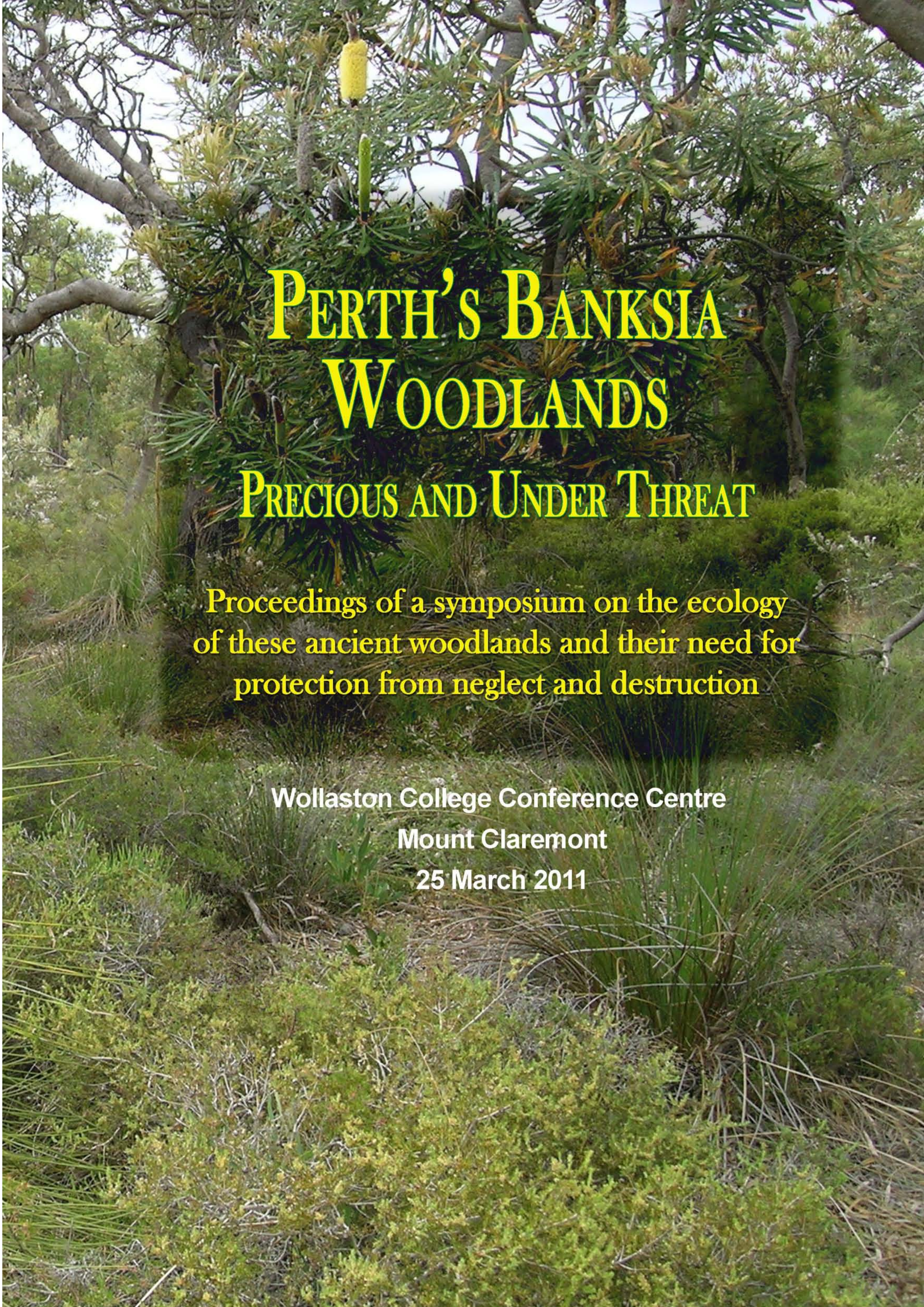

Perth's Banksia Woodlands

Precious and Under Threat

Proceedings of a symposium on the ecology of these ancient woodlands and their need for protection from neglect and destruction

Wollaston College Conference Centre
Mount Claremont
25 March 2011

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Cover: Banksia woodland and understorey at Cottonwood Crescent, Dianella (Bush Forever Site 43). Candlestick Banksia (or Biara) *Banksia attenuata* in flower in the foreground; Menzies' Banksia (or Mungyt) *Banksia menziesii* and Bull Banksia (or Mangite) *Banksia grandis* are also to be found in this reserve. Photo and cover design by Kim Sarti.

The Urban Bushland Council acknowledges generous funding assistance from Lotterywest for the symposium and production of the proceedings.

Urban Bushland Council WA Inc

lotterywest supported

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Urban Bushland Council WA Inc

WHAT IS THE URBAN BUSHLAND COUNCIL?

The Urban Bushland Council is a voluntary, non-government organisation that is an association of more than 60 community conservation groups concerned about urban bushland. It is the peak community organisation for urban bushland conservation and protection in WA.

HOW THE URBAN BUSHLAND COUNCIL FORMED

In response to continuing threats to urban bushland, including Hepburn Heights, over 40 groups represented at a workshop organised by the Conservation Council on 7th November 1992 unanimously called for the establishment of a coalition of community groups to work to protect urban bushland.

The workshop called for:

- Greater public awareness of natural heritage,
- Community participation in decision-making and in caring for urban bushland,
- A government policy to recognise and protect urban bushland.

The Urban Bushland Council was formally launched in Kings Park on 21st March 1993.

THE ROLES OF THE URBAN BUSHLAND COUNCIL

- **Local action and networking** through providing a forum to support local community groups by encouraging local action and networking and by providing access to ideas, information and expertise concerning bushland.
- **Policy development** through debate, developing and promoting policy for the protection and management of urban bushland.
- **Lobbying** by providing an avenue for influence by letter writing, submissions, delegations and media contact in seeking legislative change for bushland protection.
- **Raising public awareness** of the values and problems facing urban bushland.

CURRENT ACTIVITIES

- **Bush Forever:** The Bush Forever Amendment to the Metropolitan Region Scheme passed through Parliament in 2010, giving legal definition to all Bush Forever sites. The focus is now on getting adequate resources for management to maintain conservation values.
- **Local bushland and Perth Biodiversity Project (PBP):** We call for the retention and recurrent funding of the PBP. We encourage all Councils to implement the 'Local Government Biodiversity Planning Guidelines' (2004) and to manage their local bushland in conjunction with Friends groups to retain values.
- **Climate change:** Falling ground water levels are threatening bushland ecosystems. The UBC is calling for strategic management of ground water levels to protect sensitive areas and the fostering of a water conservation ethic in the community and within industry.
- **Perth Urban Bushland Fungi project:** This collaborative project, based at the WA Conservation Centre, is supported by the UBC – go to website: www.fungiperth.org.au
- **Other campaigns:** Numerous campaigns by Friends groups to save local and regional bushland are supported by the UBC including lobbying for the protection of endangered black cockatoos.

PREFACE

Perth is the only city in the world set in a natural landscape dominated by Banksia woodlands. Whilst the landscape relief and tree profile is subtle, these woodland communities are highly biodiverse, especially in understorey and herb layer. Indeed the Perth region is a hotspot of plant species diversity within the globally recognised south-west biodiversity hotspot for conservation priority. It is under threat. Yet Perth's Banksia woodlands are so little known and appreciated.

This symposium “Perth's Banksia Woodlands” is the second of two organised by the Urban Bushland Council WA to celebrate the 2010 International Year of Biodiversity. We understand that no meeting had been held to focus on Banksia woodlands in Western Australia since a conference held by the Royal Society of WA in October 1988. The well-attended symposium brought together scientists in the fields of botany, zoology, mycology and ecology to present their knowledge of the Banksia woodland ecosystem, its ancient origins, uniqueness, adaptations and the perilous threats which confront its sustained survival. The appendix shows the broad range of organisations represented in the audience, including many State government agencies, local authorities, community groups, consultants and interested members of the public.

The Urban Bushland Council acknowledges the generous funding by Lotterywest which enabled the employment of Amrit Kendrick to organise the one-day symposium held at the Wollaston Conference Centre in Mount Claremont and these papers. Funding also provided publicity, subsidised community attendees and the production of these proceedings, and also audio-visual recording of the day by Bryn Watkins of Entity Media. Guidance and assistance came from a Steering Group of the Urban Bushland Council's Executive Committee: Mary Gray, Kim Sarti, Christine Richardson and Treasurer Christine Allbeury, and on the day the team also included Margaret Owen, Catherine Cooper, Kevin McLean, Rob Greenwood and John Baas. The Bold Park Guides provided a much appreciated early morning guided walk in Bold Park for two groups of attendees. Others provided displays and goods for sale. Sincere thanks to all for a well organised day.

We wish to acknowledge all the speakers who generously shared their expertise and knowledge in their colourful presentations to a 'full house', and for their written papers in these proceedings. The attendance by more than 150 people and their enthusiastic questions showed that a significant part of our community cares deeply about our Banksia woodlands. Discussion and networking at lunch and tea breaks was lively as participants shared their ideas on how we can curb the threats and protect what we still have left of our amazing local fauna and flora.

The Banksia woodlands are an icon of Perth. Our Banksia trees are both ancient and unique, and their ecosystems are particularly rich in plant species, reptiles and invertebrates and probably the little-known fungi. Climate change, declining water tables from excessive groundwater abstraction and low rainfall resulting in widespread tree and shrub deaths this autumn 2011; weeds, feral animals, Dieback and most obviously clearing for urban expansion threatening the existence of these iconic woodlands, were issues raised by speakers and in discussion. Lack of legislation to recognise and protect Banksia woodlands, lack of commitment by government to management of threatening processes and piecemeal decisions allowing clearing for development pressure were all cited as key issues.

The State economy is again booming and immigration is driving housing and infrastructure development, intensifying threats to the iconic Banksia woodlands of the Swan Coastal Plain.

PROGRAMME: PERTH'S BANKSIA WOODLANDS SYMPOSIUM

25th March 2011
Wollaston Conference Centre, Wollaston Road, Mount Claremont

Session 1: Why is it so diverse Chair: Mary Gray		
8:45 – 8:55	Mary Gray Vice President Urban Bushland Council	Welcome to the Symposium
8:55 – 9:05	Liz Behjat MLC	Government Recognition of our unique Banksia Woodland
9:05 – 9:55	Greg Keighery, DEC	Banksia Woodlands: A Perth Icon
9:55 – 10:25	Neale Bougher, DEC	Fungi of Perth's Banksia Woodlands
10:25 – 10:55	MORNING TEA	
Session 2: The web of life Chair: Eddie Wajon		
10:55 – 11:35	Mike Bamford, Bamford Consulting	Wild About the Suburbs: Animal Winners and Losers of the Banksia Woodlands
11:35 – 11:55	Philip Groom, Curtin University	Functional Ecology of Banksia Root Systems and Groundwater
11:55 – 12:25	Byron Lamont, Curtin University	Beneath the Banksias
12:25 – 1:25	LUNCH	
Session 3: Fabulous fauna in the ecosystem Chair: Cath Cooper		
1:25 – 2:00	David Knowles, Spineless Wonders	Macro-invertebrates – Those With-out Backbones Among the Banksias
2:00 – 2:30	Shannon Dundas, Murdoch University	Honey Possums and their Association with Banksia Woodlands
2:30 – 3:00	Nicola Mitchell, UWA	Why Pair When the Passion's Not There? Unravelling the Curious Sex Life of the Turtle Frog
3:00 – 3:25	AFTERNOON TEA	
Session 4: Flora citizen science and other opportunities for action Chair: Rob Greenwood		
3:25 – 3:55	Judy Fisher, Fisher Research	Control of Invasives to Maintain Biodiversity in the Banksia Woodland Ecosystem
3:55 – 4:25	Bronwen Keighery, Office of the Environmental Protection Authority, WA	Below the Knees Biodiversity and How we Survey it
4:25 – 4:45	Summary of the Day - Grant Wardell-Johnson, Curtin University	

OFFICIAL OPENING OF BANKSIA WOODLAND SYMPOSIUM

HON LIZ BEHJAT MLC, MEMBER FOR NORTH METROPOLITAN REGION

Thank you for the opportunity to be here this morning to speak about Perth's precious Banksia woodlands on behalf of Environment Minister Bill Marmion, who unfortunately is unable to attend today.

One of the truly remarkable things about living in Perth is that native plants and animals are never very far from your doorstep. It is not uncommon to see a magnificent Carnaby's Cockatoo flying above the trees and rooftops, or a kangaroo grazing in nearby parkland, or an Oblong Turtle burrowing into the mud at a suburban lake. One of the reasons for this is that Perth is home to many protected bushland areas that support a number of valuable ecological communities.

We are here today to focus on Banksia woodlands – and two areas in Perth that really stand out for their Banksia woodlands are the Jandakot Regional Park to the south and Melaleuca Park to the north of Perth in the City of Swan. These areas are home to two of the most common woodland Banksia species – Menzies' Banksia (*Banksia menziesii)* and the Candlestick Banksia (*Banksia attenuata)* which thrive in Perth's sandy soils – and it is vital that these populations are protected.

I understand there are 11 different types of Banksia woodlands in the Perth area. Three of these have been listed as Threatened Ecological Communities, and a further four are listed as Priority Ecological Communities. The Government recognises these conservation requirements and is committed to balancing development and the conservation of Banksia communities in the Perth region.

Banksias have an important role in the environment, particularly as a food and habitat source for over 90 species of birds, including Carnaby's Cockatoos. Banksias also provide a valuable understorey that sustains insects, frogs, snakes, skinks and many native mammals. They are central to healthy natural ecosystems in and about Perth. We need to maintain an integrated management approach to keep Perth's bushland remnants sustainable and protected against threatening processes, such as weeds, disease and a drying climate.

One of the most serious threats to our urban bushland is *Phytophthora* Dieback. It is considered one of the biggest threats to biodiversity in Western Australia.

Also known as the 'biological bulldozer', Dieback is already threatening 40% of plant species in the south-west and has pushed more than 10 species to the brink of extinction. As many of you here would know, the soil-borne disease has infected very large areas of the south-west and is also widespread in the Perth metropolitan area. Indeed, our iconic and distinctive Banksia species are extremely susceptible to Dieback and need special management consideration. The State Government recognises the threat from Dieback and has provided $1.6 million in special natural resource management program funding to DEC to treat key Dieback outbreaks, trial eradication strategies and improve community co-operation in minimising its spread. The department is also upgrading its response to Dieback threats through improvements in training and management guidelines. Many community groups are also heavily committed to reducing the impact of Dieback on our bushland, and I specifically make mention of the activities of the Dieback Working Group.

But there is still much more we can do to protect our bushlands, including Banksia woodlands. Partnerships between State Government, local government, community groups, environmental organisations and individuals go a long way when we are talking about the conservation of fragmented, widespread tracts of important bushland. In and around Perth, several initiatives are underway that are providing a greater focus on urban bushland. The State Government is strongly committed to developing its network of regional parks. DEC manages around 15,000 hectares of regional parks in the Perth area, in addition to State forest, national parks, conservation parks and nature reserves across the State. Regional parks are a focus for conservation work, on-ground park improvements, and community liaison and participation activities. In addition, $105,000 was allocated to volunteer groups last financial year to undertake works in regional parks including rehabilitation and weed control works and enhancement of Carnaby's Cockatoo habitat as part of the Minister for Environment's $1.53 million Environmental Community Grants Program.

Other programs, like Bush Forever and Land for Wildlife, promote the preservation of natural bushland in urban and urban fringe areas.

The Land for Wildlife scheme was initially designed for agricultural areas, but it is so encouraging to see that a lot of people and organisations responsible for smaller blocks in the Perth Hills and across the metropolitan area have joined the scheme because they want to manage their remnant bushland for nature conservation. And on the subject of Bush Forever, the State Government last year reached a major milestone in the regulatory protection of 51,000 hectares of metropolitan vegetation, 12 years after the Bush Forever policy was first endorsed as Perth's Bushplan. The policy is establishing a statutory framework and greater planning recognition for the protection and future management of all Bush Forever areas.

Now I would like to touch on a subject that illustrates the challenges we face in balancing the need for growth and development in our city with the need for conservation of precious tracts of bush. As many of you will be aware, an area of Banksia woodland at Jandakot Airport is subject to development so the airport can be expanded. This has been approved by the Federal Environment Minister. The approval allows clearing of 167 hectares and will decrease the area in airport conservation precincts to 170 hectares. The State Government acknowledges that this Banksia woodland is habitat for two threatened orchid species as well as the threatened Carnaby's Cockatoo. While a significant local loss to biodiversity conservation values, we will see this conservation loss offset on a large scale via the approved offset plan. As a condition of the approval, the Federal Government has required Jandakot Airport to provide more than $9 million for conservation actions. Additionally, Jandakot Airport is required to buy 1,600 hectares of Carnaby's Cockatoo habitat, and some property has already been bought under this requirement. Conditions also require the airport to provide $150,000 a year over five years for research and recovery actions for Carnaby's Cockatoo, as well as the provision of a management plan for the remaining airport bushland that will include orchid management and extra funding. Integrating protected ecological linkages of bush with our growing city is vital to ensure biodiversity is maintained on the Swan Coastal Plain and in the Perth Hills, and the State Government has thus sought to achieve the best outcomes possible where essential development within bushland areas is approved. But it's not only from a nature conservation perspective that good bushland planning needs to be in place. It's also about community protection from bushfires. A review is underway by Mick Keelty to address bushfire risk management in the Perth Hills, following the bushfire in February that destroyed 71 homes and a large amount of bush on private and public land in parts of Kelmscott and Roleystone. Mr Keelty will be looking at, among other things, the impact of land use, environmental and building laws, practices and policies in the affected areas on bushfire mitigation, prevention and response. The reality is that if people want to live in and among bushland, they need to be aware of the environment and take measures to protect themselves and their homes. Appropriate planning and design of future development can play a significant part in reducing the risk of bushfire to life and properties. This issue is not restricted to the hills areas, but is also relevant to the coastal plain and adjacent to areas of Banksia woodlands. One of the options available to existing landowners, residents and tenants to assist in bushfire risk management can be vegetation clearance adjacent to key assets. But that needs to be done in a way that is well thought-out, and balances the conservation needs of an area with the protection needs of a community. We live in a fire-prone environment. It's something we as a community need to continue to think about. Perth is a wonderful place in which to live, and if we protect and respect the bush and recognise the need for a balanced approach to urban development, this city and its unique Banksia woodlands will remain that way for generations to come.

On that note I would like to thank you once again for inviting me to open this symposium and I wish you well in your discussions.

BANKSIA WOODLANDS: A PERTH ICON

Greg Keighery, Science Division, Department of Environment and Conservation

SUMMARY

Banksia as a genus is an ancient West Australian. Banksia woodlands, including the dominant trees of the woodland define the Perth Metropolitan area and are hence an Iconic Community of our City. They should be regarded as icons as much as the eight Perth Heritage Icons of the 13 selected in 2004 (Swan River, Fremantle Harbour, Kings Park, Albany ANZAC Day dawn service, Rottnest, Broome pearls, Ningaloo Reef, Western AFL Derby, Kalgoorlie Gold, Perth Royal Show, Bungle Bungle Ranges, His Majesty's Theatre and the Midland Railway Workshops).

INTRODUCTION

The genus *Banksia* is part of the great Southern Hemisphere family of plants, the Proteaceae, named after the Greek god Proteus (many forms). Worldwide there are 80 genera and approximately 1,770 species, of which Australia has 46 genera (57.5% of total) and approximately 1,100 species (61.7% of total). Of the 46 genera, 80.4% are confined to Australia as are 1,088 (99.5%) of the species. The Proteaceae is the third largest family in Australia after the Peas and the Myrtles.

In Western Australia there are 17 genera (21% of the world, 37% of Australia) and 740 species (41.7% of the world, 67.6% of Australia). *Banksia* (without including *Dryandra*) has 80 species, of which 63 are only found in south-west Western Australia (SWWA).

Around Perth on the Swan Coastal Plain there are only seven common trees. Three are eucalypts (Tuart, Jarrah and Marri), three are Banksias (*B. attenuata*, *B. grandis* and *B. menziesii*) and one is *Allocasuarina fraseriana*. Three of these, the Tuart and the two Banksia species (*B. attenuata* and *B. menziesii*) are the characteristic trees of Perth.

THE PAST

The Proteaceae are first recorded by "Banksia"-like pollen from the late Cretaceous (70 million years ago (MYO), suggesting a Cretaceous origin for the family. Banksia-like leaves are known from the Palaeocene (58 MYO) in eastern Australia. The origin of the genus *Banksia* lies in Gondwana perhaps in the Palaeocene (66–56 MYO) and subsequently has become largely confined to Australia.

In Western Australia a diverse array of Banksia leaf types (lobed, serrate and entire) have been recorded for Middle Eocene (49–40 MYO) at Westdale. These leaves already display the hardness (schleromorphy) of our present Banksias and may indicate the presence of nutrient poor soils, despite high rainfall. And there was no apparent need to develop adaptation to dry conditions (Hill, 1998). However, recently He *et al.*, (2011) argue that Banksia species from 61 MYO already had numerous fire traits, such as on-plant seed storage and dead floret retention (as found in *Banksia attenuata*), suggesting a distinctive period of fire had already developed. These plants were trees, but whether they were sprouting or non-sprouting is unknown. As a consequence, derived fire traits (dead leaf retention and clonality) first appeared in the Miocene (16 MYO) in Australia, perhaps after Western Australia was isolated from eastern Australia.

Rainforest Proteaceae were diverse and often dominant (at least in terms of pollen, up to 35% of pollen counts) during the Palaeocene (66–56 MYO) and Eocene (58–37 MYO), in Australia. These groups appeared to have suffered a major decline in the Eocene and many species were extinct by the end of the Eocene in eastern Australia. Macro-fossil evidence (leaves) from Tasmania suggests also that there was a higher diversity of Proteaceae early in the Pleistocene and another major extinction event occurred with the drying of Australia.

Tasmania lost at least two thirds of the species of *Banksia* present in the Pleistocene to the present (Jordan *et al*., 1998).

It appears that the original Banksias were trees. Supporting this premise are the fossil Banksia type fruits known from Walpole from the middle Eocene (49–40 MYO) and *Banksia archeocarpa* (a 38 million year old fossil from the Kennedy Range) both of which have very similar fruits to those of *B. attenuata*. So the genus *Banksia* has been present in SWWA for about 50 million years!

However, studies in SWWA suggest the situation is more complex and do not completely concur with the east. Itzstein-Davey, (2003) has shown that pollen diversity of the Proteaceae is highest during the present (less than 10,000 years ago), contributing up to 50% of pollen counts. Itstein-Davey also notes the family was diverse in the Eocene. Current adaptations by Banksias to nutrient poor soils, water availability and vertebrate pollination were already present in Eocene vegetation, which was a complex mosaic of rainforest elements and heath (Itzstein-Davey, 2007). The abundance of Proteaceae has fluctuated greatly since the Eocene, in SWWA, but currently there is a lack of macro-fossils to provide evidence which extends beyond this statement.

How the present diversity of Proteaceae evolved in SWWA is still unknown, beyond a series of key events. There was a major adaptive radiation of Proteaceae in late Cretaceous in Gondwana. The family underwent further diversification in the early Eocene rainforests in Australia. Recent speciation and extinction due to increasing aridity occurred in late Tertiary and Pleistocene (at least in Eastern Australia). This period also saw the isolation of SWWA by the Miocene inundation of the Nullarbor between 26–16 MYO, which led to the high numbers of species confined to SWWA.

Current Southern Australian and South African Proteaceae are mostly shrubs. In fact, the family has no herbs and outside of the wet tropics, few trees. Banksia in SWWA is somewhat unusual in forming trees in a Mediterranean climate on soils of very low fertility. Tree forming species are; *B. attenuata*, *B. grandis*, *B. ilicifolia*, *B. littoralis*, *B. menziesii*, *B. prionotes* and *B. seminuda*. "Semi-trees" or large single stemmed shrubs are *B. burdettii*, *B. coccinea*, *B. lemanniana* and *B. victoriae*.

More details on all of these species can be found in Collins *et al*., 2008. Two Banksia trees dominate the Banksia woodlands of the Swan Coastal Plain and the Perth Metropolitan Region. These are *B. attenuata* and *Banksia menziesii*. The taxonomy and horticulture of both of these species are covered in detail in Wikipedia entries:

http://en.wikipedia.org/wiki/Banksia_menziesii and http://en.wikipedia.org/wiki/Banksia_attenuata.

In wetter sites *Banksia ilicifolia* is found and there are scattered occurrences of *Banksia grandis*. *Banksia littoralis* is found in swamps, but these rarely form dominants in the communities in which they occur.

PERTH BANKSIAS

The Community

Banksia woodlands are the dominant structural vegetation on deep sands or lateritic sands in annual rainfalls between 600 and 900 mm for the former and 650–750 for the latter, where the dry season lasts for 5–6 months. They are the defining plant community of the Swan Coastal Plain Bioregion (SWA) and to a lesser extent the Jarrah-Forest (JF).

Beard (1990) estimated that Banksia woodland originally covered 6,229 km^2, of which over 65% has been cleared. Banksia woodland with scattered emergent Eucalypts is estimated to have covered a further 680 km^2, but this was all privately owned.

Although characteristic of the Swan Coastal Plain, Banksia woodlands are by no means confined to it. Perhaps a third of the woodland is found on the Dandaragan Plateau (part of the Swan Coastal Plain bioregion), where *Banksia prionotes* or *B. burdettii* may form the tree layer. Scattered occurrences on deep sands are found throughout the Jarrah Forest and along the Whicher Scarp. Along the wetter south coast, Banksia woodlands dominated by *Banksia ilicifolia* are found on dunes, or woodlands of *B. attenuata* or *B. littoralis* on well drained sands between the uplands and swamps and patches of sand and low sandy ridges east to the Stirling Ranges and Bremer Bay.

While Banksia woodlands are structurally similar, in that they are all low woodlands, they vary greatly in their composition. On the Swan Coastal Plain, Banksia woodlands are divided into a series of nine different vegetation complexes based on their occurrences on particular soil and landform features (Table 1). There are also 13 Floristic Community Types recorded in woodlands dominated by *Banksia attenuata* and/or *B. menziesii*, on the Swan Coastal Plain, three of which are listed as Threatened Ecological Communities (Table 2). Another seven Banksia communities are listed as priority ecological communities (DEC 2010 a & b). These communities are defined by their total floristic composition. Other distinctive related Banksia communities occur in the Whicher Range and Dandaragan Plateau.

The Dominant Species

Distribution and Habitat

Banksia attenuata and *B. menziesii* are the dominant members of Banksia woodlands of the Swan Coastal Plain and Perth Metropolitan Region.

Banksia attenuata commonly known as the Candlestick or Slender Banksia is the most widely distributed of all SWWA Banksias, growing from south of Shark Bay (Zuytdorp National Park) south to Augusta inland to the Wongan Hills, Quairading, Lake Grace, Lake Magenta and then south to West Mount Barren.

Banksia menziesii, commonly known as Firewood or Menzies' Banksia grows from north of the Murchison River to SW of Pinjarra, with isolated occurrences inland to the Wongan Hills, Toodyay and Brookton.

Both species grow as low multi-stemmed shrubs in the northern parts of their ranges with shorter leaves, and appear very distinctive, but appear to grade into the southern tree form. For example, Byron Lamont has observed that Eneabba plants of *B. menziesii* in cultivation (or the absence of fire) that the mallee forms retain a dominant trunk and develop into trees. However, Cowling and Lamont (1985) noted that the Hill River is a major change over point for the tree and shrub forms of both species and for *Banksia attenuata* both tree and shrub forms co-occur here without intermediates.

Both favour sandy soils but *B. menziesii* appears more restricted to deep sands and *B. attenuata* can grow on wetter sites. Both retain leaves for 4–5 years and grow in Spring/Summer, where weekly mean temperature is the trigger (*B. attenuata*; 16.5°C and *B. menziesii*; 15.8°C) to initiate new growth.

Flowering and Pollination

Banksia menziesii has the largest range of flower colours in the genus with flower spikes recorded as a range of pinks, chocolate, bronze, yellow and white. The flowers of *B. attenuata* are always the same yellow.

Although commonly growing together, studies by Whelan and Burbidge (1980) and Lewis and Bell (1981) have shown that the two species do not overlap in flowering periods with *Banksia attenuata* flowering in spring and early summer and *B. menziesii* in autumn and winter. Hence a continuous supply of flowers and nectar occurs when all Banksia species in both study sites are pooled. Both species have long arrested bud development. That is, they set bud primordial at the end of the growing season, which remain dormant before rapid growth/maturation and flowering, taking up to 8 months from bud initiation to flowering.

Flowering in both Banksia species is controlled by temperature not day length, *B. attenuata* flowering when mean daily temperatures for the year reach 17.8°C and mean daily total radiation for the week reaches 489 Langleys. *Banksia menziesii* flowering when mean daily temperature for the year drops to 24.2°C and mean daily total radiation for the week reaches 420 Langleys.

Because of this temperature control of flowering and the ease of observation, *Banksia attenuata* has been selected as a species for citizen climate watch: (http://www.*climatewatch.org.au/species/plants/slender-banksia*).

Both species have inflorescences, which bear hundreds of flowers, up to 1,043 in *B. menziesii* and between 1,700 and 2,000 in *B. attenuata*. Flowering proceeds from the base of the inflorescence upward over 10–20 days. Probing by honeyeaters triggers the flowers to open and places a large amount of pollen onto the bird. Although pollen is presented to the pollinator on a modified style (pollen presenter) the pollen is normally removed before the style is receptive. While it has been found that any remaining pollen can germinate on the style, both species were found to produce only outcrossed seed (Scott, 1980).

Pollination is chiefly by a range of Honeyeaters (New Holland, White-cheeked, Brown, Western Silvereyes, Red Wattlebirds, Singing and Western Spinebills) the combination of these depending on geographic location. Both native and honey bees visit flowers and can effect pollination. Honey Possums visit flowers and may have been significant pollinators of shrub Banksia species, but seem unlikely to be significant for tree species.

Both species set less than 1% of flowers as fruits, for a variety of reasons, competition, nutrient availability, predation, pollination and canopy fires. This is easily adequate for such long-lived plants. Enright and Lamont (1992) estimate that *Banksia attenuata* can live for over 300 years!

While separate flowering periods almost entirely prevent hybrids forming between the species, there may be some disturbing trends. Pollen from each species will germinate on the style of the other and a solitary hybrid between the species was recorded for the Banksia Atlas near Eneabba in 1979. Research by Byron Lamont's group has shown that disturbance (road verges with increased water and nutrients) can have major effects on flowering times in *Banksia hookeriana* and on survival of hybrids between this species and *B. prionotes*. This suggests that both unnatural disturbance (and temperature increase by climate change) could have major impacts on the separation of the two species.

Fire Ecology

Both species have a lignotuber and epicormic buds hidden under the thick protective bark, As a consequence they can easily survive fire. However, *Banksia menziesii* is more prone to damage by fires. Cowling and Lamont (1987) showed that while *B. menziesii* had 30% adult mortality after a spring burn and 7% after an autumn burn at Eneabba, *B. attenuata* had less than 2% for both. Seed release was much slower after spring burns and seedling mortality much higher in both species.

Mortality of shrub forms of *B. menziesii* plants from fire is over four times greater at Eneabba (ranging from 19–31% of plants dying) than at Perth (ranges from 3–9% of plants dying). At Eneabba, *B. menziesii* plants compensate, despite being much smaller by producing as many cones and setting more seed than Perth plants.

Banksia attenuata is moderately serotinous (serotinous refers to the proportion of follicles remaining closed in each year's crop of cones since the last fire) throughout its range, storing a moderate amount of seed in fruits in the canopy. The level of canopy stored seed increases as you travel north. For example *B. menziesii* is not serotinous at Kings Park, all seed is released at the end of the second year, whereas at Eneabba cones older than 3 years are 30% of the total cone population. In contrast *B. attenuata* plants at Northampton had cones 17 years old with viable seed and at Eneabba 70% of cones were older than 3 years. Both species showed marked declines in canopy seed storage south of Cataby.

In both species after fire (and also without fire) seed is normally retained in the capsules until rains result in seed dispersal in the winter. Successive rains rather than a single summer rain event result in seed dispersal. Germination occurs at temperatures between 15 and 20°C.

Banksia menziesii always showed low germination rates of 9–15% in the field and laboratory, compared to 70–80% for *B. attenuata*.

Recruitment is low and variable in the absence of fire. However, seed release was much slower after spring burns and seedling mortality much higher. In all, this suggests that spring burns are problematic for both species and the Banksia woodland community over time.

FURTHER READING

General

Collins, K., Collins, K. and George, A.S. (2008). Banksias. Blooming Books, Melbourne.

Beard, J.S. 1990. Plant Life of Western Australia. Kangaroo Press.

Specific

Cowling, R.M. and Lamont, B.B. (1985). Variation in serotiny in three Banksia species along a climatic gradient. Australian Journal of Ecology 10: 345–50.

Cowling, R.M. and Lamont, B.B. (1987). Post fire recruitment of four co-occurring Banksia species. Journal of Applied Ecology 24: 645–658.

DEC (Department of Environment and Conservation) (2010a). Definitions, Categories and Criteria for Threatened and Priority Ecological Communities. Department of Environment and Conservation, Western Australia.www.dec.wa.gov.au/content/view/849/2017. [Accessed on 11/3/2011]

DEC (Department of Environment and Conservation) (2010b). Threatened ecological communities endorsed by the Minister for the Environment (August 2010). Department of Environment and Conservation, Western Australia.
www.dec.wa.gov.au/content/view/849/2017

Enright, N.J. and Lamont, B.B. (1992). Recruitment variability in the re-sprouting shrub Banksia attenuata and non-sprouting congenors in the northern sandplain heaths of southwestern Australia. Acta Oecologica-International Journal of Ecology 13: 727–41.

Gibson N., Keighery B.J., Keighery G.J., Burbidge A.H. and Lyons M.N. (1994). A Floristic Survey of the Southern Swan Coastal Plain. Report for the Australian Heritage Commission. Department of Conservation and Land Management and the Conservation Council of Western Australia (Inc.).

Government of WA (2000a) Bush Forever Volume 1: Policies Principles and Processes. Ministry for Planning, Perth, Western Australia.

Government of WA (2000b) Bush Forever Volume 2: Directory of Bush Forever Sites. Department of Environmental Protection, Perth, Western Australia.

He, T., Lamont, B.B. and Downes, K.S. (2011). Banksia: born to burn. New Phytologist (web summary).

Hill, R.S. (1998). Fossil Evidence for onset of Xeromorphy and Scleromorphy in Australian Proteaceae. Australian Systematic Botany 11: 391–400.

Itzstein-Davey, F. (2003). The Representation of Proteaceae in modern pollen rain in species rich vegetation communities in South-western Australia. Australian Journal of Botany 51: 135–149.

Itzstein-Davey, F. (2007). Changes in the Abundance and Diversity of Proteaceae in South-western Australia: a Review of an Integrated Paleoenvironmental Study. Geographical Research 45(1): 43–53.

Jordan, G.J., Carpenter, R.J. and Hill, R.S. (1998). The Macrofossil Record of Proteaceae in Tasmania: a Review with new species. Australian Systematic Botany 11: 465–501.

Lamont, B.B., Whitten, V.A., Witkowski, E.T., Rees, R.G. and Enright, N.J. (1994). Regional and Local (Road Verge) Effects on Size and Fecundity in Banksia menziesii. Australian Journal of Ecology 19: 197–205.

Lewis, J. and Bell, D.T. (1981). Reproductive isolation of co-occurring Banksia species at the Yule Brook Botany Reserve, Western Australia. Australian Journal of Botany 29: 665–74.

Scott, J.K. (1980). Estimation of the outcrossing rate for Banksia attenuata R.Br, and Banksia menziesii R.Br. (Proteaceae). *Aust J Bot*, **28**, 53–59.

Whelan, R.J. and Burbidge, A.H. (1980). Flowering Phenology, seed set and bird pollination of five Western Australian Banksia species. Australian Journal of Ecology 5: 1–7.

Table One: Vegetation Complexes containing substantial areas of Banksia Woodland (underlined) in the Perth Metropolitan Region (after Table 5 in Government of WA 2000, derived from Heddle *et al*. 1980, arranged in major geomorphic units)

Dandaragan Plateau
MOGUMBER COMPLEX – SOUTH: Open woodland of *Eucalyptus calophylla,* with some admixture of *E. marginata* and a second storey of *E. todtiana - Banksia attenuata - B. menziesii - B. ilicifolia.*

Gingin Scarp
REAGAN COMPLEX: Vegetation ranges from low open woodland of *Banksia* species *E. todtiana* to closed heath depending on the depth of soil.

Foothills (Ridge Hill Shelf)
COONAMBIDGEE COMPLEX: Vegetation ranges from a low open forest and low woodland of *E. todtiana - B. attenuata - B. menziesii - B. ilicifolia* with localised admixtures of *B. prionotes* to an open woodland of *E. calophylla - Banksia* species

FORRESTFIELD COMPLEX : Vegetation ranges from open forest of *E. calophylla - E. wandoo - E. marginata* to open forest of *E. marginata - E. calophylla - C. fraseriana - Banksia* species. Fringing woodland of *E. rudis* in the gullies that dissect this landform.

Bassendean Complex
BASSENDEAN COMPLEX – NORTH: Vegetation ranges from a low open forest and low open woodland of *Banksia* species *E. todtiana* to low woodland of *Melaleuca* species and sedgelands which occupy the moister sites.

BASSENDEAN COMPLEX – CENTRAL AND SOUTH: Vegetation ranges from woodland of *E. marginata - C. fraseriana - Banksia* spp. to low woodland of *Melaleuca* species, and sedgelands on the moister sites. This area includes the transition of *E. marginata* to *E. todtiana* in the vicinity of Perth.

BASSENDEAN COMPLEX – NORTH – TRANSITION VEGETATION COMPLEX: A transition complex of low open forest and low woodland of *Banksia* species – *E. todtiana* on a series of high sand dunes. The understorey species reflect similarities with both the Bassendean-North and Karrakatta-North vegetation complexes.

Combinations of Bassendean Dunes/Pinjarra Plain/Spearwood Dunes
SOUTHERN RIVER COMPLEX: Open woodland of *E. calophylla - E. marginata - Banksia* species with fringing woodland of *E. rudis - M. rhaphiophylla* along creek beds.

CANNINGTON COMPLEX : Mosaic of vegetation from adjacent vegetation complexes of Bassendean, Karrakatta, Southern River and Vasse.

Spearwood Dunes
KARRAKATTA COMPLEX – NORTH : Predominantly low open forest and low woodland of *Banksia* spp. *E. todtiana,* less consistently open forest of *E. gomphocephala - E. todtiana - Banksia* species.

KARRAKATTA COMPLEX – NORTH – TRANSITION VEGETATION COMPLEX: A transition complex of low open forest and low woodland of *Banksia* species - *E. todtiana* on the transition zone of a series of high sand dunes between Bassendean-North and Karrakatta-North.

KARRAKATTA COMPLEX – CENTRAL AND SOUTH : Predominantly open forest of *E. gomphocephala - E. marginata - E. calophylla* and woodland of *E. marginata - Banksia* species.

COTTESLOE COMPLEX – NORTH: Predominantly low open forest and low woodland of *B. attenuata* – *B. menziesii - E. todtiana;* closed heath on the Limestone outcrops.

Wetlands
PINJAR COMPLEX: Vegetation ranges from woodland of *E. marginata - Banksia* species to a fringing woodland of *E. rudis - M. preissiana* and sedgelands

Table Two: Banksia Woodland Floristic Community Types (after Table 6 in Part 1 Government of WA 2000)

Key

Column 1: Floristic Community Type Codes

The numbers of the types additional to Gibson *et al.* (1994) are italicised if they are subsets of an existing group (in types 19, 20, 23 and 30) and italicised and preceded by an S if they are supplementary groups.

Column 2: General Description of Floristic Community Types

Descriptions are based on generalised information from all plots in the group. Structural units are categorised into forest, woodlands, shrublands, sedgelands and herblands after Gibson *et al.* (1994).

Column 3: Distribution in relation to the Perth Metropolitan Region

PMR	confined to PMR		
PMR+	predominantly in PMR	N	Northernmost location in the PMR
(PMR)	rare in PMR	S	Southernmost location in the PMR
blank	outside PMR	C	PMR central to distribution
>PMR	distribution goes well beyond the PMR		

* except for isolated occurrence outside normal range

Column 4: Average Species Richness per Floristic Community Type

Average species richness per 10m *x* 10m plot, less those species only occurring in a single plot (single records). Some community types can have a high proportion of single records and these estimates of average species richness are underestimates in some cases.

Column 5: Threatened ecological communities (TECs) and priority ecological communities (PECS).

Supergroup 3 – Uplands centred on Bassendean Dunes and Dandaragan Plateau

1	2	3	4	5
20a	*Banksia attenuata* woodlands over species rich dense shrublands	PMR+/S	64.5	EN
20b	Eastern *Banksia attenuata* and/or *Eucalyptus marginata* woodlands	PMR+/N	59.7	EN
20c	Eastern shrublands and woodlands	PMR	60.4	CR (EN)
20d	Dandaragan Plateau shrublands and woodlands		67.6	
21a	Central *Banksia attenuata - Eucalyptus marginata* woodlands	PMR/N	52.0	
21b	Southern *Banksia attenuata* woodlands		57.5	
21c	Low lying *Banksia attenuata* woodlands or shrublands	PMR+	38.5	P3
22	*Banksia ilicifolia* woodlands	>PMR/C	30.0	P2
23a	Central *Banksia attenuata - Banksia menziesii* woodlands	PMR	59.0	
23b	Northern *Banksia attenuata - Banksia menziesii* woodlands	>PMR/S	47.0	
23c	North-eastern *Banksia attenuata - Banksia menziesii* woodlands	(PMR)	53.0	
S9	*Banksia attenuata* woodlands over dense low shrublands	(PMR)/S	*38.9*	

Supergroup 4 – Uplands centred on Spearwood Dunes

1	2	3	4	5
24	Northern Spearwood shrublands and woodlands	PMR*	38.9	
25	Southern *Eucalyptus gomphocephala – Agonis flexuosa* woodlands	>PMR/S	48.1	P3
28	Spearwood *Banksia attenuata* or *Banksia attenuata - Eucalyptus* woodlands	>PMR/S	55.1	

▲ Banksia woodland - *Banksia menziesii* in foreground; Kensington Bushland, Bush Forever Site 048. (B. Keighery)

▲ New Holland Honeyeater *Phylidonyris novaehollandiae* feeding on nectar of Menzies' Banksia (Mungyt) *Banksia menziesii*. (M. Owen)

FUNGI OF PERTH'S BANKSIA WOODLANDS

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Most terrestrial ecosystems, including Banksia woodlands, have a large biodiversity of fungi. The fungi are involved in many processes that contribute to ecosystem health, such as nutrient recycling and beneficial partnerships with plants and animals. Flora, Fauna and Fungi and the interdependencies between them need to be understood and managed in order to nurture bushlands such as Perth's Banksia woodlands.

Forms and diversity

The majority of fungi are microscopic. However the most familiar fungi are those which produce spore-bearing fruit bodies clearly visible to the naked eye. They are the so-called 'larger fungi' or 'macrofungi', e.g. mushrooms, toadstools, puffballs, coral fungi, earthstars, and truffles. The current paper focuses on the macrofungi. Some macrofungi are very conspicuous such the luminescent Ghost Fungus often seen on trees around Perth every winter. Mostly the fungi are less obvious. The best time to find fungi in Perth's Banksia woodlands is through the autumn and winter months. Fungal fruiting may be briefer and less consistent in woodland regions of Australia than in wetter regions. However, this does not necessarily indicate that fewer fungi are present. In both regions a diverse range of fungal networks may be active below ground.

There are probably at least 10 times more species of fungi than plants in the world. For Western Australia that equates to about 140,000 fungi and 14,000 plant species. No one really knows how many fungi we have. Possibly only about 5–10% are discovered and named to date. The diversity of fungi in the Perth region probably rivals that of the wetter regions of Australia. Although few of the local fungi are likely to be unique to, or restricted to, Perth's Banksia woodlands, a majority of the local fungi are yet to be discovered, well-defined or named. Typical of these is a tiny mushroom fungus collected at Bold Park in 2009 initially unidentified and labelled as "*Undetermined agaric (tiny, adorned with bubbles, cream-spored, on wood)*" which recently has been determined as *Hemimycena cephalotricha* – a species which was previously unrecorded in Australia (Bougher, 2010a). Species new to science continue to be discovered in Perth's urban woodlands, such the Gregarious Bells (*Campanella gregaria*), which fruits in large numbers usually on the inside surface of bark loosely clinging onto fallen banksia logs (Bougher, 2007).

Ecological significance

Fungi interlink with flora and fauna to help sustain the health of much of Australia's natural vegetation. Fungi benefit ecosystems via their vast networks of threads (singular – mycelium, plural – mycelia), and therefore their actions occur mostly out of sight. Fungal networks recycle nutrients and can enhance plant uptake of soil nutrients, buffer plants against stresses such as disease, provide food and/or habitat for many animals, bind soil particles and contribute to soil structure and erosion control.

Fungi are significant in nutrient cycling as they capture, store, release and recycle carbon and minerals (e.g. phosphorus, nitrogen, sulphur, copper). Fungi decompose dead organic matter including lignin and cellulose (the major components of plant cell walls), making nutrients available to plants and returning organic matter to soil. Fungi have symbiotic (mutually beneficial) partnerships with many plants. Fungal networks act like an extra root system taking up, transforming and transporting nutrients from soil and delivering them to plant roots. The so-called mycorrhiza "fungus-root" systems are often superior to roots alone, and may capture nutrients in the soil far distant from roots. The fungi benefit as the plants supply sugars to them. Banksias and other Proteaceae generally do not partner mycorrhizal fungi. They have developed other non-fungal strategies to cope with low nutrient soils, such as proteoid roots. However a range of other plants in and surrounding Banksia woodlands do have beneficial fungal partners, e.g. eucalypts, sheoaks, wattles, orchids and peas.

Fungi also provide food and/or habitat for many animals – large and small. Small native marsupials such as woylies, potoroos and bandicoots are lured by aromas to dig up and eat truffle fungi (fungi with underground fruit bodies). The truffle spores pass unharmed through the gut, and are deposited in dung potentially far from the original site of consumption. The fungus benefits by dispersal of its spores. The animal benefits from the nutritional value of the fruit body. Fungi are also eaten by myriads of small soil animals such as insects. These small animals are in turn important to soil organic matter and to the food web which feeds larger animals and birds.

Surveys of fungi in Perth's Banksia woodlands

There have been no co-ordinated programs to document the diversity, abundance and distribution of fungi in Perth's Banksia woodlands. However more broadly, a collaborative project between the WA Naturalists' Club, the Urban Bushland Council and the Department of Environment and Conservation's Western Australian Herbarium – *Perth Urban Bushland Fungi* (PUBF) – began in 2004 to promote a better understanding of the significance of fungal diversity and function in Perth's bushlands and to build scientifically accurate information about fungi of the Perth region (see www.fungiperth.org.au). Numerous surveys of fungi in Perth's bushlands have been undertaken, in many cases recording fungi in local bushlands for the first time ever. However, mostly these surveys have been conducted only once at any particular bushland. In order to obtain an accurate measure of fungal diversity at any location it is necessary to survey fruit bodies at that same location over many years. Only two locations in the Perth region with significant areas of Banksia woodland have been surveyed for fungi over multiple and successive years – Bold Park and Kings Park.

Bold Park is a regionally significant urban bushland incorporating more than 400 hectares of diverse vegetation types on Spearwood and Quindalup dune systems. Surveys of fungi at Bold Park have been undertaken in line with the Bold Park Environmental Management Plan 2000–2005 and the Bold Park Management Plan for 2006–2011 as part of ongoing goals to conserve and protect the local biodiversity at Bold Park. Surveys of fungi at Bold Park were begun in 1999 to inventory the fungi by describing and identifying the species and to build a library of permanent reference herbarium specimens. One of the dominant vegetation types surveyed for fungi at Bold Park is characterised as woodland of *Banksia attenuata* and *Banksia menziesii,* with emergent *Eucalyptus gomphocephala*, over a variable understorey on grey sand. After the survey in 2010, a total of about 460 putative species of fungi have been recorded in 14 vegetation types at Bold Park. Many newly recorded fungi species have been observed each survey year since 1999 (e.g. 40% new in 2009 and 19% new in 2010). This indicates that many more as yet unrecorded species are likely to occur in the Park.

Kings Park and Botanic Garden is located only 1.5 km from central Perth and includes a regionally significant bushland covering about 267 ha of the 400 ha Park. Banksia woodland (including *Banksia attenuata, B. grandis,* and *B. menziesii*) is one of the major plant communities at Kings Park. The scientific study of fungi from Kings Park was instigated in the 1830s by pioneer botanical collectors who sent their specimens to mycologists overseas. The first known scientific record of a fungus from Kings Park was in 1839. However, subsequent efforts to document the fungi of the park have been mostly sporadic and uncoordinated and have not yielded an accurate measure of the total number of fungi species recorded to date at Kings Park. The measure is not accurate because 145 of the 285 scientific names recorded up to 2009 cannot be verified as they are not based on vouchered specimens held at a herbarium (Bougher, 2010b). In 2009, the Botanic Gardens and Parks Authority took a significant step to address the poor knowledge base about Kings Park's fungi by contracting the first of annual surveys to document the macrofungi. The survey in 2009 recorded a total of 123 species of fungi including 67% (82) new records for Kings Park. During the 2010 survey a total of 108 fungi were recorded including 47% (51) new records. After the 2009–2010 surveys, a total of 190 fungi named to species level have been recorded from Kings Park (Bougher, 2011). However, it is not possible to accurately estimate the number of fungi species known so far from Kings Park. Any estimate depends on the level of acceptance of unverified or unverifiable names recorded before 2009. Further field surveys combined with taxonomic studies will undoubtedly confirm the presence of many more species of fungi at Kings Park.

Fungi weeds, altered bushlands and microhabitats

Some of the fungi in Perth's urban bushlands undoubtedly have been introduced in recent times from elsewhere. One such species is a large member of the Ink Cap fungi that self-digest into a black liquid as they mature. It is a variant of *Coprinopsis stangliana* – a rare fungus previously known only from a few places in Europe. The first report of this fungus in Australia was from Banksia woodland in Kings Park about 12 years ago. Since then abundant crops of its statuesque fruit bodies have been spotted in many Perth urban bushlands mainly during June and July (Bougher, 2006). It seems to be restricted to highly disturbed patches such as aside of tracks among weeds particularly in Tuart/Banksia woodlands. It seems unlikely that this distinctive large fungus had been overlooked before 12 years ago and it may be spreading rapidly following its introduction into the Perth region. Many questions remain unanswered about this fungus and some other possible weedy fungi. Is this fungus native to Australia? If not, where did it come from, how and when? Does it affect bushland ecology or other fungi by rapidly spreading into and dominating new areas and potentially competing with or preventing establishment by native species?

Fungi, like flora and fauna, are sensitive to changes and disturbances in bushlands, e.g. fire, removal of host plants, loss of animal vectors, grazing by exotic animals, clearing and fragmentation. At Kings Park a succession of fungi species became active in areas burnt in 2009, e.g. the cup fungi – *Anthracobia melaloma*, *Peziza tenacella* and *Pulvinula archeri*, and the mushroom fungus – *Pholiota highlandensis*. These same species occur elsewhere throughout temperate Australia after fire. Fungi help re-establish nutrient cycling processes and plant growth after fire. The presence of the cup fungus *Peziza moravecii* at Kings Park is indicative that another type of post-disturbance fungal succession is operating at Kings Park. *P. moravecii* is an ammonia fungus – it is representative of a chemoecological group of fungi with exclusive or enhanced mycelial and fruiting activity in the presence of ammonia nitrogen. Successional assemblages of ammonia fungi can occur naturally in organic nitrogen-rich circumstances such as near animal corpses, urine and dung depositions, or other ammonia-rich post putrefaction sites.

Fragmentation of woodlands into isolated patches may affect the viability of some native fungi. For example truffle fungi in Perth's urban bushlands may be sending out their animal-attracting aromas in vain. Fungus-eating mammals are now rare or absent in Perth's bushlands. How are these truffles dispersed in the absence of their mammal vectors that formerly co-existed with them in the bushlands? Have Perth's truffles become orphans doomed to a shrinking existence within the bounds of their urban bushland patches? The reduction or absence of native mammals in urban bushlands also has implications for native coprophilous (dung-dwelling) fungi.

Recently, Portuguese millipedes have become abundant in Perth's Banksia woodlands. These exotic pests forage voraciously on the fruit bodies of fungi and their mycelia. If they continue to proliferate it is possible that the millipedes may ultimately affect the biodiversity of fungi in the woodlands. This could have consequent flow-on effects such as reduction in the functioning of mycorrhizal systems associated with native plants in the Perth region. Eradication of the millipedes needs to be tackled at the regional level.

One of the keys to protecting fungal biodiversity in Perth's bushlands is to conserve a diversity of microhabitats. The significance of retaining microhabitats in urban woodlands is evident from recent surveys in the Perth region. For example, at Kings Park in 2009–2010 fungi were recorded in a wide range of microhabitat types, but the largest majority of them (54%) were found growing on wood, emphasising the significance for fungal diversity of retaining logs and other coarse woody debris in urban woodlands. Some fungi favour certain types of logs, e.g. the Gregarious Bells as mentioned above favours the inside surface of bark loosely clinging onto fallen Banksia logs. Logs provide a moist refuge within the wood and on shaded ground. Much fungal activity persists in such microhabitats. Some fungi, e.g. certain species of *Galerina*, favour thick moss swards on the shady side of trees or large logs and are less often seen amid moss on more open ground.

Recommendations

Changed or reduced fungi diversity in Perth's Banksia woodlands may have implications for other organisms and overall ecosystem balance. Recognising changes in fungi diversity is a fundamental step for considering fungi in management of woodlands. Assessments of baseline conditions of biodiversity and changes in biodiversity over time are an integral part of many conservation and restoration activities. The currently poor information base about local fungi species impedes our undertaking and capacity to understand and manage the fungi and their interactions with other organisms. It is recommended that surveys of fungal diversity in Perth's bushlands be undertaken over many successive years to build baseline data against which to monitor changes over time, e.g. effects of major events such as fire, and the influence of management practices. Survey protocols such as developed by PUBF are now well tested locally and can be used for undertaking fungi surveys and producing permanent and accessible data. The surveys can be operated by individuals who may only have a minimal knowledge level about fungi, and are well suited for annual involvement by Friends Groups and local community volunteers.

References

Bougher, N.L. (2006). Coprinopsis stangliana – a recently introduced fungus expanding in urban bushlands of the Perth region. Nuytsia **16**: 3–10.

Bougher, N.L. (2007). The genus Campanella in Western Australia. Mycotaxon **99**: 327–335.

Bougher, N.L. (2010a). First record for Australia of the wood-inhabiting fungus Hemimycena cephalotricha: from urban bushland in Perth, Western Australia. Western Australian Naturalist **27**: 91–98.

Bougher, N.L. (2010b). History of the study of fungi at Kings Park, Western Australia. Western Australian Naturalist **27**: 61–90.

Bougher, N.L. (2011). New records of fungi and slime moulds at Kings Park, Perth, Western Australia. Western Australian Naturalist **28**: 24–42.

▲ Earthstar decomposing fungus found in leaf litter or on soil.
(K. Sarti)

WILD ABOUT THE SUBURBS: ANIMAL WINNERS AND LOSERS OF THE BANKSIA WOODLANDS

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INTRODUCTION

Perth is a sprawling, land-hungry city that lies within a global biodiversity hot-spot. Much of that biodiversity, and much of that sprawl, occurs in Banksia woodlands. The purpose of this paper is to provide a brief introduction to a small but important and often charismatic component of that biodiversity: the vertebrates. In particular, what are the features of this assemblage, how do the species fare in the face of urban expansion and what can individuals do to encourage this fauna? Massive habitat loss leads to rapid population declines during urban development, but some fauna do survive and the suburbs and wildlife are not mutually exclusive!

OVERVIEW OF THE VERTEBRATE ASSEMBLAGE

At the time of European settlement, Banksia woodlands in the Perth region had an impressive vertebrate fauna: about 10 frog species, over 50 reptile species, nearly 200 bird species and over 25 mammal species. It is an assemblage rich in species and in some cases strange in composition; and it is an assemblage that reflects the extraordinary geological and climatic history of the region. The whole south west of Western Australia is like an island stuck on the side of a large fragment of Gondwanaland, and the Banksia woodlands are a strange environment that has developed on what are comparatively young coastal sandplains attached to the side of that island! The faunal assemblage has been sculpted by Gondwanan origins, colonisation from other parts of Australia and Asia, by climate change and by the unique soil characteristics of the coastal sandplain tacked onto the side of the ancient plateau.

FROGS

Of amphibians, we have only frogs and the majority of these are arid-adapted, woodland species. The Turtle Frog *Myobatrachus gouldii* is strictly terrestrial and lays eggs, from which hatch small frogs, deep underground. Other species such as the Moaning Frog *Heleioporus eyrei* and Pobblebonk *Limnodynastes dorsalis* rely on wetlands to breed, but are entirely terrestrial for the rest of their lives, living 3–4 km from water most of the year. There are also a few species that are more strictly confined to wetland areas.

Frogs have shown remarkable resilience in the face of urban development. We still have all the species in the Perth area despite massive habitat loss. They survive around wetlands even where these are modified, and they survive even in small, degraded patches of woodland. Threats (and therefore opportunities) are:

- Drying climate and falling groundwater. Some frog populations are "the living dead", with adults still present but failing to breed because wetlands no longer flood sufficiently for them to do so.
- Gardens and garden fencing. Gardens can provide habitat. However, garden fencing prevents the annual breeding migration of adults and dispersal of juveniles.
- Changing water level fluctuations. Especially important for the Moaning Frog that is extinct at wetlands like Herdsman Lake where the water level does not rise and fall seasonally.

REPTILES

We have one of the richest reptile assemblages in the world with several species confined to the coastal sandplain. Many species of lizards and snakes are adapted to a fossorial (effectively "sand-swimming") lifestyle which means they are hard to find. These fossorial species can be incredibly abundant with more than 100 individuals/ha of tiny skinks that weigh less than 2 g each.

Reptiles have survived in urban areas even where only small, degraded bushland remnants have been retained. Large areas of bush, such as Kings Park and Bold Park, support 20–30 species and that is about what they would have supported before Perth developed around them. Bushland around Karrakatta Cemetery supports a thriving population of Bungarra (Gould's Goanna) *Varanus gouldii*. The only reptile species that has really gone from the Perth area is the Carpet Python *Morelia spilota*. At the other extreme, about five species survive in even the neatest and most biologically sterile suburban gardens without any access to native vegetation. Threats (and therefore opportunities) are:

- Habitat Fragmentation. Larger reptile species such as the Bobtail *Tiliqua rugosa* persists in tiny areas of native vegetation but disappears after some decades, probably because individuals are scattered and incapable of finding mates to breed.
- Roadkill. Larger species such as the Bobtail and Bungarra (Gould's Goanna) can suffer high levels of mortality on roads surrounding bushland remnants.
- Cats. There is growing evidence that domestic cats cause local extinction of species such as the Striped Skink *Ctenotus fallens,* Bearded Dragon *Pogona minor* and Sandhill Dragon *Ctenophorus adelaidensis*. Home gardens may be able to support more reptile species in the absence of cats.

BIRDS

The bird assemblage of Banksia woodlands is not especially rich and densities are low, but with one group of species very obvious: the honeyeaters. These are specialist nectarivores and they can survive because of the richness and abundance of nectar-producing plants.

Birds have suffered badly in the urban landscape. Only very large tracts of bushland, such as Whiteman Park, retain virtually all their original avifauna, and even then a few species have gone or are declining. In urban areas with very little remnant bushland the avifauna is very poor and often dominated by introduced species. Isolated but large tracts of bushland, such as Kings Park, have a well-documented decline in bird species richness. Species that decline tend to be more or less sedentary, whereas large and/or mobile species can survive and even flourish in urban landscapes. There are lessons in the patterns in the decline and persistence of birds.

- Size does matter. Small bushland remnants usually have fewer species of birds and tend to have some whole groups missing. Note that over time, the number of species present may decline as "extinction debt" takes hold.
- Habitat fragmentation. Isolated bushland remnants may have fewer species than remnants that are linked to other remnants by corridors of vegetation. This is a fertile area for research. The species that tend to disappear are more or less sedentary bird species (e.g. fairy-wrens, thornbills) that are prone to local extinction (cats, fire). In contrast, mobile species, such as honeyeaters and parrots, will continue to visit isolated remnants.
- Habitat degradation. The species that tend to disappear from remnants also tend to require vegetation that is at least in fair condition, such as a dense shrubby understorey. Weed invasion and vegetation changes due to frequent fires can degrade habitat.
- Cats. Probably a major cause of local extinction of sedentary bird species in small, isolated fragments.
- Fire. Alters habitat, may be some direct mortality and leaves surviving, sedentary birds more exposed to predators.
- Species interactions. The role of introduced species and over-abundant native species is uncertain, but needs to be considered. For example Rainbow Lorikeets *Trichoglossus haematodus* will displace native parrots from nest hollows.

Observations of birds are especially useful in suggesting what can be done. For example, gardens tend to provide little habitat for birds, but have great potential and gardens planted to create habitat for birds can address the problems of bushland remnant size, fragmentation and condition.

MAMMALS

The original mammal fauna of Banksia woodlands includes the extraordinary Honey Possum *Tarsipes rostratus*, small, insectivorous and larger carnivorous marsupials (dunnarts such as *Sminthopsis griseoventer* and the

Chuditch *Dasyurus geoffroii*), native rodents like the Noodji or Ash-grey Mouse *Pseudomys albocinereus*, several species of bandicoots, rat-kangaroos, possums and probably a number of small wallabies. There were also up to eight species of bats and the ubiquitous Echidna. Even in undisturbed Banksia woodland, a number of these species have disappeared, due largely to predation by foxes.

In the Perth area, native mammals have fared very, very badly. Small, terrestrial species are gone and the only survivors are some of the bat species, the Brush-tailed Possum *Trichosurus vulpecula*, the Quenda or Southern Brown Bandicoot *Isoodon obesulus* in dense vegetation around some wetlands, the Rakali or Water-rat *Hydromys chrysogaster* and the Western Grey Kangaroo *Macropus fuliginosus* that is semi-tame in some golf courses and reserves. The only native mammals to make widespread use of gardens are probably some of the bats. Gould's Wattled Bat *Chalinolobus gouldii* and the White-striped Freetail-bat *Tadarida australis* will roost in buildings and fairly commonly forage over suburbs. Both also make use of bat-boxes. Introduced species, notably Fox *Vulpes vulpes*, Rabbit *Oryctolagus cuniculus* and Black Rat *Rattus rattus*, are widespread. Mammals have done badly for a number of reasons:

- Size does matter. Most urban remnants are probably too small for many mammal species.
- Habitat fragmentation. Small mammals are like sedentary birds and sensitive to local extinction in fragmented landscapes. The Honey Possum needs to be able to move around to find seasonal flowers so although a tiny animal it may need several km^2 over the course of a year.
- Cats. Probably a major cause of local extinction of small mammals in small, isolated fragments. Reports of native mammals are many as Quenda disappearing with the arrival of cats in a neighbourhood; usually the young are taken.
- Fire. Alters habitat, may be some direct mortality and leaves surviving small mammals more exposed to predators.
- Roadkill. This may be a factor in the local extinction of mammals such as the Quenda.
- Species interactions. The role of introduced species such as cats and foxes is well-documented. A quarter to a third of the mammal fauna is extinct across large parts of Australia due to introduced predators.

CONCLUSIONS

Compared with the fauna that was present in the Banksia woodlands of the Perth region at the time of European settlement, we can draw the following conclusions:

1. All frog species are still present and survive in remnant woodlands and wetlands, with most species relying on even degraded wetlands for breeding. Some species make use of gardens.
2. Most reptile species are still present and show a remarkable ability to survive in even small, degraded remnants. Several species survive in gardens.
3. Birds are still well-represented but many species have declined or disappeared from the urban region. Species that have declined or disappeared tend to be those that are sedentary and require native vegetation (eg. fairy-wrens, thornbills). Species that have survived and even flourished are often nomads or migrants and are flexible in their habitat requirements. Appropriate gardens support a fair range of species.
4. Few mammal species survive in the urban area even where there are large remnants of bushland. The only mammals that regularly use gardens are a couple of bat species.
5. Factors which influence the survival of fauna in the urban landscape include the distribution and character of bushland remnants (size, isolation, fire history), the style of gardens and predation by cats and dogs.

Massive habitat loss is largely responsible for population declines, but a range of factors influence the persistence of species in the matrix of urban and woodland areas across the suburbs. These factors also indicate what sorts of actions can be taken to assist wildlife to persist in the urban woodland matrix. Specific factors include:

- For frogs, modifications to natural fluctuations in water levels prevent breeding in some species. It may be possible to return natural cycles to wetlands, and to avoid altering natural cycles.
- Fragmentation of habitat and reduction in landscape permeability (the extent to which animals can move across the landscape). For example, fences prevent frogs and reptiles moving around, while the lack of suitable habitat in gardens may isolate even some birds and mammals. There are many restrictions on fencing but a greater awareness of the role of public and private gardens as wildlife habitat is needed.
- Size of remnant. This is influenced by the degree of fragmentation and isolation. A small remnant that is linked to other small remnants is functionally larger than an isolated remnant of the same size. There is nothing that can be done about the size of existing remnants, but linkage can often be improved, such as through local gardens.
- Condition of remnant (important for birds but less so for reptiles). Remnant condition is a major issue; perhaps important to note that even when the vegetation is badly degraded, the remnant may still be important for many fauna species.
- Predation by cats (reptiles, small birds and small mammals) and possibly also dogs and foxes (may be significant for some mammals). Predation can lead directly to local extinction but can also increase isolation by preventing successful dispersal. Management of domestic cats provides a lot of opportunity to reduce this sort of predation.
- Fire can affect survival of species in remnants but can interact with other factors, such as remnant condition and the presence of cats or other predators. Note that fire may have management priorities other than wildlife conservation.

▲ Robber Fly (Asilidae) with a captured European Honey Bee; Landsdale Reserve. (M. Owen)

▲ Pink Fairy Orchid *Caladenia latifolia* with a Lynx Spider on the sepal; Underwood Avenue Bushland. (M. Owen)

HOW DO TREES AND SHRUBS OF PERTH'S BANKSIA WOODLANDS SURVIVE SUMMER DROUGHT?

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INTRODUCTION

Perth's Banksia woodlands inhabit nutrient-impoverished coarse sands of low water-holding capacity overlying shallow unconfined groundwater aquifers with a depth-to-groundwater ranging from < 1 m in the low lying depressions, damplands and wetlands to > 30 m atop the dune crests (Fig. 1). These soils tend to dry out to considerable depths during the hot, dry summer months (Dec–Mar), rewetting when rain falls in autumn and winter (May–Aug). Up to 8 m depth, seasonal variations in soil moisture profiles are closely tied to rainfall events, fluctuations in groundwater levels and topographic location.

The dominant deep-rooted *Banksia* species are groundwater dependent (phreatophytic), with the degree of dependency varying across the sandplain landscape (Froend and Drake, 2006; Canham *et al.* 2009). Shallow-rooted shrub species (< 1 m rooting depth) are the most drought tolerant of all woody species, having the ability to survive Perth's harsh, drought-prone summer without access to groundwater. The only exception are those species restricted to low-lying or seasonally waterlogged areas, some of which are listed in Table 1 as 'tolerant of excessive wetness'.

The ability to survive long periods of summer drought is an important determinant of species distribution and is a function of their rooting patterns and physiology, both of which underpin the foundation for a species habitat preference. Habitat preferences of the Banksia woodland flora have been known since 1968 (Table 1) and are based on the underlying hydrology and seasonal soil moisture parameters. Understanding the groundwater-use strategies employed by representative tree and shrub species of Perth's Banksia woodlands will help government and local land managers predict how the vegetation is responding to hydrological and climatic changes at the population and community level. Low rates of groundwater drawdown (9 cm year^{-1}) caused by continual years of below-average rainfall and the impacts of groundwater harvesting have caused a progressive change in the Banksia woodland flora since the mid-1970s, particularly in the low-lying areas (Groom *et al.* 2000a; 2001; Froend and Sommer, 2010). The implications for higher drawdown rates (50 cm year^{-1}) experienced near borefields is much more severe (Sommer and Froend, 2010; Froend and Sommer, 2010).

OVERSTOREY SPECIES

Perth's Swan Coastal Plain Banksia woodlands of the Bassendean and Spearwood dunal systems are dominated by an upper stratum of evergreen *Banksia* (Proteaceae) species with occasional stands of *Eucalyptus* and *Corymbia* (Myrtaceae), and *Allocasuarina* (Casuarinaceae). *Melaleuca* (Myrtaceae) tree species fringe the many wetlands. Four *Banksia* species dominate the overstorey of the older Bassendean dune system: *B. attenuata* (Candlestick Banksia), *B. menziesii* (Firewood Banksia) *B. ilicifolia* (Holly-leaf Banksia), *B. littoralis* (Swamp Banksia). *B. prionotes* (Acorn Banksia) has a preference for the sandy soils overlying limestone typical of the more coastal Spearwood dunes. *Banksia* trees, in particular, have the capacity to access groundwater and deep soil moisture sources via their deep dimorphic root system (Fig. 2), consisting of a central thick sinker root and subsurface lateral roots from which smaller sinker roots arise.

Banksia attenuata* and *B. menziesii

Banksia attenuata and *B. menziesii* co-dominate the overstorey, occurring in all topographic locations except those areas prone to waterlogging (i.e. damplands and associated low-lying depressions). Both species are classified as facultative phreatophytes, whereby the ability to access and use groundwater during the summer months is a function of groundwater depth (Zencich *et al.* 2002). There is ecological evidence to suggest that *B. menziesii* is more drought tolerant than *B. attenuata*, with only 26% of *B. menziesii* trees (as against 45% of *B. attenuata* trees) succumbing to a prolonged summer drought near a groundwater abstraction bore from the Pinjar borefield in 1991 (Groom *et al.* 2000*b;* Sommer and Froend, 2010). However, the degree of mortality was confounded by extreme summer temperatures. It has been suggested (Muir 1983) that *B. menziesii* may replace *B. attenuata* on dune slopes, being better adapted to drier conditions, whereas *Banksia attenuata* will probably persist in damper areas.

Banksia attenuata populations are able to maintain similar summer canopy transpiration rates (~170 mL cm^{-2} day^{-1}) whether groundwater is accessible (sites < 9 m groundwater depth) or not (site > 30 m groundwater depth) (Zencich *et al.* 2002). At the latter site, water used by *B. attenuata* during the spring months (Sept–Nov) is predominately stored soil water derived from the previous winter rainfall. As surface soils dry in spring (2–4% soil moisture content), *B. attenuata* trees are accessing less surface (0–0.4 m) and more subsurface (0.4–4 m) soil moisture. As the sandy soils continue to dry (0.2–3% soil moisture content) throughout the summer and early autumn months, nearly all of water used by the trees is accessed from deeper soil moisture sources (>> 4 m). The occurrence of autumn and winter rains coincide with a significant increase in the proportion of water taken from the surface and subsurface soils.

B. attenuata and *B. menziesii* seedlings grow a single sinker root > 1.5 m deep within their first year of establishment (Rokich *et al.* 2001), providing access to soil water or groundwater at relative depth. Glasshouse experiments have demonstrated that such an early investment in root biomass allows *B. attenuata* and *B. menziesii* seedlings to survive up to 140 days of drought with a rooting depth of 1 m, avoiding desiccation by restricting leaf water loss (Groom, 2002). This ability to access soil water at depth is critical for seedlings of deep-rooted species to survive their first summer. Enright and Lamont (1992) found that, in the sandy heathlands north of Perth, 1-year-old seedlings of *B. attenuata* seedlings had greater survival (34%) and were potentially accessing subsurface soil water during their first summer in interdunal swales (low-lying areas) compared with seedlings occurring on dune crests (4% survival).

Banksia ilicifolia and *B. littoralis*

Both *Banksia ilicifolia* and *B. littoralis* are obligate phreatophytes (Canham *et al.* 2009). *B. ilicifolia* is highly dependent on summer groundwater when the groundwater depth is less than 2 m (Zencich *et al.* 2002) and is restricted to topographic positions where the depth-to-groundwater is less than 10 m (Groom *et al.* 2001). Because of this dependency on groundwater at relatively shallow depths, *B. ilicifolia* is considered to be highly susceptible to declining groundwater levels (Groom *et al.* 2000*b*; Froend and Drake, 2006). *B. littoralis* is the only *Banksia* species of the northern Swan Coastal Plain confined to the fringes of wetlands and low-lying depressions. It is therefore reliant almost exclusively on shallow groundwater all year round (Zencich, 2003). Declining tree numbers in *B. littoralis* populations and poor seedling recruitment in recent years has been attributed to long-term decreases in soil moisture contents and declining groundwater levels (Groom, 2002; Groom *et al.* 2001). This makes this species the most susceptible *Banksia* to long-term declining groundwater levels and extended periods of summer drought within Perth's Banksia woodlands. Based on their physiology (Froend and Drake, 2006), the majestic *Melaleuca preissiana* trees that sometimes co-occur with *B. littoralis* are even more susceptible to long-term declines in groundwater levels, although they do possess a more extensive and deep rooting system.

UNDERSTOREY SPECIES

The woody shrub species of the Banksia woodlands can be generally classified as either shallow (< 1 m), medium (1–2 m) or deep (> 2 m) rooted (Dodd *et al.* 1984). Both shallow- and deeper-rooted shrub species co-occur over a range of groundwater depths and topographic positions, with shallow-rooted species dominating areas of relatively low groundwater depth (Groom *et al.* 2000*a*). Shallow-rooted species that only inhabit the low-lying depressions or fringe wetlands will display different seasonal water-use patterns compared with shallow-rooted species occurring on the mid and upper slopes (Groom, 2003). Drought tolerance appears to be well-developed in shrubs with restricted access to water at depth during the summer months (Dodd *et al.* 1984).

Shallow- and medium-rooted species

Hibbertia hypericoides (Dilleniaceae) typically has a shallow rooting system (although the species has been recorded as having a root system up to 2 m deep), and thus rarely has access to groundwater (Zencich *et al.* 2002), relying exclusively on shallow soil moisture sources all year round. Because of this reliance on limited soil moisture reserves during summer, *H. hypericoides* becomes summer dormant resulting in significant reductions in its leaf water loss and leaf water content (Grieve, 1956; Zencich *et al.* 2002; Veneklass and Poot, 2003). Under severe droughts *H. hypericoides* leaves will lose its green coloration (turning yellow-orange) and shrivel, all in an attempt to further minimise water loss and limit leaf functionality. This enables *H. hypericoides* to inhabit all topographical positions within the dunal landscape, except habitats where waterlogging may occur. The water relations of shallow rooted species like *H. hypericoides* are strongly influenced by the moisture content of the top 1 m of soil, quickly rehydrating in response to episodic summer rainfall events and break of season (autumn) rains (Grieve, 1956; Dodd *et al.* 1984), and are the most summer drought tolerant of all the shrub species.

The response of medium-rooting species (e.g. *Beaufortia elegans* and *Scholtzia involucrata*; both in the family Myrtaceae) to summer drought is similar to that of co-occurring shallow-rooted species, except that medium-rooted species have access to moisture at moderate soil depths (Dodd *et al.* 1984). Like *H. hypericoides*, both *B. elegans* and *S. involucrata* inhabit a wide range of topographic locations – from dune crests to wetland embankments (see Fig. 1). Medium-rooted species are unable to cope with sudden summer groundwater drawdown events (Groom *et al.* 2000*b*) as they are forced to compete with deep-rooted shrub and tree species for limited soil moisture sources. Despite an overall reduction in soil moisture content and groundwater levels on the northern Swan Coastal Plain since 1976, plant numbers of *B. elegans* and *S. involucrata* have increased or stabilised (Groom *et al.* 2000*a*).

The shallow-rooted *Pericalymma ellipticum* and *Astartea fascicularis* (both in the family Myrtaceae) only occur in low-lying, winter-wet depressions and swampy interdunes (Farrington *et al.* 1990; Groom, 2003). It is assumed that because of its restricted distribution to locations with near surface groundwater, both species are dependent on groundwater all year round, perhaps reverting to subsurface soil water during the summer months when groundwater levels decline below their maximum rooting depth. Groom (2003) monitored the water relations and water sources used by both species in an interdunal dampland during an exceptionally dry spring-summer-autumn, and found neither species was accessing groundwater during the summer period. Both species were able to maintain relatively high summer leaf water losses similar to, or greater than, the values measured during the previous spring. This suggests that shallow soil water sources were sufficient to sustain summer water-use requirements. Other studies have shown that *A. fascicularis* is able to access groundwater all year round at a groundwater depth of 0.3–1.2 m, relying more on soil moisture as the summer drought continues (Zencich, 2004). Dampland vegetation experiences a high rate of adult plant mortality as a result of progressive long-term declines in groundwater levels and soil moisture contents, and this has been observed to occur in Perth's Banksia woodlands since the 1970s (Groom *et al.* 2000*a*).

Deep-rooted species

The relatively deep rooted (> 2 m rooting depth) shrubs of *Adenanthos cygnorum*, *Stirlingia latifolia* (both in the family Proteaceae), *Eremaea pauciflora* (Myrtaceae) and *Jacksonia floribunda* (Fabaceae) all possess a rooting system consisting of a thick sinker root and subsurface laterals (Dodd *et al.* 1984).

Like many deeper-rooted species, *Stirlingia latifolia* inhabits a range of topographic positions within the Swan Coastal Plain landscape, avoiding summer water deficits by maintaining contact with groundwater via its sinker root. *S. latifolia* is able to maintain relatively high rates of transpiration throughout the summer period when the deep sinker root is accessing groundwater (Dodd *et al.* 1984), decreasing in late summer as groundwater levels naturally decline (Grieve, 1956; Dodd *et al.* 1984). Dodd and Bell (1993) suggested that the water relations of the deep-rooted *S. latifolia* were more like those of *Banksia attenuata* or *B. menziesii* than other deep-rooted shrub species, reflecting their similar distributions within the sandplains.

Adenanthos cygnorum is a coloniser of soil- and fire-disturbed sites (Lamont 1989) occurring in dense stands in the drier parts of the dunal landscape. *A. cygnorum* responds to summer water deficits by avoiding water stress as a result of severely reducing their leaf water loss (Colquhoun, 1986; Dodd *et al.* 1984; Dodd and Bell, 1993), using soil moisture when groundwater is not accessible. This allows *A. cygnorum* to occupy the full range of dunal habitats, except winter-wet depressions.

Eremaea pauciflora is classified as a "species with wide tolerance, but with maximum development on dry sites" (Table 1) and occurs over a wide range of habitats ranging from upper slopes of wetland embankments to the top of dune crests (Groom *et al*. 2000*a*) (see Fig. 1). At embankment and midslope locations, where groundwater depth varied from 3 to 7 m mid-summer, studies have shown *E. pauciflora* plants are reliant on groundwater for their summer water requirements switching to shallow soil water sources when groundwater levels drop below their maximum rooting depth (Groom 2003). Maximum rooting depth for any deep-rooted species is site specific and is partially dependent on underlying groundwater depth. At upper slope and dune crest sites, where mid-summer groundwater depth varied from 9–30 m depth, *E. pauciflora* plants are not able to access groundwater at any time of the year, and thus rely on deep soil moisture to survive the hot, dry summer period (Groom, 2003).

There are strong similarities in the water relations of *E. pauciflora* and *J. floribunda (*Dodd *et al.* 1984; Colquhoun, 1986; Dodd and Bell, 1993). Both access groundwater, or its associated capillary fringe, during the summer months and not water available from the subsurface soil. Despite a continued decline in groundwater levels in early autumn (May), the water relations of both species recovered to their non-drought status in response to the beginning of the autumn-winter rains.

DISCUSSION

Banksia trees have the capacity to access groundwater and soil moisture up to 8–9 m depth via their deep sinker roots, depending on their position within the landscape. Species classified as obligate phreatophytes (*B. ilicifolia* and *B. littoralis*) are more highly dependent on groundwater during the summer than the other *Banksia* species. The more drought tolerant *Banksia* species (*B. attenuata* and *B. menziesii*) are classified as facultative phreatophytes because of their ability to utilise more than one water source, switching to the most abundant type available. The proportion of groundwater used varies seasonally, with increased use of groundwater and deeper soil sources occurring with the onset of the dry summer, when rainfall and shallow soil water becomes less abundant (Zencich *et al.* 2002). Water use patterns of these sandplain woodlands are strongly influenced by the relative contributions of the canopy species (*Banksia* trees and deep-rooted *Adenanthos* shrubs) (Farrington *et al.* 1989). The amount of water transpired depends on the proportion of canopy cover, amount of winter-spring rainfall received, and has been shown to vary with groundwater depth (Farrington *et al.* 1989; Veneklass and Poot, 2003). Although on a species basis, tree water use may not change with topography (Zencich *et al.* 2002).

Shrub species with roots > 2 m deep can tolerate the summer soil drying phase and declining groundwater levels by conservation leaf water loss whilst either avoiding (e.g. *A. cygnorum*) or tolerating (e.g. *E. pauciflora*) the summer drought. These deep-rooted species often have a spreading root system consisting mainly of subsurface laterals similar to that of *Banksia* (Fig. 2). This allows these species to survive periods of summer drought by accessing soil moisture resources at relative depth. Deep-rooted shrub species are therefore capable of tolerating short-term declines in soil moisture and groundwater levels, switching from groundwater to soil moisture reserves when groundwater and associated capillary fringe becomes unavailable (Groom, 2003; 2004). In contrast, shallow-rooted shrub species are able to tolerate severe summer soil water deficits. This allows these species to survive the dry summer without accessing groundwater or soil water sources greater than 1 m depth. The exceptions are species that are restricted to low-lying depressions or seasonally waterlogged areas that are reliant on subsurface soil moisture or groundwater to sustain their high summer water-use (Groom, 2003).

Abstraction of groundwater from shallow, unconfined aquifers underlying the Banksia woodlands continues to impact on sandplain hydrology, resulting in shifts in species distributions along topographic gradients (Groom *et al*. 2000*a*, 2001). Declining groundwater levels caused by abstraction, in association with poor rainfall-induced groundwater recharge, have the potential to change the vegetation structure and composition of these sandplain woodlands (Groom *et al.* 2000*b*; Sommer and Froend, 2010). Species responses to soil drying and declining groundwater levels form the basis for understanding how Perth's Banksia woodland species will tolerate and survive long-term hydrological changes, and this can be explained by functional differences in rooting patterns.

REFERENCES

Canham, C.A., Froend, R.H., Stock, W.D. (2009). Water stress vulnerability of four *Banksia* species in contrasting ecohydrological habitats on the Gnangara Mound, Western Australia. *Plant, Cell and Environment* **32,** 64–72.

Colquhoun, I.J. (1986). Ecophysiological studies of two shrub species growing in the Swan Coastal Plain, Perth, Western Australia. PhD thesis, University of Western Australia.

Dodd J., Bell, D.T. (1993). Water relations of understorey shrubs in a *Banksia* woodland, Swan Coastal Plain, Western Australia. *Australian Journal of Ecology* **18,** 295–305.

Dodd J., Heddle, E.M., Pate, J.S., Dixon, K.W. (1984). Rooting patterns of sandplain plants and their functional significance. In 'Kwongan. Plant life of the sandplain'. (eds. J.S. Pate and J.S. Beard) pp. 146–177. University of Western Australia Press: Nedlands.

Enright, N.J., Lamont, B.B. (1992). Recruitment variability in the resprouting shrub *Banksia attenuata* and non-sprouting congeners in the northern sandplain heath of southwestern Australia. *Acta Oecologica* **13,** 727–741.

Farrington, P., Greenwood, E.A.N., Bartle, G.A., Beresford, J.D., Watson, G.D. (1989). Evaporation from a *Banksia* woodland on a groundwater mound. *Journal of Hydrology* **105,** 173–186.

Froend, R.H., Drake, P.L. (2006). Defining phreatophyte response to reduced water availability: preliminary investigations on the use of xylem cavitation vulnerability in *Banksia* woodland species. *Australian Journal of Botany* **54,** 173–179.

Froend, R., Sommer, B. (2010). Phreatophytic vegetation response to climatic and abstraction-induced groundwater drawdown: examples of long-term spatial and temporal variability in community response. *Ecological Engineering* **36,** 1191–1200.

Grieve, B.J. (1956). Studies in the water relations of plants. I. Transpiration of Western Australian (Swan Plain) sclerophylls. *Journal of the Royal Society of Western Australia* **40,** 15–30.

Groom, P.K. (2002). Seedling water stress response of two sandplain *Banksia* species differing in ability to tolerate drought. *Journal of Mediterranean Ecology* **3,** 3–9.

Groom, P.K. (2003). Groundwater-dependency and water relations of four Myrtaceae shrub species during a prolonged summer drought. *Journal of the Royal Society of Western Australia* **86,** 31–40.

Groom, P.K. (2004). Rooting depth and plant water relations explain species distribution patterns within a sandplain landscape. *Functional Plant Biology* **31,** 423–428.

Groom, P.K., Froend, R.H., Mattiske, E.M. (2000*b*). Impact of groundwater abstraction on a Banksia woodland, Swan Coastal Plain, Western Australia. *Ecological Management and Restoration* **1,** 117–124.

Groom, P.K., Froend, R.H., Mattiske, E.M. and Koch, B.L. (2000*a*). Myrtaceous shrub species respond to long-term decreasing groundwater levels on the Gnangara Groundwater Mound, northern Swan Coastal Plain. *Journal of the Royal Society of Western Australia* **83,** 75–82.

Groom, P.K., Froend, R.H., Mattiske, E.M. (2001). Long-term changes in vigour and distribution of *Banksia* and *Melaleuca* overstorey species on the Swan Coastal Plain. *Journal of the Royal Society of Western Australia* **84,** 63–69.

Havel, J.J. (1968). The potential of the northern Swan Coastal Plain for *Pinus pinaster* Ait. Plantations. Forests Department of Western Australia, Bulletin 76, Perth.

Lamont, B.B. (1989). Biotic and abiotic interactions in *Banksia* woodland. *Journal of the Royal Society of Western Australia*. **71,** 99–100.

Muir, B.G. (1983). Drainage, swamp structure and vegetation succession at Melaleuca Park, northern Swan Coastal Plan. *Western Australian Herbarium Research Notes* **9,** 27–39.

Rokich, D.P., Meney, K.A., Dixon, K.W., Sivasithamparam, K. (2001). The impact of soil disturbance on root development in woodland communities in Western Australia. *Australian Journal of Botany* **49,** 169–183.

Sommer, B., Froend, R. (2010). Resilience of phreatophytic vegetation to groundwater drawdown: is recovery possible under a drying climate? *Ecohydrology* **4,** 67–82.

Veneklaas, E.J., Poot, P. (2003). Seasonal patterns in water use and leaf turnover of different plant functional types in a species-rich woodland, south-western Australia. *Plant and Soil* **257,** 295–304.

Zencich, S.J. (2003). Variability in water use by phreatophytic *Banksia* woodland vegetation of the Swan Coastal Plain, Western Australia. PhD thesis, Edith Cowan University, Perth.

Zencich, S.J., Froend, R.H., Turner, J.V., Gailitis, V. (2002). Influence of groundwater depth on the seasonal sources of water accessed by *Banksia* tree species on a shallow, sandy coastal aquifer. *Oecologia* **131,** 8–19.

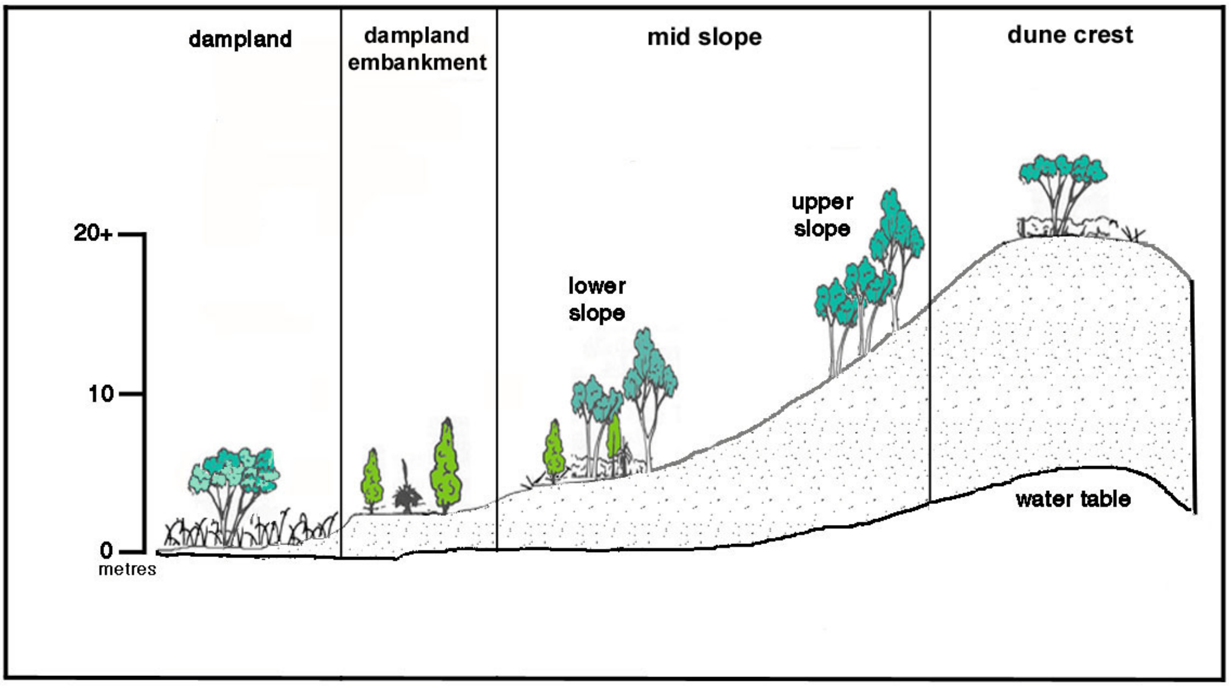


Figure 1. Topography of Perth's Bassendean dunal landscape, ranging from low-lying seasonally wet depressions to dune crests.

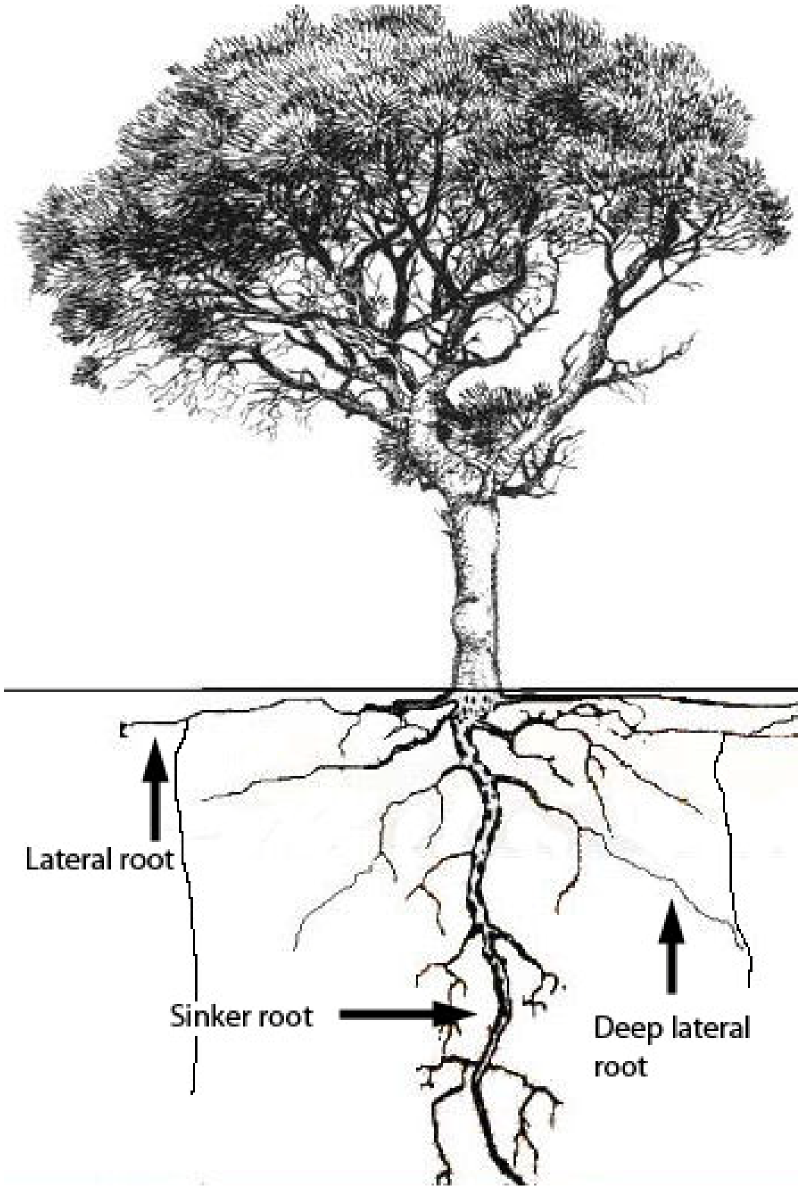


Figure 2. The dimorphic root system typical of Banksia tree occurring on Perth's Swan Coastal Plain. This consisting of a deep sinker (or tap root) and laterals. There are two types of lateral roots – subsurface and deep. Deep sinker roots may arise off the laterals, thus allowing the tree to source deep soil moisture or groundwater from a number of roots.

▲ Remnant Banksia woodland; Inglewood Triangle. (K. Sarti)

Table 1. Habitat preferences for common tree (T) and shrub species of Perth's Banksia woodlands (after Havel, 1968). Rooting depths based on information provided in Dodd et al. (1984), where shallow < 1m, medium < 2 m and deep > 2 m.

	Rooting depth / pattern
Species tolerant of excessive wetness	
Astartea fascicularis	Shallow
Banksia littoralis	Deep
Calothamnus lateralis	Unknown
Eucalyptus rudis	Deep (T)
Euchilopsis linearis	Shallow
Hibbertia stellaris	Shallow
Hypocalymma angustifolium	Shallow
Melaleuca preissiana	Deep (T)
Melaleuca rhaphiophylla	Deep (T)
Pericalymma ellipticum	Shallow
Pultenaea reticulata	Shallow
Regelia ciliata	Shallow
Species of optimum moist sites, intolerant of extremes in moisture conditions	
Adenanthos obovatus	Deep
Banksia grandis	Deep (T)
Banksia ilicifolia	Deep (T)
Banksia prionotes	Deep (T)
Corymbia calophylla	Deep (T)
Dasypogon bromeliifolius	Shallow
Eucalyptus marginata	Deep (T)
Melaleuca seriata	Deep
Xanthorrhoea preissii	Shallow
Species with wide tolerance, but with maximum development on dry sites	
Astroloma xerophyllum	Shallow
Banksia attenuata	Deep (T)
Banksia menziesii	Deep (T)
Beaufortia elegans	Medium - Deep
Boronia purdieana	unknown
Conostephium minus	Shallow
Eremaea pauciflora	Deep
Hibbertia helianthemoides	Shallow
Gastrolobium capitatum	Shallow
Jacksonia densiflora	Deep
Leucopogon conostephioides	Shallow
Leucopogon strictus	Shallow
Melaleuca scabra	Deep
Scholtzia involucrata	Medium - Deep
Species without clear-cut site preference	
Allocasuarina fraseriana	Deep (T)
Eucalyptus todtiana	Deep (T)
Nuytsia floribunda	Deep (T)
Eucalyptus gomphocephala	Deep (T)
Hibbertia subvaginata	shallow
Conostephium pendulum	Shallow-medium
Bossiaea eriocarpa	Shallow
Calytrix flavescens	Deep

BENEATH THE BANKSIAS – NOTES ON THE UNDERSTOREY OF THE BANKSIA WOODLANDS

Byron Lamont, Curtin University

DIVERSITY

About 8% of the species diversity in the Banksia woodland is understorey species that are tall shrubs, such as *Adenanthos cygnorum*, while 38% (approximately 145 species) are low shrubs, such as *Hibbertia hypericoides* (Native Buttercup) and *Hypocalymma robustum (*Swan River Myrtle*)*. The ground covers and herbs make up about 53% of the understorey diversity.

POLLINATION

Insects, mammals and birds carry out pollination in the Banksia woodland. One of the more interesting pollination stories is that of the Woolly Bush *Adenanthos cygnorum*. The single flower is immersed in a terminal whorl of leaflets whose overlapping hairs, together with the constricted neck of the perianth (the outer part of the flower), prevent access to the nectar-robbing ants. About 1–3% of the flowers are converted to fruits whose fate may follow three paths:

a) The green fruit is eaten by parrots on the plant.

b) The bracts surrounding the fruit opens out pushing the leaflets into a cup from which the fruit drops to the ground. Granivorous birds and probably rodents eat it.

c) The fruit remains in the cup where it is visited by ants. Most ants remove the fruits to their nests where they consume the basal elaisome (fleshy structure attached to seed which contains proteins).

The fruits remain dormant until the soil is disturbed or a fire occurs. Most then germinate during the next winter from an average depth of 35 mm, probably in response to a change in the temperature regime.

Although the foliage of the Woolly Bush is fibrous and probably not attractive to herbivores, there is a specialist moth, *Xylorycta* sp. which webs together the terminal leaves. It is preyed upon by a parasitoid wasp, *Campoletis* sp. Ten xyloryctid pupae were collected and seven yielded these ichneumonid wasps.

The first leaves of the new season's branchlets in mature Woolly Bush shrubs bear extrafloral nectaries on their tips. Seventeen species of ant, as well as the *Campoletis* sp. and other nectar-seeking insects, visit these glands. The nectaries are a reliable, albeit small, source of sugar for the predatory ants and wasps throughout the year. The location of the elaisome-bearing fruits and xyloryctid larvae respectively are secondary and irregular events for these insects, but vital in maintaining the fitness of the species. Woolly Bush tends to collapse as it senesces and is readily invaded by termites which eventually consume the woody stems after death, before or after fire.

FIRE RESPONSES

Fire has various effects on the understorey plants in Banksia woodland. It stimulates the *Nuytsia floribunda* (Western Australian Christmas Tree) to flower. Fire stimulates seeds from some plants, such as the Kangaroo Paw (*Anigozanthos manglesii*) to germinate. Another wildflower, Milkmaids (*Burchardia congesta*) sprouts from corms after fire.

THREATS

The most severe threats facing the Banksia woodlands are land clearing and disease. Land clearing for housing and roads is reducing the extent of Banksia woodlands. Disease, especially the *Phytophthora cinnamomi* root-rot pathogen is also reducing the area of Banksia woodland.

REFERENCES

Lamont, B. (1989). Biotic and abiotic interactions in Banksia woodland. Journal of the Royal Society of Western Australia, **71** (4): 99–100

MACRO-INVERTEBRATE FAUNA OF THE BANKSIA WOODLANDS

David Knowles, Director of Spineless Wonders

Macro-invertebrates include the insects, spiders, scorpions, centipedes, millipedes and other fauna without backbones. In fact there are far more species of macro-invertebrates on the Swan Coastal Plain than there are vertebrate species (less than 3%). Over 2,250 macro-invertebrate arthropods are listed on the Greater Perth Metro Invertebrate Database(see reference). This list covers collections, which have been made from Lower Chittering to North Dandalup Dam and from Two Rocks to Mandurah. The figure of 2,250 does not include Jarrah forest (referred to as 'JF' in IBRA).

Faunal Category	Percentage of all species in Western Australia
Insects	79.64%
Chelicerates (Spiders, Scorpions, Ticks, Mites, Harvestmen)	15.99%
Myriapids (Centipedes and Millipedes)	1.6%
Mammals	0.32%
Amphibians	0.16%
Birds	0.8%
Reptiles	0.8%
Molluscs	0.46%
Crustacea	0.23%

Table 1. Proportions of terrestrial fauna in Western Australia

People looking at biodiversity in Banksia woodland need to recalibrate their fauna perspectives. Looking at the percentages in Table 1 several questions arise:

- Should biodiversity funding be apportioned towards fauna groups where there are more keystone species?
- Do the majority of fauna surveys carried out to date on all conserved land cover 98% of the fauna?
- Do conservation managers know what fauna is on the estate they are responsible for managing?
- Should studies in the Life and Living program part of primary school curriculum apportion study time according to the numbers of species in each group of terrestrial animal life?
- Should University Zoology courses base their introductory curriculum on the general proportions in which terrestrial animal life occurs?
- Are vertebrates intrinsically more important in ecological terms than the lesser animals or is their presence dependent on invertebrate presence?

SOME BASIC TERRESTRIAL INVERTEBRATE ECOLOGICAL PRINCIPLES AND PROCESSES

Looking at the ecosystem from the leaf litter to the treetops in a Banksia woodland we identify a number of guilds of macro-invertebrates. The Recyclers include detritivores and scavengers. The subguilds are those which consume detritus of vegetable products, including sap (the exudates), those which bore into dying and dead wood, those which consume detritus of animal products (which includes sweat, fur, feathers, carcasses and dung).

Another subguild is the leaf and fungal pruners. These macro-invertebrates control plant populations. Included are the following subguilds: leaf pruners, pruners of fungal mycelium and fruiting bodies, pruners of roots, pruners of flower parts, pruners of living wood, bark pruners, consumers of seeds that are still connected and seeds that have dehisced, and sap suckers.

A third subguild is the pollinators. The great majority of the pollinators are insects. Birds only pollinate a minority of species though they are probably crucial to certain plants, such as the Banksias.

A fourth subguild is the predators. These macro-invertebrates control animal populations. Some are direct predators. Others are external and internal parasites that do not kill their host. Parasitoids, usually wasps or flies, are members of this guild that kill and usually consume their prey. Kleptoparasites steal their prey or parts thereof, which have been collected by another predator. Hyperparasites, also in this subguild, are parasites or parasitoids, whose host is a parasite or a parasitoid.

RECYCLERS
Many of the recyclers are in the leaf litter and beneath the topsoil layer of the woodland. Recyclers usually have a daily, or nightly activity cycle. Recyclers may also be opportunistic on a daily or seasonal level.

Termites are major 'movers and shakers' in this subguild. Some macro-invertebrate species are part-time recyclers, i.e. they could be leaf pruners as adults and recyclers as larvae. The Signal Fly *Lenophila* is a diurnal (active during the day) plant and animal exudates scavenger (eats sap) as an adult and a detritivore as a larva.

Ant larvae and other social insect larvae are not active feeders but are fed by adults, and their food comes from recycling.

Recyclers may be scavengers of only dead or dying plant material all their lives in non-metamorphic insects. Recyclers may be nocturnal (active during the night) and scavenge both animal and vegetable material all their lives. Recyclers may specialise in the exudates of vertebrate animals as is the case of dung beetles, which recycle macropod (kangaroos and other similar animals) faeces.

LEAF PRUNERS
Leaf pruners can be found feeding on herbs, mosses and lichens at ground level and up to the tree canopy. They are the major shapers of vegetation. Some leaf pruners, such as the ground weevil genus *Acantholophus*, may be terrestrial grazers as adults and subterranean root pruners as larvae. The grasshopper *Monistria* is diurnal, grazing at ground level all of its life.

The major leaf pruners in most habitats are the Lepidoptera, particularly the moth caterpillars. In Western Australia the adult of the unique moth *Carthaea* does not feed, but its larvae prune leaves of plants in the Proteaceae family.

A second major leaf pruning group in most habitats are adult beetles. Larval beetles may also prune leaves as in the leaf beetles (Chrysomelidae). In terms of number of species present as leaf pruners, the Family of weevils (Curculionidae) is dominant. Weevils are in fact the largest Family of living fauna. There is a weevil for every leaf pruning occasion!

FUNGAL PRUNERS
Fungivory, or the grazing, pruning or sucking of fungal structures is a subset of leaf pruning. Fungivorous feeding occurs above and below ground. The most dominant group of fungivores in many habitats are beetles of the Family Geotrupidae. Mammals such as woylies are credited with being important to native truffles, but compared to the beetles their effect is negligible. These fungivorous beetles also spread spores thereby contributing to dispersal of truffles and other fungi through the woodland.

Most fungivores are chewers but a small group of True Bugs feed by sucking. These are flattened and hide under the bark of dying trees.

SAP SUCKERS
Another group of macro-invertebrates, which control plant populations and shape vegetation are the sap suckers, the True Bugs.

Most feed on the external, above-ground surface of the host plant, but some, such as the nymphs of cicadas feed on sap below ground. Seeds dropped to the ground also attract the attention of sapsuckers. Cydnid bugs can occur in large numbers in the leaf litter in many habitats.

POLLINATORS
Insects from many guilds fly and walk to the attractions of the flower. These become the unwitting agents of the pollination process, which rejuvenates the Banksia woodland habitat.

Moths are the major nocturnal pollinators in most habitats. However, most pollination occurs during the day. A small number of moths also pollinate during the day. Native bees pollinate the greatest diversity of flower types. The Morrison Bee is well camouflaged in the iconic Banksia woodland's shrub *Verticordia nitens* (Morrison Featherflower). Some native bees are generalist pollinators while others may be restricted to a plant genus, or rarely, to a given species. Sadly, almost all native insect and bird pollinators may be displaced by the feral European honey bee.

Fifty percent of our native Jewel Beetles are generalist pollinators adapted to either the brush or open-cup flower types of our largest Western Australian plant family, the Myrtaceae. Many Families of flies also visit flowers and therefore can be potential pollinators. Some specialised beeflies have co-evolved with triggerplants to be their pollinators.

PREDATORS, PARASITES, PARASITOIDS

Predators keep populations of all guilds including themselves under control, which maintains healthy habitats. Some predators are nocturnal or diurnal while others prey during night and day. They target their prey by size, strength, odour and preferred shelter, feeding, mating, moulting and pupation sites. Most predators are chewers though there is a small group which are suckers. The sucking predator group is dominated by True Bugs.

Beetles are the major terrestrial predators in most healthy habitats. Anthicid beetles, which prey on small arthropods, can be found from ground to canopy in the Banksia woodland. Wasps control populations of a large variety of arthropods. The medium-sized terrestrial wingless females of the family Mutillidae prey on other parasitoid wasps and ground-nesting bees. Some flying wasp females parasitise wood-boring larvae of beetles and other insects that use their tunnels. The females tend to have long egg-laying tubes (ovipositors) to penetrate through wood or into bark cracks.

One of the iconic insects of the local Banksia woodlands is a medium-sized aerial predator, the adult Spoonwing Lacewing (*Chasmoptera hutti)*. Peeling bark of both standing and fallen wood creates a temporary humid microclimate for a number of specialised arthropods (including predators). Both prey and predators living under bark are typically flattened in profile.

Ants are important predators from root to canopy in most habitats. They are sometimes seasonal. High diversity in ant species is considered a good indicator of habitat health. Also, a relatively high number of ground mantis species are found in Western Australia. Almost all these species exhibit an interesting phenomenon of wingless females and winged males, which can forage above ground.

The evolution of web-building in spiders is thought to have been an ancient response to the development of wings by some insects. Webs take many forms and are placed on the ground, just above it and right up to the canopy.

A minority of flies are direct predators, the most significant group being the Robber Flies.

Looking at the top of the food chain of the arthropods, there are representatives of two other Classes in addition to the dominant Insects. The other Classes comprised of many predators are the Chilopods (centipedes) and the Arachnids (spiders, scorpions and others). Most of these top-order predators are nocturnal.

The great majority of nocturnal Arachnid predators are found on the ground. Wolf spiders are prominent in that part of the habitat. In our Banksia woodland at the very pinnacle of the arthropod food chain are the larger Urodacid scorpions. Scorpions are capable of preying on young, small vertebrates, such as small frogs, snakes and lizards. The largest local terrestrial beetle predator is a wingless Carabid. These, too, may eat small vertebrates.

The largest sucking predator, a Ground Assassin Bug, is capable of delivering the most painful reaction reported by a human. Larger nocturnal predators in the Banksia woodland include predatory crickets and katydids and trapdoor spiders.

I recommend that bushcare managers discover a more truthful picture of their fauna when they do surveys and include a survey of macro-invertebrates as well as vertebrates.

GLOSSARY

Arthropod – invertebrate animal characterised by chitinous exoskeleton and pairs of appendages

Diurnal – active during daylight hours

Dehisced – released or split open

Keystone Species – A species whose presence and role within an ecosystem has a disproportionate effect on other organisms within the system. A keystone species is often a dominant predator whose removal allows a prey population to explode and often decreases overall diversity. Other kinds of keystone species are those that significantly alter the habitat around them and thus affect large numbers of other organisms.

Nocturnal – active during hours of darkness

Larvae – immature stage in life cycle, such as newly hatched insects which have not yet metamorphosed into their adult form

RECOMMENDED READING OR REFERENCES

Abbott, I. (1985). Forest Entomology Research in Western Australia. Technical report No. 2: 1–75. Perth.

Abbott, I. (1995). Prodromus of the occurrence and distribution of insect species in the forested part of south-west Western Australia. CALMScience **1** (4): 365–464. Perth.

Aplin, K.P. and Smith, L.A. (2001). Checklist of the frogs and reptiles of Western Australia. Records of the West Australian Museum. Supplement No. 63: 51–54., Perth.

Avon Catchment Council (2009). Report for Surface Water Management and Self-Sufficiency Environmental Water Flow Requirements; Appendices A–C (p. 55–67).

Boglio, P. and Knowles, D.G. (2001). Bannister Creek Wildlife Survey (for Bannister Creek Catchment Group Inc), Perth.

Bush, B., Maryan, B., Browne-Cooper, R. and Robinson, D. (1995). A Guide to the Reptiles and Amphibians of the Perth Region. University of Western Australia Press, Perth.

Bush, B., Maryan. B., Browne-Cooper, R. and Robinson, D. (2007) Reptiles and Frogs in the Bush: Southwestern Australia. University of Western Australia Press, Perth

Common, I.F.B. (1990). Moths of Australia. Melbourne University Press.

CSIRO. (ed.). (1991). The Insects of Australia. A textbook for students and research workers. 560–600 pp., 2 Volumes. Carlton: Melbourne University Press.

Davis, J. and Christidis, F. (1997). A Guide to the Wetland Invertebrates of Southwestern Australia. West Australian Museum, Perth.

Harvey, M.S. and Yen, A.L. (1989). Worms to Wasps: An Illustrated Guide to Australia's Terrestrial Invertebrates. Oxford University Press, Melbourne.

Hangay, G. and Zborowski, P. (2010). A Guide to the Beetles of Australia. CSIRO Publishing Melbourne.

Interim Biogeographic Regionalisation for Australia (IBRA) http://www.environment.gov.au/parks/nrs/science/ibra.html

Knowles, D.G. Greater Perth Metro Database – a personal macro-invertebrate database.

Knowles, D.G. (2002). Fairfield Bushland Fauna Survey Feb–Nov (for Bannister Creek Catchment Group Inc), Perth.

Knowles, D.G. (2002) Kingsley Montessori Bushland Fauna Survey Nov (for Montessori School Kingsley), Perth.

Knowles, D.G. (2004). Leige Street Demonstration Wetland Site Fauna Survey Feb–Mar (for Two Rivers Catchment Group Inc), Perth.

Majer, J.D., Recher, H.F., and Ganeshanandam, S. (2000) Diversity patterns of eucalypt canopy arthropods in eastern and Western Australia. Ecological Entomology, **25**, 295–306. Perth.

Maryan, B., Browne-Cooper, R. and Bush, B. (2002). Herpetofauna survey of Maralla Road Bushland. West Australian Naturalist **23**(3):197–206. ,

Matthews, E.G. (1980–97) Beetles of South Australia Parts 1-7. Special Education Bulletins, South Australian Museum, Adelaide.

Matthews, E.G. and Bouchard, P. (2008). Tenebrionid Beetles of Australia. Australian Biological Resources Study, Canberra.

Raven, R.J., Baehr, B.B. and Harvey, M.S. (2002). Spiders of Australia: Interactive Identification to Subfamily CD-ROM. C.S.I.R.O. Publishing, Canberra

Savage, A. et al. (1996–8) A Biological Survey of Gwambygine Pool, (for River Conservation Society), York. Water and Rivers Commission, Perth

Wilson, S.K. and Knowles, D.G. (1988). Australia's Reptiles. A Photographic Reference to the Terrestrial Reptiles of Australia. Collins, Sydney.

Wilson, S.K. and Swan, G. (2008). A Complete Guide to Reptiles of Australia (second edition), New Holland, Sydney.

Zbororowski, P. and Edwards, T. (2007). A Guide to Australian Moths. C.S.I.R.O. Publishing, Canberra.

Zimmerman, E.C. (1994). Australian Weevils. Vols **1–6**. 1–632. C.S.I.R.O. Publishing, Canberra.

HONEY POSSUMS AND THEIR ASSOCIATION WITH BANKSIA WOODLANDS

Shannon Dundas, Murdoch University

Biology of the Honey Possum (Tarsipes rostratus)

The Honey Possum is a small marsupial endemic to the south west of Western Australia (Fig. 1). This tiny marsupial (which usually weighs between 7–16 g) has adapted to feed exclusively on nectar and pollen, a diet which requires flowering plants to be available all year round (Wooller *et al*. 1981; Wooller *et al*. 1984). The Honey Possum is the only non-flying mammal that feeds solely on nectar and pollen (Turner, 1984). An adaptation of interest is a bristled tongue, which has many papillae at the tip enabling feeding on floral pollen (Richardson *et al*. 1986).

Figure 1: The Honey Possum (*Tarsipes rostratus*) (Photo: Pat Dundas)

Adaptations to feed on nectar and pollen

The long snout and long bristled tongue are adaptations to allow these animals to bury their head into inflorescences to feed on nectar (Russell *et al*. 1989) much like the long beak and tongue of birds such as honeyeaters which feed on similar plant species. Pollen is brushed or licked off flowers (Russell *et al*. 1989). In addition to feeding specialisations, Honey Possums are also adapted generally to an arboreal lifestyle. They have a semi prehensile tail, which provides support and balance (Renfree *et al*. 1984). The toes on both the front and back feet have wide pads with extra traction allowing easy movement over branches and flowers. Honey Possums are crepuscular feeders and tend to feed actively at night (Arrese *et al*. 2003) as well as early morning and late afternoon (Hopper *et al*. 1982).

Food plants & feeding

The high biodiversity of native WA flora in the southwest can cater to the dietary needs of the Honey Possum, since different plant species have staggered flowering periods. The Banksia woodlands and sandplain heathlands of the western and southern coastlines of WA support a diverse range of flowering plants dominated by Proteaceae species and consequently, this is where the greatest number of Honey Possums have been captured (Wooller *et al.*1984). Honey Possums are a locally common species and have been noted as the most common mammal in the Fitzgerald River National Park (Chapman, 1995). They feed on species primarily from Proteaceae and to a lesser extent Myrtaceae species which are rich in nectar (Wooller *et al*. 1984). *Banksia* species are especially favoured foodplants (Richardson *et al*. 1986).

Honey possums are generally opportunistic in their selection of foodplants which relates to flowering species present in a particular area. Some animals, however, sampled over a number of days showed specific foodplant preferences (Dundas, 2008). To determine food plant species being utilised by honey possums, pollen samples are collected by wiping a sticky gel with a stain over the head of captured animals (Wooller *et al*.1983). Honey possums will inadvertently pick up pollen on their heads as they feed on nectar and pollen so this is an effective technique to determine which plant species they are utilising. Pollen grains in flowering plants are unique and foodplants can be determined by comparing samples collected from animals with reference slides collected from flowering plants in the study area (Fig. 9).

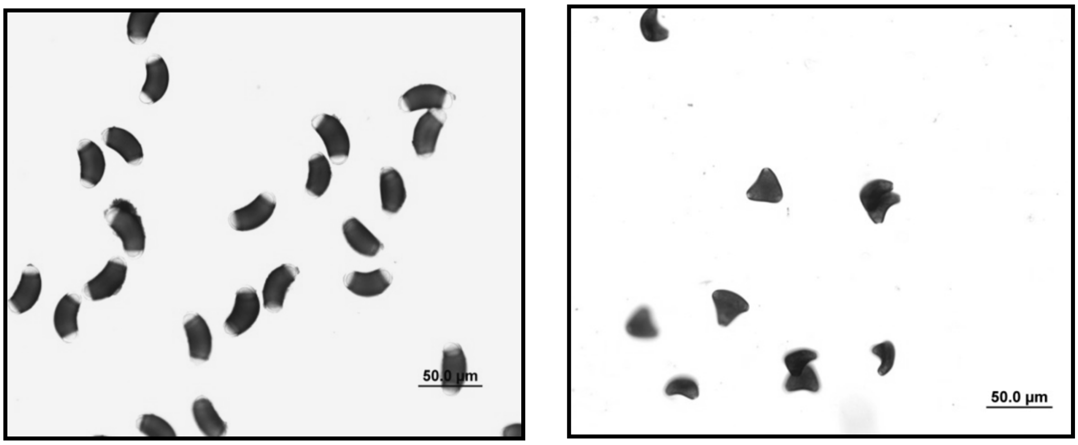


Figure 2: *Banksia plumosa* (left) and *Adenanthos cuneatus* pollen reference slides (Photo: Shannon Dundas)

A total of 20 different pollen species were sampled from honey possums collected at Cape Riche, with nine species identified as important foodplants as they were found most frequently on animals (Dundas, 2008). Based on pollen, *Banksia plumosa* subsp. *plumosa* (Fig. 3) was identified as the preferred foodplant at the Cape Riche study site followed by *Adenanthos cuneatus (*Fig. 5). Despite the common image of the Honey Possum on showy *Banksia* species such as *Banksia coccinea*, less conspicuous species which have flowers close to the ground are more frequently visited foodplants at Cape Riche (Dundas, 2008) and Fitzgerald River National Park (Saffer, 1998) Figures 3–6).

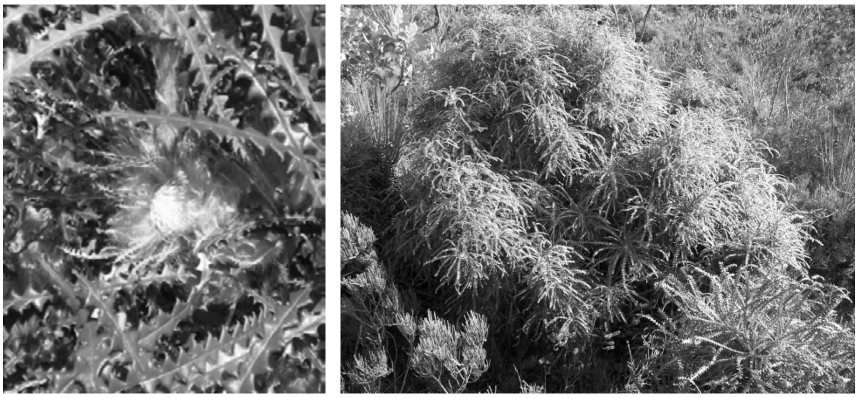


Figure 3: *Banksia plumosa* subsp. *plumosa* flower (3 cm across) left and shrub right (Photo: Shannon Dundas)

Figure 4: *Banksia nutans* flower (4–7 cm long) left and shrub right (Photo: Bill Dunstan)

Figure 5: *Adenanthos cuneatus* flower (top) and shrub (bottom left) (Photos: FloraBase 2011 online database florabase.calm.wa.gov.au).

Figure 6: *Calothamnus gracilis* flower (left) and shrub (right top) (Photos: FloraBase 2011 online database florabase.calm.wa.gov.au).

Honey Possum lifecycle and reproduction

Honey possums have marked sexual dimorphism with females tending to be larger than males (Renfree *et al*. 1984). They are aseasonal breeders and females can be found with pouch young throughout the year (Garavanta, 1997; Wooller *et al*. 1981). Although they do not have a specific breeding season, more female honey possums carrying pouch young can be found when preferred food plants are in flower which varies with location (Garavanta, 1997; Wooller *et al*. 1981). Honey possums are the smallest newborn mammals with average birth weight between 21 µg–5 mg (Renfree, 1980). Females exhibit embryonic diapause (where the growth of fertilised embryos can be delayed within the uterus) which is thought to be under environmental control such as the flowering periods of foodplants (Russell *et al*. 1989). Females have one to two litters of 2–3 young a year (Russell *et al*. 1989). They carry young in their pouch for around 56–63 days until they reach about 2–2.5 g (Renfree *et al*. 1984). Once they have left the pouch, young will be carried on the mothers back and she will suckle them until they are approximately 91 days old before they disperse on their own (Russell *et al*. 1989).

The mating system of honey possums is promiscuous with females in oestrus mating with many males and as a result, males have large scrotums which are approximately 4.2% of their total body weight (Renfree *et al*. 1984). Interestingly, males have the longest sperm of any living mammal, which indicates competitive gamete selection (Renfree *et al*. 1984). Both males and females reach sexual maturity at around six months of age (Russell *et al*. 1989).

From trapping records, the average lifespan of the Honey Possum is estimated to be one year (Wooller *et al*. 1981). Long term studies of populations in the Fitzgerald River National Park estimate the annual mortality rate (determined by capture rates) to be greater than 80% (Garavanta, 1997). The surviving population of honey possums have a high reproductive potential and are sufficient to increase the population to previous numbers within a year (Wooller *et al*. 1981). The lifecycle of the Honey Possum is correlated to nectar availability (Garavanta, 1997; Wooller *et al*. 1981) and it is thought that the annual mortality of majority of the population is due to starvation when flowering foodplants are scarce (Wooller *et al*. 1993).

Torpor in the Honey Possum

Since honey possums are so small and live within a seemingly narrow range of limits, they need a mechanism to conserve energy when food is scarce. Torpor is a state in which the body temperature is allowed to fall (on a daily basis) such that metabolic rate can be reduced by up to 90% (Fig. 7) (Collins *et al*. 1987). It is thought that torpor is initiated when critical energy levels are reached at which time honey possums enter torpor to conserve energy (Collins *et al*. 1987). Torpid honey possums have been captured in pit traps in the Fitzgerald Range National Park during March, April, June and September and with the exception of June (mid-winter), these months had the lowest daily nectar production by plants, indicating food was relatively scarce (Collins *et al*. 1987). Laboratory research demonstrates that honey possums can go into torpor for several hours at a time, usually when subjected to periods of environmental stress such as food scarcity and low temperature (Collins *et al*. 1987; Withers *et al*. 1990). Smaller honey possums enter torpor more readily when deprived of food especially when ambient air temperatures are low (Collins *et al*. 1987; Withers *et al*. 1990).

Figure 7: Honey Possum in torpor (Photo: Pat Dundas)

Researching honey possums

Honey possums are captured in pit traps which constitute a length of PVC pipe which is buried into the ground up to the rim (Fig. 8). Drift fences, which are lengths of fly wire, are placed either side of the pit trap so as honey possums intersect the drift fence, they follow it along to the pit trap and fall in. Pit traps are opened at dusk and checked at first light. Given the period of fasting honey possums experience by spending the night in a pit trap, once removed from the trap, they are fed a honey or sugar water solution for energy.

Figure 8: Honey Possum in pit trap (Photo: Shannon Dundas)

To determine habitat use and movement patterns, honey possums were fitted with tiny radio transmitters. These weigh 0.36 g and are glued to the back of the Honey Possum (Fig. 9). This temporary attachment of the transmitters means they will fall off within a week before the battery is exhausted. Honey possums were tracked primarily between dusk and dawn when they are most active, but some animals were also active during the day (Dundas, 2008). Tracking involves two people each with a handheld antenna and receiver to allow for triangulation of tracked animal locations. Each transmitter has a unique frequency which can be programmed into the receiver. Detection of the transmitter is established by an ongoing beep and the location of the animal is determined by the strength of the signal as the closer you get to the animal, the louder the beep becomes.

Figure 9: Honey Possum with attached radio transmitter (Photo: Pat Dundas)

***Phytophthora cinnamomi* in Banksia woodlands**

Phytophthora cinnamomi is a soil borne water mould which causes *Phytophthora* Dieback disease in susceptible plants (Hardham, 2005). The penetration of the roots by the pathogen results in necrotic lesions on the roots and trunk which hinder the infected plants' ability to obtain water and nutrients, eventually causing the plant to die (Shearer, 1994).

Phytophthora cinnamomi is spread within the environment by movement of water and via root-to-root contact of infected plants (Shearer, 1994). The movement of infected soil primarily carried on vehicles and shoes is a significant means by which the disease is spread (CALM, 2003).

Since *Phytophthora cinnamomi* is an introduced pathogen, many native species have limited natural resistance and are therefore severely threatened with infection by the pathogen (Shearer *et al.* 2004). Plant species within Proteaceae, Papilionaceae, Epacridaceae and to a lesser extent Myrtaceae families tend to be the most susceptible to Dieback in the Banksia woodlands and Jarrah forest of south-west Australia (Shearer *et al*. 2004). In Banksia woodlands, an estimated 32% of plant species are classified as susceptible to *P. cinnamomi*, with 15% of plant species classified as highly susceptible (Shearer *et al.* 2004).

Secondary impact of Dieback on honey possums

There is a concern for the future of Honey Possum populations in the presence of *Phytophthora cinnamomi*, particularly since this pathogen has an impact on susceptible Proteaceous species which the Honey Possum relies on for food. The spread of this pathogen is likely to have an effect on the abundance and movements of honey possums as the availability of food sources becomes seriously depleted.

In 2007, I conducted a study in a proposed conservation park close to Cape Riche located on the south coast of Western Australia, 119 km east of Albany in Western Australia (34.00° S 118.43° E) (Dundas, 2008). The site was selected based on a known Honey Possum population and the patchy mosaic of

P cinnamomi affected and unaffected habitat. The loss of primary *Banksia* species (*Banksia baxteri* and *Banksia attenuata*) as a result of *P. cinnamomi* infection resulted in the change from a tall, dense *Banksia* thicket into a low open sedge at a study site (Dundas, 2008).

Radio tracking of honey possums revealed some interesting results. Honey possums were recorded moving long distances (i.e. a 10.7 g male travelling 1.4 km (cumulative between 28 fix locations over 9 days) and a 16 g female travelling over 720 m in one night) to forage for foodplants in healthy vegetation (Dundas, 2008). Previous studies have indicated that honey possums are sedentary and only moved on average 20–30 m between traps: the longest recorded movement between traps being 125 m (Garavanta, 2000). More recent tracking has also shown honey possums are capable of moving longer distances (Bradshaw *et al*. 2007; Bradshaw *et al*. 2002).

In terms of foodplant preferences in Dieback affected areas, seven of the nine foodplant species identified from pollen collected from honey possums are recognised as being susceptible to *Phytophthora cinnamomi* (**susceptibile:** *Banksia plumosa* (formerly *Dryandra plumosa*), *Adenanthos cuneatus, Beaufortia anisandra, Banksia brunnea* (formerly *Dryandra brownii*), *Banksia nutans and Banksia tenuis* (formerly *Dryandra tenuifolia*); ***resistant:*** *Eucalyptus angulosa;* **unknown susceptibility***: Calothamnus gracilis*) (Dundas, 2008). Honey possums also used plants such as *Adenanthos cuneatus* and *Calothamnus gracilis* which were still managing to survive in affected areas but they were also seeking out favoured *Banksia plumosa* in healthy areas.

Future preservation of the Honey Possum relies on conservation of Banksia woodlands, which are so important for providing this species with food and refuge.

References

Arrese, C. & Runham, P.B. (2003). Redefining the activity pattern of the honey possum (Tarsipes rostratus) Australian Mammalogy, **23**, 169–172.

Bradshaw, S.D. & Bradshaw, F.J. (2002). Short-term movements and habitat use of the marsupial honey possum (Tarsipes rostratus). Journal of Zoology, **258**, 343–348.

Bradshaw, D., Phillips, R., Tomlinson, S., Holley, R., Jennings, S. and Bradshaw, F. J. (2007). Ecology of the Honey possum, Tarsipes rostratus, in Scott National Park, Western Australia. Australian Mammalogy. **29**, 25–38.

CALM (2003). Phytophthora cinnamomi and disease caused by it - Vol. 1 Management Guidelines (ed. Dept. CALM).

Chapman, A. (1995). A biological survey of the Fitzgerald area, Western Australia. Part 6: Terrestrial mammals. CALM Science Supplement **3**, 83–94.

Collins, B.G., Wooller, R.D., & Richardson, K.C. (1987). Torpor by the honey possum, Tarsipes rostratus (Marsupialia: Tarsipedidae), in response to food shortage and low environmental temperature. Australian Mammalogy, **11**, 51–57.

Dundas, S.J. (2008). Utilisation of Phytophthora cinnamomi affected habitats by honey possums (Tarsipes rostratus) in the Cape Riche area, Western Australia. Honours thesis. Murdoch University.

Garavanta, C.A.M. (1997). A mark-recapture study of the social organisation of the honey possum Tarsipes rostratus in the Fitzgerald River National Park, Western Australia. PhD, Murdoch University.

Hardham, A.R. (2005). Phytophthora cinnamomi Molecular Plant Pathology, **6**, 589–604.

Hopper, S.D. & Burbidge, A.A. (1982). Feeding behaviour of birds and mammals on the flowers of Banksia grandis and Eucalyptus angulosa. In Pollination and Evolution (eds J.A. Armstrong, J.M. Powell & A.A. Richards), pp. 67–75. Royal Botanic Gardens, Sydney.

Renfree, M.B. (1980). Embryonic Diapause in the Honey Possum Tarsipes spencerae. Search, **11**, p. 81.

Renfree, M.B., Russell, E.M., & Wooller, R.D. (1984). Reproduction and life history of the honey possum, Tarsipes rostratus. In Possums and Gliders (eds A.P. Smith & I.D. Hume), pp. 427–437. Australian Mammal Society, Sydney.

Richardson, K.C., Wooller, R.D., & Collins, B.G. (1986). Adaptations to a diet of nectar and pollen in the marsupial Tarsipes rostratus (Marsupiala: Tarsipedidae). Journal of zoology, **208**, 285–297

Russell, E.M. & Renfree, M.B. (1989). Tarsipedidae. In Fauna of Australia (ed W.W. Walton), Vol. 1B, pp. 769–782. Australian Government Publishing Service, Canberra.

Saffer, V.M. (1998). A comparison of foodplant utilization by nectar feeding marsupials and birds in the Fitzgerald River National Park, Western Australia. PhD, Murdoch University.

Shearer, B.L. (1994). The major plant pathogens occurring in native ecosystems of south-western Australia. Journal of the Royal Society of Western Australia, **77**, 113–122.

Shearer, B.L., Crane, C.E., & Cochrane, A. (2004). Quantification of the susceptibility of the native flora of the South-West Botanical Province, Western Australia, to Phytophthora cinnamomi. Australian Journal of Botany, **52**, 435–443.

Turner, V. (1984). Banksia pollen as a source of protein in the diet of two Australian marsupials Cercartetus nanus and Tarsipes rostratus. Oikos, **43**, 53–61.

Withers, P.C., Richardson, K.C., & Wooller, R.D. (1990). Metabolic Physiology of Euthermic and torpid honey possums, Tarsipes rostratus. Australian Journal of Zoology, **37**, 685–693.

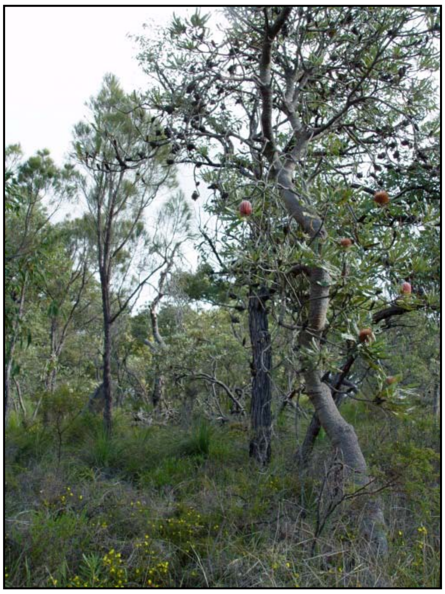
Wooller, R.D., Renfree, M.B., Russell, E.M., Dunning, A., Green, S.W., & Duncan, P. (1981). Seasonal changes in a population of the nectar-feeding marsupial Tarsipes spencerae (Marsupialia: Tarsipedidae). J. Zool., Lond., **195**, 267–279.

Wooller, R.D., Russell, E.M., & Renfree, M.B. (1983). A technique for sampling pollen carried by vertebrates. Australian Wildlife Research, **10**, 433–434.

Wooller, R.D., Russell, E.M., & Renfree, M.B. (1984). Honey possums and their food plants. In Possums and Gliders (eds A.P. Smith & I.D. Hume), pp. 439–443. Surrey Beatty, Sydney.

Wooller, R.D., Richardson, K.C., & Collins, B.G. (1993). The relationship between nectar supply and the rate of capture of a nectar-dependent small marsupial Tarsipes rostratus. Journal of Zoology, **229**, 651–658.

▲ *Grevillea vestita*; Shenton Bushland, Bush Forever Site 218. (B. Keighery)



▲ Banksia woodland with flowering *Banksia menziesii* in foreground; Woodvale Nature Reserve, Bush Forever Site 407. (B. Keighery)

▲ Striped Skink *Ctenotus impar* feeds on invertebrates in Banksia woodland. (W. Bancroft)

◄ Western Bearded Dragon *Pogona minor* on a *Banksia prionotes* cone on the ground, bitten off by a Carnaby's Cockatoo. (M. Owen)

▲ *Cortinarius microarcheri* one of the many species of mycorrhizal fungi partnering native plants in Perth’s woodlands. (N. Bougher)

▲ Spoon-winged Lacewing *Chasmoptera hutti*. (D. Knowles)

▲ White-end Bandwing Platystomatid fly. (D. Knowles)

◄ Menzies’ Banksia *Banksia menziesii* has the largest range of colour forms in the genus. (G. Keighery)

◄ Nyoongar 4-eye moth *Carthaea saturnioides* (D. Knowles)

▲ Many-flowered Fringe Lily *Thysanotus multiflorus*; Underwood Avenue Bushland. (M. Owen)

▲ Carnaby's Cockatoo *Calyptorhynchus latirostris* over Bold Park. (M. Owen)

▲ Half-ringed Bandy-Bandy *Brachyurophis semifasciatus*, one of several burrowing snakes found in Banksia woodland. (M. Bamford)

◄ Cats Paw *Anigozanthos humilis* (K. Sarti)

◄ Spiny White-stripe Ground Weevil *Acantholophus niveovittatus*. (D. Knowles)

▲ Western Spinebill *Acanthorhynchus superciliosus* on *Banksia prionotes*; Underwood Avenue Bushland. (M. Owen)

▲ *Caladenia arenicola*; Underwood Avenue Bushland. (M. Owen)

▲ Morrison Featherflower *Verticordia nitens*; Melaleuca Park. (B. Keighery)

◄ Gregarious Shells *Campanella gregaria* found on fallen logs, particularly on inside of Banksia bark. (N. Bougher)

◄ Western Small-pimpled Pyrgomorhpid Grasshopper *Monistria latevittata*.
(D. Knowles)

▲ Turtle Frogs *Myobatrachus gouldii* spend most of their lives below ground, but occasionally emerge after heavy rain; Gnangara. (N. Huang)

▲ Banksia woodland and Threatened Ecological Community; Talbot Road Bushland, Bush Forever Site 306.
(B. Keighery)

▲ Collared Sparrowhawk *Accipiter cirrhocephalus* and its kill, the introduced Laughing Turtle-Dove *Streptopelia senegalensis*. (S. Cherriman)

◄ Bristly Cottonhead *Conostylis setigera*.
(B. Keighery)

▲ Pie-bristled Whiteface Anthicid beetle. (D. Knowles)

▲ Winter Bell *Blancoa canescens*. (K. Sarti)

◄ A sand-swimming skink *Lerista planiventralis* emerging from the sand. (B. Bush)

▲ Citizen science – a quadrat marked out in Banksia woodland in readiness for sampling under the Bushland Plant Survey Program. (B. Keighery)

▲ The *Banksia* genus has been in WA at least 50 million years. Banksia fossil (left) compared to modern day *Banksia attenuata* cone. (J.S. Beard and G. Keighery)

◄ Western Bluetongue *Tiliqua occipitalis*, a large, omnivorous skink. (M. Bamford)

Long-horned Grasshopper or Katydid (Tettigoniidae); Underwood Avenue Bushland. (M. Owen) ►

▲ A Quenda *Isoodon obesulus* with large pouch young. Quendas can survive and breed in the suburbs if feral predators and domestic cats are kept under control. (S. Cherriman)

▲ Common Hovea *Hovea trisperma* var. *trisperma*. (B. Keighery)

◀ Pearl Flower *Conostephium pendulum*. (K. Sarti)

▲ *Hemimycena cephalotricha* previously unrecorded in Australia, but recently collected in Bold Park. (N. Bougher)

▲ Whistling Kite *Haliastur sphenurus* on patrol. (S. Cherriman)

▲ Camouflaged Praying Mantis *Archimantis* sp.; Underwood Avenue Bushland. (M. Owen)

▲ Two colour forms of the Banded Greenhood orchid *Pterostylis vittata*. (B. Keighery)

◄ Western Australian Christmas Tree *Nuytsia floribunda*, a hemiparasitic mistletoe. (K. Sarti)

TURTLE FROGS: BIZARRE BREEDERS IN THE BANKSIA WOODLANDS

Nicola Mitchell, University of Western Australia

The Banksia woodlands of south-western Australia are home to a variety of amphibians, including Pobblebonk, Motorbike and Moaning frogs (*Limnodynastis dorsalis, Litoria moorei* and *Heleiporus eyrei*) that forage on the forest floor and sit out dry periods in moist retreat sites. In addition, one very unusual amphibian not only feeds in the woodlands, but breeds there as well, despite the absence of standing water. Turtle frogs (*Myobatrachus gouldii*), perhaps the strangest and most secretive inhabitants of Banksia woodlands, spend most of year buried deep underground in sandy soils and only emerge following rainfall for feeding and courtship.

Turtle frogs only occur in south-western Australia and are in a monotypic genus, which means that they are highly distinctive. Their closest relatives are the sandhill frogs, *Arenophryne rotunda* and *Arenophryne xiphorhyncha,* found in the coastal dunes of Shark Bay. A feature common to all three species is direct development – where the larval (free-living and feeding) phase of development is bypassed and tiny fully formed frogs hatch from the egg capsule. Hatchlings dig their way to the surface at the end of autumn following a rainfall cue that stimulates their emergence.

Turtle frogs are decidedly un-froglike in appearance, having pinky-purplish skin, a tiny head and short limbs – superficially resembling a turtle. They are well adapted to life underground; their globular shape provides a low surface area to volume ratio that reduces the rate of water loss through the permeable skin. The hands and feet lack webbing and possess claws that allow for efficient burrowing. The sexes are similar in appearance, but females can be identified in spring and summer by the appearance of large-yolky egg follicles that are often visible through the ventral skin.

The most striking feature of turtle and sandhill frogs is their unusual mode of reproduction, where they have apparently 'dissociated' courtship from mating. Earlier research by Professor Dale Roberts from the University of Western Australia described the emergence of chorusing males following spring and summer rainfalls and the selection of mates by females. Male and female pairs then disappeared underground, yet the direct developing eggs were found immediately below the courtship site months later. Considerable effort was expended to find evidence of egg masses after courtship, but to no avail. This led Roberts to conclude that mating probably occurred several months after courtship.

A University of Western Australia research team recently received funding to further investigate the strange sex life of the turtle frog to reveal why such an unusual breeding strategy has evolved. First we explored alternative explanations for the apparent separation of courtship from mating, including the possibility that females store sperm after a mating event and use stored sperm to produce viable egg masses much later. Sperm storage is known in a handful of anuran amphibians (frogs and toads) and is common in salamanders, and hence could be a strategy employed by turtle frogs. Another explanation for the absence of egg masses around the time of courtship is that eggs are simply too difficult to find, and that egg masses found later (in late summer, early autumn) are the product of later courtship events.

To discriminate between these hypotheses we undertook a detailed study of the seasonal changes in reproductive characteristics in turtle frogs, including the maturity of the gonads (testes and ovaries) and the concentrations of reproductive hormones such as testosterone circulating in the blood.

One major obstacle we needed to overcome was to work out how to sample turtle frogs during the dry summer period when they are buried 1–2 metres underground. Sampling at this time was critical to working out whether gonads and other reproductive structures continued to mature after the spring courtship events. We achieved this by constructing a breeding enclosure at our field site in Pinjar State Forest, whereby frogs collected during courtship on the surface were relocated to the enclosure consisting of PVC piping buried flush with the soil surface. These pipes were sealed at the base with flywire, and could be removed by the researchers after a suitable interval to see if breeding activity had commenced.

Miraculously, fresh eggs and recently mated frogs were found on the day that the pipes were removed in mid-February. This allowed us to contrast the reproductive profiles of 'courting' and 'mating' frogs, and to search for evidence of sperm storage. Both sexes had the highest concentrations of sex steroids (testosterone) in their plasma during courting, similar to most animals that show reproductive behaviours when their sex hormones are at peak concentrations. However, gonad maturation (size of egg follicles, oviduct diameter, sperm concentration and viability) was more pronounced in the recently mated frogs, suggesting that courting frogs are not 'primed' for immediate mating. Our failure to find evidence of sperm storage in females that had mated then pointed us back to the simplest explanation: turtle frogs undergo courtship and mating behaviours at different times of year.

Why have turtle frogs (and the sandhill frogs) evolved such an unusual strategy? This group may have evolved from an ancestor similar to Nicholl's Toadlet (*Metacrinia nichollsi*) - a summer-breeding species with direct development from the far south west of Western Australia. The hatchlings of summer breeders typically emerge later in autumn, when frequent rainfalls provide plenty of opportunities for foraging above ground. Our work has shown that turtle frog eggs develop to hatching in about two months at the typical development temperature underground (≈22°C), meaning that eggs should be laid in late summer/early autumn in order to emerge at a favourable time. However, the dry conditions that generally prevail around this time prevents courtship activity, and has led to strong selection on frogs that take advantage of earlier opportunities to pair following rainfalls in spring. The price for such prolonged pairing before mating may be negligible, as the desiccating conditions at the soil surface in summer would generally prevent foraging or additional reproductive activity.

Turtle frogs have broken some classic 'rules' of reproduction, such as a close temporal association between courtship and mating. Studies of such bizarre breeders offer biologists a rare opportunity to determine the factors that promote mating in the absence of obvious environmental cues. Unfortunately, turtle frogs are at risk of disappearing from the greater metropolitan area due to encroaching development and clearing of the remnant Banksia woodlands. Their diet consists almost entirely of termites that feed on the roots and wood of Banksia trees. Therefore, processes that are detrimental to the health of Banksias will affect turtle frogs via a decline in their food source. One such process is water abstraction from the Gnangara underground aquifer, as lowering of the water table has been linked to death of Banksia stands. Water abstraction is potentially also directly threatening turtle frogs, as turtle frogs depend on soil-bound water for their survival during dry periods and for the successful development of their terrestrial eggs. The maintenance of functional Banksia woodlands which provide food and habitat, and that could potentially trigger mating behaviours in this species, will be critical to the long term persistence of this enigmatic amphibian.

a) b) c)

a) A male Turtle Frog calling to solicit a mate. Hundreds of males emerge to call on nights following spring rainfalls. b) Trapping for Turtle frogs in Pinjar State Forest. c) A newly hatched Turtle Frog captured during the first rains of autumn

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Further reading

Bamford, M.J. (1992). The impact of fire and increasing time after fire upon Heleioprus eyrei, Limnodynastes dorsalis and Myobatrachus gouldii (Anura: Leptodactylidae) in Banksia woodland near Perth, Western Australia. Wildlife Research **19**: 169–178.

Calaby, J.H. (1956). The food habits of the frog Myobatrachus gouldii (Gray). Western Australian Naturalist **5**: 93–96.

Edwards, D.L. (2007). Biogeography and speciation of a direct developing frog from the coastal arid zone of Western Australia. Evolution **45**: 494–505.

Nokhbatolfoghahai, M., Mitchell, N.J. and Downie, J.R. (2010). Surface ciliation and tail structure in direct-developing frog embryos: a comparison between Myobatrachus gouldii and Pristimantis (= Eleutherodactylus) urichi". Herepetological Journal **10**: 59–68.

Roberts, J.D. (1981). Terrestrial breeding in the Australian Leptodactylid frog Myobatrachus gouldii (Gray). Australian Wildlife Research 1981, **8**: 451–462.

▲ Debris of *Banksia menziesii* cones eaten by Carnaby's Cockatoo; Inglewood Triangle. (K. Sarti)

◄ Cone of *Banksia menziesii* about to shed seed. (M. Owen)

MAINTAINING THE BIODIVERSITY IN OUR BANKSIA WOODLANDS

Judy Fisher, Fisher Research

INTRODUCTION

One of the major threats to the world's biodiversity is the transformation of ecosystems through invasion (Millenium Ecosystem Assessment, 2005, World Resources Institute, 2005). In fact, invaders are as important as a driver and direct threat to biodiversity as human transformation of ecosystems and production of greenhouse gases (Sala *et al.* 2000). The Convention on Biological Diversity established international biodiversity targets to be reached by 2010 aiming to achieve a significant reduction in the rate of loss of biodiversity. Significant to achieving these targets was the prevention, control and eradication of invasive species (Convention on Biological Diversity, 2003). Unfortunately the indicators related to invasive alien species and biodiversity loss were not reached by 2010 (McGeoch *et al.* 2010).

Invasive alien species have affected native biodiversity in almost every ecosystem type in the world and are considered to be one of the greatest threats to biodiversity, human health and the economy, threatening the ecological and economic well being of the planet (Secretariat of the Convention on Biological Diversity, 2009). The Millennium Ecosystem Assessment indicated that tackling the drivers of biodiversity loss in an integrated manner is much more likely to achieve the 2010 targets than tackling them independently (World Resources Institute, 2005), hence the importance of understanding the effects and interactions of invasion on various components of the ecosystem.

Invasion of natural communities has the potential to cause enormous damage to, and transformation of ecosystems, resulting in alterations to fire regimes, nutrient cycling, hydrology and energy budgets while often reducing the abundance and survival of native species.

The ecological implications are serious indeed for the conservation of native biodiversity through alterations to plant community structure, plant succession and ecosystem processes (Fisher, 2009; Mack *et al.* 2000; Tripathi, 2009).

Important in the management, restoration and control of invasive alien species is an understanding of their effects on the distribution, abundance and population dynamics of native species and ecosystems, hydrology, soil biology and ecosystem processes. This ecosystem knowledge provides the opportunity to better manage and conserve biodiversity, with much of the prioritisation, management and policy development on invasive species to date focused on individual invasive species, to the detriment of biodiversity conservation. In Europe the single species approach has led to invasive alien species policy focusing on single species management as opposed to maintaining and restoring ecosystem services and biodiversity, which would have provided greater longer-term returns on investment and biodiversity enhancement (Shine *et al.* 2009). Similarly in Australia, where single weed species policy and management has been the focus through a Weeds of National Significance Programme, outcomes specifically related to the reduction of the impacts of invasive species on biodiversity have been limited and have not been included in management programmes (Coutts-Smith & Downey, 2006; Downey, 2006; Sinden *et al.* 2004). Evaluation of the success of the Weeds of National Significance Programme identified the need to manage and restore for natural ecosystems rather than single species (Reid *et al.* 2009).

In fact Harold Mooney, Plenary Speaker at the Ecological Society of Australia's Annual Conference in Canberra, December 2010 said:

"…the picture is not pretty, we are still suffering losses at the genetic, species, populations and ecosystem levels, examples of tipping points in ecosystem status are increasingly driven by:

climate change, land use practices and invasive species…

we must reach out beyond our immediate peer group…to devise new ways….connect with the public……" (Mooney, 2010)

This paper provides an example of how Mooney's comments are currently being implemented. The importance of incorporating the ecosystem approach into invasive alien species research, policy and management cannot be overestimated. To ensure that actions on invasive alien species translate into reduced invasive pressure and impact on biodiversity (McGeoch *et al.* 2010) it is vital to use an ecosystem approach. This paper provides a case study on ecosystem research and management in a biodiversity hot spot (Myers *et al.* 2000) in South Western Australia. The study explores the ecological impacts of invasion on the Banksia woodland, a Mediterranean fire-adapted ecosystem occurring on the most nutrient impoverished soils in the world (Beadle, 1966; Cowling & Campbell, 1980), and has determined the causes and consequences of invasion. An integrated ecosystem approach was utilised to test the following hypothesis:

Invasion of Banksia woodland by the introduced species *Ehrharta calycina* and *Pelargonium capitatum* is accompanied by an alteration in ecosystem properties and processes, whereby the degree of change is related to fire frequency and abundance of introduced species (Fisher, 2009).

METHODS

To support this hypothesis:

1. Aerial photography, analysed through a Geographic Information System was used to spatially characterise fire history and quantify changes in tree canopy cover (Fisher *et al.* 2009a) which can cause a dramatic alteration in species composition (Hastwell, 2001).
2. Fire response mechanisms, species richness and diversity of life forms within Mediterranean ecosystems are critical to maintain effective ecosystem functioning (Pate *et al.* 1984). Vegetation variables were studied in four vegetation states i.e. Good Condition (GC) (minimal invasion), Medium Condition (MC) (some invasion), Poor Condition (invaded by the South African perennial grass *Ehrharta calycina)* (PCe) and Poor Condition (invaded by the South African *Pelargonium capitatum*) (PCp) (Fisher *et al.* 2009a).
3. To determine the potential future vegetation and the introduced seed propagule pressure, the presence and abundance of species in the germinable soil seed bank was determined in the same four vegetation conditions and locations (Fisher *et al.* 2009b).
4. To determine if evidence existed for fundamental changes in key ecosystem processes, the nutrient status of soil and leaf foliage was tested in the same vegetation conditions and locations (Fisher *et al.* 2006).
5. The combination of data from Methods 1–4 provides a unique opportunity to explore the potential causes and consequences of observed changes in a biodiverse Banksia woodland (Fisher, 2009).

RESULTS

Fire History: A mean fire interval of 4.75 years between 1963 and 2000 was found to have occurred. The greatest number of fire events (six events) occurred at the heavily invaded sites (PCe and PCp), while Medium Condition sites (MC) with some invasion, experienced four fire events and Good Condition (GC) sites with minimal invasion experienced the least number, i.e. two fire events (Fig. 1) (Fisher *et al.* 2009a).

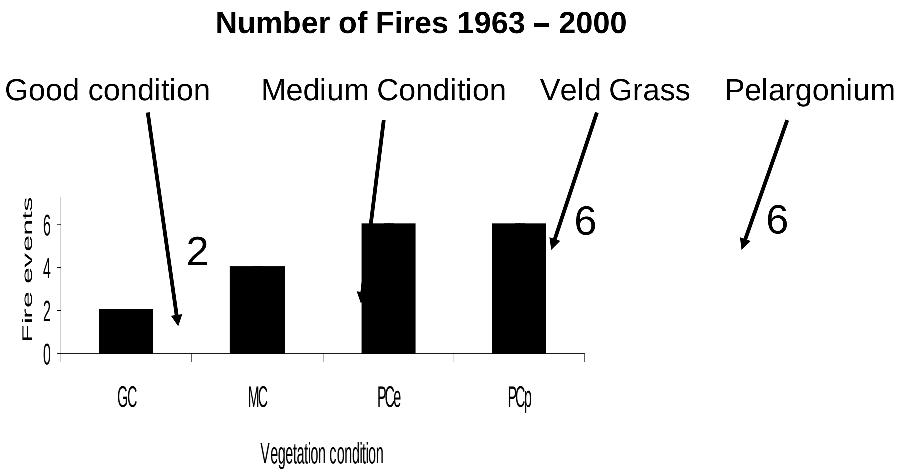


Figure 1: Number of fire events (1963–2000) in Banksia woodland in different vegetation conditions, Good Condition (GC), Medium Condition (MC), Poor Condition invaded by Ehrharta calycina (PCe) and Pelargonium capitatum (PCp).

Tree canopy dynamics and fire history: A net reduction in canopy cover in 60% of the woodland occurred and coincided with areas experiencing ≥ 4 fire events (Fig. 2) (Fisher *et al.* 2009a).

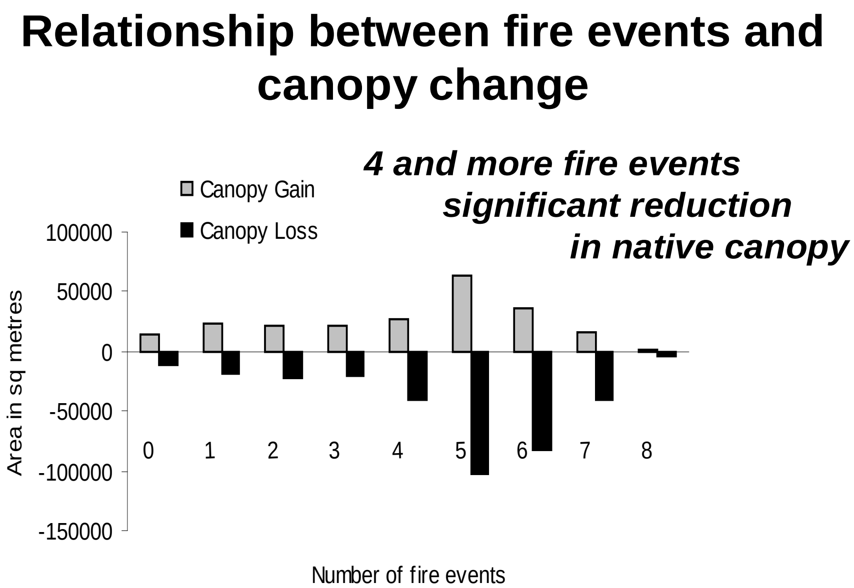
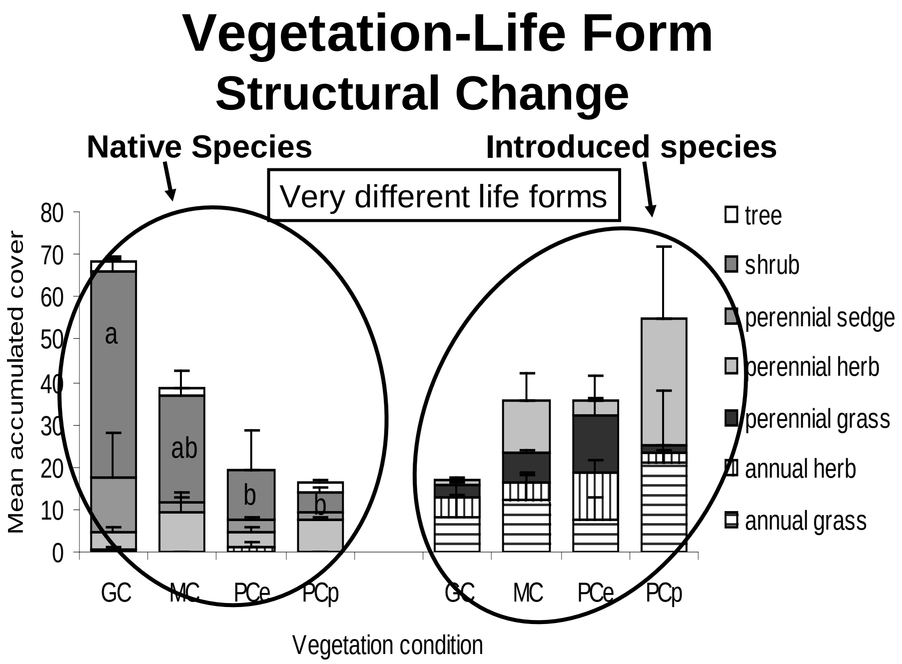


Figure 2: Canopy loss and gain between 1963 and 2000. A significant loss of canopy has occurred in areas experiencing four or more fire events in this period.

Vegetation Structure: A significant difference was found in the species richness between sites in good condition and all other sites. A structural change occurred in the vegetation with the life form composition being altered in relation to invasion (Fig. 3) (Fisher *et al.* 2009a).



Fisher et al, Biological Conservation, 2009, 142: 2270–2281

Figure 3: Mean accumulated cover and contribution of different life form categories for native and introduced species at sites in Good Condition (GC), Medium Condition (MC), Poor Condition invaded by Ehrharta calycina (PCe) and Pelargonium capitatum (PCp). (Fisher et al. 2009a).

Soil Seed bank: Native species richness decreased from sites in GC to sites in PC (both PCe and PCp) (Fisher *et al.* 2009b). Density of native germinants was significantly less than Good Condition in all other conditions (MC, PCe, PCp) (Fig. 4). The life form categories of introduced species was different from native species life forms, with introduced species being dominated by perennial and annual grasses and annual herbs; life forms uncommon in the native soil seed bank which was dominated by shrubs and perennial herbs (Fig. 5) (Fisher *et al.* 2009b).

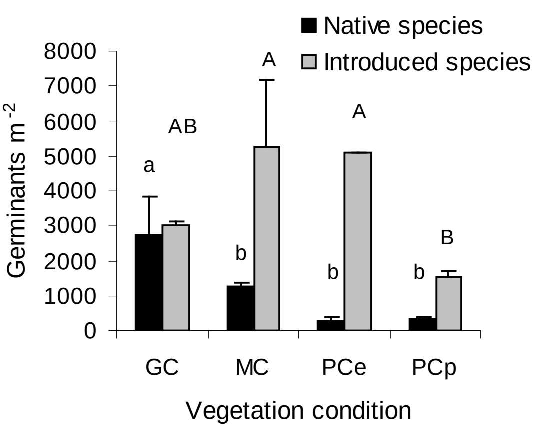


Figure 4: Density (germinants m-2) of native and introduced species in the soil seed bank collected at sites in Good Condition (GC), Medium Condition (MC), Poor Condition invaded by Ehrharta calycina (PCe) and Poor

Condition invaded by Pelargonium capitatum (PCp). Columns with different letters indicate significant differences at p < 0.05, using Tukey HSD pots hoc comparison tests (Fisher et al. 2009b).

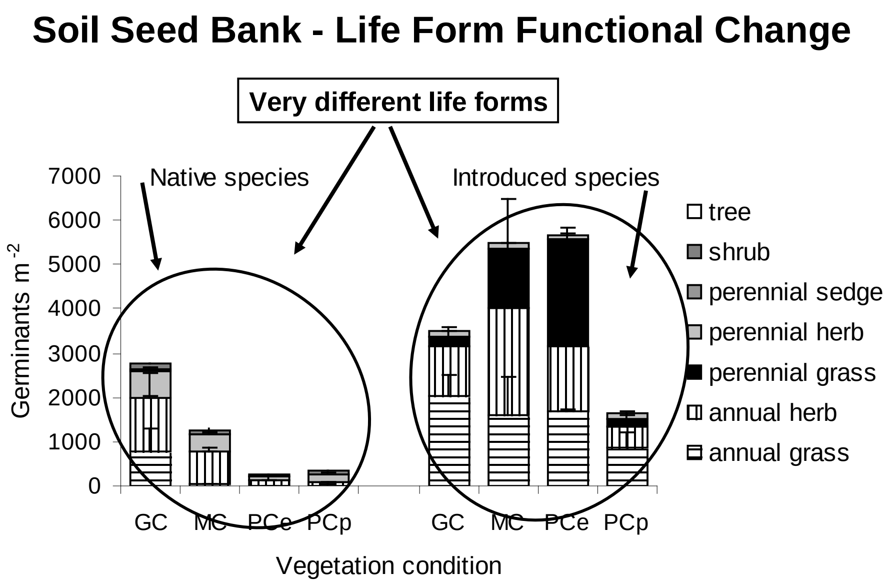


Figure 5: Life form categories among native and introduced species (germinants m-2) at sites in Good Condition (GC), Medium Condition (MC), Poor Condition invaded by Ehrharta calycina (PCe) and Poor Condition invaded by Pelargonium capitatum (PCp) in Banksia woodland

Soil and Leaf Nutrients: Soil differences among vegetation conditions were significant ($P \leq 0.05$) for soil P (total), P(HCO_3) extraction, N (total), S, EC, and pH, with significantly lower soil P (total) at Good Condition sites (Fig. 6), while differences in leaf nutrient concentrations among conditions for all species combined were significantly different among vegetation conditions for P(phosphorus), K(potassium) and Cu(copper) ($P < 0.05$). Concentrations of leaf P were lowest at Good Condition sites (GC) (Fig. 7) (Fisher *et al.* 2006).

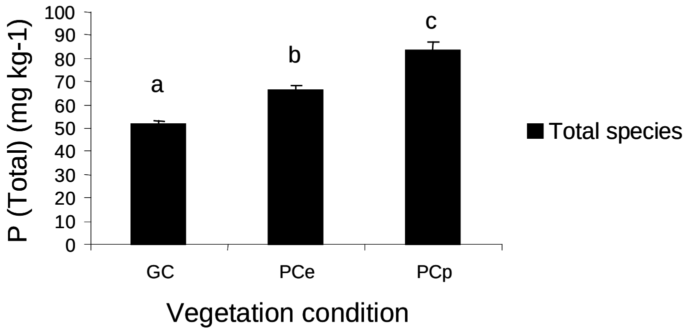


Figure 6: Mean P (total) in the soil (0–5cm) below six native and four introduced species at sites in Good Condition (GC), Medium Condition (MC), Poor Condition invaded by Ehrharta calycina (PCe) and Poor Condition invaded by Pelargonium capitatum (PCp). Columns with different letters indicate significant differences at p < 0.05, using Tukey HSD pots hoc comparison tests.

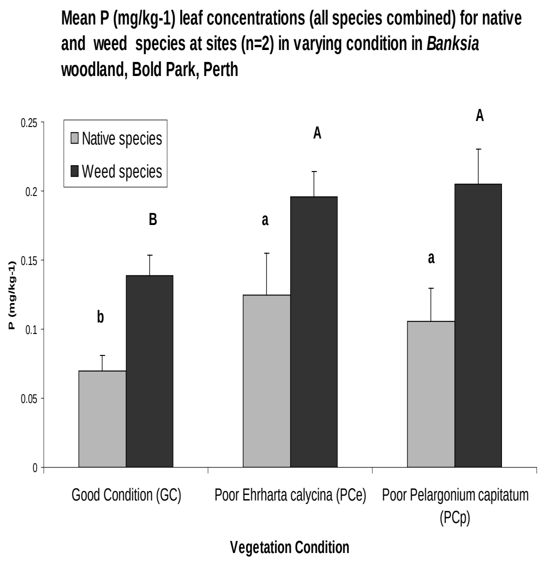


Figure 7: Leaf nutrient concentrations of Phosphorus in native and introduced species in different vegetation conditions, i.e. in Good Condition (GC), Medium Condition (MC), Poor Condition invaded by Ehrharta calycina (PCe) and Poor Condition invaded by Pelargonium capitatum (PCp).

DISCUSSION

This ecosystem research has identified a significant shift in the structural, floristic and functional characteristics of the Banksia woodland, and has provided increased knowledge of the mechanisms of change in ecosystem properties and processes which have occurred following frequent fire and invasion. Understanding the mechanisms of ecosystem change, i.e. the relationship between fire and invasion, and the subsequent ecological impacts, has provided significant knowledge to enhance the effective management of invaded biodiverse ecosystems. These results indicate strong interactions between the number of fire events, tree canopy cover, community composition and function, soil and leaf nutrient dynamics and invasion (Fig. 8). An understanding of the causes, such as this example of fire, and alterations to ecosystem dynamics, and their relationship to disturbance and invasion, provides insights to develop new and effective methods to restore ecosystem resilience thus reducing the impacts of invasive species on biodiversity (Fisher *et al.* 2009a). This study has found that the Banksia woodland is ecologically vulnerable to disturbed fire regimes despite the fundamental importance of fire in controlling and maintaining the dynamics of the ecosystem. Understanding the impacts of invasion on Banksia woodland ecosystem functioning and the ecosystem's responses to invasion allows us to make informed decisions on how best to, and what the potential is, to restore ecological function and resilience to invaded biodiverse ecosystems.

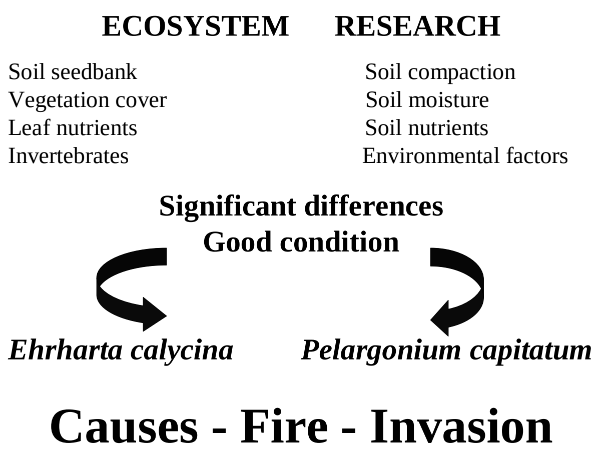


Figure 8: Components of ecosystem research conducted in Banksia woodlands. Significant differences were found between Good condition sites and all other sites for the soil seed bank, vegetation, soil and leaf nutrients, soil moisture and invertebrate studies. Significant differences were also found between Ehrharta calycina and Pelargonium capitatum sites, demonstrating that

different weed species alter the ecosystem in different ways.

Where To From Here?

William Sutherland, also a Plenary speaker at the Ecological Society's Annual Conference in 2010 said:

"….we are presiding over a global loss of biodiversity. Part of the reason…is a failure to comprehensively integrate science and practice. I suggest that we need to fundamentally change how we work."

"…..we should place our emphasis on studying the consequences of interventions…"

(Sutherland, 2010)

The incorporation of scientifically sound baseline monitoring programmes, with input from on-ground people, into intervention projects, and the identification of the consequences of interventions is providing new directions to monitor and adapt the management of altered and disturbed aquatic and Threatened Ecological Communities (TEC) in Western Australia. These programmes are being conducted in association with the communities most involved with caring for these ecosystems. The insights from these people is greatly influencing how we measure and what we measure, in order to ensure that the restoration interventions are building ecosystems resilient to, and able to respond to change.

The question we need to ask is: Why is such a project not happening across the range of Banksia woodland communities? There are untold numbers of groups working on restoring their local Banksia woodland, and this is often being done in isolation from invasion ecologists who have a depth of understanding about the ecosystem which may suggest quite different methods of action if they were to be included in the planning and execution of activities within the Banksia woodland (Gaertner, M., Fisher, J.L. *et al.* In Review). I would like to suggest that a Lead Group needs to take urgent action to co-ordinate such a project.

This case study illustrates the importance of understanding the inter-relatedness of invasion and the ecosystem. That is, understanding the causes and consequences of invasion provides an effective means to determine:

- Prioritisation
- Policy
- Management

The prioritisation, policy and management of invasive species in biodiverse ecosystems has not yet been effective. In Western Australia we have been very slow to understand the value of understanding the causes and consequences of invasion, which would provide a great opportunity for success in managing and restoring ecosystems. This approach, identified in the Introduction, provides a means to look holistically at the system to determine how best to move forward and develop the resilience of the ecosystem in the face of continual rapid change. What about change and invasive species? The following quote identifies even more reason for us to take an ecosystem approach to managing invasive species:

"Our results demonstrate that non-native species, and invasive species in particular, have been far better able to respond to recent climate change by adjusting their flowering time. This demonstrates that climate change has likely played, and may continue to play, an important role in facilitating non-native species naturalisation and invasion at the community level." (Willis *et al.* 2010)

It is time decision makers stopped dismissing the effects of invasive species on biodiversity in Western Australia. What is a key threat mentioned across all the talks we have heard at the symposium today?

i.e.
Vegetation dynamics → Root systems→ Ground-water
Birds → Reptiles → Fungi
Frogs → Macro-invertebrates
Flora → Honey Possums

Invasive species are a common and insidious threat in all these components of the Banksia woodland ecosystem. Is there a co-ordinated planned approach to tackle this and other key threats to our Banksia woodland?

Who will take responsibility to ensure that the following areas are addressed across all Banksia woodlands, in order to maintain biodiversity in Banksia woodlands?

Research → Co-ordinate
Monitor → Policy
Adjust methods → Plan
Restore

Potential Outcomes

Unless this happens we cannot maintain whatever Banksia woodlands the planners decide to leave us. What would the outcomes of such an approach be?

1. Linking the understanding of the impacts of invasive plants on ecosystem function into management actions and then informing and influencing policy.
2. Evidence-based scientific knowledge used in adapting management actions and policy during a period of rapid change.
3. More effective and cost efficient biodiversity protection from existing and future invasion.
4. More resilient plant communities.

Banksia woodlands need human assistance to protect them from:

1. Rapid land use change i.e. from a natural ecosystem to a man-made hard/concrete system with a limited life span.
2. Intolerable fire frequency.
3. Invasion.

In order to do this all Banksia woodland communities need to be:

1. Placed under legal protection from clearing, as Federally listed Threatened Ecological Communities.
2. Classified as a high priority ecosystem in urgent need of investment.
3. Subject of a research, intervention and restoration programme established and funded in association with the dedicated people who invest enormous amounts of their volunteer time.

CONCLUSION

To conclude we need to ask the scientific community, are ecologists playing a key role in providing the science required to sustain Banksia woodland biodiversity for the next 50 years? Are we currently asking and answering the right research questions to sustain Banksia woodland biodiversity for the next 50 years?

This case study has provided an example of the importance of utilising an ecosystem approach to understand the inter-relationships between biodiverse ecosystems and invasion. Ecosystem understandings and thinking provide the most effective means to assist with the prioritisation, policy development and management of invasive alien species to maintain the function, resilience and recovery of invaded biodiverse natural ecosystems. This approach would suggest that far more effective outcomes would occur if invasive species prioritisation and policy were based on ecosystems within each biogeographic region i.e. identify and prioritise ecosystems most in need of conservation and research and manage the invasive species impacts on those high priority ecosystems. In this case Banksia woodland communities would be classified as high priority ecosystems, located within a biodiversity hot spot. Research and management would be done for the ecosystem rather than for priority individual invasive species across the landscape.

REFERENCES

Beadle, N.C.W. (1966). Soil phosphate and its role in moulding segments of the Australian flora and vegetation, with special reference to xeromorphy and sclerophylly. Ecology **47**(6): 992–1007.

Convention on Biological Diversity (2003). Interlinkages between biological diversity and climate change: advice on the integration of biodiversity considerations into the implementation of the United Nations framework convention on climate change and its Kyoto Protocol.

Coutts-Smith, A. & Downey, P. (2006). Impact of weeds on threatened biodiversity in New South Wales In: Technical Bulletin p. 107. CRC for Australian Weed Management.

Cowling, R.M. & Campbell, B.M. (1980). Convergence in vegetation structure in the Mediterranean communities of California, Chile and South Africa. Vegetatio **43**: 191–198.

Downey, P.O. (2006). The development of evaluation methods and ecosystem recovery strategies, in conjunction with best practice weed management guidelines, would help integrate these currently disjunct activities, resulting in a more sustained reduction in the impact of weeds on biodiversity and ecosystem processes. Plant Protection Quarterly **21**(3): 109–116.

Fisher, J.L. (2009). Fundamental changes to ecosystem properties and processes linked to plant invasion and fire frequency in a biodiverse woodland. PhD Thesis: School of Plant Biology, p. 150. Perth: University of Western Australia

Fisher, J.L., Loneragan, W.A., Dixon, K., Delaney, J. & Veneklaas, E.J. (2009a). Altered vegetation structure and composition linked to fire frequency and plant invasion in a biodiverse woodland. Biological Conservation **142**: 2270–2281.

Fisher, J.L., Loneragan, W.A., Dixon, K. & Veneklaas, E.J. (2009b). Soil seed bank compositional change constrains biodiversity in an invaded species-rich woodland. Biological Conservation **142**: 256–269.

Fisher, J.L., Veneklaas, E.J., Lambers, H. & Loneragan, W.A. (2006). Enhanced soil and nutrient status of a Western Australian Banksia woodland community invaded by Ehrharta calycina and Pelargonium capitatum. Plant and Soil **284**: 253–264.

Gaertner, M., Fisher, J.L., Sharma, G.P. & Esler, K.J. (In Review) Invasion and restoration: The yin and yang of ecology - time to unite for a holistic approach to tackle biological invasions.

Hastwell, G.T. (2001). Facilitation and Fertile Islands: linking canopy effects with plant interactions. Department of Environmental Biology, p. 249. Adelaide: University of Adelaide.

Mack, R.N., Simberloff, D., Lonsdale, W.M., Evans, H., Clout, M. & Bazzaz, F.A. (2000). Biotic Invasions: causes, epidemiology, global consequences and control. Ecological Applications **10** (3): 689–710.

McGeoch, M.A., Butchart, S.H.M., Spear, D., Marais, E., Kleynhans, E.J., Symes, A., Chanson, J. & Hoffmann, M. (2010). Global indicators of biological invasion: species numbers, biodiversity impact and policy responses. Diversity and Distributions **16**: 95–108.

Mooney, H. (2010). Global biodiversiy science - recurrent challenges and new opportunities. In: Sustaining Biodiversity - the next 50 years, p. 360. Canberra: Ecological Society of Australia.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A. B. & Kent, J. (2000). Biodiversity hotspots for conservation priorities. Nature **403**: 853–858.

Pate, J.S., Dixon, K.W. & Orshan, G. (1984). Growth and Life Form Characteristics of Kwongan Species. In: Kwongan Plant Life of the Sandplain, eds. J.S. Pate & J.S. Beard, pp. 84–100. Perth: University of Western Australia Press.

Reid, A.M., Morin, L., Downey, P.O., French, K. & Virtue, J.G. (2009). Does invasive plant management aid the restoration of natural ecosystems? Biological Conservation **142**: 2342–2349.

Sala, O.E., Chapin III, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M. & Wall, D.H. (2000). Global biodiversity scenarios for the year 2100. Science **287** (5459): 1770–1774.

Secretariat of the Convention on Biological Diversity (2009). International Day for Biological Diversity 22 May 2009 Invasive Alien Species and threats to biodiversity. p. 30. Montreal.

Shine, C., Kettunen, M., ten Brink, P., Genovesi, P. & Gollasch, G. (2009). Technical Support to EU Strategy on Invasive Alien Species (IAS) Recommendations on policy options to minimise the negative impacts of invasive alien species on biodiversity in Europe and the EU. Final report for the European Commission. p. 35. Brussels, Belgium: Institute for European Environmental Policy (IEEP).

Sinden, J.A., Jones, R., Hester, S., Odom, D., Kalisch, C., James, R. & Cacho, O. (2004). The economic impacts of weeds in Australia. p. 65. Adelaide: CRC for Australian Weed Management.

Sutherland, W. (2010). How can ecology be used to conserve biodiversity? In: Sustaining biodiversity - the next 50 years, p. 360. Canberra: Ecological Society of Australia.

Tripathi, R. S. (2009). Alien plant invasion: A hot ecological issue. International Society of Environmental Botanists **15**(3).

Venkataraman, K. (2009). Environment - Alien Invasion. http://www.flonnet.com/fl2613/stories/20090703261306500.htm, India.

Willis, C.G., Ruhfel, B.R., Primack, R.B., Miller-Rushing, A.J., Losos, J.B. & Davis, C.C. (2010). Favorable Climate Change Response Explains Non-Native Species' Success in Thoreau's Woods. PLoS ONE **5**(1): 5.

World Resources Institute (2005). Millenium Ecosystem Assessment 2005. Ecosystems and Human Well-Being: Biodiversity Synthesis. Washington DC: World Resources Institute.

BELOW THE KNEES BIODIVERSITY AND HOW WE SURVEY IT

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INTRODUCTION

The Banksia woodlands of Perth's Swan Coastal Plain are an integral part of the city's natural environment. However, the eucalypt dominated plant communities with tall Tuart, Jarrah and/or Marri trees are often considered to be the 'real' bushland. People's attraction to all things large, the usefulness of eucalypt timber, the persistence of these trees in the built environment and the ease with which eucalypts can be grown appear to be the foundation of this belief. While all Perth's plant communities are distinctive and biodiverse, it is the Banksia woodlands that are the most diverse and restricted plant communities. Several decades of detailed quadrat and area-based floristic studies have recorded over 1,200 native taxa for Perth's Swan Coastal Plain (Gibson *et al.* 1994, Government of Western Australia, 2000). The principal aims of these studies, and the larger regional study of which they were part, were to understand the patterning, distribution and regional conservation of the native vegetation and flora to inform conservation planning (Government of Western Australia, 2000). These studies form the basis of a substantial database of the many species in Banksia woodland communities. Attached to the studies are ecological data which can be used to better know the generally inconspicuous 'below the knee' flora of the Banksia woodlands. The low shrubs, grasses, herbs and sedges of the 'below the knee' vegetation layers are vital components of the woodlands.

An integral part of the Perth quadrat and area-based studies was the participation of volunteers from the Wildflower Society of Western Australia's Bushland Plant Survey Program. This program celebrated its 20th year in 2008, the same year the Society celebrated its 50 year history (Keighery and Moyle, 2008; Keighery *et al.* 1995). The Bushland Plant Survey Program supported many of the Banksia woodland studies and a substantial number have been published by the Society (Keighery *et al.* 1993a, b and c; 1995; 1997a, b, c, d and e). The majority of the bushland areas studied by the group are part of Bush Forever Sites and summaries of the data collected can be found in the Bush Forever Site descriptions (Government of Western Australia 2000). Further information can be found on the internet compiled as part of the Perth Biodiversity Project to help better understand and manage bushland (Western Australian Local Government Association Perth Biodiversity Project, Department of Environment and Department of Conservation and Land Management, 2005).

THE 'BELOW THE KNEES' LAYER AND HOW WE DOCUMENT IT

The lowest vegetation layer or stratum ('below the knees' layer) of Perth's bushland is formed by low shrubs, grasses, herbs and sedges. This layer can be poorly observed as each of these groups are interlocked and the 'strappy leaved' plants (mostly monocots) appear superficially similar. Studies that record all the plants in a set standard area and/or a specific area are required to accurately record these plants. Studies using quadrat or point source survey techniques have been used to record the presence of these plants.

On the Swan Coastal Plain the standard area used is 10 by 10 metre (10 *x* 10 m). A set of 616 quadrats or relevés have been established on the Plain in the Perth Metropolitan Region (PMR). More than 30% of these quadrats have been located and sampled as part of the Bushland Plant Survey Program. Quadrats are located to sample 100 m^2 and are generally marked with permanent markers at each corner. Relevés also sample 100 m^2 but the area is estimated. Focusing on a standard area in a single plant community allows a valid comparison between different communities. Using a standard area has also proved to be very efficient in the Bushland Plant Survey Program. Interested people with little or no training in vegetation survey and botany can systematically observe and record the vegetation layers and plants in these layers. More than 1,100 (1,130) native taxa are known from the 616 sampled points on the Plain. Of these sampled points, 233 can be called Banksia woodland being dominated by one or more of four *Banksia* tree species – *B. menziesii*, *B. attenuata*, *B. prionotes* and/or *B. ilicifolia*. These Banksia woodland samples contain more than 600 (616) native taxa of which 86% are endemic to Western Australia (WA). The average number of species recorded in 100 m^2 of Banksia woodland in the PMR is 50. To allow for identification of such a range of plant species by volunteers who have varied levels of training in taxonomy, the volunteers collect a small sample of each plant species observed. Each specimen is systematically recorded, numbered and labelled to allow for this diversity and to overcome the need to know the name of each plant. This material is then identified, verified at the WA Herbarium (compared with a known specimen) and the recording finalised. The Wildflower Society has published a guide to this technique (Keighery, 1994) and holds regular workshops and a yearly field program to train interested people in the survey techniques.

DIVERSITY OF THE 'BELOW THE KNEES' LAYER

Upland Banksia Woodlands - common low shrubs, herbs, sedges and grasses

The diversity of low shrubs, herbs, sedges and grasses from Banksia woodlands in four Bush Forever Sites are compared in Table 1. These layers contain a diversity of species and contribute more than 70% of the diversity in the Banksia woodlands on all landforms.

Table 1: Total low shrubs, herbs, sedges and grasses from Banksia Woodlands in four Bush Forever Sites

Bushland Area (Bush Forever Site Number)	Major Landform location (habitats)	Total native plants	BW SWAFCTs (av diversity)	BW plants (approx area)	BW low shrubs, herbs, sedges , grasses (% BW total)
Kings Park[1] (BFS 317)	Spearwood Dunes (uplands)	279 (320ha)	28 (55)	269 (300ha)	193 (72%)
Wandi NR[2] (part BFS 347)	Spearwood/Bassendean Dunes (uplands)	158	23a (59)	158	124 (79%)
Lowlands[3] (BFS 368)	Bassendean Dunes (uplands and wetlands)	344 (1034ha)	21a (52), 21c (39), 23a (59)	187 (1000ha)	158 (85%)
Bullsbrook NR[4] (BFS 292)	Pinjarra Plain/Foothills (uplands and wetlands)	440 (192ha)	23a (59), 28 (55)	137 (40ha)	107 (82%)

[1] after Bennett 1988, [2] Keighery *et al.* 1995, [3] Keighery *et al.* 1993, [4] Keighery *et al.* 1997

This same pattern of diversity is mirrored in the:

- number of native herbs (247 or 40% of 616), sedges (69 or 11% of 616) and grasses (22 or 4% of 616) recorded in Banksia woodlands; and
- more common species (those found in 50% or more of the quadrats) in the different Swan Coastal Plain floristic community types (SWAFCTs) identified from the standard 100m^2 areas sampled on the Plain in the PMR (Table 2).

Table 2: Banksia Woodland Floristic Community Types (after Table 6 in Part 1 Government of WA 2000)

Key

Column 1: Floristic Community Type Codes
The numbers of the types additional to Gibson *et al.* (1994) are italicised if they are subsets of an existing group (in type 23c) and italicised and preceded by an S if they are supplementary groups.

Column 2: General Description of Floristic Community Types
Descriptions are based on generalised information from all plots in the group. Structural units are categorised into forest, woodlands, shrublands, sedgelands and herblands after Gibson *et al.* (1994).

Column 3: Average Species Richness per Floristic Community Type
Average species richness per 10m *x* 10m plot, less those species only occurring in a single plot (single records). Some community types can have a high proportion of single records and these estimates of average species richness are underestimates in some cases.

Column 4: Number of typical native low shrub species (occur in 50% or more of the quadrats)

Column 5: Number of typical native herb, sedge and grass species (occur in 50% or more of the quadrats)

Supergroup 3 – Uplands centred on Bassendean Dunes and Dandaragan Plateau

1	2	3	4	5
20a	*Banksia attenuata* woodlands over species rich dense shrublands	64.5	11	29
20b	Eastern *Banksia attenuata* and/or *Eucalyptus marginata* woodlands	59.7	13	24
20c	Eastern shrublands and woodlands	60.4	11	27
21a	Central *Banksia attenuata - Eucalyptus marginata* woodlands	52.0	5	20
21c	Low lying *Banksia attenuata* woodlands or shrublands	38.5	2	14
22	*Banksia ilicifolia* woodlands	30.0	1	8
23a	Central *Banksia attenuata - Banksia menziesii* woodlands	59.0	8	25
23b	Northern *Banksia attenuata - Banksia menziesii* woodlands	47.0	9	18
23c	North-eastern *Banksia attenuata - Banksia menziesii* woodlands	*53.0*	*5*	*9*
S9	*Banksia attenuata* woodlands over dense low shrublands	*38.9*	*6*	*9*

Supergroup 4 – Uplands centred on Spearwood Dunes

1	2	3	4	5
28	Spearwood *Banksia attenuata* or *Banksia attenuata - Eucalyptus* woodlands	55.1	2	16

The most diverse of the four layers are the herbs then the sedges, followed by the low shrubs, and the least common, are the grasses. The herbs and sedges typically form vegetation layers with densities higher than 2%, the sedges forming a layer in almost all Banksia woodland communities. The herb layer is typically dominated by a variety of species.

Typical dominant herbs are:

- *Patersonia occidentalis, Dasypogon bromeliifolius, Phlebocarya ciliata* and *Burchardia congesta*;
- species from a number of key genera - *Conostylis, Lomandra* (especially *L. hermaphrodita*), *Drosera, Anigozanthos* (especially *A. humilis* subsp. *humilis*), *Haemodorum* and *Stylidium*; and

- species from a number of key families - Asteraceae, Apiaceae and Orchidaceae (especially *Caladenia* species, particularly *C. flava* subsp. *flava*).

The sedges are principally from the Cyperaceae and Restionaceae. Individual Restionaceae and Cyperaceae species often dominate the sedge layer. Dominant Restionaceae species are *Desmocladus asper, D. flexuosa, Lyginia barbata, Hypolaena exsulca* and *Alexgeorgea nitens*. Dominant Cyperaceae species include *Lepidosperma* species, *Schoenus curvifolius* and *Mesomelaena pseudostygia*.

A low shrub layer is often present and is generally dominated by *Hibbertia* species, *Dryandra lindleyana*, *Leucopogon conostephioides* and *Bossiaea eriocarpa*. *Conostephium pendulum*, *Petrophile linearis* and *Bossiaea eriocarpa* are found in most Banksia woodlands.

After fire the relative dominance of the groups changes dramatically. Species reproducing from seed, such as the annual grass *Austrostipa compressa,* and the annual herbs – *Trachymene pilosa, Hyalospermum cotula* and *Podotheca gnaphalioides, Podotheca chrysantha* and *Waitzia suaveolens* typically dominate the below the knees layer. While some of these species are present every year (*Austrostipa compressa, Trachymene pilosa* and *Podotheca chrysantha*), they are less common and do not form a layer.

Upland Banksia Woodlands - uncommon and sometimes rare low shrubs, herbs and sedges.

The low shrubs, herbs, sedges and grasses of Banksia woodlands are typically widespread species found in the sands of the south-west of Western Australia (SWWA). However, there are some species that are uncommon and/or mostly confined to these woodlands such as the PMR, being:

- herbs – *Blancoa canescens, Caladenia huegelii* (R), *Cartonema philydroides, Drakaea elastica* (R), *Conostephium minus, Dasypogon obliquifolius, Haemodorum loratum* (P3), *Hensmania turbinata, Johnsonia pubescens* subsp. *cygnorum* (P2) and *Stylidium crossocephalum*;
- low shrubs –- *Boronia purdieana* subsp. *purdieana*, *Dryandra mimica* (R), *Grevillea bipinnatifida* subsp. *pagna* (P1). *Jacksonia sericea* (P4), *Lysinema elegans, Macarthuria keigheryi* (R), *Pithocarpa corymbulosa* (P3) and *Platysace ramosissima* (P3); and
- sedges – *Tetraria australiensis* (R), *Schoenus griffinianus* (P3) and *Apodasmia ceramophila* (P2.

Some of these species are rare (R) and one, *Jacksonia sericea*, is endemic to the PMR.

Wetland Banksia Woodlands - Low shrubs, herbs, grasses and sedges

Wetland Banksia woodlands can be dominated by *B. ilicifolia* and/or *B. littoralis*. *B. ilicifolia* dominated communities are generally damplands and rarely inundated while *B. littoralis* dominated communities are typically inundated in spring. The *B. ilicifolia* woodlands are relatively widespread (Table 2 SWAFCT 22) and are typically dominated by two herbs – *Dasypogon bromeliifolius* and *Phlebocarya ciliata*. *Stylidium repens* and *S. brunonianum* are common and sometimes even dominant in these communities. *B. littoralis* dominated communities are typically forests and are associated with a variety of sedges, commonly reaching 'above the knees'. The *B. littoralis* dominated communities are becoming increasingly rare with the effects of clearing, lowered water tables and *Phytophthora* disease.

Three rare taxa can be found in the damp woodlands in the PMR: *Jacksonia gracillima* (P3), *Byblis gigantea* (P3) and *Tripterococcus paniculatus* MS (P3).

Banksia Woodland Weeds - herbs and grasses

There is a diversity of herb and grass weeds in Banksia woodlands. The most common herbs and grasses are: **Gladiolus caryophyllaceus*, **Ursinia anthemoides*, **Hypochaeris glabra* and **Briza maxima* [* indicates introduced taxa, *i.e.* weeds]. *Gladiolus caryophyllaceus* is virtually confined to Banksia woodlands.

In areas of significant disturbance Banksia woodlands in the PMR are altered structurally by the presence of a perennial grass layer dominated by **Ehrharta calycina* (Perennial Veldt Grass). This grass competes with native taxa and it changes the fuel loads in bushland, resulting in bushland more prone to devastating hot fires. Another smothering weed is Freesia. The most community altering of the weeds are Freesias, Perennial Veldt Grass and *Gladiolus caryophyllaceus*, as they not only change the appearance of the community but also reduce the diversity of the native low shrubs, herbs, sedges and grasses. Each of these species can be controlled and removal of small infestations should be a priority for managers of bushland.

'Below the Knees' Plants as Habitat

Banksia woodlands provide habitat for many native animals. A number of these animals are discussed elsewhere in these proceedings. Of particular interest in relation to the low shrubs, herbs, sedges and grasses are the native Butterfly species that spend the majority of their lives in these layers (Table 3). The majority of the caterpillar's food sources are inconspicuous species that are often dominant species (*Phlebocarya ciliata, Patersonia occidentalis* and *Lepidosperma* species). Butterfly food plants are also important components of this layer (*Dasypogon* and trunkless *Xanthorrhoea* species).

Table 3: Butterflies and their low shrub, herb, sedge and grass food sources from Banksia woodlands (after Williams *et al.* 2010, Keighery and Huston 1994 and DEC website – www.dec.wa.gov.au).

Butterfly	**Caterpillar Food Source**	**Butterfly Food Source** (mostly ***Pimelea***, ***Dasypogon*** and ***Xanthorrhoea*** species)
Wedge Grass Skipper	Grasses – ***Microlaena stipoides***, ***Austrostipa elegantissima***, ****Ehrharta calycina***	Shrubs
Large Brown Skipper	Sedges – ***Lepidosperma* species**; Herbs - ***Phlebocarya ciliata***	***Dasypogon*** and ***Xanthorrhoea*** species
Blue Iris Skipper	Herbs – ***Patersonia occidentalis***, *P. umbrosa*	low shrubs
Western Grass Dart	Grasses – ***Microlaena stipoides***, ****Ehrharta calycina***, ****E. longiflora***	low shrubs, daisies and Lantana
Western Xenica	Grasses including ****Ehrharta calycina***	flowers bushland and gardens
Marbled Xenica	Grasses – ***Austrostipa compressa, *Ehrharta calycina***	
Yellow Admiral	Herbs – ***Parietaria debilis***, ***P. cardiostegia*** and **Urtica* species	
Spring Sun Moths	Sedges – ***Lepidosperma* species** and others	rarely feed
Graceful Sun Moth	Herbs – ***Lomandra maritima, L. hermaphrodita***	

Plant names in **bold** are common in Banksia woodlands.

CONCLUSION

Hundreds of species of low shrubs, herbs, sedges and grasses are found in our Banksia woodlands and contribute most of the diversity to these communities. While many are common in other communities on sandy soils in the SWWA they occur together in 11 distinctive floristic groups (SWAFCTs) in the PMR and are critical in defining these groups. Rigorous area specific and quadrat-based surveys are required to document these sometimes cryptic plants. At times a number of the species form layers in the community and many are important as food and shelter sources for a diversity of invertebrates.

REFERENCES

Bennett, E.M. (1988). The Bushland Plants of Kings Park. Kings Park Board, West Perth, Western Australia.

DEC (Department of Environment and Conservation) (2010). Definition of Declared Rare and Priority Flora. Department of Environment and Conservation, Western Australia. http://www.dec.wa.gov.au/content/view/5385/1556/ .

Gibson, N., Keighery, B.J., Keighery, G.J., Burbidge, A.H. and Lyons, M.N. (1994). A Floristic Survey of the Southern Swan Coastal Plain. Unpublished Report for the Australian Heritage Commission prepared by the Department of Conservation and Land Management and the Conservation Council of Western Australia (Inc.).

Government of WA (2000). Bush Forever Volume 2: Directory of Bush Forever Sites. Department of Environmental Protection, Perth, Western Australia.

Keighery, B.J. (1994). Bushland Plant Survey. A Guide to Plant Community Survey for the Community. Wildflower Society of WA (Inc.), Nedlands, Western Australia.

Keighery, G.J. and Keighery, B.J. (1993a). Part VII: Floristics of Three Bushland Areas on the Eastern Side of the Swan Coastal Plain In Floristics of Reserves and Bushland Areas of the Perth Region (System 6). Parts V–IX. Wildflower Society of Western Australia (Inc.), Nedlands.

Keighery, G.J. and Keighery, B.J. (1993b). Part VIII: Floristics of Wandi Nature Reserve. In Floristics of Reserves and Bushland Areas of the Perth Region (System 6). Parts V–IX. Wildflower Society of Western Australia (Inc.), Nedlands.

Keighery, G.J. and Keighery, B.J. (1993c). Part IX: The Flora of Three Coastal Bushland Areas (System 6 Areas M46, M91 and M106). In Floristics of Reserves and Bushland Areas of the Perth Region (System 6). Parts V–IX. Wildflower Society of Western Australia (Inc.), Nedlands.

Keighery, B.J. and Huston, J. (1994). Our Wild Plants. A Package of Information and Activities for Primary School on Native Plant Communities. Greening Western Australia.

Keighery, B.J., Keighery, G.J. and Gibson, N. (1995). Floristics of Reserves and Bushland Areas of the System Six Region Part X: Floristics of Lowlands. Wildflower Society of Western Australia (Inc.), Nedlands.

Keighery, B.J., Keighery, G.J. and Gibson, N. (1997a). Floristics of Reserves and Bushland Areas of the Perth Region (System 6). Parts XI–XV. Wildflower Society of Western Australia (Inc.), Nedlands.

Keighery, B.J., Keighery, G.J. and Gibson, N. (1997b). Part XI: Floristics of the Mundijong Road Bushland. In Floristics of Reserves and Bushland Areas of the Perth Region (System 6). Parts XI–XV. Wildflower Society of Western Australia (Inc.), Nedlands.

Keighery, B.J., Keighery, G.J. and Gibson, N. (1997c). Part XIII: Floristics of the Neerabup National Park. In Floristics of Reserves and Bushland Areas of the Perth Region (System 6). Parts XI–XV. Wildflower Society of Western Australia (Inc.), Nedlands.

Keighery, G.J., Keighery, B.J. and Gibson, N. (1997d). Part XII: Floristics of Bullsbrook Nature Reserve. In Floristics of Reserves and Bushland Areas of the Perth Region (System 6). Parts XI–XV. Wildflower Society of Western Australia (Inc.), Nedlands.

Keighery, B.J., Keighery, G.J. and Gibson, N. (1997e). Part XIV: Floristics of the Lakes Cooloongup and Walyungup Bushland. In Floristics of Reserves and Bushland Areas of the Perth Region (System 6). Parts XI–XV. Wildflower Society of Western Australia (Inc.), Nedlands.

Keighery, B., Moyle, B. and Gunness, A. (2008). Sharing a love of flora. Landscope, Volume 24, No 1. Department of Conservation and Land Management, Perth.

Western Australian Local Government Association Perth Biodiversity Project, Department of Environment and Department of Conservation and Land Management (2005). Perth Region Plant Biodiversity Project: Bush Forever Reference Sites. A web based program presenting information on over 40 Bush Forever Sites and explanatory data.

Williams, A., Powell, R., Williams, M. and Walker, G. (2010). Common Butterflies of the South-West. A Department of Conservation and Land Management Bush Book, Perth.

BANKSIA WOODLANDS IN CONTEXT AND IN FUTURE.

Grant Wardell-Johnson, Curtin Institute for Biodiversity and Climate, Curtin University

INTRODUCTION

The Southwest Australian Floristic Region (SWAFR) occupies 34,700 km^2 on a temperate margin of the world's most arid and insular populated continent. This Mediterranean-climate region is isolated by ocean and arid lands (Hopper & Gioia, 2004). The SWAFR is species rich, on old, weathered, nutrient-deficient landscapes (Hopper, 2009; Mucina and Wardell-Johnson, 2011; Sander and Wardell-Johnson, 2011), and is significant internationally as Australia's Global Biodiversity Hotspot. Thus it includes many species found nowhere else and is under increasing threat. Banksia woodlands are a diverse and important structural vegetation type in this region and are the defining plant community of the Swan Coastal Plain Bioregion within the SWAFR. My aim in this paper is to summarise presentations delivered at the Perth's Banksia Woodlands Symposium held on 25th March 2011, and to provide a perspective concerning the future of south-western Australia's Banksia woodlands in the face of humanity's greatest challenge.

The event was opened by MLC Liz Behjat who provided a State Government perspective of Western Australia's Banksia woodlands. Liz provided an overview of the reasons for continued clearing and the subsequent continuing decline of Banksia woodland in the Perth area. Liz particularly emphasised the threat of Dieback (*Phytophthora* spp.) and the need for people to take responsibility for their safety in fire-prone landscapes, of which south-western Australia is an exemplar.

ENVIRONMENT AND PLANTS

Greg Keighery provided an overview of the floristics, evolution and biogeography of Banksia woodlands. *Banksia* is a genus in the Proteaceae, a Gondwanan family with 80 genera and 1,770 species. Proteaceae is the third largest family in Australia. *Banksia* itself is a very old group, which survives fire and drought prone environments. It is a large genus with 175 spp. (*Dryandra* included). *Banksia*-dominated woodlands on sands define the Swan Coastal Plain. They include many vegetation complexes, and many Floristic Community Types (FCTs). Greg outlined many threatened, species-rich FCTs and species and the threats facing them.

Bronwen Keighery introduced Banksia woodland plant life by emphasising the plant diversity 'below the knees'. Bronwen described the plot-based survey work carried out by many people, including skilled volunteers on the Perth Coastal Plain. This includes 616 plots 10 m *x* 10 m in size, of which 213 are dominated by *Banksia*. These plots were surveyed thoroughly for vascular plants. Of the layers of vegetation, 70% of the plant species are 'below the knees'. Herbs for example are 40% of the flora (247 taxa in the 213 plots). These smaller plants also indicate the condition. Bronwen concluded by introducing 'Bush Forever', a directory of sites recognised for protection.

Byron Lamont titled his presentation 'Beneath the *Banksia*s' and provided a glimpse into the fascinating adaptations displayed by understorey plants in Banksia woodlands. For example Woolly Bush (*Adenanthos cygnorum*) demonstrates important links and interactions between plants and animals such as nectaries at the tips of leaves, and fruit transported by ants. Byron also noted the unusual pollination features displayed by south-western Australian plants. These include flower colour changes and tiny bees and nectar on *Verticordia nitens*. He also described pollination in *Stylidium* and vertebrate pollination of prostrate *Banksia* species.

There is a very ancient relationship of plants and fire with many species showing profound adaptations (including resprouting, flowering, germination, etc.) to fire regime. Fire responses demonstrate very ancient relationships between plants and their environment and fire has long been an important evolutionary factor (see Mucina and Wardell-Johnson, 2011; Keeley *et al*. 2011, He *et al*. 2011) – south-western Australia being no exception.

Byron closed by re-emphasising the many threats facing the biodiversity of south-western Australia. These include land clearing, diseases, changed fire regimes, weeds, fertilisers, pests, loss of animals and climate change. Byron advocates active intervention (for example with fire and *Banksia goodii*) because the profound impacts of human activity will mean continued loss without it.

Philip Groom provided an outline of the functional significance of rooting depth. This is an issue of particular importance given the profligate water use by the people of Perth and the rapidly declining water tables associated with the steadily declining rainfall over the past 40 years. *Banksia* in particular has a rooting strategy well-suited to a variable climate, with both sinker roots & laterals (i.e. a dimorphic root system).

Species vary in their distribution in relation to ground-water usage and drought tolerance. Thus there is a trade-off between water use and drought tolerance in Western Australian plants. Traits such as rooting depth can be measured to understand the likely impacts of change. Studies have been conducted to look at which species of plants are most vulnerable to the declining rainfall and water tables and the effects of the increasing prevalence of extremes in weather being experienced in the south-west.

FUNGI

Neale Bougher introduced what he referred to as 'The third F' after flora and fauna, fungi being in a separate Kingdom phylogenetically from flora (plants) and fauna (animals). There are also other kingdoms. He emphasised that most fungi are micro-fungi. However, there is also a vast array of macro-fungi. Macro-fungi include mushrooms, puffballs, truffles and punks. There may be 140,000 species in WA, but many are cryptic. There is presently a very low knowledge of macro-fungi, with perhaps 5–10% named.

Fungi are essential in nutrient cycling, forest health and partnerships. They strongly reflect the health of the environment. A diversity gradient is observable in numbers of native fungi in healthy bush compared to areas which include few native fungi, such as farms. Surveys of Perth bushland, particularly in Bold Park are revealing in that 19% of species recorded in the ninth comprehensive fungus survey of the park were new records to the area.

Many new taxa are regularly discovered and fungi are extremely fine-tuned to their micro-habitat. There are specialised fungi of disturbance. There have been many introductions of fungi (weed fungi), which can adversely impact biodiversity. There is a requirement for much more survey work to reveal the biodiversity of fungi in the region. There is also a need to understand linkages of fungi and other components of the environment and to conserve microhabitats.

THE FAUNA OF BANKSIA WOODLANDS

Mike Bamford introduced the vertebrate winners and losers in Banksia woodlands in relation to the changes brought about since European settlement in 1829. He provided a particularly poignant slide of a sign on land recently cleared for housing development reading '*Bringing land to life'*. Unfortunately nothing could be further from the truth – land clearing or deforestation remaining as the biggest single threat (anthropogenic climate change being a composite threat) to biodiversity in Australia and elsewhere.

Mike described the biogeography of south-western vertebrates as the biogeography of a weird mob. Many are Gondwanan in origin, but there are also more recent colonists, such as the rats – which are diverse in Australia. The Gondwanan species evolved in the presence of very ancient, nutrient poor soils (see Roberts *et al*. 1997; Hopper, 2009; Mucina and Wardell-Johnson, 2011 for examples and explanation). Frogs are particularly weird, including many species with direct development (no free-living tadpole stage) and terrestrial breeding (requiring no free-standing water). The frogs of south-western Australia are not your standard lily-pad types - they are much more fascinating!

The reptiles are very rich in Banksia woodland in particular and south-western Australia in general. Perth itself could be argued as the reptile capital of the world – for no other metropolitan area includes more reptile species. There have been relatively few (maybe none so far) extinctions of frog and reptile species in south-western Australia, despite the massive change in the region since 1829. However, there has been much local change and loss.

Birds are relatively species-poor in south-western Australia, but they are very distinct and include many endemic taxa. There have been many local extinctions and urban reserves such as Kings Park now includes a very different avifauna to that which greeted the settlers of 1829. The mammals were once very rich in Banksia woodland – but there has been a massive loss of species, including both extinctions and local extinction of many species.

The threats to the vertebrates of the region vary with group, although clearing and fragmentation impacts on all groups. Groundwater decline, water level manipulation and garden fencing (preventing dispersal and movement to breeding sites) have a high impact on frogs.

Introduced species – particularly cats have a far-reaching influence on local biodiversity. Mike Bamford and others have documented the loss of native taxa locally through the introduction of a single cat into the neighbourhood. Interactions of fire and introduced plants also have a major influence on the local fauna. Important considerations in the conservation of the remaining native fauna in the region include landscape permeability, size, linkages and condition. Mike emphasised that anthropogenic global warming is a composite threat that exacerbates clearing impacts.

Nicola Mitchell introduced the unusual sex life of the Turtle Frog (*Myobatrachus gouldii*) as a demonstration of the extraordinary adaptations to old landscapes and the unusual environments of south-western Australia. The Turtle Frog is a Banksia woodland specialist, requiring sandy soils in which to burrow. The male Turtle Frog calls in spring, and males and females pair and 'hang out' deep in a burrow. Thus they pair when it is wet and then mate in autumn. This is called 'disassociated behaviour'. The Turtle Frog is one of three species of frogs with this behaviour that reflects a drying environment over evolutionary time.

Shannon Dundas introduced Honey Possums and their association with Banksia woodlands. The Honey Possum is a very small, short-lived south-west endemic marsupial that feeds on nectar and pollen. They are opportunistic feeders, mostly on Dieback susceptible species – but not generally on the very showy *Banksia coccinea* and *Banksia baxteri*, which have very exposed inflorescences.

Dieback (caused by the soil borne pathogen *Phytophthora* spp.) impact is pronounced concerning food plant availability and the loss of primary species. Because Honey Possums rely on the continuance of Banksia woodland, it is important to take care regarding the spread and intensification of Dieback. It should be noted, however, that this profound impact of *Phytophthora* on Honey Possums does not detract from the important continuing conservation significance of Dieback-impacted Banksia woodland (see Bishop *et al*. 2010). The clearing of Banksia woodland, however, spells their end.

David Knowles introduced what he called 'Spineless wonders' – the macro-invertebrates of the Banksia woodlands. Macro-invertebrates comprise more than 79% of Western Australia's terrestrial fauna. Through slides of a fascinating variety of invertebrates, David guided the audience through a rich array of fascinating adaptations. He particularly emphasised the recyclers of dead or dying matter, which include a huge variety of species specialising on dung, leaf pruning, leaf chewing and fungivory. He also showed a rich array of pollinators and predators, emphasising the importance of macro-invertebrates in the everyday life of the planet.

Based on the huge family of beetles, David suggested that there is '*a weevil for every plant occasion*'. His fondness for weevils prompted him to question when confronted by two weevils, which might be '*the lesser of two weevils'*. David senses '*vertebrate centric plots'* against invertebrates; and urges the development of a deeper understanding of this fascinating and critically important group of organisms.

BANKSIA WOODLAND MANAGEMENT – AN ECOSYSTEM APPROACH

Judy Fisher described the importance of controlling invasive plant species to maintain biodiversity in Banksia woodlands. Judy advocates an 'ecosystem approach', demonstrating this need with an exemplar from Bold Park. There are profound interactions that lead to the way an ecosystem functions. These include the interactions of fire, canopy change (more light), weed invasion and nutrients. The soil seed bank provides the next generation and emphasises new patterns in life-form, structure and function. In short, this is the development of a new system. Invasive plant species affect native biodiversity profoundly and anthropogenic climate change is a serious threat that interacts with invasive alien plants and fire regimes.

DISCUSSION AND CONCLUSION

Banksia woodlands are highly important, diverse, species-rich environments epitomising what Greg Keighery calls the '*gnarly West Australian*'. They have declined substantially and face serious threat. There is an urgent need to understand the diversity, venerability and vulnerability of Banksia woodlands and their remarkable biota. There is also a need to achieve substantial change in policy and management if we are to make a difference to Banksia woodland conservation and management.

There will need to be additional efforts in intervention and monitoring if we are to be effective in the conservation and on-going management of Banksia woodlands. However, it is essential to consider the conservation of Banksia woodlands within a broader global conservation agenda. Anthropogenic climate change now urges such a conservation agenda. The alternative would render continued efforts irrelevant in Banksia woodland conservation.

The substantial increase in greenhouse gas emissions since 2000, and a cautious implementation of the non-binding commitments under the Copenhagen Accord puts earth on a course to warm 3.5°C by 2100 (Meinshausen *et al*. 2009; IEA, 2010). Projected anthropogenic climate change is beyond historical and ecological precedence. Even with a 0.9 degree increase since 1750 (the commencement of the industrial Revolution), substantial drying and warming has already been experienced in south-western Australia (Bates *et al*. 2008), with such trends expected to accelerate.

Recognising the difficulties in achieving mitigation, attention is increasingly turning towards living with dangerous climate change. This makes determining whether refugia for biodiversity may persist (see Keppel *et al*. 2011), and if so where. At the projected, but almost unimaginable temperature rise of 3.5°C, no attention will any longer be afforded to the conservation of Banksia woodlands.

Therefore, it is imperative that we do all we can to ensure mitigation. Mitigation is achievable only through a price on carbon as the first stage in a long process of societal change. Limited measures such as 'direct action' are also necessary, but without a price on carbon would lead to pollution becoming increasingly subsidised and eventually impossible for society to fund. Thus mitigation will become increasingly expensive and ineffective. Advocates of limited action on climate change are irresponsibly attempting to mask the urgency of the problem. Leaders in society have a responsibility to lead with courage at a time of humanity's greatest challenge. Naturally sacrifices will have to be made to bring other nations and people to the table – but the alternative is bleak.

Of course, we can all do a little to conserve Banksia woodlands and by definition other components of biodiversity, and also make a difference towards supporting a sustainable and functioning society. I suggest the following as a beginning:

1. Be involved and engaged in knowledge-building concerning Banksia woodland biodiversity and conservation, and be involved in publicity about this important source of inspiration to our community.
2. Be attuned to living in an increasingly semi-arid, highly seasonal landscape through everyday attention to our use of resources, especially energy, water and space.

3. Recognise society's skewed approach to subsidising the unsustainable use of environmental services and push in our own way an urgent price on carbon, with support for additional mitigation measures.
4. Support a broad approach to tackling climate change by being pro-active and engaged in the profound environmental challenge of our time.
5. Be aware of and draw attention to phoney political messages masking the urgency of action on climate change.
6. Be engaged in the 'Tending of our own garden' in the 'Voltairian' sense (Voltaire, 1759).

Anthropogenic climate change is by far the most far-reaching threat to biodiversity in general and to south-western Australia in particular, including the diverse Banksia woodlands which epitomise the sand plains of south-western Australia. Anthropogenic climate change is all-encompassing for it interacts with all other threats. Substantial anthropogenic climate change is inevitable, so we must be involved in adaptive strategies. However, we must also do all we can to slow and stop greenhouse emissions and be prepared to adopt the measures necessary to bring greenhouse gases to a level able to sustain human society and biodiversity, including the glorious and gnarly Banksia woodlands, which this symposium justly celebrates.

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REFERENCES

Bates, B.C., Hope, P., Ryan, B., Smith, I. & Charles, S. (2008). Key findings from the Indian Ocean Climate Initiative and their impact on policy development in Australia. Climatic Change 89: 339–354.

Bishop, C.L., Wardell-Johnson, G.W. & Williams, M.R. (2010). Community-level changes following plant pathogen invasion of Banksia woodlands in the Southwest Australian Floristic Region. Journal of Vegetation Science 21: 888–898.

He, T., Lamont, B.B., Downes, K.S. (2011). Banksia born to burn. New Phytologist 191 (1): 184–196.

Hopper, S.D. (2009). OCBIL theory: towards an integrated understanding of the evolution, ecology and conservation of biodiversity on old, climatically buffered, infertile landscapes. Plant Soil 322: 49–86.

Hopper, S.D., Gioia, P. (2004). The south-west Australian Floristic Region: evolution and conservation of a global hot spot of biodiversity. Annual Review of Ecology, Evolution and Systematics 35: 623–650.

International Energy Agency (2010). World Energy Outlook. IEA Paris.

Keeley, J.E., Pausas, J.G., Rundel, P.W., Bond, W.J. and Bradstock, R.A. (2011). Fire as an evolutionary pressure shaping plant traits. Trends in Plant Science DOI:10.1016/j.tplants.2011.04.002.

Keppel, G., Van Niel K., Wardell-Johnson, G.W., Yates, C., Byrne, M., Mucina, L., Schut, A.G.T., Hopper, S.D., Franklin, S.E. (2011). Refugia: identifying and understanding safe havens for biodiversity under climate change. Global Ecology and Biogeography (accepted 2/3/2011).

Meinshausen, M., Meinshausen, H., Hare, W., Raper, S.B., Frieler, K., Knutti, R., Frame, D.J. & Allen, M.R. (2009). Greenhouse gas emission targets for limiting global warming to 2°C. Nature 458: 1158–1163.

Mucina, L. & Wardell-Johnson, G. (2011). Landscape age and soil fertility, climate stability, and fire regime predictability: beyond the OCBIL framework. Plant and Soil. 341: 1–23

Roberts, J.D., Horwitz, P., Wardell-Johnson, G., Maxson, L. and Mahony, M. (1997). Taxonomy, relationships and conservation of a new genus and species of Myobatrachid frog from the high rainfall region of south-western Australia. Copeia 1997(2): 373–381.

Sander, J., Wardell-Johnson, G. (2011). Impacts of soil fertility on species composition and phylogenetic diversity in the high - rainfall zone of the Southwest Australian Global Biodiversity Hotspot. Plant and Soil. DOI 10.1007/S11104-011-0763-5

Voltaire (1759). Candide, ou l'Optimisme. Cramer, Paris.

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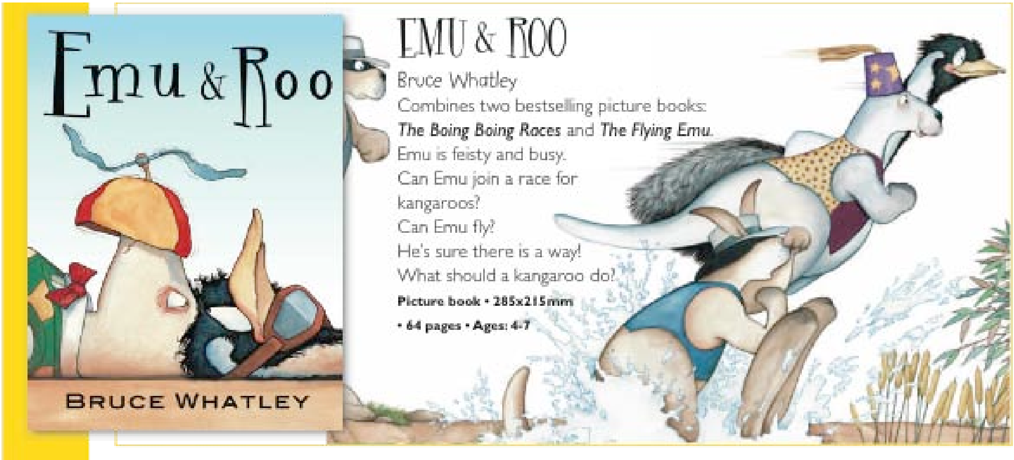
EXPLORING PERTH'S BANKSIA BUSHLAND

This activity sheet is designed to support students learning about the Banksia woodlands of Western Australia. Two sets of lesson plans, suitable for primary school age children, are provided in this section. This material, and a number of other lesson plans can also be downloaded from the Resources section of the Urban Bushland Council website at http://www.bushlandperth.org.au/

CREATURE FEATURE: MOVEMENT FOR LOWER PRIMARY

For Years 1 – 3

PART A: Read a story, which focuses the movements of Australian native animals.



Follow up discussion elicit student ideas about following points:

- Why do animals need to move?
- Discuss that different creatures have different numbers of legs.
  Count how many creatures in the 'Exploring Perth's Banksia Bushland' activity sheet have no legs/2/4 or more legs. *(Teacher could record answers in a table on the board as students provide them using numbers and generic common names (eg. Cockatoo and snake) only to identify creatures.)*
- The different ways that creatures have of moving about such as: flying/ crawling/ running/ climbing/ swimming. Students to draw circle in different colours according to method of movement – e.g. Everything that flies circle in red, everything that climbs in green.
  Minimise paper wastage by getting students in groups with laminated sheets of 'Exploring Perth's Banksia Bushland' activity sheet and pack of white board markers – simply clean off laminated sheet after activity.
- That some creatures use more than one way of moving about.
  Identify from the scene which animals use more than one way of moving about.

PART B: Create an interpretative individual and/or group dance performance based on movements of native creatures found on the 'Exploring Perth's Banksia Bushland' activity sheet.

The next part of this activity is best conducted outside or in an area where students have room to spread out. Students are given a number corresponding to an animal in the 'Exploring Perth's Banksia Bushland' activity sheet and asked to think about how that animal moves. Give students some time and space to work out how they will move like their animal.

Get students to form a circle and have some relevant music on hand (eg. sounds of the Australian bush). When music plays get students to show their moves by calling out to the centre of the circle all students/creatures with 2 legs etc, or other combinations such as all creatures that fly etc. Alternatively or as follow-on activity, get students to work in groups of 4 or 5 to create and rehearse a dance based on the movements of their animals to perform to the rest of the group.

CREATURE FEATURE: MOVEMENT FOR UPPER PRIMARY

(For Years 4 +)

PART A

Students read an **Aboriginal Dreaming Story** relating to animal movement. As follow-up activity students complete a 'Placemat Activity' - use **'Exploring Perth's Banksia Bushland'** activity sheet as a visual reference to focus thinking on animal movement.

Students work in groups of 4 and each individual records their own ideas about focus questions in a corner of an A3 page. After 10 minutes or so students share and discuss their ideas. They then work together to create a 'best group answer', for each question, in the middle of the page.

Class discussion follows.

Focus questions

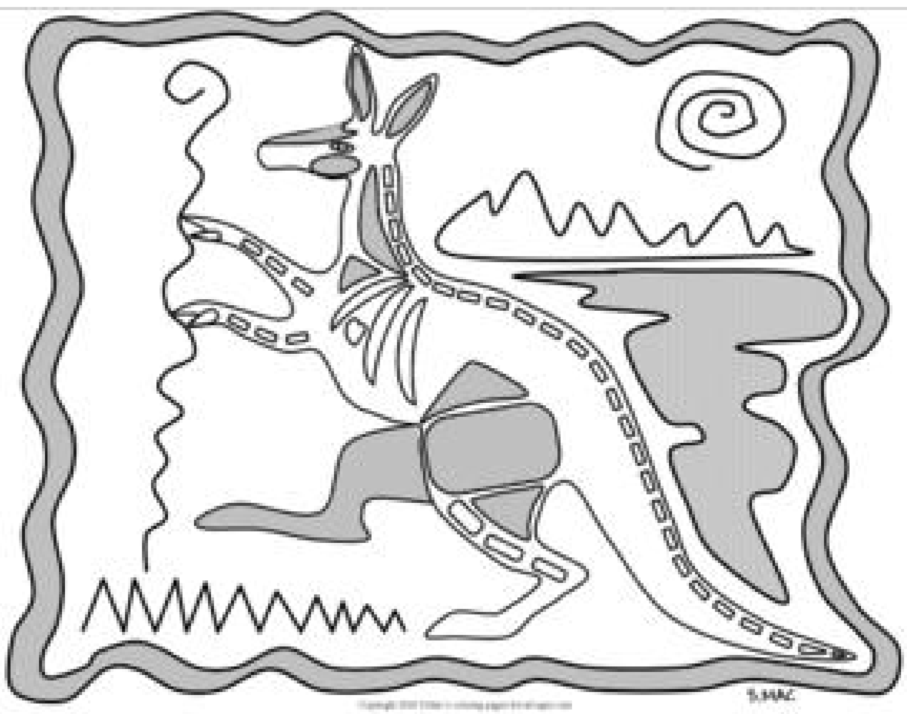
- List all the reasons you can think of why creatures need to be able to move.
- List all the ways you can think of that creatures use to move around.
- List creatures in the picture that use more than one way of moving around and what methods they use.

Dreaming Story Suggestions:

1. ***Why Emu Can't Fly*** – South Australian Dreaming Story about movements of Emu and Brush Turkey. Story is available at Oracle (Education Foundation) Think Quest site: http://library.thinkquest.org/05aug/00747/dreaming/dreaming.html
2. ***Minnawee*** - Western Australian Dreaming story about why the crocodile rolls. Has a short narrated animation video available to watch at the Australian Museum website – Stories of the Dreaming: http://australianmuseum.net.au/movie/Min-na-wee-Why-the-crocodile-rolls

PART B

Students colour in an X-ray drawing of an animal from the **'Exploring Perth's Banksia Bushland'** activity sheet, which they will then use as a cover page to the story they will write in **PART D** of this activity. Discussion should focus on the internal structures of the body that enable and support different types of movements.



PART C

Complete the table below using the 'Exploring Perth's Banksia Bushland' activity sheet as a reference. (Create a worksheet with an enlarged version of table)

For each creature include the following:

- Common Name
- Drawing of animal
- A sentence or two describing the ways in which this creature moves and the features of this creature that allows it to move in the way (or ways) it does?

A creature that flies	A creature that hops	A creature that runs
A creature that climbs	**A creature that**	**A creature that**

PART D

Students to write and illustrate their own Aboriginal Dreaming story about one of the creatures from the **'Exploring Perth's Banksia Bushland'** activity sheet and how it came to be able to move in the way that it does.

Artwork: R. Fleming. Not drawn to scale.

EXPLORING PERTH'S BANKSIA BUSHLAND

1. Candle Banksia *Banksia attenuata*
2. Flame Banksia *Banksia menziesii*
3. Jarrah *Eucalyptus marginata*
4. Woolybush *Adenanthos cygnorum*
5. Balga *Xanthorrhoea preissii*
6. Red & Green Kangaroo Paw *Anigozanthos manglesii*
7. Ghost Fungus *Omphalotus nidiformis*
8. Golden Wood Fungus *Gymnopilus allantopus*
9. Beefsteak Fungus *Fistulina hepatica*
10. Archer's Cortinar *Cortinarius archeri*
11. Australian Painted Lady *Vanessa kershawi*
12. Australian Admiral *Vanessa itea*
13. Jewel Beetle *Stigmodera roei*
14. Swamp Scorpion *Urodacus* sp.
15. Termite galleries
16. Mouse Spider *Missulena* sp.
17. Carnaby's Cockatoo *Calyptorhynchus latirostris*
18. Little Eagle *Aquila morphnoides*
19. Australian Ringneck *Platycercus zonarius*
20. Rainbow Bee-eater *Merops ornatus*, plus four eggs
21. Western Spinebill *Acanthorhynchus superciliosus*
22. Red Wattlebird *Anthochaera carunculata*
23. Splendid Fairy-wren *Malurus splendens*
24. New Holland Honeyeater *Phylidonyris novaehollandiae*
25. Striated Pardalote *Pardalotus striatus*
26. Quenda *Isoodon obesulus*
27. Black-gloved Wallaby *Macropus irma*
28. Turtle Frog *Myobatrachus gouldii*
29. Jan's Banded Snake *Simoselaps bertholdi*

Can you also find these creatures?

a. Echidna *Tachyglossus aculeatus*
b. Bobtail *Tiliqua rugosa*.
c. Tawny Frogmouth *Podargus strigoides*
d. Honey Possum or Noolbenger *Tarsipes rostratus*
e. Gould's Wattled Bat *Chalinolobus gouldii*
f. Stick Insect

Can you add other creatures to the picture? e.g. Willie Wagtail

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Urban Bushland Council WA Inc

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