Vegetation Responses to Noongar Land Management Practices in Old and Young Landscapes of South Western Australia

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BSc (GradDip)

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Thesis declaration

I, Alison Kate Lullfitz, certify that:

This thesis has been substantially accomplished during enrolment in this degree.

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The research involving human data reported in this thesis was assessed and approved by the University of Western Australia Human Research Ethics Committee. Approval #: RA/4/1/6836.

The following approvals were obtained prior to commencing the relevant work described in this thesis:

- Collaboration agreement between UWA and South West Aboriginal Land and Sea Council dated 3 November 2014 to conduct research with families of the Pallinup River area
- Letter of support from Gabbie Kylie Foundation (superceded by Esperance Tjaltjraak Native Title Aboriginal Corporation) date 22 July 2014.
- Scientific or other prescribed purpose licence to to take protected (native) flora taken from Crown land for non-commercial purposes, licence # SW016406, SW017796, SW018602, SW019315

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Abstract

Intimate and multi-dimensional connection between indigenous peoples and their ancestral land results in the acquisition of detailed, place-based ecological knowledge, which is becoming increasingly valued in contemporary biodiversity conservation and land management. This thesis presents a series of collaborative investigations of Noongar relationships with south-west Australian flora and landscapes intended to inform contemporary approaches to biodiversity conservation.

The South West Australian Floristic Region (SWAFR) exhibits an exceptionally rich flora and has been home to the Noongar people for at least 48,000 years. Through a lens of Human Niche Construction theory, Noongar relationships with south-west Australian flora were examined by conducting a review of historical and contemporary literature and drawing upon the contemporary knowledge of Noongar Elders. The merits of five key hypotheses of human niche construction theory were explored in relation to this large cultural group. Compelling evidence was found that supports Noongar niche construction.

Old, climatically buffered, infertile landscapes (Ocbils) are primary centres of plant diversity and endemism in the SWAFR, and are highly vulnerable to ecological disturbance. To this end, Ocbil theory advocates concentration of human activities in the SWAFR's young, often disturbed, fertile landscapes (Yodfels) rather than Ocbils as the best approach for preserving the SWAFR's extraordinary biodiversity. This project examined traditional knowledge of contemporary Noongar Elders of the southern coastal SWAFR to test whether patterns of disturbance dictated by Noongar custom align with Ocbil theory. Noongar activities of Ocbils and Yodfels were found to be 64-75% different to one another, with disturbance-inducing activities including camping, burning of country, movement along travel routes, hunting and other resource gathering conducted primarily in Yodfels rather than Ocbils. These findings suggest that a general regime of localised control deliberately focused Noongar disturbance in Yodfels rather than Ocbils of the southern SWAFR and appears to have contributed to conservation of its biodiversity over an extraordinarily long period of human occupation.

Noongar cultural plant diversity metrics of granite inselbergs in the south-east coastal province of the SWAFR were compared to archaeological and ethnographic evidence of long held Noongar land use patterns to look for evidence of human manipulation of cultural plant geographic distribution. A bivariate pattern of cultural plant distribution between coastal and inland granite inselbergs consistent with wider floristic patterns, environmental determinants, and Noongar mobility patterns was found, as well as positive correlations among granite inselberg size, overall plant species richness, and cultural plant species richness. A higher proportion of year round available resources was found among food plants of an occasionally occupied residential complex compared to a permanently occupied complex. Abundant occurrence of a high volume, year round root crop, *Platysace* *trachymenioides* and high cultural plant richness were found in a complex used for large gatherings of people from afar. While Noongar and environmental influences were not clearly distinguished, these findings do not rule out Noongar plant niche construction as an influence on granite plant communities of the SE SWAFR, and also suggest that traditional plant knowledge is complex and place-based in application.

Evidence of Noongar influence on the contemporary distribution of food plant, *Macrozamia dyeri,* in the south-east coastal province of the SWAFR was found through comparison of ecological, archaeological and ethnographic information. Contemporary *M. dyeri* populations were found to occur close to waterways in the west and granite outcrops in the east of the species range, a pattern which corresponds closely to differential pre-colonial Noongar occupation and movement patterns in the south-east SWAFR. Most *M. dyeri* populations were found to occur in close proximity to registered Noongar sites. Intra-population *M. dyeri* plant distribution was positively correlated with Noongar occupation preferences in relation to ground surface aspect, slope and landform type but no correlation was found between either habitat availability or latitude and population size of granite *M. dyeri* populations. Each of these findings suggest that contemporary distribution of this plant taxon, which has a long history of human use, reflects past Noongar practice, and is therefore possibly useful for interpreting past location-specific Noongar land management practices.

Variation in geographic structure and gene flow estimates between utilised and non-utilised members of the *Platysace* genus in the SWAFR suggests that humans have influenced the dispersion of *P. deflexa* and *P. trachymenioides*, in which the tubers have historically been harvested as a staple Noongar food. Differences were found in haplotype relationship networks, haplotype and nucleotide diversity, migration estimates and population expansion indices based on three non-coding regions of cpDNA, particularly when considered against the generally complex phylogeographic patterning in plant taxa of the SWAFR revealed by past studies. Consistent with a long evolutionary history, past climatic oscillations and persistence in a highly fragmented landscape, results for *P. effusa*, which has no known cultural significance, showed a general pattern of high population divergence, low gene flow and multiple refugia. In contrast, higher gene flow estimates, less divergence between populations, and ancestral common haplotypes in *P. deflexa* and in *P. trachymenioides* over the south-eastern part of its range are consistent with anthropogenic influences.

For two species of Noongar-utilised *Platysace* of the SWAFR, outcomes of tuber harvest for soil and plants were measured and observed to test whether Noongar harvest of *Platysace* tubers improved physical and nutrient plant growth characteristics of the soil, and aided tuber availability as has been suggested for other Australian Aboriginal root crops. A general trend of elevated soil nutrients as a result of *P. deflexa* harvest was found. However, soil bulk density was slightly increased following harvest. Abundance of *P. deflexa* stems was restored to that recorded pre-harvest within 12 months following harvest. The weight and volume of tubers had not returned to pre-harvest levels two years after harvest, which was expected given that harvest would not traditionally be repeated for at least four years. A higher proportion of small tubers in harvested than previously unharvested quadrats suggests that harvesting has a renewing and homogenizing influence on *Platysace* tuber crops.

Through combining archaeological, ethnographic, genetic and ecological data, this thesis presents evidence of long-held Noongar influence on the plant communities and taxa of the SWAFR. Reflecting the region's biogeographical heterogeneity, Noongar ecological influence was found to be geographically variable, and was also broadly conducive with biodiversity conservation strategies advocated by Ocbil theory. Such findings suggest that greater consideration of pre-colonial people-plant relationships and a collaborative land management approach inclusive of Noongar people would result in positive outcomes for biodiversity conservation in the SWAFR.

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Chapter 2

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Co-author contribution to work:
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Carol Pettersen and **Ron (Doc) Reynolds** have provided specialist Traditional Ecological Knowledge and input during the review process, which has contributed to the conception and interpretation of presented ideas.
David Guilfoyle reviewed the manuscript and provided advice on presented ideas.

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David Guilfoyle	[redacted]	21 February 2019

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Co-author contribution to work:
Carol Pettersen and **Lynette Knapp** have provided specialist Traditional Ecological Knowledge, cultural mentorship and input during the review process.
Stephen D. Hopper provided strategic input to all stages of the study including multiple reviews of the manuscript.

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Carol Pettersen	[redacted]	13 December 2018
Lynette Knapp	[redacted]	4 March 2019
Stephen D. Hopper	[redacted]	6 March 2019

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Preface

The research for this thesis was conducted within a western scientific framework in collaboration with Noongar Elders and cultural informants, who iteratively contributed both their traditional ecological knowledge and perspectives at numerous stages throughout the research process. This collaborative approach has enabled for much sharing of knowledge and love of country. It has also given rise to some enormous personal growth for me as I've listened and learned about Noongar kinship, family and community connections, that remain despite extraordinary post-colonial struggles to maintain cultural identity and protocol, family relationships, denial of access to traditional lands and a say in how their lands have been utilised and cared for (or not). While navigating such post-colonial history and also the many contrary and parallel dimensions of traditional Aboriginal and science-based knowledge systems, I am cognisant of my own changing perspectives through the course of this research, some of which is reflected in how this thesis has been written. In particular, Chapter 2 was written and published earlier than other chapters and reflects an earlier evolution of my thinking in relation to a need for decolonisation in the field of ethnobiology and conservation management more broadly. Here I have attempted to outline some key personal learnings and to identify how these came about.

Firstly, participation in Gabbie Kylie (now Esperance Tjaltjraak Native Title Aboriginal Corporation) field schools with Esperance Nyungar Traditional Owners, archaeologists and botanists in early and late 2014 enabled me to experience community-based cultural research (see Mitchell et al. 2013) firsthand. While I had much to learn about conducting research with Aboriginal people, participation in this research, led consultatively by Nyungar Elders guided by their own knowledge and information from archaeologists and botanists, set the tone for a community-based approach to this ethnobotanical research.

Attendance at a South West Aboriginal Land and Sea Council Wagyl Kaip working party meeting in 2014 to outline my research proposal and to ask permission to speak with traditional owner families was a somewhat confronting but important event. Some initial lukewarm reactions meant I quickly learned not to assume that Noongar people would want me to carry out what I felt was important research. I learned an invaluable lesson (especially from Aunty Carol Pettersen, who soon after became one of my PhD supervisors) to listen harder and talk less. And thus, the importance of humility was a valuable learning early in this PhD.

A more gradual but fundamental learning was the importance of intergenerational sharing of knowledge as a key pillar in Noongar society. For Elders to share their knowledge with their families must be their first priority and is more important than to share with me as a scientist. Intergenerational sharing of knowledge maintains the connection between knowledge and people,

people and country, ancestors and descendants. The more I witnessed such sharing the more it moved me and I realized its necessity. Some examples during the course of my research included:

A trip to Balladong country in 2014 with Noel Nannup. Observing Uncle Noel make a special effort to share specific knowledge with three young Noongar boys (sometimes only with them and not with the wider group) was a revelation to me. Each boy stood taller at the end of that weekend than the beginning – through learning from their Uncle on country, their identity and sense of belonging had been strengthened;

Developing a close friendship and working relationship with Uncle Eugene Eades and witnessing firsthand the cultural healing that occurs when Noongar and other people have the opportunity to share experiences at Nowanup, near Boxwood Hill;

Some wonderful times spent around Boxwood Hill, Corackerup and Jerramungup districts with extended members of the Knapp, Gray and Eades families and my own family; and

A slow trip to Esperance and beyond to Israelite Bay with Lynette Knapp and three generations of her family, visiting, recording and sharing stories belonging to her family.

These experiences and others have taught me the immense importance to families of being on country together, and to, wherever possible, facilitate family participation in field research to make the most of such opportunities. Many historical and contemporary factors have made the passing of traditional ecological knowledge from older to younger generations very difficult for Noongar families. An approach to ethnobotanical research that is open and inclusive of extended traditional owner families as a matter of course is just one means by which we can begin to rectify some past wrongs and has many additional reconciliation benefits.

A key underlying message that has emerged from this research is that traditional ecological knowledge is immensely important and is necessary for conservation of biological diversity. There are many obstacles (e.g. social attitudes, institutional policies) to achievement of a shared approach that is truly ‘two-way’ and collaborative between Traditional Owners and scientists (Hill et al. 2013), which are not addressed in this thesis. However, it does present research findings that demonstrate a need for more equitable inclusion of traditional ecological knowledge in contemporary biodiversity conservation approaches. As this thesis is written by necessity for a scientific audience, it is compatible with modern science practice but not with typical Indigenous communication styles and thus does not reflect a truly two-way approach. To this end, in collaboration with participating Noongar colleagues, I intend to develop some resources more appropriate for an Aboriginal audience to communicate key findings of the research.

Finally, as both a possible guide to other researchers and for the purpose of transparency, I outline specific methods utilised to facilitate equitable collaboration during this research project. Benefit sharing included Elders being paid a modest consultation fee and provided with all meals and transport while on country. Additional family members were welcome but were not paid, unless they were present in a carer capacity for the Elder. Information that I gathered from each Elder was written down and provided back to that person for two reasons – firstly for them to check for accuracy and to approve, restrict or veto its inclusion and publication, and secondly, to provide a record for them to keep and to share with their family as they wished. In addition, where Elders were also co-authors, they reviewed and contributed to specific chapters of this thesis in more depth. This process was carried out in accordance with individuals' preferences – some preferred to read draft manuscripts independently of me and then come back to me with comments, while others preferred to sit together and discuss the content in person. This process along with numerous iterative discussions on specific aspects of the project with some close Noongar colleagues (Carol Pettersen, Lynette Knapp and Eugene Eades) enabled a truly cross-cultural collaboration, where I was able to 'check in' with Noongar perspectives at various stages of the research process, in some instances for experimental design and execution to be adapted, and for a far richer and nuanced interpretation of findings than from a scientific perspective alone.

This thesis sets out some quantitative evidence of Noongar ecological function over millennia, and highlights a need for rightful re-instatement of strong Noongar voices in biodiversity conservation management in southwestern Australia. While I acknowledge there are significant societal and institutional obstacles to such an inclusive approach, I hope in its own small way, this research can contribute to overcoming some of these, and in doing so, honour the Elders who contributed, as well as their ancestors and their descendants. This is its intent.

Chapter 1: Introduction

While modern humans have been part of global ecosystems for at least 260,000 years (Schlebusch et al. 2017), the ecological interactions of non-industrialised societies have historically been overlooked by biodiversity conservation practitioners (Bliege Bird and Nimmo 2018; Middleton 2013). Multi-dimensional and intimate connection between indigenous peoples and their ancestral land results in the acquisition of detailed biodiversity knowledge of their local environs (Berkes 2000; Kassam et al. 2018; Lantz and Turner 2003). Such traditional ecological knowledge is becoming increasingly valued and applied in contemporary biodiversity conservation practice (Berkes 2000; Lyver et al. 2015; Middleton 2013; Prober et al. 2016).

This thesis presents an investigation of Noongar relationships with south-west Australian flora intended to inform contemporary approaches to biodiversity conservation. The investigation draws on the theory of Human Niche Construction (HNC) (Odling-Smee et al. 2003), which is becoming increasingly recognised as a driver of ecological change alongside climate and geological processes (Bliege Bird et al. 2013; Odling-Smee et al. 2013; Smith 2011a). Derived from biology, niche construction theory recognises an ability of organisms to modify their environment, possibly causing evolutionary outcomes for other organisms (Lewontin 1982; Odling-Smee et al. 2013). While niche construction activities *per se* do not necessarily promote biological conservation (Laudine 2009), HNC is a useful framework for examining relationships between small-scale societies and the biota around them. Fundamental to HNC is a premise that people are part of their natural environment and actively manipulate ecological processes for their own advantage. Noongar niche construction was identified by Hallam (Hallam 1975; Hallam 1989) and further explored by Dortch et al. (2014) and Monks (2018). However, to date the influence of HNC on south-west Australian flora has gone largely unexplored. This thesis is intended to address this gap, and go some way in underpinning collaborative flora conservation strategies based on Noongar and Western science.

South-western Australia and its Noongar First People

The South West Australian Floristic Region (SWAFR) is recognised globally for its extraordinarily high floristic diversity. It contains an estimated 8379 native vascular plant taxa, of which 47% are endemic and many are of ancient lineage (Gioia and Hopper 2017; Hopper et al. 1996). Climate buffering due to coastal proximity since the Jurassic, relative geological stability since the Permian, adaptations to weathered, nutrient-poor soils and increasing aridity, and speciation as a result of Pleistocene climatic oscillations have contributed to the SWAFR's rich flora with a long evolutionary history (Byrne 2007; Hopper 1979; Hopper 2000; Hopper and Gioia 2004; Hopper et al. 1996; Lambers et al. 2011). Much of the SWAFR's flora is concentrated in old, climatically buffered, infertile landscapes (Ocbils), unlike most global floristic regions which are dominated by young, often disturbed, fertile landscapes (Yodfels) (Hopper 2009; Hopper et al. 2016).

The SWAFR has been the traditional country (*boodja*) of Noongar people since time immemorial (Government of Western Australia 2016), with occupation dated archaeologically to at least 48,000 years BP (Turney et al. 2001). Noongar ecological knowledge and practices have developed within this Ocbil-dominated floristic region (Robertson et al. 2016). A diversity of lore dictates marriage, ceremony, and responsibility for country across fourteen nations within the Noongar ethnic group. However, universal throughout is a deep connectedness between Noongar and *boodja* (Berndt 1980). The research outlined in this thesis was carried out in collaboration with Noongar people of the south coast SWAFR, including people who identify traditionally as Menang, Merningar, Goreng, Kanang, Wudjari, Bardoc and Nyungar (Horton 1996). The south coastal SWAFR now takes in the contemporary Esperance Nyungar and Wagyl Kaip Native Title areas (National Native Title Tribunal 2018). Much of the south coast Noongar population now live in the regional centres of Albany and Esperance, but all have strong family connections to outlying districts such as the Pallinup River area and across the Esperance Nyungar region, both focal areas of this research (Figure 1.1).

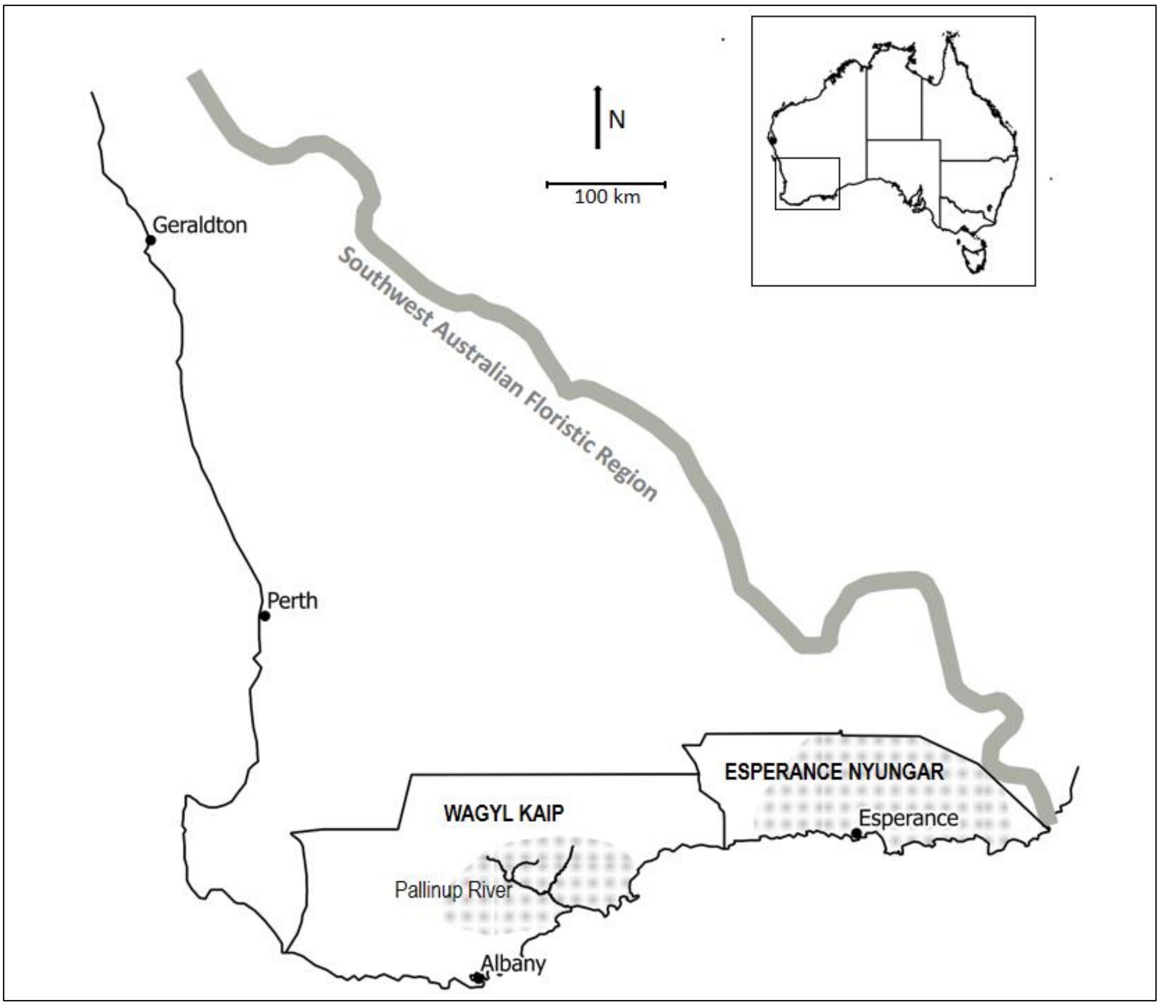


Figure 1.1: The SWAFR, Wagyl Kaip and Esperance Nyungar Native Title claim areas (National Native Title Tribunal 2018), focal areas of this research (grey dotting) and other places mentioned in the text.

Research questions

The project was intended to address several questions about Noongar relationships with the biota and landscapes of south-western Australia. Firstly, are longheld relationships between Noongar people and SWAFR biota reflected in the distributions, biology and ecology of contemporary plant taxa of the SWAFR? Secondly, can we detect specific past Noongar land practice relevant to contemporary biodiversity conservation in SWAFR plant species distributions? Thirdly, given that much of the extraordinary floristic diversity of the SWAFR occurs on some of the most globally fragile landscapes (Hopper 2009; Hopper et al. 2016), what strategies have the Noongar employed that have preserved its biodiversity over an occupation period spanning at least tens of millenia? Finally, how can two-way botanical science be used to inform Noongar cultural connection and facilitate development of a shared approach to contemporary biodiversity conservation in the SWAFR and elsewhere?

Research significance

Ens et al. (2015) found that application of traditional knowledge in contemporary biodiversity conservation practice has been geographically inconsistent in Australia, and overlaps very minimally with the country's 15 national biodiversity hotspots (Department of the Environment and Energy 2018). Five of Australia's national biodiversity hotspots are in Noongar *boodja* of south-western Australia, which, in its entirety is recognised as a global biodiversity hotspot (Mittermeier et al. 2011; Myers et al. 2000). Thus, greater contemporary application of Noongar ecological knowledge in south-western Australia may have considerable positive benefits for global biodiversity conservation.

Through adjustment of cultural activity to local eco-evolutionary feedback, it is expected that a human society's niche constructing activities will increasingly reflect natural analogues within their local environment with increasing length of occupation (Bliege Bird et al. 2013). The Ocbil-dominated SWAFR's exceptional contemporary biological diversity occurs in a context of a very long Noongar occupation. Relationships between the Noongar and SWAFR plant taxa examined in this project may also give insight to first peoples' manipulation of biota in Ocbil-dominated regions elsewhere, which occur in at least 12 of 35 global terrestrial hotspots (Hopper et al. 2016).

The project employs botanical techniques that can complement archaeological and ethnographic survey techniques to develop a shared understanding of country and culture. In addition, research outlined in Chapters 6 and 7 contributes to an improved understanding of the genus *Platysace*, which to date has received minimal attention from Western science.

Finally, this thesis presents a case study of cross-cultural collaboration in botanical research. Relevant aspects of this two-way approach are documented throughout, which it is hoped can assist others embarking on investigations in this field.

Terminology

While there are various commonly accepted spellings, I have followed the practice of most linguists and Aboriginal authors in using 'Noongar' in reference to the broad cultural bloc of south-western Australia and 'Nyungar' in reference to Esperance Nyungar traditional owners. Unless otherwise indicated, Noongar names of organisms published in this thesis are based on recordings by the linguist C.G. von Brandenstein and are shown in italics (see von Brandenstein 1977; von Brandenstein 1988).

Thesis structure

Chapters 2 to 7 are the result of collaborative projects and have multiple co-authors. Each has been written with the intention to publish as a discrete scientific paper. Consequently, papers are written from a plural, first person point of view, and there is some repetition between chapters.

Chapter 2 presents a review of historical and contemporary documented ethnographic evidence of Noongar manipulation of south-west Australian plant communities in relation to broad patterns of HNC identified by others. The aim of this chapter was to provide a useful starting point from which the role of HNC in the evolutionary biology and ecology of the SWAFR can be further examined.

Chapter 3 presents a study aimed at quantifying the alignment of traditional Noongar knowledge and behaviours and the hypotheses of Ocbil theory. Such an alignment was suggested as a result of the review presented in Chapter 2. In this study, contemporary Elders' knowledge of specific Ocbil and Yodfel places in the southern coastal SWAFR was recorded and examined in relation to biodiversity conservation principles advocated by Ocbil theory.

The study presented in **Chapter 4** was intended to detect possible signals of Noongar influence at a plant community level. This was carried out through a comparative analysis of botanical collection data for granite plant communities of the south-east province of the SWAFR and landscape-level Noongar mobility patterns in this part of Noongar *boodja.*

Chapter 5 aimed to explore Noongar influence on the contemporary distribution of a single plant species of known cultural use. The species, *Macrozamia dyeri* was chosen for this study as its use as a staple Noongar food is well-documented, it is large in size and distinct in form, and recent widespread fires across much of its range made widespread population-based survey relatively easy. Relevant habitat attributes of *M. dyeri* were examined in relation to archaeologically and ethnographically determined pre-colonial settlement patterns of the Esperance Nyungar to detect correlation and possible human influence on its contemporary distribution.

Chapter 6 presents a study in which DNA-based techniques were employed to investigate evidence of human-facilitated plant dispersal in the SWAFR. Specifically, the study tested whether two Noongar-utilised taxa in the genus *Platysace, P. deflexa* and *P. trachymenioides* exhibited differing phylogeographic patterning to *P. effusa*, which has a similar range and form to the former but no known history of human use. Phylogeographic patterns of each species were examined in relation to their respective anthropogenic histories and well-documented general phylogeographic patterns of SWAFR plants.

Lastly, **Chapter 7** aims to test whether Noongar staple root crops in the *Platysace* genus respond positively to harvest, as has been proposed for some Aboriginal root crops elsewhere in Australia. Specifically, the study aimed to test whether Noongar harvest of edible *Platysace* tubers improved the physical and nutrient plant growth characteristics of soil, and aided further *Platysace* tuber production.

Conclusions based on the findings of Chapters 2 to 7 are presented in **Chapter 8**.

Chapter 2: Human niche construction: Noongar evidence in pre-colonial south-western Australia

Abstract

Through a lens of Human Niche Construction theory, we examine Noongar relationships with south-western Australian flora and suggest influences of these relationships on contemporary botanical patterns in this global biodiversity hotspot. By conducting a review of historical and contemporary literature and drawing upon the contemporary knowledge of Noongar Elders, we examine the merits of five key hypotheses of human niche construction theory in relation to this large cultural group. We find compelling evidence of Noongar niche construction, but further research is required to test its likely ecological and evolutionary outcomes. We suggest that further collaborative, multi-disciplinary research that applies Noongar and Western science will lead to a greater understanding of biological diversity and processes in south-western Australia.

Introduction

Despite best individual and organisational efforts, biological assets of the South West Australian Floristic Region (SWAFR, sensu Hopper and Gioia 2004, Figure 2.1) continue to face human-induced pressures that threaten their survival (Laurance et al. 2011). To this end, new approaches need to be explored. Given current widespread interest in incorporating traditional knowledge into environmental management (Bliege Bird et al. 2012; Ens et al. 2015; Lyver et al. 2015; Middleton 2013) and a long occupancy by Noongar Aboriginal people (Turney et al. 2001), traditional knowledge and practices of the SWAFR's first people appear valuable, and to date largely unexplored, resources for contemporary conservation managers of south-western Australian biodiversity.

In this paper, our primary aim is to present evidence of pre-colonial human manipulation of plant communities of the SWAFR that can provide a useful starting point from which the role of Human Niche Construction (HNC) (Odling-Smee et al. 2013) in the evolutionary biology and ecology of the SWAFR can be further examined by ourselves and others. In turn, we anticipate that this process may lead to successful collaborative conservation strategies based on Noongar and Western science within the SWAFR.

Few ecosystems have persisted entirely to the present day without human influence (Halpern et al. 2008; Sanderson et al. 2002). As such, HNC has been identified (alongside climatic and geological processes) as a fundamental driver of ecosystem dynamism by archaeologists, anthropologists and increasingly by ecologists (Bliege Bird et al. 2013; McNiven 2008; Odling-Smee et al. 2013; Smith 2011a). Many researchers have identified the use of fire, disturbance of soils and organisms and other forms of habitat modification, and also specific protection measures, all applied according to cultural practices, as means by which innumerable generations of humans interacted and developed with ecosystems prior to global industrialisation (Amundsen-Meyer 2013; Bliege Bird et al. 2008; Rowley-Conwy and Layton 2011; Smith 2011a).

While we recognise that niche constructing activities per se do not necessarily represent activities that promote conservation of biodiversity, in this instance, HNC provides a useful framework for identifying some key processes in which pre-colonial human activities probably influenced biological communities of the SWAFR since the late Pleistocene. Equally, the SWAFR's exceptional contemporary biological diversity occurs in the context of human occupation spanning tens of millennia and indicates that there may well be broader lessons that Noongar culture can provide for biological conservation.

Noongar niche construction was identified by Hallam (1975); Hallam (1989) and has been explored from a zoo-archeological perspective by Dortch et al. (2014). However, the influence of HNC on the flora of south-western Australia has gone largely unexplored to date. Following a brief outline of the evolutionary background, conservation considerations and pre-colonial Noongar occupation of the SWAFR, we review HNC as a framework for examining human ecological influence, prior to focusing on evidence of HNC from the south-west Australian ethnographic record relating to vegetation management.

The SWAFR and its first human inhabitants

The exceptionally species rich SWAFR occupies 302,627 km^2 in the south-west corner of the Australian continent, and contains an estimated 8000 native plant species, of which 49% are endemic (Hopper and Gioia 2004). A maritime climate that dates to the Jurassic (180 Ma), along with relative geological stability since the Permian (250 Ma), has enabled the persistence of relictual taxa, with some lineages arising in the Cretaceous (66 Ma) (Hopper and Gioia 2004; Hopper et al. 1996). This ancient heritage, combined with adaptations to weathered, nutrient poor soils (Lambers et al. 2011), and more recent late Tertiary and Quaternary adaptations to aridity and explosive speciation associated with climatic oscillations, has resulted in the SWAFR's complex and rich contemporary flora with a long evolutionary history (Hopper 1979; Hopper 2000).

Figure 2.1: Location of Noongar country, South West Australian Floristic Region and localities of interest.

The inland SWAFR boundary corresponds approximately to the circumcision line (Tindale 1974) which culturally bounds the Noongar culture block from desert and semi-desert groups to the north and east. Noongar habitation of many parts of south-western Australia has been dated to the late Pleistocene, and to at least 48,000 years BP (Before Present) in the extreme south-west corner of the continent (Turney et al. 2001). On a geological timescale, human occupation of the SWAFR is a last-minute inclusion in a long and complex evolutionary history of south-west Australian flora. On a human timescale, Noongar occupation of the SWAFR provides an example of sustained human ecological influence (Dortch 2004), made all the more intriguing by its long and complex evolutionary history.

There can be little scientific certainty about Noongar customs of the distant past. However, contemporary oral and early colonial accounts offer insights into the recent past (Robertson et al. 2016), and appear to corroborate archaeological evidence of persistent resident populations before and during the Last Glacial Maximum (30-19,000 years BP) and increasing populations afterwards (Balme 2014; Williams et al. 2015). While the Noongar identify as a single ethnic group, fourteen smaller cultural units within the area are also recognised (Tindale 1974). Noongar cultural and linguistic characteristics include varying systems of both patrilineal and matrilineal descent and a diversity of totemic laws, while a deep attachment to land through mytho-ritual ties is universal (Berndt 1980). Connectedness to country by a descent group provides rights to its resources, rights to share its resources with others (Meagher and Ride 1980), and also responsibilities to manage natural resources and look after spiritual affairs (Berndt 1980).

Resource availability, social motive, ceremonial purpose and climate dictated past broad patterns of Noongar movement (Meagher 1974; Nind 1831) and were formalised through a six season calendar in which specific plant and animal life-stages were indicative of seasonal chronology (Collard and Harben 2010; Meagher 1974). The seasonal calendar remains important to contemporary Noongars (Bindon and Walley 1992; Scott and Brown 2005; SWALSC 2010). Land and resource rights as well as trading among Noongar groups have been well documented (Barker 1831; Berndt 1980; Drummond 1853a; Drummond 1853b; Grey 1841a; Grey 1841b; Hassell 1975; Hercock 2014; Moore 1884; Nind 1831; Oldfield 1865; Ommanney 1840; Singleton 1846). Although not universal, totemic laws dictated specific responsibilities of individuals, families, bands and clans for protection of particular plant and animal taxa (Grey 1841b; Hassell 1975) and many contemporary Noongars continue to identify with plant and animal totems (Collard 2009; Knapp 2011; Little 1994; Nannup 2013; Scott and Brown 2005; Yorkshire-Selby 2011b; Yorkshire-Selby 2011c).

Ocbil Theory

Hopper (2009) identified Old, Climatically Buffered Infertile Landscapes (Ocbils), and, converse to these, Young, Often Disturbed Fertile Landscapes (Yodfels). While Ocbils are globally rare but prominent in the SWAFR, Yodfels occupy most of the earth’s terrestrial surfaces, particularly of the Northern Hemisphere (Hopper 2009). The SWAFR is one of at least 12 of the 35 known terrestrial biodiversity hotspots in which Ocbils occur interspersed amongst Yodfels in a complex mosaic (Hopper et al. 2016). Ancient lineages, long-lived individuals and a high degree of localised endemism are pre-eminent among Ocbil flora, which often exhibit special biological traits to enable survival in infertile conditions and unusual resilience to fragmentation (Bezemer et al. 2019; Hopper 2009). Such biological traits (e.g. high levels of woody pereniality, low growth rates, investment in underground persistence structures such as tubers) suited to spatially restricted and low fertility soil habitats make

Ocbil flora highly vulnerable to accelerated disturbance regimes (Hopper 2009; Hopper et al. 2016; Leao et al. 2014).

Given their dominance in the more heavily human-populated northern hemisphere, Yodfels are the basis of most collective and widely accepted western conventional ecological understanding (and corresponding approaches to conservation management) (Hopper 2009; Hopper et al. 2016). Biodiversity and endemism retained by Ocbils, however, are disproportionately high across biodiversity hotspots (Hopper et al. 2016) and herein lies a discrepancy. Conservation strategies employed for a significant proportion of global biodiversity assets may be based on inappropriate Yodfel-derived ecological theory (Hopper 2009). Noongar ecological knowledge has originated and developed in the Ocbil-dominated SWAFR (Robertson et al. 2016). In the SWAFR, both Ocbils (e.g. granite inselbergs and kwongkan sandplain) and Yodfels (e.g. depositional river valleys, wetlands and coastal dunes) are intrinsic to Noongar culture (Bird 1985; Hallam 2014; Hopper and Lambers 2014; Robertson et al. 2016; Smith 2011b). An increased understanding of landscape-differentiated Noongar niche constructing activities may well be key to improved conservation outcomes for Ocbil flora of the SWAFR.

Human Niche Construction

Niche construction theory, in its broadest sense, was introduced by Lewontin (1982), and affords a useful means of understanding ecosystem dynamism and its evolutionary impacts. It provides a unifying framework for studies of ecology, with its focus on energy and matter flow, and evolutionary biology, focused on information flow (i.e. DNA heritability) (Odling-Smee et al. 2013). While the relative roles that niche construction and Standard Evolutionary Theory (SET) play in gene selection and the evolution of life itself remain contentious, (Laland et al. 2016; Odling-Smee et al. 2003; Turner 2016), at the very least, niche construction is a useful means of addressing feedback from organisms (including humans) to their environment. Proponents of Niche Construction Theory (NCT) (e.g. Smith 2015) hypothesise that the key point of difference between SET-based and NCT-based frameworks is a controversial assumption of unidirectional adaptation, which is that organisms adapt to changes in their environmental circumstance in the former, while the latter assumes two-way interaction between organisms and their environment (Smith 2015).

This hypothesised theoretical divide has extended to inquiry into early domestication and its role in transitions from forager to agriculture-based human life strategies, with HNC being offered as an opposing alternative to SET-based optimal foraging theory (Gremillion et al. 2014; Smith 2015). In this paper, we are primarily focused on the processes by which pre-industrial societies have modified their ecosystems rather than the possible evolutionary consequences. We use HNC frameworks explored by others (Amundsen-Meyer 2013; Bliege Bird et al. 2013; Rowley-Conwy and Layton 2011; Smith 2011a) as a point of reference for examining evidence of Noongar ecosystem modification in the

SWAFR. This should not be construed as rejection of the value and validity of SET-based models when considering biological and cultural evolution, especially as such models have embraced the concept of co-evolution since the time of Darwin's (1859) 'Origin of Species'. An evolutionary approach to human-plant interaction may also be criticised for bias towards economically rational behaviour (Barton and Denham 2016). However, HNC counteracts such bias as it allows for social or cultural practices that may be motivated primarily by cultural identity and habitus (cf. Rusack et al. 2011). Some societies may see plants and animals not as resources to be managed (in the contemporary, "western" sense) but as entities to be protected or propagated to satisfy ritual or mythological obligations and traditions (Keen 2004). HNC may not be capable of distinguishing the motivation for specific human actions, but it does offer tools for identifying the actions themselves.

Fundamental to the concept of HNC is the premise that humans are an embedded component of their natural environment, rather than an interacting but separate entity (McNiven 2008; Odling-Smee et al. 2013; Rowley-Conwy and Layton 2011; Smith 2011a) and thus, play an active role in shaping it. HNC in some form or another is considered universal amongst forager societies (Amundsen-Meyer 2013; McNiven 2008; Rowley-Conwy and Layton 2011) and may include, for example, the concentration of wild resource plants into useful stands, small-scale plant cultivation, removal of vegetation to encourage resource species, various hunting techniques and protection or enhancement of useful taxa and expansion of habitat (Bliege Bird et al. 2013; Hynes and Chase 1982; Rowley-Conwy and Layton 2011; Smith 2011a).

HNC does not, in itself, equate to sustainment of all biological resources. Laudine (2009) argued that biodiversity conservation as an aspirational notion was unlikely a conscious objective of forager societies, while Smith and Wishnie (2000) asserted that although sustainable resource management often leading to positive biodiversity outcomes is widespread among small-scale societies, voluntary conservation is rare. Although there are numerous examples of large-scale destruction of natural resources by pre-industrial societies (Diamond 2005; Ostrom et al. 1999; Smith and Wishnie 2000), there are examples of sustained societal management of natural resources over thousands of years (Dietz et al. 2003; Ostrom et al. 1999). Based largely on evidence from small-scale, pre-industrial societies, Ostrom et al. (1999) and Dietz et al. (2003) have identified specific societal characteristics probably required to manage resources sustainably, including: access to good environmental information and an understanding of its uncertainties; localised resource control nested within larger institutions; a means of dealing with conflict; effective rule compliance; physical, institutional and technological infrastructure; and processes to deal with change. Evidence exists of each of these characteristics in the Noongar ethnographic record (Berndt 1980; Hammond 1933; Hassell 1975; Howard 1980; Meagher and Ride 1980; Nind 1831; Scott and Brown 2005) and is the subject of continuing work by the authors. Ostrom et al. (1999) also point to optimal settings around the reliability, condition, diversity and limits of natural resources in shaping successful governance of them.

In a global study of HNC examples, Middleton (2013) concluded that a general decline in ecosystem heterogeneity is evident following cessation of traditional management approaches. In New Zealand, Lyver et al. (2015) determined that conservation and Maori cultural actions are interconnected due to a worldview that does not separate humans from their environment, while Bird et al. (2012) asserted a compatibility between the *Martu* (an Australian indigenous people of the Western Desert) concept of 'healthy country' and the conditions that contemporary conservation managers would consider best for biodiversity outcomes. A comprehensive review of traditional knowledge inclusion in Australia by Ens et al. (2015) highlighted examples where indigenous knowledge has informed both conservation research and management. Ens et al. (2015) also identified current gaps (including a general absence of indigenous knowledge in biodiversity hotspot conservation management), and opportunities for further cross-cultural collaboration. These examples appear to validate a case for closer alignment between context specific indigenous traditional and Western science knowledge, practice and values to improve conservation and cultural outcomes of conservation management (Bliege Bird et al. 2012; Christie 1990; Lyver et al. 2015; Middleton 2013).

Following examination of HNC activities among North American indigenous societies, as well as characteristics of their target species, Smith (2011a) proposed that broad patterns in HNC activity are evident. That there are general patterns of universality in the HNC activities of small-scale societies was broadly supported through further testing of Smith's (2011a) model by Amundsen-Meyer (2013) and is also corroborated by evidence from tropical Australia (Hynes and Chase 1982; McNiven 2008) and other global locations (Terrell et al. 2003). A comparison of these studies also highlights a degree of bias in HNC activities (and the study of them) toward their environmental context. Such biases include, for example, Smith's (2011a) emphasis on seasonal replenishment through seeding of annual taxa in predictable riparian zones due to annual snow-melt in parts of North America, and McNiven's (2008) emphasis on quarantine and translocation likely more relevant to the Torres Strait islands, than mainland locations. Smith (2011a) recognised a tendency for anthropological strategies involving wild populations to have natural analogues specific to their environment. Further, Bird et al. (2013) asserted that cultural practices fine-tuned to local environmental conditions come with time, enabled by eco-evolutionary feedback to human decision-making processes. Similarly, but at a larger scale, Ostrom et al. (1999) asserted that extensive trial and error learning by parallel, self-organised groups greatly reduces the risk of disastrous regional resource depletion.

Based on these assertions, we would expect that, although broadly reflective of general HNC patterns, with increasing length of occupation, the niche constructing activities of a particular society would increasingly reflect a bias toward local natural analogues that suit the survival of local communities of organisms on which humans depend. Exploration of this expectation is particularly compelling in the SWAFR, given its long history of Noongar occupation. However, given minimal scientific exploration of Noongar HNC to date, particularly in relation to plant communities, our aim in this paper is to present evidence of Noongar niche constructing activities within a broader global HNC framework that can be used as a basis for more specific investigation.

Methodology

An extensive review of global HNC peer-reviewed literature was undertaken. General patterns of HNC previously proposed by others (Amundsen-Meyer 2013; Hynes and Chase 1982; McNiven 2008; Smith 2011a) were examined to determine relevant broad categories of HNC activities applicable to the study area in question. Five broadly universal categories were identified, taking into account likely biases relating to climate and geographic setting. Identified categories resulting from this review include: 1) firing to reset successional sequences and create mosaics/edges; 2) in-situ management and protection of specific plant taxa; 3) extension of the geographical range of perennial plant taxa; 4) habitat modification to increase local resource abundance; and 5) restrictions and territorial markers. The results and discussion are presented under each of these categories. A summary of global HNC literature relevant to each category is presented as a synopsis under each heading.

Historical and contemporary sources were examined to identify Noongar HNC activities. Historical sources examined included the Exploration Diaries from 1827 to 1857 held by the Western Australian Government Department of Lands and Survey, and early colonial accounts of Noongar custom.

Table 2.1: Summary of terrestrial Noongar activities and protocols indicative of HNC in south-western Australian vegetation communities in historic and contemporary ethnographic record.

HNC Sub-Category	Noongar Example in SWAFR	Reference
Creating mosaics/edges and resetting successional sequences through firing		
Firing for game attraction	General conclusions and detailed specific incidents of Noongar firing between Perth and Albany.	Hallam (2014)
	Description of fired country in vicinity of Harvey south of Perth.	Grey (1841a, p141-2)
	Family recollection of patch burning for resource renewal in Albany area.	D. Coyne, 2014 pers. comm.
	Personal memory of patch burning for resource renewal in Esperance area.	D. Reynolds, 2014 pers. comm.
	Burnt ground and emergent green grass on the Hay River near Albany.	Roe (1831) in Hercock (2014)
	Native fires, good grass and game on Gairdner River in vicinity of Bremer Bay.	Roe (1835) in Hercock (2014)
	November 3rd 1848 localised burning of grassland alongside 'thicket' and 'scrub' near the Bremer Range, north-west of Esperance.	Roe (1848) in Hercock (2014)
	Recently burned 'good country' on Blackwood River near Augusta.	Bussell (nd)
	Frequent fire and abundance of resources near Albany.	Collie (1831)
	'Grassy understorey' and evidence of fire near Mt Barker (50 km north of Albany).	Collie (1832)
	Recent fires and abundant resource plants. (Grassland inferred but not present due to fire).	Bunbury (1836)
	Recently burned "very good ground' and feasting on kangaroo west of Albany.	Barker (1830) p260
	Burning for wallaby, kangaroo and other small macropods close to Albany.	Barker (1830) p262; p378-380. p382
	Burning of grassland near Kojonup.	Clark (1840)
	Burning of grassland near Perth.	Moore (1884)
	Burning of grassland near Jerramungup to attract game.	Hassell (1975) p41
	Description of a dreaming story that highlights high value of burnt ground and green grass close to water.	Hassell (1975) p203
Firing for plant resource renewal	Burning of resource plant, *Typha domingensis* near Perth.	Grey (1841b)
	Plentiful *Haemodorum*, a staple resource plant, on densely populated Swan Coastal Plain near Perth.	Grey (1841b)
Firing for access to country	Personal memory of patch burning for access to country, especially at regular campsites.	D. Reynolds, 2014 pers. comm.
	Common practice of frequent burning of vegetation at campsites.	T. Woods, 2014 pers. comm.
Firing restrictions and controls	Comment regarding permission to burn country, spatial control, and roles of men and women near Albany.	Nind (1831)
	Can only speak for country with which he has connection.	Kelly (1998)
	Burning not able to proceed until owner of country present near Albany.	Barker (1830) p382; p386
	Small-scale spatial variation in firing of forest near Harvey (100 km south of Perth).	Grey (1841a)
	Burning for grassland renewal and hunting of game in late summer and autumn.	Hassell (1975) p110
	Corroboree to mark the beginning of firing season near Jerramungup in late summer.	Hassell (1975) p113

HNC Sub-Category	Noongar Example in SWAFR	Reference
In-situ management and protection of perennial and annual species		
In-situ management	Harvest of *Dioscorea hastifolia* and resultant uneven grounds north of Perth.	Grey (1841b); Drummond (1840b); Moore (1884); Oldfield (1865)
	Digging for *Platysace deflexa* tubers and resulting soil disturbance.	Hassell (1975) p24
	Noongar man near Albany insistent on planting old stalk in ground during Barker's demonstrating potato harvest.	Barker (1830) p384
Protection of vegetation communities	Protection of spearwood thickets, and wallaby and quokka habitat from fire on south coast.	Kelly (1998)
	Firing of vegetation adjacent to dense vegetation for hunting of medium-sized macropods.	Grey (1841a)
	Group surrounding and trampling of dense vegetation for hunting near Albany.	Nind (1831)
	Use of dense Eucalypt thickets for hunting of small macropods east of Toodyay (east of Gingin).	Drummond (1853b)
	Very dense vegetation in vicinity of mallee fowl (*Leipoa ocellata*) mound sightings in the central SWAFR.	Roe (1836) in Hercock (2014)
	Use of Proteaceae flowers in thick vegetation inland of Esperance	Roe (1848) in Hercock (2014)
Protection of individual plants	Tracking and hunting of *Trichosurus vulpecula* demonstrating value of aged, hollow-bearing trees.	Nind (1831); Grey (1841b); Hassell (1975) p10
	Sourcing of fresh water from hollows in *Eucalyptus wandoo*, demonstrating value of aged, hollow-bearing trees.	Roe (1835) in Hercock (2014); Nind (1831); Moore (1835); Drummond (1853a)
	Large individuals of *Nuytsia floribunda, Eucalyptus occidentalis, Macrozamia dyeri* as well as *Xanthorrhoea platyphylla* amongst grass near highly populated Esperance Bay suggestive of close management.	Roe (1848) in Hercock (2014)
	Xanthorrhoea preissii amongst clear grassland near Denmark 50 km west of Albany, suggesting protection of this taxa within managed landscape.	Roe (1831) in Hercock (2014)
Extension in geographical distribution of perennial plant species		
Transportation of resource plants possibly resulting in new populations.	General comment regarding vegetable foods being transported to camp, (based on a comprehensive review of historical accounts).	Meagher (1974)
	Musings regarding pre-colonial human spread of edible members of *Carpobrotus* (Aizoaceae), *Acacia acuminata, Santalum acuminatum* and *Macrozamia reidlei* and ease with which Noongars in his post-colonial employ cultivate introduced garden taxa.	Drummond (1843a)
	Bringing of edible roots to camp near Albany.	Nind (1831)
	Carrying of edible roots in Noongar woman's bag.	Grey (1841b) p109
	Carrying of edible roots in Noongar woman's bag near Albany.	Moore (1884) p23
	Transport and processing of *Acacia acuminata* and *A. microbotrya* seed near Jerramungup.	Hassell (1975) p21-22
	Transport of fruit from *Exocarpos sparteus* and *Santalum spicatum* near Jerramungup.	Hassell (1975) p23
	Trading of seeds of *Macrozamia* (species could be *reidlei* or *dyeri*) near Jerramungup.	Hassell (1975) p25

HNC Sub-Category	Noongar Example in SWAFR	Reference
	Sharing of seeds of *Macrozamia reidlei* by Noongars north of Perth.	Grey (1841b) p42
	Roots and seeds ground at Noongar campsite near Walpole, 110 km west of Albany.	Roe (1836) in Hercock (2014)
	Description of detoxification of *Macrozamia* seed, suggesting transport of seed to location where water available.	Moore (1835); Drummond (1840b); Grey (1841b) p119; Moore (1884) p32; Hassell (1975) p25; Barker (1830) p304
	Occurrence of *Acacia cyclops* at particular non-coastal sites considered indicative of past Noongar camp.	L. Knapp, 2015 pers. comm.
	Noted *Macrozamia reidlei* growing adjacent to fish traps near Denmark	Barker (1830) p258
Habitat modification to increase local resource abundance (aside from use of fire)		
Resource increase	Deliberate cultivation of *Hakea drupaceae* at granite outcrops to enhance reptile habitat near Albany.	L. Knapp, 2014 pers. comm.
	Deliberate *gnamma* creation and enhancement at southern coastal granite outcrops.	G. Yorkshire-Selby, 2014 pers. comm.
	Breaking down of *Xanthorrhoea preissii* and *X. platyphylla* tops to attract *Bardistus cibarius* larvae.	Nind (1831); Grey (1841b) p116; Eyre (1841)
	Regular cleaning of *gnammas* to remove buildup of sediment.	L. Blight, 2014 pers. comm.
Restrictions and territorial markers		
Restrictive law	Outline of laws relating to land and resource 'ownership'.	Grey (1841b) p97-98, 120
	Marriage laws as an instrument for gaining and restricting land access.	Nind (1831); Grey (1841b) p96
	Disturbance of *Nuytsia floribunda* by Menang Noongar restricted aside from certain times of the year and certain people (near Albany).	L. Blight, 2014 pers. comm.
	Laws that prohibit individuals from harming a totem species.	Grey (1841b) p97; Hassell (1975) p86
	Restriction of taking tubers or rhizomes when resource plant is in seed.	Grey (1841b) p99-100
	Restriction on spearing kangaroo.	Barker (1830) p289
	Property rights to *Xanthorrhoea sp.*, kangaroo, wallaby and *Macrozamia reidlei* seed caches.	Barker (1830) p309
	Displeasure of Menang Noongars of unknown Wilomon man arriving uninvited to Albany area.	Barker (1830) p323
	Restrictive use of a water body near Albany, only used for drinking when ill and never camped near.	Barker (1830) p342
	Restriction of wild dog young to elders only.	Hassell (1975) p75
	Restrictive access to mountainous areas in southern Noongar country	C. Pettersen, 2016 pers. comm.
	Restrictive access to kwongkan sandplain and mountainous areas.	Oldfield (1865), Hassell (1975)
	Restriction on eating of emu flesh.	Grey (1841b) p114
Territorial markers	*Eucalyptus pleurocarpa* as a marker of being in one's own country.	D. Reynolds, 2014, G. Yorkshire-Selby, 2014, L. Knapp, 2015 pers. comm.
	Extensive patch of *Nuytsia floribunda* a territorial boundary where entry forbidden.	Little, 1994

Personal oral recollections of Noongar authors (Ron (Doc) Reynolds, Carol Pettersen) and other contemporary southern coastal Noongars were also drawn upon to supplement documented sources. Identified Noongar HNC activities were assigned to the categories broadly identified in the global literature. Noongar evidence is presented in the results and discussion as a discrete section under each category heading following the global synopsis of each category. Noongar names of organisms published here are based on recordings by the linguist C.G. von Brandenstein and are shown in italics (see von Brandenstein 1977; von Brandenstein 1988).

Results and Discussion

For each category of HNC investigated, a synopsis, followed by Noongar evidence of HNC in the SWAFR is presented below.

Firing to reset successional sequences and create mosaics/edges

Synopsis

Periodic alteration of vegetation communities, usually through the use of fire, is a widely documented activity employed by forager societies (Amundsen-Meyer 2013; Smith 2011a). By increasing the relative abundance of early successional stage plants through disruption to later stage, slow growing plants, and increasing interface areas between successional stages of vegetation, firing can result in a higher availability of human (and animal) food plants across a broad range of environments (Amundsen-Meyer 2013; Bowman and Prior 2004; Hallam 2014; Jones 1969; Rowley-Conwy and Layton 2011; Smith 2011a). The mosaic of varied plant communities of multiple successional stages created by small-scale firing also results in increased in-patch diversity, providing a greater suite of available food plants and habitats for prey animals (Bliege Bird et al. 2008; Bliege Bird et al. 2012; Bliege Bird et al. 2013; Smith 2011a).

Documented reasons for firing of vegetation among forager societies include encouragement of green pick to attract hunted game (Amundsen-Meyer 2013; Fuhlendorf et al. 2008; Jones 1969; Kost 2013; Murphy and Bowman 2007; Rowley-Conwy and Layton 2011; Russell-Smith et al. 1997), increasing habitat availability for game (Bliege Bird et al. 2012; Bliege Bird et al. 2013), entrapping or flushing out game during hunting (Kost 2013; Russell-Smith et al. 1997), improving access for movement and camps (Amundsen-Meyer 2013; Kost 2013; Rowley-Conwy and Layton 2011; Russell-Smith et al. 1997), increasing yields of plant resources (Atchison 2009; Shipek 1989), demonstrating rights to country (Bliege Bird et al. 2008; Rowley-Conwy and Layton 2011), promoting resource plants through removal of competing plant taxa (Amundsen-Meyer 2013; Russell-Smith et al. 1997; Walsh 1990), protection of particular resource-bearing plants or habitats through back-burning (Amundsen-Meyer 2013; Kelly 1998; Kost 2013; Russell-Smith et al. 1997), and reducing populations of pest organisms (Amundsen-Meyer 2013).

Noongar evidence

Burning of country by Noongar people to alter vegetation mosaics of the SWAFR has been well-documented in historical accounts (Grey 1841a; Hercock 2014) and contemporary literature (Abbott 2003; Abbott 2014; Hallam 2014; Kelly 1998; Kost 2013) and is also remembered by some contemporary Noongar Elders. A contemporary Menang Noongar Elder relayed his father's description of patch burning as "creating next year's Coles New World" (an Australian supermarket chain) (D. Coyne 2014 pers. comm.), while one of the authors (Ron (Doc) Reynolds), an Esperance Nyungar Noongar Elder, remembers Nyungar men burning through wetlands in the Esperance area, both to ease walking through country and to attract food animals, in particular *Pibiljurr* (the Australian Bustard, *Ardeotis australis)*. Abbott (2003) identified 229 Noongar firing events recorded in historical documents for the period 1658-1888 in southwestern Australia.

Throughout the detailed observations recorded by Roe in his 1830-1840s exploration diaries, frequent reference is made to Noongar burning activities (Hercock 2014). For example, Roe noted on December 10th 1831 that country in the Hay River valley near Albany "would have been troubled alike with a thick underwood had not a portion of it been burnt off, and admitted of a young green grass", while on November 29th 1835, he noted good grassy land extending along the banks of the Gairdner River east of Bremer Bay, and that traces of game were numerous near an old native hut that had "probably been occupied by the natives whose fires we had seen here yesterday". Importantly, Roe also noted that Noongar burning regimes varied according to ecosystem, such as an observation on November 3rd 1848 during an expedition from Cape Riche to the Russell Ranges east of Esperance of localised grassland burning, where adjacent close thicket and scrub (likely kwongkan sandplain, an Ocbil) remained unburned.

As Roe's primary exploration objective was to identify suitable pastures for the expansion of colonial livestock production, the location and extent of grasslands as well as less productive lands were well-documented, and, for example, often referred to sandplain as 'useless scrub' or 'impenetrable brushes'. Roe also noted an association between important Noongar resource tree species such as *Eucalyptus occidentalis* (Myrtaceae) and *Acacia* (Fabaceae) species with the occurrence of grasses, freshwater, kangaroos and other game animals. Thus, in addition to direct observations of Noongar burning, Roe's diaries appear to extensively describe the results of burning activities, namely the grassed woodlands occurring low in the landscape (likely Yodfels) offering an abundance of food plants for humans and resource animals. This point was also noted by Abbott (2014) in a synopsis of the fauna and ecology recorded in Roe's exploration diaries and corroborated by other early colonial records (Barker 1831; Bunbury 1836; Bussell nd; Clark 1840; Collie 1831; Collie 1832; Hassell 1975; Moore 1884), that link descriptions of 'open land' with firing activities.

Although most records of Noongar burning relate to the procurement of animal resources, Gott (1982), in part based on Grey's (1841b) observations on the Swan Coastal Plain, suggested that firing likely promoted the availability of staple plant underground storage organs through return of nutrients to the soil, reduced leaf litter, clearing spaces for seed germination, maintaining an open vegetation structure and through exploitation of their ability for rapid regeneration following fire (Pate and Dixon 1982). Gott (1982), in a description of the resource plant, *Typha domingensis* (Typhaceae), of which the rhizome was usually collected, pounded and roasted into cakes (Drummond 1842c; Eyre 1845; Grey 1841b; Moore 1884), suggested that heavy harvesting and burning of *Typha* species (also a recorded Aboriginal practice in Eastern Australia) likely promoted growth of young plants and prevented unwanted spread across large shallow water bodies (presumably to which access was required for gathering other fresh water resources). Grey (1841b) suggested that "the natives must be admitted to bestow a sort of cultivation upon this root, as they frequently burn the leaves of the plant in the dry seasons in order to improve it". Grey (1841b) also commented that "Haemodorum are very plentiful" in the "sandy desert country which surrounds for many miles the town of Perth", which may suggest promotion of this genus through burning or other means by the dense Noongar population (Hallam 2014) of the Swan Coastal Plain. Promotion of plant resource abundance may also account for other early colonial observations such as those of Roe on 12th and 13th February 1835 respectively of firing "ironstone country" on ridges in *Eucalyptus marginata, Corymbia callophylla* (Myrtaceae) and *Eucalyptus wandoo* woodland near Albany (Hercock 2014), habitat for *Pteridium esculentum* (Dennstaedtiaceae), numerous Orchidaceae taxa and members of *Haemodorum* (Haemodoraceae), all of which constitute Noongar staples (Daw et al. 2011; Drummond 1842a; Drummond 1842b; Meagher 1974) and respond positively to fire (Black and Mooney 2006; Coates et al. 2006; Lamont and Downes 2011).

Figure 2.2: (Clockwise from top left), seeds of *Acacia cyclops,* eaten by south coast Noongars; *Tjaltjraak* (*Eucalyptus pleurocarpa),* a marker of country for south coast Noongar families; *Macrozamia dyeri,* of which the seeds *(pauyin)* were eaten, adjacent to lizard traps on granite inselberg east of Esperance; *Pain,* fruit of *Carpobrotus modestus; Wonyill,* fruit of *Santalum acuminatum, Quadin,* rhizomes of *Haemodorum discolor; Joowaq,* tubers of *Platysace deflexa* (centre). Photo credits: AL, SH.

That Noongar burning regimes were strictly controlled is demonstrated in the early colonial literature of Barker (1831) and Nind (1831), the latter of whom documented that "all of them have a right to break down grass trees, kill bandicoots, lizards, and other animals, and dig up roots; but the presence of the owner of the ground is considered necessary when they fire the country for game". Kelly (1998) also asserted that firing regimes were ecosystem- and ownership-specific, and that he, as a Noongar man of the Manjimup district, could not speak of firing activity across Noongar country more broadly, but only for his own country. Likewise, Grey (1841a) described country in the vicinity of Harvey as "thickly clothed with mahogany trees" (*Eucalyptus marginata*) that in some places was "completely destroyed by the native fires" and in others was "encumbered by the fallen trunks", suggesting a tightly controlled and small-scale firing regime. Also of note, is Hassell's (1975) comment on the seasonality of firing for grassland renewal, which, she reported, was carried out in late summer and early autumn, prior to the first winter rains and following completion of nesting for ground-dwelling birds and mammals. Kost (2013) categorised some historical Noongar firing events according to the Interim Biogeographic Regionalisation of Australia (IBRA; Thackway and Cresswell 1995) although caution is required due to high botanical spatial variation at a much finer scale (Hopper 1979). Kost (2013) also documented some recollections of firing by contemporary Noongars, and noted a broad consistency with historical records in relation to seasonality, control and intent.

In-situ management and protection of specific plant taxa

Synopsis

Observed concentrations of economically valuable plants close to well-used sites have been considered the result of deliberate or accidental cultivation, protection or in-place encouragement of specific taxa in preference to taxa of limited value for human use (Atchison 2009; Hynes and Chase 1982; Kelly 1998; Russell-Smith et al. 1997; Smith 2011a). Such activities in relation to resource plants have been well-documented for both temperate and tropical environments. These include specific harvest methods for edible, underground storage organs to protect plant propagules (Gott 1982; Hynes and Chase 1982; Russell-Smith et al. 1997) and create suitable conditions for resource growth (Amundsen-Meyer 2013; Gott 1982; Smith 2011a), protection from trampling (Hynes and Chase 1982) and fire (Amundsen-Meyer 2013; Atchison 2009; Kelly 1998; Russell-Smith et al. 1997), deliberate non-use for firewood or building (Byrne et al. 2013; Smith 2011a), selective removal of competing vegetation (Gott 1982; Smith 2011a) and ownership of trees (Hynes and Chase 1982; Kitagawa and Yasuda 2008). Specific actions aimed at increasing crop size and quality (Amundsen-Meyer 2013; Fowler 2000; Kitagawa and Yasuda 2008; Smith 2011a) are also documented.

Noongar evidence

The most heavily documented Noongar root crop is the yam-like, *Wuagarn* (*Dioscorea hastifolia* (Dioscoreaceae)). Frequent observations of *Wuagarn* harvest and of resulting dug-up grounds were made by Grey (1841b), Drummond (1840b) and Oldfield (1865) in Noongar country north of Perth. Moore (1884) recorded near Gingin, having to “change our course on account of the ground which here consisted of a deep red loam, being so cut up into holes as to be almost impassable. The native “Yam” seems to be very abundant here.” Hallam (1989) asserted that the well-documented abundance of *Dioscorea hastifolia* in fertile areas north of Perth was due in part to frequent, seasonal harvest by Noongars. Root harvest of *Yaindyert* (*Typha domingensis)*, was also well documented on the Swan Coastal Plain (Drummond 1836; Drummond 1842c; Grey 1841b; Hallam 1989; Hallam 2014; Moore 1884) and across Noongar country (Oldfield 1865). Hallam (1989); Hallam (2014) considered pre-colonial Noongar occupation of the Swan Coastal Plain and its hinterland to be largely sedentary, due to an abundance of both *Dioscorea hastifolia* and *Typha domingensis* which have complementary seasonal availability (September to May and May to August respectively). Likewise, in northern Noongar country Grey (1841b) described a “thickly populated” district among fertile *Wuagarn* grounds and freshwater swamps from which *Yaindyert* was harvested. Other Noongar root crops that appear heavily harvested include numerous members of the Orchidaceae (Drummond 1842b), several members of *Platysace* (Apiaciae) (Drummond 1840a; Drummond 1843b; Drummond 1853b; Hassell 1975; Moore 1884; Nind 1831) members of *Haemodorum* (Haemodoraceae) (Drummond 1840b; Drummond 1842a; Hassell 1975; Oldfield 1865), particularly *H. spicatum* (Grey 1841b; Nind 1831) and members of *Thysanotus* (Asparagaceae) (Drummond 1842a). Indeed, in the Jerramungup area, Hassell (1975) noted long trenches of disturbed soil made by women digging for the much relished tubers of *Joowaq* (*Platysace deflexa)* (Figure 2.2).

That particular resources and habitats were protected from fire in Noongar country is clearly apparent in early colonial records and was also highlighted by Kelly (1998). Nind (1831), Grey (1841b) and Drummond (1853b) gave detailed accounts of hunting for medium-sized macropods (likely the Western Brush Wallaby, *Macropus irma* or Tammar Wallaby, *Macropus eugenii*) in which a dense thicket of vegetation was surrounded, trampled at its outer boundary, with wallabies flushed out and becoming entangled in the knocked down vegetation. This description highlights the value of dense vegetation as game habitat resource to Noongar people and likely deliberate protection of some habitats from fire disturbance. Similarly, Roe’s October 13th 1836 diary entry (Hercock 2014), concluding that “numerous fallen trees or saplings which crossed each other, and sometimes defied a passage” were due to an infrequency of fire was likely not merely coincidental to his recording of two *Ngauw* nests (the Mallee Fowl, a mound-building megapode, *Leipoa ocellata)* on the same day in country in the vicinity of Kellerberrin. Due to its requirement for extensive leaf litter, the *Ngauw* is particularly fire-sensitive (Parsons and Gosper 2011) and its eggs an important Noongar food source (Hassell 1975; Scott and Brown 2005).

Noongars used the seed cones (Hassell 1975; Nind 1831), flowers (Bates 2004; Meagher 1974; Nind 1831) and seeds (Knapp 2014) of members of the Proteaceae family. Given that many Proteaceae taxa, especially obligate seeders are fire-sensitive (Barrett et al. 2009), Roe's November 19, 1848 observation of finding bark baskets filled with "honey flowers" (likely a Proteaceae species) amongst "thicket and scrub" (likely Ocbil kwongkan sandplain) indicates that such resources may also have been protected from frequent fire (Hercock 2014).

Accounts of hunting for *Quumarl* (Western Brush-tailed Possum, *Trichosurus vulpecula*), requiring tracking of an individual to its tree-hollow nest (Grey 1841b; Hassell 1975; Nind 1831), and the sourcing of fresh water from hollows of the *Warnda (Eucalyptus wandoo)* tree (Drummond 1853b; Hercock 2014; Moore 1835; Moore 1884; Nind 1831) suggest that certain trees (particularly of age enough to bear hollows) were highly valued, and were likely afforded protection from disturbance. Likewise, specific reference to shrubs and trees that offered cover for game hunters in grassland is also indicative of a heightened value worthy of protection (Eyre 1845; Grey 1841b).

On the return leg of his expedition from Cape Riche to the Russell Ranges, Roe observed near Esperance Bay on December 10, 1848 clumps of *Nuytsia floribunda* (Loranthaceae) and *Eucalyptus occidentalis*, *Macrozamia dyeri* (Zamiaceae) (Figure 2.2) of "gigantic size" as well as "tolerable grass among dwarf grass trees" (*Xanthorrhoea platyphylla* (Xanthorrhoeaceae)) in a river valley close to Esperance Bay, which on the preceding day he had described as "somewhat better peopled" (Hercock 2014). Each of Roe's noted plant species is of high and multi-faceted importance in Noongar culture and their prominence in a highly- populated area appears due to management practices. In addition, Roe's numerous observations of both "wattle" (likely *Gnaamarur, Acacia cyclops* (Figure 2.2) or *saligna*) and "*yeit*" (a misapplied Noongar name referring to *Eucalyptus cornuta* that we now understand referred to *Mauw* (*Eucalyptus occidentalis*)) in otherwise grass-covered valleys on the south coast (Hercock 2014) are again likely the result of deliberate protective and/or enhancement measures. Likewise, Roe's observation near Wilson Inlet (40 km west of Albany) on December 12, 1831 of "very good grassy land, sometimes wet, with grass trees and requiring very little clearing" (Hercock 2014) may indicate the employment of measures to protect and promote members of the important resource plant genus *Xanthorrhoea* in favour of other taxa.

Extension of the geographical distribution of plant taxa

Synopsis

Extension beyond a species' wild range is a niche constructing activity with evolutionary consequences for that target species and possibly others (Rowley-Conwy and Layton 2011). The present day distribution of some human-used perennial plant taxa populations has been attributed to human agency (Kondo et al. 2012; Rangan et al. 2015) as a result of collection and transport of fruit or seed (Amundsen-Meyer 2013; Gott 2008; Head et al. 2002; Hynes and Chase 1982; Rowley-Conwy and

Layton 2011; Smith 2011a), processing (Allen 1974) and deliberate broadcast of seed (Smith 2011a; Walsh 1990), and transplanting of tubers (Hynes and Chase 1982; Russell-Smith et al. 1997).

Noongar evidence

That long distance movement of plant propagules was customary among Noongar is indisputable with numerous early European records of the deliberate movement of roots (Grey 1841b; Moore 1884; Nind 1831), seeds (Grey 1841b; Hassell 1975) and fruits (Hassell 1975). Through such custom, Noongars may well have (deliberately or inadvertently) influenced current distribution patterns of some SWAFR plant taxa (Gott 1982). Meagher (1974) cited numerous records of plant foods being brought to camp by women and children, while Nind (1831) mentioned specifically the transporting of roots, and Roe on November 14, 1835 observed where roots and seeds had been ground at a campsite near Nornalup (Hercock 2014). Dense occurrences of the staple, tuberous food plant, *Platysace trachymenioides,* observed by the authors (AL, SH, RR, DG) around culturally important granite outcrops inland north of Esperance, may also be the result of Noongar movement and in-situ cultivation.

Drummond (1843a) suggested that an unusual occurrence of the important resource plant, *Maanqaart* (*Acacia acuminata)* and the widespread occurrence of the regularly transported food plant, *Wonyill* (*Santalum acuminatum* (Santalaceae)) (Figure 2.2) and fruit resource, *Pain, (Carpobrotus* (Aizoaceae)) (Figure 2.2) as likely due to Noongar cultivation. In addition, Drummond (1843a) noted the presence of important seed resource, *Macrozamia*, at favourite Noongar campsites. Use of leaching technology to detoxify the seed of *Macrozamia dyeri* (Figure 2.2) in the Esperance area and *Macrozamia reidlei* further west has been employed by Noongars since at least the late Pleistocene (c. 13,200 BP) (Smith 1982). That the seeds were a staple food and procedures for detoxification were well documented by early Europeans (Barker 1831; Drummond 1840b; Grey 1841b; Hassell 1975; Moore 1884) and required the collection, soaking or long-term underground storage, drying and roasting prior to eating (Smith 1982). This likely included the transport of seed to specific locations, and particularly to locations where fresh water was available for processing (e.g. *gnammas* (rock pools)). Hassell (1975) observed the use of *Macrozamia* fruit by *Wirlomin* Noongars in the Jerramungup area, but also commented that, as it did not occur in the area, it was procured through trade following removal of the seed, suggesting cultural restrictions around their procurement and use, possibly linked to its toxicity.

Among some contemporary Menang Noongar Elders, the occurrence of certain *Acacia* species is considered indicative of past campsites (L. Knapp 2015 pers. comm.). In observations of the *Wirlomin* Noongar group during the 1870s, Hassell (1975) documented the collection, transport to camp, processing at camp and storage for later use of the seed of *Maanqaart, Acacia acuminata* and *Manna, A. microbotrya*, describing the grinding of seed as “a source of great merriment” due to the seeds "hopping about all over the place". Inevitable (but possibly unintentional) broadcasting during seed processing, as well as the common practice of frequent burning of vegetation at campsites (recalled by Ron (Doc) Reynolds and Menang Noongar Elder, T. Woods (2014 pers. comm.)) would likely have enhanced opportunities for seedling establishment through increased soil nutrient availability, reduced competition from other plants and/or breaking of seed dormancy (Bell 1999).

Several phylogeographic studies have been carried out in recent years on plant taxa that feature prominently in Noongar culture (although none were specifically aimed at detecting the influence of pre-colonial human agency). Such taxa include *Eucalyptus occidentalis* (Elliott and Byrne 2003), *E. marginata* (Wheeler et al. 2003), *E. wandoo* (Dalmaris et al. 2015), *Acacia acuminata* (Broadhurst and Coates 2002; Byrne et al. 2002), *Santalum spicatum* (Byrne et al. 2003) and *Macrozamia reidlei* (Byrne et al. 1997). To varying degrees, all of these studies show intraspecific DNA variation consistent with a hypothesis of human dispersal in Noongar country, and indicate the value of more targeted studies in this field.

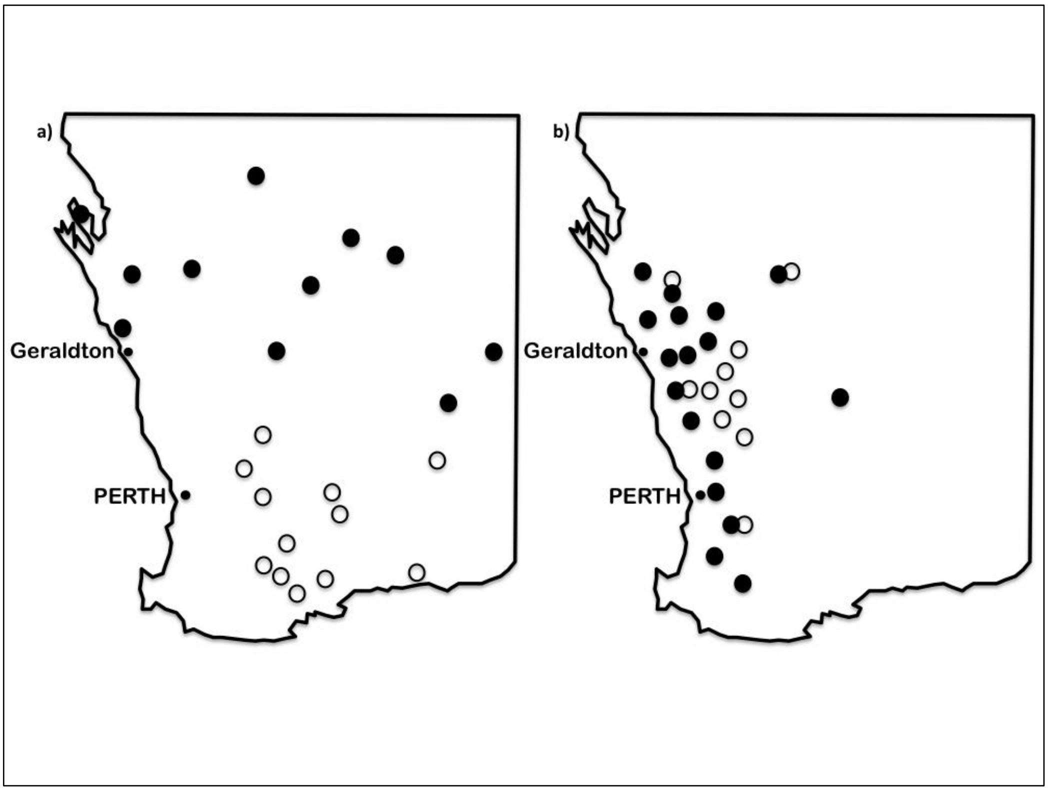


Figure 2.3: Geographical locations of lineages observed in phylogeographic studies of a) *Santalum spicatum* and b) *Acacia acuminata*, where closed and open circles represent separate lineages (Byrne 2007).

Habitat modification to increase local resource abundance

Synopsis

Examples of both plant (Amundsen-Meyer 2013; Fowler 2000; Smith 2011a) and animal (Lourandos 1983; Smith 2011a) resource enhancement through habitat modification have been documented. Smith (2011a) suggested that prey abundance increase strategies consist of either enhancement of a habitat to attract or increase numbers of prey, or constraint of prey movement to assist with capture. Others have highlighted that resource renewal activities occur within a broader social and religious context which may include rituals for deceased ancestors (Amundsen-Meyer 2013) or expressions of oneness with totems (Laudine 2009).

Noongar evidence

In south-western Australian estuaries, fish traps were extensively employed (Grey 1841b; Moore 1884; Shenton and Wells 1837) as both a habitat modification and prey constraint, while *karda mia* (lizard 'traps'), consisting of a granite slab propped by a smaller rock to catch reptile prey on granite outcrops, are hypothesised to have been used throughout Noongar country (Bindon 1997; Guilfoyle et al. 2013; Rossi 2014; Smith 1993). A contemporary Menang Noongar Elder described the deliberate cultivation of a particular plant species, *Hakea drupacea* (Proteaceae) adjacent to granite sheets in the Albany area as a means (through upward force from root growth) of enhancing granite exfoliation to gain flat slabs for use in lizard trap construction (L. Knapp 2014 pers. comm.).

The southern coastal Noongar practice of *gnamma* creation and enhancement through localised firing of granite was primarily intended to increase supply of fresh water for human consumption (G. Yorkshire-Selby 2014 pers. comm.). However, the resultant increase in freshwater habitat availability was valued by a range of fauna (Hassell 1975) and undoubtedly had positive outcomes for edible aquatic plants such as *Cycnogeton lineare* (Juncaginaceae) and *Myriophyllum petraeum* (Haloragaceae), eaten by Esperance Nyungars, including one of the authors (RR). Regular cleaning of *gnammas* according to protocol that ensures retention of seed store and microbes would also likely have assisted aquatic plant survival on granite outcrops (Jenkin et al. 2011).

The breaking down of *Xanthorrhoea priessii* (Grey 1841b; Nind 1831) and *X. platyphylla* (Eyre 1845; Nind 1831) tops to attract the highly-savoured (Barker 1831; Drummond 1840b; Wilson 1829) *Bardi,* larvae of the beetle *Bardistus cibarius,* was a widely used Noongar habitat modification technique. Although simple in technique, contemporary accounts (L. Blight 2014b pers. comm.) as well as Nind's (1831) record of the Menang Noongar procedure demonstrate that the method was tightly controlled by strict laws and that there were serious consequences for individuals who did not abide.

Restrictions and territorial markers

Synopsis

Although most studies of Aboriginal interactions with plants are focused on resource exploitation, specific plants and vegetation communities are important markers of ceremonial use, territoriality and how well country is cared for (Bliege Bird et al. 2008; Chase 1989; Hynes and Chase 1982). Chase (1989) and Amundsen-Meyer (2013) highlighted complexities in custom relating to use of particular plant resources from temporal, spatial and human perspectives (e.g. a particular plant may be utilised for a specific purpose, by a specific age/gender, at a particular ceremony and site, whereas its use may vary in a different time, place or social context).

Noongar evidence

Menang, Bibbulmun and Whadjuk Noongar laws ascribe great spiritual importance to the plant, *Muattyaur (Nuytsia floribunda)* and its disturbance is prohibited by these groups of the western coast of south-western Australia (Hopper 2010). However, its disturbance for use as a food (Hassell 1975) and for personal adornment (Hopper 2010) is recorded among other Noongar groups, and is allowable at certain times by specific people in Menang Noongar country (L. Blight 2014a pers. comm.). In addition, Little (1994) described an area just south of Perth in which *Muattyaur* grew extensively as a territory boundary where entry was restricted. Similarly, Esperance Nyungar Noongar Elders (including Ron (Doc) Reynolds) describe *Tjaltjraak (Eucalyptus pleurocarpa*) (Figure 2.2) as a marker of being in one's own country (G. Yorkshire-Selby 2014 pers. comm.) and its north-easternmost distribution appears closely correlated with the granite inselbergs that mark the boundary between Noongar and Ngadju country. Restrictions regarding Noongar movement through kwongkan sandplain due to an association with 'evil spirits' was documented by Hassell (1975) in the Jerramungup area and Oldfield (1865) further to the north, while spiritual beings in mountainous areas (also Ocbils) are documented historically (Hassell 1975) and well known to contemporary south coast Noongars (including author Carol Pettersen) among whom access remains restricted.

Laws relating to land ownership and marriage instituted strict and specific controls over access to Noongar land, as well as its plant and animal resources (Grey 1841b). Both Nind (1831) and Grey (1841b) described authorisation between neighbouring groups to gather particular resources from each others' land at certain times, and also described marriage as an instrument for connection (and therefore land access) between groups. Certain laws reserved particular foods for particular people (Grey 1841b), such as the reserving of dingo young for old people (Hassell 1975) and young men being unauthorised to eat emu flesh (Grey 1841b); prevented individuals from harming their totems (Grey 1841b; Hassell 1975) and dictated seasons and life stages for gathering of plant and animal resources (e.g. that plant resources should not be gathered when bearing seed) (Grey 1841b). It appears that Noongar law instituted both sustainability of resources and societal wellbeing through such prescriptions. Further, stories inherited by contemporary Noongar Elders (e.g. Knapp 2011) and accounts of dreaming stories documented in the early colonial literature (e.g. Hassell's recounting of a story in which the grinding and baking of *Acacia acuminata* seed is central) reflect the longstanding, intrinsic position of Noongar people and their law among the biota and landforms of south-western Australia.

Conclusion

Given the long time-frame for fine-tuning of Noongar niche construction activities in the Ocbil-dominated SWAFR, it appears that knowledge and behaviours congruent with maintaining biological diversity and institutionalised in traditional Noongar law probably resulted in changes to the ecosystems in south-western Australia through the late Pleistocene and Holocene. This brief review indicates that disturbance-inducing Noongar niche constructing activities were likely greater in the SWAFR's Yodfels than Ocbils, but highlights several avenues for further investigation of the role that humans have played in shaping the biota of the SWAFR. Study of past and contemporary distributions of plant taxa at community, species and intraspecific levels in combination with ethnographic and archaeological evidence, contemporary testing of the ecological outcomes of traditional disturbance processes, and reinterpretation of previous studies (such as in plant phylogeography) through a niche construction lens are likely to shed new light on our understanding of south-west Australian biota.

HNC is a useful theoretical framework for examination of specific Noongar niche construction practices and their likely influences on SWAFR ecosystems, although we suggest that a SET-based approach is equally valid and probably complementary. Examination of such human interactions with SWAFR flora in the context of its long and complex evolutionary history can direct new perspectives for its conservation. In particular, a strategy of targeted fire and soil disturbance and highly localised conservation management appears consistent with both past Noongar practice and emerging knowledge of rapid species turnover and high genetic differentiation across SWAFR landscapes. Collaborative research engaging traditional owners, ecologists and archaeologists, that examines the likely ecological and evolutionary implications of past Noongar practice on country, is an important step for conserving the extraordinary biological communities of south-western Australia.

Chapter 3: The Noongar of south-western Australia: a case study of long-term biodiversity conservation in a matrix of old and young landscapes

Abstract

Home to the Noongar people for at least 48,000 years, the South West Australian Floristic Region (SWAFR) exhibits an exceptionally rich flora, with old, climatically buffered, infertile landscapes (Ocbils) being primary centres of plant diversity and endemism within a matrix of young, often disturbed, fertile landscapes (Yodfels). We examined traditional knowledge of contemporary Noongar Elders of the southern coastal SWAFR to test whether patterns of disturbance dictated by Noongar custom align with Ocbil theory. Targeted, semi-structured interviews were conducted with Elders on adjacent Ocbil and Yodfel sites at Peniup, while traditional knowledge of two larger areas, Wagyl Kaip and Tjaltjraak, was analysed for patterns of differential landscape use. We found concentration of Noongar disturbance in the southern SWAFR's Yodfels rather than Ocbils – a pattern which aligns with Ocbil theory and is the best approach for preserving the SWAFR's extraordinary biodiversity. SIMPER testing found that Noongar activities of Ocbils and Yodfels were 64-75% different to one another, while Pearson's chi-square tests revealed that camping, burning of country, movement along biddis/tracks, hunting and other resource gathering were primarily Yodfel rather than Ocbil activities. Noongar harvest of plants occurred in both Ocbils and Yodfels, and cultural importance was attached to both landscape types, but for differing reasons. Contemporary Noongar traditional knowledge reflects a general regime of deliberately focused disturbance in Yodfels rather than Ocbils of the southern SWAFR. This regime, as well as a highly diverse flora of ancient lineage following at least 48,000 years of occupation, suggests that Noongar traditional knowledge is both valuable and necessary for continued conservation of the SWAFR's biological diversity. Further investigations along these lines would be profitably targeted on cultural practices in other Ocbil-dominated global biodiversity hotspots.

Introduction

Most human societies have developed in landscapes that are relatively young, often disturbed by natural erosional processes, and are consequentially endowed with fertile soils. Although biodiversity may be moderate in such young landscapes, biological productivity is accentuated (Gough et al. 2000; Lambers et al. 2011; Rajaniemi 2002). Yet some humans also live successfully in less favorable landscapes – old and often rocky, with deeply weathered infertile soils, especially where the region is climatically buffered through reasonable proximity to prolonged oceanic influence. Such poor soils often support rich floras with high endemism levels. In fact, 12 of the world's 35 terrestrial biodiversity hotspots are dominated by old, climatically buffered, infertile landscapes, termed Ocbils (Hopper

2009; Hopper et al. 2016). In this context, targeted conservation strategies for conservation of Ocbil biota have the potential for significant positive outcomes for global biodiversity.

Ocbil theory (Hopper 2009) differentiates between the attributes and conservation needs of biota existing on Ocbils, such as granite or laterite uplands, and those of young, often disturbed, fertile landscapes (Yodfels) such as coastal dunes or wetlands. Hopper et al. (2016) later identified old, climatically buffered fertile landscapes (Ocfels) as a third extremity of three axes of landscape age, disturbance regimes (especially climatic buffering) and soil fertility (Figure 3.1), although Ocbils and Yodfels remain the most contrasting qualitative axes endpoints, and are the focus of this study.

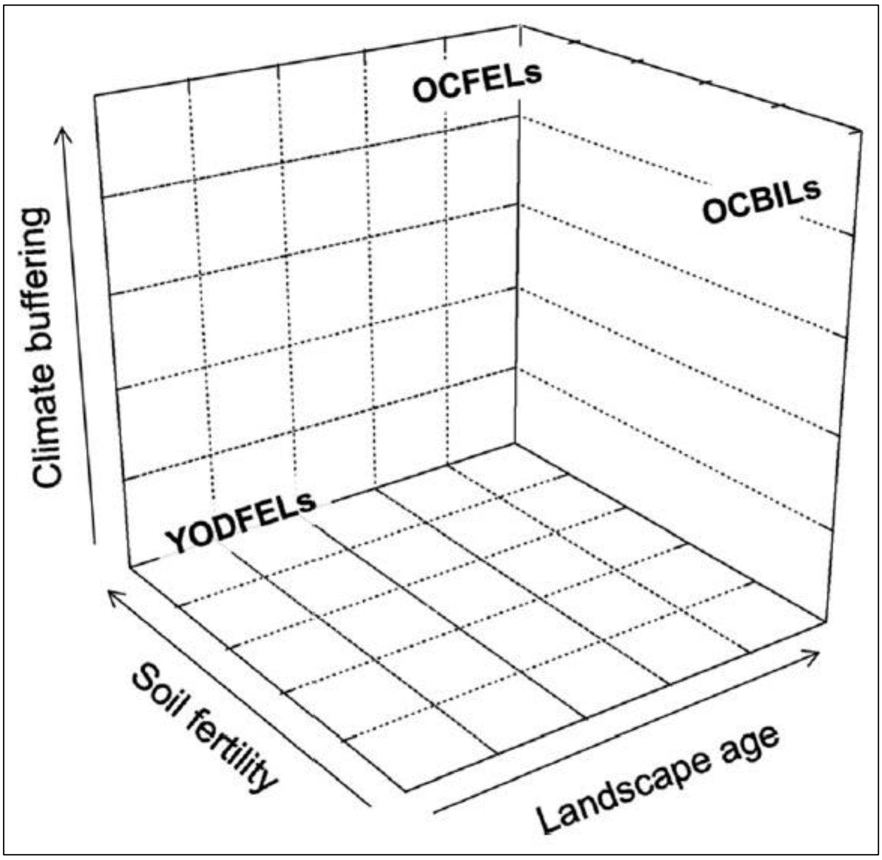


Figure 3.1: The three axes of landscape age, disturbance regimes (climatic buffering) and soil fertility that distinguish Ocbils, Yodfels and Ocfels from one another (source: Hopper et al. 2016)

Yodfels make up most of the Earth's landforms. Hopper (2009) identified that Yodfel plants tend to be recently evolved, have wide dispersal mechanisms, and are nutritional and biological generalists, making them common and widespread, tolerant to some human disturbance, but vulnerable to prolonged fragmentation. The well-established process of succession, where colonizing taxa are nurse plants for late successional, longer-lived taxa is apparent in Yodfels (Hopper 2009; Lavergne et al. 2004; Valiente-Banuet et al. 2006). Disturbance enables renewal of this process once late successional taxa reach end of life.

Ocbils have a long history of prolonged weathering and climatic buffering, free of disturbances such as marine inundation, glaciation and dune-forming dust storms (Hopper 2009). They are extremely phosphorus-limited and are dominated by specialist flora (Hopper et al. 2016; Lambers et al. 2012; Lambers et al. 2011). Ocbils contain a high proportion of relictual plants, and are more likely to support small populations of long-lived plant taxa, exhibiting maintenance of genetic diversity (Bezemer et al. 2016), and specialist traits for site-specific nutrient procurement in phosphorus-limited landscapes, e.g. carnivory, cluster and sand-binding roots (Lambers et al. 2012; Lambers et al. 2011; Lambers et al. 2014). In addition, traits such as long juvenile periods, small and/or disjunct populations, soil-type specificity and limited dispersal capability suggest vulnerability of Ocbil flora to frequent fire (Barrett et al. 2009; Enright et al. 2014; Holmes et al. 2000), and other natural and human disturbance (Arianoutsou et al. 2013; Leao et al. 2014). Given specific vulnerabilities, a strategy of minimal human disturbance of Ocbils is advocated (Hopper 2009; Hopper et al. 2016).

Since Hopper's (2009) introduction of Ocbil theory, its hypotheses have been rigorously tested (e.g. Hmeljevski et al. 2017; Hopper et al. 2016; Morellato and Silveira 2018; Zappi et al. 2017), and increasingly underpin our understanding of biological assets in Ocbil-dominated global floristic regions (Adam 2012; Dayrell et al. 2016; Gibson et al. 2010; Hopper et al. 2016; Lambers et al. 2012; Lambers et al. 2011; Mucina and Wardell-Johnson 2011; Sander and Wardell-Johnson 2011; Silveira et al. 2016; Standish and Hobbs 2010). We consider that continued inclusion of its principles in conservation policy and practice will have positive outcomes for biodiversity of these regions. However, while Ocbils support higher plant diversity and endemism than Yodfels, they are far geographically rarer. Correspondingly, most of the world's biological research (and resulting management theory) has been focused in the latter, and may have limited relevance to conservation of Ocbil organisms (Hopper 2009; Hopper et al. 2016; Lusk and Bellingham 2004). Traditional knowledge of indigenous peoples of Ocbil-dominated regions may be key to modern conservation of their biota. We have examined indigenous traditional knowledge of one of the world's Ocbil-dominated floristic regions and a global biodiversity hotspot (Mittermeier et al. 2011) in light of Ocbil theory.

Much of the exceptionally rich flora of the South West Australian Floristic Region (SWAFR) (Figure 3.2) is concentrated on Ocbils, which occur within the SWAFR among a matrix of younger, more fertile and/or frequently disturbed landscapes (Hopper et al. 2016). Ocbils in our study area comprise granite outcrops, quartzite ranges and kwongkan (sandplain) uplands overlying granite or spongolite, while Yodfels are wetland flats, depositional valleys and granite outcrop fringes and wind-blown sand dunes. The SWAFR has been home to its Noongar first people for at least 48,000 years (Turney et al. 2001), enabling fine-tuning of cultural practice to local biological conditions (Bliege Bird et al. 2013; Lullfitz et al. 2017). Noongar ecological knowledge is institutionalised in a geopolitical system that originated and applies to landscapes of the Ocbil-dominated SWAFR (Robertson et al. 2016). In Chapter 2, Lullfitz et al. (2017) suggested that traditional Noongar knowledge and behaviours might align with hypotheses of Ocbil theory, and identified that better understanding of this alignment may lead to improved outcomes for biodiversity, possibly through revived application of Noongar ecological knowledge.

Both Ocbils and Yodfels of the SWAFR are fundamental to traditional Noongar culture (Bird 1985; Hallam 2014; Hopper and Lambers 2014; Robertson et al. 2016; Smith 2011b). A propensity amongst forager societies to increase and/or maintain resource access through mimicing natural events (Smith 2011a) and to refine these activities over long periods (Bliege Bird and Nimmo 2018; Bliege Bird et al. 2013), suggests the evolution through time of specific human behaviors adapted to and based upon ecological drivers within a local landscape. To this end, given an enduring presence of Noongar in the SWAFR, we expect that specific management actions, passed on through Noongar lore and custom to contemporary Elders, were tuned to differential requirements of Ocbil and Yodfel organisms. In this study, we recorded and examined Elders' knowledge of specific Ocbil and Yodfel places in the southern SWAFR to test whether traditional Noongar ecological practices are consistent with biodiversity conservation practices prescribed by Ocbil theory.

Methodology

Study area and structure

This study was conducted in the southern coastal SWAFR (Figure 3.2). It comprised 1) gathering and comparing Elders' traditional knowledge about adjacent Yodfel and Ocbil sites at Peniup, south of Jerramungup (Figure 3.3); and then 2) compiling traditional knowledge gathered from across the broader Wagyl Kaip and Tjaltjraak areas to test whether findings at Peniup were consistent at a regional scale.

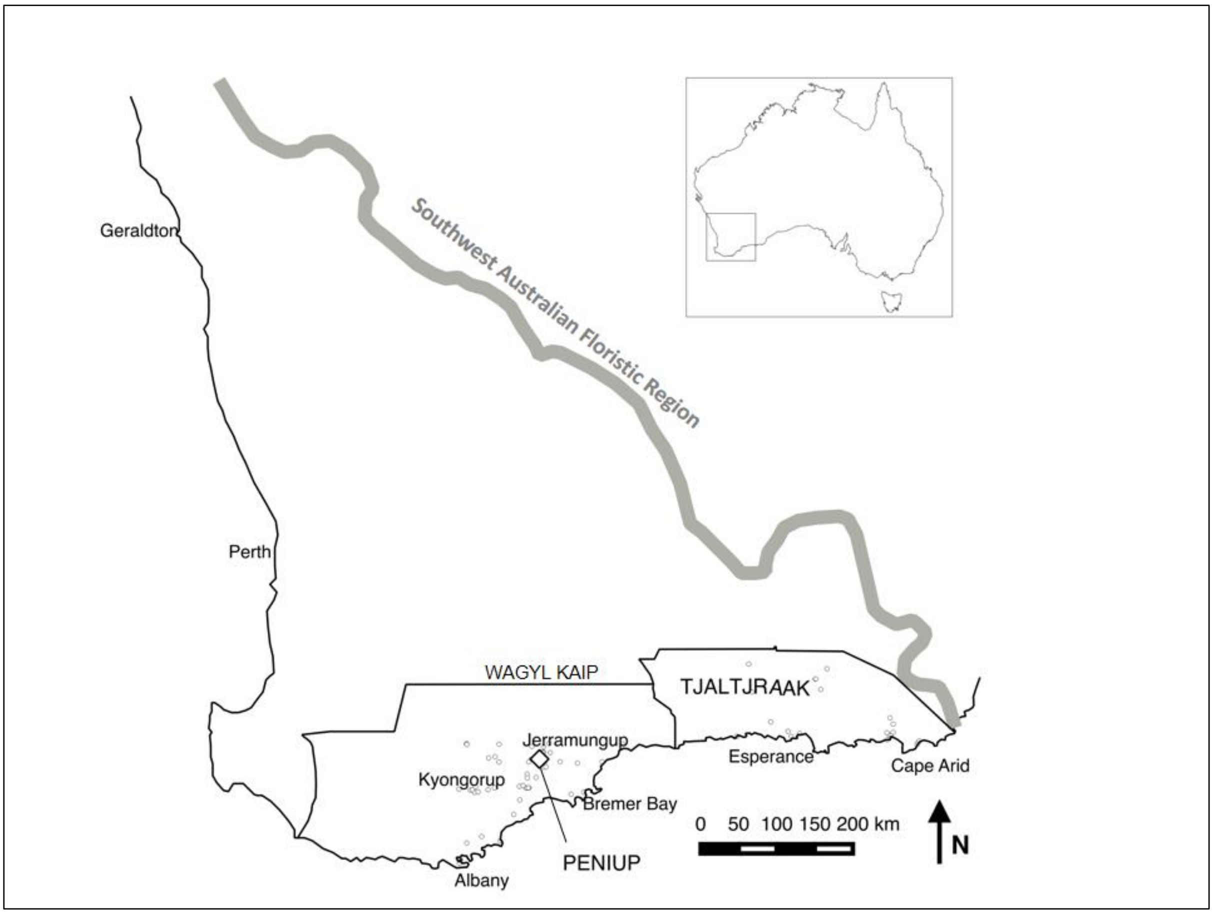


Figure 3.2: Location of the study area, Tjaltjraak Native Title and Wagyl Kaip Indigenous Land Use Agreement boundaries (National Native Title Tribunal 2018) and SWAFR boundary (Gioia and Hopper 2017). Grey circle markers indicate Ocbil and Yodfel places to which Elders referred during interviews.

For the first stage of the study, a Yodfel and an Ocbil site were chosen in the Pallinup River area, where botanists (Alison Lullfitz and Stephen Hopper) visited with nine Elders (including co-authors, Carol Pettersen, Aden Eades, Averil Dean, Lynette Knapp, Eliza Woods, Treasy Woods and Eugene Eades) in four family-based groups. The Yodfel site comprised the Peniup Creek and adjacent woodland vegetation characterised by a canopy of *Eucalyptus occidentalis* and understorey of *Allocasuarina huegeliana, Acacia cyclops, Acacia saligna, Melaleuca acuminata* and *Templetonia retusa* on deep sandy loam. The Ocbil site was dominated by several granite outcrops and low kwongkan vegetation overlying shallow granite. The vegetation at this site was more diverse, with the granites dominated by *Calothamnus quadrifidus, Allocasuarina huegeliana, Acacia lasiocalyx* and *Borya constricta*, and kwongkan vegetation comprising a low mallee Eucalypt canopy of *E. pleurocarpa, E. phaenophylla* and *E. thamnoides* with a Proteaceae-rich understorey including *Banksia media, Calothamnus quadrifidus, Grevillea tetragonaloba,* and *Platysace deflexa*.

Figure 3.3: (clockwise from top left) Peniup Creek and adjacent woodland Yodfel at Peniup site; granite inselberg Ocbil at Peniup site; example of wetland and coastal dune Yodfel (background) and granite inselberg Ocbil (foreground) of Wagyl Kaip area; example of remobilised coastal dune Yodfel (foreground) and granite inselberg Ocbil (background) of Tjaltjraak area.

The second stage of the study took in two larger geographical areas, the Wagyl Kaip indigenous land use agreement and Tjaltjraak (Esperance Nyungar) native title areas in western and eastern parts of the southern coastal SWAFR respectively. Traditional knowledge of 11 Wagyl Kaip Elders and eight Tjaltjraak Elders was compiled to inform this stage.

Interviews

Semi-structured interviews were conducted and recorded with Elders at Peniup in accordance with University of Western Australia Human Research Ethics Approval (HREA) RA/4/1/6836. During interviews, Elders recounted their experience and knowledge of each site, including identification and discussion of culturally significant plants. Discussion about site use was specifically framed around Elders' recall of particular activities at each place, either first hand or told to them by family. Specifically, Elders addressed questions about whether sites were likely used for camping, hunting animals, gathering plants and/or other resources, moving through on a biddi/track, how and if it may have been burned, or whether access may have been restricted or held in particular reverence due to ceremonial or other reasons. Relevant information about places other than Peniup was also recorded during these interviews. Where these places could be unambiguously identified as either a Yodfel or Ocbil, this information was included in the second stage analyses. Interviews were transcribed, and seven categories were determined to represent the range of site activities or significance discussed for each location during visits to Peniup (Table 3.1).

Table 3.1: Categories of site activity/significance discussed during on-country interviews.

Site activity	Included
Camp	Camping overnight or longer, usually referring to a family group.
Harvest plants	Plants harvested for any purpose.
Hunt game	Hunting of any terrestrial, vertebrate animals, mainly refers to mammals, but possibly also birds or reptiles.
Gather other resources	Any other resources not included in the above two categories (e.g. fish, invertebrates, honey, lithic resources). Does not include water.
Culturally Important	Where a site featured in a creation story, was known by its traditional name, or was of particular importance to a family.
Move through	A place on a biddi/track.
Burn	Where country was deliberately burned. (Does not include stationary campfires).

Traditional Noongar knowledge included for the Wagyl Kaip and Tjaltjraak areas respectively was recorded during interviews conducted by AL with Elders from 19 February 2014 to 6 November 2016, also in accordance with HREA RA/4/1/6836. These interviews were conducted as part of a wider body of research. Questions were less specific to our research question than the first stage interviews. Relevant Elders' knowledge that had been previously recorded during the 2007-09 Linkage Project was also included in the Wagyl Kaip analysis. Again, inclusion of these records complied with HREA RA/4/1/6836.

Ethnographic data compilation

Each relevant statement of knowledge made by Elders during interviews was tabulated, along with the location to which it related. Information included in each statement was interpreted and categorised in accordance with site activity categories. For example, from the following statement about Peniup Creek, we interpreted that people camped at the site, that it was periodically burned, and that plants were harvested for use as shelter and bedding:

> *"The site wouldn't be dirty like this [pointing to dead branches and wood on ground] because it would be burned and that would be cleaned up. There wouldn't be branches everywhere. Our family would have come to camp in a clear place like this, and we'd use those bushes [Melaleuca acuminata] for thatching and putting down underneath to sleep on, making the bush breaks. They only camped where it was clean." (Averil Dean, 23 April 2015)*

In this way, a matrix of positive responses (i.e. that an activity *was* carried out at a location) and non-positive responses for each site activity for each statement at each location was generated. Non-positive responses were either negative (i.e. that an activity *was not* carried out at a location) or neutral (i.e. where *no indication was given* in relation to an activity occurring at a location) but were not differentiated.

The targeted nature of first stage interviews conducted at Peniup compared to the second stage were considered more likely to engender negative statements relating to activities at specific location than those recorded during the second stage. Therefore all statements recorded during the first stage (mostly relating to Peniup but also to some other locations in the Wagyl Kaip area) were also included in a second matrix of negative or non-negative (i.e. positive or neutral) statements for each site activity and location.

During interviews of both stages, burning of country emerged as a prominent discussion point. As data were of sufficient quantity to provide meaningful interpretation, we compiled statements regarding burning into key themes, in order to inform our broader question about differential Ocbil and Yodfel activities. Where Elders identified that burning was undertaken at a site, its purpose (if given) was assigned to one or more categories including to a) clear vegetation or control pests at a camp; b) provide easier access for walking through country; c) protect resources; d) encourage green grass to attract game; and e) encourage access to other resources (e.g. plant foods, mushrooms, firewood and water). For example, Averil Dean's statement above was interpreted that, in this instance, burning was carried out to clear a suitable area for camping.

Classification of sites

We conservatively included only statements referring to landscapes at the extreme, unambiguous Ocbil/Yodfel termini of the landscape age, soil fertility and disturbance axes (Figure 3.1; Table 3.2). Classification of Yodfel and Ocbil places visited and to which Elders referred during interviews was based on soil-landscape subsystems mapped by the Western Australian Department of Agriculture and Food (now Department of Primary Industries and Regional Development) (*sensu* Purdie et al. 2004), as well as ground-truthing during site visits. The soil-landscape subsystem of each place for which we recorded Noongar cultural information was identified. In most instances, author observations of topography, geology, soil and vegetation concurred with documented soil-landscape subsystems. Minor discrepancies were deemed due to local-scale data inadequacies on which the original soil-landscape mapping units were based (Purdie et al. 2004). In all discrepant instances, ground-truthing in relation to documented soil-landscape subsystem descriptions indicated that the site fell into a geographically close subsystem and was therefore reclassified to the latter. Table 3.2 shows all included Ocbil and Yodfel soil-landscape subsystems. Site classification was carried out independently of Elders' statement information in order to reduce the likelihood of classifier bias.

Table 3.2: Locations to which Elders referred, corresponding soil-landscape subsystems (Purdie et al. 2004), and landscape type classification as Ocbil or Yodfel (Hopper 2009). Source author/s are indicated in parentheses where a previously unpublished Noongar name has been utilised (TW – Treasy Woods; AD – Averil Dean; LK – Lynette Knapp; CP – Carol Pettersen; AE – Aden Eades; RR – Ron (Doc) Reynolds).

Region	Landscape type	Soil-landscape subsystem	Site locations
Peniup	Yodfel	Yarmalup 1	· Peniup Creek
	Ocbil	Yarmalup 6	· Beringa Upland
Wagyl Kaip	Yodfel	Boulongup	· Lake Pleasant View
		Bremer 4	· Ocumup Swamp
		Jonacoonak 4	· Fitzgerald Inlet
		King 2	· Wilyun Pools
		Lower Fitzgerald 3	· Mygenup, Gairdner River (CP)
		Lower Pallinup 3	· Marra (Pallinup) River · River pool on Pallinup River, Boxwood Hill · Chillinup crossing, Pallinup River · Pallinup River woodland, Boxwood Hill · Peter's Crossing, Pallinup River
		Lower Pallinup 8	· Miller's Point, Pallinup River
		Major Valleys 7	· Kalgan River
		Meerup 1	· Bremer Bay (now caravan park)
		Meerup beach phase	· Cape Riche
		Meerup podzols over calcareous sand	· Intersection Quaranup Rd /Frenchman Bay Rd
		Middle Pallinup 1	· Creeks in the Pallinup catchment · Swamp and surrounding *Eucalyptus occidentalis* woodland, Boxwood Hill · Corackerup Creek
		not classified	· Doubtful Island · Watami (Green Island)
		Stirling Range 6	· *Eucalyptus wandoo* flats, base of Kyongorup (Stirling Ranges)
			· Chester Pass, Kyongorup
		Toompup 4	· Peenebup Creek
		Upper Pallinup 5	· Gnowangerup townsite · Rocky Ongerup · Borden reserve · Borden townsite · Yongermere, Upper Pallinup River
		Yarmalup 1	· Carlawilgiup (AE) · Gairdner River at Monkey Rock

Region	Landscape type	Soil-landscape subsystem	Site locations
		Yarmalup 2	· Jerramungup townsite
	Ocbil	Barrow upper slope phase	· Borongorup (Porongorup Range)
		Gardner granite phase	· Kooranup on Kinjarling Tarling (Vancouver Peninsula) (LK)
		Jerramungup 6	· Keetchimindarup (Reynolds Hill) (CP, LK)
		Middle Pallinup 7	· Nowanup Upland
		Stirling Range 1	· Toolbrunup, Kyongorup · Marbenup, Kyongorup (TW, AD) · Cowamartup, Kyongorup (TW, AD) · Bullay Meal (Bluff Knoll), Kyongorup (LK) · Warrnup, Kyongorup (TW, AD) · Toolbernup, Kyongorup (TW, AD) · Ellen Peak, Kyongorup
		Stirling Range 2	· Kyongorup peaks
		Whoogarup 2	· Dukartar (West Mt Barren and Mt Bland) (LK) · Narpalungup (eastern Barren Ranges) (LK) · Weedjarup (East Mt Barren) (LK)
		Yarmalup 6	· Granite uplands in Pallinup catchment
Tjaltjraark	Yodfel	Ca25	· Jorndee Creek · Seal Creek · Poison Creek · Estuaries in Esperance area
		Esperance 2E3c phase	· Dalyup · Esperance townsite · Lake Monjingup
		Gore 1	· Merrivale wetlands
		Ney 2	· Flats north of Bebernornup (RR)
		Thomas River 2	· *E. occidentalis* woodland, Upper Thomas River
		Tooragullup 1	· Pink Lake edge · Fanny Cove
		Tooragullup 4	· Bandy Creek
		Tooragullup 6	· Eastern end, Kennedy Beach, Cape Arid · Belinup
		Wittenoom 2	· Marbaleerup (fringe)
		Young 1	· Lort River · The Cups
	Ocbil	Ney 1	· Granites inland of Poison Creek · Thomas River Rd flat rock · Boyatup Hill
		Wittenoom 1	· Granites inland of Esperance · Wittenoom Hills stone arrangements · Marbaleerup (granite)

Data analysis

Matrices of site activity and landscape type data were analysed in *Primer v6* (Clarke and Gorley 2006) using multivariate statistical methods, comprising non-Multi-dimensional Scaling (nMDS) and SIMPER. nMDS enabled patterns of similarity and difference between site activities on Ocbils and Yodfels to be visualised, while SIMPER analyses quantified the similarity within and difference between Ocbil and Yodfel site activities at Peniup and for the Wagyl Kaip and Tjaltjraak areas. This was carried out for the positive/non-positive matrices of statements relating to Peniup, and the Wagyl Kaip and Tjaltjraak areas, and for the negative/non-native matrix that included all statements made during visits to Peniup.

If site activities were independent of landscape type, we expected that positive statements relating to each activity would be evenly distributed between Ocbil and Yodfel locations. To test this hypothesis, for each activity category, a Pearson's Chi-square goodness of fit test was undertaken to determine whether the observed abundance of positive statements differed from an expected even distribution between landscape types. Box and whiskers plots of these were generated using R version 3.3.1 (R Core Team 2016).

Results

Elders' traditional knowledge of Peniup showed that Noongar activities differed significantly between landscape types, with most activities likely to occur at the Yodfel site along and adjacent to the creek rather than the granite upland Ocbil site. An nMDS of 148 positive/non-positive statements (Figure 3.4) relating to Peniup showed a degree of clustering among Ocbil and Yodfel statements respectively, while SIMPER testing (Table 3.3) revealed 75% dissimilarity between activities of the Peniup Ocbil and Yodfel. In addition, Noongar activities likely to have been carried out at the Peniup Ocbil appear to be more specific than those along the Yodfel creekline, given greater similarity among Peniup Ocbil (54%) than Yodfel statements (29%).

Elders expressed absolute statements against camping, hunting and burning in Peniup and Wagyl Kaip Ocbils. An nMDS of 273 negative/non-negative statements regarding Peniup and the Wagyl Kaip area distinguished several statements regarding Ocbils from an otherwise undifferentiated group relating to both Ocbils and Yodfels. SIMPER testing of this matrix revealed 100% dissimilarity between Ocbil and Yodfel activities, based on negative statements about camping, hunting and burning at Ocbil locations.

Among 166 positive/non-positive statements about the Wagyl Kaip area, the same pattern as for Peniup was apparent, where Ocbil and Yodfel activities were 70% dissimilar, as well as higher similarity among Ocbil activities (80%) than those of Yodfels (29%). Contrast between Ocbils and Yodfels was less obvious in the 52 positive/non-positive statements relating to the Tjaltjraak area. However

SIMPER testing still revealed 64% Ocbil-Yodfel dissimilarity in activities, but less similarity among Ocbil activities (25%) than Yodfel activities (49%).

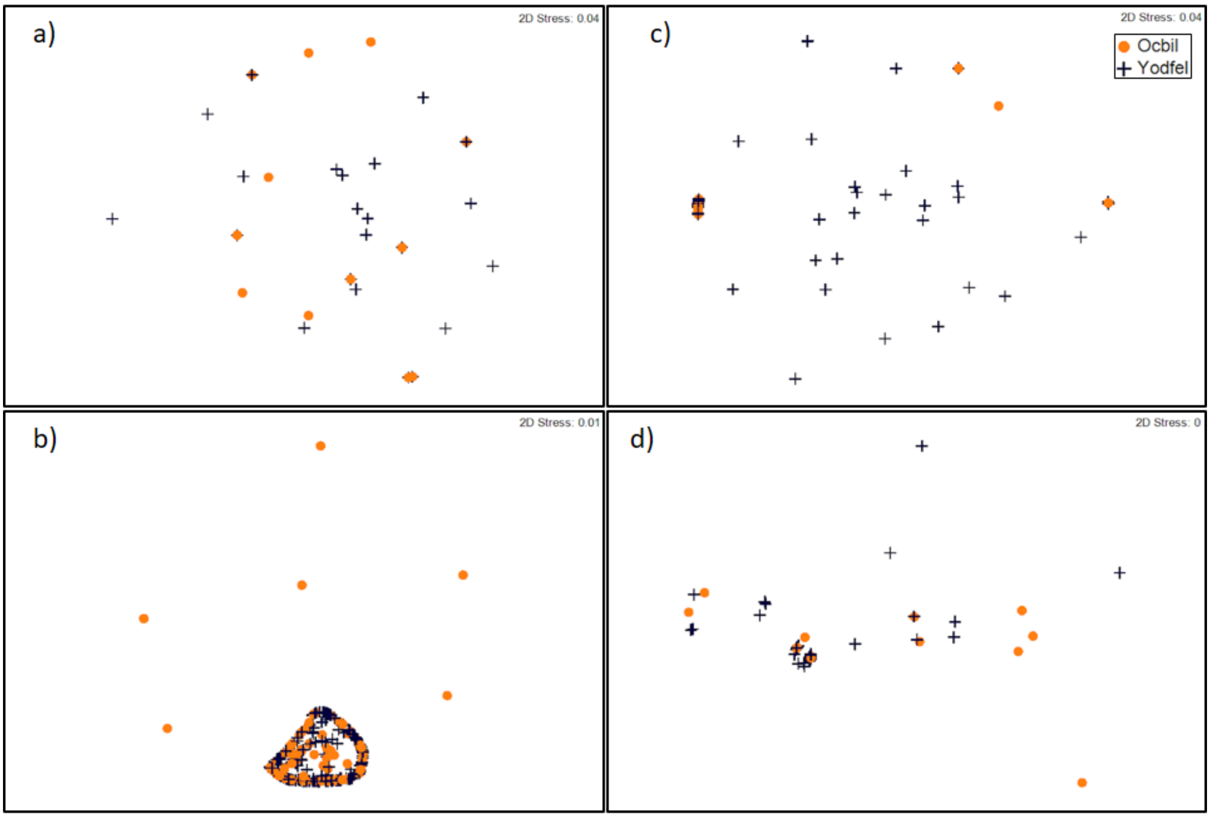


Figure 3.4: nMDS of site activities discussed by Elders for Ocbils and Yodfels of a) Peniup (positive/non-positive), b) Peniup and Wagyl Kaip (negative/non-negative), c) Wagyl Kaip (positive/non-positive) and d) Tjaltjraak (positive/non-positive), based on Bray-Curtis resemblance with minimum Kruskal stress of 0.1.

Table 3.3: Results of one way SIMPER test of difference between and similarity within Ocbil and Yodfel site activities at Peniup and for the Wagyl Kaip and Tjaltjraak regions based on Bray-Curtis resemblance. Average dissimilarity or similarity of contributing activities shown where ≥1%. *All statements regarding Yodfel sites for Peniup/Wagyl Kaip were non-negative.

Matrix type	Positive/non-positive			Negative/ non-negative
Location	**Peniup**	**Wagyl Kaip**	**Tjaltjraak**	**Peniup/ Wagyl Kaip**
Yodfel-Ocbil dissimilarity (%)	75 harvest plants (24), camp (17), burn (11), hunt (10), gather other resources (6), important (5), move through (2)	70 important (26), camp (17), harvest plants (13), move through (4), gather other resources (4), burn (4)	64 harvest plants (26), camp (13), gather other resources (12), important (10), move through (2), hunt (1)	100 camp (74), burn (9), hunt (8)
Yodfel similarity (%)	29 camp (12), harvest plants (9), burn (5), hunt (1), gather other resources (1)	29 camp (12), important (10), harvest plants (5), gather other resources (1), move through (1)	49 harvest plants (45), camp (2), gather other resources (2)	not calculated*
Ocbil similarity (%)	54 harvest plants (51), hunt (1), important (1), gather other resources (1)	80 important (80)	25 harvest plants (20), important (3), camp (1), gather other resources (1)	5 camp (5)

A total of 96 Elders' statements relating to Peniup, and 37 and 40 statements relating to the Wagyl Kaip and Tjaltjraak areas respectively contained information about traditional use of a total of 90 plant taxa. Of statements that included plant knowledge, 45% of those about Peniup were in relation to the Yodfel and 55% to the Ocbil, while 89% and 75% related to Yodfels of the Wagyl Kaip and Tjaltjraak areas respectively.

In a total of 115 statements about Peniup or of the wider Wagyl Kaip and Tjaltjraak areas, Elders expressed knowledge of both Ocbil and Yodfel locations being important. Classification to the 'important' category was based on inclusion in a creation story, a place being known by its traditional name, or a place that featured heavily within a particular family's history. Detailed examination of statement content in this category revealed that Ocbils featured heavily in creation stories and were often identified by traditional names, while importance of Yodfel sites was due to use as historical family campsites, association with a creation story, or due to a particular significance of waterways. Often, importance was mentioned in relation to restrictions of use.

Pearson's chi-squared testing revealed that all activities except those in the 'important' category significantly differed in accordance with landscape type (Figure 3.5) and were not evenly distributed across Ocbils and Yodfels. At Peniup and the two larger geographic areas, there was a greater abundance of positive statements regarding all activities in Yodfels than in Ocbils. Exceptions were the 'important' category which was either evenly distributed or greater in Ocbil locations than Yodfels across all areas, and 'harvest plants', which was greater for the Ocbil than the Yodfel at Peniup, but not so across the larger areas.

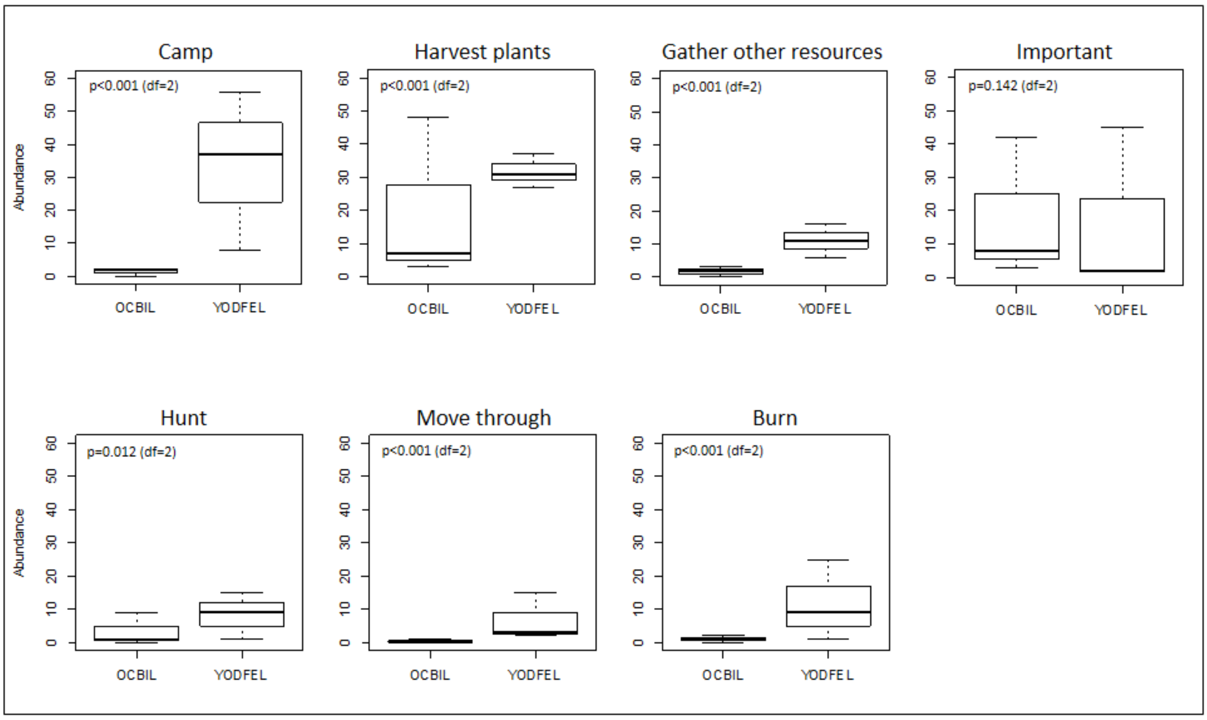


Figure 3.5: Box and whiskers plots of the abundance of positive statements of Elders for each activity at Peniup and in the Wagyl Kaip and Tjaltjraak areas. Pearson's Chi-square testing p-values and degrees of freedom are shown on each plot.

Over 100 statements from 18 Elders related to burning country, approximately half of whom recalled first-hand experiences as children. Eighty seven of these statements indicated cultural protocol in relation to fire. Several key themes in statements of numerous Elders across multiple family groups were identified and are summarised in Table 3.4. Specific vegetation communities indicated by Elders as being fired or where fire was avoided are listed in Table 3.5. In addition, 63 statements from 17 Elders included specific reasons for burning country. The proportion of these statements in each reason category were: a) clear vegetation or control pests at a camp (17%); b) provide easier access for walking through country (17%); c) protect resources (4%); d) encourage green grass to attract game (40%); and e) encourage access to other resources (21%).

Table 3.4: Key themes regarding protocols relating to burning identified in Elders' statements in relation to Peniup and the Wagyl Kaip and Tjaltjraak areas. (n= number of statements).

Theme	Summary of statements
Centrality to culture (n=16, noted by 10 Elders)	That burning is multi-dimensionally central to Noongar life, the health of people and country. That Elders grew up knowing that burning of country was 'just what you do', part of the responsibility of looking after country, and strongly linked to spiritual beliefs, access to basic food and shelter needs, and how and where people moved through country.
Control (n=38, noted by 10 Elders)	That only particular people within Noongar society could make decisions regarding burning of country. Some Elders expressed hesitance to speak of burning or would only speak in relation to a particular place or experience due to concern about their personal right to speak on such matters. Tight control while undertaking burning was described in detail. Elders talked about green branches being used to sweep and beat the fire in the way that wet hessian bags may be used, with participants, usually in family groups under the direction of an adult, arranged in a circular or linear manner along the fire edge. In answer to whether they wore shoes while burning, at least six Elders replied that both adults and children were barefoot, indicating that burns were highly controlled.
Location (n=43, noted by 13 Elders)	Elders indicated that some places were burned more than others. Whether a place was burned or not was determined by observations of the resources that it could provide. Whether kangaroos frequented a site, whether particular grasses preferred by game were present, and whether soil conditions were damp enough for mushrooms were some cited reasons for burning. Creeklines were particularly mentioned as resource-rich areas that were targeted for burning; while moort thickets (*Eucalyptus platypus,* often on Ocbils) were specifically mentioned as areas where burning was avoided due to trees being readily killed by fire, and for their value as habitat for particular resources such as mallee fowl *(Leipoa ocellata)* and tammar *(Macropus eugenii)*.
Patch size and spacing (n=21, noted by 10 Elders)	All Elders who mentioned the size of burned patches referred to their smallness, with actual size, where mentioned, ranging from approximately 0.2 – 2 ha. Reasons cited for burning only small patches were to easily retain control of the fire, to concentrate game into small burned patches or to only enable room to camp. Systematic burning of patches in rotation and adjacent to one another or a waterway (as a firebreak) were also described.
Timing (n=28, noted by 12 Elders)	Many Elders referred to predicting the weather through observations of animal behavior as a key influence on timing of burning, as well as direct weather observations, particularly wind direction. Seasonal timing was referred to regularly, with cooler times of the year being overwhelmingly preferred (approximately March to September). Reasons for this were to promote a cool burn that could be readily controlled and restricted to undergrowth compared to a hot burn, with cool soil and air temperature and overnight dampness being cited as key factors. Several Elders mentioned a preference for afternoons for burning to make use of damp evening conditions to control the fire.

Table 3.5: Vegetation communities identified by Elders as either being specifically targeted for firing or where firing would be avoided in the study area. (Note: as the topic of firing nor all vegetation communities uniformly discussed during this study, this should not be interpreted as an exhaustive list; n= number of statements).

Vegetation communities to which Elders referred as being targeted for firing
Eucalyptus occidentalis woodlands (n=13)
Creekline vegetation of the Pallinup river catchment (n=3)
Grassy uplands with emergent *Eucalyptus loxophleba* and *Allocasuarina huegelliana* on the Pallinup River (n=10)
Allocasuarina huegeliana woodlands (n=1)
Eucalyptus wandoo woodlands (n=2)
Kwongkan sandplain (north of the Fitzgerald Inlet) (n=1)
Melaleuca cuticularis thickets (n=1)
Eucalyptus platypus thickets (n=1)
Wetland vegetation in the Merrivale area east of Esperance (n=1)
Vegetation communities to which Elders referred in relation to avoiding fire
Eucalyptus platypus thickets (n=6)
High kwongkan upland surrounding granites (n=3)

Discussion

Contemporary Noongar knowledge relating to a specific Ocbil and Yodfel at Peniup as well as two broader geographical areas suggests that human disturbance activities such as camping, burning of country, movement along biddis/tracks, hunting and other resource gathering were far more prevalent in Yodfels than Ocbils of the southern coastal SWAFR. This concurs with archaeological evidence of southern coastal Noongar land use that suggested a primary focus in valley bottoms, wetlands and coastal dunes rather than kwongkan sandplain (Bird 1985; Dortch 2008; Dortch 2009; Hayward 2008; Smith 1993) and also with early colonial accounts of differential Yodfel and Ocbil Noongar activity (Eyre 1841; Hercock 2014). That this may, in part, reflect an archaeologically well-tested positive correlation between human occupation and fresh water sources and also places offering comfortable shelter and slope conditions (Cochrane et al. 2013; Smith 1993) was demonstrated by some Elders' views that, for example, more resource animals are found near creeks and rivers, or that a high, exposed point in the landscape would be an unlikely campsite.

Hopper (2009) hypothesised that selective pressures on more readily disturbed Yodfel flora favour those taxa that are widely dispersed and nutritional generalists, while taxa of long lived, narrowly dispersed individuals and specialised nutritional traits are favoured in Ocbil conditions. Human disturbance may result in negative or positive effects on a plant taxon depending on its particular life strategy; with nutritional generalists that exhibit a fast life history (i.e. r-selected (Pianka 1970)) more likely to respond positively to disturbance than a specialised, slowly reproducing (K-selected) species (Bliege Bird et al. 2013). We expect the taxa of Yodfels to have responded more positively to Noongar niche construction than that of Ocbils. While motive is likely multi-faceted, our findings support a hypothesis that Noongar traditional ecological knowledge broadly reflects a biodiversity conservation strategy congruent with Ocbil theory, particularly in the context of archaeological and documented historical evidence.

The locally specific nature of Noongar custom was evident in the varying patterns of Ocbil and Yodfel use we found between the Wagyl Kaip (including Peniup) and Tjaltjraak areas. A relatively greater focus of traditional activities on granite inselbergs in the Tjaltjraak than the Wagyl Kaip area likely accounts for a less striking difference between Ocbil and Yodfel activities in the Tjaltjraak area compared to Peniup and across Wagyl Kaip, as well as a greater similarity in Tjaltjraak Yodfel than Ocbil activities. Large waterways are scarce in eastern and inland parts of the Tjaltjraak area, to which most Tjaltjraak traditional knowledge in this study relates. This scarcity of waterways necessitated reliance of both Nyungar people and the animals they hunted on *gnammas* in granite outcrops for water. Granite inselbergs and adjacent woodlands, were (and remain) a focus of Nyungar activity, particularly in the inland Tjaltjraak area (Bindon 1997; Gunn et al. 2017; Smith 2011b). This difference was also evident during discussions of movement through country, with navigation by granite inselbergs emphasised by Tjaltjraak Elders, while Wagyl Kaip Elders talked of waterways as movement corridors.

Reasons given by Elders for burning were overwhelmingly biased toward Yodfel rather than Ocbil activities, with hunting, camping, moving along biddis/tracks, and accessing other resources mentioned most frequently, and all more likely carried out in Yodfels than Ocbils. Examples include that base camp sites were “cleaned up” through burning, with snake and tick habitat removed, and firewood created, while burned country attracted kangaroos and other game (e.g. Australian bustard, *Ardeotis australis*), and made it easier to access wetlands. Decisions about where to burn were largely based on resource availability, with waterways being particular emphasised, and some areas intentionally avoided. This, along with a strong thematic emphasis on strict burning protocols, small, tightly-controlled, but location-specific fires, and frequent burning of some locations, all suggest a strong focus of burning in Yodfels compared to Ocbils. A regime of frequent burning along waterways and adjacent woodlands in Yodfels, and infrequent burning of Ocbil vegetation again coincides with documented early colonial observations (Eyre 1841; Hercock 2014; Lullfitz et al. 2017).

In general, we found that most knowledge of plant harvest was expressed by Elders in relation to Yodfel sites, possibly reflecting a greater proportion of time spent around waterways, fertile woodlands and other Yodfel locations, compared to Ocbils. However, plant harvest did feature heavily in interviews at the Peniup granite upland, indicating that overall Noongar knowledge of cultural plants takes in both Ocbil and Yodfel taxa, taking advantage of the extraordinary plant diversity offered by the SWAFR’s Ocbils. The Proteaceae, which are richly represented on depauperate soils of the SWAFR and include numerous fire-sensitive members (Cowling and Lamont 1998) are one such Ocbil-prevalent plant group. Based on Elders' traditional knowledge recorded during this study, along with other contemporary and historic sources (Bates 2004; Drummond 1840a; Drummond 1840b; Drummond 1853b; Hassell 1975; Meagher 1974; Nind 1831), extensive and multi-dimensional Noongar use of the Proteaceae is indisputable. Examples include use of seed and nectar as a food source, use of seed cones for movement of fire and even use of dead flower heads as a hairbrush (LK, CP). Employment of an infrequent burning regime by Noongars in Ocbil plant communities would certainly have been conducive to Proteaceae conservation, and corresponding protection of this important group of resource plants was possibly one reason for avoidance of burning Ocbils.

Unlike most statements regarding the Wagyl Kaip and Tjaltjraak areas, all of those relating to Peniup were given as part of targeted interviews addressing our research question of differential Ocbil and Yodfel use. To this end, substantially greater collaborative field time was spent at Peniup than other locations across the wider areas. Differing survey effort is reflected in a far greater number of statements regarding plant use in the Peniup granite upland compared to Ocbils of the two wider geographic areas, and highlights the value of conducting two-way science collaboratively and on country. Sufficient time spent in-situ enabled Elders to recall natural history knowledge often acquired during childhood, and for biologists to identify plant taxa, share their knowledge and to seek clarification from Elders about particular aspects of information they have shared. Although the value of traditional knowledge to contemporary biodiversity conservation is becoming increasingly acknowledged (Bliege Bird et al. 2018; Bliege Bird and Nimmo 2018; Bliege Bird et al. 2013; Bonta et al. 2017; Ens et al. 2015; Lyver et al. 2015; Middleton 2013; Rossetto et al. 2017), a systematic review of its inclusion in Australian conservation practice found that its application so far has occurred largely outside of internationally recognised hotspots, including the SWAFR (Ens et al. 2015). Our findings highlight traditional Noongar knowledge as a valuable conservation resource in the SWAFR and we suggest a greater application of two-way science here and in other Ocbil-dominated biodiversity hotspots.

While Yodfels are the focus of day-to-day traditional Noongar activities, our study highlighted also the importance of Ocbils in Noongar culture. Elders' recounting of creation stories, and expression of spiritual or ceremonial significance of places, reflected integration between Noongar country, personal wellbeing and social cohesion that is often considered a universal feature of indigenous life ways (Cuerrier et al. 2015; Lyver et al. 2015; Sutton et al. 2013). We found that Ocbils featured more than Yodfels in creation stories, were most often indicated as powerful spiritual places or known ceremonial grounds, and usually had access restrictions based on gender or site-specific use. Aside from historic family campsites, importance of Yodfels was most often expressed in relation to significance of waterways (again, related to creation beliefs), with several Elders recalling ceremonial spirit-appeasing activities that were conducted on arrival during family outings. SIMPER analysis found the 'important' category particularly influential in differentiating Ocbils and Yodfels of the Wagyl Kaip area, which was likely due to an overwhelming expression of creation stories, spiritual significance and restricted access to Kyongorup (the Stirling Ranges). Elsewhere, symbolic importance associated with stories, spiritual beings and ritual has been linked to biodiversity protection (Bhagwat and Rutte 2006; Shrestha and Medley 2016). Accounts included in our study demonstrate that Noongar protocol appeared to strongly dictate use of and access to Ocbils, reflecting a possible acknowledgement of their fragility. Similar attributions of protocols and spiritual significance to Ocbil landforms are evident in the Blue Mountains of eastern Australia (Bowdler 1981), Venezuelan Guayana (Huber and Zent 1995) and Bushmanland in South Africa (Skotnes 2007), which suggests some commonality among indigenous societies of Ocbil-dominated origin in protection of Ocbil biota.

The exceptional local endemism of Ocbil-dominated regions makes broad vegetation categorisation and corresponding conservation approaches inappropriate, and poses unique problems for modern Ocbil conservation managers that are unlikely to concern their Yodfel counterparts. The restrictive and locally specific nature of Noongar custom highlighted in our findings and by others (e.g. Kelly 1998) suggests that Noongar geopolitical systems were well matched in scale to the SWAFR's edaphic and biological heterogeneity. That local experts made local decisions in relation to burning, access to resources and even to entering specific places, reflects that in Noongar society, intimate knowledge of country was (and remains) highly valued. High levels of local endemism means every remaining fragment of Ocbil in the SWAFR is unique (Hopper 2009), even if small and isolated, and is likely to be important to its local Noongar custodians. Modern conservation managers in the SWAFR may learn from the traditional Noongar approach of localised decision-making by those most intimately connected to these small fragments. In addition, the local specificity of Aboriginal fire management demonstrated by our study and others (Karskens 2017; Silcock et al. 2016) signifies that assumptions of universality in Aboriginal land management (e.g. Gammage 2012) are flawed, and that misapplication could lead to poor biodiversity outcomes in Ocbils and other fire-sensitive ecosystems.

Conclusion

Our findings suggest that, although localised in application and control, a general regime that focused disturbance activities in Yodfels rather than Ocbils applied across southern coastal Noongar country. In this way, the SWAFR's geologically younger and more readily disturbed landscapes such as coastal dunes, wetlands and river valleys that support widespread, readily regenerative plant taxa were subject to daily Noongar management. On the other hand, strict protocol restricted regular and universal access to old landscapes, such as quartzite ranges and granite uplands that support small populations of highly specialised flora. This general conservation strategy intrinsic to traditional Noongar custom appears to align closely with Ocbil theory. Our findings, as well as a highly diverse flora of ancient lineage following at least 48,000 years of human occupation, suggests that Noongar traditional knowledge is both valuable and necessary for continued conservation of the SWAFR's biological diversity. Further investigations along these lines would be profitably targeted on cultural practices elsewhere in the SWAFR and other regions rich in Ocbils, including 12 of the world's global biodiversity hotspots (Hopper et al. 2016). Moreover, given its significance to human origin, a special focus on the significance of the Ocbil/Yodfel uses by early *Homo sapiens* in Southern Africa may well prove to be rewarding.

Chapter 4: Nyungar cultural influences on granite inselberg plant distribution and abundance

Abstract

There are numerous examples globally of present day native plant species' distributions that are the result of long histories of manipulation by First Nations peoples. Using plant presence data collected over a 40-year period, we examined the species richness and beta diversity of native plants of cultural significance ("cultural plants") recorded on granite inselbergs in Nyungar country of the South-west Australian Floristic Region. Our objective was to look for evidence of human manipulation of cultural plant geographic distribution by comparing plant diversity metrics to archaeological and ethnographic evidence of long held Nyungar land use patterns in light of traditional plant use. We found a bivariate pattern of cultural plant distribution between coastal and inland granite rocks consistent with wider floristic patterns, environmental determinants, and Nyungar mobility patterns. We also found positive correlations among granite inselberg size, overall plant species richness, and cultural plant species richness. These findings neither discount Nyungar niche construction in shaping granite inselberg plant communities nor do they provide certainty of an anthropological role. However, a higher proportion of year-round available resources was found among food plants of an occasionally occupied residential complex used periodically for large meetings of people from afar, compared to a permanently occupied complex. This finding, along with the abundant occurrence of a high volume, year-round root crop, *Platysace trachymenioides*, in the complex of inselbergs and flatrocks used for large gatherings and high cultural plant richness at the meeting place itself, is suggestive of Nyungar plant niche construction. Such vegetation patterns indicate that traditional Nyungar plant knowledge is complex and locally specific in its application, and reflects the well-recognised floristic richness and complexity of south-western Australia. We suggest targeted, cross-cultural, and multi-disciplinary research that uses measures of relative abundance and phylogeographic techniques to further investigate long-standing people-plant relationships in Nyungar country.

Introduction

Complex plant-people relationships are evident among indigenous peoples worldwide and go well beyond the utilitarian value of individual plant species. Specific plant taxa or communities and their characteristics are indicative of past and present human, and possibly spiritual being presence at places (Amundsen-Meyer 2013; Barton and Denham 2016; Bradley 2006; Eriksson 2014; Hynes and Chase 1982; Levis et al. 2018), and as such, are intrinsically linked to a peoples' ancestry, cosmology, ritual, and convention (Barton and Denham 2016; Chase 1989; Lepofsky and Lertzman 2008; Levis et al. 2018; Walsh 1990; Walsh 2008; Walsh et al. 2013). For example, in the southern South West Australian Floristic Region (SWAFR, sensu Gioia and Hopper 2017; Hopper and Gioia 2004), groves of

Acacia cyclops have been described as indicative of past ancestral campsites (Lullfitz et al. 2017 (Chapter 2)), while stands of *Muert* (*Eucalyptus platypus*) represent close bonds between members of a family (with the Noongar word *Muert* also meaning family) (Pettersen 2015b). Occurrence of plant taxa well outside their main range may also reflect cultivation of food, otherwise useful or totemic species (Lullfitz et al. 2017; Wheeler et al. 2003). Thus, understanding past and continuing effects of First People's plant interactions on current floristic patterns can not only guide contemporary biodiversity conservation, but also affirm ancestral connection for traditional owners, promoting positive outcomes for people and country (Bliege Bird and Nimmo 2018; Lepofsky and Lertzman 2008; Levis et al. 2018; Middleton 2013).

Human niche construction (HNC) is a useful framework through which to examine people-plant relationships among small-scale societies (Bliege Bird et al. 2013; Smith 2011a). HNC recognises the reciprocal relationship between people and their environmental conditions (Bliege Bird et al. 2013; Eriksson 2016; Odling-Smee et al. 2003; Smith 2011a). Its premise is that people are part of their natural environment, not simply using the resources it provides, but actively manipulating ecological processes to enhance accessibility, abundance, and predictability of economic resources they require (Amundsen-Meyer 2013; Coughlan and Nelson 2018; Lepofsky and Lertzman 2008; Levis et al. 2018; Smith 2011a). Such activities have resulted in the concentration of economically valuable plant resources around historic sites utilised by small-scale societies through multi-generational efforts (Amundsen-Meyer 2013; Atchison 2009; Bayliss-Smith 2003; Bishop et al. 2015; Bliege Bird et al. 2013; Coughlan and Nelson 2018; Gremillion 2014; Hallam 2014; Head et al. 2002; Hynes and Chase 1982; Levis et al. 2017; Levis et al. 2018; Shipek 1989; Smith 2011a).

Detecting HNC poses challenges for researchers, especially where traditional management has ceased. The strongest evidence is that relating to animals, where physical structures, such as fish weirs, visibly remain in the archaeological record (Smith 2014). Detecting plant manipulation is more difficult for several reasons. Firstly, natural succession may have erased, or at least masked, past anthropogenic effects on floristic communities (Lepofsky and Lertzman 2008; Smith 2014). Secondly, human societal legacies within plant communities likely vary with the nature of human practice among small-scale societies, as well as the landforms that they have historically occupied (Amundsen-Meyer 2013; Bliege Bird et al. 2013; Chase 1989; Levis et al. 2017; Marston 2011; Shipek 1989). Marston (2011) advocates that different methods are required to detect resource diversification (e.g. diverse use of plant species by Khoe-San peoples of South Africa's Cape (De Vynck 2014)) and intensification (e.g. concentrated renewal of berry patches by the Blackfoot of the North American Great Plains (Amundsen-Meyer 2013)) among small-scale societies. Amundsen-Meyer (2013) found a more subtle HNC signature of the Kayapo in diverse Amazon forest compared to that of the Blackfoot in relatively simple, temperate grasslands, while Levis et al. (2017) found a weaker human impact on rainforest floristic distributions of the Guiana Shield compared to less diverse parts of Amazonia to the south-west and east. Amundsen-Meyer (2013) also reported difficulty in detecting HNC among highly mobile societies, where less time spent at each place means less opportunity to manipulate plant taxa, as well as a need for taxa to self-sustain during periods of human absence. She noted, for Amazonian Kayapo, that food plants requiring greater human attention to usefully yield were more likely to grow at places of continuous occupation, whereas food plants with low maintenance requirements and long harvest times were concentrated at more distant and periodically occupied sites.

A third difficulty for detecting human plant manipulation is that similar patterns of biodiversity may result from dissimilar processes (Burkle et al. 2016), making it difficult to distinguish the effect of individual processes, while correlation between human and environmental influences may have a confounding effect on plant distribution and abundance measurement (Lepofsky and Lertzman 2008; Levis et al. 2017). A multifaceted and multidisciplinary approach is required to distinguish between natural and human-assisted translocation of plants (Bayliss-Smith 2003; Hofman and Rick 2018; Lepofsky and Lertzman 2008; Levis et al. 2017; Levis et al. 2018; Mensing et al. 2018). An approach combining ethnographic, archaeological, paleaobotanical, and ecological methods to examine the human and botanical history at a site, current species' distribution and abundance, the relationship between humans and a particular plant species, unique attributes of a particular population, and the biological (including genetic) attributes of the species is required (Day 2013; Hofman and Rick 2018; Lepofsky and Lertzman 2008).

The SWAFR has been home to the Noongar for at least 48,000 years (Turney et al. 2001), and its landscapes and biodiversity are embedded in traditional Noongar knowledge and custom (Robertson et al. 2016; Yorkshire-Selby 2011a). The region is internationally recognised for high species turnover and extraordinary plant diversity (Gibson et al. 2017; Myers et al. 2000), most of which is concentrated on old, climatically buffered, infertile landscapes (Ocbils), such as granite inselbergs (Hopper 2009; Hopper et al. 1997; Hopper et al. 2016). The Noongar use many plant resources rather than relying heavily on a few, and these are harvested from both Ocbils and young, often disturbed, fertile landscapes (Yodfels) (see Chapter 3). However, most Noongar activities in the southern SWAFR, particularly those associated with ecological disturbance, are concentrated in Yodfels (see Chapter 3), which typically support fewer endemic and more widespread taxa than Ocbils (Hopper 2009; Hopper et al. 2016).

The Esperance Nyungar are one of 14 groups of the Noongar cultural bloc (Tindale 1974). The modern-day Tjaltjraak Native Title boundary is broadly reflective of the extent of Nyungar country, although contemporary Elders understand that occurrence of the *Tjaltjraak* mallee (*Eucalyptus pleurocarpa* and

E. extrica) is indicative of Nyungar country (Figure 4.1). That Nyungar niche construction has occurred on granite inselbergs of the south-eastern SWAFR is demonstrated by the presence of both *karda mia* (lizard traps; Mitchell 2016), a resource enrichment strategy for reptile game (Guilfoyle et al. 2013; Rossi 2014), and the enhancement of fresh water resources through creation and enlargement of *gnammas* for use by people, animals, and aquatic plants (Yorkshire-Selby 2014). In addition, the presence of stone tools and arrangements, etchings, and rock paintings as well as stories that remain within contemporary Nyungar families are evidence of a long history of their ceremonial and ancestral importance (Mitchell 2016; Smith 1993). A historically focused Nyungar use of granite inselbergs makes it likely that signals of cultural plant use may also be evident in granite and surrounding floristic communities. We examined the presence of cultural plants on granite inselbergs in relation to their use, as well as archaeological and ethnographic evidence of long held human land use patterns in traditional Nyungar country.

Variation in plant community composition from site to site across a landscape may be influenced by multiple processes, both abiotic and biotic, many of which may be correlated (Burkle et al. 2016; Levis et al. 2017). In the SWAFR, both climatic gradients and edaphic heterogeneity are key influences on spatial patterns in floral composition (Gibson et al. 2004; Gioia and Hopper 2017; Hopper 1979; Hopper and Gioia 2004). Analysis of plant specimen data held in the Western Australian Herbarium has revealed a bivariate floristic pattern in the south-eastern SWAFR coastal and inland areas equating to the Esperance and Boylya floristic districts, respectively (Gioia and Hopper 2017). This pattern correlates with a gradient of increasing aridity from coastal to inland areas and approximately aligns with Nyungar conceptualisation of landscape as “coast country” and “the inland” (Smith 1993). Coastal and inland zones have been identified for analytical purposes for broadscale archaeological studies conducted in this area (Mitchell 2016; Smith 1993).

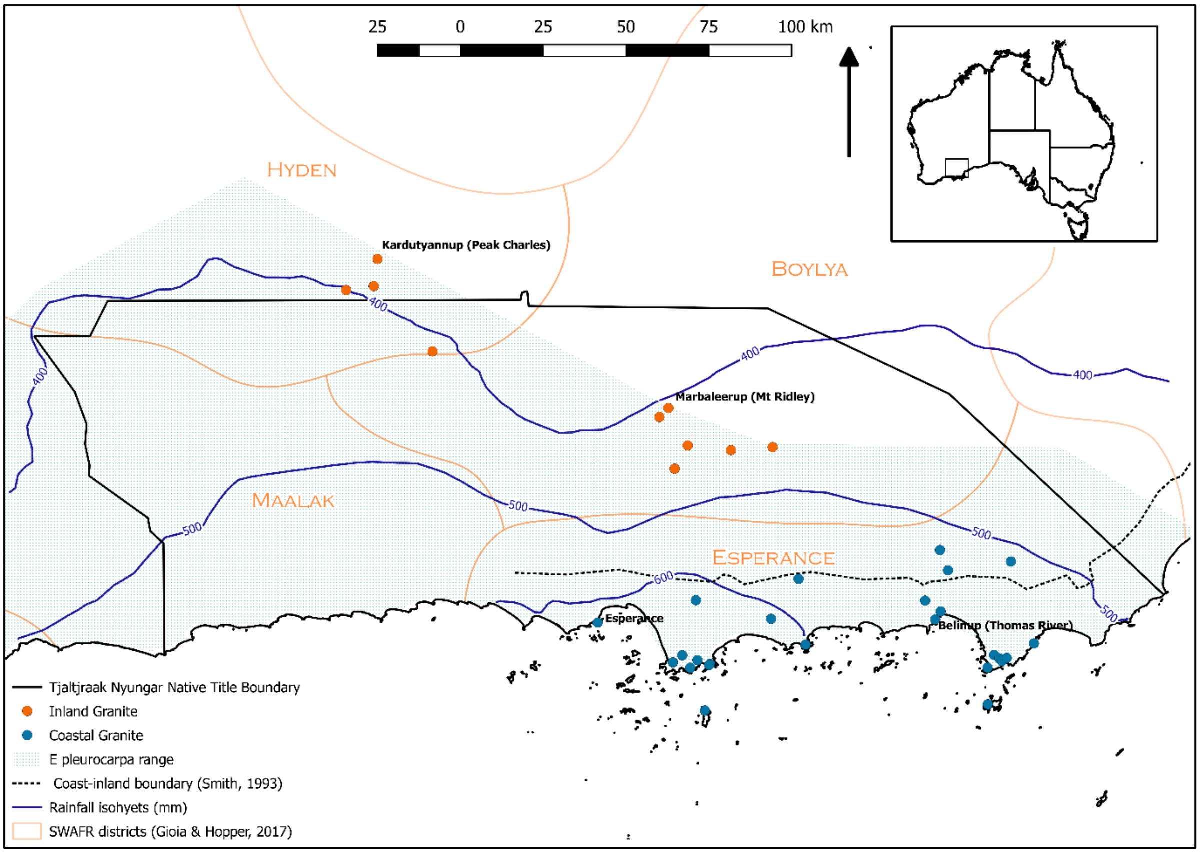


Figure 4.1: Location of study area showing Esperance Nyungar country (indicated by Tjaltjraak Nyungar Native Title boundary), coastal and inland granites, floristic districts (Gioia and Hopper 2017) and distribution of *Tjaltjraak (Eucalyptus pleurocarpa* and *E. extrica)* in the south-eastern SWAFR. Granite inselbergs of the Esperance and Boylya floristic districts were classified as 'coastal' and 'inland' respectively. Rainfall isohyet data sourced from Worldclim 2 (Fick and Hijmans 2017). Smith's (1993) study area extended across eastern Nyungar country indicated by extent of dashed line.

Smith (1993; 2011b) found that the greatest number and most heavily used Nyungar occupation sites were on granite inselbergs compared to other nearby landforms. She also identified proximity to fresh water as the most important variable in Nyungar site selection. This likely accounts for both a greater reliance on granites for seasonal freshwater while inland, and for less overall time spent in this region than in the higher rainfall coastal zone where freshwater is also reliably available from wetlands, rivers, and coastal dunes. This bivariate land use pattern dividing inland and coastal areas, as well as the significance of granites to Nyungar traditional life, is reflected in local ethnographic accounts (Mitchell 2016; Smith 1993).

Based on his own and previous archaeological research (in particular, Guilfoyle 2011; Smith 1993; Smith 2011b) along with ethnographic accounts, Mitchell (2016) suggested that traditional Nyungar life in coastal areas consisted of day-to-day activities centred around semi-sedentary base camps with logistical forays made to nearby sites for food gathering, tool-making, observing country, and ceremonial and other activities but not occupied for long periods. He concluded that Belinup, with its large granite sheet adjacent to the estuarine Thomas River mouth, a freshwater wetland and surrounding dunes, was likely a semi-sedentary base camp within a residential complex of nearby granites, dunes, and waterbodies, and that at least some people were in residence year-round (Figure 4.2). Other near-coastal base camps are likely, particularly further west, but have not been as intensively surveyed (Mitchell 2016). In contrast, occupation of the inland Marbaleerup (Mt Ridley) complex was considerably less frequent and certainly not sedentary, although evidence suggests that large gatherings periodically occurred (Mitchell 2016). In addition, extensive rock art and archaeological features, as well as diverse contemporary Aboriginal accounts indicate that the Marbaleerup inselberg especially is of significant, regional ceremonial importance (Gunn et al. 2017; Mitchell 2016). Mitchell's (2016) lithics analysis at granite sites in the Marbaleerup complex found very high diversity in both raw materials and technologies, supporting an interpretation of the Marbaleerup inselberg itself as a place of aggregation (i.e., large regional meetings), while other sites in the complex were interpreted as special purpose ceremonial and logistical sites that support the aggregation model. Unlike Marbaleerup, lithics analysis of the Belinup complex did not support its use for aggregation, but rather as an important focal area for substantial local activities (Mitchell 2016).

Mitchell's (2016) archaeological and ethnographic synopsis that compared likely Nyungar past practice in the Belinup and Marbaleerup complexes (Figure 4.2), as well as firsthand knowledge of Nyungar authors (RR, AD) and other contemporary Elders, provided us with an opportunity to compare their contemporary ethnobotanical characteristics. Given correlation between patterns of Nyungar mobility, relative rainfall, and broad vegetation patterns of the south-eastern SWAFR, we would expect difficulty in distinguishing pre-colonial anthropogenic influences on granite plant communities from other factors. However, existence of both botanical data as well as a landscape-level understanding of Nyungar mobility patterns (Gunn et al. 2017; Mitchell 2016; Smith 1993; Smith 2011b) provided an opportunity for an exploratory investigation of historic anthropogenic influences on granite plant communities of the south-eastern SWAFR. This study was broadly investigative in nature, intended to detect possible signals of Nyungar influence in south-eastern granite plant communities and to identify further approaches to test such influence.

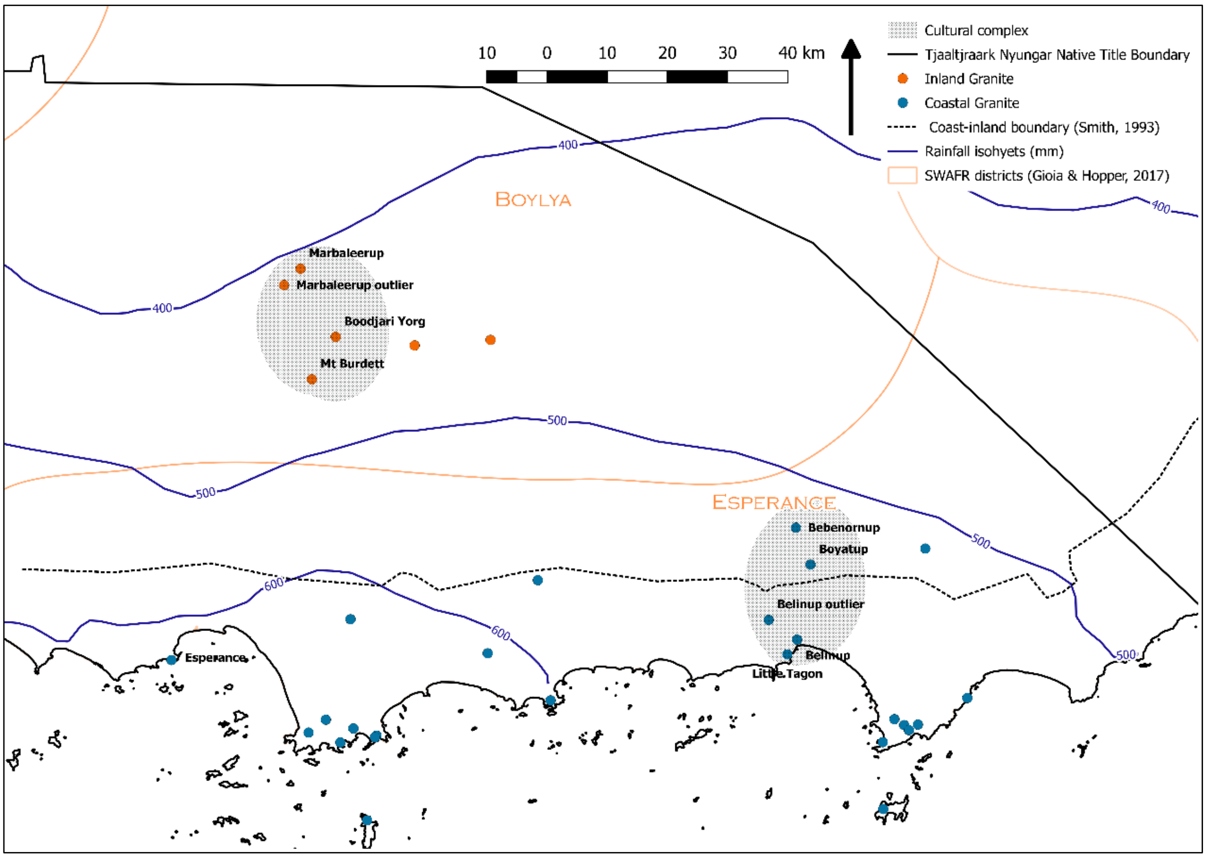


Figure 4.2: Location of Marbaleerup and Belinup cultural complexes.

Specific hypotheses were tested, comprising (1) that the distribution of Nyungar cultural plants likely reflects general patterns of biological diversity, given a correlation between pre-colonial Nyungar mobility patterns, relative rainfall, and broad vegetation patterns. Given a more concentrated focus of Nyungar activities on granites in inland than in coastal areas where Nyungar activity was dispersed across granites and adjoining landforms, (2) that a higher richness of cultural plants is evident at inland than at coastal granites. Nyungar life at Belinup was largely sedentary in nature, while Marbaleerup was only periodically occupied (Mitchell 2016). Amundsen-Meyer (2013) suggested that plants concentrated at permanent occupation sites might require greater tending and be available for shorter or less predictable periods than those at occasionally occupied sites. We hypothesised (3) that a higher proportion of food plants present at the Marbaleerup granites were predictably available year-round than at the Belinup granites. Finally, (4) we predicted that a resource taxon that could sustain periodic large gatherings of people would be abundant within the Marbaleerup complex, given that Marbaleerup was traditionally an aggregation site (Gunn et al. 2017; Mitchell 2016).

Methodology

Field sampling

Granites were chosen for sampling based on geographical representation and microhabitat diversity. Presence data of species was based primarily on comprehensive field herbaria compiled by Stephen Hopper (SDH) from 1977 to 2015. The random stratified walk survey technique (Hopper et al. 1997; Newbey and Hnatiuk 1985; Newbey et al. 1995) was employed for floristic collections on granite inselbergs. This entailed collecting on random walks stratified by searching for rare microhabitats such as *gnammas* and seeps rather than within quadrats. Common microhabitats such as bare rock, cryptogamic crusts, herbfields, shrublands, and woodlands as far off the rock edge as granite endemic taxa extended, were sampled on the random walks. Surveys were approximately two to more than four hours in duration, and individual inselbergs were surveyed on multiple visits to ensure adequate seasonal sampling.

Field herbaria were recently digitally collated by Peggy Fiedler (PLF) and SDH through a thorough process of quality assurance and updating of plant identification to produce a table with plant names using modern taxonomic publications and field guides that are backed up by herbarium specimen voucher collections (e.g. papers in *Nuytsia, Flora of Australia*). Additional taxa on inselbergs were obtained from specimen label data at the Western Australian Herbarium where specimens came from habitats sampled for the field herbaria studies. We then subsampled the floristic lists by assigning species as Nyungar cultural plants.

Assignation as Nyungar cultural plants

All taxa recorded across the 35 sites were classified according to their known cultural value and likelihood of human transfer from one location to another. Those where no evidence of cultural use and no close relationship with others of known cultural value were discounted and not considered further. The remaining taxa for which a cultural use had not been ruled out were given a one, two, or three star rating based on confidence levels using a similar approach to that utilised by The Plant List (2013) (http://www.theplantlist.org/) in relation to reliability of formal plant names. Expanded detail and examples of star-rating assignation are outlined in Table 4.1. Taxa were classified to the level of species, as this was considered most consistent with our understanding of Noongar classification and nomenclature systems, given that in some instances, there are several Noongar names for the same species, and conversely, there appears to be one Noongar name that refers to a suite of similar taxa (e.g. *Walyamur*, referring to blue-flowering *Thelymitra* species) (Hopper & Lullfitz, unpublished).

Table 4.1: Criteria for assignation of taxa as Nyungar cultural taxa to determine inclusion in analyses.

Rating classification	Criteria
Three star	Indisputable evidence for cultural use or value, and for which a positive identification was made, based on: firsthand accounts of Noongar use given by traditional owners in the field to authors who were able to confirm scientific identification of taxon, OR where there were four or more contemporary or historical accounts of a taxon's use and for which identification was indisputable.
Two star	Some evidence of cultural value existed, but: this evidence was uncorroborated by multiple sources, or there was possibility of identification error, OR cultural use was only specified to genus level but did not relate to specific species.
One star	No evidence of use or cultural value has presented but closely related to taxa for which strong evidence exists.

Only cultural taxa for which a three star rating was assigned were included in our analyses. In addition, criteria relating to likelihood of human transfer were applied. To this end, cultural taxa of which living propagules were utilised (i.e., seeds, fruits, and underground storage organs) were included, while in the most part, taxa for which evidence exists only of stem, leaf, flower, gum, or timber use were excluded. We considered that spiritual and totemic value of a taxon may increase the likelihood of its being carried or deliberately propagated, and that contemporary recall of a name may indicate that it was well known and of high significance either spiritually or as a resource (Rusack et al. 2011). To this end, where there were numerous references to a taxon's spiritual or ceremonial significance and also where a name was given by at least two contemporary sources, it was also included in our analysis.

Data analysis

All three star cultural taxa of which anthropogenic propagule transfer was likely were included in our analyses. To visually detect a pattern in cultural plant distribution across all sites, a Bray-Curtis distance matrix of cultural species based on co-occurrence and a Bray-Curtis distance matrix of sites based on species presence were produced in R (R Core Team 2016) using the Vegan package (Oksanen et al. 2016). Both distance matrices were clustered using the Ward criterion (Ward 1963), and used to produce a heatmap in R (R Core Team 2016).

Correlation between cultural and overall species richness, as well as each of these parameters and rainfall and inselberg area (transformed by Log10), was tested using a Pearson's correlation test. Scatterplots were produced in R to visualise correlation between these variables.

To determine whether there was a difference in the contribution of cultural taxa to the overall species richness in plant communities of coastal and inland granites, the proportion of cultural taxa making up the plant richness at each site was calculated. An unpaired t-test between coastal and inland sites was conducted and a box and whiskers plot produced in R.

Food plants occurring in the Belinup and Marbaleerup cultural complexes were categorised according to whether the utilised resource was available year round or seasonally (Table 4.2). An unpaired t-test between number of year round resource taxa occurring at Belinup and Marbaleerup sites was conducted and a box and whiskers plot produced in R. Finally, as an indicator of plant prevalence, for each food plant species occurring in the Marbaleerup complex, we determined the number of sites at which it was recorded, in order to detect a plant resource possibly utilised to support periodic large gatherings.

Table 4.2: Seasonal availability of food plants of the Belinup and Marbaleerup cultural complexes.

Available year round	Seasonally available
Banksia media	*Acacia acuminata*
Banksia speciosa	*Acacia cyclops*
Caladenia flava	*Acacia saligna*
Eriochilus dilatatus	*Astroloma compactum*
Hakea bicornata	*Astroloma epacridis*
Hakea cinerea	*Astroloma prostratum*
Hakea clavata	*Billardiera fusiformis*
Hakea corymbosa	*Billardiera heterophylla*
Hakea drupacea	*Exocarpos sparteus*
Hakea laurina	*Lomandra hastilis*
Hakea lissocarpha	*Macrozamia dyeri*
Hakea prostrata	*Santalum acuminatum*
Hakea recurva	*Santalum spicatum*
Hakea trifurcata	
Hakea varia	
Lyperanthus serratus	
Nuytsia floribunda	
Platysace trachymenioides	
Prasophyllum gracile	
Prasophyllum parvifolium	
Pyrorchis nigricans	
Thelymitra crinita	
Thysanotus patersonii	

Results

A total of 82 three star cultural plant taxa were recorded across all granite inselbergs. Based on cultural species present, sites clustered into two broad groups of inland and coastal granite inselbergs (Figure 4.3). Plant taxa also clustered broadly into two groups, with a distinct suite of inland-only cultural plants apparent. Within the second cluster of plant taxa was a distinct group of plants that occurred approximately evenly across both inland and coastal granites, while a third group occurred primarily on coastal granites.

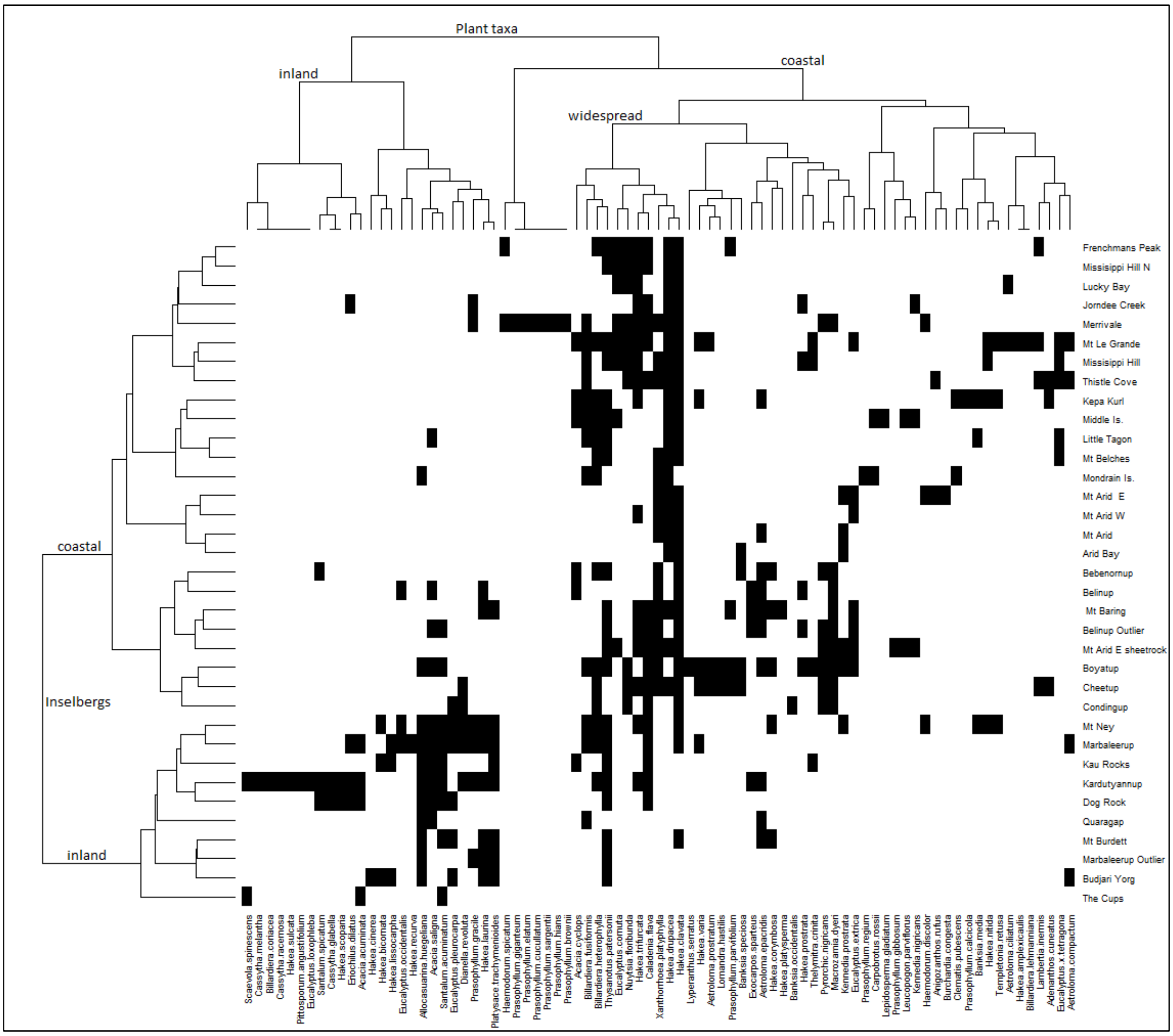


Figure 4.3: Heatmap showing clustering dendrograms of inselberg sites (rows) and cultural plant taxa (columns).

A very strong positive correlation was found between the richness of cultural and all plant species at granite inselbergs, while neither overall richness nor that of cultural plants was correlated with average annual rainfall (Figures 4.4a to 4.4c). However, a weak positive correlation between size of granite inselbergs (measured as area) and both overall and cultural plant richness was found (Figures 4.4d and 4.4e).

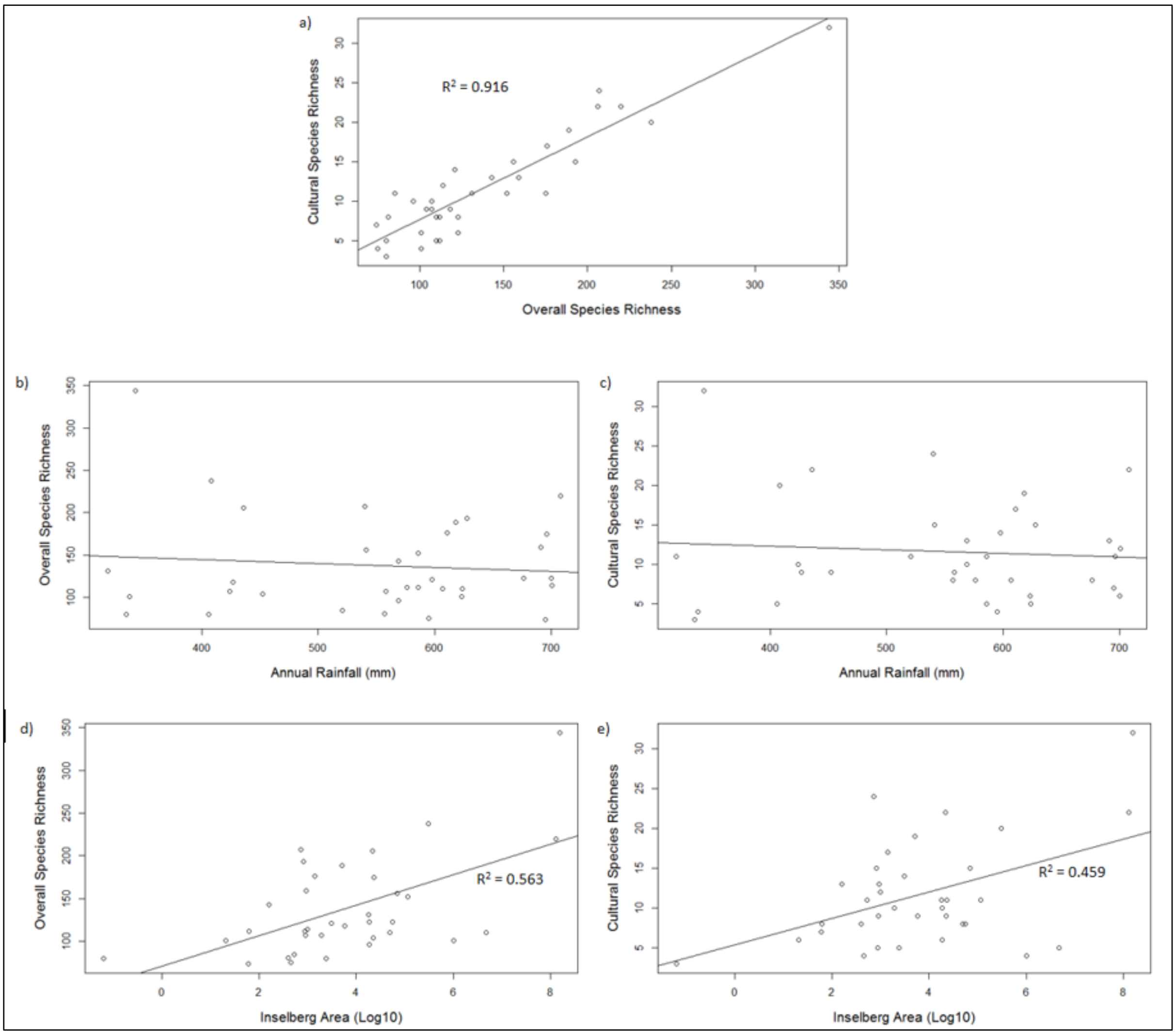


Figure 4.4: Scatterplots of linear regression model of a) cultural and overall species richness, b) overall species richness and annual rainfall, c) cultural species richness and rainfall, d) overall species richness and Log10 of inselberg area and e) cultural species richness and Log10 of inselberg area. R^2 values shown where p value $< 0. 05$.

Unpaired t-tests detected no difference in overall richness or richness of cultural taxa (Figure 4.5a and 4.5b). There was also no difference in the proportion of cultural plant contribution to overall species richness between inland and coastal granites (Figure 4.5c).

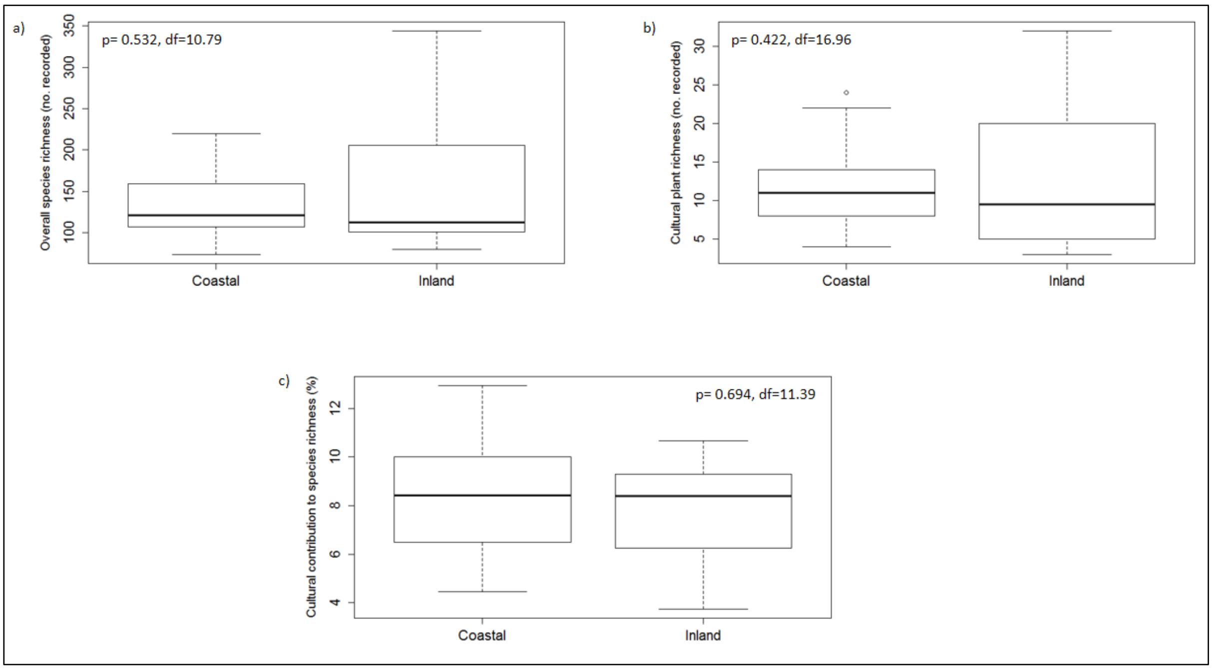


Figure 4.5: Box and whiskers plots showing median and interquartile range of a) total species richness, b) cultural plant richness and c) contribution of Nyungar cultural plants to overall species richness of granite inselbergs in the coastal compared to inland zone.

More taxa providing predictable, year round food resources were among the food plants occurring at sites in the Marbaleerup than the Belinup cultural complex (Figure 4.6). Of the food plants recorded at Marbaleerup sites, 81. 5% were available year-round, compared to 51. 8% of those at Belinup sites.

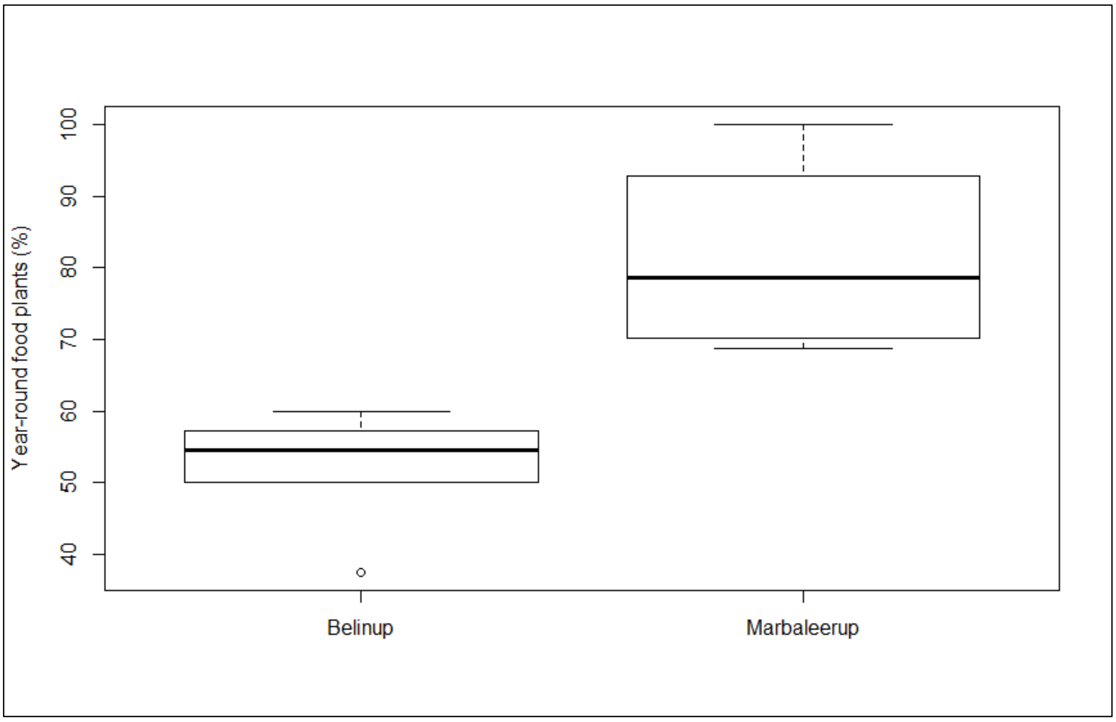
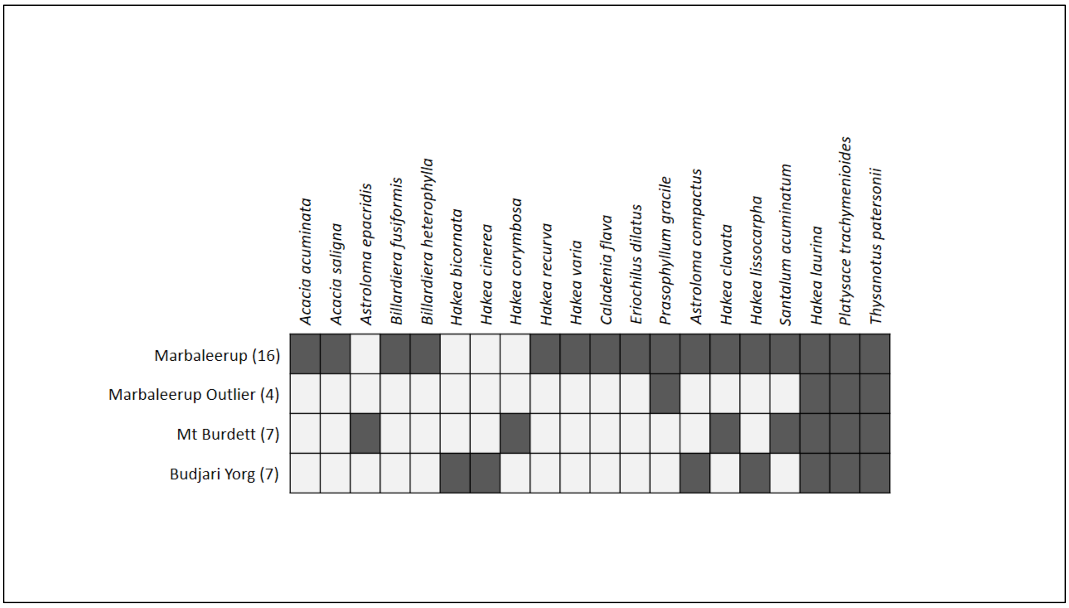


Figure 4.6: Box and whiskers plots showing median and interquartile range of year-round perennial food plants as a percentage of all food plants at granite inselbergs of the Belinup and Marbaleerup cultural complexes (p=0. 017, df=4. 74).

The Marbaleerup inselberg itself was most rich in food plants of any sites in the Marbaleerup complex (Figure 4.7). Based on their occurrence at all surveyed granite inselbergs of the Marbaleerup complex, the three most abundant food plants we found in this complex were *Hakea laurina, Platysace trachymenioides* and *Thysanotus patersonii* (Figure 4.8).



	Acacia acuminata	*Acacia saligna*	*Astroloma epacridis*	*Billardiera fusiformis*	*Billardiera heterophylla*	*Hakea bicornata*	*Hakea cinerea*	*Hakea corymbosa*	*Hakea recurva*	*Hakea varia*	*Caladenia flava*	*Eriochilus dilatus*	*Prasophyllum gracile*	*Astroloma compactus*	*Hakea clavata*	*Hakea lissocarpha*	*Santalum acuminatum*	*Hakea laurina*	*Platysace trachymenioides*	*Thysanotus patersonii*
Marbaleerup (16)	■	■		■	■				■	■	■	■	■	■	■	■	■	■	■	■
Marbaleerup Outlier (4)													■					■	■	■
Mt Burdett (7)			■					■							■		■	■	■	■
Budjari Yorg (7)						■	■							■		■		■	■	■

Figure 4.7: Recorded food plant taxa at sites within the Marbaleerup cultural complex. Dark grey shows presence, and food plant richness at each site is shown in parentheses.

Figure 4.8: Nyungar food plants that were present at all granites within the Marbaleerup complex. From left to right, nectar-rich inflorescence and fruit (containing edible seed) of *Hakea laurina, Platysace trachymenioides* (edible tubers), *Thysanotus patersonii* flower (above), twining stem (middle) and edible tubers (below).

Discussion

Nyungar plant Human Niche Construction

A bivariate pattern of cultural plant distribution between coastal and inland granites of south-eastern SWAFR Nyungar country was consistent with a wider floristic pattern found by Gioia and Hopper (2017), while richness of cultural species was strongly correlated with overall richness. This finding suggests that Nyungar HNC in relation to plants was geographically variable rather than broadly uniform, likely targeted toward resource rich nodes (e.g. large granite inselbergs) and biased toward maintaining diversity. As historical inland Nyungar activities were more confined to granites than in coastal areas (Smith 1993; Smith 2011b), we hypothesised that this may have resulted in Nyungar cultural plants being more concentrated at granites in the inland than the coastal zone where other landforms (e.g. coastal dunes, estuarine fringes) were also occupied. We found no difference in cultural plant richness of granites between zones, which did not support our hypothesis. Amundsen-Meyer (2013) suggested that the footprint of mobile small-scale societies is less obvious than those who are more sedentary. Nyungar occupation of the inland zone was more transient than in the coastal zone and this transience may have countered any effect of a more concentrated reliance on inland than coastal granite inselbergs. This divergence in land use pattern highlights a need for more targeted and comprehensive analyses than our exploratory approach here to quantify past anthropological influence on granite inselberg plant communities of the south-eastern SWAFR.

Archaeological and ethnographic work comparing the Marbaleerup and Belinup cultural complexes (Gunn et al. 2017; Mitchell 2016) enabled us to compare granite inselberg plant communities in these complexes in light of a more fine-grained understanding of past Nyungar occupation than exists for the south-eastern SWAFR more broadly. Consistent with Amundsen-Meyer's (2013) prediction that resource plants concentrated at sedentary occupation sites may require greater human attention than those at more distant, occasionally occupied sites, we found that a higher proportion of food plants present at the inland granites of the Marbaleerup complex were predictably available year-round than at the coastal granites of the Belinup complex. Given our small sample size, we are mindful not to overstate this result as definitive evidence of Nyungar HNC. However, we recommend further investigation of such a phenomenon in Esperance Nyungar country and in other parts of the SWAFR where fine-grained understanding of past Noongar occupation exists.

Recent archaeogical research also highlighted Marbaleerup as an aggregation site, where various peoples from long distances periodically met (Gunn et al. 2017; Mitchell 2016). To this end, we examined food plant taxa recorded at Marbaleerup granites to assess whether they could support large periodic gatherings of people. Three food taxa were recorded at all Marbaleerup granite inselbergs, and of these, we considered *Platysace trachymenioides* (of which tubers are consumed), most likely to provide adequate food volumes for large groups of people. Elsewhere, tubers have been incorporated into small scale societal diets at times of diminishing availability of other resources (Gremillion 2014; Walsh 1990), or have been deliberately enriched in patches to sustain food resources and enable longer residency times (Denham and Barton 2006). Widespread occurrence of *P. trachymenioides* at south-eastern SWAFR inland granites and all in the Marbaleerup complex, as well as our evidence of high prevalence and positive response to harvesting (see Chapter 7) suggests that this taxon may have been historically enriched by Nyungars to enable extended periods of residence and/or occupation by large groups. Also of note is Mitchell's (2016) finding of a much higher lithic artefact diversity at Marbaleerup than surrounding granites within the cultural complex, suggesting that stone tools were brought in from afar. High lithics diversity at Marbaleerup coincided with a much greater richness of food plants than surrounding logistical sites, which may be attributable to its greater size, but may also indicate that propagules have been transported here from further afield during aggregation events.

Plant management practices

Widespread creation of resource plant stands may have proved difficult for the Nyungar due to a lack of widely common suitable habitat in conditions of edaphic heterogeneity, a sharp climatic gradient and specialised plant attributes. Our findings of a coastal-inland bivariate distribution of cultural taxa, as well as increasing cultural and overall plant richness corresponding with granite inselberg size support this. To this end, *in situ* encouragement rather than widespread translocation of taxa may have been more usual. Periodic cool burning in surrounding woodlands of granite inselbergs (Lullfitz et al. 2017; Prober et al. 2016) likely promoted prevalence of some fast-growing (e.g. various *Acacia* species) and tuberous resource taxa (e.g. *Thysanotus patersonii*, *Platysace trachymenioides* and various Orchidaceae). For tuberous taxa, we expect Nyungar harvest also promoted resources through aeration of the soil, and improved access to nutrients and water as has been found elsewhere (Barton and Denham 2016; Head et al. 2002). The widespread occurrence of some taxa, including *Thysanotus patersonii, Caladenia flava,* and *Acacia saligna* may be a legacy of such past practices. Long–lived fruit and nut-bearing taxa have been managed *in situ* elsewhere through selective culling of competing vegetation and deliberately selective use (Hynes and Chase 1982; Smith 2014). Cool Nyungar burning in granite-adjacent woodlands likely protected longer-lived resource taxa (e.g. *Hakea* species, *Santalum acuminatum*) and again, may be reflected in their widespread distribution. Targeted and comparative measures of abundance may assist us in understanding the lasting effect of such activities within Nyungar cultural landscapes.

Lepofsky and Lertzman (2008) suggested that occurrence of particular desirable phenotypes of utilised plant taxa (e.g. large fruit size) may indicate past selective management by people, which has been documented elsewhere (e.g. Amundsen-Meyer 2013; Kitagawa and Yasuda 2008; Smith 2011a). Evidence at Marbaleerup of increased prevalence, tuber consistency, and palatability in *Platysace* *trachymenioides* following harvest (see Chapter 7), as well as observed heavy crops of large fruited *Wolgil* (*Santalum acuminatum*) suggest that further examination of specific plant attributes may be worthwhile in understanding effects of historic Nyungar-plant relationships. Further, where selective management has resulted in an eco-evolutionary outcome (Eriksson 2014; Shipek 1989), detection of common haplotypes or those associated with desirable morphological characteristics may also be useful in determining anthropogenic influences on utilised plant taxa.

Although environmental heterogeneity may have made plant translocation difficult for the Nyungar, elsewhere small scale societies have been known to deliberately target appropriate habitat during translocation efforts (Amundsen-Meyer 2013; Shipek 1989). For the Nyungar, specific cool, mesic habitats provided by topography and surface runoff of inland granite inselbergs may have been suitable for some plant taxa most commonly occurring on the coast. We found some taxa (e.g. *Hakea laurina, Thysanotus patersonii*) were widely present across both coastal and inland zones, or were recorded unexpectedly in either zone (e.g. predominantly coastal occurring *Acacia cyclops* at Kau Rocks, predominantly inland occurring *Platysace trachymenioides* at Mount Baring). We do not suggest this alone as evidence of past Nyungar translocation. However, such species may be worthy targets of future collaborative studies that examine plant genetics as well as Nyungar management and mobility patterns. Such studies elsewhere in Australia indicate that movement of plant propagules by Aboriginal peoples has resulted in widespread transfer of plant taxa (Bell et al. 2014; Rangan et al. 2015; Rossetto et al. 2017).

Plant resource management in Ocbils

That we recorded a total of 82 cultural plant species in granite inselberg habitats, coupled with our finding of correlation between cultural and overall plant richness, indicate that high overall plant diversity in the south-eastern SWAFR is reflected in the diverse range of taxa utilised by Nyungar people. We found Nyungar niche construction difficult to detect, which is consistent with a general trend of greater HNC subtlety and promotion of resource diversity in biodiverse Ocbil-dominated regions (e.g. Guiana Shield, South Africa's Cape) than those dominated by Yodfels (e.g. North American Great Plains, Amazon Basin) (Amundsen-Meyer 2013; De Vynck 2014; Hopper 2009; Hopper et al. 2016; Levis et al. 2017). While the Ocbil plant communities of granite inselbergs and their immediate fringe were the focus of our study, Noongar practices that promote resource plant abundance appear concentrated in Yodfels of the SWAFR (see Chapter 3). Such practices include the concentration of *Dioscorea hastifolia* in river alluvium of the west coast (Hallam 1989; Hallam 2014), promotion of game-attracting grasses through burning (see Chapter 3), and the concentration of useful *Acacia* species at campsites (Lullfitz et al. 2017 (Chapter 2)). A targeted examination of cultural plant presence and relative abundance across broader landscape components of the south-eastern SWAFR may be required to provide clarity around Nyungar intensification legacies within contemporary plant communities.

Post-colonial impacts on Nyungar plant management

Encroachment of European colonial society meant that widespread traditional Nyungar management of the south-eastern SWAFR likely ceased approximately 150 years ago. Numerous *karda mia* and *gnammas* on granite inselbergs across the south-eastern SWAFR are ready evidence of pre- and early-colonial Nyungar niche construction (Hopper et al. 2016; Timms 2013; Tuckett 2010). However, no such obvious evidence exists in relation to plants, suggesting that the effects of succession may have erased past Nyungar-induced patterns. Given that Nyungar plant manipulation in the south-eastern SWAFR has been dated to at least 13,000 years BP (Smith 1982) and is likely much longer (Tobler et al. 2017), more lasting legacies probably remain in the DNA of cultural plants and possibly pollen records of occupation sites. Molecular phylogeographic and paleoethnobotanical techniques may be most useful in examining historical Nyungar influences on plant biodiversity.

Forced societal breakdown and land access denial following European colonisation may have impacted more on intergenerational plant knowledge transmission among Noongar than on Aboriginal peoples of more remote parts of the Australian continent (Rusack et al. 2011). To this end, we expect there are probably numerous culturally important plants of the SWAFR that, to date, remain undocumented. Our analysis found that 82 species (roughly 8% of the total flora recorded on south-eastern SWAFR granite inselbergs) are known to be of Nyungar cultural significance (i.e. fitted our criteria for three-star rating based on confidence levels). However, we estimated that a further 300 species were of probable (two star) or possible (one star) cultural significance, but at present are not supported by conclusive evidence. Recent collaborations between southern coastal Elders and botanists have revealed that plant knowledge remains among contemporary Elders that has not been recorded to date (Hopper, Knapp, Lullfitz unpublished). We recommend that collaborative efforts focused on recording of Noongar plant knowledge be prioritised in the interests of contemporary and future plant conservation efforts and societal well-being.

Other methodological considerations

For the Colombian Amazon, Levis et al. (2018) and Levis et al. (2017) proposed an anthropogenic cause for hyperdominance of domesticated compared to non-domesticated plants. Levis et al. (2017) measured abundance, richness, and overall distribution of plant taxa in relation to known archaeological sites. While we utilised plant presence data to estimate cultural species richness of granite inselbergs and to examine beta diversity, estimates of relative abundance would substantially improve our understanding of Nyungar influence on flora of the south-eastern SWAFR. We have evidence of exceptional prevalence of important food plants around well known and well documented cultural sites, perhaps best exemplified by *Platysace trachymenioides* throughout the Marbaleerup complex and other inland sites, and *Macrozamia dyeri* at coastal granites, and especially Belinup (see Chapter 5). In addition, we note more broadly that some Noongar food plants appear to be among the most common and widespread taxa of the SWAFR as a whole. For example, four well known Noongar food taxa in the *Acacia* genus, *A. acuminata*, *A. microbotrya, A. saligna* and *A. cyclops,* and many other food taxa (e.g. *Thysanotus patersonii, Haemodorum spicatum, Hakea laurina, Santalum acuminatum, S. spicatum*) are distributed widely. In addition, phylogeographic studies of some of these taxa (*A. acuminata*, *S. acuminatum*, *S. spicatum*) show higher than expected homogeneity (i.e gene flow) among populations, suggestive of an anthropogenic vector (reviewed in Lullfitz et al. 2017 (Chapter 2)). Such parallels highlight the value of a multifaceted approach to investigate long held SWAFR plant-people relationships.

Like other small scale societies (Amundsen-Meyer 2013), Nyungar plant resource harvest is inextricably linked to ritual, respect for ancestors, and stories of creation (Pettersen 2015, Hassell 1975). Visiting plant harvest sites as a family enables Elders to teach younger generations about plant management and creation stories, and for memories of ancestors to be renewed. In this way, the creation, enhancement, and maintenance of plant resource patches has not only ensured ongoing resource supply, but also enabled connection to country, family, and cultural history, and intergenerational sharing of traditional ecological knowledge. Such inextricable and multifaceted links are invaluable, not only to ethnobotanical research but also to biodiversity conservation and broader social well-being. We advocate a research approach that includes a strong component of field-based collaborative research with Nyungar Elders and their families.

Conclusion

This study explored Nyungar niche construction in relation to plants of granite inselbergs. Our intention was to detect possible patterns of anthropogenic influence, identify taxa to focus further investigations and to refine research methods. Each of these objectives has been achieved. Our findings suggest that long term Nyungar occupation of the south-eastern SWAFR may have influenced the cultural plant distribution on granite inselbergs and that Nyungar plant HNC was likely geographically variable, reflecting edaphic heterogeneity and climatic gradients. A difference in the degree of human attention to yield resources between permanent and occasionally occupied sites and a prevalence of the high yielding, low maintenance food crop *Platysace trachymenioides* in the Marbaleerup aggregation complex may be legacies of past Nyungar management. Targeted methods to comprehensively examine these findings and pursue other questions about people-plant relationships should include Nyungar and science-based knowledge systems and multiple disciplines. We suggest that further research will be most valuable if conducted using such a collaborative approach.

Chapter 5: Contemporary distribution of *Macrozamia dyeri* (Zamiaceae) is correlated with patterns of Nyungar occupation in south-east coastal Western Australia

Abstract

Indigenous societies' interactions with their significant plants may result in contemporary plant distribution patterns that reflect these relationships, such as concentration of resource species close to occupation sites or transport routes. Seeds of the cycad, *Macrozamia dyeri* are a food of the Nyungar First People of the South East Coastal Province of the Southwest Australian Floristic Region. Processing of the seeds by leaching in soil or water enables detoxification and preservation of the pre-colonial staple, a Nyungar technique that has been archaeologically dated to at least 13,000 years BP. During multiple field trips in Nyungar country, we recorded the location of all observed populations of *M. dyeri*, and measured the distance of each population to cultural landscape features and recorded heritage sites. We also compared within-population plant distribution characteristics to Nyungar occupation preferences around granite inselbergs. We found strong evidence of Nyungar influence on the contemporary distribution of *M. dyeri.* Populations of *M. dyeri* occur close to waterways in the west and to granite outcrops in the east of Esperance Nyungar country, which corresponds closely to differential pre-colonial patterns of Nyungar occupation and movement across country. Abundance of *M. dyeri* populations was negatively correlated with distance to registered Nyungar sites, and 75% of all *M. dyeri* populations occured within 3.2 km of a registered Nyungar site. We also found no correlation between habitat availability and population size of eastern granite populations, but found that Nyungar occupation preferences in relation to ground surface aspect, slope and landform type correlated with intra-population *M. dyeri* plant distribution, which suggests that a mutualistic relationship with Nyungar people has influenced its distribution. We suggest that contemporary *M. dyeri* distribution reflects past Nyungar practice, and is therefore useful for interpreting past location-specific Nyungar land management practices to inform contemporary conservation management. Our findings demonstrate that along with edaphic, climate and other environmental factors, consideration of place-based, pre-colonial human dispersal and land management practices is important for plant conservation in Australia, particularly for taxa with prolonged use by humans. Further, we suggest that analyses of long-lived *Macrozamia* elsewhere in Australia may be useful in identifying important past Aboriginal land practices.

Introduction

The distribution of contemporary plant species are influenced by past and current habitat availability (Burkle et al. 2016; Byrne 2008; Hopper et al. 2016) and reproductive traits (Broadhurst et al. 2017;

Enright et al. 2014). Where mutualistic relationships exist between a plant species and another organism, the habitat requirements and biological traits of the partner organism are also deterministic in the plant species' distribution (Brontstein 1989; Swarts and Dixon 2009; Warren 2016). Humans are one such organism with which some plant taxa have a mutualistic relationship. Indigenous societies worldwide have concentrated resource plants close to occupation sites (Amundsen-Meyer 2013; Atchison 2009; Bradley 2006; Hallam 2014; Hynes and Chase 1982; Levis et al. 2017; Levis et al. 2018), along transport routes (Amundsen-Meyer 2013; Massy 2017; Shipek 1989), and intensified and/or diversified plant communities to improve food security (Hallam 1989; Hofman and Rick 2018; Levis et al. 2017; Levis et al. 2018; Shipek 1989; Terrell et al. 2003). Protocols that link plant horticulture and social structure (Bradley 2006; Chase 1989; Hofman and Rick 2018; Shipek 1989; Terrell et al. 2003) and restrict access to plant resources (Bradley 2006; Hallam 1989; Shipek 1989) also reflect people-plant relationships that may have influenced distribution of plant species.

Evolutionary history, human use and seed dispersal of *Macrozamia dyeri*

Macrozamia (Zamiaceae) is an exclusively Australian genus of cycads (Stevenson 1990; Zhifeng and Thomas 1989). It comprises 41 recognised species, all of which are dioecious (Forster 2004; Hill 2003). Three closely related *Macrozamia* species, including *M. dyeri* (Ingham et al. 2013; Preece et al. 2007), occur in the Southwest Australian Floristic Region (SWAFR, *sensu* Hopper and Gioia 2004). *Macrozamia dyeri* is distributed patchily across the Esperance and Maalak floristic districts of the SWAFR (Gioia and Hopper 2017) and entirely within the traditional and contemporary boundaries of Esperance Nyungar people (Figure 5.1). The total population of *M. dyeri* is estimated to be in excess of 10,000 individuals (Hill 2003). It is disjunct to other *Macrozamia*, the nearest record being of *M. reidlei* approximately 250 km to the west (Atlas of Living Australia 2018). Aside from von Mueller's (1885) original description, we found no published research specifically relating to *M. dyeri* biology. However, studies of other *Macrozamia* indicate that these cycads are slow-growing and long-lived (Pate 1993) and have mostly poor seed dispersal in modern populations (Burbidge and Whelan 1982; Ornduff 1990; Terry et al. 2008). *Macrozamia* species respond positively to fire (Grove et al. 1980; Ornduff 1991) and germinate readily from seed (Donaldson et al. 2003; Norman and Mullins 2005). Their population level mast-seeding habit varies with access to water, nutrients, sunlight and possibly fire (Halliday and Pate 1976; Ornduff 1990; Ornduff 1991). *Macrozamia* have highly visible strobili for several months during seed development (Asmussen 2009) and are likely pollinated by host-specific beetles and thrips (Ornduff 1990; Terry et al. 2008).

Macrozamia seeds have long been utilised as a food source by Aboriginal Australian peoples following processing to remove harmful amounts of cycasin and to aid preservation (Asmussen 2008; Beaton 1982; Hopper and Lambers 2014; Macintyre and Dobson 2018). There are historical and contemporary accounts of *Macrozamia* use and processing by Noongar first peoples of the SWAFR (Bindon and

Walley 1992; Drummond 1840b; Grey 1841b; Hassell 1975; Moore 1835; Smith 1982) and its abundance at large Noongar occupation sites (Barker 1831; Drummond 1843a; Hallam 1989; Hallam 1991; Hercock 2014). Macintyre and Dobson (2018) found a high fat content (40%) in edible processed sarcotesta of *M. fraseri* seed, and suggested that *Macrozamia* were an important fat-rich resource for pre-colonial Noongar during cold, wet winters of south-western Australia. One of our authors (Annie Dabb (AD)) recalls that her family's name for *M. dyeri* seed is *Ngerriny*. She recalls consuming *M. dyeri* seed that had been cooked in a fire by her father, but had not been previously buried or soaked, as a child near Esperance. She also recalls the ripe seed being picked from the plant when just soft to touch. Lynette Knapp (LK) recalls an older female relative storing seeds of *M. reidlei* in a pit lined with *Eucalyptus marginata* leaves as a child near Albany (Figure 5.1), while Carol Pettersen (CP) recalls that *Macrozamia* seed was an important food relied on during travel. She described her family burying *M. dyeri* and *M. reidlei* seed below their sleeping area to hasten processing with fire and body warmth. In 1889 a story published in the *Australian Advertiser* described a Nyungar family carrying *M. dyeri* seeds along with other plant foods in a kangaroo skin bag at Duke of Orleans Bay near Esperance (Green 1989). Hassell (1975) documented *Macrozamia* seeds being brought to the Jerramungup area, west of Nyungar country (*boodja*), through trade. She described the threading of edible sarcotesta of *Macrozamia* seed onto a string-like rush for storage and trade, a technique tested by Macintyre and Dobson (2018), who found no evidence of decay after 12 months.

While most archaeological evidence of *Macrozamia* use by Aboriginal Australians has been dated to the mid Holocene (e.g. Beaton 1982; McCarthy 1964), discovery of *M. dyeri* seeds in a pit lined with *Xanthorrhoea platyphylla* leaf material at Cheetup in Cape Le Grand National Park (Figure 5.1) is evidence of *M. dyeri* use by the Esperance Nyungar from the late Pleistocene, some 13,000 years BP (Smith 1982; Smith 1996). In addition, several grinding tools, possibly used for processing of *M. dyeri* seeds, have been found during archaeological survey (Guilfoyle 2011; Mitchell 2016; Smith 1993; AL, RR (unpublished)) within our study area.

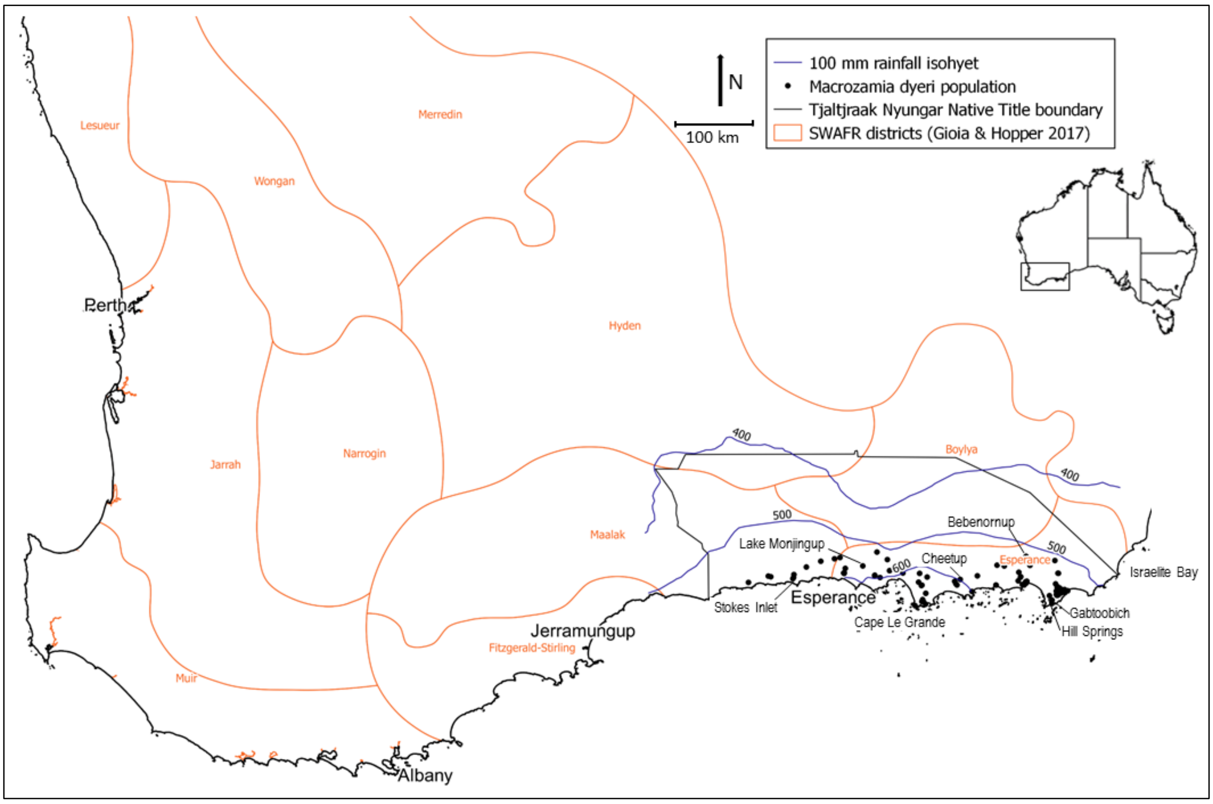


Figure 5.1: Map of the study area showing location of *Macrozamia dyeri* populations, SWAFR district boundaries (Gioia and Hopper 2017), 100 mm isohyets for study area and locations mentioned in the text. The Tjaltjraak Native Title boundary is administered by the Esperance Tjaltjraak Native Title Aboriginal Corporation and indicates the traditional and contemporary boundary of the Esperance Nyungar people.

Ecological and reproductive attributes of *Macrozamia* species suggest that access to seed resources probably required considerable planning, husbandry and management by Aboriginal Australian peoples. Spatial and temporal variability in population-level masting (Halliday and Pate 1976; Terry et al. 2008) would have required considerable and regular monitoring of populations across country. Highly visible strobili (Asmussen 2009) would have aided resource monitoring, and enabled harvests to be planned in advance. That different populations produced seed from year to year likely aided food security and meant that seed was moved across country, particularly from remote camps to base camp sites. Storability of a plant resource not only enables occupation times of small-scale societies to be extended (Testart 1982), but also may provide a mobile food supply for travel and trade (Atchison et al. 2005). Seed storability may have facilitated their heavy use (Hallam 1991). Storability may also have encouraged sedentism (Testart 1982), and somewhat negated any lack of predictability in seed production. While periodic, low intensity Aborinal firing may have promoted survival, growth and reproduction of *Macrozamia* plants through stimulation of nitrogen fixation (Grove et al. 1980; Halliday and Pate 1976) and removal of vegetation competing for sunlight and/or water (Grove et al. 1980; Ornduff 1990), Asmussen (2009) found no clear evidence to suggest that seed production can be synchronised by firing to produce large crops available for mass gatherings, as previously suggested (Beaton 1982).

Despite the patchy distribution of *Macrozamia reidlei*, Byrne and James (1991) found high gene flow and low genetic differentiation between populations in western Noongar *boodja*, a pattern compatible with long-distance seed dispersal. The large seeds, conspicuous, brightly-coloured strobili and fleshy red sarcotesta of *Macrozamia* suggest that they are dispersed by animals (Burbidge and Whelan 1982; Hall and Walter 2013; Hall and Walter 2014). Granivores probably consume the non-toxic sarcotesta (Hall and Walter 2014) rather than kernels that contain cycasin at toxic levels (Burbidge and Whelan 1982; Hall and Walter 2014). Small mammals have been found to cache and disperse *Macrozamia* seed over short distances (up to 25 m) (Asmussen 2008; Burbidge and Whelan 1982; Hall and Walter 2013; Snow and Walter 2007). Large birds, such as emu (*Dromaius novaehollandiae*) and Australian raven (*Corvus coronoides*) have been recorded moving seed of *M. reidlei* at least 300 m (Nield 2014). There is also compelling evidence to suggest a very long, but now historic role of megafauna in *Macrozamia* seed dispersal (Burbidge and Whelan 1982; Hall and Walter 2013; Hall and Walter 2014). The contemporary range of *M. dyeri* appears to be limited on its south side by the coast and by decreasing rainfall to its north (Figure 3.2), which coincides with the same broad floristic pattern found by Gioia and Hopper (2017). However, the occurrence of *M. dyeri* across both the Maalak and Esperance floristic districts (Gioia and Hopper 2017) suggests that factors other than biotic and environmental may also have influenced its distribution. Its occurrence only within Esperance Nyungar country raises a possible Nyungar role in its distribution.

Esperance Nyungar mobility patterns

In the south-eastern coastal SWAFR, Esperance Nyungar mobility and occupation patterns varied across Nyungar *boodja*, from west to east, and also from coastal to inland areas, although as *M. dyeri* occurs only within approximately 20 km of the coast, we do not discuss the latter any further here. Near the coast, a Nyungar occupation pattern centred in semi-sedentary complexes has been proposed (Mitchell 2016; Smith 1993; 2011b). Smith's (1993; 2011b) comprehensive residential mobility hypothesis remains the basis of an accepted understanding of Esperance Nyungar settlement, and has been further refined with the addition of localised models of logistical mobility (Guilfoyle 2011; Mitchell 2016). Smith (1993), whose archaeological work was undertaken from immediately east of the town of Esperance to Israelite Bay, found 58.7% of Nyungar sites within 15 km of the coast were on granite outcrops, compared to 20.3% on coastal dunes, 21% adjacent to waterways and none on sandplain (also termed 'kwongkan' (Hopper and Lambers 2014; 'quowken' Brooke 1896). Although high visibility of stone artefacts and debitage on granite compared to more vegetated surfaces may have caused some bias in the archaeological pattern, contemporary Nyungar accounts corroborate the importance of granite outcrops and their immediate surrounds to Esperance Nyungars for occupation (Mitchell 2016) and that kwongkan was very rarely occupied (RR).

In western parts of Nyungar *boodja*, major rivers were transport routes between coastal and inland areas, and occupation was centred around resource-rich wetlands such as Monjingup Lake, estuaries such as Stokes Inlet, and along rivers and creeks (Mitchell 2016). In the drier east, granite outcrops were, and still are, foci for Nyungar activity (Figure 5.2; Bindon 1997; Mitchell 2016; Smith 2011b). Granite outcrops provide important freshwater sources such as *gnammas* (rock pools), seeps and soaks. Outcrops are rich in ecological resources, and were used to navigate along the coast and to inland areas. They could also provide protection from cold southerly and south-westerly winds (Bindon 1997; Gunn et al. 2017; Smith 2011b). In the east of Nyungar *boodja*, Belinup, a large granite outcrop, surrounded by dune adjacent to the estuarine Thomas River mouth and a small freshwater lake, was a large, regionally important, residential complex (Mitchell 2016). At Belinup, Mitchell (2016) found extensive archaeological material and many strong ethnographic connections among contemporary Nyungar. While he found an extraordinary abundance of lithics (i.e. stone tools and tool production debitage) at Belinup, he also found that most were of local origin, with little diversity in lithic type or material. This led Mitchell (2016) to conclude that while Belinup was heavily occupied by Nyungar, it was unlikely that people from further afield regularly gathered there in large numbers. Smith (1993) and Guilfoyle (2011) identified the wetlands and granites in the Woodup Swamp area as another possible complex that was heavily occupied.

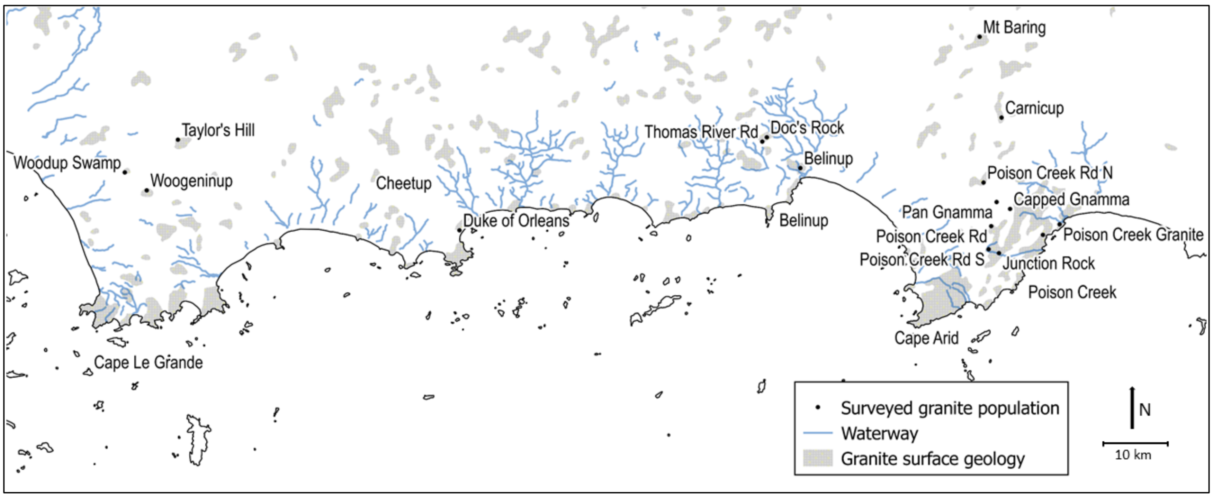


Figure 5.2: Map of surveyed granite populations of *Macrozamia dyeri* (Table 5.1) in eastern Nyungar *boodja*. Surface hydrology data source: Geoscience Australia (2018). Surface geology data source: Stewart et al. (2008).

Aside from proximity to fresh water, Smith (1993) found site aspect to be the most important predictor of Nyungar settlement patterns. Of the sites surveyed by Smith (1993), 78% were in positions sheltered from prevailing cold, rain-bearing south-westerly winds. Elsewhere in southern Australia, slope has been found as a key predictor of archaeological site locations, although it was not included in Smith’s (1993) analysis. For example, in the southern highlands of Victoria, Cochrane et al. (2013) found more artefacts occurred on subdued rather than steep slopes, and suggested that comfort for campsites and travel were probable reasons for choice of Aboriginal camp sites and tool-making places. Here, we have examined relevant habitat attributes of *Macrozamia dyeri* in relation to archaeologically and ethnographically determined past settlement patterns of the Esperance Nyungar to assess whether a human influence on its distribution is detectable.

Based on the literature review above, we hypothesised that the contemporary distribution of *Macrozamia dyeri* has been influenced by Nyungar traditional practice. To test this hypothesis, we firstly examined whether the distribution of *M. dyeri* populations across the four landforms included in Smith’s (1993) analysis correlates with Nyungar site preferences evident in the archaeological and ethnographic record. To examine possible influence of environmental factors on *M. dyeri* distribution, we also tested whether the size of some granite *M. dyeri* populations was positively correlated with habitat availability and latitude. A lack of correlation may indicate other influences, such as the habitat preferences of seed dispersal organisms, on *M. dyeri* distribution. Secondly, to assess the likelihood that non-random distribution of *M. dyeri* is due to a Nyungar influence, we tested whether proximity of *M. dyeri* populations to natural surface water features and granite outcrops correlated with west to east variability in Nyungar residential mobility patterns as documented by Smith (1993). We also investigated a relationship between *M. dyeri* abundance and distance to Nyungar archaeological sites, given the findings of Levis et al. (2017) that Amazonian resource plant abundance decreased with increasing distance from archaeological sites. Thirdly, we examined site characteristics of *M. dyeri* populations to detect correlation with site use patterns of Nyungar (Smith 1993) and Aboriginal people elsewhere in southern Australia (Cochrane et al. 2013). Specifically, we tested whether there were more plants growing at sites with an aspect offering protection from southerly and south-westerly winds, and if more plants grow on subdued rather than steep slopes in granite *M. dyeri* populations. Finally, we tested whether abundance and spatial extent off-granite in *M. dyeri* populations was greater where dune rather than kwongkan predominantly surrounded outcrops. If so, this may reflect Nyungar occupation preferences (Smith 1993).

Methodology

Population distribution

During five collaborative on-country excursions from February 2014 to November 2017, we recorded and compiled all observed *Macrozamia dyeri* populations that were opportunistically observed (e.g. visible from vehicle tracks, observed during the course of other work). Where we could accurately determine locations of vouchered collections from Australian herbaria (Australasian Virtual Herbarium 2017), these populations, and some previously recorded by SH in floristic surveys of granite outcrops (e.g. Hopper et al. 1997) were also included in our compilation.

Populations were categorised according to Smith's (1993) landforms as occurring on granite, dune, wetland or kwongkan. Granite landforms included those on or immediately (within 5 m) of granite sheets dominated by granite-endemic species, such as *Anthocercis viscosa, Hakea drupacea* and *Calothamnus quadrifidus*. Dune consisted of mobile, coastal white sand dominated by *Acacia* species and *Banksia speciosa.* Kwongkan consisted of non-mobile, grey sandy soil, dominated by *Agonis baxteri, Allocasuarina humilis, Hakea corymbosa, Xanthorhoea platyphylla,* numerous small shrub and prostrate Proteaceae, and, at many sites, mallee (multi-stemmed) eucalypts. Wetland vegetation was dominated by *Eucalyptus occidentalis* and/or *Melaleuca cuticularis* in wet depressions. Populations were also categorised as 'western' or 'eastern', based on whether they were west or east of the most eastern major waterway (Bandyup Creek) (see Figure 5.4) (Geoscience Australia 2018). Distance of each *Macrozamia dyeri* population to the nearest surface water feature (including all minor flow paths) was measured using QGIS 2.14.22. Surface geology data (Stewart et al. 2008) and satellite imagery (Google n.d.) were used to locate and measure distance to nearest granite outcrop of each *M. dyeri* population in QGIS. The distance of *M. dyeri* populations from nearest registered Aboriginal sites (Department of Planning, Lands and Heritage 2018) was measured in QGIS. Where registered sites took in several features across a landscape, distance to their centre was measured using the QGIS 'polygon centroid' geometry tool. A Pearson's correlation test was carried out to determine correlation between population frequency and distance to nearest registered Aboriginal site.

Within-population analyses of Macrozamia dyeri on granite outcrops

Seventeen of the total 33 granite outcrop *Macrozamia dyeri* populations were surveyed in November and December 2016 by AL. Most populations were chosen for inclusion due to good visibility and ease of access resulting from wildfires in 2015 and 2007. Some populations with a longer unburned history were included to increase the overall number and geographical spread of granite populations sampled (Table 5.1). The large size and distinctive form of *M. dyeri* combined with recent fire history at many sites meant that plants were highly visible, although some juvenile plants below dense vegetation may have been missed. All visible *M. dyeri* plants growing within 5 m of the granite edge were recorded. The location of each plant was recorded on a handheld GPS, and for each plant, the surface slope and aspect, and whether plants were adult or juvenile were also recorded. Plants with a visible above-ground trunk were considered adult. Surface slopes were estimated by eye, following calibration of estimates at the outset of field work using a clinometer. Slope of each plant location was categorised as flat (no discernible slope), gentle (0-4°), moderate (5-10°) or steep (>10°), consistent with Cochrane et al. (2013). A handheld compass was used to determine surface aspect of each plant location in the field.

At each population, *Macrozamia dyeri* plants and their distance from the granite edge were recorded along a 50 m transect established perpendicular to the granite edge at the point where most plants had been recorded during survey of the 5 m granite perimeter. Landforms and vegetation surrounding each granite were observed and the dominant surrounding landform was categorised as dune, kwongkan or wetland in accordance with Smith (1993). During botanical surveys, archaeological features at each site were recorded, where seen, but were not comprehensively searched for.

The area of granite at each population was calculated using QGIS. All nine possible surface aspects were categorised as sheltered (west, north-west, north, north-east, east and south-east facing and also where no aspect was discernible) or unsheltered from cold, prevailing winds (south and south-west facing). All possible surface slopes were categorised as comfortable (flat and gentle) or uncomfortable (moderate and steep).

Statistical analyses were carried out in R (R Core Team 2016). A Pearson's correlation test was used to determine correlation between granite area and population size, and latitude and population size. Binomial tests were used to assess whether a greater proportion of plants occurred in sheltered than unsheltered aspects than would be expected if plants were randomly distributed across all possible surface aspects (i.e. more than 7/9 (78%) sheltered and less than 2/9 (22%) unsheltered). To assess whether a greater proportion of plants occurred on comfortable than uncomfortable slopes than would be expected in random slope conditions (i.e. more than 2/4 (50%) on comfortable and less than 50% on uncomfortable slopes), binomial tests were used. For both aspect and slope, binomial tests were carried out for all plants, as well as only adult plants, across all sampled populations in entirety, and for each population that had a big enough sample size for analysis. Abundance of *Macrozamia dyeri* and spatial extent of off-granite population was calculated using data collected along transects. A Mann-Whitney *U* test was conducted to assess whether there was a difference in off-granite spatial extent of granite populations between granites surrounded by different dominant landforms.

Results

Eighty seven populations of *Macrozamia dyeri* were compiled across Esperance Nyungar *boodja*, of which 24 were included on the Australasian Virtual Herbarium and 63 were recorded by the authors (AL, SH) (Figure 5.3). Among these populations, consistent co-occurrence with important Nyungar places, particularly around granite outcrops, adjacent coastal dunes, and freshwater lakes was observed. Across 17 populations of *M. dyeri* growing immediately adjacent (within 5 m) to granite outcrops, 1834 plants, of which 709 were adult were recorded.

Figure 5.3: (clockwise from top left) *Macrozamia dyeri* growing on SW facing slope at Belinup with dune on south and south-west sides (photographer facing SW); Terrence Yorkshire among *M. dyeri* on dune surrounding Carnicup granite; *M. dyeri* on fringe of Poison Creek Road South granite with Nyungar lizard traps in foreground; Stephen Hopper at Capped Gnamma granite surrounded by *M. dyeri* in kwongkan; Annie Dabb and Ron (Doc) Reynolds among *M. dyeri* at Lake Monjingup; *M. dyeri* growing in dune at Woodup with other resource plants, *Nuytsia floribunda* and *Xanthorrhoea platyphylla*; (centre) young *M. dyeri* plant germinating from kernel. Photo credits: AL.

Comparison of *Macrozamia dyeri* habitat

Macrozamia dyeri populations were not evenly distributed across landforms (p=0.002), with 33 populations recorded on granite, 26 on dune, 19 at wetlands and nine in kwongkan. The granite outcrops on which *M. dyeri* abundance was surveyed ranged in area from 0.01 to 101.49 ha (Table 5.1). There was no significant correlation between total *M. dyeri* abundance (*r*=0.22, p=0.40) or adult *M. dyeri* abundance (*r*=0.27, p=0.29) and the area of granite outcrops. There was also no significant correlation between latitude and total *M. dyeri* abundance (r=-0.21, p=0.42) or adult *M. dyeri* abundance (r=-0.30, p=0.24).

Table 5.1: Attributes of granite populations of *Macrozamia dyeri* surveyed in this study. Year of last fire in parentheses after site name. Nyungar occupation synopsis based on findings of Smith (1993), Mitchell (2016), and interpretation of traditional owners and archaeologists during collaborative field work. 'Semi-permanent' indicates base camp, 'logistical' indicates satellite site of base camp, 'occasional' indicates a place occasionally occupied enroute during travel. Where number of *M. dyeri* plants shown, total number is followed by number of adults in parentheses. Proportions are in bold where significant (p<0.05), and in italics where likely significant, but have reduced statistical accuracy due to small sample size Confidence level (95%) of proportions in parentheses. Surface aspects that were west, north-west, north, north-east, east and south-east facing and also where no aspect was discernable were considered sheltered. South and south-west facing aspects were considered unsheltered. Flat and gentle slopes were considered comfortable and medium and steep slopes were considered uncomfortable.

Site name and fire history	Granite Area (ha)	Dominant surrounding landform	Nyungar occupation synopsis	Total no. *M. dyeri* plants	No. plants on sheltered aspect	Proportion sheltered		No. plants on comfortable slope	Proportion on comfortable slopes	
						All plants	Adult plants		All plants	Adult plants
Woodup Swamp (2015)	4.48	Dune	Semi-permanent	76 (33)	69 (27)	0.91 (0.83-1)	0.82 (0.67-1)	36 (26)	0.47 (0.38-1)	0.79 (0.64-1)
Woogeninup (2015)	19.26	Dune	Semi-permanent	114 (29)	96 (21)	0.84 (0.77-1)	0.72 (0.56-1)	82 (13)	0.72 (0.64-1)	0.45 (0.29-1)
Taylor's Hill (2015)	26.16	Kwongkan	Occasional	5 (4)	4 (4)	Very low population	Very low population	5 (4)	Very low population	Very low population
Duke of Orleans	0.19	Dune	Logistical	22 (11)	19 (10)	*0.86* *(0.68-1)*	*0.91* *(0.64-1)*	22 (11)	1 (0.85-1)	1 (0.74-1)
Thomas River Rd (2007)	6.84	Kwongkan	Logistical	32 (31)	32 (31)	1 (0.91-1)	1 (0.91-1)	32 (31)	1 (0.90-1)	1 (0.89-1)
Doc's Rock (2007)	6.84	Kwongkan	Logistical	307 (160)	275 (140)	0.90 (0.86-1)	0.88 (0.82-1)	307 (160)	1 (0.99-1)	1 (0.98-1)
Belinup (2007)	31.51	Dune	Semi-permanent	961 (293)	710 (228)	0.74 (0.71-1)	0.78 (0.74-1)	704 (214)	0.73 (0.71-1)	0.73 (0.68-1)
Mt Baring (2015)	101.49	Kwongkan	Logistical	66 (52)	62 (49)	0.94 (0.87-1)	0.94 (0.86-1)	66 (52)	1 (0.95-1)	1 (0.93-1)
Carnicup (2015)	7.43	Dune	Logistical	124 (28)	114 (23)	0.92 (0.87-1)	0.82 (0.66-1)	79 (20)	0.64 (0.56-1)	0.71 (0.54-1)
Poison Creek Rd N	1.06	Kwongkan	Logistical	45 (21)	45 (21)	1 (0.94-1)	1 (0.87-1)	45 (21)	1 (0.92-1)	1 (0.85-1)
Capped gnamma	0.01	Kwongkan	Occasional	4 (4)	4 (4)	Very low population	Very low population	4 (4)	Very low population	Very low population

Site name and fire history	**Granite Area (ha)**	**Dominant surrounding landform**	**Nyungar occupation synopsis**	**Total no. *M. dyeri* plants**	**No. plants on sheltered aspect**	**Proportion sheltered**		**No. plants on comfortable slope**	**Proportion on comfortable slopes**	
						All plants	**Adult plants**		**All plants**	**Adult plants**
Pan gnamma	0.31	Kwongkan	Occasional	2 (1)	2 (1)	Very low population	Very low population	2 (1)	Very low population	Very low population
Poison Creek Rd	0.75	Kwongkan	Occasional	21 (8)	21 (8)	1 (0.87-1)	*1 (0.69-1)*	21 (8)	1 (0.85-1)	1 (0.66-1)
Poison Creek Rd S	0.26	Kwongkan	Logistical	24 (16)	20 (12)	0.83 (0.66-1)	0.75 (0.52-1)	22 (15)	0.92 (0.75-1)	0.94 (0.72-1)
Junction granite	0.92	Kwongkan	Logistical	21 (11)	18 (10)	*0.86 (0.67-1)*	*0.91 (0.64-1)*	21 (11)	1 (0.85-1)	1 (0.74-1)
Seal Creek granite (2015)	0.42	Dune	Logistical	3 (3)	3 (3)	Very low population	Very low population	2 (2)	Very low population	Very low population
Poison Creek granite (2015)	2.44	Dune	Logistical	7 (4)	7 (4)	Very low population	Very low population	2 (1)	Very low population	Very low population
All sites	210.37	n/a	n/a	1834 (709)	1501 (596)	0.82 (0.80-1)	0.84 (0.82-1)	1452 (594)	0.84 (0.83-1)	0.84 (0.81-1)

Population distribution in relation to Nyungar residential patterns

Overall, the distance of *Macrozamia dyeri* populations to the nearest surface water feature decreased while distance to granite outcrops increased from west to east in Nyungar *boodja* (Figure 5.4). The mean distance of western *M. dyeri* populations to the nearest surface water feature was 0.2 km (SE=0.05) compared to a mean of 1.19 km (SE=0.21) to the nearest waterway in eastern Nyungar *boodja* (Figure 5.4). The mean distance of western populations to the nearest granite outcrop was 2.41 km (SE=0.51) compared to a mean distance of 0.31 km (SE=0.09) to the nearest granite outcrop in eastern populations.

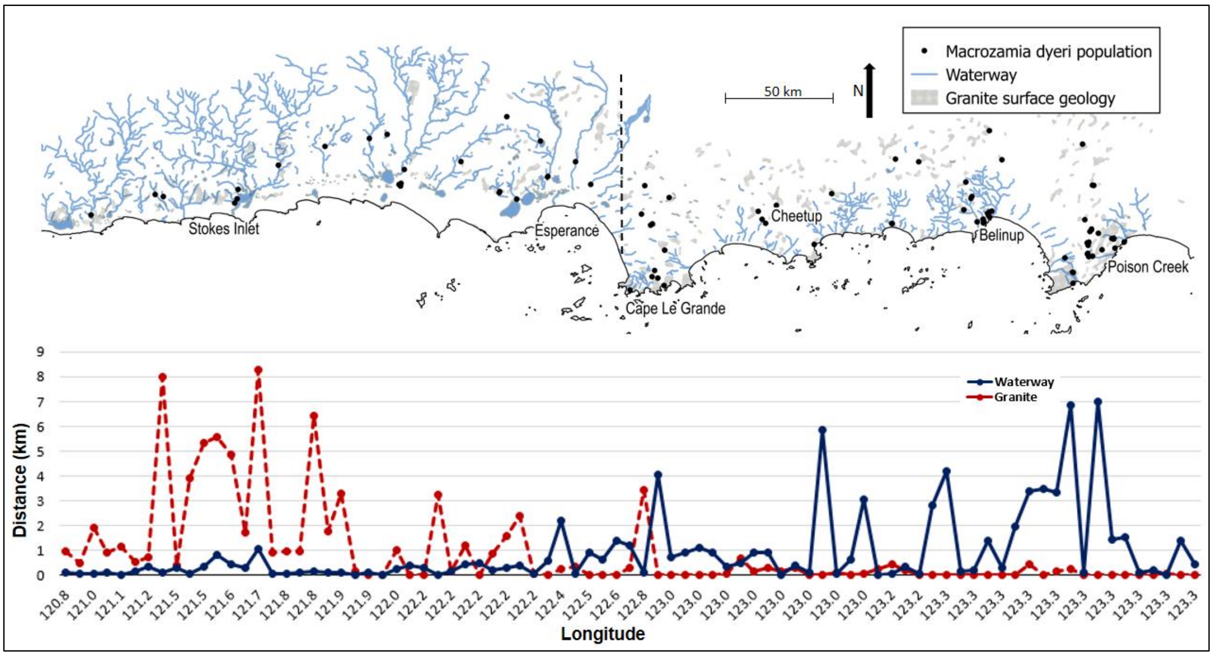


Figure 5.4: Location of recorded *Macrozamia dyeri* populations, and distance of each population to nearest natural surface water feature and granite surface in relation to longitude (decimal degrees). Dashed line indicates eastern extent of major waterways. Surface hydrology data source: Geoscience Australia (2018). Surface geology data source: Stewart et al. (2008).

Across its entire range, we found that, frequency of *Macrozamia dyeri* populations was negatively correlated (*r*=-0.63, p<0.01) with distance from the nearest of 302 registered Nyungar archaeological sites (Figure 5.5). The mean distance between *M. dyeri* populations and the nearest registered site was 3.17 km (SE=0.49), and, while the furthest distance between a population and a registered site was 19.8 km, 75% of populations were within 3.2 km of a registered site.

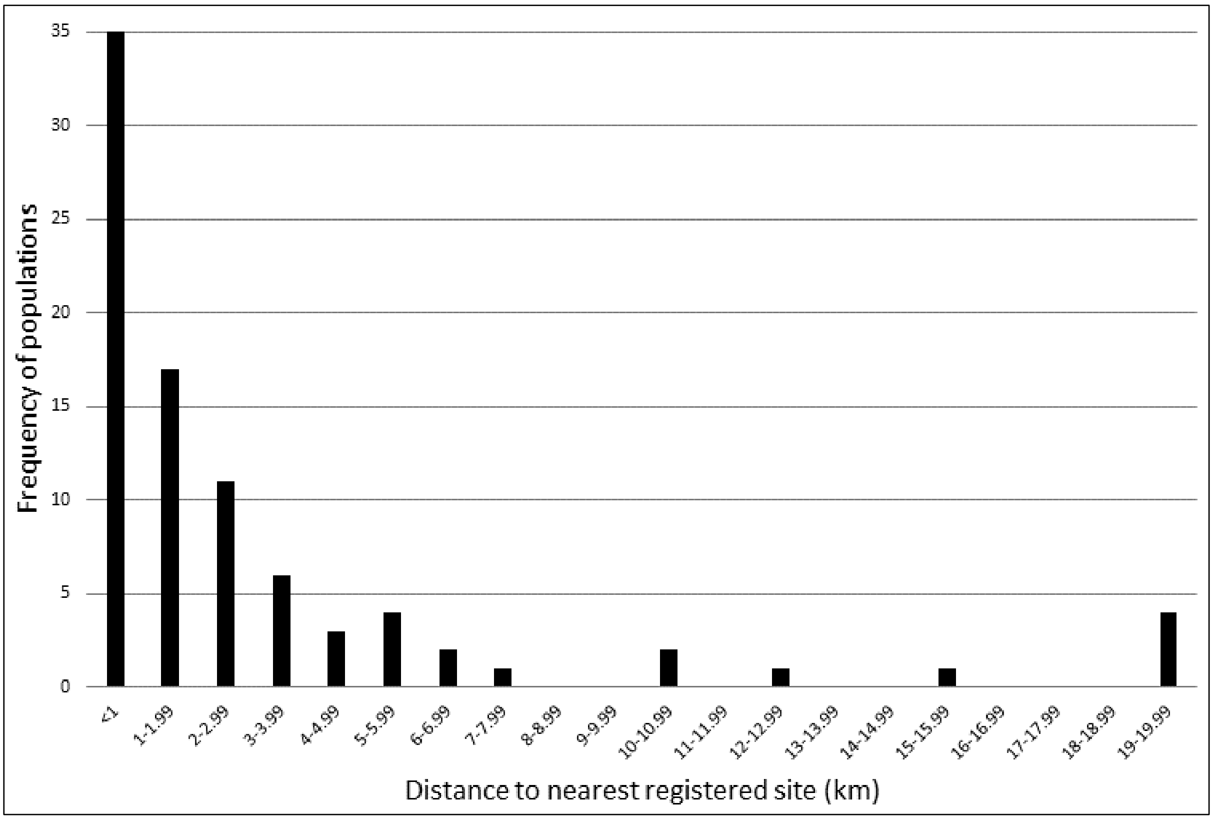


Figure 5.5: Number of *Macrozamia dyeri* populations recorded in relation to distance from nearest pre-colonial Nyungar site registered with Department of Aboriginal Affairs (WA), showing negative correlation between number of populations and distance from nearest site (*r*=-0.63, p<0.01).

Within-population distribution of *Macrozamia dyeri* on granite outcrops

Across all surveyed granite populations in total, we found a greater proportion of sampled *Macrozamia dyeri* and adult *M. dyeri* plants occurring on sheltered ground surface aspects than unsheltered south or south-west-facing aspects (Table 5.1). Where sample size was sufficient for analysis, this was also apparent for most, but not all, granite outcrop populations, and was less so among adult *M. dyeri* plants, than for all *M. dyeri* plants.

We found a greater proportion of all sampled and adult *M. dyeri* plants occurring on comfortable slopes than uncomfortable slopes. This was the case across all sites in their entirety, and also at each population (where sample size was sufficient for analysis) (Table 5.1).

Dune was the dominant landform surrounding seven surveyed granites and kwongkan predominantly surrounded 10 granites. Wetland was not the dominant landform at any of the surveyed granite populations. Extent of populations from the granite edge around outcrops surrounded predominantly by dune was greater than those on outcrops surrounded predominantly by kwongkan (Table 5.1). At populations embedded in dunes, the mean distance of *M. dyeri* plants from the granite edge was 27.3 m (SE=1.3), which was significantly higher than a mean distance of 11.6 m (SE=0.8) at populations surrounded by kwongkan (Mann Whitney *U*=8134, p<0.01) (Figure 5.6). In transects of the granites embedded in dunes, there were 0.35 plants/m^2, compared to 0.16 plants/m^2 of the granites surrounded by kwongkan. Across both site types, there were 0.08 adult plants/m^2.

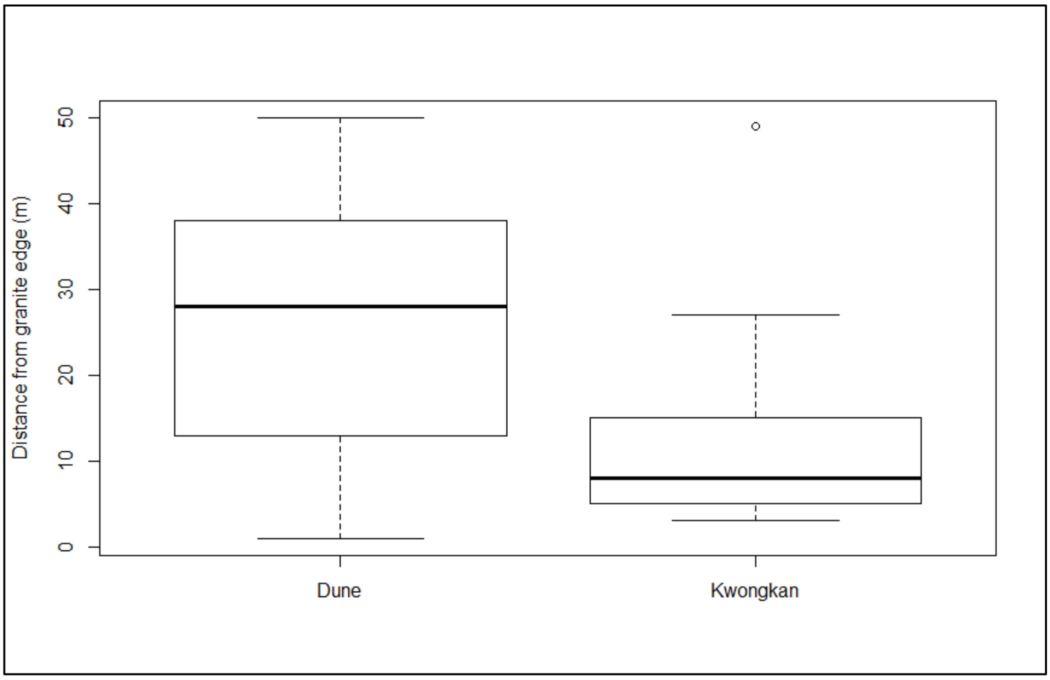


Figure 5.6: Box and whiskers plots showing median and interquartile range of distance from granite edge of *M. dyeri* populations of granite outcrops surrounded predominantly by dune (7) and by kwongkan (10) respectively.

Discussion

We have quantified and observed abundant occurrences of *Macrozamia dyeri* close to well-documented occupation sites in Nyungar *boodja* of the south-eastern SWAFR, just as Hallam (1989) documented in west coast Noongar *boodja* for *M. reidlei* and other staple resource plants, and has been documented elsewhere for cycads (Bradley 2006) and other resource plants (Amundsen-Meyer 2013; Atchison 2009; Head et al. 2002; Levis et al. 2017). While populations of *M. dyeri* occur in all of the landforms included by Smith (1993) in her analysis of Nyungar residential patterns, most populations were on granite, dune and wetlands and the least were in kwongkan, which correlates with Nyungar occupation preferences. Given granite outcrops occupy a very small proportion (<5%) of the total landscape, these data unequivocally demonstrate a non-random geographic distribution which may be associated with preferred camping sites of Nyungars.

Size of granite populations of *Macrozamia dyeri* in eastern Nyungar *boodja* did not correlate with either the size of granite outcrops around which they grew or with latitude (and thus rainfall variation), which suggests that contemporary distribution of granite populations is not solely due to habitat availability, but that other factors, such as differential use by Nyungars or other dispersal vectors, or availability of microhabitats may have been influential. We observed *M. dyeri* plants growing across a range of microhabitats on granite outcrops, including in soil pockets, crevices, across all aspects and slopes and a range of soil moisture conditions. While variation in water and nutrient availability may influence growth and reproduction of *M. dyeri* (Halliday and Pate 1976; Ornduff 1990; Ornduff 1991), no pattern in abundance was observed in relation to these factors. While we can only speculate on habitat preferences of extinct but possibly mutualistic megafauna, a review of habitats used by possible contemporary non-human *M. dyeri* dispersers revealed no strong preference for granite outcrops over woodlands, sandy heathlands or wetlands (Burbidge et al. 2004; How and Hillcox 2000; Kitchener et al. 1980; Morris 2000; Nield et al. 2015).

The importance of granites to Nyungar people is multi-dimensional. The ephemeral presence of fresh water in *gnammas*, the concentration of plants and animals used as food resources, use of granites as navigational markers across large tracts of otherwise low-relief land, and association of granites with ancestral beings and continued ceremonial rituals are all reasons for Nyungar visitation (and visit restriction) to specific outcrop locations (Bindon 1997; Gunn et al. 2017; Smith 2011b). The patchy distribution of *M. dyeri* populations and lack of correlation to environmental factors may reflect the role of the species in a broader, place-based cultural and ancestral identity (Chase 1989) that includes spatial and temporal specificity of economic exploitation of plants. Where the horticulture and harvest of *M. dyeri* were practised in association with other cultural practices (Hallam 1989; Head et al. 2002), other reasons for visiting particular granite outcrops (e.g. ceremonial, tool-making) may have influenced the cycad's distribution.

Most *Macrozamia dyeri* populations are located close to registered Aboriginal sites in Nyungar *boodja*, and they decrease in abundance with increasing distance from registered sites. This corroborates a probable Nyungar influence on the distribution of *M. dyeri* populations. Pre-colonial Nyungar occupation and transport of *M. dyeri* seed focused heavily on waterways in the west and granites in the east of Nyungar *boodja* (Figure 5.4), which we found was reflected in variation in the distance of contemporary *M. dyeri* populations both to waterways and granite outcrops.

We found that intra-population distribution of *Macrozamia dyeri* plants around granite outcrops coincided with flat or gentle slopes most comfortable for human occupation and movement. While gravity and shelter preferences of other mutualistic organisms may have some role in this, we suggest that past Nyungar seed processing and storage activities involving *M. dyeri* may also have influenced contemporary distributions of the cycad. It is probable that seed processing activities were most comfortably carried out on flat surfaces, including campsite locations (CP, AD). This distribution pattern was apparent in our analysis of all sampled plants and also for adult plants only, many of which may have been alive prior to disruption of Nyungar management that resulted from European colonisation in the late 19th century (Pate 1993).

Our analysis of intra-population distribution in relation to surface aspect indicated that, overall, more *Macrozamia dyeri* plants growing close to granite outcrops occur in locations sheltered from southerly and south-westerly winds that prevail during cold, winter months. At some sites, this correlation was not always so, but in such instances we observed that while surface aspect did not provide protection, adjacent microrelief, such as a proximal dune did (Figure 5.3). Such site conditions were observed at Belinup, Woodup Swamp, Woogeninup, Duke of Orleans and Carnicup granites (Figure 5.2). This, again, indicates a possible Nyungar influence in the contemporary occurrence of the cycad.

We found that populations of *Macrozamia dyeri* at granites surrounded predominantly by dunes extended further from the immediate granite edge than populations at granites predominantly surrounded by kwongkan. While this may reflect an intrinsic habitat preference, this finding again correlates with archaeological and ethnographic evidence that dunes were more heavily occupied by Nyungar than kwongkan (Smith 1993; Smith 2011b). Further examination of site preferences for *M. dyeri,* along with field measurements of soil and climate parameters at a microhabitat scale may clarify environmental factors in its distribution.

Interpretation of pre-colonial patterns of *Macrozamia dyeri* use

High abundance of *Macrozamia dyeri* plants found at the Belinup, Doc's Rock and Thomas River Road granites (Figure 5.2; Table 5.1), and observed in dunes surrounding Belinup and the Thomas River mouth, suggests that *M. dyeri* seeds may have been harvested from further afield and brought to the Belinup base camp and surrounding logistical sites for processing and storage. Mitchell's (2016) characterisation of Belinup as an important, semi-sedentary base for family groups rather than a site of regular, large gatherings of people from afar, as well as first hand experiences of *M. reidlei* processing (LK) and *M. dyeri* consumption (AD) in everyday contexts, suggests subsistence usage of *M. dyeri* seeds. In the central Queensland highlands, Asmussen (2009) also concluded Aboriginal use of *M. moorei* seeds to be of subsistence use, rather than for large, ceremonial gatherings as asserted by Beaton (1982). We suggest that abundant *M. dyeri* at Belinup, as well as in surrounding, easily accessible populations, assisted semi-sedentary Nyungar occupation at Belinup. Abundance of *M. dyeri* at Woodup Swamp and Woogeninup granites and observed in dunes surrounding Woodup Swamp and Lake Monjingup also corroborates with heavy Nyungar occupation of these areas (Figure 5.3).

The extraordinarily abundant population of *Macrozamia dyeri* at Belinup suggests that the population was regularly replenished from seeds brought in from other populations. Reproductive traits of *Macrozamia,* such as synchronised population-level masting, highly visible strobili, and year-to-year variability in seed production between populations (Asmussen 2009), would have encouraged advanced planning of harvest, and movement of seed between sites within an occupation complex, particularly to those most heavily occupied sites (e.g. Belinup). Storability would have enabled strategic caching of seed and may account for some sizeable, contemporary populations at sites along travel routes or periodically used for logistical or ceremonial purpose (e.g. Bebenornup, Mt Baring, Figures 5.1, 5.2). The potential to enhance seed production through increased access to water and nutrients (Connell and Ladd 1993; Ornduff 1990; Pate 1993) may account for populations on fresh water springs such as Gabtoobich and Hill Springs on the slopes of Mt Arid. Such combined exploitative practices would have created or enhanced *M. dyeri* populations as fixed patch resources, increasing Nyungar food security and capacity for sedentism in coastal areas of Nyungar *boodja* (Hallam 1989; Hofman and Rick 2018; Testart 1982). While such propositions are somewhat speculative, our findings of multiple correlation between *M. dyeri* distribution and Nyungar occupation patterns provide evidence of a link between such instances of *M. dyeri* occurrence at Nyungar cultural places.

One of our authors (LK) understands that *Macrozamia dyeri* seed was valued for its availability in large quantities and storability, but was not a savoured food, although AD recalls enjoying their flavor when eaten soft after cooking. While there is archaeological evidence at Cheetup (Smith 1982) and ethnographic accounts of Noongar *Macrozamia* seed storage elsewhere, AD recalls her family eating cooked but not buried or soaked seed, suggesting that use of the resource was both variable and versatile. At semi-permanent occupation sites such as Belinup, stored *M. dyeri* seeds may have been a useful fallback resource for times of scarcity. Carrying of preserved *M. dyeri* seed possibly assisted Nyungar to traverse places with few or unfamiliar resources, or may have been carried for trade. Long distance travel along the southern coast was regularly carried out by some authors' ancestors (LK, CP). The seeds to which Hassell (1975) refers in the Jerramungup area could have been those of *M. dyeri* from Nyungar *boodja* or *M. reidlei* from further west. Hassell's (1975) description of only the sarcotesta being carried for long distance trade corroborates with the restricted distribution of *M. dyeri* to *boodja* of the Esperance Nyungar and lack of sympatry with other *Macrozamia* species.

In several instances during our field surveys, we were guided to low-relief granite sheets containing *gnamma* (e.g. Capped Gnamma and Pan Gnamma granites, Figures 2, 3) by the presence of *Macrozamia dyeri* that we would not otherwise have distinguished from low kwongkan vegetation where fresh water is very scarce. This suggested to us the possibility of deliberate Nyungar planting to aid navigation, particularly as a marker of minor fresh water sources restricted to *gnamma*. Such planting of seeds along songlines by Aboriginal Australians has been documented elsewhere (Massy 2017) and may explain the presence of single individuals or very small populations of *M. dyeri* at low-occupancy sites located between larger Nyungar sites. Such small populations at intermittent and small but strategically located water sources may also reflect their use by Nyungar as a 'travelstop' rather than for lengthy periods of occupation.

Indication of Nyungar land management practices

Macrozamia dyeri was chosen to investigate a link between past Nyungar mobility patterns and contemporary plant distributions because there is extensive contemporary and historical evidence of processing and consumption of seeds of the species, including archaeobotanical evidence from

Cheetup (Smith 1982). Also the distinctive form and large size of the cycad made it relatively easy to survey, especially in recently burnt kwongkan and dunal vegetation. Atchison et al. (2005) suggested that while ethnobotanical evidence exists for many traditional plants of Aboriginal Australia, archaeobotanical evidence is poorly preserved and highly fragmented. They also suggested, from taxa that have preserved well in the archaeobotanical record, that we may extrapolate historical relationships between people, plants and landscapes to other ethnobotanical taxa. Strong correlations between Nyungar occupation patterns and *M. dyeri* distribution may provide insights into long-lasting Nyungar interactions with other plants and landscapes of the south-eastern SWAFR. Relative abundance of *M. dyeri* appears indicative of differential Nyungar occupation intensity. Accumulation of seed from elsewhere and low intensity burning regimes probably promoted recruitment, growth and possibly reproduction of *M. dyeri* at heavily occupied sites.

Plant community similarity (i.e. beta-deviation) has been found to be significantly lower in burned than unburned landscapes, due largely to niche selection of fire-tolerant taxa, a phenomenon that increases with scale (Myers et al. 2015). Selective burning at settlement sites and close-by strategic locations would have enabled the Nyungar to create predictable plant resource patches of highly-utilised, fire-tolerant taxa such as *M. dyeri, Acacia* species, *Xanthorrhoea platyphylla* and *Nuytsia floribunda* in the south-eastern SWAFR. Lepofsky and Lertzman (2008) suggested that changes in vegetation mosaics are a useful indicator of anthropogenic influence on landscapes. Nyungar fires were tightly controlled (temporally and spatially), of low intensity, and small in spatial extent (see Chapter 3). We would expect the ecological influence of such fires also to be localised and consistent between sites, compared to those of natural fires, of which intensity, frequency and magnitude are more variable. Given that *M. dyeri* are long-lived and fire tolerant, their locally abundant occurrence around heavily occupied sites (e.g. Belinup, Woodup, Lake Monjingup) may reflect a past regime of frequent, low intensity firing by Nyungar people. This is particularly so given contemporary Nyungar understanding that campsites were periodically burned (e.g. for pest control, maintenance of clear areas) and recollection of Nyungar burning in the Woodup area for hunting of Pibiljurr (*Ardeotis australis*) (RR). The tightly controlled small-scale nature of Nyungar fires would have enabled sustained access to resource taxa less tolerant of fire (e.g. some Proteaceae members) that, with greater fire scale, may be outcompeted by fire-tolerant taxa. We suggest that the overall patchy distribution of *M. dyeri* may, in part, reflect Nyungar fire regimes in the south-eastern coastal SWAFR. Experimental approaches to testing this prediction merit future work.

Biodiversity conservation considerations

Hall and Walter (2013) suggested that because processing of cycad seeds for food by Aboriginal Australians may have destroyed the seed, such use was unlikely to influence cycad dispersal. However, Noongar processing did not destroy the seed kernel (Grey 1841b; Macintyre and Dobson 2018) and is unlikely to have prevented germination (Figure 5.3). Such significant underplaying of a human dispersal role for *Macrozamia* does not reflect sophisticated plant horticulture and broader resource management techniques of many First Nations people globally (e.g. Bradley 2006; Head et al. 2002; Levis et al. 2017). Likewise, Forster (2004) made no mention of human dispersal in discussion of *Macrozamia* genetic patterns. Conversely, Silcock (2018) suggested that numerous plant translocations are likely to have occurred in at least 50,000 years of Australian human history, but much knowledge of Aboriginal translocations remains undocumented and therefore overlooked or underestimated by contemporary ecologists. Such translocations may account for unusual, disjunct populations in the Australian flora. Lullfitz et al. (2017) (see Chapter 2) and Hofman and Rick (2018) advocated consideration of ethnographic information when interpreting biogeographic, DNA-based or other studies of possibly translocated taxa. We do not refute Hall and Walter's (2013; 2014) compelling argument for megafauna dispersal, but suggest that humans may also have played an important dispersal role. Mutualism between Nyungars and *M. dyeri* appears to have enabled long-distance seed dispersal to continue following extinction of previously mutualistic megafauna, and demonstrates a biodiversity conservation benefit of continuing traditional Nyungar practice in the south-eastern SWAFR. Elsewhere, a decline of plant species has been linked with post-colonial Aboriginal absence from landscapes and subsequent reorientation of traditional management methods (Atchison 2009; Head et al. 2002). We suggest that inadequate consideration of long-lasting human activities on dispersal and ecological influences are a considerable oversight in the development of appropriate conservation methodology for some species.

High abundance of *Macrozamia dyeri* at historically well-populated Nyungar occupation sites and correlation between its distribution and Nyungar mobility patterns demonstrate that sustained, pre-colonial Nyungar land management may have influenced some plant distributions in the south-eastern SWAFR. Further, 13,000 year old evidence of Nyungar processing of *M. dyeri* seed (Smith 1982) suggests the long term nature of Nyungar plant cultivation practices in the south-eastern SWAFR. DNA-based examination of *M. dyeri* phylogeography would clarify some of the hypotheses that we have presented here, and may even present a rare opportunity to compare both extant populations and ancient DNA, given seeds of *M. dyeri* have previously been found in the archaeobotanical record (Smith 1982).

Ocbil theory and Nyungar cultural adaptation

Granite outcrops in our study region meet the definition of Ocbils, or old, climatically-buffered infertile landscapes. Hopper et al. (2016) proposed that 'there may well be merit in future research on human evolution and cultural adaptation on Ocbils', and used an illustration of one of us (RR) standing amongst lizard traps (*karda mia*) on Mt Baring (Figure 5.2) to convey the special research opportunities available in Noongar country for better understanding of prolonged cultural adaptations developed by people living in landscapes where Ocbils such as granite outcrops are prevalent. This study exemplifies such research opportunities. The strong correlation between *M. dyeri* populations and Nyungar occupation at granite outcrops demonstrates several innovative cultural adaptations aimed at improved food security in otherwise climatically-marginal country. Further, greater size and spatial extent of *M. dyeri* populations on granites surrounded by dune, a young, often disturbed, fertile landscape (Yodfel) rather than kwongkan (an Ocbil) corroborates with differential Nyungar use of Yodfels and Ocbils outlined in Chapter 3. We commend further work on this topic.

Conclusion

Through combining archaeological, ethnographic and ecological data, we have presented strong evidence to support our hypothesis that Esperance Nyungar have been influential in the contemporary distribution of *Macrozamia dyeri*. Further, given the prominence and discontinuous distribution of *M. dyeri* in the landscape, we suggest that its occurrence may be useful as an indicator of location-specific past Nyungar land management practice, including localised burning, from which extrapolation of ecological outcomes for other taxa is made possible. We suggest that further analyses of *Macrozamia* distributions in Noongar *boodja* and elsewhere may be useful in the reconstruction of past Aboriginal land management practice. Our research demonstrates that predictive distribution models used for biodiversity conservation in Australia should include Aboriginal ethnographic information as well as edaphic, climate and other environmental factors, particularly for plant taxa with long-held human relationships.

Chapter 6: *Platysace* (Apiaceae) of south-western Australia: silent story tellers of an ancient human landscape

Abstract

High gene flow and a population structure that corresponds to human rather than geographic drivers are genetic patterns likely to be exhibited by plant taxa in which human-facilitated migration has been a historical influence. We examined variation in geographic structure and gene flow estimates between two utilised and a non-utilised members of the *Platysace* genus in south-western Australia to identify whether a human influence on the dispersion of the utilised taxa was detectable. The tubers of *P. deflexa* and *P. trachymenioides* have historically been harvested for food by Noongar traditional owners, while *P. effusa* has no known cultural significance. Differences between utilised and non-utilised taxa were evident in haplotype relationship networks, haplotype and nucleotide diversity, migration estimates and population expansion indices based on three non-coding regions of chloroplast DNA, particularly when considered against the generally complex phylogeographic patterning in south-west Australian plant taxa revealed by past studies. Results for *P. effusa* showed a general pattern of high population divergence, low gene flow and multiple refugia, consistent with a long evolutionary history and past climatic oscillations and persistence in a highly fragmented landscape. In contrast, higher gene flow estimates, less divergence between populations, and ancestral common haplotypes in *P. deflexa* and in *P. trachymenioides* over the south-eastern part of its range are consistent with anthropogenic influences. This study contributes to building an understanding of human influences on south-west Australian plant taxa that have been present since the late Pleistocene, but to date, have received little scientific attention.

Introduction

The influence of long held indigenous people-plant relationships on the distribution of 'wild' plant species has become increasingly recognised by the scientific community in recent years (Coughlan and Nelson 2018; Levis et al. 2017; Rangan et al. 2015; Rossetto et al. 2017). Noongar occupation of south-western Australia has been dated archaeologically to at least 48,000 years BP (Turney et al. 2001), which corresponds with mtDNA evidence that dates the regionalisation of Aboriginal Australians to approximately 50,000 years before present (BP) (Tobler et al. 2017). The country, or *boodja* of the Noongar closely aligns with the Southwest Australian Floristic Region (SWAFR), which also takes in some of the traditional country of Ngadju people, who are inland neighbours to the immediate north-east (Prober et al. 2016). Climate and resource availability, as well as social and ceremonial purpose, dictated broad patterns of pre-colonial Noongar movement across the SWAFR (Meagher 1974; Nind 1831), while contemporary Elder knowledge and historical records demonstrate a diverse and extensive knowledge of Noongar cultural plants (Bird and Beeck 1988; Lullfitz et al. 2017; Meagher

1974). Long held Noongar ecological influence through practices such as firing, plant harvest and habitat construction are well documented (Hallam 2014; Hopper and Lambers 2014; Kelly 1998; Lullfitz et al. 2017) in the SWAFR, a global biodiversity hotspot (Mittermeier et al. 2011), and it is probable that this includes dispersal of some SWAFR plant taxa. While DNA-based techniques have offered evidence of human-facilitated plant dispersal in Australia (Bell et al. 2014; Kondo et al. 2012; Rangan et al. 2015; Rossetto et al. 2017) and elsewhere (Chair et al. 2011; Roullier et al. 2013; Zerega et al. 2004; Zhang et al. 2004), they have not yet been employed for such purpose in the SWAFR. South-western Australia is an excellent region within which to explore anthropogenic influence on dispersal of plants as there is an increasing record of Noongar plant knowledge and practice (Hopper, Lullfitz, Knapp, unpublished) and well documented phylogeographic patterns of plants across the region (Binks et al. 2015; Broadhurst et al. 2017; Byrne 2007; Byrne 2008; Byrne et al. 2014; Llorens et al. 2017; Sampson et al. 2015; Tapper et al. 2014a).

Legacies of people-plant relationships are numerous (e.g. Amundsen-Meyer 2013; Levis et al. 2018; Mensing et al. 2018), although those of First Nation societies can be difficult to detect (Hofman and Rick 2018; Lepofsky and Lertzman 2008). Traditional plant management techniques, such as selective harvest or transplanting, have the potential to change morphological and genetic attributes of taxa (Lepofsky and Lertzman 2008; Levis et al. 2017). Thus, studies of genetics are a useful tool for understanding past human influences (Hofman and Rick 2018). Where distribution patterns of a taxon do not fit expected biogeographic patterns, a human influence on its distribution may be indicated (Hofman and Rick 2018). Taxa in which human-facilitated migration has been a historical influence exhibit a general genetic pattern of high gene flow and a lack of population structure, or one that corresponds to human rather than geographic drivers (Bell et al. 2014; Chair et al. 2011; Kondo et al. 2012; Rangan et al. 2015; Rossetto et al. 2017; Roullier et al. 2013; Zhang et al. 2004). Studies in other parts of the continent have found unexpected genomic homogeneity in plant taxa utilised by Aboriginal Australians across a broad habitat range (Bell et al. 2014) and a highly dissected landscape (Rossetto et al. 2017). Increased within-population diversity is expected where multiple introductions have occurred (Lowe and Allendorf 2010; Roullier et al. 2013; Stockwell et al. 2003), whereas a single introduction may result in the founder effect, reducing within-population diversity (Templeton 1980).

Previous phylogeographic studies of plant taxa within the highly biodiverse SWAFR present some consistent patterns reflecting a long evolutionary history in an area of relative geological stability. Plant taxa of the drier inland SWAFR (Hopper 1979) often exhibit extensive genetic variation and structure, likely attributable to a combination of increased post-Miocene aridity, multiple Pleistocene climate-driven population expansions and contractions, and natural population isolation due to edaphic complexity and life-history traits conducive to survival in old, climatically buffered, infertile landscapes (Ocbils) (Broadhurst et al. 2017; Byrne 2007; Byrne et al. 2014; Byrne and Hines 2004; Byrne and Hopper 2008; Byrne et al. 2002; Byrne et al. 2011; Coates 2000; Hopper 2009; Hopper et al. 2016; Llorens et al. 2015; Sampson et al. 2015; Tapper et al. 2014b). Patterns of locally distributed, often population-specific, high haplotype diversity in the SWAFR are consistent with a hypothesis of local persistence and limited migration due to climatic dynamism and edaphic heterogeneity (Byrne 2007; Byrne 2008) although a few species do show signals of contraction to, and expansion from, large refugia (Byrne 2007; Dalmaris et al. 2015; Nistelberger et al. 2014; Tapper et al. 2014b). Prolonged population isolation and divergence is especially prevalent among SWAFR granite endemic taxa, due to prolonged persistence of granite outcrops as inselbergs since the Cretaceous (Twidale and Bourne 1998) and presence of specific mesic habitats unavailable through much of the intervening landscape (Byrne and Hopper 2008; Hopper et al. 1996; Marchant 1973; Tapper et al. 2014a; Tapper et al. 2014b). Pre-colonial patterns of Noongar occupation were driven largely by access to fresh water, particularly in low rainfall areas (Mitchell 2016; Smith 2011b). In most coastal areas, waterways provide higher food and water resource concentration compared to intervening areas, and are important traditional foci of cultural activity (Mitchell 2016; Smith 2011b). Granite outcrops are important cultural landscape elements throughout Noongar and Ngadju country, (Bindon 1997; Mitchell 2016; O'Connor and Prober 2010; Prober et al. 2016), particularly inland (Smith 2011b), providing nodes of resource concentration and water availability suitable for specific ceremonial use and for meetings of large groups (Mitchell 2016). In the south-eastern part of the SWAFR, east of Esperance where prominent waterways are scarce, granite outcrops were (and remain) a key focus of traditional cultural activities (Mitchell 2016; Smith 2011b).

The tubers of four species of the genus *Platysace* Bunge that occur within the SWAFR (Figure 6.1) have historically provided a staple food for the Noongar people. These comprise *P. deflexa* (Hassell 1975; Nind 1831), *P. trachymenioides* (von Brandenstein 1977; von Brandenstein 1988), *P. maxwellii* (Meagher 1974), and *P. cirrosa* (Drummond 1840a; Moore 1884; Nannup 2014). Tubers were often carried as a readily transportable food and water source (Hassell 1975; Knapp 2015; Moore 1884; Nind 1831; Pettersen 2015a). While no specific written record of Noongar propagation of these taxa is known, an early record in Albany (Barker 1831) described application of pre-existing Noongar propagation skills to root crops in colonial vegetable gardens. A contemporary Menang Noongar Elder describes likely propagation (either deliberate or accidental) of *P. deflexa* as ‘commonsense’. She recalls storing store-bought root vegetables in the ground to maximise shelf life prior to owning a refrigerator, a behavior learned from her Noongar mother, who also taught her about *joowaq (P. deflexa)* and other plant foods (Pettersen 2018). *Platysace trachymenioides* is less prevalent in historic literature and not readily recalled by contemporary Noongars in comparison to other staple food taxa, possibly indicating it may have been less savored (Rusack et al. 2011), and therefore considered a 'necessary' rather than 'desirable' food option (Knapp, unpublished).

Platysace is a poorly studied genus of the Apiaceae family containing approximately 30 perennial, herbaceaous or sub-shrub, bisexual or andromonoecious taxa, pollinated by insects and confined to the Australian continent (Hart and Henwood in press; Henwood and Hart 2001). *Platysace* species have been found difficult to propagate from seed or transplants (Keighery 1982; Woodall 2010), with germination being particularly poor among taxa spreading via tubers (Keighery 1982). A requirement for well-drained, sandy soils, and a readiness to sucker from a rhizomatous root was observed in *P. deflexa* (Woodall 2010), consistent with personal observations by one of us (AL) of rhizomatous growth of both *P. deflexa* and *P. trachymenioides*, particularly following soil disturbance. *Platysace effusa*, although not tuberous, appears confined to kwongkan vegetation, sometimes sympatric with *P. deflexa*, and is likely to require similar soil conditions to *P. deflexa.*

Maternal inheritance and lack of recombination makes analysis of chloroplast DNA (cpDNA) a useful means of assessing historical influences on intraspecific genetic structure of angiosperm taxa (Byrne 2008; Byrne et al. 2014). Given poor seed germination, particularly among tuberous *Platysace* species, it is expected that a reliance on clonal reproduction will have led to low within-population diversity (Binks et al. 2015; Millar et al. 2010), while this, combined with specific soil habitat requirements, will have led to population isolation and high levels of divergence (Broadhurst et al. 2017; Byrne et al. 2014).

In this study, we tested whether two Noongar-utilised taxa, *P. deflexa* and *P. trachymenioides* exhibited differing phylogeographic patterning to another species of the genus with similar range and form, *P. effusa*. Ethnographic evidence suggests that *P. effusa* was not utilised by people as it is non-tuberous and is unknown as a food source to contemporary Noongar Elders (Lullfitz and Hopper, unpublished). *Platysace trachymenioides* occurs on granite outcrops across inland parts of the SWAFR from Northampton to Esperance, while both *P. deflexa* and *P. effusa* occur within kwongkan vegetation, mainly in the southern SWAFR, although *P. effusa* is also recorded in the northern sandplains (Figure 6.1).

We expect that natural dispersal patterns would result in strong genetic structuring corresponding with geographic and/or past climatic drivers, while human-facilitated dispersal may cause homogenisation between populations and high within-population diversity if multiple introductions have occurred. We hypothesise that, due to a long history of localised persistence within multiple refugial populations, the granite species *Platysace trachymenioides* would exhibit a high degree of genetic diversity and structure, and no evidence of recent population expansion, in the absence of human influence on its dispersal. This would also be the case for the sandplain taxa, *P. deflexa* and *P.*

effusa, although to a lesser degree due to greater connectivity among populations than those on granite outcrops. However, if people have influenced dispersion of the utilised taxa, we predict evidence of minimal geographic structuring and recent population expansion in the utilised species *P. trachymenioides* and *P. deflexa*, but patterns of localised persistence in the non-utilised *P. effusa.* The specific genetic characteristics that we hypothesise for each species if dispersal of *P. trachymenioides* and *P. deflexa* has been subject to anthropogenic influences are outlined in Table 6.1.

Table 6.1: Expected genetic characteristics of *P. trachymenioides* and *P. deflexa* (Noongar-utilised) and *P. effusa* (not utilised) where historical human-facilitated dispersal has occurred.

	P. trachymenioides	***P. deflexa***	***P. effusa***
Total diversity	Low	Low	High
Population differentiation	Low	Low	High
Haplotype network	Central, common node	Central, common node	Multiple nodes
Within-population diversity	High	High	Low
Recent population expansion	Yes	Yes	No

Methodology

Sampling and extraction

Populations were sampled across the entire geographic ranges of *Platysace deflexa* (Figure 6.1)*,* *P. trachymenioides* (Figure 6.2) and *P. effusa* (Figure 6.3). *Platysace trachymenioides* was sampled most intensively in the SE part of its range as localised Noongar mobility patterns are well documented for this area (Gunn et al. 2017; Smith 2011b). In total, leaf samples were collected and analysed from 12, 25 and nine populations of *P. deflexa*, *P. trachymenioides* and *P. effusa* respectively. Between three and eight individuals were sampled from each population. Leaf samples were also collected and analysed from individuals of *P. juncea* and *P. compressa* for use as outgroups. A specimen from each population was forwarded to the Western Australian Herbarium (accession number: 7659).

Genomic DNA was extracted from freeze-dried leaf matter using the DNeasy Plant Mini Kit (Qiagen, Valencia, California, USA) in accordance with manufacturer's instructions, with two minor variations. These were the addition of 3 µL of RNAse A following disruption of samples, and addition of 50 µL to final elutions.

Sequencing and analysis

Variable success in extraction and sequencing of samples resulted in between two and eight samples of cpDNA from each population being sequenced and analysed. Following primer trials of cpDNA regions known to detect variation (Byrne and Hankinson 2012), the intergenic spacer regions, *trnS-trnG, psbD-trnT* and *ndhC-trnV* were selected based on amplification success and variability. PCR amplification was carried out in accordance with Shaw et al (2007) with 1.5mM (*trnS-trnG*), 2.5 mM (*psbD-trnT*) or 3.0 mM (*ndhC-trnV*) $MgCl_2$ and annealing temperatures of 52°C. PCR product was cleaned with Sera-mag SpeedBeads (Fisher #09-981-123) prepared in accordance with Rohland and

Reich (2012) and sequenced by Macrogen Inc. (Seoul, South Korea). Sequence chromatograms were quality checked using ABI Sequence Scanner 2.0 (Applied Biosystems, Foster City, CA, USA), then imported into Geneious R9 (Biomatters, Auckland, NZ) where they were edited for miscalls, trimmed, and forward and reverse sequences assembled into consensus sequences. Each region was aligned using CLUSTAL-W (Thompson et al. 1994), trimmed to equal lengths and concatenated in Geneious R9.

Sequences were analysed in DNASP 5.1 (Librado and Rozas 2009) to identify haplotypes, and a maximum likelihood phylogeny of all haplotypes was built based on the Jukes-Cantor model and 100 bootstraps using the PhyML plugin (Guindon et al. 2010) for Geneious R9 (Figure 6.4). Based on clustering of haplotypes (see Results) further analyses were undertaken according to species (*P. trachymenioides, P. deflexa* and *P. effusa*), clade (*P. trachymenioides* SE) and a fourth set of *P. trachymenioides* populations distributed across a similarly sized geographic area to *P. deflexa* and *P. trachymenioides* SE in the southern extent of the species' range (*P. trachymenioides* SW) (Table 6.2). Relationships among haplotypes in each group were determined by constructing a median-joining maximum parsimony (MJMP) network in Network (Bandelt et al. 1999). Haplotype and nucleotide diversity (H_D, π) were calculated in DNASP, and mean number of haplotypes per population (Hap_{pop}) and number of populations containing shared haplotypes was calculated. Differences in the number of haplotypes per population (Hap_{pop}) between groups were tested with ANOVA in R version 2.4.0. Indices of ordered and unordered within population diversity (h_S, v_S) and total diversity (h_T, v_T) were calculated in PERMUT (Pons and Petit 1996). Population differentiation was estimated with G_{ST} and N_{ST} and significance tested with 10,000 permutations in PERMUT. As G_{ST} estimates are based on haplotype frequencies, while N_{ST} accounts for genetic distances between haplotypes, phylogeographic structuring is indicated where $N_{ST} > G_{ST}$ (Pons and Petit 1996). Pairwise F_{ST} (Hudson et al. 1992) was calculated for each population pair of each group using DNASP. To test the assumption of neutral evolution, Ramos-Onsins & Rozas R_2, Tajima's D and Fu's F_S statistic were calculated for each group using DNASP.

Results

Haplotypes

The *trnS-trnG, psbD-trnT* and *trnV-ndhC* regions gave sequence lengths of 731 bp, 1578 bp and 715 bp in length respectively. Ninety eight unique haplotypes were identified across all 3024 bp and 239 individuals (including outgroups) (Table 6.2). A phylogenetic tree showed one well-supported large clade and one moderately supported large clade, along with a number of other groups with little support (Figure 6.4). One large clade with 96% bootstrap support comprised haplotypes present in all *P. deflexa* populations except Dalyup plus seven haplotypes present in *P. effusa* and one present in *P. trachymenoides* SW. The other large clade had moderate bootstrap support (68%) and comprised the majority of haplotypes present in *P. trachymeniodes* along with three haplotypes present in *P. effusa.* Within this clade there was a further subclade with very high bootstrap support (100%) that comprised all haplotypes present in SE populations of *P. trachymenioides*, with three haplotypes of the SW *P. trachymenioides* populations basal to the clade*.* The remaining haplotypes formed a clade of five branches with mixed grouping of haplotypes present in *P .trachymeniodes* SW, *P. effusa* and *P. deflexa* (Figure 6.4). Although haplotypes from different species were mixed in clades, all identified haploytypes were specific to only one defined species. While haplotypes present within *P. trachymeniodes* and *P. deflexa* were generally related, haplotypes in *P. effusa* showed greatest variation with haplotypes related to those present in some *P. trachymenioides* SW populations and in *P. deflexa*.

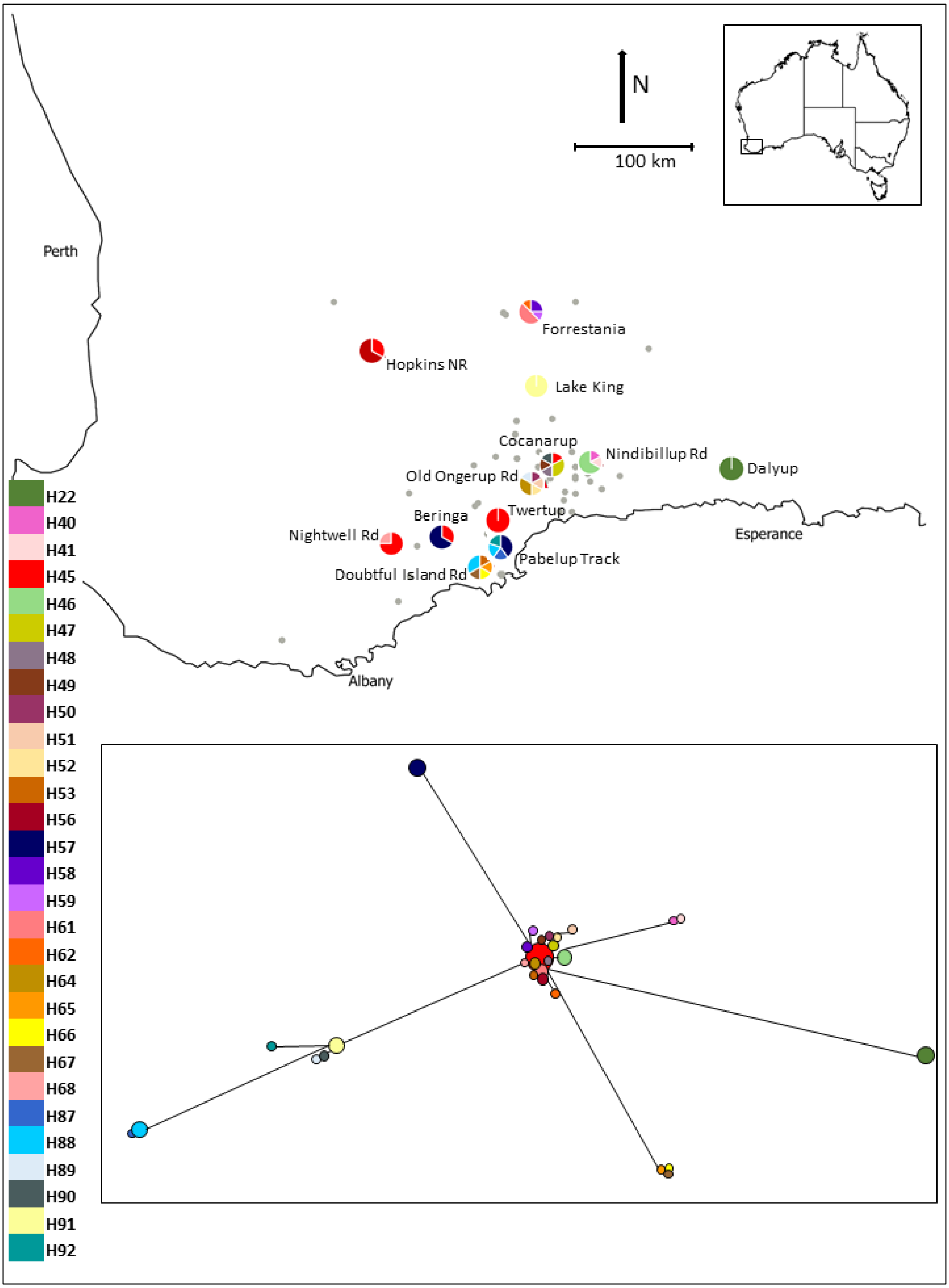


Figure 6.1: Location of sampled populations (showing haplotypes) and record locations held by the Western Australian herbarium (WA Herbarium Specimen Database) (in grey) and haplotype network (inset) of *Platysace deflexa*. Haplotype network circle size reflects haplotype frequency; line length reflects genetic distance.

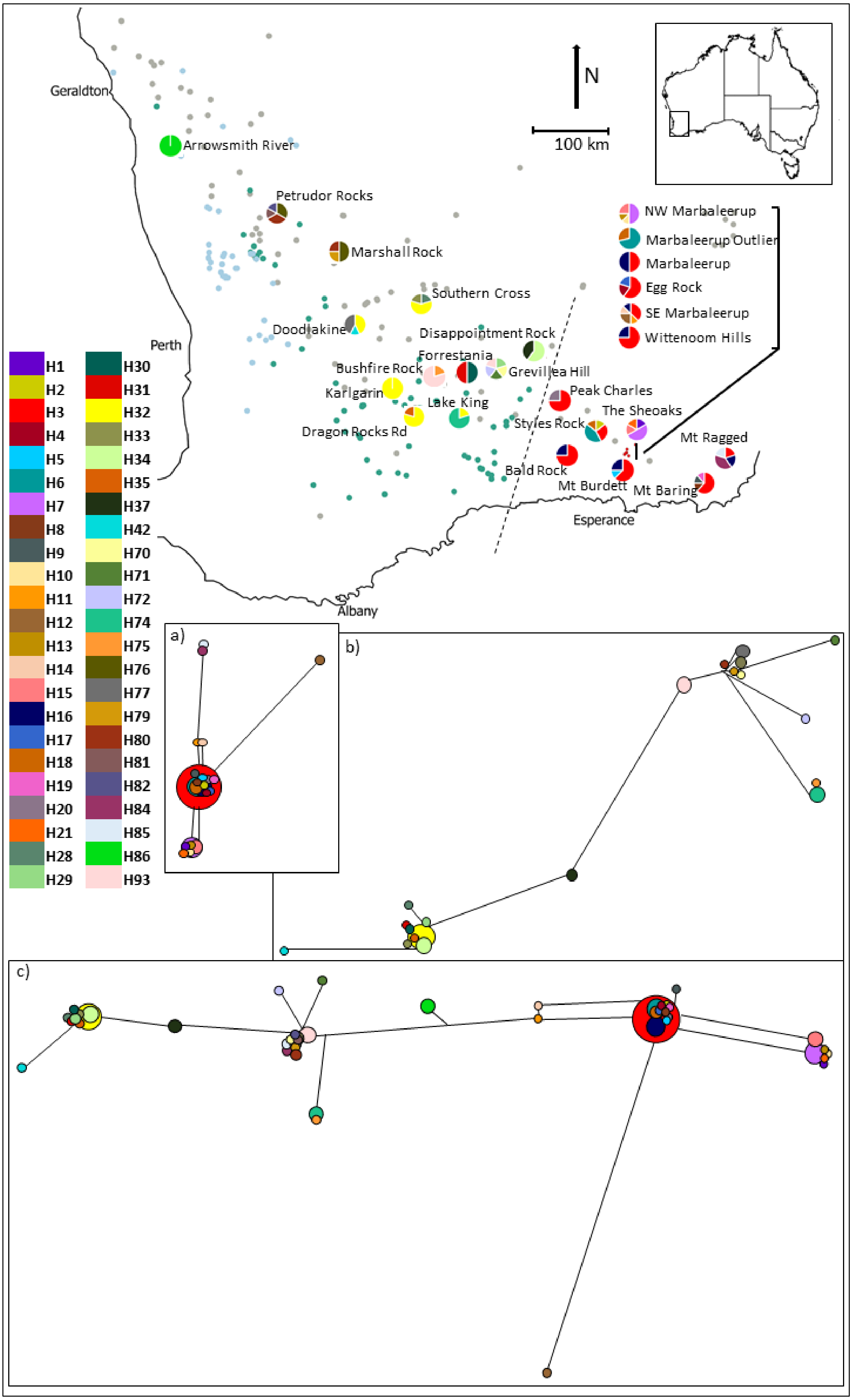


Figure 6.2: Location of sampled populations (showing haplotypes) and haplotype networks (insets) of a) SE populations, b) SW populations and c) all populations of *Platysace trachymenioides.* Record locations held by the Western Australian herbarium (WA Herbarium Specimen Database) of *P. trachymenioides* (grey) and other known *Platysace* food taxa, *P. maxwellii* (teal) and *P. cirrosa* (blue).

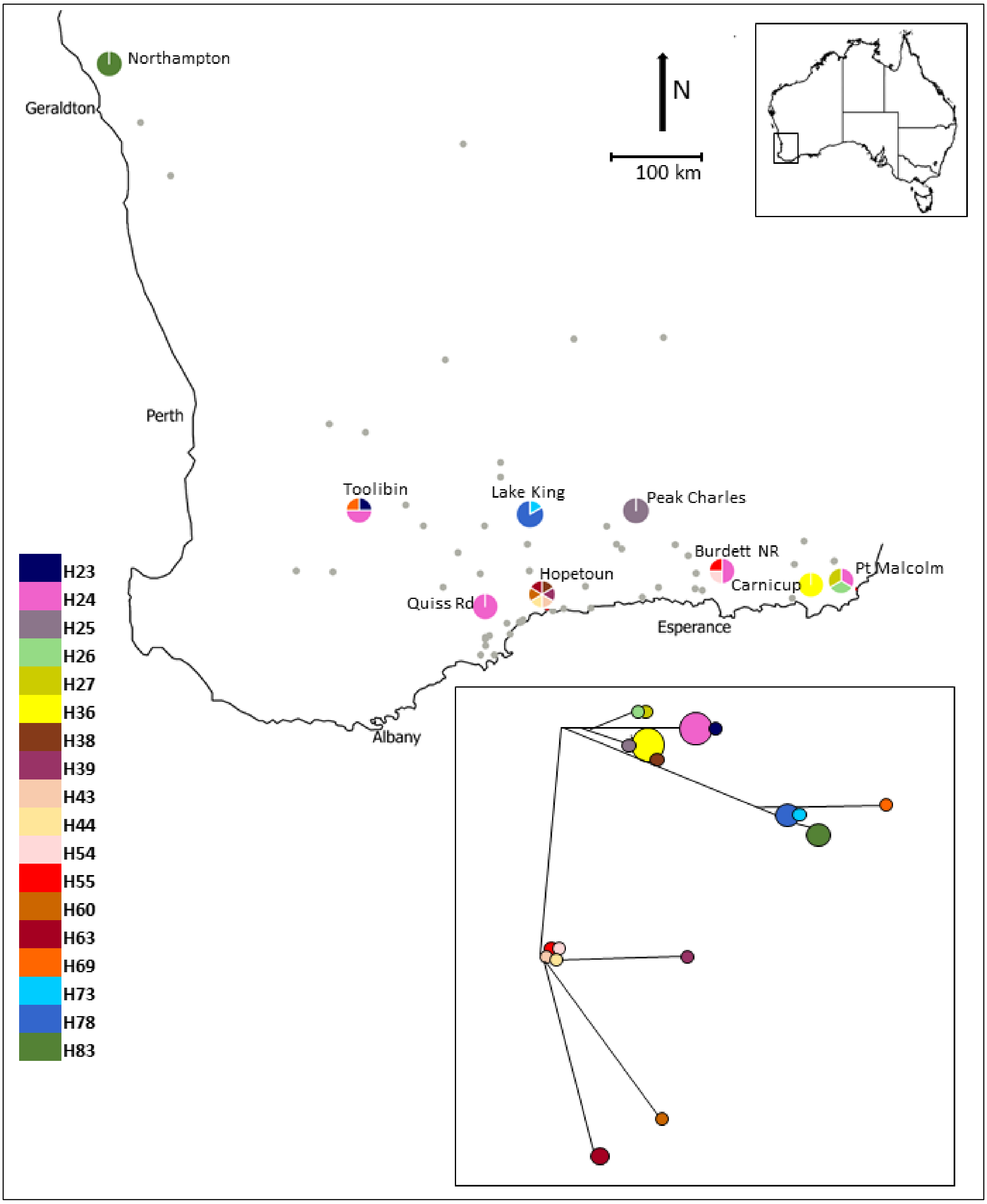


Figure 6.3: Location of sampled populations (showing haplotypes) and record locations held by the Western Australian herbarium (WA Herbarium Specimen Database) (in grey) and haplotype network (inset) of *Platysace effusa.* Haplotype network circle size reflects haplotype frequency; line length reflects genetic distance.

Table 6.2: Characteristics of 46 populations of *Platysace* (excluding outgroups) sampled across the SWAFR. Shared haplotypes in bold. Number of individuals with haplotype in parentheses.

Population	**Species**	**Group**	**Location**		***n***	**Haplotypes**
Forrestania	*P. deflexa*	deflexa	-32.41537	119.68960	8	H58(2), H59(1), H61(4), H62(1)
Hopkins Nature Reserve	*P. deflexa*	deflexa	-32.71956	118.28954	3	H45(1), H56(2)
Beringa Upland	*P. deflexa*	deflexa	-34.10928	118.86664	3	H45(1), H57(2)
Pabelup Track	*P. deflexa*	deflexa	-34.11473	119.44754	5	H57(2), H87(1), H88(1), H92(1)
Doubtful Island Rd	*P. deflexa*	deflexa	-34.29537	119.27204	6	H53(1), H65(1), H66(1), H67(1), H88(2)
Old Ongerup Rd	*P. deflexa*	deflexa	-33.70521	119.75987	6	H50(1), H51(1), H52(1), H64(2), H89(1)
Cocanarup	*P. deflexa*	deflexa	-33.60144	119.89841	6	H45(1), H47(2), H48(1), H49(1), H90(1)
Nindibillup Rd	*P. deflexa*	deflexa	-33.54003	120.25641	6	H40(1), H41(1), H46(4)
Lake King	*P. deflexa*	deflexa	-32.96575	119.76266	3	H91(3)
Nightwell Road	*P. deflexa*	deflexa	-34.18300	118.41393	4	H45(3), H68(1)
Twertup	*P. deflexa*	deflexa	-34.03042	119.39009	4	H45(4)
Dalyup	*P. deflexa*	deflexa	-33.61978	121.49329	5	H22(5)
Northampton	*P. effusa*	effusa	-28.22095	114.63749	5	H83(5)
Burdett Nature Reserve	*P. effusa*	effusa	-33.51555	122.11961	4	H24(2), H54(1), H55(1)
Pt Malcolm	*P. effusa*	effusa	-33.72811	123.74331	3	H24(1), H26(1), H27(1)
Quiss Road	*P. effusa*	effusa	-33.95228	119.15726	2	H24(2)
Peak Charles	*P. effusa*	effusa	-32.89585	121.13118	2	H25(2)
Hopetoun	*P. effusa*	effusa	-33.92795	120.01442	7	H38(1), H39(1), H43(1), H44(1), H60(1), H63(2)
Toolibin	*P. effusa*	effusa	-32.94235	117.62368	4	H23(1), H24(2), H69(1)
Lake King	*P. effusa*	effusa	-32.96586	119.76270	6	H73(1), H78(5)
Carnicup	*P. effusa*	effusa	-33.79120	123.27054	7	H36(7)
The Sheoaks	*P. trachymenioides*	SE	-33.19767	122.25416	6	H1(1), H7(3), H15(1), H21(1)
Wittenoom Hills	*P. trachymenioides*	SE	-33.39333	122.18636	8	H3(6), H16(2)
Egg Rock	*P. trachymenioides*	SE	-33.29517	122.12482	5	H3(3), H4(1), H17(1)
Mt Burdett	*P. trachymenioides*	SE	-33.45716	122.14353	8	H3(5), H5(1), H16(2)
Marbaleerup Outlier	*P. trachymenioides*	SE	-33.31542	122.09416	7	H6(5), H18(2)
SE Marbaleerup	*P. trachymenioides*	SE	-33.33339	122.15515	8	H3(3), H11(1), H12(2), H14(1), H16(1)
NW Marbaleerup	*P. trachymenioides*	SE	-33.25364	122.12911	8	H7(4), H10(1), H13(1), H15(2)
Marbaleerup	*P. trachymenioides*	SE	-33.29590	122.11810	2	H3(1), H16(1)
Mt Ragged	*P. trachymenioides*	SE	-33.46501	123.46161	5	H3(1), H16(1), H84(2), H85(1)
Styles Rock	*P. trachymenioides*	SE	-33.12661	121.80419	7	H2(1), H3(2), H6(3), H18(1)
Peak Charles	*P. trachymenioides*	SE	-32.76401	121.28252	4	H3(3), H20(1)
Bald Rock	*P. trachymenioides*	SE	-33.41872	121.37393	4	H3(3), H16(1)
Mt Baring	*P. trachymenioides*	SE	-33.71415	123.24572	8	H3(5), H8(1), H9(1), H19(1)
Grevillea Hill	*P. trachymenioides*	SW	-32.30555	120.13685	5	H29(1), H70(1), H71(1), H72(1), H93(1)
Disappointment Rock	*P. trachymenioides*	SW	-32.13029	120.92850	5	H34(3), H37(2)
Bushfire Rock	*P. trachymenioides*	SW	-32.44135	119.34741	5	H75(1), H93(4)
Forrestania	*P. trachymenioides*	SW	-32.41507	119.68961	2	H30(1), H31(1)
Doodlakine	*P. trachymenioides*	SW	-31.74874	118.08566	7	H32(3), H42(1), H77(3)
Southern Cross	*P. trachymenioides*	SW	-31.46392	119.25102	5	H28(1), H32(3), H33(1)
Marshall Rock Rd	*P. trachymenioides*	SW	-30.85106	117.90540	4	H76(2), H79(1), H80(1)
Dragon Rocks Rd	*P. trachymenioides*	SW	-32.88170	118.99515	5	H32(4), H35(1)
Lake King	*P. trachymenioides*	SW	-32.96592	119.76302	5	H32(1), H74(4)
Karlgarin	*P. trachymenioides*	SW	-32.49953	118.71374	2	H32(2)
Petrudor Rocks	*P. trachymenioides*	other	-30.43252	116.96202	6	H76(2), H80(2), H81(1), H82(1)
Arrowsmith River	*P. trachymenioides*	other	-29.49509	115.45447	4	H86(4)

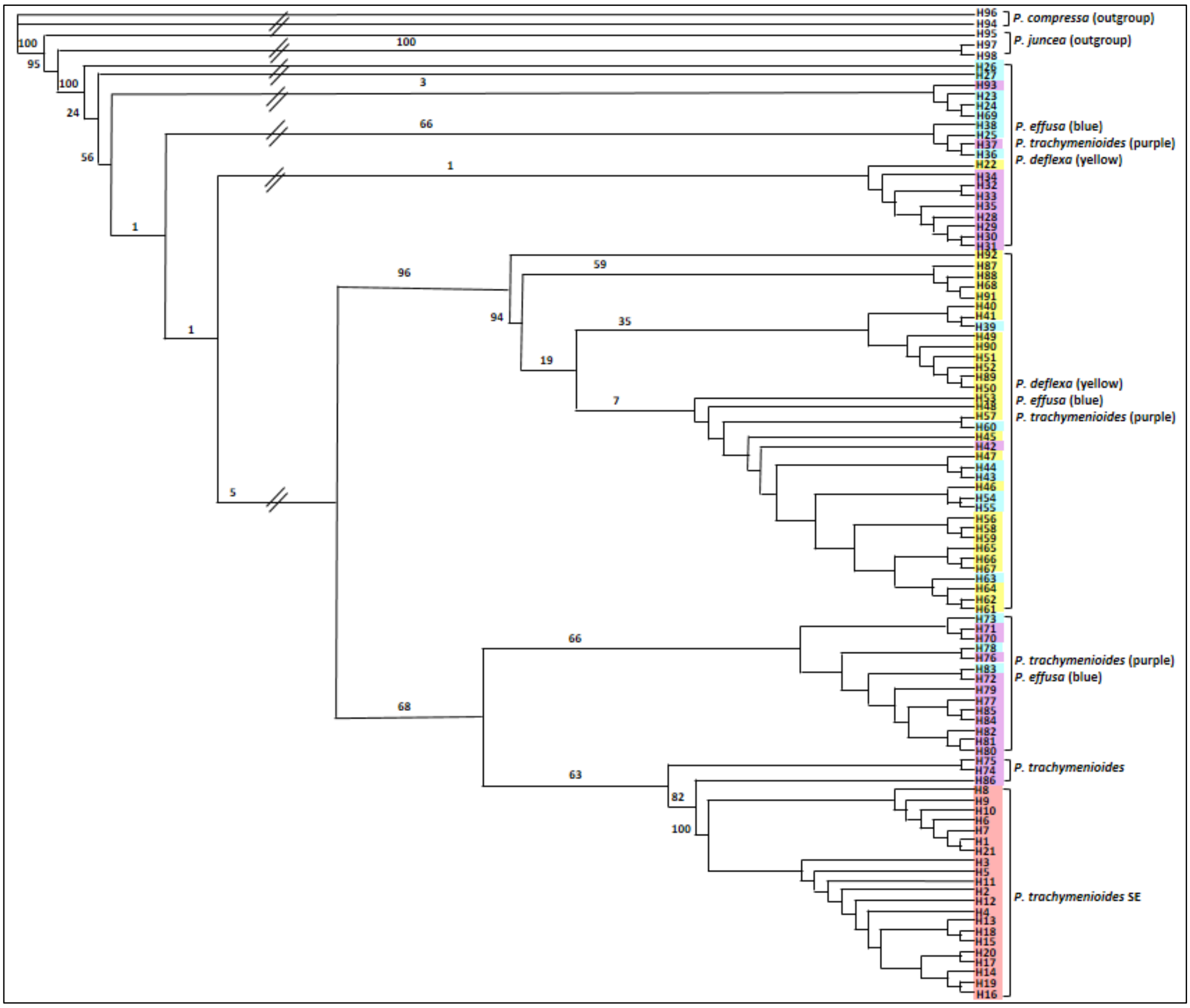


Figure 6.4: Maximum likelihood phylogeny of all haplotypes across all sampled individuals of *Platysace deflexa*, *P. effusa*, *P. trachymenioides*, *P. juncea* and *P. compressa* based on Jukes-Cantor model and 100 bootstraps.

Haplotype and nucleotide diversity

Haplotype diversity (H_D) was highest in *P. deflexa* (0.952) and lowest in *P. trachymenioides* SE (0.816) (Table 6.3), while nucleotide diversity (π) was lowest in *P. trachymenioides* SE (0.102) and *P. deflexa* (0.167) and highest in *P. trachymenioides* SW (0.279) and *P. effusa* (0.232). The mean number of pairwise nucleotide differences (K_t) was low for *P. deflexa* and *P. trachymenioides* SE and moderate to high for *P. effusa* and *P. trachymenioides* SW.

Population differentiation

N_{ST} was significantly greater than G_{ST}, and both ordered and unordered population differentiation indices (h_T, v_T) were significantly greater than zero, across all groups, indicating that all groups have significant population structure (Table 6.3). *Platysace trachymenioides* SE had the lowest proportion of private haplotypes (73.91%), followed by *P. trachymenioides* SW (80%), while those in *P. deflexa* and *P. effusa* were considerably higher (89.66% and 94.44% respectively). All *P. trachymenioides* SE populations had shared haplotypes. This was also the case for most populations of *P. trachymenioides* SW (88.89%), while shared haplotypes occurred in only 44.44% and 58.33% of *P. effusa* and *P. deflexa* populations respectively.

Platysace trachymenioides SE had a considerably lower fixation index (F_{ST}) (0.309) than other groups, while that of *P. deflexa* (0.525) was somewhat lower than other groups also.

Table 6.3: Measures of genetic diversity and structure for 46 populations of *Platysace deflexa*, *P. effusa*, *P. trachymenioides*, across the SWAFR. Standard errors in parentheses unless otherwise indicated; number of transition/transversion sites followed by indel sites shown in parentheses after number of polymorphic sites; significant results shown in bold; *N_{ST}>G_{ST} (P=0.05); ** N_{ST}>G_{ST} (P=0.01).

Test/Measure	Statistic	*P. deflexa* (n=12)	*P. effusa* (n=9)	*P. trachymenioides* SE (n=13)	*P. trachymenioides* SW (n=10)	*P. trachymenioides* (all) (n=25)
No. of samples		59	40	80	45	135
No. of haplotypes		29	18	23	20	46
No. polymorphic sites		168 (36, 132)	180 (34, 146)	250 (25, 225)	121 (48, 73)	338 (71, 267)
Haplotypes/pop	Hap_{POP}	2.917	2.333	3.154	2.5	2.84
Private haplotypes	%	89.66	94.44	73.91	80.0	78.26
Pops with shared haplotypes	%	58.33	44.44	100	80.0	88.0
Haplotype diversity	H_D	0.952 (0.002)	0.918 (0.004)	0.816 (0.004)	0.897 (0.005)	0.923 (0.001)
Mean pairwise nucleotide diff	K_t	28.11 (1.624)	41.787 (2.929)	25.585 (1.268)	33.73 (2.233)	56.43 (2.111)
Nucleotide diversity	π	0.167 (0.011)	0.232 (0.018)	0.102 (0.006)	0.279 (0.021)	0.167 (0.007)
Within pop diversity (unordered)	h_S	0.574 (0.108)	0.565 (0.167)	0.664 (0.047)	0.631 (0.790)	0.631 (0.049)
Within pop diversity (ordered)	v_S	0.391 (0.126)	0.350 (0.138)	0.338 (0.188)	0.415 (0.133)	0.191 (0.061)
Total diversity (unordered)	h_T	0.958 (0.036)	0.972 (0.03)	0.82 (0.063)	0.943 (0.041)	0.941 (0.024)
Total diversity (ordered)	v_T	0.971 (0.215)	0.999 (0.128)	0.845 (0.289)	0.966 (0.062)	0.958 (0.079)
Pop differentiation (unordered)	G_{ST}	0.401 (0.11)	0.419 (0.185)	0.190 (0.054)	0.331 (0.08)	0.329 (0.054)
Pop differentiation (ordered)	N_{ST}	**0.597 (0.134)****	**0.650 (0.12)****	**0.699 (0.136)****	**0.571 (0.132)***	**0.801 (0.06)****
Fixation index (Hudson et al 1992)	F_{ST}	0.525	0.675	0.309	0.626	0.798
Migration rate (Hudson et al 1992)	Nm	0.45	0.24	1.12	0.30	0.13
Tajima's D	D	-0.123 (P=0.583)	-0.08 (P=0.562)	-0.12 (P=0.584)	-0.119 (P=0.584)	-0.125 (P=0.598)
Fu's F_S	F_S	-0.13 (P=0.549)	-0.097 (P=0.532)	0.01 (P=0.542)	-0.083 (P=0.542)	-0.732 (P=0.578)
Ramos-Onsins & Rozas R_2	R_2	**0.103 (P=0)**	**0.112 (P=0)**	**0.099 (P=0)**	**0.107 (P=0)**	**0.088 (P=0)**
IBD (Mantel test)	r	0.371 (P=0.073)	0.331 (P=0.103)	0.22 (P=0.144)	0.008 (P=0.46)	**0.571 (P=0.001)**

Haplotype relationships

Haplotype networks show differing patterns in the respective relationships among haplotypes of each group (Figures 6.1 to 6.3). The haplotype networks of both *P. deflexa* (Figure 6.1) and *P. trachymenioides* SE (Figure 6.2a) formed an approximate star structure, with each containing a single common haplotype, closely aligned with several closely related but less frequent haplotypes, located central (and presumably ancestral) to more distant haplotypes radiating from this group. In comparison, the networks of both *P. effusa* (Figure 6.3) and those of *P. trachymenioides* SW (Figure 6.2b) were more linear in shape, and do not show a central core of haplotypes, but rather, multiple nodes of single haplotypes or haplotype clusters.

Population diversity

Platysace trachymenioides SE had the highest number of haplotypes per population (3.154) of all groups, followed by *P. deflexa* (2.917) (Table 6.3), but there was no difference in number of haplotypes per population among groups (P=0.491) or among species (P=0.583). No pattern in ordered or unordered within-population diversity indices (h_S, v_S) was discernable among the groups, aside from a lower v_S in *P. trachymenioides* across its entire range than in any of the four other groups.

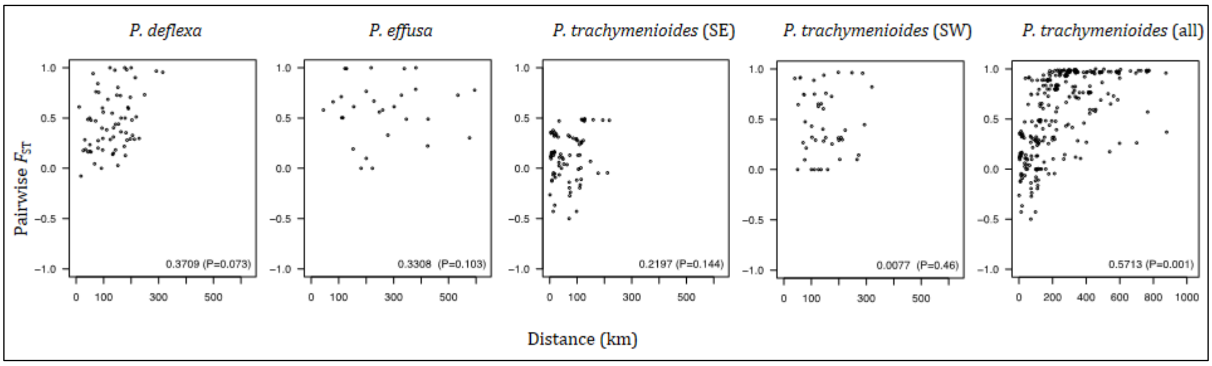


Figure 6.5: Scatterplots of pairwise F_{ST} and geographical distance (km) for populations of *Platysace deflexa*, *P. effusa*, *P. trachymenioides* Note differing x axis scale for *P trachymenioides* (all) than other groups.

The Ramos-Onsins & Rozas R_2 test statistic was significantly low for all groups, indicating population expansion. Both *P. trachymenioides* SE and *P. deflexa* had a lower R_2 statistic than *P. trachymenioides* SW or *P. effusa*, but the lowest R_2 statistic among groups was for *P. trachymenioides* across its entire range (0.088 (Table 6.3). Neither Tajima's D or Fu's *F* statistic were significant for any group, but most values were negative consistent with populations expansion.

Discussion

In light of longheld patterns of occupation and plant resource use of the first peoples of south-western Australia, our results suggest that humans have played a role in past dispersion and contemporary phylogeography of some *Platysace* taxa. While all species (and groups) showed population structure consistent with a hypothesis of local persistence, as expected given the evolutionary history of plants in the region, differences in degrees of structure at an intra-specific level suggest varying levels of anthropogenic influence on each of our study species. A lesser degree of structure in the utilised *P. deflexa* than in the non-utilised *P. effusa* suggests a homogenising influence on the former that is likely to be anthropogenic and that is not present for the latter. Most interestingly, our results revealed an unexpected degree of structuring in *P. trachymenioides*, which included strong differentiation of the SE clade, providing evidence for regional differences in genetic patterns and consistent with a recent population expansion in this part of its range. Varying human use of the species across its range is one explanation for this expansion. Further investigation that targets the timing of this expansion may help to clarify.

Species relationships and divergence in *Platysace trachymenioides*

The phylogeny of cpDNA sequences of *P. deflexa*, *P. effusa* and *P. trachymenioides* shows some complex relationships that likely reflect lineage sorting among these species. Although the major clades contained mixtures of the species, haplotypes were not shared among species, and separation of haplotypes in populations where the species co-occurred indicates no evidence of hybridisation. The close relationship between *P. deflexa* and *P. effusa* means that differing patterns in genetic signals are meaningful. The phylogeny showed a clade with the majority of haplotypes of *P. trachymenioides* that was separated into two clades representing the SE and SW of the distribution. This differentiation within *P. trachymenioides*, provides further opportunity to investigate the differences in genetic signals due to anthropogenic influence.

Platysace trachymenioides SE clade occurs within an area that is broadly consistent with cultural boundaries of the group now known as the Esperance Nyungars, with strong cultural ties with Ngadju to the north (Mitchell 2016). This may indicate that *P. trachymenioides* was more readily eaten in this area than across its entire range. Indeed the only known written record of this species being eaten is from this area (von Brandenstein 1977; von Brandenstein 1988), although a historical description of 'kukine' in the northern SWAFR may also refer to this species (Drummond 1843b). In addition, *P. trachymenioides* SE occurs across an area that is not sympatric with other *Platysace* taxa from which tubers are a known food, and that were likely eaten in preference to *P. trachymenioides* due to superior palatability (see Figure 6.2). It is interesting that *P. trachymenioides* was barely known by contemporary Esperance Nyungars, aside from a suggestion that it is 'desperation food' (Knapp, unpublished) and a recollection of its distinctive smell (Williams-Bennell 2017), indicating that it was not a much-savoured favourite, but rather a food of necessity, predictably occurring in abundance on granites, which were also nodes of occupation.

Genetic patterns of anthropogenic dispersal

Our hypothesis was supported that we would find differing genetic patterns in species that are utilised by Noongar people compared to that in species not utilised. We found the expected patterns of high genetic diversity and differentiation due to localised persistence throughout historical time frames in all species, as is common in species in the SWAFR (Byrne et al. 2014). Superimposed on this background pattern of genetic diversity, we found differing patterns in *P. deflexa* and *P. trachymenioides* SE compared to *P. effusa* and *P. trachymenioides* SW.

The contrasting haplotype networks of *P. trachymenioides* SW and *P. effusa* and those of *P. trachymenioides* SE and *P. deflexa* are particularly informative. The nodal and branched haplotype networks of *P. trachymenioides* SW and *P. effusa* are consistent with a hypothesis of local persistence, limited migration and multiple, localised refugia influenced by multiple climatic oscillations and substrate complexity. While climatic and edaphic conditions, as well as plant life strategies, are analogous across all taxa, haplotype relationships within the *P. deflexa* and *P. trachymenioides* SE groups are not similar to those of *P. trachymenioides* SW and *P. effusa,* contrary to what we would expect for related species with shared evolutionary history. Rather, the respective star-like shape of the networks of *P. deflexa* and *P. trachymenioides* SE, each with a cluster of a common haplotype and closely related haplotypes at its centre, suggests a dispersal vector operating between populations of these taxa that has not been present for *P. effusa*.

Shared haplotypes were present in all populations of *P. trachymenioides* SE, which is counter to usual expectation of a SWAFR granite outcrop endemic, in which we would expect populations to be highly differentiated (Byrne 2008; Moran and Hopper 1983; Tapper et al. 2014b). This may be due in part to more intensive sampling of SE populations than *P. trachymenioides* populations across its full range, but also indicates the presence of a dispersal vector that is not present for most SWAFR granite taxa. Shared haplotypes were also present in *P. trachymenioides* SW populations, although to a lesser extent, which may indicate that human influence on this species extends beyond the SE clade, but simply to a lesser degree. Indeed *P. trachymenioides* is present at many granite outcrops across the entire inland SWAFR, and the importance of granite outcrops as Noongar cultural nodes also extends across this area (Bindon 1997). Comparatively lower estimated migration rates in *P. trachymenioides* SW and across all of *P. trachymenioides* compared to that in *P. trachymenioides* SE also supports differential Noongar use of this food source in the south-east compared to the rest of its range.

We hypothesised that if Noongar people have influenced dispersion of the utilised taxa, we would find evidence of minimal phylogeographic structuring and recent population expansion in the utilised groups, *P. deflexa* and *P. trachymenioides,* but patterns of phylogeographic structure and high diversity in the non-utilised *P. effusa*. A comparatively lower overall nucleotide diversity in *P. trachymenioides* SE and *P. deflexa* than in *P. effusa* and *P. trachymenioides* SW are consistent with an anthropogenic influence on the former, as is the considerably lower haplotype diversity in *P. trachymenioides* SE. Overall haplotype diversity was not comparatively low in *P. deflexa* although this does not rule out anthropogenic influence but rather reflects its cultural complexity, and is discussed in more depth below. Although not significant, the Ramos-Onsins & Rozas R_2 statistics for *P. trachymenioides* SE and *P. deflexa* were lower than those of *P. effusa* and *P. trachymenioides* SW, indicating a human selective pressure (i.e. selective tuber harvest and movement) in these taxa that is absent for the taxa groups never or rarely utilised by Noongars.

Our results suggest a comparatively higher level of population connectivity in *Platysace* taxa in which the tubers have been traditionally harvested by the Noongar than in *P. effusa*. Further, given poor seed germination and unlikely seed dispersal across large distances, movement of genetic material between populations is most likely to have occurred via tubers than other propagules. Two of us (AL and SH) have observed diggings from rabbits around wild populations of *P. trachymenioides* and *P. deflexa*, suggesting animals also consume *Platysace* tubers. However, migration distances make spread between populations appear implausible for any mammal other than humans.

Lower differentiation between populations in *P. trachymenioides* SE compared to *P. deflexa* may reflect differences in mobility of Noongars, with greater movement necessitated by scarcer resource availability in the eastern SWAFR compared to more southern, central parts (Smith 2011b). In the range of *P. trachymenioides* SE, comparative scarcity of food and water resources meant Noongars relied heavily on granite outcrops, limiting the length of occupation at a particular site and the overall population living in that landscape, and likely led to resources being carried further than in more resource rich areas to the south-west. With fewer family groups and less site availability, general patterns of occupation were likely less complex than more southern, central areas, where particular sites were known to be set aside for each family group (Pettersen 2015a). This pattern of occupation would also explain the absence of shared haplotypes between geographically close populations of *P. deflexa* and that overall haplotype diversity was not comparatively low, highlighting that social protocol was an important dictator of Noongar occupation and movement.

Genetic patterns of continual use

Comparatively lower genetic differentiation found for *P. trachymenioides* SE, and to a lesser extent, *P. deflexa* than other groups is consistent with a greater proportion of shared haplotypes in the Noongar-utilised species than other groups (Lowe 2010). This pattern is consistent with high gene flow found in cultural taxa elsewhere in Australia (Bell et al. 2014; Rangan et al. 2015; Rossetto et al. 2017) and suggests multiple introductions. This fits with a seasonal pattern of occupation and movement between sites that is known to have been practiced by Noongar family groups.

Platysace trachymenioides SE and *P. deflexa* had the highest number of haplotypes per population of all groups, suggesting multiple past introductions of migrant individuals consistent with longterm, continuous Noongar patterns of site use. A pattern of higher unordered within-population diversity of *P. trachymenioides* SE, other *P. trachymenioides* and *P. deflexa* compared to *P. effusa*, may also reflect this cultural pattern; however, this was not strong enough to be conclusive, and no patterns were discernable when comparing ordered within-population diversity indices (Pons and Petit 1996). As standard errors of within-population indices were generally high, heterogeneity in sample size, and in some instances, low numbers of individuals per population, may have reduced the reliability of these results, which can be sensitive to sampling artefacts (Hudson et al. 1992).

Regular harvesting of *Platysace* tubers by Noongars would likely promote rhizomatous clonal growth over sexual reproduction by favoring clonal genotypes competing for ecological space, possibly reducing within-population diversity (Binks et al. 2015; Millar et al. 2010). We expect this effect would be further enhanced where selective harvest has been carried out, based on desirable soil or tuber attributes. Lack of a clearly discernable pattern in within-population diversity between groups may be due to a combined effect of harvest (which would reduce diversity) and human-facilitated migration (which would increase diversity). Further studies that consider soil and site conditions as well as tuber attributes (such as size and palatability), and ideally, also consider recombination effects by including nuclear DNA, could help to resolve this. In addition, further comparison of genetic variability across a broader range of cultural and non-cultural plant taxa, with specific attention to the plant resource type (e.g. seed vs tuber) may clarify whether human use has influenced within-population diversity of SWAFR plant taxa.

The historic importance of Marbaleerup (Figure 6.2) as a meeting place for Noongar, Ngadju and surrounding peoples from further afield (Gunn et al. 2017; Mitchell 2016) provides explanation for the very high number of shared haplotypes among *P. trachymenioides* SE populations. Strong archaeological and ethnographic evidence suggests that people regularly travelled long distances to attend meetings at Marbaleerup itself, while granite inselbergs within its close vicinity were used for logistical and ceremonial activities that supported such large gatherings (Mitchell 2016). That all shared haplotypes within the *P. trachymenioides* SE group are present in the Marbaleerup cultural complex (including Marbaleerup, Wittenoom Hills, Egg Rock, Mt Burdett, Marbaleerup Outlier, SE Marbaleerup and NW Marbaleerup) coincides with its cultural prominence as a predictable, abundant and readily transportable food source that could support large gatherings and provide sustenance for long distance travel (see Chapter 7). Further, extensive populations of *P. trachymenioides* recently observed by SH in another Eastern Noongar rock art location (Gunn et al. 2017), the Chiddarcooping cultural complex (not sampled for this study), also supports its importance as a food resource to support periodic large gatherings.

Further considerations

The intra-specific relationships were somewhat unresolved in our phylogeny, suggesting that there may be some hybridisation or incomplete lineage sorting between taxa (Byrne et al. 2002). The lack of clustering of the Dalyup population with other *P. deflexa* populations was particularly surprising and was checked in the field post-analysis for possible mis-identification. However, all identified haplotypes were found to be species-specific, even where multiple species co-occur at close range (*P. deflexa, P. trachymenioides* and *P. effusa* at Lake King and *P. deflexa* and *P. trachymenioides* at Forrestania), indicating that current means of identifying species are likely to be reliable. Tests based on nuclear DNA are usually more powerful than cpDNA due to effects of recombination (Hudson 1992), and could help to resolve lineage sorting. In addition, a further study of the genus that includes other known food taxa, *P. maxwellii* and *P. cirrosa* as well as a second non-tuberous, granite endemic, *P. juncea* (largely confined to granite fissures therefore an unlikely food source) would add further to our understanding of the role of humans in dispersion of the SWAFR's *Platysace* species.

Conclusion

The presence of consistent phylogeographic patterns that reflect a long evolutionary history in complex edaphic conditions in plants of the SWAFR has provided a useful background against which to test the role of humans in *Platysace* phylogeography. However, this complex environmental backdrop combined with nuanced but longterm landscape use dictated by restrictive and other protocols of the Noongar people, indicated from the outset that any detectable patterns relating to human use were likely to be subtle, and therefore dictated our multi-faceted analysis. Variations found between species subject to cultural use and those that were not, particularly in haplotype relationships networks, haplotype and nucleotide diversity, estimation of migration, and tests of population expansion, are all indicative of a human influence on the dispersion of those *Platysace* taxa utilised for food. This study highlights the presence of a long term human influence on south-west Australian biodiversity, and will provide a useful baseline for future phylogeographic studies of the numerous cultural taxa of the SWAFR and other Ocbil-dominated floristic regions. It also highlights the importance of a strong connection between Noongar cultural heritage and biodiversity conservation management in the SWAFR.

Chapter 7: Ecological aspects of *Platysace* (Apiaceae) tuber harvest by the Noongar of south-western Australia

Abstract

Less seasonally restricted and often higher in carbohydrates than other plant resources, root crops are an important staple in many traditional diets of Aboriginal Australia. In many instances root crop taxa have been managed intergenerationally through harvest to optimise resources they provide and demonstrate respect for ancestors. We measured and observed outcomes for soil and plants of tuber harvest for two species of *Platysace* Bunge that have historically been important food staples for Noongar traditional owners of inland south-western Australia. We aimed to test whether Noongar harvest of *Platysace* tubers improved physical and nutrient plant growth characteristics of the soil, and aided tuber availability as has been suggested for other Australian Aboriginal root crops. We found that in harvested quadrats of *Platysace deflexa* soil sulphur and potassium levels were significantly increased compared to control quadrats and that this trend was similar for other soil nutrients, including nitrogen, phosphorus and organic carbon. Harvest resulted in a slight increase in soil bulk density. This result was unexpected, and may reflect our lack of adherence to traditional harvest methods. We found that abundance of *P. deflexa* stems was restored to that recorded pre-harvest within 12 months following harvest. While the weight and volume of tubers had not returned to pre-harvest levels two years after harvest, this was expected given that traditionally harvest would not be repeated for at least four years. A higher proportion of small tubers in harvested than previously unharvested quadrats suggests that harvesting has a renewing and homogenizing influence on *Platysace* tuber crops. Finally, site-based differences in post-harvest stem abundance, and tuber volume, mass and abundance in *P. deflexa* and *P. trachymenioides* indicate that particular *Platysace* populations were likely preferentially harvested over others due to superior crop abundance and/or palatability.

Introduction

Root crops are generally carbohydrate-rich and less seasonally restricted than many seed or fruit resources in traditional Aboriginal Australian diets (Gott 1982; Gott 2005). Continent-wide, many were reliable emergency and/or staple components of pre-colonial Aboriginal Australian diets (Gott 1982; Gott 2005; Hallam 1989; Head et al. 2002; Hynes and Chase 1982; Meagher 1974; Russell-Smith et al. 1997; Veth and Walsh 1988; Walsh 1990), and continue to remain important bush foods (Head et al. 2002; Hopper and Lambers 2014; Lullfitz et al. 2017; Russell-Smith et al. 1997; Walsh 1990; Yibarbuk 2001). In many instances, patches of root crop plants managed through vegetative reproduction, have become heritable assets passed from generation to generation (Barton and Denham 2016; Hallam 1989; Hynes and Chase 1982), and sometimes linked to ancestral beings (Head et al. 2002; Hynes and Chase 1982; Walsh 2008). Underground plant parts eaten as root crops include tubers (e.g. *Dioscorea* species), rhizomes (e.g. *Typha domingensis*), corms (e.g. *Burchardia umbellata*) and bulbs (e.g.

Haemodorum species) (Drummond 1843b; Gott 1982; Gott 2005; Hallam 1989; Hallam 1991; Head et al. 2002; Hynes and Chase 1982; Veth and Walsh 1988).

Root crop taxa commonly reproduce asexually from underground propagules, and consequently, often occur in dense clumps, meaning that small patches can be targeted to efficiently acquire large food volumes (Gott 1982; Walsh 1990). It has been suggested that Aboriginal harvest of root resource plants has promoted localised reproduction and increased their density in concentrated patches through exploitation of these ecological attributes (Denham 2008; Gott 1982; Hallam 1991; Pascoe 2014). Hallam (1989); Hallam (1991) suggested that well-documented intensive harvesting and husbandry of *Wuagarn (Dioscorea hastifolia)* by west coast Noongars (e.g. Grey 1841b; Moore 1884) resulted in highly productive patches of this tuberous plant occurring close to residential sites, extending resource availability and promoting sedentism. Hallam (1991) recognised that *Wuagarn* patches near modern-day Perth were so fixed and well-defined that they were documented on early settler maps (e.g. Chauncey 1878). Likewise in south-eastern Australia, Pascoe (2014) suggested that cultivation through harvest, soil tillage and firing of the root crop, *Murnong (Microseris lanceolata)*, was instrumental in a sedentary existence among the Wathaurong and other Aboriginal peoples of modern-day Victoria.

Specific ecological mechanisms whereby Aboriginal harvest has improved root crop production have been proposed. It is suggested that digging of the soil aerates and loosens the soil, improving conditions for seed germination, root penetration and rain water saturation, encourages desirable phenotypic responses such as tuber growth, incorporates litter into soil, deepens and removes rock from the soil profile, and breaks up underground propagules to aid reproduction (Denham 2008; Gott 1982; Gott 2005; Hallam 1989; Head et al. 2002; Walsh 2008). In the case of Noongar exploitation of *Dioscorea hastifolia,* Hallam (1989) suggested that nutrient-rich, alluvial locations were targeted by Noongar for *Dioscorea hastifolia* harvest, and possibly, population establishment. Gott (1982) suggested that targeted firing and selective rhizome propagation of *Typha* species by southern Australian Aboriginal peoples enabled biomass to be removed and controlled, allowing thinned, superior rhizomes to grow. She also suggested that tuber harvest promoted rhizomatous growth in *Cycnogeton lineare,* that Aboriginal firing promoted rhizomatous growth of *Pteridium esculentum* and root growth of the south-east Australian staple, *Murnong (Microceris lanceolata)*. Through facilitating vegetative reproduction over sexual reproduction, root crop harvest likely encouraged the growth of new, palatable tubers, corms or rhizomes over older ones (Pascoe 2014). It may also have reduced phenotypic variation, and possibly genotypic variation through clonal growth, thereby increasing resource homogeneity (Denham 2008). A propensity for vegetative reproduction has enabled transport and propagation of root crop taxa at preferred locations for human utility (Barton and Denham 2016; Gott 1982; Hallam 1989; Hynes and Chase 1982; Russell-Smith et al. 1997; Shipek 1989; Silcock 2018).

In contemporary northern Aboriginal Australia, root crop harvest practices include intentional re-planting of vegetative propagules for *Dioscorea*, *Ipomaea* and other root crops (Head et al. 2002; Hynes and Chase 1982; Russell-Smith et al. 1997), and deliberate leaving of a depression on the ground surface to aid concentration of water, nutrients and litter at a yam site (Head et al. 2002). Head et al. (2002) recorded a decline in yam production at one site, attributed in part to Aboriginal harvest having recently reduced, and also recorded propagules being deliberately transplanted to a more easily accessed site. Yen (1989) recorded targeted harvesting of 'bush potatoes' (possibly *Ipomoaea costata*) at disturbed road verges and railway edges, and suggested that such practice was based on a traditional understanding that tillage increased root production. Soil mounds in the archaeological record in Victoria have also been attributed to root crop production, likely *Microseris lanceolata* (Balme and Beck 1996; Silcock 2018).

Historical and contemporary accounts, as well as our own first-hand experiences, indicate that root crop harvest generally requires substantial commitment of time and labour (Hallam 1989; Head et al. 2002; Meagher 1974) and was a regular task for much of the year (Denham 2008; Hallam 1989). Occurrence of root crop taxa in intensive patches probably facilitated sharing of labour, caring for young children and opportunities for social interaction among women, who usually are primarily responsible for root crop husbandry and harvest (Gott 1982; Hallam 1989; Hallam 1991; Hassell 1975; Head et al. 2002; Walsh 1990).

Tubers of four species of *Platysace* Bunge, were a staple food source for Noongar in pre-colonial inland south-western Australia, and are still known and/or utilised by contemporary Noongars. *Platysace* is a small genus of perennial, herbaceaous or small shrubs, pollinated by insects and only occurring on the Australian continent (Hart and Henwood in press; Henwood and Hart 2001). Noongar-utilised species are *joowaq (P. deflexa)* (Hassell 1975; Nind 1831), *P. maxwellii* (Meagher 1974), *P. trachymenioides* (von Brandenstein 1977; von Brandenstein 1988), and *conna* or *karno (P. cirrosa)* (Drummond 1853a; Moore 1884; Nannup 2014). *Platysace* have been found difficult to propagate from seed or transplants (Keighery 1982; Woodall 2010). However *P. deflexa* and *P. trachymenioides* sucker readily from a rhizomatous root, particularly in disturbed soil (Woodall 2010, AL unpublished field notes). While *Platysace deflexa* requires well-drained, sandy soils (Woodall 2010), *P. trachymenioides* usually occurs in sand or loam adjacent to granite outcrops (see Chapter 6).

Historical and contemporary accounts, suggest that *Platysace* harvest was a regular activity causing considerable, localised soil disturbance in south-western Australia. Hassell (1975) described the regular and intensive harvest of *Joowaq* (*P. deflexa*) by Noongar women, and consequent high soil turnover near Jerramungup in the 1880s. She linked plentiful *Joowaq* with high numbers of people, and described a large group of women and children near Jerdacuttup, camped for at least several weeks and harvesting *Joowaq* from an extensive patch. Earlier, Eyre (1845) and his Menang Noongar companion Wylie observed in June 1840 similar harvesting by women and a boy west of the Young

River. Meagher (1974) recorded first-hand observations of Aboriginal women from Mingenew harvesting 84 tubers from a single *P. maxwellii* plant by digging to a depth of approximately half a metre. She also observed preferential harvest of younger tubers. In Albany, Barker (1831) observed pre-existing proficiency in the propagation of colony-introduced root crops by Noongar in Albany. We have observed three Noongar-utilised *Platysace* taxa growing in dense patches that often coincide with important cultural places in south-western Australia (Lullfitz et al. 2017 (Chapter 2)), and phylogeography of *P. deflexa* and *P. trachymenioides* suggests a human role in their distributions (see Chapter 6). Both our Noongar Elder co-authors (Carol Pettersen (CP) and Lynette Knapp (LK)) are familiar with several *Joowaq* patches to which they regularly return for harvest. So do Noongar *Platysace* staple root crops respond positively when harvested, as proposed for some Aboriginal root crops elsewhere in Australia?

We aimed to test whether Noongar harvest of *Platysace* tubers improved physical and nutrient plant growth characteristics of the soil, and aided further *Platysace* tuber production. To test this, we measured soil chemical attributes and bulk density prior to harvest, and then two years following harvest of *P. deflexa* in paired harvested and unharvested quadrats, to detect any changes in soil characteristics that may be attributable to harvest. Secondly we tested whether plant abundance was greater in harvested than unharvested *P. deflexa* quadrats. We also tested whether the size of the tuber crop (measured by mass and volume) was increased through harvest-induced soil disturbance, and whether harvesting encouraged growth of more palatable, younger tubers over tough, older tubers. Finally, we made field observations of abundance, tuber quality and quantity in harvested and unharvested quadrats of *Platysace trachymenioides* three years after initial harvest.

Methodology

Platysace deflexa harvest

Dense patches of *Platysace deflexa* at nine sites in the Boxwood Hill area of southern Western Australia were chosen to conduct the harvest experiment (Figure 7.1, Table 7.1). All sites were located in road reserves in areas that included several large tracts of native vegetation interspersed with cleared land under broadacre agriculture production. Average annual rainfall ranges from 406 mm to 452 mm at weather stations located within the study area, with most occuring in the months of April through September (Bureau of Meteorology 2018). At each site two square quadrats of 1m^2 were established within 5 m of one another.

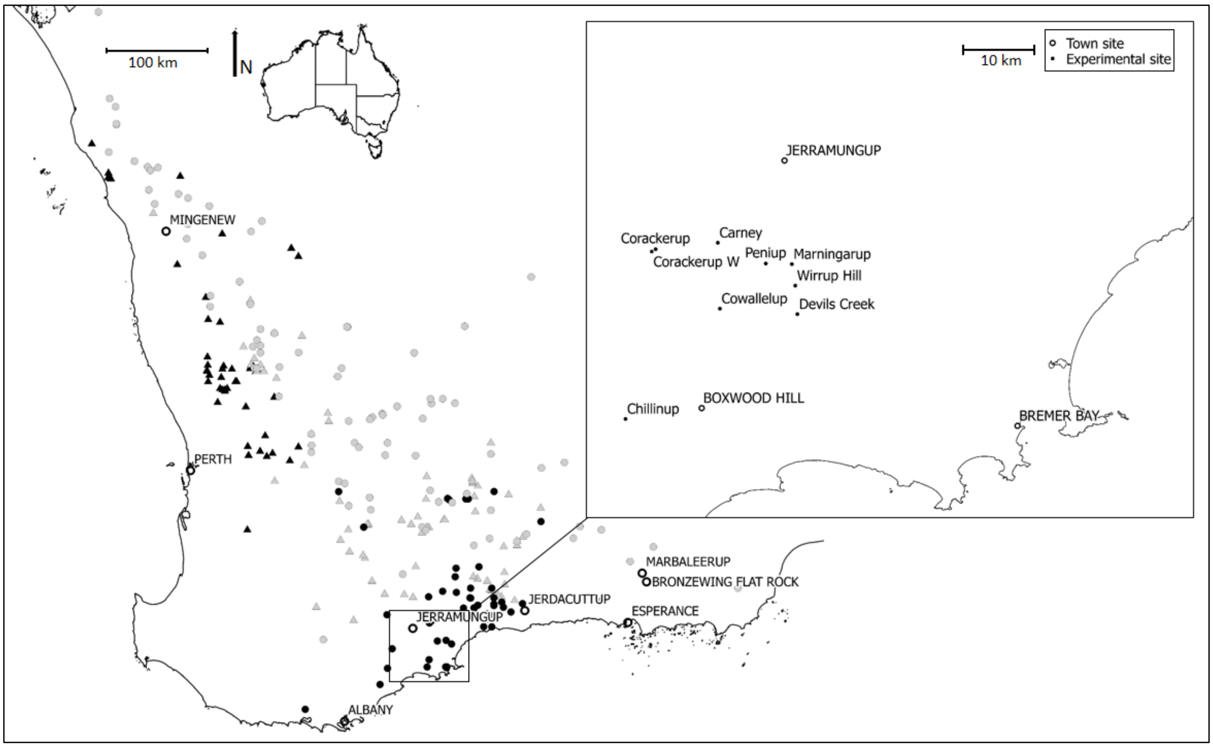


Figure 7.1: Map of study area (inset), towns and places mentioned in the text (open circle) and WA herbarium collection records for *Platysace deflexa* (black circle), *P. trachymenioides* (grey circle), *P. maxwellii* (grey triangle) and *P. cirrosa* (black triangle).

Table 7.1: Characteristics and location of *P. deflexa* quadrat sites.

Site name	Latitude	Longitude	Site description and vegetation	Soil
Chillinup	34.3811	118.5898	Kwongkan with emergent mallee, including *Eucalyptus incrassata, E. pleurocarpa, Calothamnus quadrifidus, Isopogon buxifolius,* numerous Myrtaceae and Proteaceae small shrubs.	Brown loamy sand
Devil's Creek	34.2039	118.9420	Open *Allocasuarina huegeliana* woodland with sparse understorey including *Hakea laurina, Grevillea nudiflora, Dianella revoluta* and numerous introduced weeds including extensive *Eragrostis curvula*.	Grey loamy sand
Wirrup Hill	34.1555	118.9378	Kwongkan with emergent mallee, including *Eucalyptus captiosa, E. pleurocarpa, Lambertia inermis, Exocarpos sparteus, Isopogon buxifolius,* numerous Myrtaceae and Fabaceae small shrubs.	Light grey sand
Marningarup	34.1191	118.9307	Kwongkan with emergent mallee, including *Eucalyptus captiosa, E.* aff. *annulata, E. pleurocarpa, Calothamnus quadrifidus, Acacia cyclops, Grevillea nudiflora,* numerous *Thelymitra crinita*, other Myrtaceae small shrubs, and introduced grasses (e.g. *Eragrostis curvula, Avena fatua*)	Grey loamy sand
Peniup	34.1181	118.8773	Kwongkan with emergent mallee, including *Eucalyptus* aff. *annulata, E. pleurocarpa, Isopogon formosus, Lambertia inermis,* numerous other small Proteaceae and Myrtaceae shrubs. Adjacent to *E. occidentalis* woodland in minor creek.	Light grey sand
Carney	34.0828	118.7789	Very dense low kwongkan with emergent mallee, including *Eucalyptus sinuosa, E.* aff. *annulata, E. pleurocarpa, Hakea corymbosa, Exocarpos sparteus, Allocasuarina humilis, Dryandra formosus, Daviesia pachyphylla*, numerous Proteaceae small shrubs.	Gravelly brown loamy sand
Corackerup	34.0937	118.6515	Low kwongkan with emergent mallee and *Allocasuarina huegeliana,* including *Eucalyptus* aff. *uncinata, Grevillea tetragonoloba, Calothamnus quadrifidus, Exocarpos sparteus, Isopogon formosus, Allocasuarina humilis* and numerous Myrtaceae small shrubs.	Light brown sand
Corackerup W	34.0978	118.6436	Low kwongkan with emergent mallee and *Allocasuarina huegeliana,* including *Eucalyptus* aff. *uncinata, Isopogon buxifolius, Calothamnus quadrifidus, Exocarpos sparteus, Allocasuarina humilis* and numerous Myrtaceae small shrubs.	Brown loamy sand
Cowallelup	34.1945	118.7832	Kwongkan with emergent mallee, including *Eucalyptus pleurocarpa, Calothamnus quadrifidus, Exocarpos sparteus, Isopogon formosus, Acacia myrtifolia,* and numerous myrtaceous shrubs	Brown loamy sand

In July 2015, *P. deflexa* tubers from one quadrat at each site were harvested (referred to subsequently as 'harvest quadrats'), while the other quadrat was left unharvested as a control (referred to subsequently as 'control quadrats'). This was carried out by Alison Lullfitz (AL) following discussion and approval from CP and LK, who were not present during the harvest. Prior to harvest, the number of individual stems of *P. deflexa* plants were counted in both quadrats. Due to high clonality, it was difficult to define each individual *P. deflexa* plant, thus total number of stems in each quadrat were counted as a measure of abundance. Also prior to harvest, a soil sample for chemical analysis and a second 293 cm^3 soil core for bulk density analysis were taken from the SW corner of each quadrat.

Harvesting comprised digging the entire $1m^2$ quadrat to a depth of 50 cm using a traditional *wana* (digging stick) and removing all *P. deflexa* tubers growing within this area. The number, mass and volume of harvested tubers from each quadrat was recorded. Soil cores were oven dried at 110°C for 12 hours and then weighed for calculation of bulk density (Hunt and Gilkes 1992). Soil samples were sent to the CSBP soil and plant laboratory in Bibra Lake, Western Australia for chemical analyses, including phosphorus (Colwell), potassium (Colwell), sulphur (KCl 40), organic carbon (Walkley Black) and ammonium nitrogen.

Platysace deflexa stems in each harvest and control quadrat at all sites were counted in July 2016. Stems were counted and soil samples and cores taken (as per 2015) from the NW corner of all quadrats in July 2017. Harvesting of *P. deflexa* tubers from all control and harvest quadrats was undertaken by AL under the field supervision of CP. In addition to total number, mass and volume of harvested tubers, number of small tubers (less than 2.5 cm in diameter) in each quadrat was recorded. Bulk density of all 2017 soil cores was measured (as per 2015) and soil chemical analyses were repeated for 2017 soil samples, again by the CSBP soil and plant laboratory.

All statistical analyses were carried out in R (R Core Team 2016). For each quadrat, the change in bulk density, phosphorus, potassium, ammonium nitrate, sulphur and organic carbon from 2015 to 2017 was calculated. A paired Mann Whitney *U* test was carried out for the control and harvest quadrats for each parameter to determine whether there had been significant changes during this period.

Paired Mann Whitney *U* tests were conducted to test for difference in *P. deflexa* stem abundance between control and harvest quadrats in each year (including both pre- and post-harvest in 2015), and also for difference between years for both control and harvest quadrats. The same tests were also undertaken to test for differences in mass and volume of harvested tubers between 2015 and 2017 harvest quadrats, and between respective harvest quadrats from both years and 2017 control quadrats. Finally, a paired Mann Whitney *U* test was carried out to determine whether the proportion of small tubers (diameter<2.5 cm) differed between the 2017 harvested control and harvest quadrats.

Platysace trachymenioides harvest

During a collaborative field school with Esperance Nyungar traditional owners in February 2014, several small plots (approximately $1m^2$) of *Platysace trachymenioides* were harvested close to two culturally important granite outcrops, Marbaleerup and near Bronzewing flat rock, 60 km inland from the town of Esperance. Two harvested sites at Marbaleerup were revisited in November 2017, at which time, tubers were harvested from these plots and from plots immediately adjacent that had not been harvested in 2014 but were in the same patch. Observations of tuber size, shape and palatability were recorded from the previously harvested and unharvested plots at each site.

Results

Platysace deflexa harvest

In the control quadrats, nitrogen, sulphur and potassium levels decreased and organic carbon and phosphorus levels did not change from 2015 to 2017 soil samples (Figure 7.2, Table 7.2). In the harvest quadrats, there was no significant change in soil nutrient parameters between 2015 and 2017 samples. Our comparison between harvest and control quadrat soil samples found that sulphur and potassium level reduction from 2015 to 2017 was significantly greater for control than harvest quadrats. While soil bulk density in control quadrats remained unchanged, it significantly increased in harvest quadrats from 2015 to 2017. However, not enough for bulk density increase to be significantly different to that in control quadrats (Figure 7.2, Table 7.2).

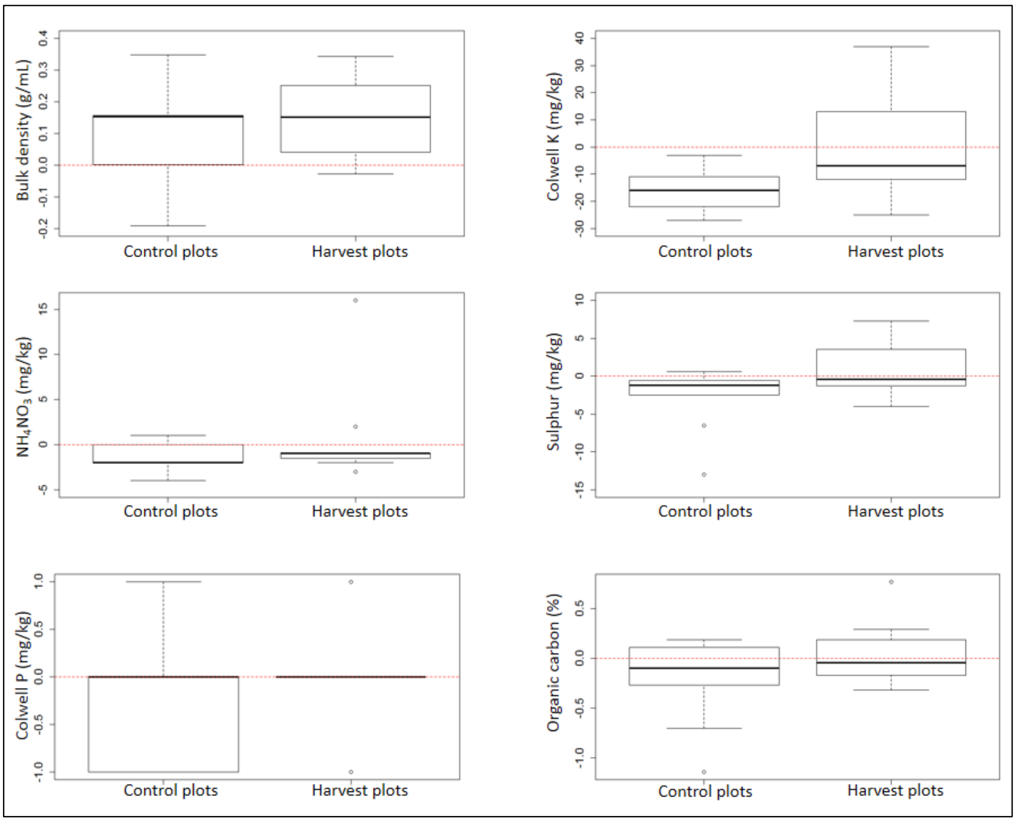


Figure 7.2: Box and whiskers plots showing median and interquartile range of change in soil parameters in control quadrats and harvest quadrats for *Platysace deflexa* from 2015 to 2017. All samples were taken prior to harvest being carried out.

Table 7.2: Results of Mann Whitney *U* tests for change in soil physical and chemical characteristics between 2015 and 2017 for control and harvest quadrats, and difference between 2015-17 soil change in control quadrats and harvest quadrats. Significance: * p≤0.05, ** p≤0.01.

Parameter	2015-17 change Control quadrats	2015-17 change Harvest quadrats	Change difference between control and harvest quadrats
Bulk density (g/mL)	none	increase*	none
Ammonium nitrate (mg/kg)	decrease*	none	none
Colwell Phosphorus (mg/kg)	none	none	none
Colwell Potassium (mg/kg)	decrease**	none	harvest<controls*
Sulphur (mg/kg)	decrease*	none	harvest<controls*
Organic carbon (%)	none	none	none

We found no significant change in *Platysace deflexa* stem abundance in control sites from year to year, nor between harvest quadrats prior to harvesting in 2015, in 2016 or 2017 (Figure 7.3). There was also no difference between control or harvest quadrats in any given year, besides in 2015 immediately following harvest when no stems remained in the harvest quadrats. In 2016 and 2017, we generally observed more stems close to harvest quadrat perimeters that appeared to have originated from rhizomes of adjacent plants outside of harvested quadrats, although in most harvest quadrats, some small stems were dispersed throughout each quadrat (Figure 7.4).

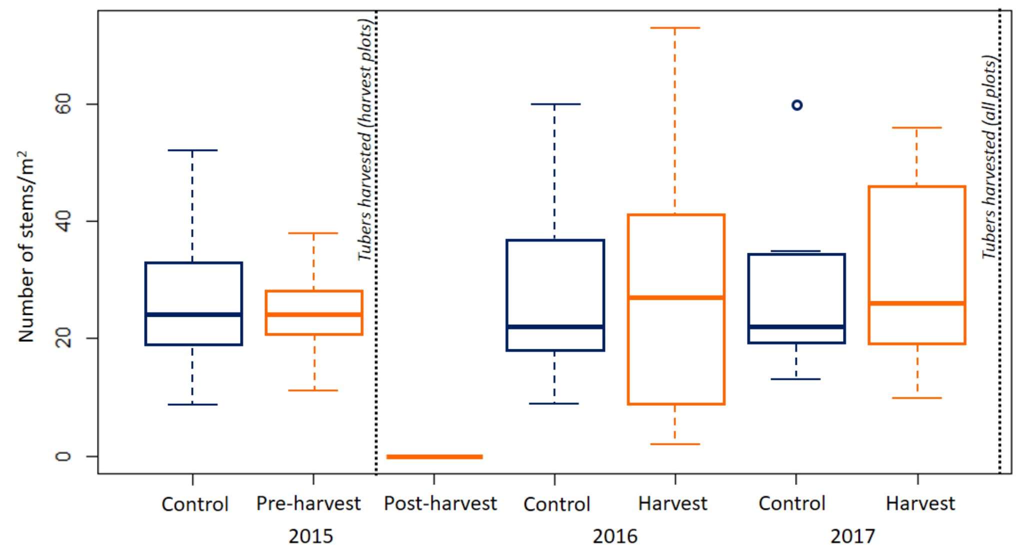


Figure 7.3: Box and whiskers plots showing median and interquartile range of number of stems per m^2 in control and harvest quadrats for *Platysace deflexa* in each experiment year.

Figure 7.4: (Clockwise from top left) CP at Peniup *Platysace deflexa* control quadrat in 2017; CP at Peniup *P. deflexa* harvest quadrat in 2017; rhizomatous growth from *P. deflexa* tuber harvested from Peniup harvest quadrat; new *P. deflexa* tubers at edge of Devils Creek harvest quadrat in grey, loamy sand; total *P. deflexa* tubers harvested from Peniup harvest quadrat; small tubers in *P. trachymenioides* harvest plot in water-shedding red clayey loam site at Marbaleerup; large tubers of *P. trachymenioides* harvest plot in water-gaining deep, grey sand site at Marbaleerup (book dimensions 15 cm x 21cm).

Both the mass and volume of tubers harvested in 2017 from harvest quadrats were significantly less than those of tubers from harvest quadrats in 2015 and the control quadrats in 2017 (Figure 7.5). In 2017 the total number of tubers harvested from the control quadrats (median=44) did not differ significantly from those harvested from the harvest quadrats (median=36). However, the proportion of small tubers (diameter<2.5 cm) in the 2017 harvest quadrats (median=90%) was significantly greater than in the control quadrats (median =54%) (Figure 7.6).

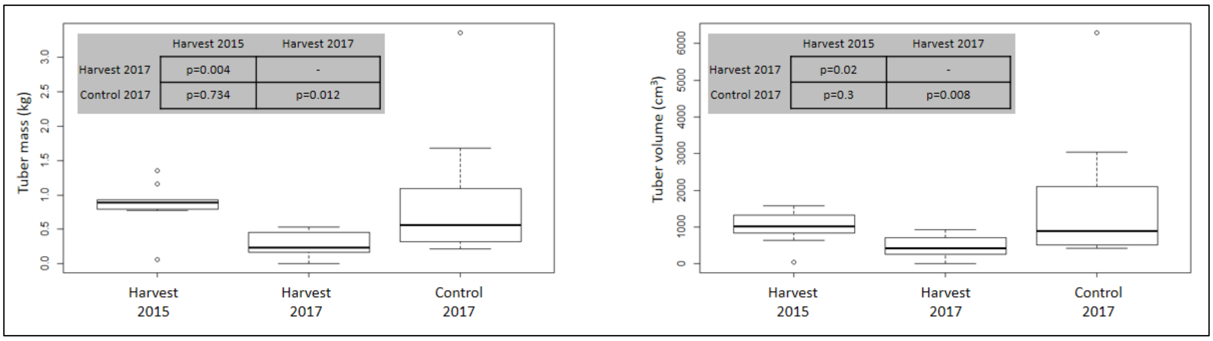


Figure 7.5: Box and whiskers plots showing median and interquartile range of mass and volume of *P. deflexa* tubers harvested from harvest quadrats in 2015 and 2017 and from control quadrats in 2017. Results of paired Mann Whitney *U* tests shown in top left corner.

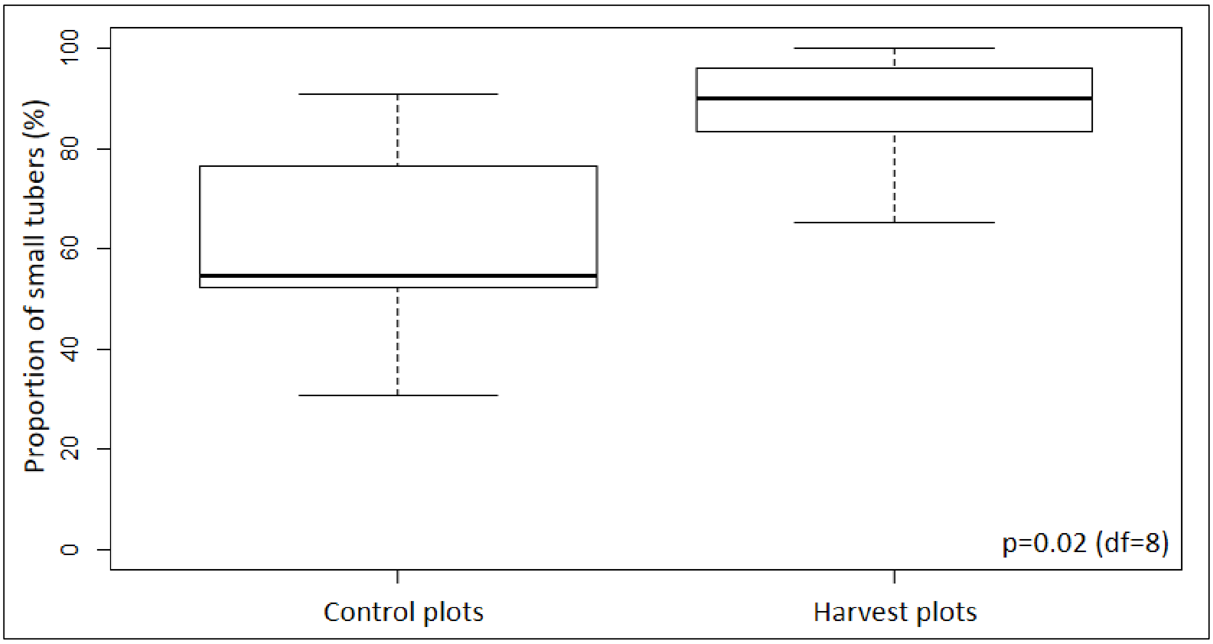


Figure 7.6: Box and whiskers plots showing median and interquartile range of proportion of small *Platysace deflexa* tubers (diameter<2.5 cm) in total number of tubers harvested from control and harvest quadrats in 2017.

Platysace trachymenioides harvest

In 2017, we observed several differences between *Platysace trachymenioides* tubers harvested from plots that had been previously harvested in 2014 and adjacent unharvested plots, particularly in one patch located in a water-gaining site in deep sand below an overstorey of *Allocasuarina huegelliana.* Tubers dug from the previously harvested plot were more numerous and more consistent in appearance of shape and compared to those in the unharvested plot (Figure 7.4). We also noted substantial differences in tuber yield from plots between this and another patch at the same granite outcrop located higher upslope in gravelly, red clay loam below *Thryptomene australis* subsp. *brachyandra*. The latter yielded very few small tubers in comparison to the former, from which many large tubers were dug.

Discussion

Harvest effects on soil and plant attributes

Soil chemical results of this experiment, particularly a significant decrease in soil nitrate, phosphorus and sulpur in *Platysace deflexa* control plots remains unresolved to us, and may need a more replicated and longer experiment to understand causal factors that may be associated with year to year seasonal variation. However, elevated soil sulphur and potassium levels and an overall general trend of soil nutrient elevation in harvest compared to control quadrats suggests that harvesting of tubers may have had a positive influence on soil nutrient levels. It would appear that disturbance of the soil may have encouraged release of nutrients through stimulation of soil microorganisms and other biochemical processes (Brady and Weil 2008). This concurs with suggestions that aeration and incorporation of litter in the soil during harvest has a positive influence on soil plant growth conditions for traditional root crops (Gott 1982; Gott 2005; Head et al. 2002). A slight increase in bulk density of harvest quadrats from 2015 to 2017 was counter to suggestions that harvest would result in loosening (Gott 1982) and increased friability of soil (Pascoe 2014), and is discussed further below.

We found that one year after harvest of *Platysace deflexa* tubers, stem abundance was restored to pre-harvest levels. This was similar to findings of Gott (2005) that 75% of pre-clearing density was restored 14 months after experimental digging for tubers of *Pterostylis nutans*. While abundance of *P. deflexa* was quickly restored, the volume and mass of tubers had not restored to pre-harvest amounts two years after harvest. This result was expected by Noongar Elder co-authors (CP and LK), who would not return to harvest *P. deflexa* tubers from a site less than four years after a previous harvest.

A higher proportion of small *Platysace deflexa* tubers was harvested from harvest quadrats than control quadrats in 2017, indicating that harvesting had a significant positive tuber renewal effect. We observed a similar harvest effect in *P. trachymenioides* at Marbaleerup, where tubers were straighter and more uniform in the previously harvested quadrat than where we had not already harvested (Figure 7.4). To this end, as suggested for other taxa (Denham 2008; Pascoe 2014), we expect that regular harvest of *Platysace* patches would have a homogenizing effect on tuber size and shape, and also have positive outcomes for palatability due to younger tuber age.

Greater variability between sites in *Platysace deflexa* stem abundance following harvest than prior (Figure 7.3) suggests that response to harvest is affected by site factors. In other parts of Australia, particular root resource patches are known as being especially productive or for palatability or size of their crops (Head et al. 2002; Walsh 1990). For *Platysace*, site factors such as soil type, slope and corresponding water gaining characteristics may influence tuber productivity of sites and response to soil disturbance. We observed considerable variation in the number and quality of tubers harvested among *Platysace trachymenioides* quadrats three years after harvest. Quadrats in a water-gaining location in deep, easily dug sand below *Allocasuarina huegeliana* yielded tubers that were larger, more numerous, and more regular in size and shape than quadrats in the higher slope location in red clayey loam below *Thryptomene australis,* which yielded very few small tubers (Figure 7.4). It would be surprising if such observations of variability were not made by long past Noongar, and we expect that patches of *Platysace* would have been differentially targeted as a result. Those offering easier digging, greater production and more comfortable conditions were likely more regularly harvested than others, leading to positive feedbacks to tuber production over long periods. A larger scale collaborative harvest experiment that includes greater replication and a longer time period than ours may help to unravel further aspects of variation in site-based harvest feedback mechanisms for both tuber and soil characteristics.

A collaborative approach

Design of this experiment, particularly for harvest quadrats to be dug in entirety to ensure removal of all tubers, was intended to standardise the area from which tubers were removed enabling comparison of yield between quadrats. While small, the size of quadrats reflected the area of disturbed soil observed during contemporary Noongar harvest. However, this approach to tuber harvest did not necessarily reflect traditional harvest methodology but was more akin to traditional European methods of cultivation 'in straight lines'. This point was made to AL by CP during her supervision of the 2017 harvest, who suggested that a more traditional method would be to dig along the roots of *P. deflexa* to find the tubers, resulting in a more linear soil disturbance over a greater area than our 1m^2 quadrats. Our observations of greater post-harvest stem growth at the perimeters rather than middle of quadrats suggests that more linear soil disturbance described by CP and previously by Hassell (1975) would likely lead to a more rapid recovery of *Platysace* than we found in this experiment.

While Gott (1982) suggested that harvest of root crops has a loosening effect on soil and Pascoe (2014) pointed to early colonial account of friable soil resulting from traditional *Murnong* harvest, agricultural tillage based on European methods is usually expected to have a compacting effect on soil, reflected by high bulk density (Brady and Weil 2008). The post-harvest bulk density increase in this study, may be because our harvest method did not entirely replicate Noongar methodology but was more 'white-fella' in approach, as suggested by CP in the field. This scenario is reminiscent of Pascoe's (2014) south-east Australian example of a demonstration by Aboriginal traditional owners to colonialists of their traditional cultivation technique that would minimise soil erosion as an alternative to English ploughing. It highlights the importance of collaboration between traditional owners and conservation scientists at all stages of research of this nature, and also the conservation value of local traditional ecological knowledge application.

Other considerations

In the Keep River area of northern Australia, Head et al. (2002) noted a symbiotic co-occurrence of *Dioscorea* yam procurement and quarrying, where rocks dug up during excavations for yams were stockpiled, providing ready access to flaking stone. When harvesting *Platysace trachymenioides* at Bronzewing flat rock, where an abundance of *P. trachymenioides* coincides with elaborate Nyungar-constructed stone arrangements, we noted numerous small granite boulders of similar size to arranged stones during digging. Our observation at Bronzewing flat rock suggests the possibility of a similar symbiosis between Nyungar ceremonial and subsistence activities here.

Finally, in this experiment, we did not set out to test the likelihood of population establishment through the movement and planting of *Platysace deflexa* tubers. However, following consultation with Elders, approximately 20 small tubers that were harvested in 2017 were planted in previously disturbed, light grey sand in mallee emergent kwongkan on AL's property at Boxwood Hill. To date, this has resulted in germination of six *P. deflexa* plants. It demonstrates that, despite difficulties encountered by others to germinate *P. deflexa* (Keighery 1982; Woodall 2010), new population establishment is relatively easy in appropriate soil and site conditions, and was plausibly, and indeed, likely undertaken by pre-colonial Noongars.

Conclusion

These results suggest that Noongar *Platysace* tuber harvest in south-western Australia may have had soil nutritional outcomes conducive for plant growth, and positive outcomes for abundance of *Platysace* plants. As Noongar Elders advocate a four year interval between harvests, the decrease in tuber volume and mass after two years that we found was not unexpected. We suggest that a longer harvest interval may have yielded more substantial tuber crops. Renewal and resetting of tuber age following harvest likely homogenised crops and increased their overall palatability, given our finding of more small tubers among harvested than unharvested quadrats. Finally, based on our finding of differential responses to harvest between sites, *Platysace* populations offering easy-to-dig soil and superior productivity were probably targeted by Noongar more often than others, resulting in positive feedback responses to tuber production at these sites. We recommend further experimental work to clarify such feedback responses and to identify heavily harvested sites of the past.

Chapter 8: Conclusion

Existence of a highly diverse flora of ancient lineage (Hopper et al. 1996) following at least 48,000 years of human occupation (Turney et al. 2001) suggests that pre-colonial Noongar custom was largely congruous with conservation of the SWAFR's biological diversity and processes. This thesis presents research on Noongar residential and management patterns in relation to landscape; contemporary distributions of plant taxa at community, species and intraspecific levels analysed in combination with ethnographic and archaeological evidence; and ecological outcomes of a traditional Noongar disturbance process. The aim of such research was to further scientific understanding of pre-colonial Noongar influences on south-west Australian biota to inform a shared approach to contemporary biodiversity conservation in the SWAFR. To this end, a summary of findings in relation to Noongar niche construction activities and their relevance to contemporary biodiversity conservation is presented in Table 8.1.

Table 8.1 Key findings regarding Noongar niche construction activities and their potential application to contemporary biodiversity management in south-west Australia.

Finding	Application to contemporary biodiversity management
Noongar custom comprises differential use and importance of landscapes in southwestern Australia. This includes a general trend of greater soil and vegetation disturbance activity in Yodfels and lesser (often restricted) use of Ocbils.	Reinstatement of this high level Noongar approach to differential landscape use as a general principle across multiple aspects of contemporary human occupation (e.g. prescribed burning, location of infrastructure, visitor management in fragile places) is likely to maximise positive outcomes for native plant conservation of south-west Australian landscapes.
Patterns in contemporary distribution of Noongar cultural plants (e.g. *Platysace* food species, *Macrozamia dyeri*) may be useful for understanding pre-colonial Noongar occupation and disturbance patterns, and are meaningful to Noongar cultural identity.	Increased understanding of botanical indicators of past occupation sites and disturbance activities may be useful in identifying places of particular cultural importance and for understanding fire and other disturbance history to guide contemporary or future site use. Noongar inclusion in decision-making regarding placement of cultural taxa in ecological restoration may result in increased human connectedness to future restored landscapes.
Congruent with a naturally high botanical heterogeneity of southwestern Australia and in line with the locally specific nature of Noongar custom, Noongar management and use of cultural plants appears variable across species ranges and to have a high degree of local specificity.	Inclusion of local Noongar knowledge and people in biodiversity management may result in optimal decision-making and methodology appropriate to local landscapes and conditions.
Cultural plants may have greater genetic homogeneity than those of minimal Noongar significance.	May be more latitude in translocation of plant species that have a long shared history with humans than those that do not.

Research findings demonstrated through several lines of enquiry that Noongar relationships with south-west Australian biota have had ecological and evolutionary influence in the SWAFR. Also evident was that ecological disturbance resulting from pre-colonial Noongar activities was not homogeneous across SWAFR landscapes but concentrated in particular places, probably resulting in plant community alteration at such locations. Although intensive management, including firing, of some sites probably resulted in removal of some plant taxa, evidence presented here suggests that pre- and early-colonial patterns of Noongar use of landscapes were broadly consistent with plant conservation. Also apparent is that Noongar custom reflects the extraordinary floristic heterogeneity within the SWAFR.

Patterns of Noongar landuse and biodiversity conservation

An analysis of knowledge held by contemporary southern coastal Noongar Elders outlined in Chapter 3 found that most disturbance-inducing Noongar activities (e.g. associated with campsites, firing of country) were traditionally carried out in young, often disturbed, fertile landscapes (Yodfels) rather than old, climatically buffered, infertile landscapes (Ocbils). Noongar Ocbil activities were more likely of a special-purpose nature, often restricted to particular individuals and linked to creation stories and ceremony. Thus, like for other indigenous people globally (Bhagwat and Rutte 2006; Huber and Zent 1995) it was found that the symbolic importance of Noongar places appeared linked to biodiverse fragile landscapes, and that Noongar traditional ecological knowledge broadly reflects a biodiversity conservation strategy congruent with Ocbil theory.

The restrictive and locally-specific nature of Noongar custom reflects a geopolitical system aligned with exceptional local endemism and high plant species turnover, both characteristic of the SWAFR (Gibson et al. 2017; Hopper et al. 1996). Findings presented in Chapter 4 include strong correlation between Noongar conceptualisation of *boodja* (Smith 2011b) and biogeographic boundaries influenced by climatic gradients and edaphic heterogeneity (Gioia and Hopper 2017). Noongar plant knowledge is extensive and place-based rather than broadly uniform in its application, reflecting the SWAFR's overall floristic richness and its edaphic and biological heterogeneity. Localised decision-making and specificity of fire control may be valuable lessons for modern conservation managers (see below).

That Nyungar niche construction activity was difficult to detect in contemporary plant communities of granite inselbergs (Chapter 4) was consistent with findings of other researchers in global Ocbil-dominated regions (Amundsen-Meyer 2013; De Vynck 2014; Levis et al. 2017). This finding corroborates with contemporary Noongar accounts of greater disturbance in Yodfels than in Ocbils (Chapter 3) and also with evidence of greater intensification of *Macrozamia dyeri* on coastal dunes than kwongkan (Chapter 5). In combination, these lines of enquiry indicate a Noongar regime that is biased toward plant resource diversification in Ocbils and intensification in Yodfels.

Evidence of Noongar ecological and evolutionary influence in the SWAFR

Findings of correlation between *Macrozamia dyeri* distribution and archaeologically and ethnographically determined Nyungar residential patterns, and also of shared haplotypes, low haplotype diversity and high estimated gene flow between populations of Noongar-utilised *Platysace* species strongly suggest that humans have influenced the dispersion of some plant taxa of the SWAFR. Besides their use as Noongar staple foods, these taxa have little in common, and are therefore likely 'tip of the iceberg' examples of far-reaching Noongar influence on dispersion of taxa of utilitarian or other Noongar significance. These findings and also a positive effect on Noongar-utilised *Platysace* abundance of tuber harvest (Chapter 7) demonstrates that a long-lasting Noongar influence is present in the ecological and evolutionary biology of at least some plants endemic to the SWAFR. These findings suggest that along with edaphic, climate and other environmental factors, ethnographic information of First Nation people should be included in biodiversity conservation planning processes, particularly for plant taxa with long-held human relationships.

Botanical detection of past Noongar land practice

Geographic discontinuity and prominence of *Macrozamia dyeri* at pre-colonial Noongar base camps (Chapter 5) suggests that its relative abundance may be a useful indicator of location-specific past Nyungar intensive land use that probably included frequent firing. With such information, suitable locations for contemporary prescribed burning and extrapolation of ecological outcomes of Noongar management for other plant taxa may be possible. Analyses of *Macrozamia* distributions in other parts of Noongar *boodja* may also prove useful for reconstruction of pre-colonial land management practices in the SWAFR. Further, distributional analysis of other culturally-important, fire tolerant and long-lived plant taxa may be useful for providing insight to past human landscape management in the SWAFR and elsewhere. Equally, distributions of culturally-important and fire sensitive plant taxa may be insightful in this regard.

Abundance of Noongar-utilised *Platysace* taxa at specific locations is a possible indicator of past tuber harvest (and therefore soil disturbance), particularly in populations that include common, widespread haplotypes (Chapters 4 and 6). Discussions with Elders revealed that families had preferred harvest locations for *Platysace* tubers which corroborated with our finding of site-based variation in ecological response to *Platysace* harvest, indicating that some soils and places were more readily targeted for intensive harvest than others (Chapter 7). Such collaborative, multi-faceted analysis of the ecology, phylogeography and contemporary distributions of other Noongar taxa may prove valuable to enable interpretation of past Noongar land management over wider parts of the SWAFR.

Use of botanical techniques to inform Noongar cultural connection

Noongar plant harvest is inextricably linked to ritual, respect for ancestors and stories of creation (Hassell 1975; Pettersen 2015c). Carrying out plant harvest and other cultural activities on country as a family enables intergenerational knowledge transfer and remembrance of ancestors. Thus plant resource patches are important cultural components of the landscape that are intrinsically linked to familial and social wellbeing and continuation of culture (Bradley 2006; Chase 1989; Head et al. 2002; Walsh 2008). Research findings in relation to phylogeography of *Platysace* taxa (Chapter 6), contemporary distribution of *Macrozamia dyeri* (Chapter 5), and relative cultural plant richness (Chapter 4) demonstrate how application of modern DNA-based methods and targeted and comparative measures of cultural plant abundance and richness can assist in reaffirming cultural connections to *boodja*. Abundance of the staple food plant, *P. trachymenioides* within the

Marbaleerup complex and a very high relative cultural plant richness at the Marbaleerup granite corroborated its use as an aggregation site of regional importance. Likewise, abundance of *M. dyeri* at Belinup, Woodup Swamp and Lake Monjingup corroborated past Noongar use of these sites as semi-permanent base camps. Detection of widespread common haplotypes in *P. trachymenioides* and *P. deflexa,* particularly at important Noongar locations, was consistent with their use as important Noongar staples. Detection of common haplotypes and phylogeographic analysis of other cultural plants would probably prove useful for understanding broader pre-colonial Noongar patterns in the SWAFR.

Ongoing collaboration with key Elders throughout each stage of this research, including shared experiences on country, enabled scientific findings to be interpreted in light of first hand Noongar knowledge and perspectives. An on-country, two-way approach enabled Elders to recall childhood knowledge, for Elders and botanists to accurately identify plant taxa, and for iterative discussions about aspects of Noongar plant management, utility and ecology. This resulted in a richer and more nuanced interpretation of findings than would have been achievable from a solely non-Aboriginal perspective.

A multi-faceted approach that investigated the ecological effects of *Platysace* harvest (Chapter 7), DNA-based *Platysace* phylogeography (Chapter 5) and also interpopulation abundance of *P. trachymenioides* (Chapter 3) enabled findings of each investigation to be corroborated with one another and also with ethnographic and archaeologically derived information about Noongar mobility patterns and specific site uses. In addition, inclusion of experimental *Platysace* harvest enabled valuable opportunities for both intergenerational and cross-cultural exchange of Noongar traditional ecological knowledge.

Future research priorities

Several priorities for future research have emerged from the projects outlined in this thesis. Firstly, HNC was identified as a useful lens through which to consider ecological outcomes of Noongar occupation of the SWAFR. Further investigations framed around HNC theory may prove fruitful in the SWAFR and elsewhere. Further investigations focused on geographic variability of Noongar plant HNC, and particularly differential Noongar use of Ocbils, Yodfels and old, climatically buffered fertile landscapes (Ocfels) (Hopper et al. 2016) would enable more fine-grained understanding of Noongar biodiversity conservation strategies in the SWAFR and may also inform biodiversity conservation in other global regions rich in Ocbils.

Human factors (interpreted through ethnographic and archaeological evidence) should be considered alongside environmental factors when interpreting past and current plant distributions and plant phylogeographic findings. Targeted cultural plant surveys that include measurement of relative abundance would improve the understanding of Noongar influence on flora of the SWAFR. In addition, further phylogeographic studies of staple Noongar food plants, particularly those that are widespread and common in distribution likely would yield informative findings for interpretation of past Noongar mobility and landscape use. A focus on plant taxa with long-held human relationships, such as *Macrozamia* and some *Hakea* and *Acacia* species may enable interpretation of past human land use helpful to contemporary biodiversity conservation strategies based on traditional ecological knowledge. Finally, further collaborative harvest experiments are recommended as they are likely to yield complementary findings to phylogeography and plant distribution studies, and also enable important opportunities for connection to country and for collective interpretation of findings and development of contemporary biodiversity conservation strategies.

Conclusion

Through combining archaeological, ethnographic, genetic and ecological data, this thesis presents evidence of Noongar influence on the plant communities and taxa of the SWAFR. Such influence was found to be geographically variable, reflecting the region's biogeographical heterogeneity and broadly conducive with biodiversity conservation strategies advocated by Ocbil theory. These findings suggest that greater consideration of pre-colonial people-plant relationships and inclusion of Noongar people and land management strategies would result in positive outcomes for biodiversity conservation in the SWAFR.

Finally, findings of this thesis clearly demonstrate that Noongar traditional ecological knowledge is a much-needed resource for future conservation of the SWAFR's biodiversity. Collaborative research outlined in this research revealed that considerable traditional ecological knowledge remains among contemporary Noongar Elders that is not documented in scientific literature. Consensual and culturally appropriate documentation of such knowledge should be prioritised to maximise both biodiversity conservation success and societal wellbeing.

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Appendix A Noongar plant species referred to in thesis

Scientific name	Noongar name	Significance	Source*
Acacia microbotrya	*Manna*	food	Eugene Eades, Treasy Woods, Lynette Knapp, Averil Dean, Hansen & Horsfall (2016), Bird & Beeck (1988), Meagher (1974), von Brandenstein (1988), Hassell (1975), Drummond (1840; 1843), Hammond (1933)
Acacia saligna	*Wuanga*	food	Eliza Woods, Eugene Eades, Aden Eades, Gail Yorkshire-Sellby, Meagher (1974), von Brandenstein (1988), Perth NRM (2016)
Acacia cyclops	*Quanert, Gnaamarur*	food, medicinal	Eliza Woods, Eugene Eades, Lynette Knapp, Carol Pettersen, Wayne Williams, Gail Yorkshire-Selby, Treasy Woods, Veronica Williams, Doc Reynolds, Kevin Reynolds, Hansen & Horsfall (2016), von Brandenstein (1988)
Acacia acuminata	*Mangaart, Maanqaat*	food, medicinal	Eliza Woods, Eugene Eades, Aden Eades, Averil Dean, Zac Webb, Stan Loo, Hansen & Horsfall (2016), Meagher (1974), Bird & Beeck (1988), von Brandenstein (1988), Drummond (1840; 1843), Hassell (1975), Collie (1832), Roe (1848) in Hercock (2014) , Barker (1830)
Adenanthos cuneatus	*Tuular*		Lynette Knapp, von Brandenstein (1988)
Allocasuarina huegeliana	*Kwel*	seasonal indicator, reduce thirst, camp	Treasy Woods, Averil Dean, Gail Yorkshire-Selby, Aden Eades, Eugene Eades, Bird & Beeck (1988), Roe (1848) in Hercock (2014)
Anigozanthus rufus	*Yonger mar*		Lynette Knapp, von Brandenstein (1988)
Astroloma ciliatum	*Mull*	food	Carol Pettersen, Lynette Knapp, Eugene Eades, Bindon (1997), Bindon & Walley (1992)
Astroloma prostratum	*Mull*	food	Carol Pettersen, Lynette Knapp, Aden Eades, Eugene Eades, Eliza Woods, Bird & Beeck (1988), Bindon & Walley (1992)
Astroloma compactum	*Mull*	food	Carol Pettersen, Lynette Knapp, Aden Eades, Eugene Eades, Eliza Woods, Bindon & Walley (1992)
Astroloma epacridis	*Mull*	food	Carol Pettersen, Lynette Knapp, Eugene Eades, Bindon & Walley (1992)
Banksia occidentalis	*Waal*	food, medicinal, fire transport	Hansen & Horsfall (2016), Meagher (1974), Roe (1835) in Hercock (2014), von Brandenstein (1977; 1988), Nind (1831), Hammond (1933)
Banksia media	*Mungitch*	food, fire transport, hair brush	Treasy Woods, Averil Dean, Aden Eades, Meagher (1974), Roe (1835) in Hercock (2014), von Brandenstein (1977), Nind (1831), Hammond (1933)
Banksia speciosa	*Mungitch*	food, fire transport, hair brush	Veronica Williams, Meagher (1974), Roe (1835) in Hercock (2014), von Brandenstein (1977), Nind (1831)
Billardiera lehmanniana	*Kurup*	food	Eugene Eades, Eliza Woods, Bird & Beeck (1988), Meagher (1974), von Brandenstein (1988)
Billardiera coriacea	*Noodgen, Nearnum*	food	Doc Reynolds, Treasy Woods, Averil Dean, Gail Yorkshire-Selby, Lynette Knapp, Bird & Beeck (1988)

Scientific name	**Noongar name**	**Significance**	**Source***
Billardiera fusiformis	*Kumuk*	food	Doc Reynolds; Annie Dabb
Billardiera heterophylla	*Kumuk*	food	Averil Dean, Carol Pettersen, Lynette Knapp, Stan Loo, Eugene Eades, Eliza Woods, Bird & Beeck (1988), von Brandenstein (1988)
Burchardia congesta	*Kara*	food	Daw et al. (2011), Drummond (1842) in Pate & Dixon (1982), SERCUL (2014), Perth NRM (2016)
Caladenia flava		food	Eugene Eades, Eliza Woods
Carpobrotus rossii	*Bain, Pain*	food, medicinal	Terry Yorkshire, Doc Reynolds, Veronica Williams, Treasy Woods, Gail Yorkshire-Selby, Lynette Knapp, Stan Loo, Eliza Woods, Hansen & Horsfall (2016), Meagher (1974), von Brandenstein (1988), Drummond (1843), Roe (1835; 1848) in Hercock (2014), Barker (1831)
Cassytha racemosa		medicinal, twine	Doc Reynolds, Hansen & Horsfall (2016), von Brandenstein (1988)
Cassytha glabella		medicinal, twine	Doc Reynolds, Hansen & Horsfall (2016)
Cassytha melantha		medicinal, twine	Doc Reynolds, Hansen & Horsfall (2016)
Clematis pubescens	*Duruk*	medicinal?	Doc Reynolds, Lynette Knapp, Bindon (1997)
Corymbia callophylla	*Marri*	medicinal	Lynette Knapp, Larry Blight, Hansen & Horsfall (2016)
Cycnogeton lineare		food	Doc Reynolds
Dianella revoluta		medicinal, twine	Hansen & Horsfall (2016), Drummond (1842), Perth NRM (2016)
Dioscorea hastifolia	*Wuagarn*	food	Grey (1841); Drummond (1840), Moore (1884), Oldfield (1865), Hallam (2014), von Brandenstein (1988)
Eriochilus dilatatus		food	Treasy Woods
Eucalyptus salmonophloia	*Wuerlak*	medicinal, water (gnamma) tree	Hansen & Horsfall (2016), von Brandenstein (1988), O'Connor & Prober (2010)
Eucalyptus x tetragona	*Tjaltjraak*	territory indicator	Doc Reynolds, Gail Yorkshire-Selby, Lynette Knapp, Carol Pettersen, von Brandenstein (1988)
Eucalyptus loxophleba	*Doatta (H&H)*	medicinal	Hansen & Horsfall (2016), Meagher (1974), Bindon (1997), Bird & Beeck (1988), von Brandenstein (1988), Drummond (1843)
Eucalyptus marginata	*Djara, Jarrah*	medicinal	Moore (1884), Hansen & Horsfall (2016), Roe (1835) in Hercock (2014), Grey (1841)
Eucalyptus pleurocarpa	*Tjaltjraak*	territory indicator	Doc Reynolds, Gail Yorkshire-Selby, Lynette Knapp, Carol Pettersen, von Brandenstein (1988)
Eucalyptus occidentalis	*Mauw*	medicina	Treasy Woods, Hansen & Horsfall (2016), Meagher (1974), Bindon (1997), von Brandenstein (1988), Roe (1848) in Hercock (2014)
Eucalyptus extrica	*Tjaltjraak*	territory indicator	Doc Reynolds, Gail Yorkshire-Selby, Lynette Knapp, Carol Pettersen, von Brandenstein (1988)
Eucalyptus cornuta	*Yandel, Yeit*	medicinal	Hansen & Horsfall (2016), von Brandenstein (1988)
Eucalyptus platypus	*Moort, Muert*	timber, medicinal, hunting habitat, ceremonial	Aden Eades, Eugene Eades, Eliza Woods, Carol Pettersen, Lynette Knapp, Hansen & Horsfall (2016)
Eucalyptus wandoo	*Warnda*	water (gnamma) tree	Roe (1835) in Hercock (2014), Nind (1831), Moore (1835; 1884), Drummond (1853)

Scientific name	Noongar name	Significance	Source*
Exocarpos sparteus	*Chiuck*	food, borongor (totem)	Kevin Reynolds, Doc Reynolds, Carol Pettersen, Lynette Knapp, Treasy Woods, Averil Dean, Gail Yorkshire-Selby, Aden Eades, Eugene Eades, Eliza Woods, Hansen & Horsfall (2016), Daw et al. (2011), von Brandenstein (1977; 1988), Hassell (1975), Nind (1831)
Geranium solanderi	*Wardi wardi*	medicinal	Treasy Woods, Averil Dean, Carol Pettersen, Lynette Knapp, Eugene Eades, Hansen & Horsfall (2016), Oates (1977) in Pate & Dixon (1982), Drummond (1840)
Haemodorum spicatum	*Mearn*	food	Treasy Woods, Lynette Knapp, Hansen & Horsfall (2016), Meagher (1974), Bird & Beeck (1988), Bindon (1997), Daw et al. (2011), von Brandenstein (1988), Bindon & Walley (1992), Collie (1832), Drummond (1842), Hammond (1933), Little (1994), Perth NRM (2016)
Haemodorum discolor	*Kooting, Gorgon, Quadin*	food	Kevin Reynolds, Doc Reynolds, Treasy Woods, Averil Dean, Gail Yorkshire-Selby, Henry Dabb, Carol Pettersen, Aden Eades, Eliza Woods, Drummond (1842), Hammond (1933)
Hakea amplexicaulis		food	Lynette Knapp
Hakea scoparia	*taanttyin*	food	Lynette Knapp, von Brandenstein (1988)
Hakea sulcata		food	Lynette Knapp
Hakea recurva		food	Lynette Knapp
Hakea platysperma		food	Lynette Knapp
Hakea cinerea		food	Lynette Knapp
Hakea preissii	*Jarnock mert*	food	Lynette Knapp, von Brandenstein (1988)
Hakea bicornata		food	Lynette Knapp
Hakea lissocarpha		food	Lynette Knapp, City of Joondalup (2019)
Hakea nitida		food	Lynette Knapp
Hakea varia		food	Lynette Knapp
Hakea corymbosa		food	Lynette Knapp
Hakea prostrata	*Janda*	food	Lynette Knapp, Perth NRM (2016), City of Joondalup (2019)
Hakea laurina	*Kodjit*	seasonal indicator, food	Carol Pettersen, Lynette Knapp, Aden Eades
Hakea trifurcata		food	Lynette Knapp, City of Joondalup (2019)
Hakea drupacea		food, habitat modification	Lynette Knapp
Hakea clavata		food	Lynette Knapp
Kennedia nigricans	*Walyarak*	twine	Lynette Knapp, Carol Pettersen
Kennedia prostrata	*Wollung*	medicinal	Hansen & Horsfall (2016), City of Joondalup (2019), Perth NRM (2016)
Lambertia inermis	*Chidiuk*	food	Treasy Woods, Averil Dean, Carol Pettersen, Aden Eades
Lepidosperma gladiatum	*Gerbion*	food	Doc Reynolds, Gail Yorkshire-Selby, Daw et al. (2011), von Brandenstein (1988)
Leucopogon parviflorus	*Duluk*	food	Doc Reynolds, Lynette Knapp, Bindon (1997)

Scientific name	**Noongar name**	**Significance**	**Source***
Lomandra hastilis		poison	Lynette Knapp
Lyperanthus serratus	*Car*		Lynette Knapp, Daw et al. (2011), Bird & Beeck (1988), Drummond (1842)
Macrozamia dyeri	*Ngerriny, pauyin*	food	Lynette Knapp, Carol Pettersen, Annie Dabb, Doc Reynolds
Macrozamia reidlei	*Bayoo, Bayu, Djeeljeri, Djiridji*	food	Daw et al. (2011), Bird & Beeck (1988), Drummond (1842,) Hallam (2014), Perth NRM (2016)
Macrozamia fraseri	*Bayoo, Bayu, Djeeljeri, Djiridji*	food	Daw et al (2011), Bird & Beeck (1988), Drummond (1842), Hallam (2014), McIntyre and Dobson (2017), Perth NRM (2016)
Myriophyllum petraeum		food	Doc Reynolds
Nitraria billardierei	*Gnoomp, Wilyomuk*	food	Doc Reynolds, Carol Pettersen, Lynette Knapp
Nuytsia floribunda	*Munjee, Moodjal, Muattyaur*	ceremonial, seasonal indicator, food	Doc Reynolds, Treasy Woods, Averil Dean, Lynette Knapp, Stan Loo, Eugene Eades, Annie Dabb, Meagher (1974), Bindon (1997), Bindon & Walley (1992), von Brandenstein (1977; 1988), Larry Blight, Perth NRM (2016)
Pittosporum angustifolium		medicinal	Hansen & Horsfall (2016)
Platysace deflexa	*Youaq, Joowaq*	food, water	Lynette Knapp, Carol Pettersen, Aden Eades, Eugene Eades, Eliza Woods, Hassell (1975), Nind (1831)
Platysace cirrosa		food, water	Nannup (2014), Drummond (1840), Moore (1884)
Platysace maxwellii		food, water	Meagher (1974)
Platysace trachymenioides	*Kukine*	food, water	von Brandenstein (1977; 1988), Drummond (1840)
Prasophyllum calcicola	*Djubac*	food	Meagher (1974), Nind (1831), Hammond (1933), Barker (1830)
Prasophyllum sargentii	*Djubac*	food	Meagher (1974), Nind (1831), Hammond (1933), Barker (1830)
Prasophyllum cucullatum	*Djubac*	food	Meagher (1974), Nind (1831), Hammond (1933), Barker (1830)
Prasophyllum regium	*Djubac*	food	Meagher (1974), Nind (1831), Hammond (1933), Barker (1830)
Prasophyllum hians	*Djubac*	food	Meagher (1974), Nind (1831), Hammond (1933), Barker (1830)
Prasophyllum brownii	*Djubac*	food	Meagher (1974), Nind (1831), Hammond (1933), Barker (1830)
Prasophyllum giganteum	*Djubac*	food	Meagher (1974), Nind (1831), Hammond (1933), Barker (1830), Drummond (1842)
Prasophyllum elatum	*Djubac*	food	Meagher (1974), Nind (1831), Hammond (1933), Barker (1830)
Prasophyllum gibbosum	*Djubac*	food	Meagher (1974), Nind (1831), Hammond (1933), Barker (1830)
Prasophyllum parvifolium	*Djubac*	food	Meagher (1974), Nind (1831), Hammond (1933), Barker (1830)
Prasophyllum gracile	*Djubac*	food	Meagher (1974), Nind (1831), Hammond (1933), Barker (1830)
Pteridium esculentum	*Munda*	food, medicinal	Hansen & Horsfall (2016)
Pyrorchis nigricans	*Car, Djubuc*	food	Treasy Woods, Averil Dean, Aden Eades, Stan Loo, Bird & Beeck (1988), Daw et al. (2011), Bindon & Walley (1992)

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Santalum spicatum	*Willarak*	food, medicinal	Aden Eades, Hansen & Horsfall (2016), Bird & Beeck (1988), Meagher (1974), Bindon (1997), von Brandenstein (1988), Hassell (1975), Roe (1848) in Hercock (2014), O'Connor & Prober (2010)
Santalum acuminatum	*Wolgol, Wanyill*	food	Doc Reynolds, Veronica Williams, Treasy Woods, Lynette Knapp, Steve Wood, Aden Eades, Hansen & Horsfall (2016), Daw et al. (2011), Bindon (1997), Meagher (1974), von Brandenstein (1988), Bindon & Walley (1992), Drummond (1843), Hammond (1933), Roe (1848) in Hercock (2014), O'Connor & Prober (2010)
Scaevola spinescens		medicine	Veronica Williams, Gail Yorkshire-Selby, Henry Dabb, Aden Eades, Hansen & Horsfall (2016)
Templetonia retusa	*Yackal Djar*	seasonal indicator	City of Joondalup (2019), von Brandenstein (1988)
Thelymitra crinita	*Walyamur*	food	Treasy Woods, Averil Dean, Carol Pettersen, Daw et al. (2011)
Thysanotus patersonii	*Djunga djunga, Djungala*	food, water	Terry Yorkshire, Gail Yorkshire-Selby, Lynette Knapp, Drummond (1842), O'Connor & Prober (2010)
Typha domingensis	*Yaindyert*	food	Doc Reynolds, Grey (1841), Hallam (2014), Eyre (1845), SERCUL (2014)
Xanthorrhoea platyphylla	*Palak*	fastener, medicinal, fire starter	Doc Reynolds, Veronica Williams, Larry Blight, Gail Yorkshire-Selby, Aden Eades, Eugene Eades, Meagher (1974), von Brandenstein (1977; 1988), Bindon & Walley (1992), Nind (1831), Grey (1841), Eyre (1841), Barker (1830), Collie (1832), Hammond (1933), Roe (1848) in Hercock (2014)
Xanthorrhoea preissii	*Balga, Palak*	fastener, medicinal, fire starter	Roe (1831) in Hercock (2014), City of Joondalup (2019), Moore (1884), Bird & Beeck (1988), Grey (1841), Drummond (1842; 1843)

*Where source is listed as name only with no date, refers to Noongar Elder or cultural informant who collaborated on this research. Information was provided during the research period.