (12.3%) versus local soil (10.6%) variables.

Across the range of salmon gum woodlands, the sets of regional variables demonstrated a stronger influence on the floristic patterns than that of the local soil composition. The small overlap between the influence of the regional and local variables indicated a weak relationship between climate (strongest regional subset of variables) and soils (strongest local subset) despite their similar influence on the floristics patterns as shown in the ordinations. The high unaccounted proportion of the variance may be attributed to land management practises, for example grazing (not measured in the Wheatbelt), fine scale disturbances (Økland & Eilertsen 1994), other soil nutrients, soil moisture or micro-topographic position. The results here compared favourably with other partial analyses of floristic composition. For example Borcard et al. (1992) also had a high level of unexplained variance (63.3%).

5.4 Biogeographical boundaries

This study confirms the significant biogeographical boundary between the Avon Wheatbelt/Mallee and Coolgardie (GWW) IBRA regions and gives a preliminary indication that the data indicated patterns from north to south rather than east to west as suggested by the subregional IBRA boundary.

The range wide analysis revealing the significant differences between salmon gum communities in the Wheatbelt and the GWW confirms the appropriateness of a major biogeographical boundary between the Avon Wheatbelt/Western Mallee and Coolgardie (GWW) IBRA region. There are two distinct communities in each region with about a third of the species encountered unique to the each region (Wheatbelt 39% and GWW 32% with an overlap of 28% species in common). This community distinctiveness and differences in threatening processes between the two regions warrant the Wheatbelt salmon gum communities being included in the Threatened Ecological Community (TEC) nomination. This nomination recognises the urgent need to conserve what little woodland remains in all parts of the Wheatbelt (Kennedy 2011). Much of the remnant woodlands containing salmon gum are on private land and it is important that landowners appreciate the scarcity of the woodland type and the ecological processes that drive its existence (and demise), restore degraded remnants and persist with re-establishment efforts (Hussey & Wallace 1993).

The only cross-regional community, the *Eucalyptus salmonophloia-Melaleuca pauperiflora* s. *fastigiata* community, demonstrates is a minor gradient of species turnover across the above major biogeographical boundary. This feature cannot be verified as previous surveys which have sampled across this boundary do not have adequate number of plots on both sides (Brown 1989; Fox 2001b). Fox (2001b) also concluded a major difference between her Mt Jackson salmon gum plots (in the Coolgardie Region) and her Wheatbelt plots.

There appears to be a less prominent boundary between the Avon Wheatbelt and Mallee IBRA Regions indicating a gradual turnover in native species across this boundary strengthening the definition of the Wheatbelt eucalypt woodlands as being in both the Avon Wheatbelt IBRA region and western Mallee sub-region.

The current survey questions the validity of the sub IBRA biogeographic boundary within the Coolgardie IBRA Region which is currently in a north-south direction between two groups of the 23 vegetation systems defined by Beard (Beard 1975, 1981b; Environment Australia 2000). It has not been possible to ascertain the criteria for drawing the boundary this direction between certain systems. An east-west boundary, indicated by the division between the two main communities, would also reflect the climatic zones. Further surveys of all vegetation types in the region would clarify this.

5.5 Implications for conservation land management in the GWW

Although the native vegetation of the GWW is largely intact and not fragmented by permanent clearing, it has been subjected to many disturbances including timber cutting, grazing by domestic and feral animals, mining exploration and mineral extraction activities, sandalwood harvesting, as well as recurrent fires and weed infestations (Yates, Hobbs*, et al.* 2000; DEC 2010). The implications and significance of this research for land management at local and regional levels stem from the recognition of two distinct communities in the GWW, the provision of benchmark sites and stronger understanding of floristic composition.

5.5.1 Anthropogenic impacts

Ongoing land management to conserve the diversity and health of plant and animal communities requires knowledge of the impact of past, present and proposed actions. The results of the analyses and general observations derived from this study provide input into this understanding.

Although the initial intention was to sample undisturbed old growth woodland there were not enough sites available, so some sites subjected to grazing and timer cutting were sampled with derived impact level indices. The varying levels of historical disturbance influence the environmental variables and may confuse the interpretation of what was driving the floristic patterns.

5.5.1.1 Grazing

The influence of grazing pressure on floristic composition is not clear from the study dataset. Grazing was confounded with the north-south split between the two main communities. It is likely that the natural differences in the vegetation are an underlying driver of the pastoral activity, rather than grazing being the main driver of the floristic difference between groups.

Many plots in the *E. salmonophloia-Maireana sedifolia* community were in pastoral leases, presumably due to available fodder (chenopods) and had poor cover of organic crust, possibly due to stock trampling. The *E. salmonophloia-Eremophila ionantha* community had a taller, shrubby, non-chenopod component that was not attractive to pastoralists.

Contrary to expectations and findings in the Wheatbelt, there were few exotic species in the GWW plots with high grazing impact indices, and only one of the six plots considered to be heavily grazed (5) contained any weeds (3 one perennial species and 2 annual). This observation could be an artefact of the site selection criteria to avoid edges and disturbances. This finding in largely intact vegetation contrasted with the highly fragmented landscape of the Wheatbelt where more exotic species were recorded in heavily grazed plots (Pettit *et al.* 1995; Fox 2001b).

Less cover of organic crust occurred on the soils with higher concentrations of silt and clay that supported the low chenopod shrublands favoured for grazing (i.e. the *E.*

salmonophloia-Maireana sedifolia community). It is well known that stock do damage to the fragile layer of cryptograms and algae (e.g.Graetz & Tongway 1986; Eldridge & Kwok 2008). This consequence is supported by Fox (2001b) and Yates *et al.* (2000) who also found that cover of cryptograms was significantly lower in grazed compared to ungrazed woodlands. Similarly, the relationship of high phosphorus levels in soils with respect to grazing pressure could represent natural levels or be the result of pastoral activity. Higher phosphorous and nitrogen in grazed woodlands was also noted by Fox (2001b) and Yates *et al.* (2000). The cover of litter did not significantly differ between the two main communities indicating no relationship with grazing concurring with the findings of Fox (2001b) but contrary to those of Yates *et al.* (2000). Further detailed analysis of grazing levels, species composition and climate within the *E. salmonophloia-Maireana sedifolia* community, is required to reveal more information about these relationships.

5.5.1.2 Timber cutting

There was no difference in the understorey composition between the cut and uncut GWW plots, based on the derived timber cutting levels. Most of the heavily cut sites fell into the *E. salmonophloia-Eremophila ionantha* community, which also contained uncut plots. These were close to towns and generally had denser stands of timber. This result is consistent with the findings of Williamson (1983).

5.5.1.3 Fire

The different composition and structure of the two main communities in the GWW has implications for fire management: the more open, low chenopod understorey of the *E. salmonophloia-Maireana sedifolia* community is less flammable and susceptible to fire than the taller closed non-chenopod (with more flammable oil laden *Eremophila* spp) *E. salmonophloia-Eremophila ionantha* community (Gill *et al.* 1981; Groves 1981; Murphy *et al.* 2013). An examination of the fire history, as part of the GIS stratification process to guide site selection, confirmed that vast areas in the northeast GWW had hardly experienced any fires. However in the south-west there was evidence of extensive, multiple fires, burning vast areas of sandplain shrublands, mallee and into the woodlands resulting in very few long unburnt areas of the woodland. This pattern corresponded to the distribution of the *E. salmonophloia-Maireana sedifolia* and *E. salmonophloia-Eremophila ionantha* communities. Consequently, the rarer old growth patches and corridors of the *E. salmonophloia-Eremophila ionantha* community warrant special protection from future fires.

5.5.2 Benchmarking & Monitoring

As the plots in the current GWW survey were located in largely undisturbed, mature vegetation, they form valuable reference sites for assessing conservation values and monitoring management actions, recovery from natural disturbances (e.g. fire) and long-term changes due to climate change.

Although the ex-pastoral leases of Credo and Jaurdi are now part of the DPaW estate, they will bear the scars of grazing for some time, especially in proximity to the old homesteads. Repeated monitoring of the plots established in this study could also be beneficial towards understanding rates of ecosystem recovery in the grazed plots, monitoring climate change impacts and impacts of other potential future disturbances such as fires, storms or floods.

5.6 Methodological issues

Several issues arise from the selected methods. These include possible improvement to the survey design, problems arising from the amalgamation of data from different surveys, obtaining optimal data quality, and how to choose the most suitable statistical methods. The GWW classification is considered more robust than the range-wide classification of all plots as the larger plots incorporates more species and cover values were incorporated. This robustness is reflected in the more clearly defined diagnostic species, which are important for potential ongoing applications such as modelling community distributions.

5.6.1 Data quality and amalgamation

When data from separate sources are combined, potential issues arise that may compromise the quality. These differences may include the purpose, methods (including quadrat size and cover measurement) observer bias, date, season, preceding weather, and taxonomy (Illyés *et al.* 2007; Jansen & Dengler 2010).

Differences in survey purpose were an important in this study. The aim of the SAP Wheatbelt survey was to sample all the plant communities present, and replicating samples was not a priority. In addition, there are limited typical remnants available. Furthermore, the WWF survey focused on the farmers' remnant as a whole and plots may have been placed on ecotones between communities in an attempt to pick up the most understory species. Conversely, the 100 GWW plots were selected specifically to sample pure salmon gum woodlands.

It was possible to minimize the differences in the methods and quadrat size prior to the GWW sampling by adopting similar methodology and collecting presence/absence (P/A) data from nested 100 m^2 quadrats. However, this meant that the GWW data was compromised because of the necessity to reduce the size of the plots to a quarter of the area, the data to presence or absence values and thus apply a different weighting to the species in classifications and ordinations. When P/A data was used to define communities, the recurrent combination of species identifies the groups. The resemblance matrices of the 400 m^2 cover data and the 100 m^2 P/A data were only 74% similar indicating that the more comprehensive data may have better captured the within community variations. However, when considering the two main GWW communities, there is a notable similarity in plot membership between those produced from the GWW and range-wide analyses.

Differences in floristic composition (especially in the annuals) due to various sampling dates and a range of botanists of could have been alleviated by re-sampling the wheatbelt plots. The wheatbelt plots that were resampled showed an average of 90% similarity of species composition between dates. Taxonomic changes are a major issue in WA as new species are still being discovered and many revisions are underway.

Therefore, it is important when amalgamating data sets to consider the objectives for which the data was collected and accept that differences may not be able to be resolved due to the range of reasons for collecting data. Good quality data that incorporates cover values in each stratum, adequate plot size and standardised plot positioning is preferable if data sets are to be combined.

5.6.2 Survey design

Future surveys should consider a larger plot size especially in the more open woodlands of the GWW. National standard specification of 1 ha was developed for rangelands after the current survey had commenced (White *et al.* 2012). The use of a one ha plot would capture more species by including the variability between the open ground between trees and the shaded, littered ground beneath trees as well as potentially picking up the moist, nutrient enriched depressions that support annuals. Species accumulation curves for two salmon gum woodland sites show the curve begins to asymptote around 1 ha in Salmon gum woodland (S. Prober unpublished data from plots in the north-west GWW). Generally the constancies (the proportion of plots containing certain species) of all species within a specific community increases with increasing plot size(e.g. Dengler *et al.* 2009). However, plots with higher species richness may not necessarily produce more realistic floristic patterns if that richness is due to edge effects with adjacent communities (Smith 2010). In spite of this, time constraints arising from using larger plots in this study would have resulted in fewer samples and comparisons with previous surveys in the GWW would not have been possible unless nested samples were included.

A number of minor issues arose from the methodological processes. A more consistent objective estimate of cover would have been achieved using a point intercept method (Friedel & Shaw 1987a, 1987b) rather than subjective estimates used here. Rigorous and consistent collection and analysis of soil samples is an essential but unfortunately very costly exercise ($240 per sample in 2012). However, selection of a smaller suite of chemicals could be achieved by not analysing all highly correlated variables. More detailed and coherent digital soil and geology layers across the whole region would have better informed site selection and allowed greater clarification the roles of these factors in determining the floristic patterns.

Ideally, it would be desirable for the data from this survey to be stored in a state-wide or national vegetation data base but this is yet to exist. The Global Index of Vegetation-Plot Databases (GIVD; http://www.givd.info) (Dengler *et al.* 2011) contains only 1 record from Australia in its set of 197 databases with 2,906,211 vegetation registered plots (as of 20/12/2013). Ninety seven of these databases used TURBOVEG (Hennekens & Schaminée 2001) which was used in the current study.

5.6.3 Numerical methods

With multivariate analysis, it is possible to select the methods that provide desired or anticipated results. In the current study a variety of ordination methods were applied to explore the data as they all contributed to the understanding. The CA ordination highlighted the influence of outliers. NMDS reflected the similarity distances that related to the geographical position of the plots. In this study, the constrained (CCA) and unconstrained (PCA with environmental overlays) analyses largely agreed that the important variables that influenced the floristic patterns were mean annual rainfall, temperature, and Phosphorus levels.

The benefits of partial CCA, identifying the contribution of regional and local variables to the floristic patterns, were in the clearer understanding of the role of scale and the guidance for future data collection to incorporate variables that may explain some of the unaccounted variance.

Several software packages were utilised to perform classification, ordination and sorting of the data. Although it was not possible to compare how well they performed a few comments can be made. The objective use of OptimClass in JUICE that is not commonly used in Australia, overcomes personal preferences or subjective choice of classification methods. Classifications were carried out in JUICE using PC-ORD (McCune & Mefford 2011), Syntax (Podani 2001 but not presented here) and PRIMER (Clarke & Gorley 2006). PRIMER had limited choices and could not carry out all the OptimClass recommendations. PC-ORD easily facilitated the CA, PCA, NMDS and CCA ordinations. CANOCO (Ter Braak & Šmilauer 2002) was preferable for CCA as the graphical package CanoDraw provided options for displaying the quantitative and nominal variables, suppressing variables and overlaying the classification. PRIMER only had a few options for ordinations, such as PCA and NMDS, but had several useful tools, such as the Draftsman plot for visual and numerical presentation of similarities between environmental variables, and SIMPROF useful for suggesting possible clusters in the dendrograms and comparing with OptimClass. JUICE (Tichý 2002) was a useful software package from which to carry out OptimClass PC-ORD for clustering hierarchical cluster analysis and CANOCO for ordinations, and to arrange the phytosociological table.

5.7 Future research

5.7.1 Modelling distributions of plant communities

The data collected from these sites and the communities identified in the GWW classification are intended for use as input into the predictive modelling of the distribution of the salmon gum communities in the GWW. As this data included cover estimates the identification of dominant species it is more robust than presence/absence data and will therefore provide necessary input to the mapping of the vegetation. The protocol used to map two areas in the Kimberley region could reasonably be applied to the GWW when more plot-based data is collected. This protocol used digital geology maps, remotely sensed layers and ‘decision trees’ such as the Classification and Regression Tree (CART).

However, sites extrapolated using the distribution of the six simplified geology/soil/regolith units may suggest a spread of salmon gum much wider than occurs in reality. Geology is available at a scale of 1:250,000 and although coarse, it may be suitable considering the large area to be covered. Unfortunately, it is not all in a digital form and several of the maps have non-matching legends due to the different interpretations of the surface regolith, so considerable preparation is need. Soil maps are at a course scale and appear to show more detail in the Wheatbelt than the GWW. The soil landscape mapping which is currently underway in the GWW may provide a good base for the modelling. As discussed above, the distribution of understorey species is much broader than that occurring solely under salmon gum and the modelling may reflect this. Other types of woodlands occur on the colluvial and alluvial soils. A limitation of this survey and its application to modelling community distribution is that it only focused on pure stands of salmon gum and a classification of all sites containing the *E. salmonophloia* may provide a better community classification comparable with other studies.

5.7.2 Further survey

Understanding floristic patterns in pure salmon gum woodlands and the environmental factors that drive these patterns is an integral step in exploring the range of communities associated with this species and the complexity of woodlands in south-western Australia. A potential extension of this project would be to compile and analyse a much larger data set, including all existing plots containing salmon gum from the GWW and Wheatbelt to determine the influence of co-dominants, landscape position (as it would include plots on foot-slopes of ranges) and soils.

To assess whether the patterns found in perennial species are reflected in the distribution and composition of annual species, the plots could be revisited after considerable rainfall, expanded to one hectare, and supplemented with extra plots if necessary. Using several smaller quadrats within the patch would also pick up more of the local site patchiness and impact of shade (Leach & Givnish 1999).

As mentioned previously broader survey of other vegetation types (e.g. other woodlands, sandplain shrublands and granite rock communities) is need to clarify the sub regional and regional IBRA boundaries and to provide input into a vegetation model of the whole region.

Investigations into plant functional traits would be interesting. For example; comparison of a) seed dispersal modes of generalist versus indicator species, b) leaf characteristics of species in the major communities or c) leaf characteristics in one species across the rainfall gradient.

Within the GWW, detailed experimental surveys in grazed areas are required to determine whether grazing has modified the vegetation or if only certain vegetation types have attracted pastoralist activity. Assessing the impact of grazing on cover and function of organic crust and nutrient levels could be made in conjunction with assessing changes in grazing pressure as livestock are removed if leases are added to the conservation estate. Data relevant to timber cutting (tree height, diameter at breast height and number of coppicing stems) collected during this survey is available to further investigate the impact of the harvesting and assess regeneration.

5.8 Conclusion

This broad systematic survey of pure salmon gum communities in the Great Western Woodlands is the first major study of semi-arid woodland understorey in south-western Australia. Data previously collected from the adjacent Wheatbelt incorporated to assess patterns across the full distribution of salmon gum, provided one of the few vegetation studies to traverse these two biogeographic regions.

Floristic composition in salmon gum woodlands across their range were driven primarily by rainfall, temperature and the ratio of summer to winter rainfall, with subsidiary influences of pH, phosphor levels and proportion of sand in the soil. Importantly, strong differences were detected between Wheatbelt and GWW communities, highlighting the threatened status of most the Wheatbelt salmon gum woodlands. Recognition of two distinctive woodland types in the GWW will facilitate conservation planning, and ecological management particularly with respect to fire. The plots and data may also be of value in the future; for ongoing monitoring and to inform vegetation distribution models.

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7 APPENDICES

Appendix 7-1 Spatial data used to select GWW sites.

Category	GIS Layers	Source *	Comments
BIOGEOGRAPHICAL			
Climate	Köppen-Geiger 10’ 1975	CliMond	(see Kriticos et al. 2012 for derivation)
Boundary	GWW boundary	DPAW	
Geology	Regolith	GSWA, DMPE	4 units.
	Geology (1:100K & 1:250K) images	GSWA, DMPE	Inconsistence labelling across sheets
	Geology 1:1M (digitised) maps	GSWA, DMPE	Very general
Soils	Atlas of Soils for WA 2M	(CSIRO 1967; Northcote *et al.* 1967)	23 units
Flora	Locations of SG collections in the Perth Herbarium	Nature Map and on Atlas of Living Australia	
Vegetation	Pre_European Vegetation	DPAW & DAF	digitised from regional vegetation maps
	Beards Vegetation Systems	DAF	
Biogeographic regions	IBRA Sub biogeographic regions	Australian Government Environment Department	(Thackway & Cresswell 1995)
DISTRUBANCE			
Timber cutting activity	Goldfields tramways	DPAW	
	Woodline areas dates cut and purpose	Kealley and DPAW	
Roads	Compilation from 21 sources	DPAW, Main Roads, GEODATA	
Grazing pressure	distance to waterpoints (taking into account fences) and homesteads	GEODATA Australia and Pastoral layer from DAF	Measured on topographic layers

	Pastoral grazing pressure and date de-stocked	Department of Agriculture and Pastoral Protection Board	
Tenure	pastoral leases	DPAW and DAFF	Permissions granted
	Mining leases and tenements	DMPE	
	Vacant Crown Land	DPAW	Permission granted
	Conservation estate	DPAW	Permission granted
Fire	Fire history (time since last fire).	DPAW data from satellite imagery since 1975	-long unburnt >50 years

Abbreviations; DPAW WA Department of Parks and Wildlife previously DEC WA Department of Environment and Conservation Parks and Wildlife), DAF (WA Department of Agriculture and Food. GSWA Geological Survey WA, DMP WA Department of Mines Petroleum and Energy.

Appendix 7-2 GWW and Wheatbelt Site locations

Plot	Latitude	Longitude
01LCR	-32.8203	119.5844
02MH1	-32.18	119.7108
03HT1	-31.2989	120.0853
04HT2	-31.7786	120.6344
05MCD	-32.2972	120.7448
06PRS	-31.7755	122.6125
07BUL	-30.5049	119.5266
08KTS	-31.2629	121.5547
09KTC	-31.534	121.8056
10KTE	-31.2523	121.2215
11KTN	-31.2219	121.5887
12KTR	-31.5255	121.9417
13CHW	-31.6216	121.1867
14CHN	-31.6484	121.1606
15CHR	-31.6304	121.6794
16BR1	-31.4824	121.4149
17BR2	-31.5972	121.5825
18CHE	-31.1438	121.8159
19WGT	-31.5018	121.6864
20WGW	-31.52	121.5656
21MDC	-31.8679	121.8351
22MDW	-31.4242	121.4799
23NSN	-32.1241	121.7235
24WLB	-31.8135	121.9315
25BIN	-31.7028	121.8523
26YEL	-31.9052	119.6985
27BRB	-31.3426	120.3302
28LKS	-30.3309	121.9919
29MMW	-30.4402	121.3821
30BAC	-30.1513	121.4733
31MTV	-30.1312	121.4596
32LON	-31.6623	121.1658
33CAL	-31.1536	121.5131
34ENU	-30.8543	118.959
35EGR	-30.555	121.1867
36KWS	-30.5367	118.8732
37DHR	-29.8992	119.8593
38MJN	-30.7025	119.3844
39MJS	-30.9117	119.6195
40CAR	-30.7336	119.5389
41KLY	-30.1294	119.7144
42HAS	-30.1581	119.1728
43HAN	-30.4146	119.7248
44HAW	-30.6254	119.0191
45HTR	-30.7079	119.6543
46MTD	-30.5187	119.0371
47JDN	-30.4362	119.9366
48GLT	-30.8272	119.9631
49JWH	-30.5879	120.0377
50JMF	-30.6801	120.1038
51JDN	-30.7809	120.1462
52JTW	-30.8368	120.1502
53JHS	-30.8219	120.1674
54JDW	-30.8015	120.0843
55JTC	-30.8212	120.3545
57JSD	-30.8216	120.1907
58JDS	-30.1196	120.0269
61CRS	-30.4954	120.8522
62CRW	-30.4303	120.7319
63CER	-30.4349	120.4987
64CRN	-30.3757	120.7467
65CRE	-30.374	120.848
66BAD	-30.3675	121.272
67BAO	-30.3685	121.2668
68CAR	-30.4353	121.0179
69WCR	-30.4407	120.4934
70CFT	-30.1908	120.6641
71DVH	-30.0081	120.661
72JTE	-30.8198	120.3527
73STW	-30.8946	120.8705
60FHN	-33.0684	120.0466
74PCE	-32.9262	121.1289
75PCN	-32.7376	121.164
76SGT	-32.9787	121.6494
77OHN	-32.008	121.2112
78LJN	-32.0149	120.8118

Plot	Latitude	Longitude
79LJW	**-32.3071**	**120.5789**
80LJS	**-32.4081**	**120.6276**
81BRS	**-32.6576**	**120.785**
56WLG	**-31.3781**	**120.3422**
59VRN	**-31.2485**	**120.9309**
82MH2	**-32.2511**	**119.7767**
83HNR	**-32.8631**	**121.3864**
84NSE	**-32.8244**	**122.4264**
85WGR	**-31.1706**	**122.095**
86WDL	**-31.9069**	**122.7058**
87MDS	**-31.6156**	**122.2917**
88MDN	**-31.8544**	**122.1361**
89MDE	**-31.1619**	**122.3933**
90CWD	**-31.1117**	**122.5344**
91MMN	**-30.1061**	**121.0289**
92MMC	**-30.2528**	**121.96**
93AVD	**-30.8164**	**122.5212**
94PHS	**-30.2355**	**122.5181**
96KUR	**-30.5278**	**122.2562**
95PJS	**-30.3538**	**122.4141**
97CHF	**-30.9955**	**122.8492**
98ZAN	**-31.0276**	**123.5962**
99COO	**-31.0515**	**123.054**
100RT	**-31.0094**	**122.2155**
101WY	**-31.1771**	**117.4579**
102TO	**-31.5759**	**118.2178**
103NG	**-31.5128**	**118.1652**
104YO3	**-31.9445**	**116.9766**
105WE	**-31.2764**	**118.6482**
106BE	**-30.6604**	**118.4769**
107HY1	**-32.6147**	**119.1028**
108HY2	**-32.8217**	**119.0661**
109HY3	**-32.7465**	**119.0652**
110HY4	**-32.6428**	**119.3394**
111KN1	**-32.5112**	**118.5471**
112KN2	**-32.3968**	**118.8184**
113KN3	**-32.3472**	**117.8199**

Plot	Latitude	Longitude
114LG1	**-33.3467**	**118.823**
115LK	**-33.2469**	**119.5511**
116NN1	**-30.994**	**116.1895**
117NN2	**-30.792**	**116.0588**
118PI1	**-33.4921**	**119.091**
119PI2	**-33.3665**	**118.8992**
120QU1	**-32.0414**	**117.5215**
121QU2	**-31.878**	**117.5458**
122QU3	**-32.0484**	**117.4079**
123LB	**-33.3584**	**118.8266**
124LK2	**-33.0921**	**119.6772**
125LM	**-33.4916**	**119.0898**
126MM	**-30.8399**	**117.9051**
127TR	**-30.9358**	**117.4574**
128WA1	**-30.6156**	**116.0073**
129WA2	**-30.5487**	**116.0367**
130WK	**-32.5585**	**117.6323**
131WU	**-29.8305**	**116.9553**
132W6	**-31.0711**	**116.5469**
133W7	**-31.0992**	**116.6167**
134W10	**-31.3164**	**116.7269**
135W11	**-31.305**	**116.6225**
136W53	**-31.3247**	**117.1368**
137W74	**-30.5726**	**118.0521**
138W76	**-30.7026**	**117.994**
139W85	**-31.2876**	**118.4106**
140W104	**-31.9778**	**118.4214**
141W124	**-31.1117**	**117.9014**
142W152	**-30.0347**	**116.9831**
143W160	**-29.6136**	**116.225**
144W187	**-29.815**	**116.1417**
145W191	**-30.7461**	**116.3656**
146W215	**-33.309**	**119.1946**
147YO1	**-31.8978**	**116.8638**
148YO2	**-31.9457**	**116.9751**

Appendix 7-3 Soil analysis

Soil Analysis conducted by WA Government Chemistry Laboratory

Methods

Fine grinding <0.2mm (for the total analysis)

pH Measured by pH meter using a glass electrode on a 1:5 extract of soil and 0.01 M CaCl2 (ChemCentre method S03) (Method 4B1 in Rayment & Higginson 1992),

Electrical Conductivity (EC) Measured by conductivity meter at 25C on a 1:5 extract of soil and deionised water. (ChemCentre method S02) (Method 3A1 in Rayment & Higginson 1992)

Organic carbon (OC) was determined, on soil ground to less than 0.15 mm, by Walkley & Black (W&B) (Walkley 1947). The procedure is based on oxidation of soil organic matter by dichromate in the presence of sulphuric acid. The heat for the reaction is supplied by the heat of dilution of the sulphuric acid with the aqueous dichromate. (ChemCentre method S09)

Total N* Total Nitrogen is measured by Kjeldahl digestion of soil (Coper sulphate-potassium sulphate catalyst). Total nitrogen is measured as ammonium-N by automated colorimetry by the nitroprusside.dichloro-S-triazine modification (Blakemore et al. 1987) of the Berthelot indophenol reaction reviewed by (Searle 1984). (ChemCentre method S10) (Method 7A2 in Rayment & Higginson 1992)

Total P: Total Phosphorus is measured by colorimetry on the Kjeldahl digest for total N using a modification of the (Murphy & Riley 1962) molybdenum blue procedure (ChemCentre method S14)

Available Phosphorus Samples of soil are extracted in 0.5 M sodium bicarbonate solution (pH 8.5) for 16 hours at 23-over-end shaking technique. Inorganic phosphorus in the centrifuged extract is measured using automated colorimetry. Orthophosphate in the extract reacts with a reagent containing ammonium molybdate, potassium antimony tartrate, ascorbic acid as reductant and sulphuric acid to form a blue complex ion. (ChemCentre method S12) (Murphy & Riley 1962) (Rayment & Higginson 1992),

Available Potassium displaced from soil by dilute salt or acid solutions is considered to be a measure of plant available potassium. In this procedure 0.5 M sodium bicarbonate (pH 8.5) is used as the extracting solution (soil:solution ratio 5:100, 16 hour extraction). Modification of the standard test for bicarbonate-extractable potassium (soil to solution ratio 1:100). The greater soil to solution ratio used in this procedure provides improved accuracy and precision for sandy soils containing relatively low concentrations of extractable potassium (<100). (ChemCentre method S17.1) (Jeffery 1982)

Exchangeable Cations (Ca, Mg, Na and K) were measured by 3 procedures (ChemCentre methods S21-S22) (Rayment & Lyons 2011)

a. 1M NH4Cl at pH 7.0. - Used for neutral soils (pH (H2O) between 6.5 and 8

Cations (Ca, Mg, Na and K) were measured by ICP-AES - Inductively coupled plasma - atomic emission spectrometry. Soluble salts were removed from soils with EC(1:5) >20 mS/m by washing with glycol-ethanol.

b. 0.1 M BaCl2 (unbuffered) - used for acidic soils only (pH <6.5).

Cations (Ca, Mg, Na, K, Al and Mg) were measured by ICP-AES - Inductively coupled plasma - atomic emission spectrometry. Soluble salts were removed from soils with EC(1:5) >20 mS/m by washing with glycol-ethanol.

c. 1 M NH4Cl, pH 8.5 used for calcareous soils. Cations (Ca, Mg, Na and K) were measured by flame AAS (atomic absorption spectrophotometry).

Sand/silt/clay Australian Standard AS 1289.C6.3
In this procedure, silt and clay contents are determined from density measurements on a sedimenting suspension. Sedimentation times of silt (0.02 to 0.002mm) and clay (less than 0.002mm) sized particles are calculated from Stoke's Law, assuming spherical particle shape. Sand fractions (0.02 to 2.0mm) are determined by sieving and weighing. (ChemCentre method S06).

Appendix 7-4 Derivation of disturbance variables

A Grazing Impact - data input

Land tenure (Pastoral lease or ex pastoral lease obtained from DEC Tenure layers),

The grazing impact at each plot in the GWW was calculated using land tenure, distance from homesteads and water-points (taking the presence of fences into account) obtained from the 1997 AULIG topographic maps and DAFF WA. A 1,3,5,9, km buffer created around each water point simulated the zone of decreasing grazing (as sheep rarely travel more than 5 km and cattle more than 8 km from water). Generalised station wide stocking rates; carrying capacity (CC) and dry sheep equivalent (DSE) obtained from the Pastoralist Protection Board though the DAFFW gave a very rough indications of what may be happening at sites as the grazing level range considerable across each station (often much higher near the homestead, yards and water points).

Grazing was not considered in the range-wide analysis, as different grazing practises in the Wheatbelt meant that the set of factors, to include in an index, was different, (e.g. distance from water point not relevant), or not available. Generally, the SAP Wheatbelt plots were located in the least disturbed sites available implying grazing was absent. Some original data sheets from the SAP and WWF surveys did mention evidence of grazing and it was assumed that many of the WWF plots on private property were subjected to grazing at some time.

B Timber Cutting Impact – data input

Timber cutting information was compiled from a map of timber cutting areas and tramlines (rail) based on historical maps (DEC 2011), oral historical accounts (Bunbury 2002) and Ian Kealley (personal communication 2011). Early cutting was within a mile of the tramline (Bunbury 2002) and further when trucks were used. Timber cutting impact for each GWW plot was compiled from a map of timber cutting areas and tramlines (rail) and the number of stumps, coppicing trees and trees less that approx 100 yrs old at each site (Kealley 1991; Hobbs 2001).

Appendix 7-5 Environmental variables for GWW plots

See supplementary spreadsheet S1.

Appendix 7-6 Environmental variables for range-wide salmon gum plots

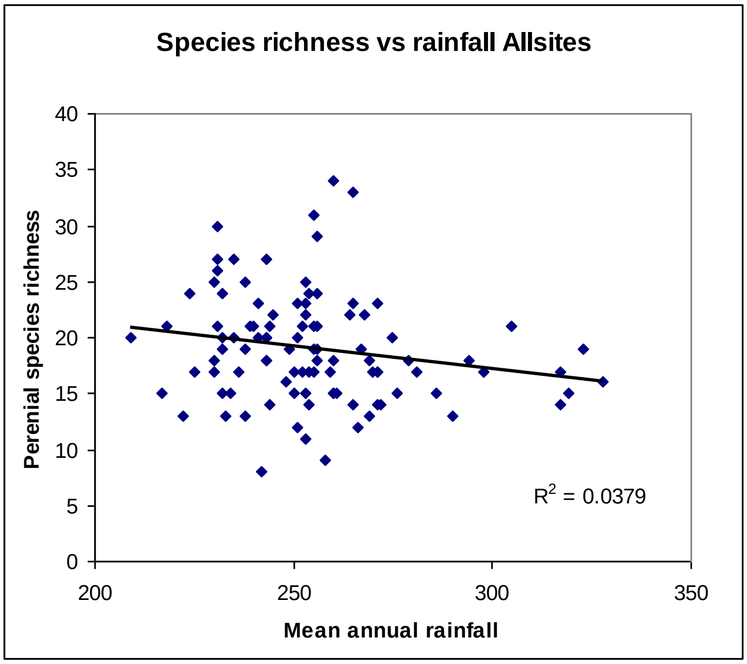
See supplementary spreadsheet S2.

Appendix 7-7 OptimClass DAC (data analysis combinations) options.

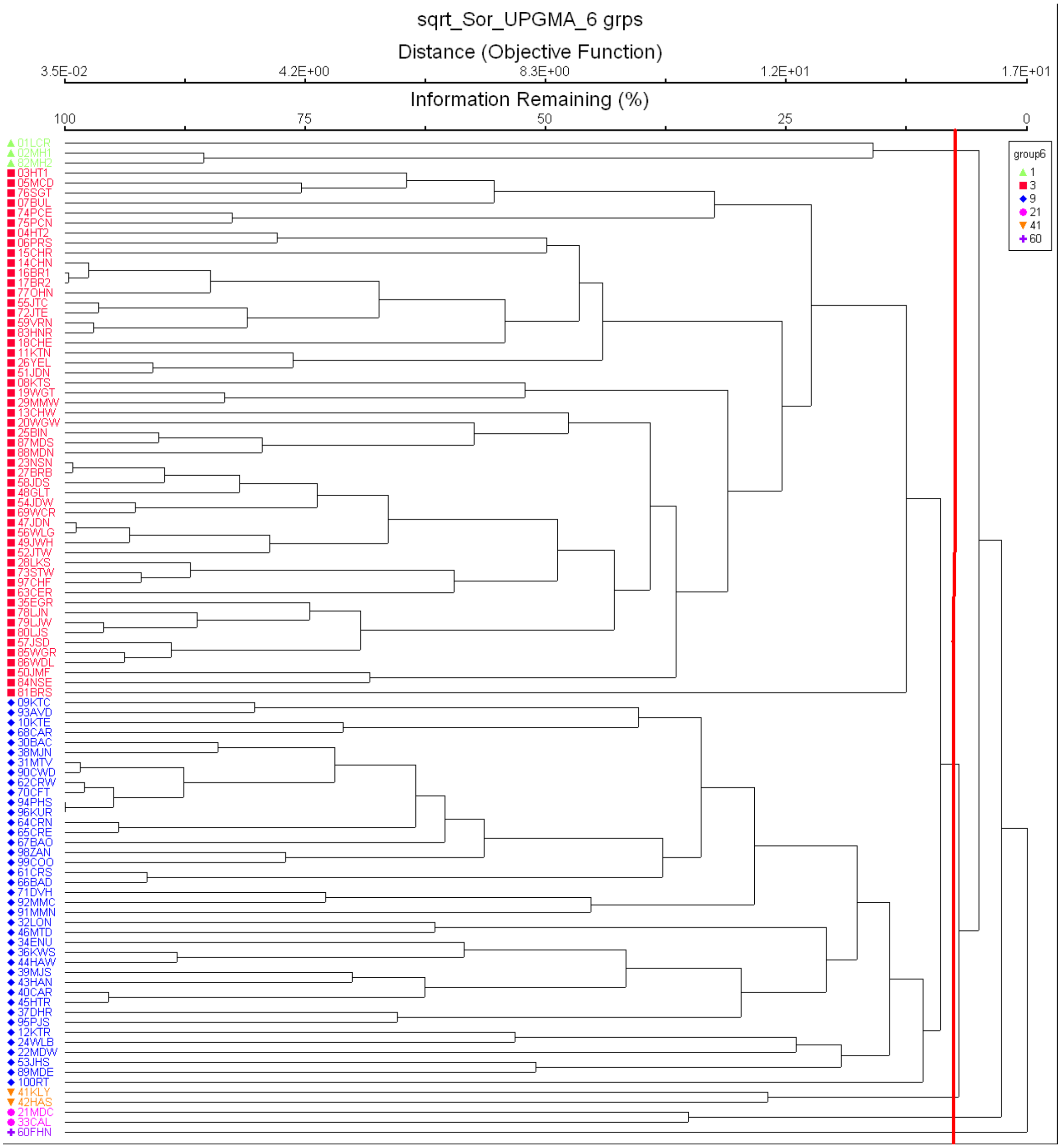
Data-analytical combination	Transformation *	Resemblance Measure	Clustering Method
DAC1	Log	Sørensen (Bray-Curtis)	Group Average (UPGMA)
DAC2	Log	Euclidean Distance	Ward's Method
DAC3	Log	Sørensen (Bray-Curtis)	Flexible Beta (-0.25)
DAC4	Log	Rel. Sorensen (Rel. Manhattan)	Flexible Beta (-0.25)
DAC5	Log	Rel. Sorensen (Rel. Manhattan)	Group Average (UPGMA)
DAC6	Power (0)	Sørensen (Bray-Curtis)	Group Average (UPGMA)
DAC7	Power (0)	Euclidean Distance	Ward's Method
DAC8	Power (0)	Sørensen (Bray-Curtis)	Flexible Beta (-0.25)
DAC9	Power (0)	Rel. Sørensen (Rel. Manhattan)	Flexible Beta (-0.25)
DAC10	Power (0)	Rel. Sørensen (Rel. Manhattan)	Group Average (UPGMA)
DAC11	Power (0.5)	Sørensen (Bray-Curtis)	Group Average (UPGMA)
DAC12	Power (0.5)	Euclidean Distance	Ward's Method
DAC13	Power (0.5)	Sørensen (Bray-Curtis)	Flexible Beta (-0.25)
DAC14	Power (0.5)	Rel. Sørensen (Rel. Manhattan)	Flexible Beta (-0.25)
DAC15	Power (0.5)	Rel. Sørensen (Rel. Manhattan)	Group Average (UPGMA)
DAC16	Power (1)	Sorensen (Bray-Curtis)	Group Average (UPGMA)
DAC17	Power (1)	Euclidean Distance	Ward's Method
DAC18	Power (1)	Sørensen (Bray-Curtis)	Flexible Beta (-0.25)
DAC19	Power (1)	Rel. Sørensen (Rel. Manhattan)	Flexible Beta (-0.25)
DAC20	Power (1)	Rel. Sørensen (Rel. Manhattan)	Group Average (UPGMA)

* Power; 0 = P/A, 0.5 = Square Root, 1=no transformation.

Appendix 7-8 Relationship of species richness to rainfall.



Appendix 7-9 Dendrogram of GWW plots



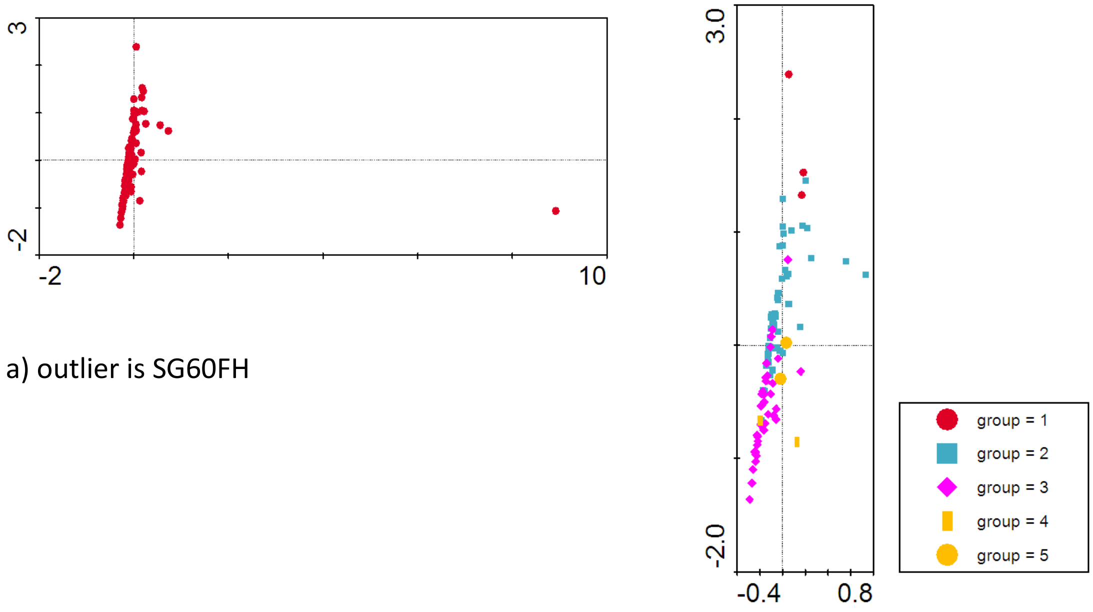
Method: square root transformed cover data using a Sorensen (Bray-Curtis) coefficient/dissimilarity matrix and group average (UPGMA) classification method. The 6 group level is marked (produced in PC-ORD).

Appendix 7-10 Phytosociological table for GWW plots

See Supplementary spreadsheet S3.

Colours are slightly inconsistent with dendrogram, maps and ordinations due to the palate available in JUICE is violet (not Pink) and 6 is grey

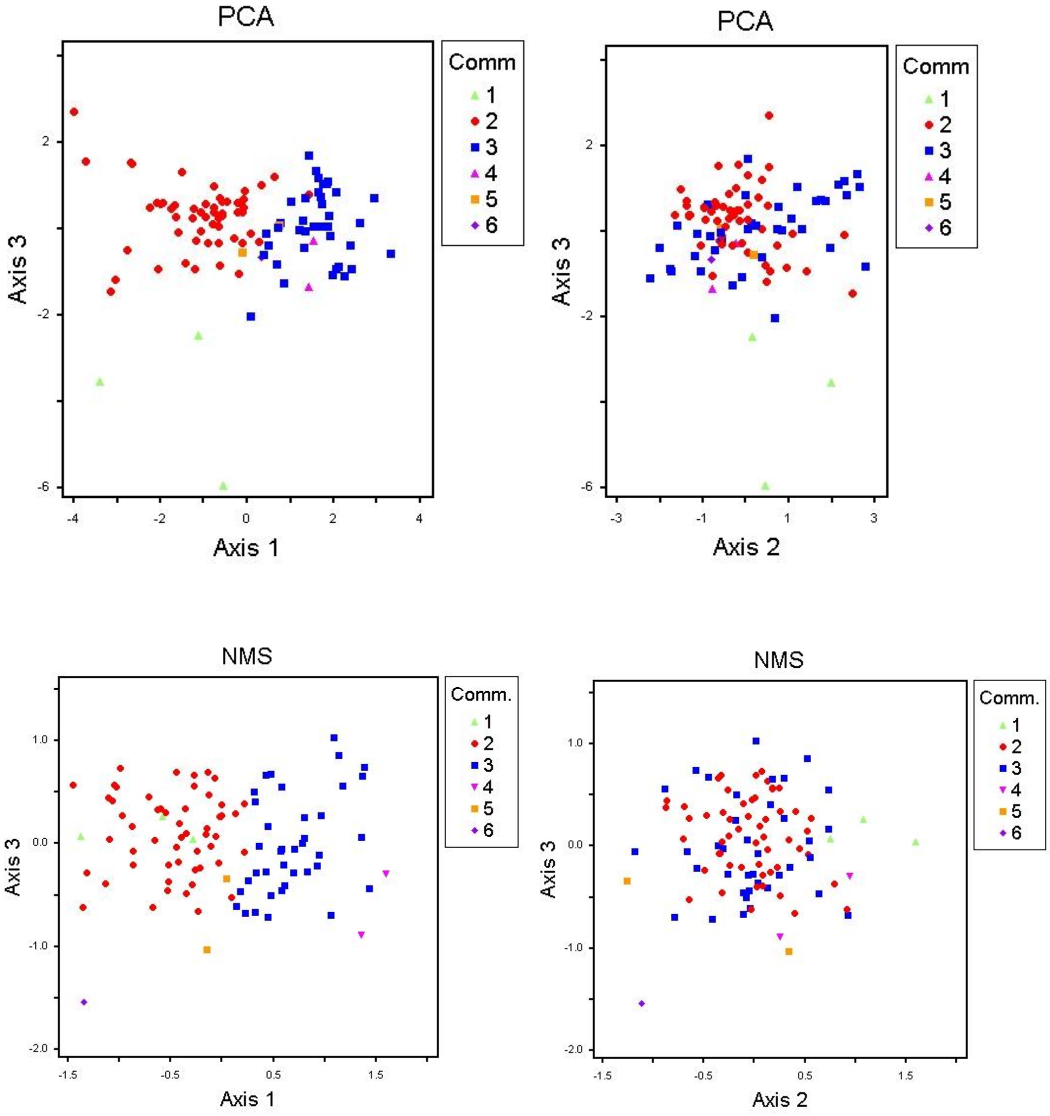
Appendix 7-11 CA ordinations carried out on a) 100 (SG60 outlying) and b) 99 sites showing outliers SG1, SG2, & SG82 (community1)



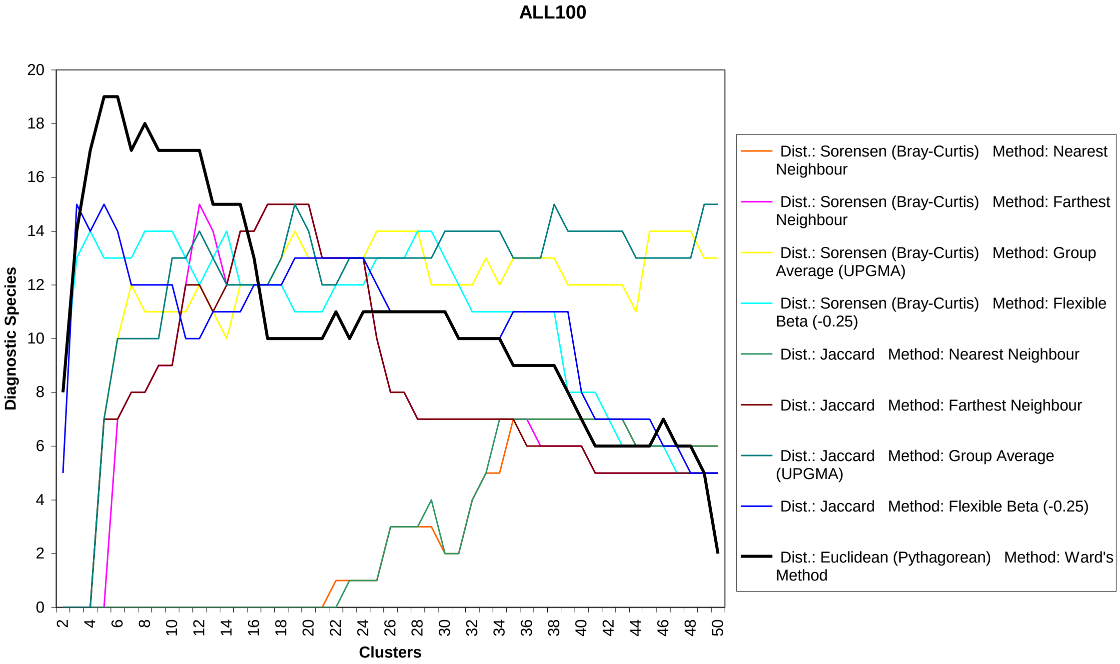
a) outlier is SG60FH

b).

Appendix 7-12 PCA and NMDS ordination of GWW data Axes 1 & 3 and 2 & 3.



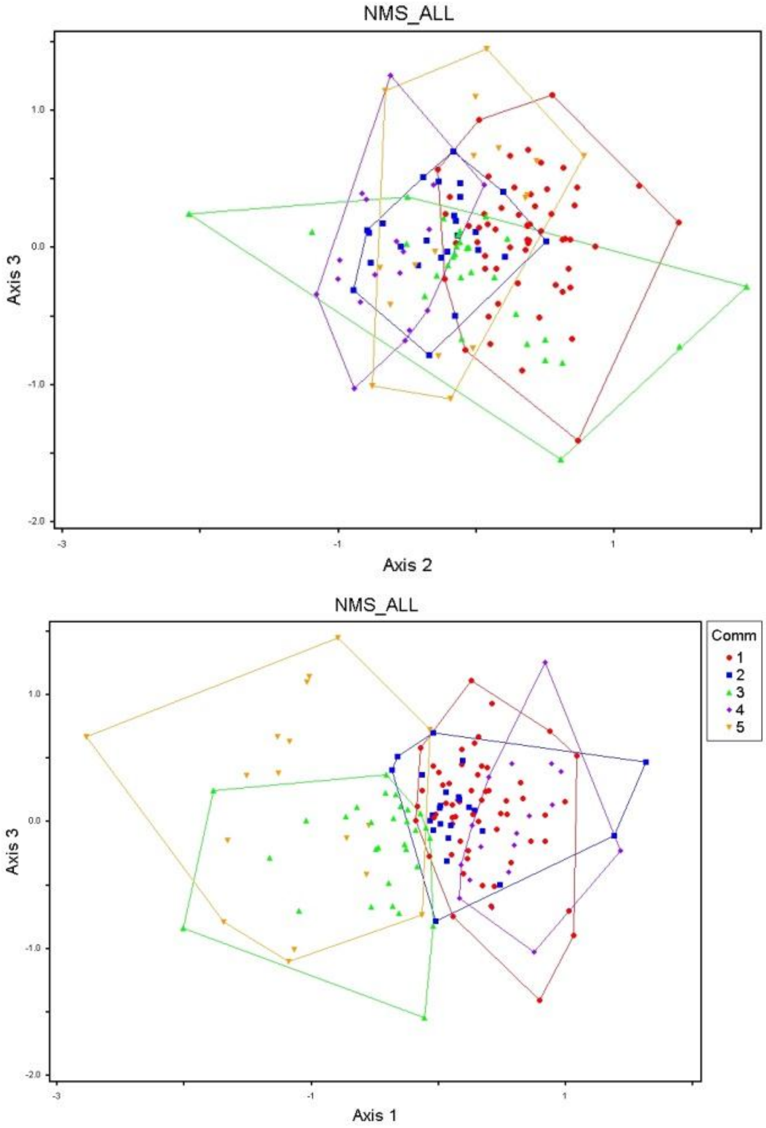
Appendix 7-13 OptimClass graph for Range wide analysis



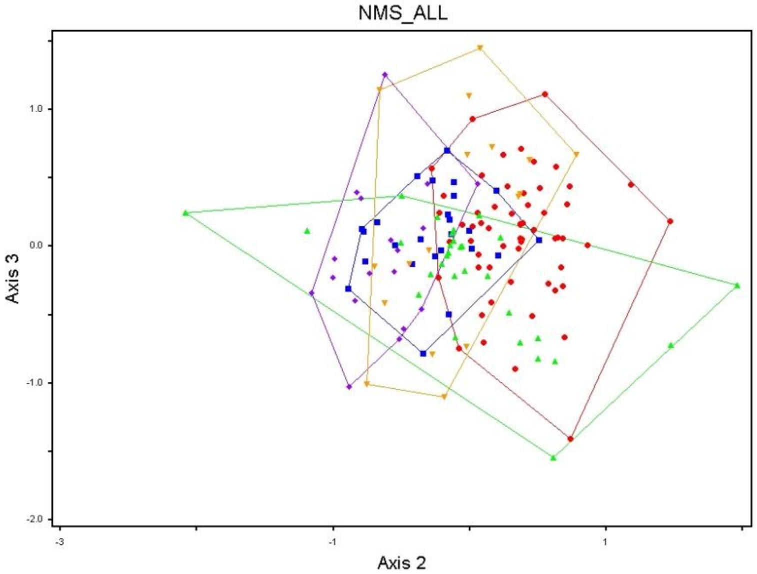
Appendix 7-14 Phytosociological table for range-wide analysis

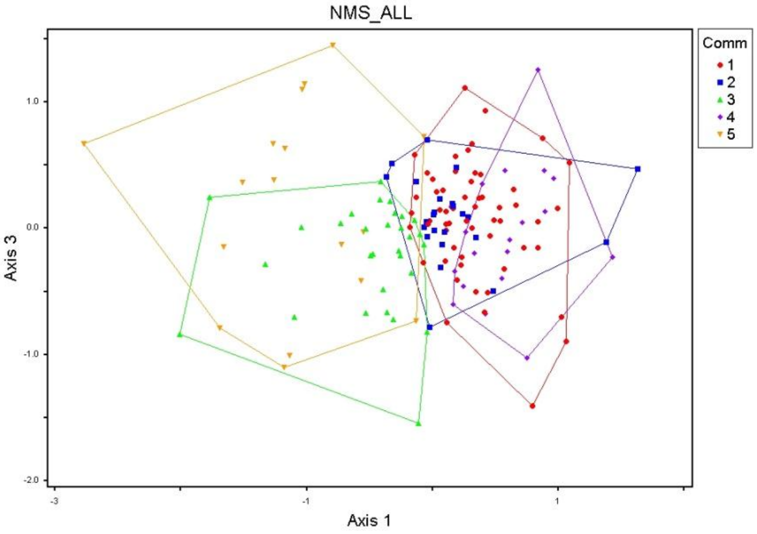
See Supplementary spreadsheets S4.

Appendix 7-15 NMDS ordination for axes 1 & 3 and 2 & 3.



Appendix 7-16 NMD ordinations of ALL GWW and WB plots Axes 1&3 and 2&3.





S1 Environmental data for Ch3 GWW

Site	Tann	MTClQ	TCPMn	TDQ	Tseas	Pann	Pseas	PannSeas	PWrQ	PWetP	SDth	TWI	MIH	ALT	SLOPE	VB	NLF	GI	TCI	Geol	EC	pH	Sand	Silt	Clay	OrgC	Ntot	Ptot	Ca	K	Mg	Na	Aspect	Slope	tree	shrub	herb	litter	BG	OrgCst
01LCR	16.8	10.7	4.4	19.7	1.68	323	31	0.94	69	10	1.1	9.29	0.53	393	0.30	0	dl	1	1	All	4	5.9	86	7	7	0.86	0.05	77	2.7	0.57	3.1	0.33	135	1	35	52	1	25	40	15
02MH1	17	10.7	4.3	19.9	1.72	317	31	0.92	69	10	1.1	8.89	0.53	394	0.48	0	dl	1	1	Eol	23	6.2	55	34.5	10.5	2.5	0.186	360	9.4	3.1	7.6	2.3	225	1	25	99	1	50	30	1
03HT1	17.1	10.6	4.2	19.5	1.76	286	27	0.74	71	9	0.9	5.18	0.48	410	0.48	0	gr	1	1	Grt	6	6	83.5	5.5	11	1	0.063	66	4.3	0.66	2.2	0.28	0	0	13	51	0	40	50	1
04HT2	17.3	10.8	4.3	17.9	1.77	271	23	0.54	74	8	0.9	5.42	0.43	446	0.70	0	gr	1	1	Col	9	6.2	84.5	5	10.5	1.04	0.06	49	3.3	0.42	3.6	0.45	0	0	60	28	1	50	35	15
05MCD	17.5	11.2	4.7	19.2	1.68	269	20	0.45	71	8	0.7	4.46	0.39	336	1.56	0	gr	1	3	Col	9	6.2	73.5	14.5	12	1.11	0.076	71	5.1	1	4.6	0.64	0	0	20	50	1	25	45	1
06PRS	17.4	10.7	4.1	19.9	1.83	298	34	0.95	67	11	0.9	7.48	0.53	424	0.63	6.25	dl	1	2	Col	7	6.7	77	9.5	13.5	0.94	0.053	73	7.5	1.2	3.5	0.29	90	1	10	10	2	20	80	2
07BUL	18.8	11.3	4.3	20.9	2.01	255	35	0.77	66	9	0.9	7.10	0.43	400	0.40	56.25	gr	1	1	Col	34	7.7	65.5	14.5	20	2.11	0.105	83	13	0.98	4.7	0.9	180	1	25	30	0	40	25	15
08KTS	18.4	11.9	5	17.9	1.75	243	23	0.14	75	8	1.4	9.41	0.32	332	1.07	37.5	dl	2	1	Col	21	8	62	23.5	14.5	2.28	0.192	280	16	2.1	5.8	0.59	0	0	20	50	5	60	30	3
09KTC	18.5	11.9	5	17.9	1.75	243	24	0.13	74	8	0.9	9.71	0.32	322	0.78	0	dl	2	1	All	16	7.8	48	34	18	1.42	0.138	200	14	2.4	6.8	0.62	135	1	20	45	1	35	40	1
10KTE	18.6	12	5.1	18.1	1.74	238	24	0.12	74	8	1.1	8.11	0.31	336	0.55	0	dl	2	2	Oth	27	7.9	65	15	20	1.13	0.108	170	9.6	1.3	5.3	1.3	180	1	20	15	1	25	55	2
11KTN	18.5	11.9	5	17.9	1.75	243	24	0.14	75	8	1.1	6.11	0.32	302	0.48	0	dl	2	2	Col	10	6.8	72	12	16	0.87	0.073	150	6.4	1.2	5.3	1.5	135	1	35	13	1	40	60	2
12KTR	18.5	11.9	5	18	1.74	243	24	0.14	74	8	0.9	4.76	0.32	319	0.75	0	dl	2	2	Col	32	7.6	69	16.5	14.5	0.93	0.077	150	7.2	1	4	1.7	112	1	15	27	1	50	10	0
13CHW	17.7	11.2	4.6	17	1.72	269	20	0.26	75	8	0.7	8.98	0.37	390	0.37	25	gr	2	4	Col	29	6.1	70	18	12	1.54	0.102	140	6.5	1.6	5.6	1.4	270	1	19	22	1	52	30	30
14CHN	17.6	11.2	4.6	17	1.72	271	20	0.27	75	8	0.7	8.17	0.38	398	0.43	87.5	dl	2	4	All	5	5.7	81	8.5	10.5	1	0.069	72	5.9	0.57	3.1	0.22	0	0	25	33	0	60	10	6
15CHR	17.5	11	4.5	17.5	1.73	272	20	0.27	76	8	0.9	4.08	0.39	450	0.71	0	gr	1	3	Snd	12	6.5	74.5	9.5	16	1.58	0.088	69	5.3	0.87	3.4	0.29	135	1	15	17	1	60	65	60
16BR1	17.8	11.3	4.7	17.1	1.74	271	21	0.27	76	8	1.1	9.99	0.37	450	0.53	100	dl	1	4	Col	6	6.4	76	8.5	15.5	0.8	0.057	55	6	0.59	3.2	0.22	0	0	5	50	0	30	65	60
17BR2	17.8	11.3	4.7	17.1	1.74	265	21	0.27	76	8	0.7	8.70	0.37	401	0.16	100	dl	1	4	All	6	6.2	79.5	8	12.5	1.04	0.074	65	5.3	0.86	3.4	0.28	0	0	20	26	0	45	40	60
18CHE	17.6	11.2	4.6	17	1.73	271	20	0.23	75	8	0.7	7.33	0.37	402	0.87	0	gr	2	4	Snd	4	6.2	76	10.5	13.5	1	0.063	62	5.3	0.73	3.7	0.29	0	0	10	35	0	15	80	80
19WGT	18.1	11.6	4.8	17.5	1.72	252	21	0.16	74	8	1.4	6.75	0.34	321	1.76	0	dl	2	3	All	45	7.7	68.5	16.5	15	1.23	0.091	160	11	1.5	5.8	1.9	90	1	20	34	0	41	33	1
20WG	18.1	11.6	4.8	17.5	1.72	256	21	0.17	74	8	1.4	7.58	0.35	339	2.01	0	dl	2	3	All	15	7.5	54	24.5	21.5	1.59	0.132	150	16	1.8	8	0.29	0	0	10	30	0	30	22	10
21MDC	18.2	11.8	4.7	16.3	1.7	244	23	0.15	76	8	0.9	9.62	0.33	289	0.35	75	dl	4	1	All	84	7.5	48.5	30.5	21	1.28	0.105	160	10	1.7	7.8	3.1	180	1	20	1	0	20	75	1
22MD	18.1	11.6	4.7	16.9	1.71	245	22	0.16	75	8	1.4	7.18	0.34	332	1.44	0	dl	4	2	Col	100	7.7	57	25	18	1.61	0.134	160	10	1.7	5.8	3.3	0	0	35	20	2	50	45	25
23NSN	17.6	11.4	4.5	15	1.66	267	19	0.23	75	7	0.7	10.59	0.37	279	0.29	0	dl	1	2	All	9	6	72	18	10	0.91	0.065	97	3.6	0.89	4.1	1.1	315	1	25	30	0	20	75	60
24WLB	18.5	12	5	18	1.74	243	23	0.13	74	8	1.4	5.54	0.32	312	0.29	0	dl	2	3	Col	130	7.9	55.5	29.5	15	1.7	0.143	230	13	2.6	6.4	1.7	90	1	25	55	0	60	20	10
25BIN	17.7	11.3	4.5	15.1	1.7	254	20	0.15	75	8	0.9	4.06	0.37	348	1.46	0	gr	1	3	Col	15	7.9	66.5	16	17.5	1.41	0.121	160	14	1.6	4.6	0.43	45	1	25	21	0	45	50	30
26YEL	17.8	10.8	4	19.1	1.89	260	32	0.87	65	9	0.9	5.59	0.45	392	0.51	0	gr	1	2	Col	24	7.2	63	22	15	1.48	0.1	110	12	1.8	7.6	1.1	0	0	35	50	0	50	30	18
27BRB	18.1	11.3	4.5	18	1.84	255	26	0.57	72	8	0.3	6.03	0.39	384	0.33	12.5	gr	1	2	Grt	11	6.2	80.5	10	9.5	1.14	0.081	100	4.3	1.2	3.2	0.49	0	0	15	50	0	40	35	15
28LKS	18.9	12.1	5.2	19.1	1.8	231	28	0.14	75	8	1.1	8.32	0.29	347	0.58	81.25	dl	2	3	All	6	6	56.5	24	19.5	1.09	0.088	190	8.6	1.2	4.7	0.21	0	0	40	35	1	50	40	15
29MM	18.8	12	5	19	1.8	232	28	0.13	73	8	1.1	7.56	0.3	368	0.84	0	dl	5	3	Col	20	7.8	76.5	11	12.5	1.03	0.087	170	8.9	0.86	1.8	0.51	180	1	20	30	1	30	50	1
30BAC	19.2	12.1	5	18.6	1.87	232	29	0.11	75	8	1.2	6.21	0.3	401	0.93	0	dl	4	4	Snd	18	7.7	80.5	8	11.5	0.97	0.073	150	6.5	0.55	2.1	0.95	90	1	20	25	0	30	60	0
31MTV	19.2	12.1	5	18.6	1.87	232	29	0.11	75	8	1.2	6.21	0.3	393	0.93	0	dl	4	4	Snd	13	7.9	76.5	10.5	13	1.29	0.115	180	12	0.9	1.6	0.08	135	1	30	20	0	35	55	0
32LON	18.5	11.8	5.2	17.9	1.78	260	26	0.21	80	8	0.5	8.44	0.34	395	1.28	6.25	dl	2	4	All	14	7.8	44	28.5	27.5	1.44	0.138	170	20	1.8	7.6	0.4	135	1	40	60	7	20	30	0
33CAL	18.5	11.8	5.2	17.9	1.78	258	26	0.20	81	8	0.5	6.72	0.34	398	1.27	0	dl	5	3	Col	49	7.8	52	34	14	1.65	0.127	290	16	2.9	7.8	2.1	180	1	25	15	0	50	40	0
34ENU	18.7	11.4	4.5	21.4	1.98	264	38	0.95	62	10	0.6	7.13	0.46	340	1.32	0	dl	2	2	Col	8	7	66	16	18	1.08	0.072	130	11	1.1	6.1	0.53	135	1	20	5	17	30	60	15
35EGR	19	11.6	4.8	21	2.01	252	36	1.02	63	9	0.8	5.00	0.42	381	0.15	25	sl	1	1	Col	8	6.5	77	6.5	16.5	1.11	0.072	110	6.1	0.91	2.2	0.2	342	1	40	10	1	60	80	5
36KWS	18.7	11.3	4.5	20.8	2.01	251	36	0.97	64	10	0.8	7.96	0.44	349	0.36	93.75	pl	3	1	Col	9	6.7	68	18	14	1.42	0.093	180	8.6	1.7	6	0.81	0	0	25	1	25	60	75	1
37DHR	19	11.3	4.1	19.8	2.07	253	33	0.53	73	9	1.4	5.62	0.39	458	1.05	25	pl	4	1	Col	50	7.7	53	18.5	28.5	1.48	0.1	190	14	1.6	6.9	3.1	0	0	15	2	25	37	60	0
38MJN	19.1	11.5	4.3	20.5	2.05	232	34	0.68	68	9	0.4	5.33	0.4	424	0.41	6.25	dl	4	2	Col	28	7.9	66	19	15	1.86	0.128	140	15	1.4	3.3	0.68	180	1	15	8	10	70	85	5
39MJS	18.9	11.4	4.3	20.3	2.04	242	34	0.71	68	9	1.4	5.03	0.41	431	0.50	0	dl	2	1	Col	19	7.2	56.5	30	13.5	1.71	0.11	200	14	2.2	8.2	1.2	0	0	20	5	10	30	80	3
40CAR	18.5	11.1	4.2	21.3	1.98	270	35	0.85	65	10	0.9	4.84	0.45	387	0.66	0	pl	2	1	Col	12	6.3	71.5	11.5	17	1.5	0.086	140	6.2	1.2	4.5	0.72	0	0	20	10	5	70	80	3
41KLY	18.6	11.3	4.3	20.8	1.97	268	34	0.77	65	9	0.9	6.50	0.42	384	0.51	0	pl	1	2	Col	13	7.5	74.5	10	15.5	1.27	0.079	93	9.5	1.2	2.9	0.23	0	0	10	17	10	50	80	3
42HAS	18.6	11.2	4.1	20.1	2.01	266	32	0.62	70	9	1.4	11.16	0.41	450	0.27	100	dl	1	1	Col	15	7.9	56.5	25.5	18	1.41	0.103	150	17	2.5	3.7	0.3	0	0	10	2	5	40	90	3
43HAN	18.4	10.9	4	19.9	2.02	260	31	0.59	73	9	1.4	9.47	0.43	483	0.79	0	dl	1	1	Col	6	6.5	59.5	23.5	17	1.59	0.097	260	7.3	1.8	5.4	0.26	0	0	15	4	0	35	80	5
44HAW	18.8	11.3	4.2	20.3	2.02	253	33	0.65	69	9	1.4	11.90	0.41	436	0.63	100	dl	1	1	Col	13	6.8	65	16.5	18.5	1.21	0.073	150	9.9	1.4	6.2	1.9	0	0	20	3	18	60	80	5
45HTR	18.8	11.3	4.2	19.5	2.01	254	30	0.49	75	8	1	5.82	0.39	490	0.63	0	dl	1	1	Col	19	7.7	61.5	17	21.5	1.97	0.124	130	19	2.1	6.1	0.44	0	0	20	22	7	60	75	1
46MTD	18.6	11.1	4.2	19.3	1.99	259	30	0.52	74	9	1	7.65	0.4	491	0.17	0	dl	2	1	Col	28	7.4	50.5	23	26.5	2.69	0.165	150	16	1.6	7.4	1	0	0	50	12	6	85	90	1
47JDN	18.6	11.2	4.3	19.3	1.98	261	30	0.54	73	8	1.4	10.50	0.4	471	0.38	6.25	pl	3	1	All	15	7.8	63	19	18	1.32	0.094	130	15	1.5	3.7	0.22	0	0	20	5	0	90	90	2
48GLT	18.5	11.3	4.3	19.1	1.93	256	30	0.69	69	8	0.9	4.22	0.4	393	0.75	0	pl	1	3	Col	22	7.1	73	11.5	15.5	1.4	0.075	96	10	1.4	4.2	0.79	0	0	20	8	2	50	85	2
49JWH	18.6	11.4	4.4	19.3	1.95	256	29	0.57	72	8	1.2	5.58	0.39	432	0.41	68.75	pl	2	1	Col	24	7.6	55.5	18.5	26	1.4	0.097	120	14	1.6	5.6	0.69	0	0	15	20	1	30	30	2
50JMF	18.5	11.3	4.4	19.2	1.93	255	28	0.56	72	8	0.9	9.71	0.39	425	0.62	50	pl	2	4	Col	7	6.8	63.5	16	20.5	1.19	0.078	110	11	1.5	5.6	0.29	0	0	30	4	1	25	50	25
51JDN	18.3	11.2	4.3	19	1.92	255	28	0.58	73	8	0.5	5.36	0.4	456	1.32	0	dl	3	4	Lat	9	6	71.5	12	16.5	2.03	0.108	170	6.7	1.1	6.4	0.54	135	1	40	10	2	55	85	10
52JTW	18.4	11.3	4.4	19.1	1.91	253	28	0.58	72	8	1.1	6.05	0.39	441	0.16	56.25	dl	2	4	All	18	7.5	65.5	15	19.5	1.41	0.082	100	21	1.5	7.1	0.63	315	1	25	12	1	40	75	2
53JHS	18.4	11.3	4.4	19.1	1.91	253	28	0.56	72	8	0.9	10.79	0.39	416	0.88	100	dl	4	4	All	38	7.2	59.5	22.5	18	1.12	0.079	140	12	1.5	5.7	1.4	315	1	35	1	1	40	95	0
54JDW	18.4	11.2	4.3	19	1.92	253	28	0.60	71	8	0.9	4.62	0.4	423	0.46	0	gr	3	3	Col	19	6.6	75	10.5	14.5	1.11	0.061	84	8	1	4	0.94	315	1	12	3	1	30	80	2
55JTC	18.4	11.4	4.6	18.4	1.89	250	27	0.49	75	8	1.1	4.42	0.38	429	0.31	50	pl	2	4	Col	21	7.6	60	19.5	20.5	2.08	0.159	140	16	1.8	8.1	0.63	0	0	20	9	1	55	80	5
56WLG	18.2	11.3	4.7	18.1	1.82	251	25	0.40	77	8	1.4	6.33	0.37	443	0.34	87.5	pl	2	2	Col	16	7.9	63	17.5	19.5	1.39	0.099	100	18	2.1	3.2	0.23	0	0	20	20	3	25	70	35
57JSD	18.3	11.2	4.4	19	1.9	256	28	0.57	73	8	0.5	6.85	0.39	429	0.30	0	dl	3	3	Col	8	6.7	82	5.5	12.5	1.16	0.061	66	7.3	0.83	1.7	0.12	0	0	40	8	7	45	60	0
58JDS	18.4	11.4	4.5	19.1	1.89	254	28	0.59	72	8	1.1	6.62	0.38	406	0.59	0	gr	4	4	Col	17	8	71	15.5	13.5	2.01	0.141	150	15	1.3	3.6	0.34	225	1	12	5	1	40	85	12
59VRN	18	11.4	4.8	18.1	1.78	260	24	0.32	79	8	0.9	4.93	0.37	400	0.81	0	gr	2	4	Col	17	7.9	67.5	13.5	19	1.09	0.08	81	14	1.2	3.1	0.26	0	0	10	15	7	30	80	40
60FHN	16.2	10.9	5.1	19	1.45	319	27	0.72	73	10	1	7.55	0.53	373	0.30	0	dl	1	1	Col	27	7.1	77	8.5	14.5	1.96	0.099	70	8.6	0.74	5.4	0.74	315	1	45	5	4	70	85	3
61CRS	18.9	11.8	5	19	1.88	235	27	0.26	79	8	0.5	7.74	0.33	380	0.29	68.75	dl	3	3	Col	13	7	46	26.5	27.5	2.19	0.148	180	18	1.9	10	0.52	0	0	70	11	5	45	60	0
62CRW	18.9	11.7	4.8	19	1.9	240	27	0.27	79	8	1.1	9.57	0.34	447	0.31	100	dl	2	4	Col	18	7.9	58	17	25	1.15	0.09	140	15	1.7	4.6	0.76	0	0	40	15	5	60	78	5
63CER	18.5	11.3	4.6	18.6	1.92	244	27	0.33	81	8	1.1	6.76	0.37	488	0.45	0	gr	2	4	Col	7	6.7	75.5	12	12.5	1.66	0.097	140	9.1	1.4	3.8	0.14	0	0	40	20	0	50	75	3
64CRN	19	11.8	4.9	19.1	1.91	238	28	0.28	79	8	1.1	10.02	0.33	412	0.39	100	dl	3	4	Col	15	7.9	72	14	14	1.31	0.097	130	14	1.2	2.8	0.24	0	0	10	25	2	50	75	25
65CRE	19.1	11.9	5	19.2	1.9	235	28	0.25	77	8	1.1	6.16	0.32	434	0.42	50	dl	3	2	Col	17	7.8	75.5	10	14.5	1.94	0.124	120	15	1.1	2.4	0.24	180	1	75	5	2	75	85	0
66BAD	19.1	12	5	18.5	1.88	231	29	0.13	76	9	0.5	7.13	0.31	436	0.28	0	dl	2	4	All	8	6.4	26.5	39.5	34	2.33	0.166	220	18	2	9.8	0.35	360	1	25	15	2	20	30	0
67BAO	19.1	12	5	18.5	1.88	231	29	0.15	76	9	1.2	7.41	0.31	436	0.28	0	dl	3	2	Col	20	7.4	59	19.5	21.5	1.39	0.102	170	17	1.5	7.4	0.47	360	1	20	28	4	40	65	0
68CAR	19	11.9	5	19.2	1.88	230	28	0.20	77	8	1.1	6.27	0.32	437	0.26	0	pl	3	3	Col	29	7.2	59	21	20	1.1	0.074	170	12	1.6	7.2	1.5	360	1	10	15	8	15	75	30
69WCR	18.8	11.6	4.7	18.8	1.92	248	27	0.37	78	8	1.1	5.85	0.36	454	0.40	0	gr	1	4	Col	4	5.7	84	5.5	10.5	0.71	0.036	69	2.9	0.67	2.2	0.19	360	1	30	37	1	30	65	25
70CFT	19.1	11.8	4.9	18.5	1.94	239	29	0.28	77	9	1.1	5.88	0.33	446	0.39	100	dl	3	2	Col	17	7.9	66	16	18	1.6	0.117	150	15	1.7	3.6	0.39	360	1	60	24	3	70	80	30
71DVH	19.3	11.9	4.9	18.7	1.96	241	30	0.23	79	9	1.2	9.57	0.33	448	0.97	81.25	dl	4	1	Col	16	7.2	69	13.5	17.5	1.4	0.091	160	13	1.5	5.4	0.66	360	1	60	5	25	40	60	0
72JTE	18.5	11.4	4.6	18.4	1.89	250	27	0.48	75	8	1.1	11.24	0.37	418	0.43	100	pl	2	4	Col	13	7.4	82	5.5	12.5	1.1	0.061	68	11	0.72	1.7	0.1	360	0	15	30	2	30	0	12
73STW	18.5	11.7	5	17.9	1.82	249	26	0.30	80	8	0.5	4.43	0.34	413	0.20	18.75	dl	2	4	All	13	7.4	82.5	5.5	12	1.2	0.06	61	12	0.68	1.7	0.1	360	0	20	5	5	20	80	40
74PCE	16.8	11.4	5.2	19.7	1.46	305	20	0.44	68	8	0.8	7.12	0.44	260	0.25	87.5	dl	1	1	Col	5	6	86.5	6	7.5	0.68	0.04	36	3.8	0.65	1.8	0.16	360	0	20	12	5	25	60	35

S1 Environmental data for Ch3 GWW

Site	Tann	MTClQ	TCPMn	TDQ	Tseas	Pann	Pseas	PannSeas	PWrQ	PWetP	SDth	TWI	MIH	ALT	SLOPE	VB	NLF	GI	TCI	Geol	EC	pH	Sand	Silt	Clay	OrgC	Ntot	Ptot	Ca	K	Mg	Na	Aspect	Slope	tree	shrub	herb	litter	BG	OrgCst
75PCN	17	11.4	5.1	19.5	1.51	290	19	0.43	66	8	0.8	11.08	0.42	288	0.09	100	gr	1	3	Col	8	6.6	63.5	18.5	18	1.18	0.071	60	10	2.1	5.3	0.37	360	0	15	7	5	15	70	50
76SGT	16.6	11.3	5	21.9	1.46	328	24	0.47	65	9	0.8	5.87	0.53	246	0.63	0	pl	1	2	Col	12	6.2	67.5	18	14.5	1.83	0.092	85	9.1	1.9	6.4	0.82	360	0	20	6	28	15	40	20
77OHN	17.5	11.3	4.6	18.7	1.67	265	19	0.31	72	7	0.7	7.88	0.37	337	0.43	100	pl	1	3	Col	12	6.9	67	12	21	0.95	0.049	64	10	1	5	0.52	360	0	15	13	12	20	70	40
78LJN	17.6	11.4	4.7	18.7	1.68	265	20	0.42	70	7	0.3	5.15	0.38	313	0.64	56.25	sl	1	2	Eol	7	6	86	5.5	8.5	0.84	0.049	100	3.1	0.75	3	0.36	180	10	15	10	10	40	70	40
79LJW	17.2	11.2	4.8	19.4	1.63	275	21	0.53	70	8	1.1	6.31	0.42	340	0.63	0	sl	1	1	Eol	8	6.2	80.5	10	9.5	1.17	0.064	140	4.3	1.1	4.6	0.75	0	0	20	12	10	60	80	15
80LJS	17	11.1	4.7	19.2	1.61	281	21	0.51	70	8	1.1	3.22	0.43	311	2.19	0	sl	1	1	Eol	13	6.1	72	16.5	11.5	2.39	0.13	280	7.2	1.5	7.7	1.2	225	2	10	10	32	40	70	10
81BRS	16.8	11.1	4.9	19.4	1.54	294	20	0.49	70	8	0.5	8.89	0.43	339	0.43	0	dl	1	1	Eol	18	6.2	69	16	15	1.71	0.093	120	8.3	1.8	4.9	1.1	0	0	10	8	15	50	85	30
82MH2	17	10.7	4.3	19.9	1.72	317	31	0.92	69	10	1.1	8.77	0.53	400	0.19	0	gr	1	1	Snd	14	5.9	80	8.5	11.5	1.29	0.064	72	4.2	1.1	4.7	1	0	0	14	15	1	35	80	40
83HNR	17.2	11.1	4.5	19	1.64	279	18	0.31	71	8	0.7	8.86	0.39	365	0.38	6.25	gr	1	2	Eol	19	7.4	63.5	17.5	19	1.25	0.069	78	16	2.1	7.1	0.66	0	0	20	20	1	20	50	20
84NSE	17.3	11.2	4.3	14.8	1.64	276	20	0.23	78	8	0.7	5.57	0.38	345	0.57	0	gr	1	1	Col	9	6.4	79.5	10	10.5	1.39	0.083	160	8	1.6	4.3	0.41	0	0	25	2	4	50	90	5
85WGR	17.4	11.2	4.3	14.9	1.64	256	24	0.18	78	9	0.7	4.86	0.36	337	1.15	0	gr	1	3	Col	5	5.3	83	10	7	1.08	0.061	110	3.2	0.68	2.5	0.32	0	0	15	12	4	50	75	30
86WDL	17.7	11.4	4.4	15.1	1.67	251	23	0.16	78	8	0.7	5.36	0.35	337	0.64	0	gr	1	4	Col	10	6.3	77.5	11	11.5	1.46	0.081	94	6	1.3	5.4	0.69	0	0	15	12	10	40	65	25
87MDS	18	11.6	4.5	16.1	1.68	241	24	0.15	77	8	0.7	8.65	0.33	300	0.58	100	pl	3	4	Eol	5	6.5	88.5	4.5	7	0.64	0.04	71	3.1	0.71	3.3	0.16	0	0	10	13	3	30	70	10
88MDN	18.2	11.7	4.6	18.3	1.73	236	24	0.11	78	8	1.4	7.27	0.33	292	0.20	12.5	dl	3	4	All	31	7.5	76	11.5	12.5	1.73	0.104	97	14	1.2	6.2	1	0	0	20	17	3	60	80	5
89MDE	18.2	11.8	4.6	17.7	1.71	238	24	0.13	77	8	1.4	5.52	0.32	265	0.77	6.25	dl	4	3	Oth	140	7.6	74	15	11	1.39	0.087	120	7	1.3	5.6	3	0	0	15	2	5	25	90	15
90CWD	18.7	12.1	4.7	18.9	1.75	230	29	0.09	77	9	1.1	9.15	0.29	299	0.31	100	sl	4	1	Eol	12	7.4	59	24	17	1.07	0.08	180	16	2.2	6.2	0.35	0	0	10	12	4	20	80	40
91MMN	18.6	11.8	4.7	18.7	1.79	225	29	0.11	75	8	1.1	4.48	0.33	378	0.52	0	dl	4	3	Col	27	7.9	61	20	19	1.31	0.097	160	19	1.7	4.3	1.3	360	1	12	11	7	20	85	0
92MMC	18.7	11.9	4.9	18.9	1.79	231	28	0.10	74	8	1.1	9.86	0.31	381	0.36	0	dl	4	4	All	15	7.9	48	28	24	1.21	0.088	170	16	2.3	6.1	0.5	0	0	20	10	10	25	60	0
93AVD	18.5	11.7	4.4	18.8	1.79	234	30	0.08	79	10	0.5	6.06	0.31	388	0.62	0	dl	5	2	Col	17	8.1	68	17.5	14.5	1.33	0.101	210	15	1.8	4.2	0.78	0	0	10	4	22	40	50	0
94PHS	19.4	12.3	4.8	19	1.85	218	35	0.00	75	10	1.2	6.06	0.26	261	1.31	0	sl	4	2	Col	31	8	76	11.5	12.5	0.82	0.061	140	9.2	1.1	2.5	0.57	0	0	15	12	2	25	70	2
95PJS	19.1	12.1	4.7	19.5	1.84	217	34	0.04	76	10	1.2	5.67	0.27	362	0.05	0	dl	5	3	Snd	14	8.2	74.5	15.5	10	0.61	0.048	140	9	1	3.6	0.73	0	0	10	20	5	15	60	30
96KUR	18.8	11.9	4.5	19.1	1.83	224	32	0.08	77	9	1.2	3.88	0.3	388	1.10	0	dl	4	3	Col	30	7.9	72	14	14	1.12	0.084	140	13	1	4.4	0.9	0	0	10	2	10	15	70	7
97CHF	18.8	12.1	4.6	19	1.74	222	31	0.06	74	9	1.1	11.37	0.28	221	0.16	100	dl	3	1	Col	14	7.8	68.5	13.5	18	1.09	0.075	89	15	1.4	4.3	0.15	0	0	20	16	2	35	75	15
98ZAN	18.6	12.1	4.4	18.9	1.7	209	30	0.06	66	8	1.1	5.52	0.23	272	0.56	75	dl	2	1	All	6	6.7	72	13.5	14.5	0.89	0.065	130	8.9	1.8	4.2	0.27	0	0	15	11	15	50	65	15
99COO	18.3	11.7	4.3	18.5	1.73	230	30	0.05	74	9	1.1	5.11	0.3	298	1.29	0	dl	2	2	All	13	7.1	77.5	11.5	11	1.01	0.07	100	8	1.1	4.3	0.79	0	0	10	15	10	15	80	15

Plot	TCP	TDO	Tiso	Pann	PannSeas	Pseas	Tann	P	Elev	SDth	VBI	TWI	MIWQ	GEOL	EC	pH	OrgC	NTOT	PTOT	Pav	Kav	Mg	Ca	K	Clay	Silt	Sand
01LCR	4.4	14.2	0.5	335	0.86	29.00	16.8	9.80	382	1.1	4.70	9.29	0.08	All	4	5.9	0.86	0.05	77	2	200	3.1	2.7	0.57	7	7	86
02MH1	4.3	14.3	0.5	333	0.92	31.00	17	9.33	384	1.1	4.77	8.89	0.08	Eol	23	6.2	2.5	0.186	360	20	1100	7.6	9.4	3.1	10.5	34.5	55
03HT1	4.2	14.2	0.49	323	0.75	28.00	17.1	8.40	426	0.9	1.46	5.18	0.08	Grt	6	6	1	0.063	66	3	250	2.2	4.3	0.66	11	5.5	83.5
04HT2	4.3	14	0.48	310	0.55	23.00	17.3	8.43	432	0.9	0.61	5.42	0.08	Col	9	6.2	1.04	0.06	49	2	160	3.6	3.3	0.42	10.5	5	84.5
05MCD	4.7	14.1	0.5	292	0.46	20.00	17.5	5.48	338	0.7	0.00	4.46	0.08	Col	9	6.2	1.11	0.076	71	5	380	4.6	5.1	1	12	14.5	73.5
06PRS	4.1	14.5	0.49	335	0.95	34.00	17.4	8.90	390	0.9	0.00	7.48	0.07	Col	7	6.7	0.94	0.053	73	2	370	3.5	7.5	1.2	13.5	9.5	77
07BUL	4.3	14.4	0.46	299	0.77	35.00	18.8	6.76	420	0.9	2.57	7.10	0.06	Col	34	7.7	2.11	0.105	83	0.2	350	4.7	13	0.98	20	14.5	65.5
08KTS	5	14	0.48	275	0.14	23.00	18.4	6.61	349	1.4	1.81	9.41	0.08	Col	21	8	2.28	0.192	280	22	760	5.8	16	2.1	14.5	23.5	62
09KTC	5	14	0.48	272	0.16	21.00	18.5	6.61	322	0.9	0.00	9.71	0.08	All	16	7.8	1.42	0.138	200	13	900	6.8	14	2.4	18	34	48
10KTE	5.1	14.1	0.48	268	0.12	24.00	18.6	10.01	300	1.1	3.71	8.11	0.08	Col	27	7.9	1.13	0.108	170	7	460	5.3	9.6	1.3	20	15	65
11KTN	5	14	0.48	272	0.14	24.00	18.5	10.01	332	1.1	0.00	6.11	0.08	Col	10	6.8	0.87	0.073	150	4	480	5.3	6.4	1.2	16	12	72
12KTR	5	14	0.48	271	0.15	21.00	18.5	6.61	320	0.9	0.00	4.76	0.08	Col	32	7.6	0.93	0.077	150	8	400	4	7.2	1	14.5	16.5	69
13CHW	4.6	14	0.49	294	0.25	20.00	17.7	5.76	393	0.7	1.86	8.98	0.08	Col	29	6.1	1.54	0.102	140	8	550	5.6	6.5	1.6	12	18	70
14CHN	4.6	14	0.49	296	0.27	20.00	17.6	8.67	409	0.7	2.69	8.17	0.08	All	5	5.7	1	0.069	72	2	320	3.1	5.9	0.57	10.5	8.5	81
15CHR	4.5	13.9	0.48	301	0.27	20.00	17.5	5.97	445	0.9	0.00	4.08	0.08	Col	12	6.5	1.58	0.088	69	5	370	3.4	5.3	0.87	16	9.5	74.5
16BR1	4.7	13.9	0.48	295	0.27	21.00	17.8	5.91	399	1.1	3.83	9.99	0.08	Col	6	6.4	0.8	0.057	55	2	230	3.2	6	0.59	15.5	8.5	76
17BR2	4.7	13.9	0.48	294	0.28	20.00	17.8	5.94	397	0.7	3.75	8.70	0.08	All	6	6.2	1.04	0.074	65	5	350	3.4	5.3	0.86	12.5	8	79.5
18CHE	4.6	14	0.49	296	0.18	24.00	17.6	5.82	402	0.7	1.94	7.33	0.08	All	4	6.2	1	0.063	62	4	300	3.7	5.3	0.73	13.5	10.5	76
19WGT	4.8	14.1	0.49	284	0.16	21.00	18.1	5.90	331	1.4	0.87	6.75	0.08	All	45	7.7	1.23	0.091	160	13	610	5.8	11	1.5	15	16.5	68.5
20WGW	4.8	14.1	0.49	284	0.17	21.00	18.1	5.90	358	1.4	1.87	7.58	0.08	All	15	7.5	1.59	0.132	150	10	650	8	16	1.8	21.5	24.5	54
21MDC	4.7	14.4	0.49	279	0.19	21.00	18.2	7.84	291	0.9	2.97	9.62	0.08	All	84	7.5	1.28	0.105	160	11	640	7.8	10	1.7	21	30.5	48.5
22MDW	4.7	14.3	0.49	282	0.12	23.00	18.1	7.27	336	1.4	0.00	7.18	0.08	Col	100	7.7	1.61	0.134	160	12	590	5.8	10	1.7	18	25	57
23NSN	4.5	14.3	0.5	294	0.26	18.00	17.6	5.65	281	0.7	0.00	10.59	0.09	All	9	6	0.91	0.065	97	7	320	4.1	3.6	0.89	10	18	72
24WLB	5	14.1	0.48	272	0.19	20.00	18.5	6.61	311	1.4	1.41	5.54	0.08	Col	130	7.9	1.7	0.143	230	23	900	6.4	13	2.6	15	29.5	55.5
25BIN	4.5	14.2	0.49	294	0.15	20.00	17.7	8.16	351	0.9	0.00	4.06	0.08	Col	15	7.9	1.41	0.121	160	10	580	4.6	14	1.6	17.5	16	66.5
26YEL	4	14.4	0.48	306	0.90	32.00	17.8	4.88	382	0.9	0.61	5.59	0.07	Col	24	7.2	1.48	0.1	110	6	580	7.6	12	1.8	15	22	63
27BRB	4.5	14.2	0.48	295	0.59	26.00	18.1	10.05	388	0.3	1.48	6.03	0.07	Grt	11	6.2	1.14	0.081	100	9	500	3.2	4.3	1.2	9.5	10	80.5
28LKS	5.2	13.8	0.47	260	0.10	30.00	18.9	8.84	341	1.1	2.60	8.32	0.07	All	6	6	1.09	0.088	190	8	450	4.7	8.6	1.2	19.5	24	56.5
29MMW	5	13.8	0.47	262	0.09	31.00	18.8	8.96	365	1.1	1.74	7.56	0.07	Col	20	7.8	1.03	0.087	170	7	350	1.8	8.9	0.86	12.5	11	76.5
30BAC	5	13.9	0.46	266	0.09	31.00	19.2	4.63	389	1.2	1.48	6.21	0.07	Col	18	7.7	0.97	0.073	150	9	230	2.1	6.5	0.55	11.5	8	80.5
31MTV	5	13.9	0.46	266	0.09	31.00	19.2	4.63	389	1.2	1.48	6.21	0.07	Col	13	7.9	1.29	0.115	180	9	370	1.6	12	0.9	13	10.5	76.5
32LON	5.2	13.7	0.47	290	0.28	20.00	18.5	10.18	414	0.5	1.90	8.44	0.08	All	14	7.8	1.44	0.138	170	7	690	7.6	20	1.8	27.5	28.5	44
33CAL	5.2	13.6	0.47	291	0.22	25.00	18.5	5.64	433	0.5	0.85	6.72	0.08	Col	49	7.8	1.65	0.127	290	30	1100	7.8	16	2.9	14	34	52
34ENU	4.5	14.4	0.47	303	0.96	38.00	18.7	4.92	360	0.6	1.62	7.13	0.06	Col	8	7	1.08	0.072	130	6	460	6.1	11	1.1	18	16	66
35EGR	4.8	14.3	0.46	286	1.06	36.00	19	6.44	367	0.8	0.00	5.00	0.06	Col	8	6.5	1.11	0.072	110	5	310	2.2	6.1	0.91	16.5	6.5	77
36KWS	4.5	14.3	0.46	299	0.97	36.00	18.7	6.48	398	0.8	2.96	7.96	0.06	Col	9	6.7	1.42	0.093	180	8	640	6	8.6	1.7	14	18	68
37DHR	4.1	14.4	0.45	295	0.49	32.00	19	5.88	471	1.4	0.60	5.62	0.07	Col	50	7.7	1.48	0.1	190	11	600	6.9	14	1.6	28.5	18.5	53
38MJN	4.3	14.4	0.46	291	0.87	37.00	19.1	5.65	401	0.4	1.70	5.33	0.07	Col	28	7.9	1.86	0.128	140	6	540	3.3	15	1.4	15	19	66
39MJS	4.3	14.4	0.46	295	0.85	36.00	18.9	5.35	413	1.4	0.00	5.03	0.07	Col	19	7.2	1.71	0.11	200	12	780	8.2	14	2.2	13.5	30	56.5
40CAR	4.2	14.5	0.47	307	0.81	35.00	18.5	6.05	373	0.9	1.53	4.84	0.06	Col	12	6.3	1.5	0.086	140	5	450	4.5	6.2	1.2	17	11.5	71.5
41KLY	4.3	14.5	0.47	296	0.51	32.00	18.6	6.48	358	0.9	1.45	6.50	0.06	Col	13	7.5	1.27	0.079	93	3	440	2.9	9.5	1.2	15.5	10	74.5

Plot	TCP	TDO	Tiso	Pann	PannSeas	Pseas	Tann	P	Elev	SDth	VBI	TWI	MIWQ	GEOL	EC	pH	OrgC	NTOT	PTOT	Pav	Kav	Mg	Ca	K	Clay	Silt	Sand
42HAS	4.1	14.3	0.46	302	0.50	32.00	18.6	6.54	454	1.4	2.98	11.16	0.07	Col	15	7.9	1.41	0.103	150	7	860	3.7	17	2.5	18	25.5	56.5
43HAN	4	14.2	0.45	309	0.62	31.00	18.4	6.24	475	1.4	0.00	9.47	0.07	Col	6	6.5	1.59	0.097	260	15	670	5.4	7.3	1.8	17	23.5	59.5
44HAW	4.2	14.4	0.46	297	0.75	34.00	18.8	6.16	421	1.4	3.95	11.90	0.07	Col	13	6.8	1.21	0.073	150	4	540	6.2	9.9	1.4	18.5	16.5	65
45HTR	4.2	14.1	0.45	301	0.68	31.00	18.8	6.58	474	1	0.55	5.82	0.07	Col	19	7.7	1.97	0.124	130	9	790	6.1	19	2.1	21.5	17	61.5
46MTD	4.2	14.1	0.46	304	0.61	30.00	18.6	7.59	495	1	2.98	7.65	0.07	Col	28	7.4	2.69	0.165	150	5	690	7.4	16	1.6	26.5	23	50.5
47JDN	4.3	14.2	0.46	300	0.54	30.00	18.6	6.51	466	1.4	3.95	10.50	0.07	All	15	7.8	1.32	0.094	130	5	540	3.7	15	1.5	18	19	63
48GLT	4.3	14.3	0.47	294	0.69	30.00	18.5	7.17	390	0.9	0.61	4.22	0.07	Col	22	7.1	1.4	0.075	96	3	430	4.2	10	1.4	15.5	11.5	73
49JWH	4.4	14.2	0.46	295	0.57	29.00	18.6	9.60	425	1.2	2.88	5.58	0.07	Col	24	7.6	1.4	0.097	120	6	590	5.6	14	1.6	26	18.5	55.5
50JMF	4.4	14.2	0.46	296	0.56	28.00	18.5	9.42	417	0.9	2.50	9.71	0.07	Col	7	6.8	1.19	0.078	110	3	490	5.6	11	1.5	20.5	16	63.5
51JDN	4.3	14.1	0.46	299	0.58	28.00	18.3	7.56	458	0.5	0.90	5.36	0.07	Col	9	6	2.03	0.108	170	6	400	6.4	6.7	1.1	16.5	12	71.5
52JTW	4.4	14.2	0.47	294	0.58	28.00	18.4	7.70	407	1.1	2.54	6.05	0.07	All	18	7.5	1.41	0.082	100	5	500	7.1	21	1.5	19.5	15	65.5
53JHS	4.4	14.2	0.47	294	0.56	28.00	18.4	7.70	410	0.9	2.98	10.79	0.07	All	38	7.2	1.12	0.079	140	10	550	5.7	12	1.5	18	22.5	59.5
54JDW	4.3	14.2	0.47	297	0.60	28.00	18.4	7.47	406	0.9	0.00	4.62	0.07	Col	19	6.6	1.11	0.061	84	4	370	4	8	1	14.5	10.5	75
55JTC	4.6	14.1	0.47	294	0.49	27.00	18.4	9.42	416	1.1	3.94	4.42	0.07	Col	21	7.6	2.08	0.159	140	8	720	8.1	16	1.8	20.5	19.5	60
57JSD	4.4	14.1	0.47	297	0.59	28.00	18.3	5.55	442	0.5	0.68	6.85	0.07	Col	8	6.7	1.16	0.061	66	2	280	1.7	7.3	0.83	12.5	5.5	82
58JDS	4.5	14.2	0.47	292	0.37	29.00	18.4	10.31	399	1.1	0.74	6.62	0.07	Col	17	8	2.01	0.141	150	6	460	3.6	15	1.3	13.5	15.5	71
61CRS	5	13.8	0.46	284	0.26	27.00	18.9	8.75	414	0.5	2.52	7.74	0.08	Col	13	7	2.19	0.148	180	7	620	10	18	1.9	27.5	26.5	46
62CRW	4.8	13.8	0.46	288	0.27	27.00	18.9	9.23	442	1.1	2.84	9.57	0.08	Col	18	7.9	1.15	0.09	140	10	620	4.6	15	1.7	25	17	58
63CER	4.6	13.8	0.46	299	0.33	27.00	18.5	7.14	488	1.1	1.76	6.76	0.08	Col	7	6.7	1.66	0.097	140	8	490	3.8	9.1	1.4	12.5	12	75.5
64CRN	4.9	13.9	0.46	286	0.28	28.00	19	9.21	427	1.1	3.93	10.02	0.08	Col	15	7.9	1.31	0.097	130	10	480	2.8	14	1.2	14	14	72
65CRE	5	13.9	0.46	281	0.25	28.00	19.1	9.07	421	1.1	3.41	6.16	0.07	Col	17	7.8	1.94	0.124	120	4	420	2.4	15	1.1	14.5	10	75.5
66BAD	5	13.8	0.46	271	0.13	29.00	19.1	8.66	420	0.5	1.97	7.13	0.07	All	8	6.4	2.33	0.166	220	10	650	9.8	18	2	34	39.5	26.5
67BAO	5	13.8	0.46	271	0.15	29.00	19.1	8.66	414	1.2	1.92	7.41	0.07	Col	20	7.4	1.39	0.102	170	8	520	7.4	17	1.5	21.5	19.5	59
68CAR	5	13.8	0.46	278	0.20	28.00	19	9.14	419	1.1	3.78	6.27	0.07	Col	29	7.2	1.1	0.074	170	12	540	7.2	12	1.6	20	21	59
69WCR	4.7	13.9	0.46	293	0.37	27.00	18.8	9.26	446	1.1	3.90	5.85	0.08	Col	4	5.7	0.71	0.036	69	3	270	2.2	2.9	0.67	10.5	5.5	84
70CFT	4.9	13.9	0.46	287	0.28	29.00	19.1	8.83	434	1.1	3.85	5.88	0.07	Col	17	7.9	1.6	0.117	150	6	580	3.6	15	1.7	18	16	66
71DVH	4.9	13.9	0.45	288	0.23	30.00	19.3	8.66	449	1.2	2.89	9.57	0.07	Col	16	7.2	1.4	0.091	160	10	630	5.4	13	1.5	17.5	13.5	69
72JTE	4.6	14.1	0.47	293	0.48	27.00	18.5	9.42	416	1.1	4.60	11.24	0.07	Col	13	7.4	1.1	0.061	68	1	250	1.7	11	0.72	12.5	5.5	82
73STW	5	13.8	0.47	291	0.30	26.00	18.5	9.85	409	0.5	3.82	4.43	0.08	All	13	7.4	1.2	0.06	61	1	250	1.7	12	0.68	12	5.5	82.5
60FHN	5.1	13.2	0.52	341	0.72	27.00	16.2	6.15	369	1	2.70	7.55	0.1	Col	27	7.1	1.96	0.099	70	4	320	5.4	8.6	0.74	14.5	8.5	77
74PCE	5.2	13.5	0.52	312	0.44	20.00	16.8	6.44	265	0.8	2.89	7.12	0.09	Col	5	6	0.68	0.04	36	1	260	1.8	3.8	0.65	7.5	6	86.5
75PCN	5.1	13.8	0.52	295	0.43	19.00	17	6.57	254	0.8	3.97	11.08	0.08	Col	8	6.6	1.18	0.071	60	1	630	5.3	10	2.1	18	18.5	63.5
76SGT	5	13.6	0.52	335	0.47	24.00	16.6	7.02	256	0.8	1.54	5.87	0.09	Col	12	6.2	1.83	0.092	85	3	590	6.4	9.1	1.9	14.5	18	67.5
77OHN	4.6	14.2	0.5	289	0.31	19.00	17.5	5.56	320	0.7	2.94	7.88	0.08	Col	12	6.9	0.95	0.049	64	1	400	5	10	1	21	12	67
78LJN	4.7	14.2	0.5	288	0.42	20.00	17.6	5.29	315	0.3	4.54	5.15	0.08	Eol	7	6	0.84	0.049	100	3	300	3	3.1	0.75	8.5	5.5	86
79LJW	4.8	14.1	0.5	299	0.53	21.00	17.2	8.71	329	1.1	1.65	6.31	0.08	Eol	8	6.2	1.17	0.064	140	6	400	4.6	4.3	1.1	9.5	10	80.5
80LJS	4.7	13.9	0.51	303	0.51	21.00	17	8.44	338	1.1	0.00	3.22	0.08	Eol	13	6.1	2.39	0.13	280	14	550	7.7	7.2	1.5	11.5	16.5	72
81BRS	4.9	13.7	0.51	307	0.49	20.00	16.8	9.64	333	0.5	2.98	8.89	0.09	Eol	18	6.2	1.71	0.093	120	8	540	4.9	8.3	1.8	15	16	69
56WLG	4.7	13.9	0.47	296	0.45	24.00	18.2	10.48	416	1.4	3.53	6.33	0.08	Col	16	7.9	1.39	0.099	100	4	720	3.2	18	2.1	19.5	17.5	63
59VRN	4.8	13.8	0.48	297	0.32	24.00	18	7.91	426	0.9	0.00	4.93	0.08	Col	17	7.9	1.09	0.08	81	3	440	3.1	14	1.2	19	13.5	67.5
82MH2	4.3	14.3	0.5	334	0.93	31.00	17	9.33	394	1.1	4.79	8.77	0.08	Col	14	5.9	1.29	0.064	72	2	350	4.7	4.2	1.1	11.5	8.5	80

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Plot	TCP	TDO	Tiso	Pann	PannSeas	Pseas	Tann	P	Elev	SDth	VBI	TWI	MIWQ	GEOL	EC	pH	OrgC	NTOT	PTOT	Pav	Kav	Mg	Ca	K	Clay	Silt	Sand
84NSE	4.3	14.3	0.5	303	0.47	21.00	17.3	5.75	334	0.7	1.69	5.57	0.1	Col	9	6.4	1.39	0.083	160	1	490	4.3	8	1.6	10.5	10	79.5
85WGR	4.3	14.3	0.5	293	0.10	28.00	17.4	5.48	334	0.7	0.51	4.86	0.1	Col	5	5.3	1.08	0.061	110	3	350	2.5	3.2	0.68	7	10	83
86WDL	4.4	14.4	0.5	288	0.18	23.00	17.7	5.26	339	0.7	1.43	5.36	0.09	Col	10	6.3	1.46	0.081	94	2	450	5.4	6	1.3	11.5	11	77.5
87MDS	4.5	14.4	0.5	280	0.13	24.00	18	4.69	291	0.7	2.74	8.65	0.09	Eol	5	6.5	0.64	0.04	71	2	310	3.3	3.1	0.71	7	4.5	88.5
88MDN	4.6	14.3	0.49	281	0.19	22.00	18.2	6.14	336	1.4	2.92	7.27	0.09	All	31	7.5	1.73	0.104	97	2	420	6.2	14	1.2	12.5	11.5	76
89MDE	4.6	14.4	0.49	276	0.11	28.00	18.2	6.36	294	1.4	1.68	5.52	0.09	Col	140	7.6	1.39	0.087	120	4	450	5.6	7	1.3	11	15	74
90CWD	4.7	14.6	0.49	267	0.09	29.00	18.7	4.52	296	1.1	2.94	9.15	0.08	Eol	12	7.4	1.07	0.08	180	7	650	6.2	16	2.2	17	24	59
91MMN	4.7	14.1	0.47	277	0.03	35.00	18.6	8.65	354	1.1	0.00	4.48	0.08	Col	27	7.9	1.31	0.097	160	11	640	4.3	19	1.7	19	20	61
92MMC	4.9	14	0.47	269	0.06	33.00	18.7	10.00	361	1.1	5.60	9.86	0.07	All	15	7.9	1.21	0.088	170	8	800	6.1	16	2.3	24	28	48
93AVD	4.4	14.4	0.48	277	0.08	30.00	18.5	4.52	382	0.5	0.56	6.06	0.08	Col	17	8.1	1.33	0.101	210	15	710	4.2	15	1.8	14.5	17.5	68
94PHS	4.8	14.4	0.47	247	0.00	35.00	19.4	6.39	356	1.2	0.61	6.06	0.07	Col	31	8	0.82	0.061	140	6	370	2.5	9.2	1.1	12.5	11.5	76
96KUR	4.5	14.3	0.47	268	0.08	32.00	18.8	8.25	404	1.2	0.00	3.88	0.08	Col	30	7.9	1.12	0.084	140	4	390	4.4	13	1	14	14	72
95PJS	4.7	14.4	0.47	256	0.04	34.00	19.1	7.61	360	1.2	1.42	5.67	0.07	Col	14	8.2	0.61	0.048	140	11	410	3.6	9	1	10	15.5	74.5
97CHF	4.6	14.8	0.49	256	0.06	31.00	18.8	8.85	284	1.1	3.98	11.37	0.08	Col	14	7.8	1.09	0.075	89	1	470	4.3	15	1.4	18	13.5	68.5
98ZAN	4.4	15	0.5	221	0.06	30.00	18.6	8.19	278	1.1	3.73	5.52	0.07	All	6	6.7	0.89	0.065	130	5	570	4.2	8.9	1.8	14.5	13.5	72
99COO	4.3	14.7	0.49	263	0.05	30.00	18.3	9.58	369	1.1	0.00	5.11	0.08	All	13	7.1	1.01	0.07	100	3	420	4.3	8	1.1	11	11.5	77.5
100RT	4.6	14.3	0.48	282	0.09	29.00	18.5	8.51	368	1.1	0.00	4.79	0.08	Col	98	7.8	1.52	0.097	130	6	530	3.9	12	1.5	13	19	68
101WY	5.9	13.9	0.48	321	1.68	52.00	18.4	5.57	324	1	1.94	7.24	0.05	Col	6	5.9	1.5	0.118	140	10	360	3	4.1	0.82	9	8	83
102TO	5.2	13.8	0.48	325	1.45	46.00	18	7.90	331	0.9	0.00	4.39	0.06	Grt	13	5.7	1.57	0.109	140	8	240	3.4	3.3	0.54	10.5	7.5	82.5
103NG	5.5	13.9	0.48	308	1.42	45.00	18.3	7.30	278	1	3.83	7.18	0.05	All	6	6.4	1.1	0.091	100	6	680	4.4	9.2	1.9	14.5	22.5	63
104YO3	4.8	14.8	0.5	382	2.53	64.00	17.6	7.56	226	1	0.94	6.74	0.05	Col	17	5.6	1.57	0.086	130	7	230	5.6	4.2	0.52	14.5	10	75.5
105WE	4.8	14.2	0.47	322	1.32	44.00	18.2	6.69	335	0.9	0.00	6.14	0.06	Col													
106BE	5.1	14.2	0.47	281	1.24	37.00	18.9	5.95	344	0.9	4.97	4.76	0.06	Eol	16	8.3	1.84	0.136	140	16	550	2.13	12.51	1.72	1.2	3.5	95.3
107HY1	4.4	14.5	0.51	344	1.14	40.00	16.8	6.55	327	1	3.99	11.95	0.07	All	18	6.4	0.85	0.034	28	0.2	88	1.18	2.77	0.22	2.8	2.6	94.5
108HY2	4.2	14.1	0.51	346	1.14	41.00	16.3	9.83	397	0.9	1.81	7.74	0.07	Col	13	6.6	1.94	0.079	74	5	240	3.54	5.27	0.64	4.3	3.8	91.9
109HY3	4.2	14.3	0.51	347	1.14	41.00	16.4	6.69	359	1	0.00	9.35	0.07	Col	5	6.8	1.63	0.078	66	2	210	2.55	4.52	0.51	2.8	2.9	94.3
110HY4	4.5	14.3	0.51	338	0.98	36.00	16.8	6.54	350	1	0.57	6.09	0.08	Grt													
111KN1	4.5	14.6	0.51	322	1.46	47.00	17.1	5.93	307	0.3	0.00	4.40	0.06	Col	17	7.1	2.04	0.102	74	4	420	5.54	8.9	1.32	2.7	4.1	93.2
112KN2	4.4	14.8	0.5	334	1.31	44.00	17.3	4.87	301	1	3.94	5.47	0.06	All	16	7.1	0.94	0.044	46	0.2	240	1.61	4.08	0.57	6.5	2.8	90.7
113KN3	4.6	13.8	0.49	346	2.02	54.00	16.8	6.61	334	1	1.87	4.83	0.06	Col	38	6.4	2.26	0.105	94	3	260	3.12	4.51	0.41	3.7	2.5	93.7
114LG1	4.9	13.3	0.52	337	1.12	39.00	16.1	9.74	297	0.3	4.67	9.83	0.08	Eol													
115LK	5.1	13.2	0.53	345	0.75	30.00	16.2	6.47	341	1	2.51	10.07	0.09	Col	21	5.9	2.68	0.129	93	7	170	2.76	7.17	0.4	3.8	2.2	94
116NN1	6.2	13.7	0.49	472	3.11	74.00	18.1	7.99	264	1	0.00	4.06	0.04	All													
117NN2	6.3	13.8	0.49	459	3.08	73.00	18.3	7.35	240	0.9	0.00	4.22	0.04	Col													
118PI1	5	13	0.53	358	0.84	33.00	15.9	6.14	301	1	1.88	8.65	0.09	All	94	6.6	3.7	0.179	90	4	420	8.51	8.52	1.08	2.8	1.2	96
119PI2	4.9	13.3	0.53	341	1.03	37.00	16	6.17	303	1	3.98	11.44	0.08	Eol	7	6.3	1.1	0.05	38	3	130	1.42	2.91	0.31	3.8	2.6	93.6
120QU1	5	14.3	0.5	317	2.01	56.00	17.6	5.39	238	1	3.66	4.91	0.05	All	59	6.2	1.67	0.106	98	5	210	2.32	6.36	0.36	4.1	4.8	91.2
121QU2	5.1	14.4	0.49	312	1.99	56.00	17.8	4.97	241	1	2.78	9.08	0.05	All	16	6.4	1.67	0.088	71	5	240	3.16	4.06	0.44	4.2	6.1	89.8
122QU3	4.9	14.4	0.5	330	2.05	56.00	17.6	9.27	251	1	0.63	8.84	0.05	All	6	6.2	1.3	0.066	74	4	200	2.41	3	0.39	1.7	4.7	93.7
123LB	4.9	13.3	0.52	337	1.12	38.00	16.1	6.27	297	0.3	4.83	12.36	0.08	Col	11	6.5	0.87	0.038	35	0.2	100	1.1	2.7	0.21	2.4	1.9	95.7
124LK2	5	13.4	0.52	337	0.80	29.00	16.3	5.86	345	0.9	0.00	6.01	0.09	Eol													

Plot	TCP	TDO	Tiso	Pann	PannSeas	Pseas	Tann	P	Elev	SDth	VBI	TWI	MIWQ	GEOL	EC	pH	OrgC	NTOT	PTOT	Pav	Kav	Mg	Ca	K	Clay	Silt	Sand
126MM	5.9	13.8	0.47	299	1.27	46.00	18.8	5.04	328	1.2	0.00	4.41	0.05	Grt	86	7.8	1.67	0.106	87	7	510	4.77	10.83	1.15	3.8	3.1	93.1
127TR	6.1	13.8	0.47	295	1.63	51.00	18.7	5.97	318	1.2	0.00	4.59	0.04	Col	13	7.3	2.14	0.142	140	10	500	4.02	12.75	1.31	3	4.7	92.3
128WA1	6.3	14.1	0.49	426	2.93	69.00	18.7	5.35	198	0.9	4.95	4.96	0.05	All													
129WA2	6	14.2	0.49	413	2.80	68.00	18.6	8.97	248	1	0.00	5.11	0.05	Lat													
130WK	5	13.7	0.5	340	2.08	56.00	16.8	5.82	266	1	4.97	4.62	0.06	Col	21	6.4	2.11	0.102	80	5	260	3.4	7.16	0.52	6.2	4.9	88.9
131WU	6	14.5	0.47	295	1.54	51.00	19.6	6.77	312	0.9	3.70	5.98	0.05	Col	18	7.9	1.11	0.07	85	5	280	1.7	10.15	0.82	3.4	3.4	93.2
132W6	6.2	13.8	0.49	391	2.54	67.00	18.2	9.54	271	1	0.63	6.17	0.05	Grt													
133W7	6.2	13.8	0.49	377	2.47	66.00	18.3	6.15	258	1	0.60	4.96	0.05	Grt													
134W10	6	14.2	0.49	365	2.42	65.00	18.3	6.02	229	0.9	0.00	4.55	0.05	Col													
135W11	5.9	14	0.49	390	2.56	67.00	18	9.73	264	1	5.42	4.73	0.05	Col													
136W53	5.7	14.2	0.49	337	1.98	57.00	18.3	8.42	257	1	0.00	4.23	0.05	Col													
137W74	5.3	13.8	0.46	321	1.38	44.00	18.5	6.03	421	0.7	0.00	6.03	0.05	Grt													
138W76	5.7	13.8	0.47	304	1.29	45.00	18.8	6.85	348	1	0.00	3.86	0.05	Col													
139W85	5.1	13.9	0.47	319	1.38	45.00	18.2	5.64	328	0.9	0.00	5.41	0.05	Col													
140W104	4.8	14.4	0.49	340	1.41	45.00	17.5	7.87	348	0.7	0.55	6.25	0.06	Grt													
141W124	5.8	13.9	0.48	304	1.37	48.00	18.7	4.97	282	1	3.93	6.19	0.05	All													
142W152	6.1	14.3	0.47	292	1.60	52.00	19.4	5.45	298	0.4	0.00	4.30	0.04	Grt													
143W160	6.3	14.7	0.48	319	2.11	62.00	19.7	7.12	313	1	2.94	7.26	0.04	Col													
144W187	6.2	14.5	0.48	346	2.29	64.00	19.2	7.06	328	0.9	0.00	4.66	0.04	Grt													
145W191	5.9	14	0.48	387	2.53	66.00	18.3	9.86	304	0.9	0.89	6.51	0.05	Col													
146W215	4.9	13.4	0.53	349	0.90	34.00	16	5.46	328	0.9	2.74	9.09	0.09	Col													
147YO1	4.8	14.8	0.5	397	2.64	65.00	17.6	7.19	235	0.9	0.55	5.18	0.05	Col	26	8	2.39	0.142	91	6	600	5.53	14.32	1.4	2.5	3.9	93.6
148YO2	4.8	14.8	0.5	382	2.53	64.00	17.6	7.56	226	1	0.94	6.74	0.05	Col	8	6.5	1.8	0.098	120	5	260	4.58	4.38	0.58	5.2	5.9	89

S3 Two way table for GWW analysis Ch3

		01LCR	02MH1	82MH2	72JTE	55JTC	15CHR	77OHN	83HNR	59VRN	14CHN	16BR1	17BR2	18CHE	06PRS	04HT2	27BRB	23NSN	58JDS	48GLT	69WCR	54JDW	52JTW	49JWH	47JDN	56WLG	26YEL	51JDN	11KTN	86WDL	85WGR	57JSD	78LJN	79LJW	80LJS	35EGR	13CHW	07BUL	29MMW	28LKS	97CHF	73STW	63CER	20WGW	88MDN	87MDS	25BIN	81BRS	84NSE	50JMF	75PCN	74PCE	76SGT	05MCD	03HT1	19WGT	08KTS	98ZAN	66BAD	61CRS	70CFT	62CRW	71DVH	96KUR	94PHS	90CWD	31MTV	99COO	30BAC	38MJN	64CRN	65CRE	67BAO	68CAR	10KTE	09KTC	93AVD	53JHS	92MMC	91MMN	46MTD	32LON	95PJS	37DHR	44HAW	36KWS	34ENU	43HAN	39MJS	40CAR	45HTR	100RT	12KTR	24WLB	89MDE	22MDW	21MDC	33CAL	41KLY	42HAS	60FHN
Daviesia scoparia		1	4	1																																																																																															
Acacia dissona v. dissona			0.5																																																																																																
Bentleya diminuta		5																																																																																																	
Lomandra micrantha s.		0.5																																																																																																	
Platysace maxwellii		1																																																																																																	
Thelymitra petrophila				0.5																																																																																															
Westringia cephalantha v.		5																																																																																																	
Eucalyptus yilgarnensis			20	4																																																																																															
Eremophila ionantha			0.5	4		0.5		1	0.5	0.5	3	0.5	1	0.5	2	1	3	3	0.5		0.5	0.5	2	10	12	3	4	1	1				5				0.5			1		2	0.5	3			1			0.5			0.5	20	1				1	0.5		0.5													2		0.5	0.5			1					2			5	7		1								
Alyxia buxifolia					1		0.5	3	0.5	2	3	3	4	5	0.5	1	2	1	0.5	0.5						1		0.5	2	0.5	0.5		1	3					0.5				0.5	0.5	0.5	1					4		0.5		0.5																																0.5										
Grevillea acuaria							0.5		2		1	1	7	4	15	0.5	0.5					0.5								0.5											0.5																		2																																																
Exocarpos aphyllus					2	0.5	1	2	1	2	2	3	2	2	1	1	1	2	2	1	1	0.5	1	0.5	1	2	2	0.5	0.5	2	1	0.5	0.5	0.5	2	0.5	3	5	1	1	1	0.5		2			2	0.5		0.5					1	2	1	0.5					0.5	0.5		1			0.5				1	0.5		0.5			0.5	0.5					0.5	0.5		0.5							0.5		14					
Acacia nyssophylla		1		0.5				0.5	4								2	2	0.5	1	2	2										1	1						1						0.5		2		2	7	6	5	8	7			1																																												
Cratystylis conocephala																			6													10	0.5		0.5	7			10					0.5			18	0.5	3																							0.5																																		
Acacia colletioides					1	2					1	1	4											3																		1																																																													
Acacia merrallii	7															3			0.5							2			1	0.5																															2	0.5		1																																																
Eremophila caerulea s. caerulea							1		1		7	3	4																																																																																							
Santalum acuminatum		1			2	0.5	2	2	1	2	0.5	1			1	1									1	0.5									0.5	0.5	1		1				0.5		2	3	1	1		0.5	0.5	0.5	1	1	0.5	0.5																						4			2			2						1				0.5					1				1	
Olearia pimeleoides								0.5									0.5			0.5		0.5																									0.5		0.5		0.5																																							0.5														
Eremophila oppositifolia s.					0.5		4				2																0.5	0.5	1																																	1																					0.5																						
Senna artemisioides s. filifolia		0.5	0.5	0.5	1	0.5		2	3	0.5	0.5	0.5	1	0.5		0.5	1	0.5	2	1	0.5	1	3	0.5	1	2	0.5	1	0.5		2	2	0.5	0.5		2	2	2	2	2	4	2	18	3		0.5	0.5	1	2	2	2	1	0.5	20		0.5	0.5	2	5	0.5	0.5		1	2	2	3	4	2	1	2	0.5	0.5	0.5				0.5		0.5			1						0.5		0.5	0.5		0.5	0.5					6		
Eremophila decipiens		0.5	0.5						0.5								2	0.5		0.5					0.5	0.5			1	1	2	1	0.5	0.5	0.5	0.5		2			0.5	0.5			0.5	0.5		1			0.5				0.5		0.5		1	0.5						0.5																0.5	0.5								0.5										
Olearia muelleri		5			0.5	0.5	2	1	0.5	0.5	0.5	1	4	7	0.5	0.5	1	0.5	0.5	0.5	1	0.5	1	0.5	0.5	0.5	1	0.5	0.5	1			4	2	4	10	2	3	0.5	1		1	0.5		0.5	0.5	0.5	0.5	0.5		0.5	0.5	0.5	1		0.5	1	2			0.5			0.5	0.5		1	0.5	0.5	2	2	0.5				0.5					0.5	0.5								0.5		3				0.5			0.5	0.5	1
Eremophila interstans s.					0.5	2														1													0.5		0.5																		0.5																																	1																						
Acacia enervia s. enervia								2			2	1	2						2																																								1				0.5																	2																							
Santalum spicatum														3						0.5		0.5						0.5													2						0.5	1																					1															2																		
Amyema miquelii																												0.5	0.5	0.5		0.5						0.5									1																																																										
Maireana sedifolia	19																				0.5																					0.5				3																			2	8	5		10	7	7	5	3	4		20	2	5	3	4	5	2			4											8	15	0.5	0.5	0.5	0.5				
Atriplex vesicaria																									5																									1	0.5	0.5	2		1	0.5													0.5			2	1	1		0.5							2	21	0.5		0.5	1	2	17	20	3	14		6	7	3	5	0.5		0.5	2	0.5					
Ptilotus nobilis								0.5													0.5			0.5	0.5	0.5							0.5	0.5			0.5		0.5	0.5	1																			1		0.5	0.5	0.5	0.5	0.5	0.5			0.5			0.5				0.5	0.5	0.5	0.5	1			0.5			0.5			0.5					0.5		0.5						
Maireana triptera																				0.5		0.5					0.5									0.5						0.5																			0.5	1	2	0.5	10	0.5				0.5						1						2	1					1	5	10	1		1			0.5								
Paspalidium gracile																																																														0.5				0.5	0.5												0.5			0.5			0.5																				
Sclerolaena drummondii																																																																																	0.5	0.5					1				0.5																		
Maireana radiata																																																									0.5																									1	0.5															0.5	0.5	0.5				0.5			0.5					
Ptilotus divaricatus																																																																																											0.5	1	0.5			0.5												
Tecticornia disarticulata																																																																																																			15	34	5	0.5					
Sclerolaena diacantha			0.5	0.5				0.5	0.5					0.5		0.5	0.5		0.5				0.5						0.5	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5	0.5	0.5		0.5		0.5	0.5	0.5	0.5		0.5										1		0.5	0.5	0.5	2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		0.5		0.5	0.5	0.5	0.5	2		0.5	0.5	0.5	0.5	0.5	0.5	0.5	2	0.5	0.5	0.5	2	0.5		0.5	0.5					
Ptilotus obovatus																							0.5							0.5	0.5	0.5	0.5	2	0.5	0.5			0.5	0.5			0.5	0.5		0.5												0.5	0.5	4	2	0.5	0.5	2	0.5	0.5	0.5	0.5	0.5	0.5		2	0.5	0.5			0.5				0.5					0.5	0.5	2	0.5						0.5				0.5		0.5		
Eremophila scoparia						0.5			4	0.5				8	1				0.5	3	3	0.5	0.5	0.5		0.5	6	0.5	1	0.5	0.5							3	1	8	2	0.5	1	0.5	2	3	8		0.5					7	0.5	2	3	0.5	0.5	2	2	10			3	0.5	4	4	6	4	0.5	1	15	2	3			0.5	2		1	1	0.5	2	0.5		0.5	3			5		0.5	3		0.5			0.5	1	
Atriplex nummularia																			2	0.5						2					0.5			1							1						0.5	0.5										3	20			1	10	1	4	2	2	1	1		0.5	4				0.5	6	3	3		3	8	3	1			3		0.5	1	5	4	5	0.5		0.5		0.5	2	2		0.5	
Maireana pyramidata																																																													0.5	1		0.5												4	4		5	2						7											0.5	0.5			0.5	2			
Sclerolaena obliquicuspis																																									0.5					0.5																									0.5	0.5														0.5		0.5						0.5									0.5		0.5			0.5	0.5			
Mesembryanthemum nodiflorum																																																																																																				0.5				
Austrostipa platychaeta					0.5				1	0.5																				0.5																										0.5	0.5																																								0.5														2	0.5	0.5
Solanum orbiculatum																																							0.5																						0.5																																		0.5	0.5				0.5								1	0.5	
Eriochiton sclerolaenoides								0.5		0.5											0.5		0.5	0.5	0.5	0.5	0.5																																								0.5	0.5									1	0.5	0.5																					2	0.5			0.5						0.5	0.5	
Zygophyllum eremaeum																						0.5																0.5			0.5	0.5	0.5	0.5					0.5															0.5			0.5		0.5		0.5						0.5		0.5					0.5	0.5			0.5										0.5				0.5		0.5	0.5	
Chenopodium gaudichaudianum																																																																																																							0.5		
Dodonaea bursariifolia																																																																																																										0.5
Eremophila psilocalyx																																																							0.5																																																		2
Coopernookia strophiolata																																																																																																										0.5
Dodonaea glandulosa																																																																																																										1
Eucalyptus calycogona																																																																																																										5
Gahnia ancistrophylla																																																																																																										0.5
Leucopogon brevicuspis																																																																																																										0.5
Scaevola spinescens		5		0.5	11	5	3	2	3	2	2	3	3	2	1	0.5	0.5	1	1	0.5	1	2	0.5	1		0.5	4	2	2	1	4	0.5	0.5	0.5	1	1	6	20	3	5	2	2			1	3	1		1		2	3	22	15	25	1	0.5					0.5		0.5	0.5		0.5	3			0.5	0.5	0.5		0.5	0.5		0.5													2	0.5		0.5	0.5	0.5	1			0.5		
Austrostipa elegantissima				0.5		0.5	0.5	0.5			0.5	0.5			0.5	0.5	0.5		0.5	1	0.5	0.5	0.5	0.5	0.5	1	0.5			0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5		0.5	0.5	0.5	0.5		0.5	0.5	0.5			0.5	0.5		0.5	0.5	0.5	0.5	0.5	0.5			0.5		0.5	1	0.5	0.5	1	0.5	0.5	0.5	0.5	0.5	0.5					0.5	0.5	0.5				0.5	1		2	0.5		0.5			0.5	0.5				
Rhagodia drummondii			0.5														1	0.5	2	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5			0.5	1	2	2	3	1	0.5		1				0.5	0.5			0.5	0.5	0.5	0.5	0.5		0.5	1						0.5	2									0.5	0.5	0.5	0.5	0.5	1				1	0.5		0.5	3		0.5	0.5	0.5	1			0.5	0.5							1	0.5		
Austrostipa nitida		0.5	0.5		0.5	0.5		1	0.5	1		0.5			0.5		0.5			0.5	0.5		0.5	0.5	0.5	1				0.5		1		0.5				0.5		0.5	0.5	0.5	0.5			0.5		0.5		0.5									4		0.5	0.5	0.5	0.5	0.5	0.5	1			2	0.5		0.5		0.5	0.5		0.5	0.5	0.5	0.5		0.5	0.5	0.5	0.5														1		
Maireana trichoptera								0.5					0.5				0.5		0.5	14							0.5	0.5	0.5	0.5		1	0.5					0.5	0.5					0.5	0.5		0.5											0.5			0.5	0.5	0.5	0.5	0.5	0.5		0.5	1	1			0.5	0.5				0.5						0.5		1	4	1		0.5	0.5					0.5				0.5	0.5	
Acacia hemiteles		30	8	7	0.5	0.5			0.5	6		3	8	15							2					2												1		0.5	5	6	4	2	0.5		3	2								0.5			1	0.5	0.5			1					1	6													2											0.5							
Enchylaena tomentosa																			0.5											0.5	0.5	0.5	0.5	2	0.5		1	0.5													0.5												0.5	0.5	0.5	0.5	0.5	1		0.5	0.5	0.5	0.5						2					0.5	0.5	1			1		0.5	0.5	0.5			0.5							0.5	1			
Pittosporum angustifolium	19										0.5												0.5					0.5	0.5		0.5		2		0.5		0.5																	1				0.5	0.5		1	1	0.5	0.5					0.5			0.5	0.5	0.5			0.5	0.5	0.5	1					0.5			2				0.5						15			3	
Atriplex bunburyana																		1	1	1	1				1	1	0.5				0.5			2	7	10				5					0.5															5				0.5											0.5						1					2								3				0.5	15						3	
Ptilotus holosericeus				0.5								0.5			0.5		0.5									0.5						0.5					0.5	0.5							0.5		0.5											0.5					0.5					0.5	0.5					0.5						0.5	0.5							0.5		0.5										0.5		0.5		
Maireana georgei														0.5				0.5	0.5		2		0.5	0.5					0.5	0.5	0.5						0.5	0.5		1	0.5															0.5			0.5				0.5	0.5	2				0.5		1			0.5			0.5						0.5	1		0.5	0.5	3		0.5		0.5		1					0.5				
Enchylaena lanata																		0.5														0.5	0.5	1	5	1							0.5															0.5			0.5				0.5	0.5	2								0.5	0.5		0.5	0.5	0.5	0.5	0.5	0.5	0.5		1												0.5	0.5			1			
Sida spodochroma																											0.5	0.5						0.5								0.5	0.5								0.5	0.5											0.5		0.5				1	1		0.5			0.5	0.5	0.5										0.5																			0.5	

	01LCR	02MH1	82MH2	72JTE	55JTC	15CHR	77OHN	83HNR	59VRN	14CHN	16BR1	17BR2	18CHE	06PRS	04HT2	27BRB	23NSN	58JDS	48GLT	69WCR	54JDW	52JTW	49JWH	47JDN	56WLG	26YEL	51JDN	11KTN	86WDL	85WGR	57JSD	78LJN	79LJW	80LJS	35EGR	13CHW	07BUL	29MMW	28LKS	97CHF	73STW	63CER	20WGW	88MDN	87MDS	25BIN	81BRS	84NSE	50JMF	75PCN	74PCE	76SGT	05MCD	03HT1	19WGT	08KTS	98ZAN	66BAD	61CRS	70CFT	62CRW	71DVH	96KUR	94PHS	90CWD	31MTV	99COO	30BAC	38MJN	64CRN	65CRE	67BAO	68CAR	10KTE	09KTC	93AVD	53JHS	92MMC	91MMN	46MTD	32LON	95PJS	37DHR	44HAW	36KWS	34ENU	43HAN	39MJS	40CAR	45HTR	100RT	12KTR	24WLB	89MDE	22MDW	21MDC	33CAL	41KLY	42HAS	60FHN
Marsdenia australis																																							0.5	0.5	0.5													0.5					0.5	0.5	0.5		0.5	0.5	0.5	0.5			0.5	0.5							0.5				0.5		0.5															0.5				
Rytidosperma caespitosum	0.5						0.5																					0.5								0.5	0.5	0.5	0.5										0.5			0.5		0.5											0.5											0.5	0.5												0.5								0.5				
Atriplex stipitata		30	0.5																		0.5										0.5	0.5			0.5		0.5												2										7									3				0.5													1		0.5											6	0.5		
Acacia erinacea						0.5	0.5				1			0.5	0.5							0.5	0.5				0.5												1															0.5																3	0.5			1																												0.5
Pimelea microcephala																						0.5							0.5	0.5																0.5								0.5			0.5	1							0.5			0.5		0.5			1	0.5					1																			
Zygophyllum ovatum																			0.5			0.5				0.5																			0.5																		0.5	0.5			0.5		0.5									0.5				0.5																							
Zygophyllum glaucum				0.5	1									0.5				0.5													0.5																																								0.5																												1		
Solanum nummularium																									0.5				0.5	0.5	0.5	0.5				0.5			0.5			0.5	0.5		0.5	0.5			0.5												0.5				0.5		0.5		0.5	0.5				0.5	0.5									0.5																				0.5				
Senna stowardii				0.5																																						0.5				0.5																	0.5				0.5								0.5										1													0.5						
Chenopodium curvispicatum																														0.5																	0.5									0.5					1										1				0.5																					0.5	0.5					
Lycium australe																																	0.5																																								1		0.5					1													0.5						
Maireana marginata																0.5	0.5																					0.5																																										0.5			1														0.5	0.5			
Dodonaea viscosa s.																						0.5												0.5										2						1																																																6		
Dodonaea lobulata																																																							0.5	0.5		1	0.5						0.5																																				
Austrostipa scabra																																											0.5								0.5									0.5								0.5																	0.5														0.5
Senna cardiosperma																2		0.5	1												0.5									0.5															1																								0.5						0.5														
Aristida contorta																																																		0.5																							0.5																									
Thysanotus patersonii or	1						0.5						0.5																	0.5					0.5									0.5						0.5																																													0.5				
Templetonia ceracea	1						1	1	2	1																3	5																																																																										
Dianella revoluta v. revoluta	0.5									0.5																																																																																								
Eucalyptus vittata	10																																																	1																																																		
Acacia jennerae		0.5														0.5									2					2	1																2	1							0.5																																										1		
Rhagodia preissii		1	0.5																												0.5														0.5				0.5																																																	0.5
Eremophila parvifolia s.																																					1						2												0.5															2																					0.5								
Chenopodium desertorum s.																											0.5																												0.5																			2																									
Eremophila interstans s. virgata						2																																																																									5	10																				
Eremophila dempsteri						0.5						0.5				15																				0.5																					1																				2																										
Eremophila rugosa							5	0.5																				1									1																																																											0.5							
Sclerolaena cuneata																																					0.5																																										2	0.5	1	0.5																		
Eremophila alternifolia																												1										0.5	0.5																																					1						1					0.5														
Maireana planifolia																																	0.5								0.5																																							0.5	0.5																	0.5					
Acacia tetragonophylla																															0.5										0.5																												0.5														0.5																2		
Acacia excentrica																																															2					1				0.5																																													
Rhagodia crassifolia																																												0.5		0.5										0.5																																											
Rhyncharrhena linearis																																																	0.5								0.5																																									0.5		
Sclerolaena fusiformis																						0.5														0.5																																									0.5																						
Maireana integra																																	0.5																																																	0.5	0.5																
Sarcozona praecox																																				1										1	0.5																																																			
Lomandra effusa																																																		1	0.5	0.5																																																
Microcybe multiflora							2				2																																											0.5																																													
Melaleuca pauperiflora s.														3																																								7																																													
Eucalyptus urna					10	5																																																																																														
Westringia rigida											1		0.5																																																																																								
Acacia burkittii																						0.5																1																																																												
Eucalyptus salicola																																5	5																																																																		
Acacia sp. narrow phyllode (B.R.						0.5																						0.5																																																																							
Eremophila glabra s. glabra																																					1																	0.5		1						1																																	0.5					
Dodonaea stenozyga											0.5				2						1																														0.5																																																1
Dissocarpus paradoxus																																																													1																0.5															0.5				0.5			
Solanum lasiophyllum																																																														0.5				0.5														0.5																		
Casuarina pauper																																																														0.5	0.5																		1																		
Eremophila oldfieldii s.																																																																		4	1						0.5																											
Alectryon oleifolius s. canescens																																																														0.5	1																													0.5									
Senna artemisioides s. x																																																									3									0.5																												0.5			
Maireana pentatropis																																										0.5			0.5																																													0.5									
Schismus arabicus																																																																																														0.5	0.5				0.5
Eremophila maculata s.																																																																													4			1																		
Salsola australis																																																													0.5				0.5																																		
Salvia verbenaca																																																									0.5	0.5																																								
Swainsona canescens																																																									0.5	0.5																																								
Frankenia interioris																																																																							0.5										0.5																
Frankenia desertorum																																																																									0.5										1															
Diocirea microphylla						0.5																																																																																													
Melaleuca teuthidoides											0.5																																																																																									
Acacia resinistipulea													0.5																																																																																							
Sclerolaena parviflora															0.5																																																																																					
Austrostipa hemipogon															0.5																																																																																					
Atriplex quadrivalvata v.																																				0.5																																																															
Lysiana casuarinae																																					0.5																																																														
Maireana carnosa																																					0.5																																																														

	01LCR	02MH1	82MH2	72JTE	55JTC	15CHR	77OHN	83HNR	59VRN	14CHN	16BR1	17BR2	18CHE	06PRS	04HT2	27BRB	23NSN	58JDS	48GLT	69WCR	54JDW	52JTW	49JWH	47JDN	56WLG	26YEL	51JDN	11KTN	86WDL	85WGR	57JSD	78LJN	79LJW	80LJS	35EGR	13CHW	07BUL	29MMW	28LKS	97CHF	73STW	63CER	20WGW	88MDN	87MDS	25BIN	81BRS	84NSE	50JMF	75PCN
Ptilotus gaudichaudii																																							0.5											
Acacia enervia s. explicata																																									2									
Olearia dampieri s. eremicola																																													0.5					
Eucalyptus olivina																																															0.5			
Melaleuca eleuterostachya																																															1			
Disphyma crassifolium																																															2			
Daviesia argillacea																																															1			
Acacia prainii																																																	0.5	
Eucalyptus gracilis																																																		1
Leptomeria preissiana																																																		0.5
Cryptandra recurva																																																		
lepidosperma spsg76																																																		
Grevillea huegelii																																																		
Myoporum platycarpum s.																																																		
Eremophila deserti																																																		
Sida calyxhymenia																																																		
Eremophila longifolia																																																		
Casuarina obesa																																																		
Eragrostis dielsii																																																		
Convolvulus remotus																																																		
Eragrostis lacunaria																																																		
Eucalyptus griffithsii																																																		
Sclerolaena brevifolia																																																		
Cratystylis subspinescens																																																		
Daviesia spmystery																																																		
Oxalis perennans																																																		
Chloris truncata																																																		
Maireana platycarpa																																																		
Paspalidium constrictum																																																			
Acacia warramaba																																																		
Maireana appressa																																																		
Solanum hoplopetalum																																																		
Minuria cunninghamii																																																		

	74PCE	76SGT	05MCD	03HT1	19WGT	08KTS	98ZAN	66BAD	61CRS	70CFT	62CRW	71DVH	96KUR	94PHS	90CWD	31MTV	99COO	30BAC	38MJN	64CRN	65CRE	67BAO	68CAR	10KTE	09KTC	93AVD	53JHS	92MMC	91MMN	46MTD	32LON	95PJS	37DHR	44HAW	36KWS	34ENU	43HAN	39MJS	40CAR	45HTR	100RT	12KTR	24WLB	89MDE	22MDW	21MDC	33CAL	41KLY	42HAS	60FHN
Ptilotus gaudichaudii																																																		
Acacia enervia s. explicata																																																		
Olearia dampieri s. eremicola																																																		
Eucalyptus olivina																																																		
Melaleuca eleuterostachya																																																		
Disphyma crassifolium																																																		
Daviesia argillacea																																																		
Acacia prainii																																																		
Eucalyptus gracilis																																																		
Leptomeria preissiana																																																		
Cryptandra recurva	0.5																																																	
lepidosperma spsg76		3																																																
Grevillea huegelii				1																																														
Myoporum platycarpum s.						2																																												
Eremophila deserti						0.5																																												
Sida calyxhymenia								3																																										
Eremophila longifolia																0.5																																		
Casuarina obesa																						2																												
Eragrostis dielsii																							0.5																											
Convolvulus remotus																									0.5																									
Eragrostis lacunaria																												0.5																						
Eucalyptus griffithsii																													2																					
Sclerolaena brevifolia																													0.5																					
Cratystylis subspinescens																														1																				
Daviesia spmystery																														0.5																				
Oxalis perennans																															1																			
Chloris truncata																																0.5																		
Maireana platycarpa																																0.5																		
Paspalidium constrictum																																		0.5																
Acacia warramaba																																				2														
Maireana appressa																																											0.5							
Solanum hoplopetalum																																													1					
Minuria cunninghamii																																													1					

S4 Two way table for rangewide analysis Ch4

	98ZAN	94PHS	95PJS	31MTV	90CWD	10KTE	96KUR	92MMC	12KTR	66BAD	67BAO	24WLB	89MDE	91MMN	93AVD	68CAR	21MDC	65CRE	88MDN	22MDW	100RT	61CRS	35EGR	64CRN	70CFT	62CRW	71DVH	32LON	53JHS	37DHR	39MJS	41KLY	44HAW	57JSD	36KWS	42HAS	34ENU	43HAN	04HT2	97CHF	28LKS	29MMW	99COO	30BAC	11KTN	87MDS	20WGW	77OHN	38MJN	73STW	05MCD	58JDS	69WCR	72JTE	83HNR	85WGR	13CHW	17BR2	23NSN	25BIN	48GLT	52JTW	55JTC	16BR1	27BRB	49JWH	75PCN	14CHN	18CHE	50JMF	56WLG	54JDW	59VRN	07BUL	51JDN	63CER	47JDN	15CHR	45HTR	84NSE	26YEL	81BRS	103NG	74PCE	03HT1	02MH1	82MH2	01LCR	06PRS	76SGT	09KTC	08KTS	106BE	19WGT	78LJN	86WDL	127TR	79LJW	80LJS	46MTD	40CAR	105WE	111KN1	112KN2	118PI1	33CAL	142W152	126MM	138W76	141W124	139W85	143W160	101WY	137W74	124LK2	136W53	130WK	60FHN	144W187	109HY3	125LM	134W10	133W7	145W191	135W11	132W6	147YO1	129WA2	128WA1	117NN2	116NN1	131WU	121QU2	120QU1	102TO	122QU3	114LG1	123LB	110HY4	140W104	119PI2	107HY1	115LK	108HY2	113KN3	146W215	104YO3	148YO2
Eremophila glabra s. glabra	1						1																																		1																																																		1																																																						
Solanum lasiophyllum			1				1																																																																																																																																													
Paspalidium gracile		1					1	1															1																																																																					1																																																							
Chenopodium curvispicatum	1											1	1	1		1																						1																																																																																																															
Eremophila oldfieldii s. angustifolia						1																																									1	1																																																																									1																																											
Chenopodium desertorum s.																																													1																																																		1																																																								
Dodonaea lobulata					1					1																																																																																				1																																																						
Maireana sedifolia		1		1	1	1	1		1		1			1		1	1	1	1		1	1		1	1	1																				1		1	1												1																																																																																									
Senna artemisioides s. x artemisioides										1							1																																																																																																																																	
Maireana pyramidata			1							1	1	1			1	1	1						1																																																																							1														1																																												
Marsdenia australis		1								1							1						1				1																								1	1			1																																																													1	1																																																									
Eremophila parvifolia s. auricampa																		1	1		1																								1																																																		1																																																								
Dissocarpus paradoxus								1				1														1																																																																																																																								
Salsola australis				1																						1																																																																																																																										
Swainsona canescens										1												1																																																																																																																													
Salvia verbenaca										1												1																																																																																																																													
Tecticornia disarticulata									1				1	1							1																																																																																					1																																											
Sclerolaena cuneata								1						1														1																																																																																																																							
Sclerolaena obliquicuspis								1				1			1		1																													1																																																										1																																												
Sida spodochroma		1		1			1			1								1									1	1											1					1																																1										1																																																																			
Eremophila maculata s. brevifolia								1																			1																																																																																																																											
Senna stowardii																											1	1													1																																																																																																							
Eremophila rugosa																																													1			1																																																																																																					
Senna cardiosperma	1																																					1															1								1				1																																																																																						
Eremophila alternifolia																												1								1			1																																																		1																																																								
Santalum spicatum																												1													1		1		1																1	1							1																																																																																	
Ptilotus nobilis	1	1					1	1					1		1						1			1	1	1	1					1	1				1			1							1														1	1				1											1																				1																																																									
Ptilotus obovatus		1		1	1		1			1	1						1					1	1	1		1	1						1	1	1	1		1				1		1			1									1																																		1			1			1										1																									1																					
Sclerolaena drummondii														1		1																																																																																							1																																												
Solanum nummularium	1			1			1																	1		1																					1	1								1	1																1													1																		1	1				1																																																						
Eremophila scoparia		1	1	1		1		1	1	1	1	1				1		1	1	1		1		1		1		1	1	1						1	1	1		1	1	1	1	1	1	1	1		1		1	1	1		1				1									1		1	1	1	1	1	1			1	1	1								1												1		1																																																						
Amyema miquelii																								1																												1																																																																																																												
Atriplex nummularia		1			1	1	1	1						1	1		1				1				1	1	1						1		1						1	1	1										1							1																																1		1											1	1		1		1				1	1					1																																																									
Pimelea microcephala																						1		1																									1																		1				1	1																														1					1															1			1																																																
Cratystylis conocephala																				1																								1						1							1		1	1																																				1	1		1																																																																										
Maireana trichoptera	1	1	1		1							1											1		1					1		1		1		1	1	1		1									1	1			1					1							1																1																1						1				1				1		1								1	1	1					1	1																																									
Maireana planifolia														1																	1																																																																																																				1																					
Maireana radiata									1							1				1											1						1	1																																																																																																																	
Austrostipa nitida	1		1		1		1	1						1		1				1			1		1			1				1	1								1					1		1																						1	1	1	1				1	1		1				1				1							1		1	1								1																																																														
Eremophila interstans s. interstans														1																			1																		1										1																																																																																														
Atriplex bunburyana												1				1					1											1					1																		1						1						1	1				1																			1			1	1	1		1	1	1																																																							
Maireana triptera							1	1		1										1	1		1	1	1					1		1		1										1																				1												1			1																										1																																	1																		
Zygophyllum glaucum																		1														1																					1		1												1																																																																																			
Atriplex vesicaria			1		1				1			1	1	1	1					1								1	1	1	1		1			1			1						1																			1												1																									1															1				1		1				1			1	1																																								1		1													1		1				
Eremophila dempsteri						1																															1																									1																														1				1																																																							
Microcybe multiflora s. multiflora																																																1															1																																																																																													
Senna artemisioides s. filifolia		1		1	1		1	1		1															1	1				1				1		1			1		1		1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1		1	1	1		1	1	1		1	1	1		1	1			1	1		1				1																1																															1								1	1				
Maireana georgei																	1	1			1						1				1		1					1	1				1																			1																		1																				1										1										1	1												1																																								1														
Acacia tetragonophylla																									1								1	1																																																																																																																			
Solanum orbiculatum										1																						1				1	1																																																																																																																
Eucalyptus salicola																																																																																															1			1																																																							
Rhagodia crassifolia																			1																																																																									1																																										1																		
Acacia colletioides																																																						1				1			1	1																																																																																												
Austrostipa scabra																								1																								1																																					1																																																																
Eremophila ionantha								1	1	1											1					1	1										1		1			1		1				1	1	1	1		1		1		1		1	1			1	1	1	1	1		1	1	1	1	1			1	1		1		1		1	1					1			1		1		1		1		1		1		1									1																																				1																		
Eremophila interstans s. virgata																												1																			1																																																			1																																																			
Eriochiton sclerolaenoides																								1		1				1						1		1																								1										1	1				1															1																																																															
Eremophila oppositifolia s. angustifolia										1				1																															1								1														1										1			1																						1					1					1																																						
Pittosporum angustifolium								1		1	1				1							1						1			1	1			1						1											1																		1											1											1				1								1	1		1	1				1										1								1																												1		1	1	1										
Rhyncharrhena linearis										1																						1																																					1																																																															1																		
Enchylaena tomentosa	1	1	1		1			1			1			1			1						1		1	1	1		1				1	1	1		1						1		1																				1	1															1											1																	1		1	1	1							1		1		1											1																														1	1	1	1	1	1												1	1
Acacia nyssophylla	1																																		1								1								1		1		1				1				1		1				1		1			1													1		1	1			1		1						1																																																																				

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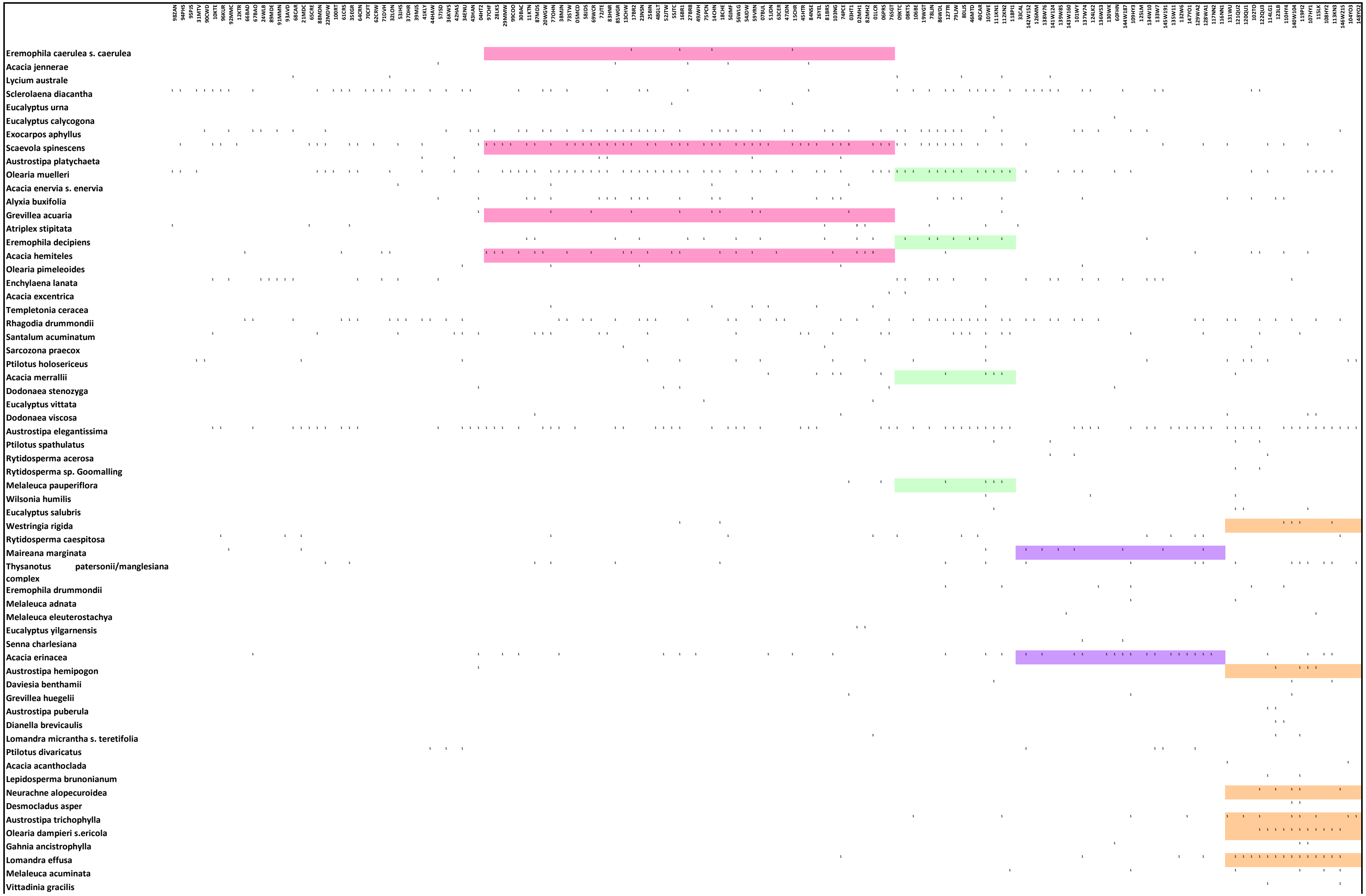

98ZAN 94PHS 95PJS 31MTV 90CWD 10KTE 96KUR 92MMC 12KTR 66BAD 67BAO 24WLB 89MDE 91MMN 93AVD 68CAR 21MDC 65CRE 88MDN 22MDW 100RT 61CRS 35EGR 64CRN 70CFT 62CRW 71DVH 32LON 53JHS 37DHR 39MJS 41KLY 44HAW 57JSD 36KWS 42HAS 34ENU 43HAN 04HT2 97CHF 28LKS 29MMW 99COO 30BAC 11KTN 87MDS 20WGW 77OHN 38MJN 73STW 05MCD 58JDS 69WCR 72JTE 83HNR 85WGR 13CHW 17BR2 23NSN 25BIN 48GLT 52JTW 55JTC 16BR1 27BRB 49JWH 75PCN 14CHN 18CHE 50JMF 56WLG 54JDW 59VRN 07BUL 51JDN 63CER 47JDN 15CHR 45HTR 84NSE 26YEL 81BRS 103NG 74PCE 03HT1 02MH1 82MH2 01LCR 06PRS 76SGT 09KTC 08KTS 106BE 19WGT 78LJN 86WDL 127TR 79LJW 80LJS 46MTD 40CAR 105WE 111KN1 112KN2 118PI1 33CAL 142W152 126MM 138W76 141W124 139W85 143W160 101WY 137W74 124LK2 136W53 130WK 60FHN 144W187 109HY3 125LM 134W10 133W7 145W191 135W11 132W6 147YO1 129WA2 128WA1 117NN2 116NN1 131WU 121QU2 120QU1 102TO 122QU3 114LG1 123LB 110HY4 140W104 119PI2 107HY1 115LK 108HY2 113KN3 146W215 104YO3 148YO2

Eremophila caerulea s. caerulea
Acacia jennerae
Lycium australe
Sclerolaena diacantha
Eucalyptus urna
Eucalyptus calycogona
Exocarpos aphyllus
Scaevola spinescens
Austrostipa platychaeta
Olearia muelleri
Acacia enervia s. enervia
Alyxia buxifolia
Grevillea acuaria
Atriplex stipitata
Eremophila decipiens
Acacia hemiteles
Olearia pimeleoides
Enchylaena lanata
Acacia excentrica
Templetonia ceracea
Rhagodia drummondii
Santalum acuminatum
Sarcozona praecox
Ptilotus holosericeus
Acacia merrallii
Dodonaea stenozyga
Eucalyptus vittata
Dodonaea viscosa
Austrostipa elegantissima
Ptilotus spathulatus
Rytidosperma acerosa
Rytidosperma sp. Goomalling
Melaleuca pauperiflora
Wilsonia humilis
Eucalyptus salubris
Westringia rigida
Rytidosperma caespitosa
Maireana marginata
Thysanotus patersonii/manglesiana complex
Eremophila drummondii
Melaleuca adnata
Melaleuca eleuterostachya
Eucalyptus yilgarnensis
Senna charlesiana
Acacia erinacea
Austrostipa hemipogon
Daviesia benthamii
Grevillea huegelii
Austrostipa puberula
Dianella brevicaulis
Lomandra micrantha s. teretifolia
Ptilotus divaricatus
Acacia acanthoclada
Lepidosperma brunonianum
Neurachne alopecuroidea
Desmocladus asper
Austrostipa trichophylla
Olearia dampieri s.ericola
Gahnia ancistrophylla
Lomandra effusa
Melaleuca acuminata
Vittadinia gracilis

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	98ZAN	94PHS	95PJS	31MTV	90CWD	10KTE	96KUR	92MMC	12KTR	66BAD	67BAO	24WLB	89MDE	91MMN	93AVD	68CAR	21MDC	65CRE	88MDN	22MDW	100RT	61CRS	35EGR	64CRN	70CFT	62CRW	71DVH	32LON	53JHS	37DHR	39MJS	41KLY	44HAW	57JSD	36KWS	42HAS	34ENU	43HAN	04HT2	97CHF	28LKS	29MMW	99COO	30BAC	11KTN	87MDS	20WGW	77OHN	38MJN	73STW	05MCD	58JDS	69WCR	72JTE	83HNR	85WGR	13CHW	17BR2	23NSN	25BIN	48GLT	52JTW	55JTC	16BR1	27BRB	49JWH	75PCN	14CHN	18CHE	50JMF	56WLG	54JDW	59VRN	07BUL	51JDN	63CER	47JDN	15CHR	45HTR	84NSE	26YEL	81BRS	103NG	74PCE	03HT1	02MH1	82MH2	01LCR	06PRS	76SGT	09KTC	08KTS	106BE	19WGT	78LJN	86WDL	127TR	79LJW	80LJS	46MTD	40CAR	105WE	111KN1	112KN2	118PI1	33CAL	142W152	126MM	138W76	141W124	139W85	143W160	101WY	137W74	124LK2	136W53	130WK	60FHN	144W187	109HY3	125LM	134W10	133W7	145W191	135W11	132W6	147YO1	129WA2	128WA1	117NN2	116NN1	131WU	121QU2	120QU1	102TO	122QU3	114LG1	123LB	110HY4	140W104	119PI2	107HY1	115LK	108HY2	113KN3	146W215	104YO3	148YO2
Eucalyptus phenax s. phenax																																																																																																																	1																							1							
Melaleuca lateriflora																																																																																																																																														1	1				1		
Rytidosperma setacea																																																																																																					1	1																			1				1																					1			1	1	1	1	1			
Rhagodia preissii																																																																																	1				1	1																							1			1	1	1	1	1		1			1				1	1				1	1				1				1		1		1			1		1	1	1
Dianella revoluta																																																																																																																	1																1						1					1	1							
Dodonaea bursariifolia																																																																																																																									1		1				1										1					1				1			
Templetonia sulcata																																																																																																								1						1	1										1			1		1		1				1		1	1			1		1	1	1	1	1	1		1	1
Lepidium rotundum																																																																																																								1		1																1	1	1	1											1	1						1	1			1	
Comesperma integerrimum																																																																																																							1																				1				1			1				1	1															
Atriplex semibaccata																																																																																																																	1		1		1				1	1		1																								
Austrostipa pycnostachya																																																																																																								1																	1				1																				1			1			
Eremophila glabra s. elegans																																																																																																																																																1							1	
Melaleuca uncinata																																																																																																																									1											1		1									1	1					
Acacia microbotrya																																																																																																																					1									1		1										1						1					
Austrostipa variabilis																																																																																																											1																	1								1															1		
Daviesia pachyloma																																																																																																																																1												1								
Eremophila lehmanniana																																																																																																																																	1								1												
Cheilanthes austrotenuifolia																																																																																																							1																									1																				
Acacia acuminata																																																																																																																									1			1				1													1								
Dodonaea inaequifolia																																																																																																																						1									1																				
Acacia aestivalis																																																																																																													1																		1	1																			
Acacia meisneri																																																																																																																																																					1	1
Dampiera lavandulacea																																																																																																																																		1												1									
Eucalyptus loxophleba s. loxophleba																																																																																																																						1						1				1																					1	1
Hakea preissii																																																																																																																															1	1																				1
Acacia bidentata																																																																																																																									1				1	1		1	1																			
Melaleuca coronicarpa																																																																																																																						1												1																			
Daviesia hakeoides																																																																																																																							1								1	1		1																	
Eucalyptus wandoo																																																																																																																											1								1																	