Flora Conservation Course 2009

FOLDER CONTENTS

FLORA CONSERVATION COURSE TIMETABLE September 2009

	Monday 21	Tuesday 22	Wednesday 23	Thursday 24	Friday 25
7:00	Breakfast	Breakfast	Breakfast	Breakfast	Breakfast
8:00	Welcome (15 mins) and housekeeping (15 mins)	Plant disease	Ecophysiology	Recovery Catchments	Plant ID and FloraBase
	Flora Conservation in WA				
9:00				Fungi	
		Assessments	Assessments		plant ID prac
10:00	Morning tea	Morning tea	Morning tea	Morning tea	
	Flora legislation	Seed Conservation	TEC's	Translocations	Morning tea
11:00					plant ID prac
12:00		Lunch	Course Summary	Assessments	Assessments
	Lunch	Disease and seed prac	Lunch		Summing up (15 mins) and Farewell (15 mins)
1:00	Monitoring techniques		TEC prac	Lunch	Lunch
				Translocation prac	Depart 1:30
2:00	Monitoring prac				
3:00					
4:00					
5:00					
6:00					
6:30	Dinner	Dinner	Dinner	Dinner	

Presentation	**Speaker**
Welcome	Brad Barton
Flora conservation in WA	Dave Coates
Flora Legislation	Ken Atkins
Monitoring techniques	Kim Williams & Andrew Webb
Plant disease/diagnosis	Colin Crane & Chris Dunne
Seed conservation	Andrew Crawford & Anne Monaghan
Ecophysiology	Pieter Poot
TEC	Val English & Monica Hunter
Course Summary	Dave Coates
Recovery catchments	Roger Hearn
Fungi	Richard Robinson
Translocation	Leonie Monks
Plant ID and FloraBase	Ryonen Butcher
Plant id prac	Rob Davis
Summing up	Melanie Smith
Farewell	Peter Keppel

Field / practical
Classroom presentation
Free time
Meals

2009 COURSE PARTICIPANTS

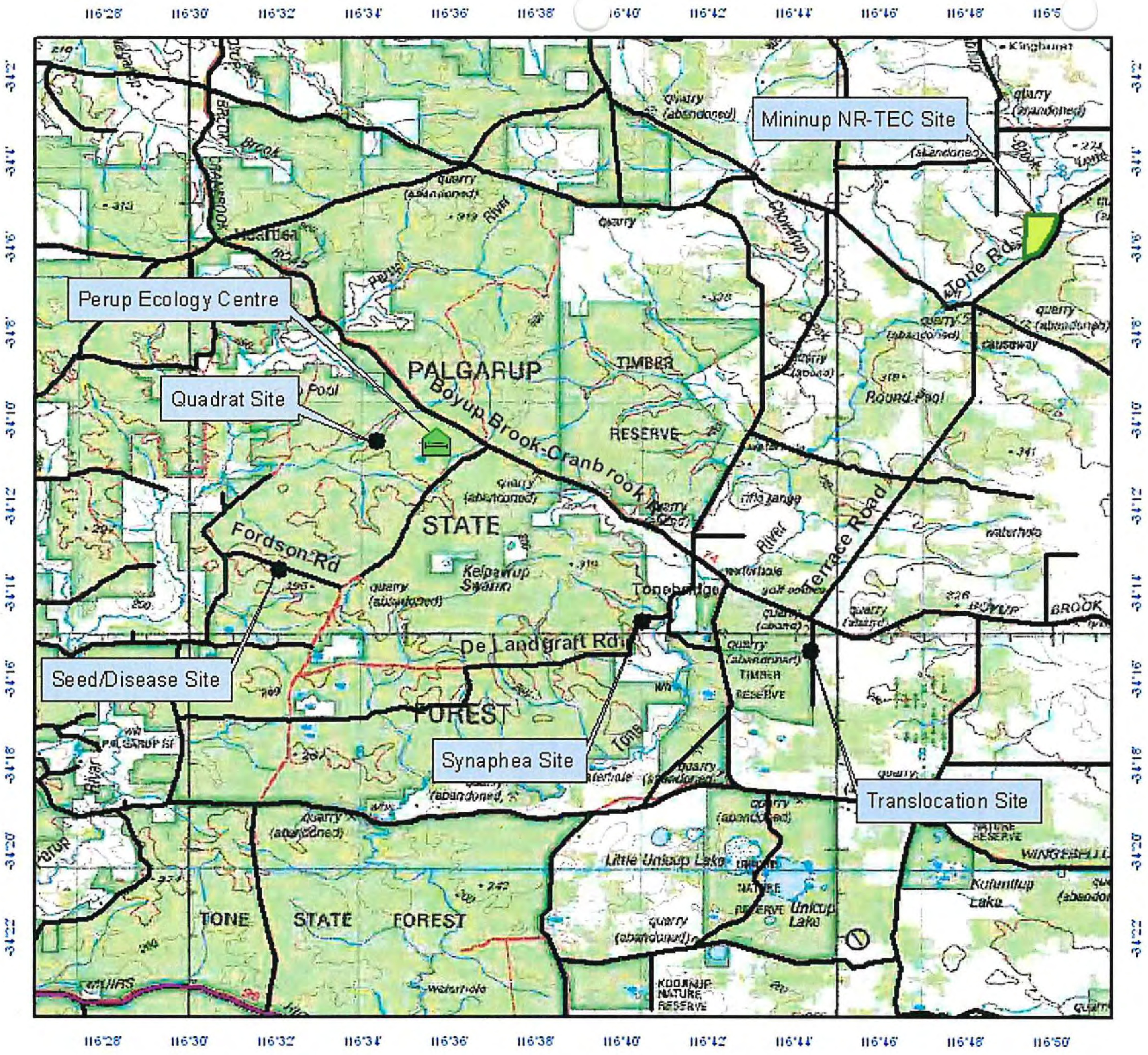
Peter Barness Native Veg Officer & Regional LUP Warren Region	Fiona Bujok Environmental Officer Native Vegetation Conservation Branch	Stephen Butler Revegetation Officer Esperance District
Hayden Canon Conservation Employee Donnelly District	Patrick Cavalli Land Planning Officer Swan Region	Rodney Clifton Sustainable Resources Officer Forest Management Branch Bunbury
Jessica Donaldson Technical Officer – Threatened Flora Species & Communities Branch - Kensington	Nicole Godfrey Manager Peron Captive Breeding Centre Shark Bay District	Jennifer Jackson Flora Conservation Officer Goldfields Region
Vanessa Jackson Reserves Officer Goldfields Region	John Lizamore Recovery Catchment Officer Esperance District	Mark Moore Nature Conservation Officer Yilgarn District
Michael Pasotti Assistant Operations Officer Perth Hills District	Erica Shedley Project Officer Great Southern District	Jana Sturis Technical Officer – Covenants Species & Communities Branch - Kensington
Malcolm Wright Senior Investigator Native Vegetation Conservation Branch		

COURSE PRESENTERS

Ken Atkins Manager Species and Communities Branch Kensington	Brad Barton Regional Nature Conservation Leader Manjimup	Ryonen Butcher Research Scientist WA Herbarium	Dave Coates Principal Research Scientist Science Division Kensington
Colin Crane Senior Tech Officer Science Division Kensington	Andrew Crawford Technical Officer Threatened Flora Seed Centre - Kensington	Rob Davis Technical Officer WA Herbarium	Chris Dunne Research Scientist Science Division Kensington
Val English Principal Ecologist Species and Communities Branch Kensington	Roger Hearn Regional Ecologist Manjimup	Monica Hunter Ecologist Species and Communities Branch Kensington	Anne Monaghan Technical Officer Threatened Flora Seed Centre - Kensington
Leonie Monks Research Scientist Science Division Kensington	Pieter Poot Research Scientist Science Division Kensington	Richard Robinson Regional Ecologist Manjimup	Kim Williams Regional Leader Nature Conservation Bunbury
Ian Wilson District Nature Conservation Coordinator Manjimup			

COURSE COORDINATORS

Melanie Smith Senior Botanist Species and Communities Branch Kensington	Kelly Poultney Rare Flora Admin. Officer Species and Communities Branch Kensington



Flora Course Sites

Legend

- Flora Course Sites
- Roads
- Perup Ecology Centre

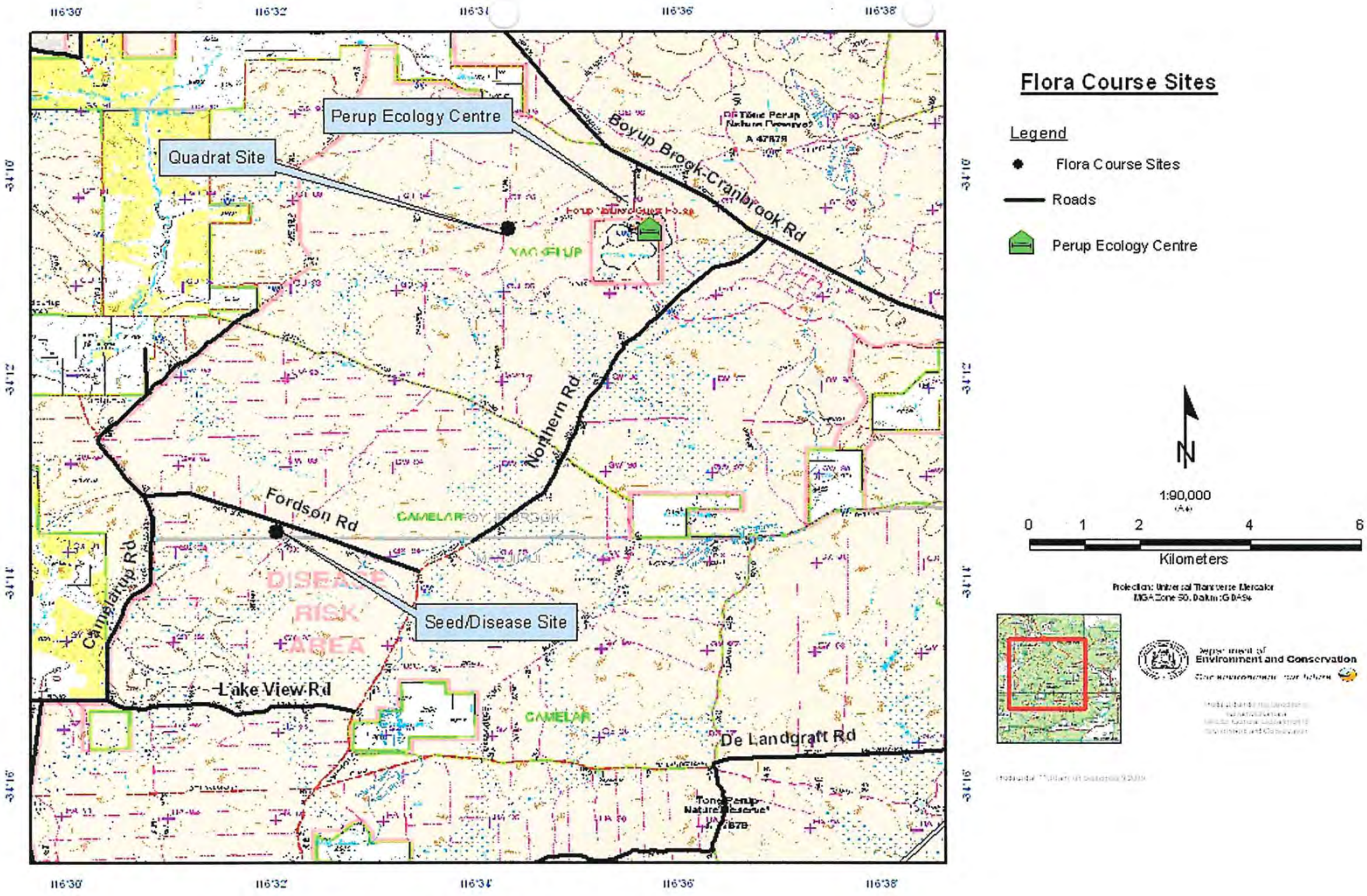
1:250,000

0 2.5 5 10 15

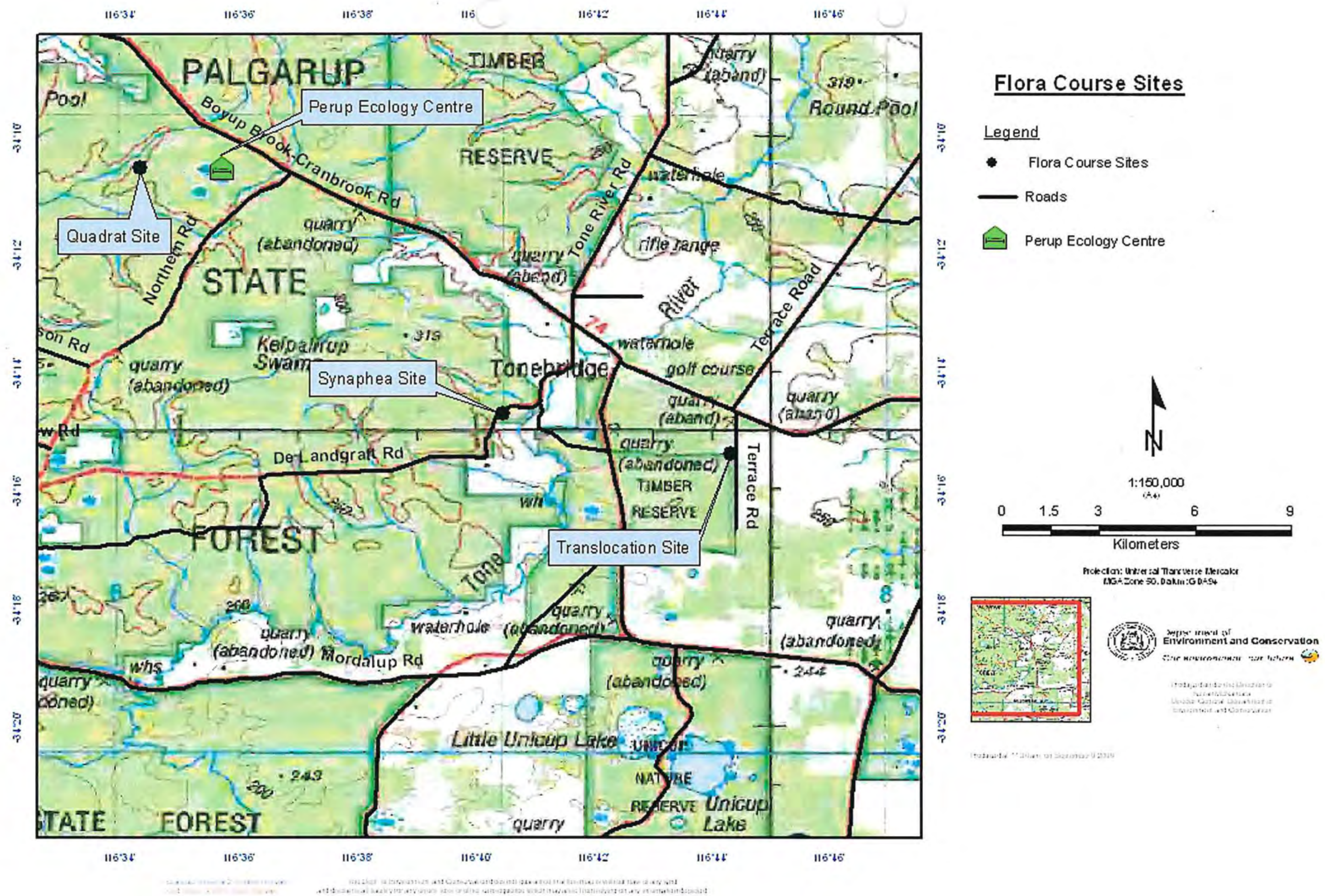
Kilometers

Projection: Universal Transverse Mercator
MGA Zone 50, Datum: GDA94

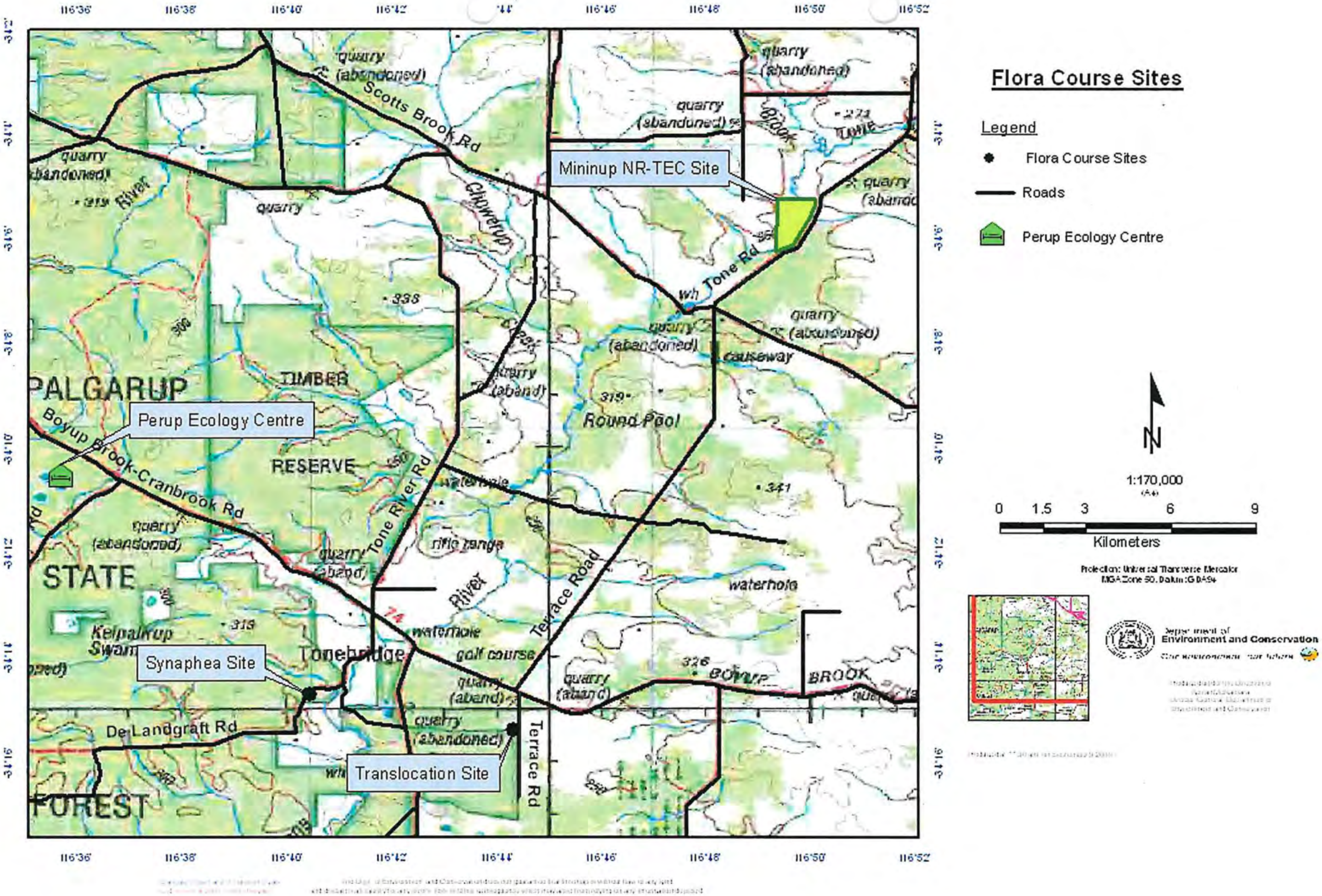
Department of Environment and Conservation



Flora Course Sites
Legend
Flora Course Sites
Roads
Perup Ecology Centre
Perup Ecology Centre
Quadrat Site
Seed/Disease Site
Boyup Brook-Cranbrook Rd
Northern Rd
Fordson Rd
Camelarup Rd
Lake View Rd
De Landgraft Rd
DISEASE
RISK
AREA
CAMELAR
YACKELUP
1:90,000
0
1
2
4
6
Kilometers
Projection: Universal Transverse Mercator
MGA Zone 50, Datum: GDA94
Department of
Environment and Conservation
116°30'
116°32'
116°36'
116°38'
116°34'
-34°10'
-34°12'
-34°14'
-34°16'



Flora Course Sites
Legend
Flora Course Sites
Roads
Perup Ecology Centre
Perup Ecology Centre
Quadrat Site
Synaphea Site
Translocation Site
PALGARUP
TIMBER
RESERVE
STATE
FOREST
Boyup Brook-Cranbrook Rd
Northern Rd
Tone River Rd
Terrace Road
Terrace Rd
De Landgraft Rd
Mordalup Rd
Tonebridge
Kelpainup Swamp
Little Unicup Lake
Unicup Lake
NATURE RESERVE
Round Pool
rifle range
golf course
waterhole
quarry (abandoned)
1:150,000
0 1.5 3 6 9
Kilometers
116°34' 116°36' 116°38' 116°40' 116°42' 116°44' 116°46'
34°10' 34°12' 34°14' 34°16' 34°18' 34°20'
Environment and Conservation



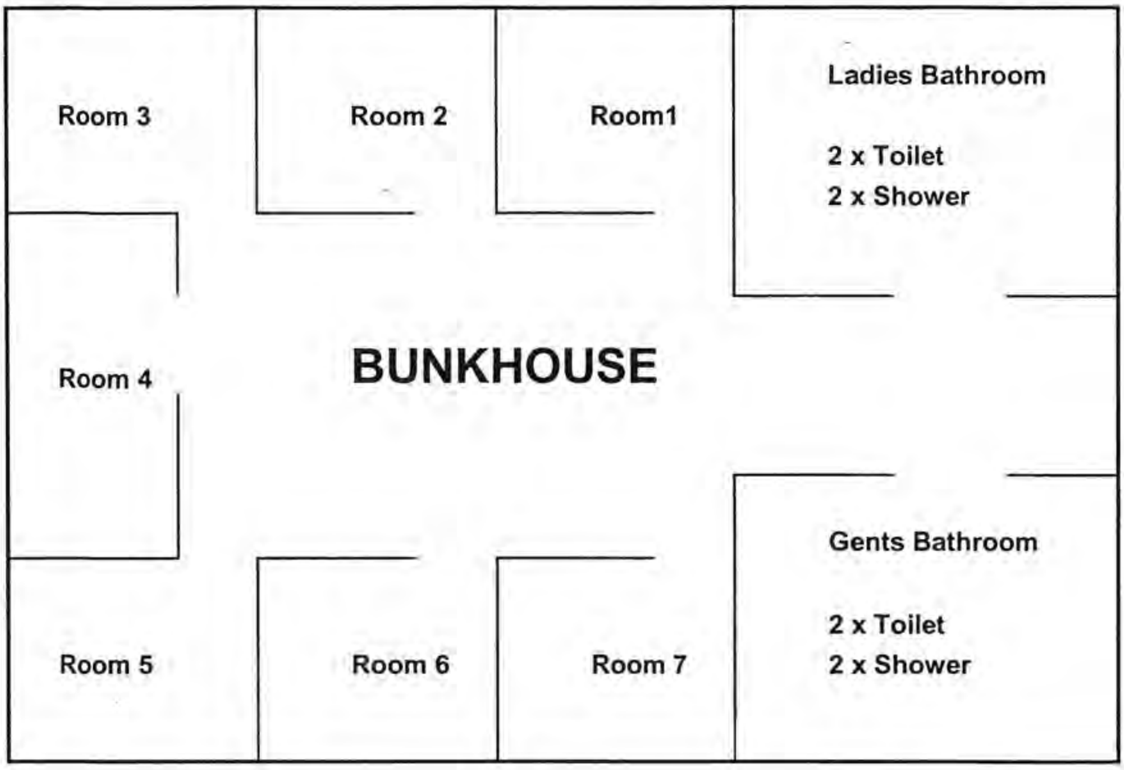
Flora Course Sites
Legend
Flora Course Sites
Roads
Perup Ecology Centre
Mininup NR-TEC Site
Perup Ecology Centre
Synaphea Site
Translocation Site
PALGARUP
STATE
FOREST
TIMBER
RESERVE
Scotts Brook Rd
Boyup Brook-Cranbrook Rd
Tone River Rd
Tone Rd
Terrace Road
Terrace Rd
De Landgraft Rd
Tonebridge
Round Pool
Kelpalkrup Swamp
causeway
rifle range
golf course
waterhole
quarry (abandoned)
1:170,000
0 1.5 3 6 9
Kilometers
Projection: Universal Transverse Mercator
MGA Zone 50, Datum: GDA94
Department of Environment and Conservation

FLORA MANAGEMENT COURSE 2009 Perup Forest Ecology Centre

WORK GROUPS and DUTY ROSTER

Chamelaucium	Eremophila	Verticordia	Caladenia
Mark Moore	Rodney Clifton	Patrick Cavalli	Malcolm Wright
Jennifer Jackson	Fiona Bujok	Vanessa Jackson	Nicole Godfrey
John Lizamore	Stephen Butler	Peter Bamess	Hayden Canon
Erica Shedley	Jana Sturis	Jessica Donaldson	Michael Pasotti

	Chamelaucium	*Eremophila*	*Verticordia*	*Caladenia*
Monday	Bathrooms	Sweep yard, cleanup rubbish	Kitchen	Sweep dormitory hall and lab
Tuesday	Sweep dormitory hall and lab	Bathrooms	Sweep yard, cleanup rubbish	Kitchen
Wednesday	Kitchen	Sweep dormitory hall and lab	Bathrooms	Sweep yard, cleanup rubbish
Thursday	Sweep yard, cleanup rubbish	Kitchen	Sweep dormitory hall and lab	Bathrooms
Friday	Bathrooms	Sweep yard, cleanup rubbish	Kitchen	Sweep dormitory hall and lab



ROOM 1	Jennifer	Jessica	
ROOM 2	Fiona	Vanessa	Jana
ROOM 3	Nicole	Erica	
ROOM 4	Peter	Michael	
ROOM 5	Patrick	Hayden	
ROOM 6	Malcom	Rodney	
ROOM 7	Stephen	John	

Department of
Environment and Conservation

Our environment, our future

Flora Conservation Course

Western Australia's Flora: Origins, Endemism, Rarity and Conservation

Prepared by:

David Coates, Science Division, Kensington
Colin Yates, Science Division, Kensington

Prepared for:

Flora Conservation Course

Version 1.0 (September 2007)

1 Patterns of Plant Diversity

Western Australia has an ancient flora with many relict species. A large number of these species have geographically restricted ranges.

Many of the species have naturally fragmented disjunct distributions. There is an unusually high proportion of naturally rare plants in the southwest of the state.

One example is the taxon *Dryandra montana* It is found in the eastern Stirling Range montane thicket and heath community. As of 2003 there were only a total of 46 mature plants, 5 juveniles and 15 seedlings. It is a highly susceptible species, and possibly biologically extinct.

In the South-West Botanical Province there are around 8,000 species of vascular plants.

Significant events in the evolution of the southwest flora MYA = million of years ago	
65 MYA	Australia splits from Antarctica
57 MYA	sclerophyllous genera of the Myrtaceae and Proteacea have become a significant component of the flora
30 MYA	isolation from eastern Australia
5 MYA	onset of aridity and disappearance of rainforests
1.6 MYA	present—continuous climatic fluctuations in Transitional Rainfall Zone

2 Ancient Flora and Evolutionary History

There are several major factors in the evolution of the South West flora. The ancient landscape has remained unglaciated and above sealevel for 200 million years. No significant mountain uplifting or volcanic activity has occurred. There is a complex mosaic of soils types. And the dynamic climatic changes during the late Tertiary and Quarternary (1.6 million years to the present) have also contributed to the process.

3 Threats

Four main threats are

- Habitat Fragmentation from clearing
- Phytophthora dieback
- Mining
- Climate change

4 Habitat Fragmentation

The fragmentation of habitats is a major and pervasive threat to species and ecosystems in south-west Western Australia.

Gene flow in fragmented landscapes may be affected by the size, the shape, the quality and the connectivity of the remnants.

Gene transfer among paddock wandoo trees has been studied. It was found that in some cases genes did travel by pollen transfer across paddocks for several kilometers.

5 Rarity and threat in the Flora

The concept of biological rarity is somewhat intuitive. It is determined relative to certain factors, and is dependent on scale. In biology, rarity generally relates to geographic range, the specificity of the habitat, and the abundance of the taxon. Rare plants are often characterized by small populations, fragmented and isolated populations, and a small geographic range. Over 2000 plant taxa are currently considered rare in southwest Western Australia. That is approximately 25% of the flora.

There are many causes of rarity. The geologic and evolutionary history of a plant can make it rare. Also, a myriad of ecological interactions like edaphic factors, predation, competition, pollination, fire sensitivity and climate can lead to a plant becoming rare.

Other factors that lead to rarity are the reproductive biology of the plant, and how specific a habitat it requires. The population dynamics of the plant can lead to it becoming rare if it does not easily or frequently move into new areas. Its stochasticity, or the way the plant reproduces often determine whether it can move into new areas.
Human activities such as certain types of land management, habitat conversion and harvesting can also make a plant rare.

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6 Rarity and threat in southwest Western Australia

A significant number of the southwest flora species occur in the state's agricultural region where 75 percent of the vegetation has been cleared. Much of the flora exists in remnant areas of native vegetation. The remnants vary in size, shape and connectivity to other remnants. The majority of the flora is found on landscapes affected by disturbance and by changes to hydrological regimes. Also, much of the flora is located in landscapes where exotic weeds and diseases have been introduced. In some areas the weed and disease problems have become prevalent.

6.1 Case Studies on *Acacia lobulata*, *Lambertia echinata* complex, *Adenanthos pungens*, *Verticordia fimbrilepsis* complex and *Tetratheca aphylla* complex

Acacia lobulata is an example of a species which is geographically restricted (with a narrow habitat specificity) but is locally abundant.

The four subspecies of *Lambertia echinata* are highly susceptible to *Phytophthora c.* and phosphate appears to be ineffective in combating the disease for this species. There are only 75 plants in the wild of the *echinata* subspecies. A translocation of 190 plants failed. All three populations are in decline, because they are infected with *Phytophthora cinnamomi*..

There are two subspecies of *Adenanthos pungens,* both of which are geographically restricted and patchily distributed. They are locally abundant but rare due to habitat loss. They are also susceptible to *Phyotphthora cinnamomi*. In four populations there are just over 1000 plants remaining. One of their sites is in the Lake Chinocup mining area.

The species *Verticordia fimbrilepsis* subspecies *fimbrilepsis* is also rare due to habitat loss. It is geographically and regionally patchy. Sometimes it is locally abundant. In the Wheatbelt there are 7 populations comprised of 1.631 plants. There are also 5 road reserves comprised of 914 plants. Unfortunately there are significant weed infestations in the road reserves. In the jarrah forest there are two populations, comprised of more than 69,000 plants.

There is a complex of Tetratheca species and subspecies in the Wheatbelt. One species, *Tetratheca aphylla*, has four subspecies. One is found near Newdegate and is geographically restricted and may be locally rare. Another is found near Bungalbin and is geographically restricted but locally abundant.

Another similar species, *Tetratheca nephelioides* is geographically restricted and locally rare. *Tetratheca erubescens* is geographically restricted and is probably locally rare. *Tetratheca harperi* is geographically restricted and locally abundant. *Tetratheca paynterae* subspecies *paynterae* is geographically very restricted and locally abundant. And *Tetratheca paynterae* subspecies *cremnobata* is geographically restricted and locally abundant.

7 Threatened Flora

There are 357 plant taxa in South-West Western Australia listed as threatened under the IUCN guidelines. Although many were probably naturally rare, the most likely reasons for their threatened status is likely to be habitat destruction and land degradation. Ongoing threats associated with the contemporary landscape are contributing to the decline of the remaining populations.

8 Ecological studies and recovery

Case study of *Grevillea althoferorum*

There are two geographically disjunct populations of this Grevillea. One is in a road reserve and the other is in a nature reserve. There are 168 plants in one of the populations and 250 plants in the other. The species is critically endangered. Studies of the plant have shown that seed set is low or absent and seedling recruitment is negligible. Reproduction may be restricted to clonality. The likely reason for low seed set is a lack of viable and compatible pollen on stigmas. These intrinsic biological factors are contributing to the rarity of *Grevillea althoferorum*.

In-situ management efforts need to be made to maintain conditions which encourage or allow clonal reproduction. This could be fire. Also it is important to control threats which could destroy existing plants. The opportunities for translocation are limited by the ability to produce new plants from either cuttings or tissue culture. The resilience and fitness of the young plants after planting will be a determining factor.

Another couple of rare plants, *Acacia aprica* and *Acacia cochlocarpa* subspecies *cochlocarpa* produce masses of viable seed but are still only found in a handful of sites. Seed production does not seem to cause an increase in population. The more likely reasons for population decline seem to be lack of seed germination and seedling establishment. The regeneration niche could be enhanced with careful use of fire. Promoting germination with fire and controlling weeds may correct the age structure of populations.

However, all the populations of these acacias are small and none are located on a secure reserve. The land tenure where they are located includes disturbed road reserves, private property and one species only exists in one population of 117 plants. Therefore both taxa are highly susceptible to extinction. The highly desirable course of action would be to create some new populations and conduct *in situ* management of the existing populations.

9 Recovery of Threatened Flora

The first step in recovering species is to determine their conservation status using survey and risk assessment. Then, once it is determined if the species is threatened or rare and poorly known, a priority can be allocated to the species. For threatened species their precise status is determined, either critically endangered, endangered or vulnerable. Then, a recovery program is devised and population priorities are determined, based on analysis of trends and whether factors in decline can be resolved.

For those taxa that are rare or poorly known the perceived threats and the rarity of the plants are used to decide on what priority they have. After additional study it is found that some of the taxa are rare but not threatened, while others are neither rare nor threatened. If it is not threatened it is removed from the list. If it is threatened it is monitored. Recovery actions are implemented and if the limiting factors are overcome, the taxa can recover successfully.

In conjunction with these *in situ* management actions, there is also an *ex situ* seed bank to assist in conserving some species. The DEC Threatened Flora Seed Centre endeavors to collect seeds from 100 species or taxa per year.

The major conservation issues with the Western Australian flora are 1) to manage and ameliorate major threatening processes, 2) to understand the interactions between effects of small population, fire regimes and weed invasion and competition, and 3) to know more about the flora.

With management of threatening processes, it is important to prevent further habitat fragmentation, to ameliorate alterations in hydrological regimes, to keep *Phytophthora* dieback out of areas, to use appropriate fire regimes and to control invasive weeds. In gaining an understanding of the small population effects, studies are carried out on small remnants under management and on areas managed on rangelands.

To increase the knowledge of the flora there still remain taxa to be named and taxa for which the conservation status needs to be ascertained. 1717 taxa are not formally named and out of that number, 458 Declared Rare Flora and Priority Flora are not formally named. For 1780 rare plant species their conservation status is not known. There is also very poor knowledge of non-vascular flora, estimated to be about 100,000 species of which we know how to identify only 2033 species.

10 Some useful references

Gibson, N., Coates, D.J. and Thiele, K.R. 2007 *Taxonomic research and the conservation status of flora in the Yilgarn Banded Iron Formation ranges.* Nuytsia 17

Version 5.0

Western Australia's Flora: Origins, Endemism, Rarity and Conservation

David Coates

Science Division
Department of Environment and Conservation

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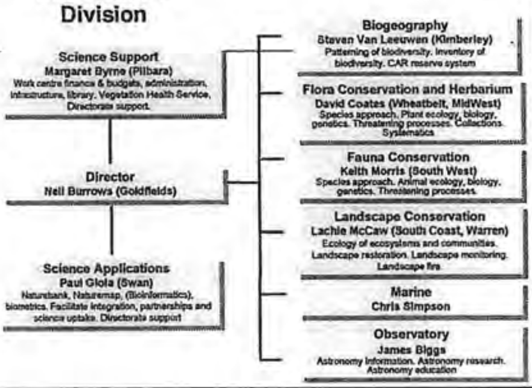
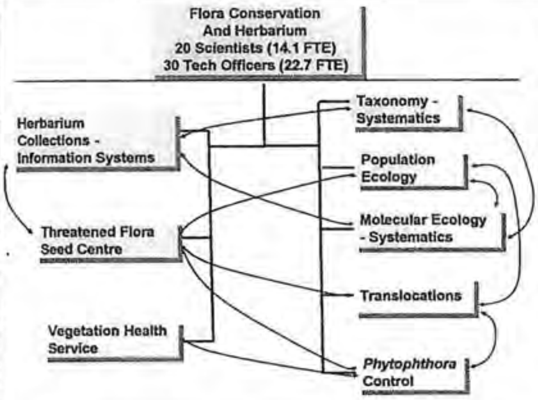
Our environment, our future

DEC Science Division





April 2010 building complete?

Outline of talk

- Patterns of plant diversity in the south-west
- Ancient flora and evolutionary history
- State of knowledge of WA flora
- Climate Change
- Rarity
- Rarity, genetic structure and evolutionary patterns
- Rarity and threat in the flora
  - *Phytophthora* dieback
  - Habitat fragmentation
  - Mining
- Ecological studies and implications for recovery
- Recovery of threatened flora
- FloraBase

Patterns of plant diversity in the south-west

- Ancient flora with many relict species
- Large number of species have geographically restricted ranges
- Many species have naturally fragmented disjunct distributions
- High proportion of naturally rare plants in the south-west
- Rare species often have fragmented disjunct distributions with significant genetic variation between populations

not continuous in the landscape.

Global biodiversity hotspots

Conservation International
February 2005

34 HOT SPOTS.
Internationally.

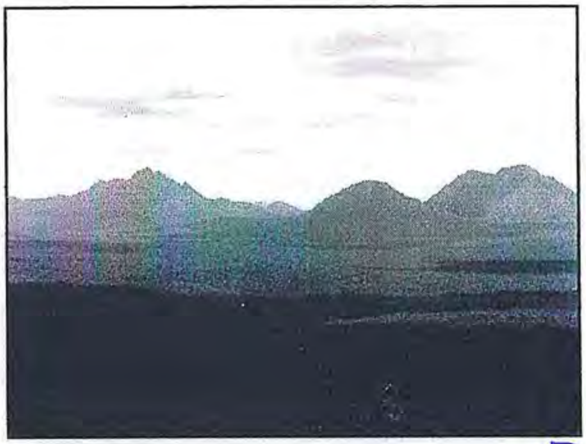
Biodiversity hotspots in Western Australia global and national

8 IN WA.
5 in the south west
pilbara
Carnarvon basin
Kimberley.

Plant species richness and endemism in the southwest

Hopper and Gioia 2008 submitted

Hopper & Gioia Paper:
Annual reviews of
systematics & ecology.



Stirling Range NP –
65% infected with
dieback

refugia for climate
change

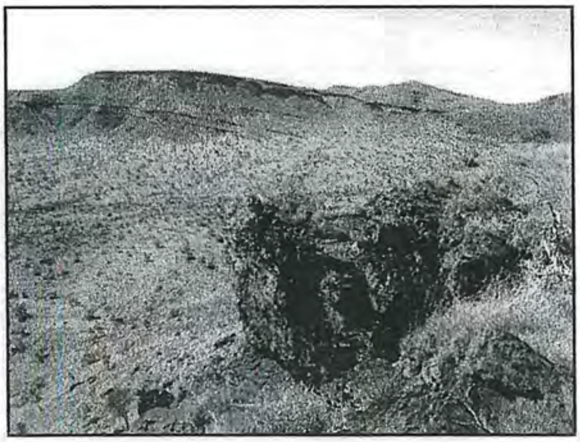
Lesuer

wheatbelt

Verticordias in
Newdegate

Kalbarri

BIF



Pilbara

Hammersley Ranges

Wandoo Woodlands

E darling Scarp

Little Sandy Desert -

Ancient Flora and Evolutionary History

Fossil record and molecular DNA studies indicate an ancient flora

fossil from Cape Range (left) Banksia attenuata (right).

Significant events in the evolution of the southwest flora

- 65 million yrs ago - Australia splits from Antartica.
- 57 million yrs ago - sclerophyllous genera of the Myrtaceae and Proteaceae a significant component of the flora
- 30 million yrs ago - isolation from eastern Australia
- 5 million years ago - onset of aridity and disappearance of rainforests
- 1.6 million to present - continuous climatic fluctuations in Transitional Rainfall Zone

End of Gondwana.

Major Factors Influencing the Evolution of the South West Flora

- Ancient landscape remaining **unglaciated** and above sea level for 200 million yrs
- No significant mountain uplifting or volcanic activity
- 5 million years ago - onset of aridity and disappearance of rainforests
- Dynamic climatic changes during the late Tertiary - Quaternary (1.6 mill yrs bp to present)

20,000 yrs ago last glaciation in N America.

VERY OLD AND STABLE LANDSCAPES!

State of knowledge of WA flora

WA Flora - State of Play

- 13,089 taxa (species, subspecies, varieties)
- 2,813 rare, threatened and poorly known
- 391 Threatened flora
- 1,539 unpublished
  - many lack suitable guides to their identification
  - many are poorly known, under-collected or rare
- Estimate 10-15% remain unknown to science
- Over 300 new species described in 2007

Specially funded project for BIF - special Nuytsia publication.

Outcome of recent taxonomic studies in banded ironstone formations and other key areas considered for mining

- Contributions from at least 35 local and interstate botanists
- 94 new taxa described
  - 20 families, 34 genera
  - 30 from BIF
- Special issue of the Herbarium peer-reviewed journal "Nuytsia"
- 45 manuscripts

others from
· Greenstone Ranges
· Ravensthorpe Ranges.

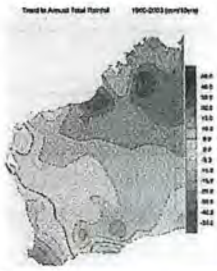
Currently doing work in the Pilbara & vicinity flora focus.

Climate Change

Becoming more of an issue, but how do we plan / manage for it.

Climate change will affect most WA species and ecosystems

- *Directly:*
  - changed temperature
  - Changed rainfall
  - extreme weather events
  - increased CO_2
- *Indirectly:*
  - changed fire regimes
  - pests & diseases
  - altered hydrology and water availability
  - land clearing
- But – which factors, which species, how and how much with what response?



Climate change unit set up in Science Division. Modelling to get some predictions.

WA species - likely responses to climate change

- **Some will persist** through physical and behavioural change (phenotypic plasticity) and evolutionary adaptation
- **Some will contract** to refugia
- **Some will migrate**
- **Some will become extinct**
- **Major changes to our biodiversity are unavoidable**

Nambung NP.

Banksia resprouted from epicormic buds in response to drought - not fire.

Climate change and biodiversity management: what can we do?

- Maintain or increase existing organic carbon e.g. manage land clearing, revegetation, fire, grazing etc. to increase net phytomass & reduce greenhouse gas emissions
- Assist species and ecosystems to cope e.g. manage other threats and disturbances, such as weeds, ferals, fire; provide migration corridors; enhance gene pools etc.
- Protect vulnerable biota e.g., reserve system design, assisted migration, translocations, off-reserve programs, *ex situ* conservation.

Rarity

Biological Rarity

- Rarity is an intuitive, relative, scale dependent concept
- In biology it generally relates to:
  - geographic range
  - habitat specificity
  - abundance of a taxon
- Rare plants are often characterised by :
  - small populations
  - fragmented / isolated populations
  - small geographic range
- **2813 plant taxa are currently considered rare in Western Australia, approx. 20% of the flora**

Four categories of rarity in vascular plants

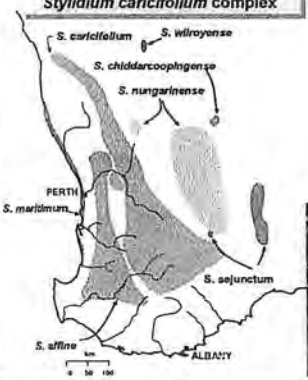
SPATIAL DISTRIBUTION	TEMPORAL PERSISTENCE: SHORT	TEMPORAL PERSISTENCE: LONG
WIDE	*SHORT / WIDE*	*LONG / WIDE*
NARROW	*SHORT / NARROW*	*LONG / NARROW*

Fiedler & Ahouse 1992

Many causes of rarity

- **Geologic and evolutionary history**
- **Myriad of ecological interactions (e.g. edaphic factors, predation, competition, pollination, fire sensitivity, climate)**
- **Reproductive biology**
- **Habitat specificity**
- **Population dynamics and influence of environmental and demographic stochasticity**
- **Human activities - habitat conversion, land management, harvesting**

Distribution of taxa in the *Stylidium caricifolium* complex

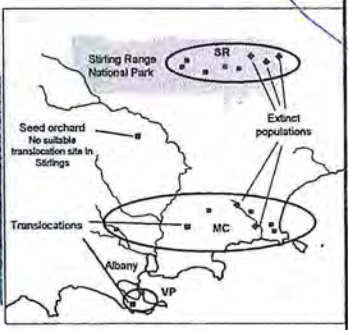


Genetic diversity, rarity and extinction

- Over 2500 plant taxa are currently considered rare in south-west Western Australia, approx. 25% of the flora
- Many of these species are characterised by:
  - Small populations
  - Fragmented / isolated populations
  - Small geographic range
- Localised extinction and loss of genetic diversity are increasing

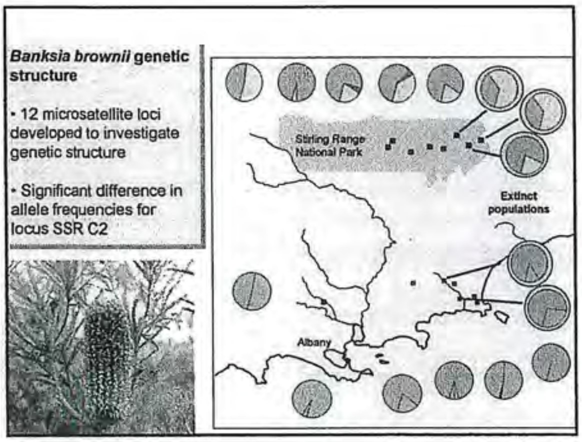
Rarity, genetic structure and evolutionary patterns

Banksia brownii collection/sample sites for genetic structure study based on 12 microsatellite loci

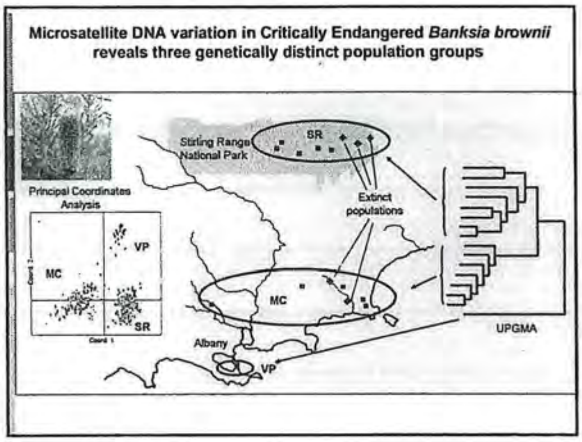


Extinct due to phytophthora.

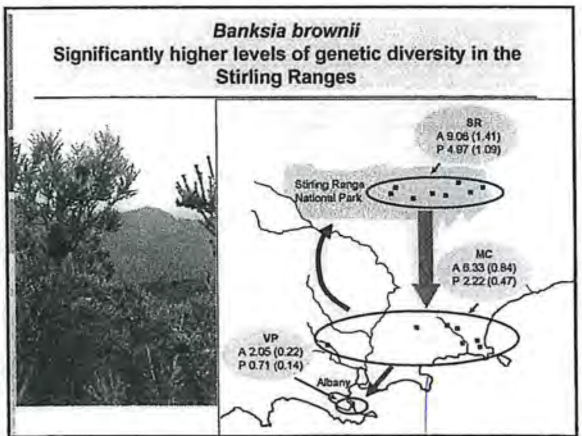
DNA genetic markers



pie charts represent genetic loci.



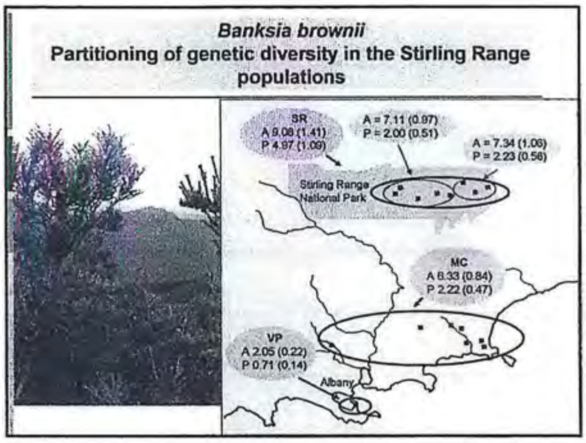
Separated & been different for a long period of time.



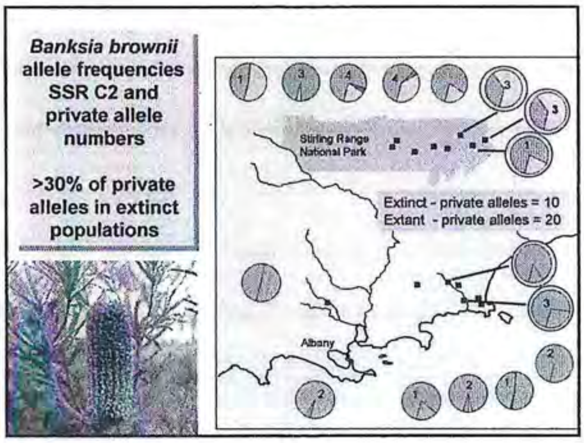
A - allelic richness
P - private allelic richness.

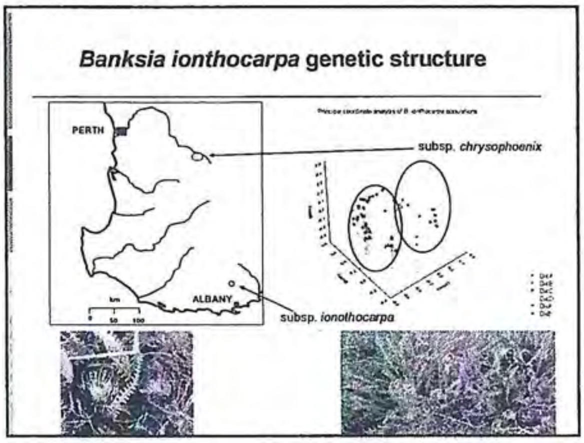
Stirling Range pops either original pops or refugial

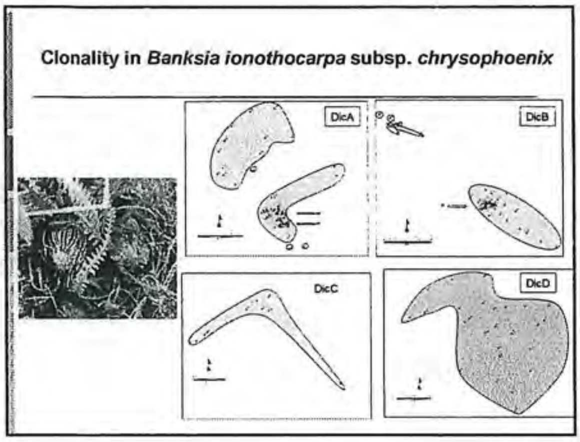
assumed recently derived popn.

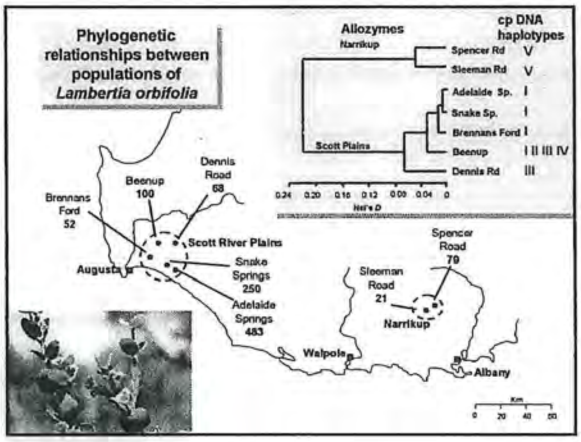


lost a lot of diversity in the extinct popn



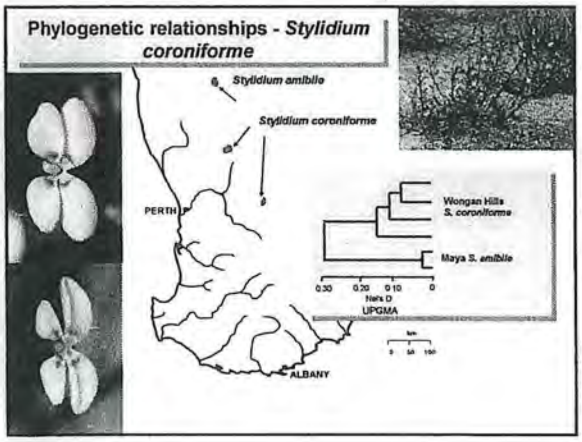






chloroplast DNA you can age the popn

morphological difference is minute!



Conclusions

A significant component of the flora consists of rare and geographically restricted species that:

- Have patchy (fragmented) / disjunct population systems
- Show significant population genetic structure and consist of more than one distinct evolutionary lineage (multiple conservation units, ESU's)
- Are often phylogenetically distant from closely related congeners and many are likely relictual (Tertiary ?)

Implications for Conservation

Significant population genetic and phyleogeographic structure within species will have implications for:

- Germplasm collection strategies:
  - Rare and threatened taxa
  - Vegetation rehabilitation / habitat restoration
- Recovery and translocation of threatened taxa
- Planning habitat restoration (provenance variation)
- The commercial utilisation of local native species
- Conservation of genetic resources and reserve design

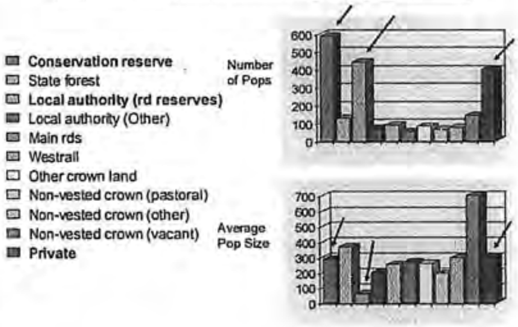
Rarity and threat

Rarity and Threat in SW Australia

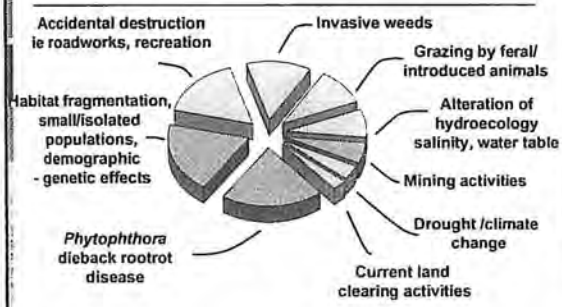
Significant component of the south west flora:

- Occurs in the agricultural region where 75% of native vegetation is cleared
- Exists in remnants of native vegetation of varying size, shape and connectivity
- Occurs In a landscape where disturbance and hydrological regimes have changed
- Occurs In a landscape where exotic weeds and diseases have been introduced and are prevalent

Distribution of Threatened Flora in WA According to Land Tenure



Threats to Declared Rare (Threatened) Flora in Western Australia



Case studies: rarity and threat

- *Dryandra montana*
- *Verticordia fimbrilepis*
- *Lambertia echinata*
- *Phytophthora* dieback
- Habitat fragmentation
- Mining

Banksia montana

- Eastern Stirling Range montane thicket and heath community
- Extremely localised distribution
- Highly susceptible to *Phytophthora*
- Total plants: 46 mature plants, 5 juveniles, 15 seedlings

– have not survived

Verticordia fimbrilepis subsp. fimbrilepis

- Patchy distribution
- Sometimes locally abundant,
- Threatened due to habitat loss/fragmentation
- Threatened by invasive weeds

– roadside popns no recruitment

Lambertia echinata sub sp. _echinata_: conservation status

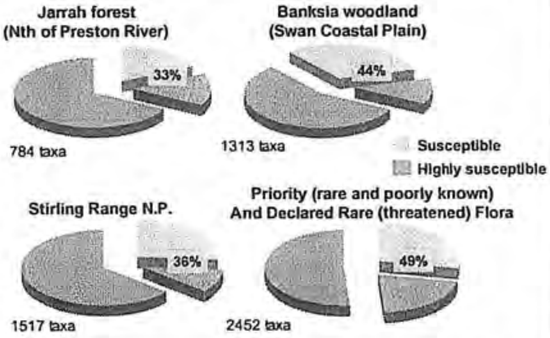
- Highly susceptible to *Phytophthora*
- 3 populations (all infected; all in decline)
- Total 76 plants
- Translocation of 190 plants failed
- Phosphite appears ineffective

Case studies: rarity and threat

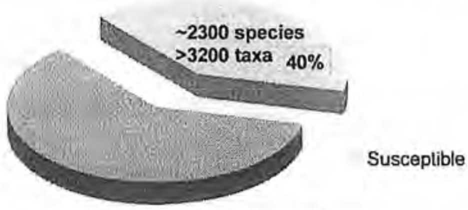
***Phytophthora* dieback**

60% of the Stirling Range National Park impacted by *Phytophthora*

Susceptibility of flora to *Phytophthora*



Susceptibility of flora in the South West Botanical Province



Total in south west Botanical Province
5710 species and > 8,000 taxa

Case studies: rarity and threat

Habitat Fragmentation

Key questions associated with land clearing and habitat fragmentation

- What impact does the loss of species from remnants have on species persistence?
  - Of particular concern is the loss of mutualisms between some plant species and their animal pollinators
  - Or the loss of predators which regulate herbivore populations
- What impact do changes in abiotic environment (e.g. hydrology) have on species persistence?
- What impact do introduced pathogens, feral predators, environmental weeds have on species persistence?
- What impact do changes in the fire regime have on a species persistence?
- **What impact does population size and landscape context have on species persistence**

Habitat fragmentation - key issues

- Habitat fragmentation often results in small, isolated, disturbed populations
  - → fewer pollinators
  - → changed pollinator behaviour
  - → increased inbreeding
  - → reduced reproductive output
- Thresholds of size (100 – 200 plants?) and possibly isolation below which population persistence less likely
- Population density and age are likely to be critical confounding factors – fire
- Gene flow insufficient for "genetic rescue"

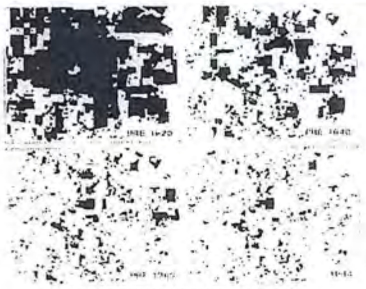
Fewer viable seeds produced.

Large scale habitat destruction and fragmentation effects

Calothamnus quadrifidus, Eucalyptus wandoo

- Inbreeding
- Reproductive output
- Gene flow

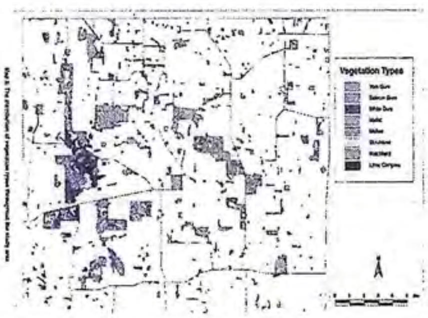
The fragmentation of habitat is a major and pervasive threat to species and ecosystems in south-west Australia

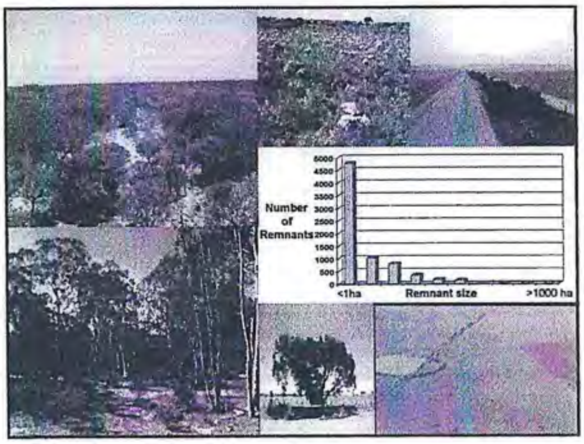


KELLERBERRIN STUDY AREA 1600km²
UNCLEARED LAND

CSIRO work 1990's

Vegetation in Dongolocking area following land clearing





lots of very small remnants.

PROJECT CP10: Genetic and ecological viability of plant populations in remnant vegetation

NSW/ACT
Andrew Young, Linda Broodhurst, David Field,

Western Australia
David Coates, Margaret Byrne, Colin Yates, Carole Elliott, Christopher Gage, Jane Sampson and Richard Hobbs

Calothmnus quadrifidus

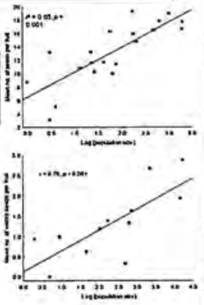
- Long-lived woody shrub
- Bird – mammal pollinated
- Common but patchy distribution in scrub/heath

Recent work suggest 12 different taxa of C. quadrifidus

Calothamnus quadrifidus sites

Pop	Population Location	Landscape context	Pop. size (no. plants)
M	Hill Rd	Disturbed road verge	1
K	Hill Rd	Disturbed road verge	3
T	Parnell Rd	Undisturbed road verge	3
L	Hill Rd	Disturbed road verge	4
J	Dongolocking Rd	Undisturbed road verge	13
N	Tincurren Rd	Disturbed road verge	22
B	Tooliban South Rd/Old Line Rd junction	Large undisturbed remnant	23
D	Dwelyerdine Rd	Small undisturbed remnant	26
G	Dongolocking Rd	Undisturbed road verge	173
S	Wishbone Rd	Disturbed road verge	64
O	Roberts - private property	Small undisturbed remnant	74
C	Toolibin Rd South	Disturbed Road Verge	57
R	Grey Rd , Harrismith Rd junction	Undisturbed road verge	42
P	Temby - private property	Small undisturbed remnant	205
Q	Temby - private property	Small undisturbed remnant	174
H	White Well Rd	Undisturbed road verge	485
E	Dongolocking Nature Reserve A19096	Large undisturbed remnant	645
F	Dongolocking Nature Reserve A19096	Large undisturbed remnant	1938
A	Dongolocking Nature Reserve A19090	Large undisturbed remnant	2014
I	Hurdle Creek Nature Reserve 20070	Large undisturbed remnant	1029

Population size and seeds set in *Calothamnus quadrifidus* and *Eucalyptus wandoo*



As populations get smaller

- Fewer seeds produced per fruit (increased seed abortion)
- Thresholds of size (100-200 plants?)

Increased inbreeding depression

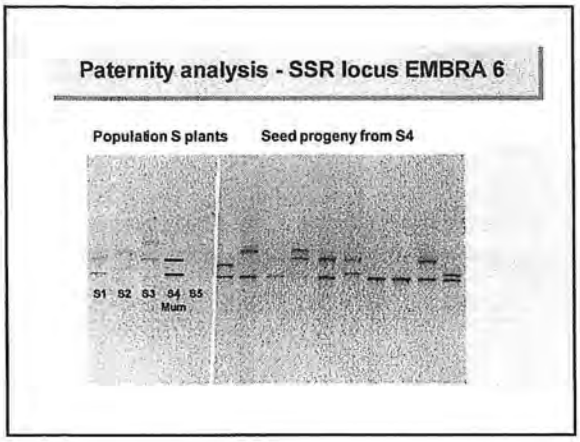
External gene flow (pollen flow) assessed using DNA microsatellites is not sufficient to "genetically rescue populations"

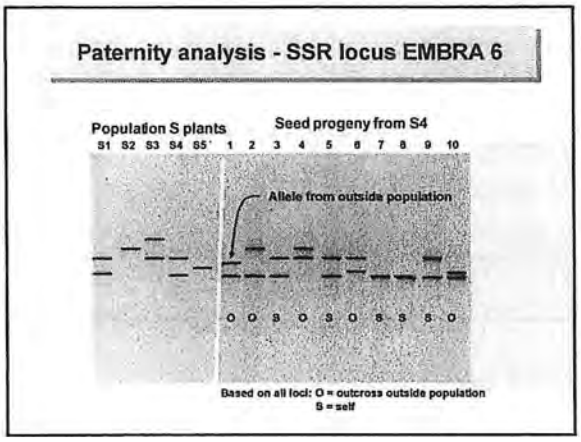
Eucalyptus wandoo

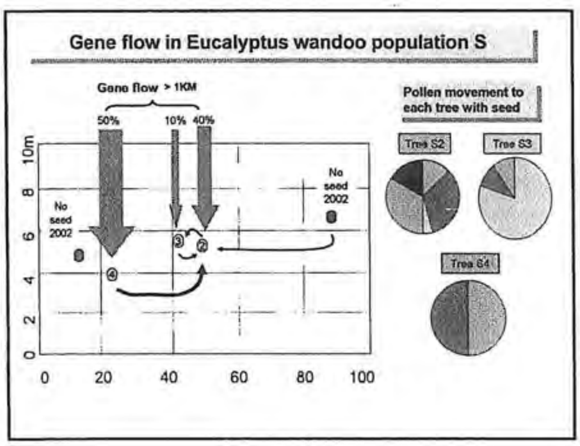
- **Long-lived tree**
- **Insect / bird pollinated**
- **Common but patchy distribution. Key component of woodland remnants.**

Eucalyptus wandoo sites

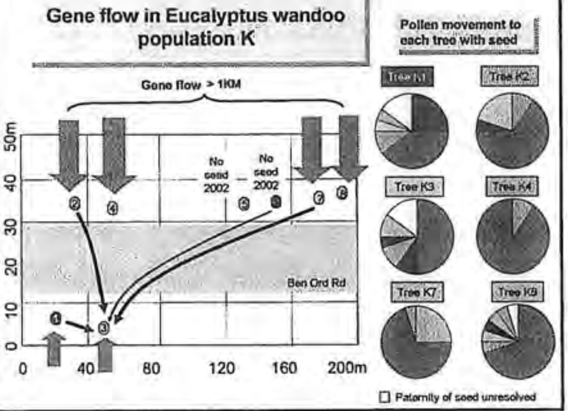
Population	Location	Landscape context	Pop. size (no. plants)
J	Ben Ord Rd	Disturbed road verge	2
L	Springhurst Rd	Disturbed road verge	5
S	Ward Rd	Disturbed road verge	5
K	Ben Ord Rd	Disturbed road verge	9
R	Fox Rd	Disturbed road verge	40
O	Painters Rd	Distrurbed road verge	40
F	Rowells Rd	Distrurbed road verge	47
N	Wickepin Rd - Shire reserve	Undisturbed small remnant	173
C	114 Rd - Shire reserve	Undisturbed small remnant	107
G	Murray Rd/Wishbone Rd	Undisturbed small remnant	493
E	Wickepin Rd - Shire reserve	Undisturbed small remnant	244
Q	Dongolocking Nature Reserve 19083	Undisturbed large remnant	781
M	Nippering Rd - Shire reserve	Disturbed small remnant	1898
B	Dongolocking Rd - Shire reserve	Undisturbed small remnant	805
I	Dwolyerdine Rd - rd reserve	Disturbed small remnant	704
H	Wedin Reserve	Undisturbed large remnant	14732
D	Dongolocking Nature Reserve 19083	Undisturbed large remnant	17556
P	Robinson Rd - Shire reserve	Undisturbed large remnant	2581
A	Dongolocking Rd - Shire reserve	Undisturbed small remnant	2315


Paternity analysis - SSR locus EMBRA 6
Population S plants
Seed progeny from S4
S1 S2 S3 S4 S5
Mum


Paternity analysis - SSR locus EMBRA 6
Population S plants
Seed progeny from S4
S1 S2 S3 S4 S5 1 2 3 4 5 6 7 8 9 10
Allele from outside population
O O S O S O S S S O
Based on all loci: O = outcross outside population
S = self


Gene flow in Eucalyptus wandoo population S
Gene flow > 1KM
50%
10% 40%
No seed 2002
No seed 2002
Pollen movement to each tree with seed
Tree S2
Tree S3
Tree S4
10m
8
6
4
2
0
0 20 40 60 80 100

Gene flow in Eucalyptus wandoo population K



Key issues

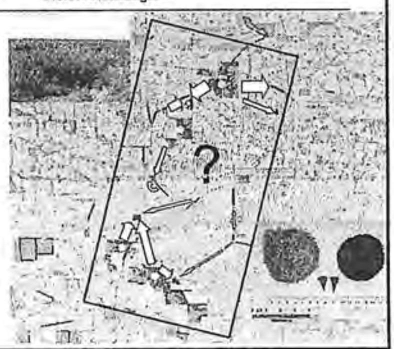
- Thresholds of size (100 – 200 plants?) and possibly isolation below which population persistence is unlikely
- Small and or isolated populations / remnants are less suitable as sources of seed for re- vegetation
- High levels of gene flow in *E. wandoo* and *C. quadrifidus* despite fragmentation- but is genetic rescue possible?
- Paddock trees and small vegetation remnants are likely to be critical for gene flow in the landscape but may not themselves be viable

Gene Flow in a Highly Fragmented Landscape

Tanya Llorens, David Coates, Margaret Byrne, Colin Yates
Heidi Nistelberger

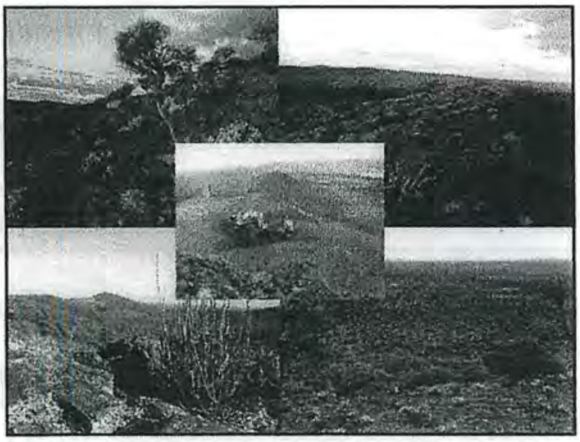
Quantify patterns of pollen movement by tracking gene flow using DNA markers

- How important are small and large remnants as pollen sources?
- What influence is landscape configuration having on connectedness between remnants?



Case studies: rarity and threat

Mining



BJF

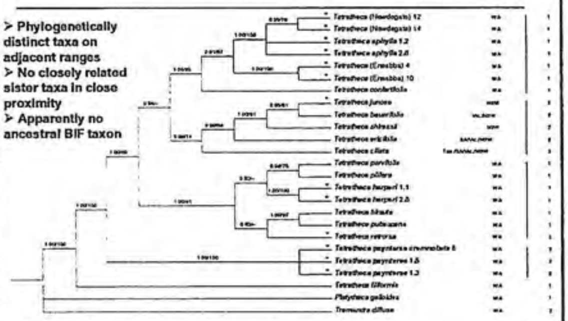
Windarling

Tetratheca species conservation status:

- Each of the 7 taxa exist as 1 or a few geographically restricted populations
- 6 taxa in areas targeted for mining or already on mine sites
- T. *paynterae* subsp. *paynterae* – 30% of population removed for mining

Phylogenetic relationships among *Tetratheca* species

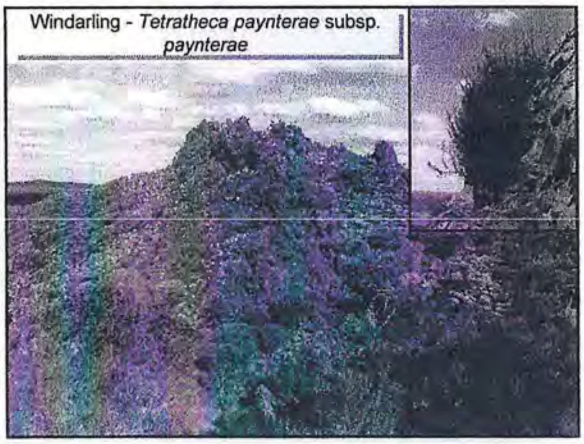
- Phylogenetically distinct taxa on adjacent ranges
- No closely related sister taxa in close proximity
- Apparently no ancestral BIF taxon



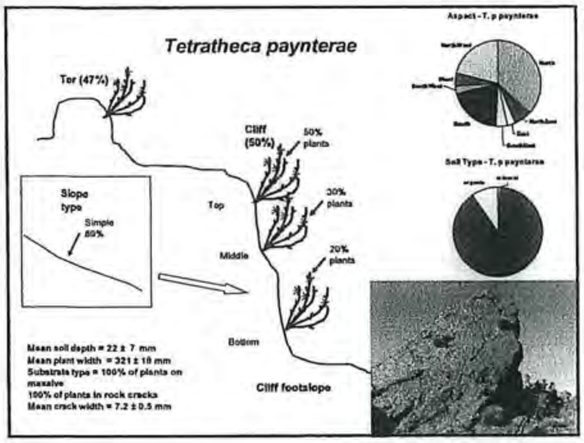
Butcher R et al. (2007). Australian Systematic Botany. 20, 126-138

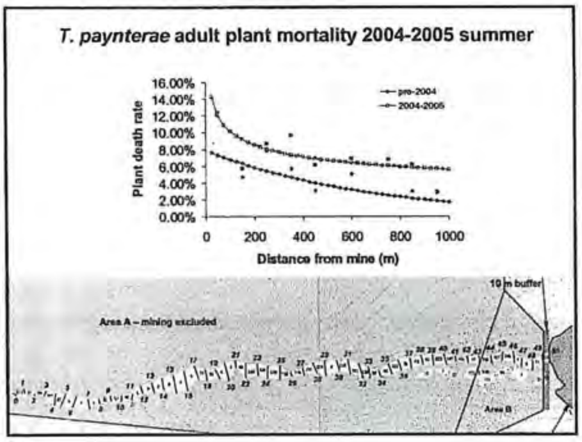
Very ancient sp.

Windarling - *Tetratheca paynterae* subsp. *paynterae*

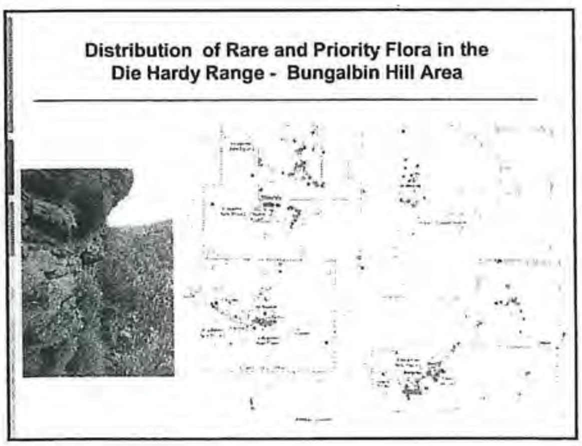


2060 plants removed from a population of 7000 in 2004
Possibility of a further 20% of the population being removed with expansion of the mine



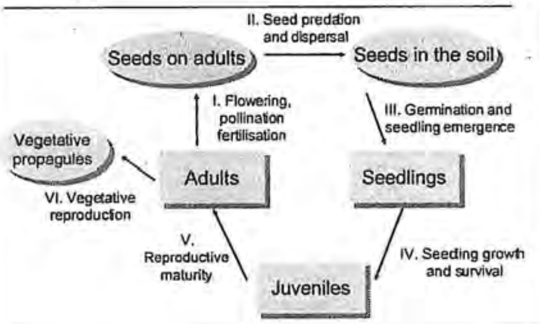


motality distance from the mine



Ecological studies and recovery

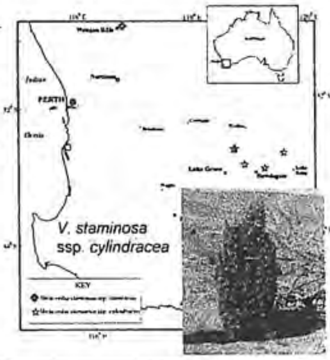
Stages and transitions in the plant life cycle



Spatial distribution

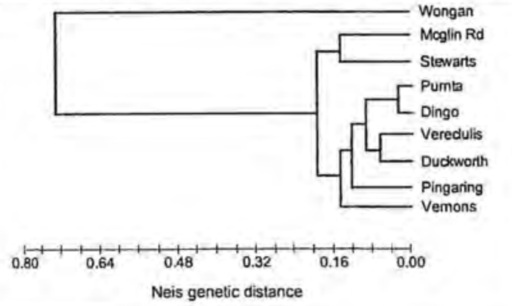
V. staminosa ssp. *staminosa*

Granite outcrop endemic with disjunct distribution c. 400km

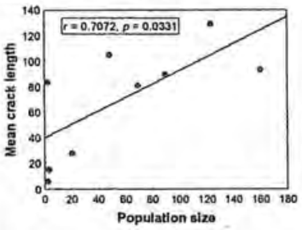


Temporal persistence

Phylogenetic relationships among populations of Verticordia staminosa

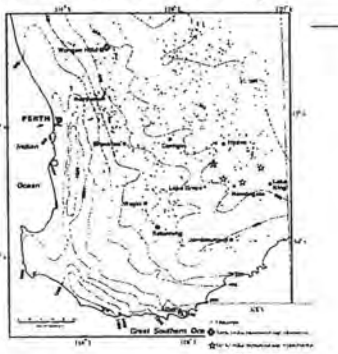


Taxon ecology - habitat specificity within outcrops



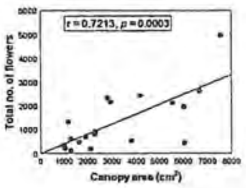
V. staminosa *is very habitat specific, being restricted to growing within cracks in the granite*

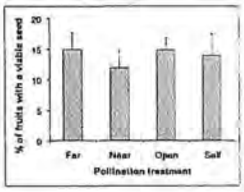
Taxon ecology- habitat specificity, location of granite outcrops across the landscape



Reproductive biology

- Bird pollinated, but introduced honeybee now the most frequent flower visitor
- Flowers abundantly
- Self-compatible

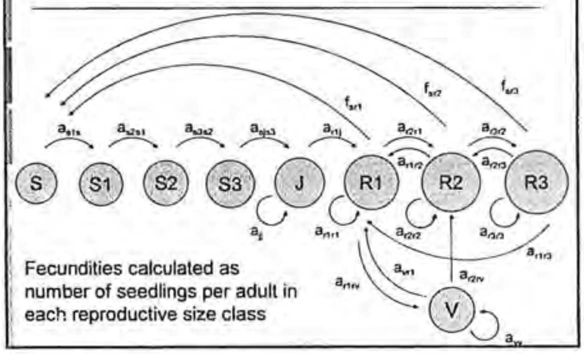




Environmental stochasticity and population dynamics

- Rainfall variation (161-675 mm, mean 392 mm)
- Fire (two fires in 20 years on a granite complex to the north-east, receiving 90 mm less rainfall)
- We investigated the influence of both sources of environmental stochasticity on population dynamics and viability with a stage structured transition matrix model built using the software RAMAS metapop v.5

Conceptual stage structured model of life cycle pathways for *V. staminosa* ssp. *staminosa*



Fecundities calculated as number of seedlings per adult in each reproductive size class

Conclusions

The results concur with the hypothesis that the interaction of environmental history and population biology are more important than ecological factors such as habitat specificity and intrinsic characters like reproductive biology for understanding rarity in *V. staminosa* ssp. *staminosa*

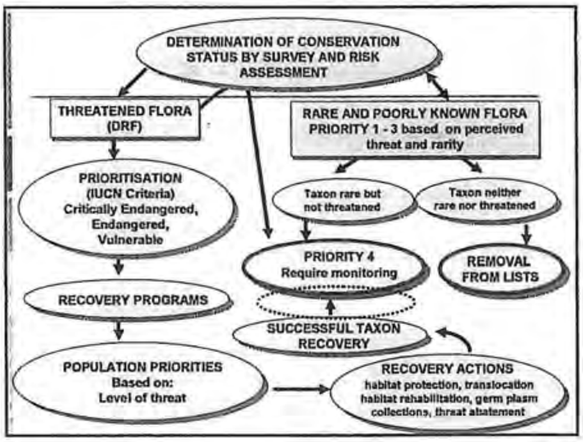
Conservation implications

- Land-tenure and need to protect granite rock habitats
- Climate models predict for a range of emission scenarios that winter wet season rainfall will decline across most of southwestern Australia
- Population Viability modelling indicates that under increased aridity the population will decline
- If continued monitoring shows an increase in adult mortality we should be concerned – increased incidence of fire maybe particularly important in this respect

Recovery of threatened flora

Threatened Flora recovery

- Flora recovery teams
- Interim Recovery Plans
- Research, experimental management
- Full Recovery Plans
- Regional Management Programs
- DEC programs, eg Threatened Flora Seed Centre, databases, re-introductions / translocations
- Other agencies – BGPA



Threatened Flora Seed Centre

- Established 1993 to focus on *Phytophthora* threatened taxa
- 1382 taxa - 2283 collections
- 283 threatened taxa
- 647 taxa listed as rare and poorly known (Priority listed taxa)

Translocations of Critically Endangered Flora in Western Australia

DEC has 55 translocations underway



Global Strategy for Plant Conservation Target 8 for 2010 achieved

70% (60% required) of WA threatened flora in *ex situ* conservation and 13% (10% required) used in reintroduction



Western Australian flora and major conservation issues

- Manage and ameliorate major threatening processes
  - Habitat fragmentation – small population effects
  - Altered hydrological regimes
  - *Phytophthora* dieback
  - Inappropriate fire regimes
  - Invasive weeds
- Understand the interactions between small population effects, fire regimes and weed invasion/competition
  - Small remnant management
  - Rangelands management
- Taxonomic knowledge of the flora
  - 1539 taxa (13%) not formally named
  - 458 taxa (18.6%) DRF and Priority Flora not formally named
  - 1903 taxa are rare but conservation status not known
  - Very poor knowledge of non vascular flora (2033 out of 100,000+)

Strategic Plan 2008-2017

Vision: Sound science supporting the conservation of WA's biodiversity

- Internal (Science Div.) workshops
- Service Directors
- External input:
  - Dr Steve Morton CSIRO
  - Prof. Richard Hobbs Murdoch Uni
  - Prof. Alistar Robertson UWA
- Other planning processes:
  - State Biodiversity Conservation Strategy
  - Forest Management Plan
  - Regional Nature Conservation Service Plans
  - National priorities

Challenges & Opportunities

- Grow permanent staff expertise to meet future challenges e.g. Climate Change
- Cost pressures – budget and recruiting issues
- 'Brain drain' as skilled and experienced staff leave the workforce or are attracted to better opportunities
- Grow partnerships and alternative sources of revenue
- Biodiversity Futures Major Research Facility
- Grow partnerships with other Divisions such as Regional Services and Nature Conservation through avenues such as adaptive management projects
- Building/maintaining a science presence in 'remote' areas
- Improve publication performance
- Improve communication/uptake/impact of science
- Improve accommodation & collocation of metro centres

Department of
Environment and Conservation

Our environment, our future

Flora Conservation Course

Threatened Flora in Western Australia

Prepared by:

Ken Atkins, DEC, Kensington
Melanie Harding,DEC, Kensington

Prepared for:

Flora Conservation Course

Version 4.0 (January 2009)

1 Western Australian Flora

Western Australia has a rich flora, with some 13,000 vascular plant species, about 10,000 of which are formally named. This is about half of the total Australian flora. Some areas are particularly rich, for example, over 800 species are known from the Lesueur area near Jurien Bay, over 1,200 from the Stirling Range National Park, and about 1,400 species from the Fitzgerald River National Park. These three areas are the most species rich, and represent over a quarter of the flora of Western Australia.

On an international scale, by comparison the flora of Western Australia is ten times the total British vascular flora of 1200, and represents some 4.8% of the estimated world vascular flora of 250,000 species.

The Western Australian flora is also unique, with the majority of species being endemic, that is, found nowhere else in the world. 79% of the 6,000 species in the south-west, for example, are endemic to Western Australia.

Part of the reason for the high level of species diversity and uniqueness, especially in the south west agricultural region, is because this landform is extremely old, and has largely weathered in-situ. This has meant that the soils and habitats in the region tend to be a mosaic, and the flora in them have evolved in isolation over a very long time period. The result is a complex series of different evolutionary paths across the landscape.

2 Threatened Flora

Western Australia also has a large number of plant species that are threatened, or potentially threatened, with becoming extinct. A third of Australia's total of threatened plant species are from Western Australia, while the proportion rises to 46% if rare and poorly known species are included.

There are many reasons for the occurrence of threatened flora. These may relate to natural or evolutionary factors, or to artificial influences resulting from human activity.

Species that are very rare may be threatened as a consequence of their low numbers, that is, they may become extinct through the chance loss of some individuals. Species may be naturally rare because they are dependant on specific, limited habitats, or because they are part of an evolutionary process: either newly evolving species (it is estimated that 40% of WA's flora has evolved from hybridisation), or species that are naturally declining through changed environmental conditions (e.g. relict Gondwanan flora).

The clearing or degrading of bushland is a major threatening process - referred to as habitat loss. Not only does this threaten existing populations, but it also limits the opportunities for the establishment or expansion of populations. Degradation processes include grazing, fertilizer and herbicide drift, weed competition, inappropriate fire regimes and the introduction of pests and diseases. One of the most significant threats to species and habitats is *Phytophthora* dieback.

Given the great species and habitat diversity of the southwest agricultural region, it is not surprising to find that many of the threatened species in this State are from this region. This can be seen from the table of comparison of threatened, poorly known and rare species between DEC regions (Attachment 1), whereby the Midwest, Wheatbelt and South Coast Regions account for nearly three quarters of the species. The State map of the distribution of the threatened flora (Attachment 2) shows that the concentration of populations is in the agricultural regions of the wheatbelt and the western coastal plain - both extensively cleared landscapes.

3 Roadside Vegetation

Uncleared roadverges represent tracts across the landscape of the original vegetation. In areas that have been extensively cleared, as in the wheatbelt, these vegetation strips represent significant areas of remnant vegetation. More importantly they contain a random selection of vegetation types, whereas remnants on adjoining lands tend to be more selective, with specific vegetation types associated with arable soils in particular being poorly conserved.

Road verges hence have a proportionately higher number of restricted habitats and rare species of flora. The narrowness of many of these road reserves, coupled with the road maintenance activities to which they are subjected also means that many of these rare species are also threatened.

A quarter of threatened flora populations in Western Australia are found on road verges, with over three quarters of these being along roads managed by local authorities, the remainder being along main roads. Population sizes along the local authority-managed roads tend to be several-fold smaller than those found on other land tenures, including main roads, which demonstrates the difficult task in managing rare flora on these roadsides, where a large number of small populations are involved.

4 Declared Rare Flora

Existing legislation uses the term "rare flora" for threatened flora. It is necessary to continue to use the term "Declared Rare Flora" (or DRF) when quoting the legislation until it is changed, but the term is used for species that are threatened, rather than just rare in numbers. DEC Policy Statement No 9 (Conservation of Threatened Flora in the Wild) lists the policies and strategies for the management of Declared Rare Flora.

5 Legislation

Rare flora is defined in subsection 23F(1) of the *Wildlife Conservation Act 1950* as "flora for the time being declared to be rare flora for the purposes of this section." Further clarification is provided in subsection 23F(2):

> "Where the Minister is of opinion that any class or description of protected flora is likely to become extinct or is rare or otherwise in need of special protection, he may, by notice published in the Government Gazette declare that class or description of flora to be rare flora for the purposes of this section throughout the State".

6 The Schedule of Declared Rare Flora

The Schedule (list) of Declared Rare Flora is reviewed annually.

Plants which are protected flora declared under the Wildlife Conservation Act may be recommended for gazettal as Declared Rare Flora if they satisfy the following criteria:

i) The taxon (species, subspecies, variety) is well-defined, readily identified and represented by a voucher specimen in a State or National Herbarium. It need not necessarily be formally described under conventions in the International Code of Botanical Nomenclature, but such a description is preferred and should be undertaken as soon as possible after listing on the schedule.

ii) Have been searched for thoroughly in the wild by competent botanists during the past five years in most likely habitats, according to guidelines approved by the Director General of DEC.

iii) Searches have established that the plant in the wild is either:

a) rare;

<u>or</u>

b) in danger of extinction (including presumed extinct);

<u>or</u>

c) deemed to be threatened and in need of special protection.

(Plants which occur on land reserved for nature conservation may be considered less in need of special protection than those on land designated for other purposes).

<u>or</u>

d) presumed extinct.

iv) In the case of hybrids, or suspected hybrids, the following criteria must also be satisfied:

a) they must be a distinct entity, that is, the progeny are consistent within the agreed taxonomic limits for that taxon group;

b) they must be [capable of being] self perpetuating, that is, not reliant on the parent stock for replacement; and

c) they are the product of a natural event, that is, both parents are naturally occurring and cross fertilisation was by natural means.

That status of a rare plant in cultivation has no bearing on this matter. The legislation refers only to the status of plants in the wild, but this includes plants established in the wild as part of an approved recovery (translocation) program.

Plants may also be deleted from the schedule of Declared Rare Flora once they are determined to no longer meet the requirements for listing.

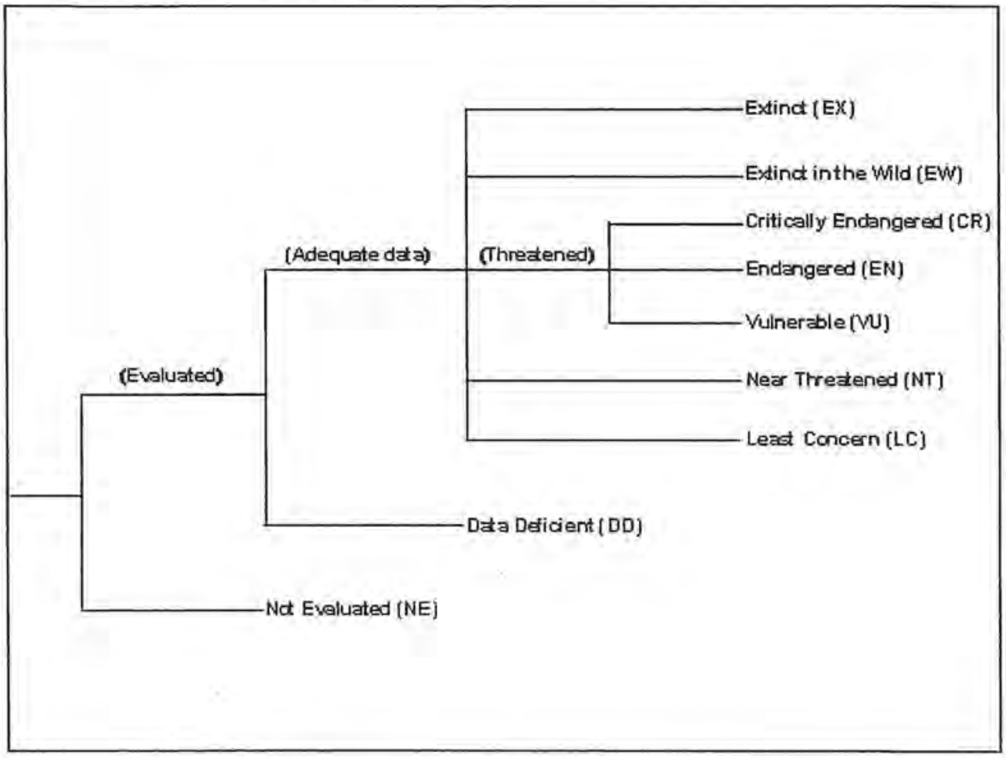
There are currently (as Gazetted on 5 August 2008 in the 2008(2) schedule) 391 extant, plus 13 presumed extinct, taxa of Declared Rare Flora. Taxa are managed at infraspecific levels where these exist, ie at subspecies or variety level.

7 Ranking Declared Rare Flora

With the large number of Declared Rare Flora, priorities need to be set for undertaking management actions, and to assist in assessing the relative impact of threats to the flora, such as where land development is proposed.

The International Union for the Conservation of Nature (IUCN, or World Conservation Union) has developed a set of criteria and guidelines for assigning species into conservation categories, with specific categories for threatened species – commonly known as the IUCN Red List of Threatened Species.

The IUCN categories, and their relationship, are shown below:



DEC has adopted the IUCN classification system for threatened species (Declared Rare Flora) (refer to DEC's Policy Statement No 50 - Setting Priorities for the Conservation of Western Australia's Threatened Flora and Fauna), and all listed extant threatened species are ranked as either Critically Endangered, Endangered or Vulnerable, depending on their risk of extinction. The guidelines and criteria for ranking threatened species is available on the IUCN website at: http://www.iucnredlist.org/info/categories_criteria2001

8 "Taking" Declared Rare Flora

In the Wildlife Conservation Act (subsection 6(1)) the following definition is given:

> ""to take" in relation to any flora includes to gather, pluck, cut, pull up, destroy, dig up, remove or injure the flora or to cause or permit the same to be done by any means;"

Thus, taking Declared Rare Flora would include not only direct injury or destruction by human hand or machine but such activities as allowing stock to graze on the flora, introducing pathogens that attack it, altering soil moisture or its inundation regime, allowing air pollutants to harm foliage etc.

Declared Rare Flora is afforded special protection under the Wildlife Conservation Act (section 23F(3)), whereby rare flora may not be taken by any person unless that person has the written consent of the Minister (for the Environment). This applies to any land, and to any person irrespective of whether the person has a licence to take protected flora or has the land manager's permission. This provision is also binding on the Crown, and hence all Government officers also require Ministerial permission to take rare flora, either by direct or indirect means.

In the case of declared rare plants which need fire or disturbance for regeneration, burning or disturbance at an appropriate time may not adversely affect the survival of the population. However, if existing plants would be injured, it constitutes "taking" under the Act. Therefore, Ministerial approval is required prior to causing a disturbance which affects any species of rare flora, whether it be positive management or otherwise. This also includes taking herbarium voucher specimens and seed for regeneration or storage.

The Department of Environment and Conservation has statutory responsibilities for rare flora conservation. This is a major commitment because, as referred above:

i) Western Australia has a flora that is exceptionally rich in localised and rare endemic plant species. Moreover, areas where rare species are concentrated coincide predominantly with the wheatbelt and other areas where there has been extensive clearing or modification of the native flora.

ii) Section 23F of the Wildlife Conservation Act prohibits the taking (injury or destruction) of Declared Rare Flora by any person on any land throughout the State without the consent in writing of the Minister. A breach of this provision may lead to a fine of up to $10,000. The flora provisions of the Act are binding on the Crown.

iii) The Act prescribes that Declared Rare Flora be protected on all categories of land throughout the State, and hence it presence may interfere with other land management objectives.

9 Priority Flora

In addition to the schedule of Declared Rare Flora, DEC maintains a supplementary listing referred to as the Priority Flora List. This lists those flora which may be rare or threatened but for which there is insufficient survey data available to accurately determine their true status, and those taxa which have been determined as being rare, but are currently not threatened. 2,429 taxa were listed as priority flora in September 2008.

The Priority Flora are ordered according to the perceived urgency for further survey to determine their conservation status.

The Priority List assigns top priority for survey to those plants whose known populations are few and on land under threat (Priority 1). Second are taxa with few populations known, and which occur on lands considered secure for conservation (eg. nature reserves, national parks, water reserves - Priority 2). Priority 3 taxa have several known populations, or the taxon is widely distributed, and the taxon is deemed to be not under immediate threat. And lastly, taxa that have been adequately surveyed and found to be secure but require monitoring to check that their conservation status doesn't change are assigned Priority 4. Full definitions are provided in Attachment 3.

Priority flora do not have the same level of protection as Declared Rare Flora, but should be managed in a similar manner until their status has been confirmed as being not rare or threatened.

10 The Need to Conserve Rare Flora

Western Australia's rare flora needs to be conserved for many reasons under the broad headings of ultruism, aesthetics, economics and ecology.

Altruistically we should conserve all species of flora because they are discrete entities and deserve to persist. Such an argument, however, depends solely on the beliefs of the individual.

From an aesthetical point of view, species conservation means that the public is able to keep seeing the species, and enjoying the sight in itself, and the total landscape effect. Again beauty is in the eye of the beholder.

In an economical sense, rare flora represent a largely untouched resource with unknown potential. The value of most of our species of rare flora (and more common species) for drugs and medicines, foods, genetic additives, horticultural species etc is unknown. This resource should therefore be maintained for its future potential.

The role that individual species play in maintaining ecosystem processes, and the integrity of ecosystems, is largely unknown. The role that rare flora species play in maintaining the health and function of natural areas thus cannot be assumed, and such species should be maintained in their natural areas as part of good vegetation management practice to maximise the resilience and functionality of these areas.

Species abundance changes through time. Rare species may either be declining towards extinction, or they may be in early developmental stages and could eventually become relatively common as climatic changes occur. Thus the rare flora of today may be essential elements of future vegetation structures.

Such vegetation - climatic changes normally occur over extended periods, measured in geological time. With current unnatural global climatic changes being predicted, however, such vegetation changes will need to occur at a rate faster than can be naturally accommodated by speciation. Thus there will be even greater selection pressure on existing species to maintain vegetation compositions. Rare species will have as much chance of being able to persist under new climatic regimes as more common species. It is therefore imperative in areas of remnant vegetation such as in the wheatbelt, and along isolated road reserves, that options for future vegetation development be maintained by retaining the current diversity of species.

11 Wildlife Management Programs

DEC's Policy Statement No 44 deals with Wildlife Management Programs. Such Programs are prepared for the management of individual species or groups of species. For threatened flora management, two types of Wildlife Management Programs are prepared:

> DEC Region or District summary status programs which document the current population status of the species in an area, and recommend management and research actions. These have been prepared for all Regions and Districts in the South West Land Division; and
>
> Species Recovery Plans (and Interim Wildlife Management Guidelines or Interim Recovery Plans) which document the current knowledge for a species and provide detailed strategies for the management or recovery of the species. Full Recovery Plans have also been prepared for selected taxa, ie *Acacia anomala*, *Banksia cuneata*, *Eucalyptus rhodantha* and *Stylidium coroniforme*.

According to DEC Policy, Interim Recovery Plans are prepared within one year of ranking for all taxa listed as Critically Endangered.

12 Management Strategies

Many remnants are on lands set aside for purposes other than flora conservation. Flora conservation can thus be a potential inhibition to the normal operation of that land, whether it be a road reserve, farmland, urban area or other land purpose. Good planning and land management can however achieve flora conservation without inhibiting the other uses, and at the same time provide soil conservation, aesthetics and other valuable benefits. Current Main Roads practices are a good example of this.

Rare flora management on road verges presents some specific problems. These problems are related to the purpose to which these reserves are set aside, and to the constraints presented by their size and shape. Such management constraints are also found with many other vegetation remnants.

The shape and size of many remnants results in an insidious, but equally threatening, impact on the flora as does inappropriate landuse practices. Weeds, fertilizer, herbicides, feral animals and fire are some of the major influences on remnants, over which the land manager may have limited control.

Again the use of appropriate procedures to deal with incursions or reduce the incidence of incursions from adjoining lands will reduce their impact.

Weeds and feral animals are perhaps the more difficult management problems in terms of preventing incursions and treating areas after colonization has occurred. Methods are being developed for managing these problems, but there is still a long way to go in developing management techniques that are sensitive to the environment that is being protected.

Some management notes are:

Grazing - fence areas off.

Fire - ensure fire frequency and seasonality is ecologically based, that is, is not too frequent to promote exotic weeds, and allows the native plants to set seed etc. Areas of native bush do not need to be regularly 'cleaned up'.

Rabbits - use of explosives to destroy warrens without damaging the vegetation.

Weeds - minimise disturbance (including fire) and fertilizer drift to reduce weed growth. Use of selective herbicides that do not affect the native flora. Careful use of sprays when treating encroaching weeds such that the native vegetation and rare flora is not affected.

Accidental destruction - mark areas, especially where works are undertaken, e.g. roadsides or firebreaks. Rationalise, and block off, access tracks.

Exposure - maintain a healthy area of bush, especially around the rare flora, to provide protection and ensure a continuation of the remnant.

Fungal pathogens (dieback) - restrict access, promote hygiene, phosphite application.

One specific aspect of threatened flora conservation and recovery is the collection and storage of propagating material, the propagation of such material, and the establishment of new populations in the wild, or enhancement of existing populations. This is addressed in DEC's Policy Statement No 29 - Translocation Threatened Flora and Fauna. DEC collaborates with the Botanic Gardens and Parks Authority in this area. Research is being undertaken into storage techniques (including cryostorage), and methods of propagating some of the species. The DEC Threatened Flora Seed Centre also maintains a store of threatened flora seed for long term ex-situ conservation, and for use in translocation work.

Management strategies being undertaken by DEC also include the searching for, documentation and monitoring of rare flora populations; the maintenance of a rare flora database; land acquisition; and research into the biology, ecology and management of rare flora.

13 Confidentiality

The precise location of rare flora populations is kept confidential. This is designed to protect the plants from illicit taking, and from damage either to the plants or the habitat by people wishing to view them. Rare flora locations on private property especially are treated confidentially to safeguard the rights of the property owner who might otherwise be subject to enquires from interested individuals.

Locations of rare flora are provided where this is deemed to be in the better interests of the plants. Thus, for example, land owners/managers, mining tenement holders, local authorities etc. are informed of rare flora populations on, or adjacent, to their operations. Requests for rare flora locality data should be directed to DEC so that the reason can be vetted, and a record kept of such requests.

SPECIES AND COMMUNITIES BRANCH AND THREATENED FLORA CONSERVATION

Version: 2009

Department of Environment and Conservation

AIM OF THE COURSE

To provide Departmental staff with knowledge of the Department's Species and Communities Branch, and threatened flora legislation and conservation

CONTENT

- Role of Species and Communities Branch
- Key Definitions
- Flora conservation legislation
- Declared Rare Flora
- Threatened Species Scientific Committee
- Applications to 'take'
- Ranking of threatened flora
- Priority Flora
- Flora Conservation and Recovery

LEARNING OUTCOMES

1. Outline the key roles and responsibilities of Species and Communities Branch
2. Demonstrate an understanding of Declared Rare Flora, its legal protection, and the administrative process associated with applications to take Declared Rare Flora

LEARNING OUTCOMES (2)

3. Explain the IUCN ranking system
4. Demonstrate an understanding of Priority Flora
5. Outline the key processes involved in the conservation and management of threatened flora

SPECIES AND COMMUNITIES BRANCH ROLES:

- Legislation development & advice
- Policy development & advice
- Management and licensing advice
- Species & community recovery planning
- Operation of biodiversity conservation programs
- Maintenance of data and information
- Processing DRF permits

SPECIES AND COMMUNITIES BRANCH ROLES:

- Flora Management

Threatened flora - listing process
- ranking process
- interim recovery plans
- management support
- permits to take
- databases

Other flora - general flora management advice
- industry management plans
- licensing advice

SPECIES AND COMMUNITIES BRANCH ROLES:

- Fauna Management

Threatened fauna - listing process
- ranking process
- interim recovery plans
- management support
- licences to take
- Western Shield
- databases

western shield

Other Fauna – general flora management advice
- industry management plans
- licensing advice

SPECIES AND COMMUNITIES BRANCH ROLES:

- Threatened ecological communities
  - listing process
  - ranking process
  - interim recovery plans
  - management support
  - database

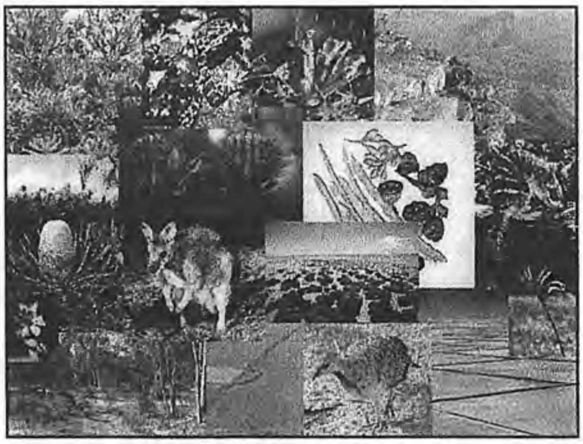
SPECIES AND COMMUNITIES BRANCH ROLES: 5

- Wetlands Conservation

  - Ramsar
  - classification
  - assessment
  - EIA advice
  - management support
  - database

SPECIES AND COMMUNITIES BRANCH ROLES: 6

- Off-reserve Conservation
  - Land for Wildlife
  - Nature Conservation Covenants
  - Roadside Conservation Committee
  - Incentive Programs



THREATENED FLORA CONSERVATION

THREATENED FLORA

Three levels of formal protection:

International – CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora)

Commonwealth – EPBC Act 1999

State – Wildlife Conservation Act 1950

Wildlife Conservation Act 1950 - 1979

'Protected Flora' is all W.A. native flora in:

- Spermatophyta (flowering, conifers, cycads)
- Pteridophyta (ferns, fern allies)
- Bryophyta (mosses, liverworts)
- Thallophyta (algae, fungi, lichens)

'To take' flora includes both direct (gather, pluck, cut, destroy, dig up or remove) and indirect (to cause taking) means.

Wildlife Conservation Act

Section (S23F): 'Rare Flora'
is flora declared by the Minister to be
- likely to become extinct;
- is rare; or
- otherwise needs special protection

'Declared Rare Flora' = 'Threatened Flora'

Only applies to natural or recovery popns.

Listed as 'Extant' and 'Presumed Extinct'

THREATENED SPECIES SCIENTIFIC COMMITTEE (TSSC)

- Ministerially appointed
- appointment by expertise (incl. DEC, BGPA, Museum and university)
- meets at least annually
- recommends additions, deletions and rank
- recommends specific management actions
- recommendations endorsed by DEC Corp Exec & Cons Commission, & referred to Minister for approval

DEPARTMENTAL POLICY STATEMENTS

No 9 - Conservation of Threatened Flora in the Wild

No 29 - Translocation of Threatened Flora and Fauna

No 44 - Wildlife Management Programs

No 50 - Setting Priorities for the Conservation of Western Australia's Threatened Flora and Fauna

CALM Policy 9 – Conservation of Threatened Flora in the Wild

To be replaced with the draft Policy 9 - Conserving Threatened Species and Ecological Communities, that incorporates other existing Policies

A species [of flora] may be recommended for declaration as threatened flora by the Western Australian Threatened Species Scientific Committee if it satisfies the following criteria:

(i) The species occurs naturally in Western Australia, is well defined and represented by a voucher specimen in a State or National Herbarium. While it need not necessarily be formally described under conventions in the International Code of Botanical Nomenclature, such a description is preferred and should be undertaken as soon as possible after listing on the schedule.

(ii) It has been established that the species in the wild:

a) is extinct, ie, there is no reasonable doubt that the last individual has died, or

b) meets criteria for listing as threatened in the current version of *IUCN Red List Categories Prepared by the IUCN Species Survival Commission.*

(iii) In the case of hybrids, or suspected hybrids, the following criteria must also be satisfied:

(a) they must be a distinct entity, that is, the progeny are consistent within the agreed taxonomic limits for that taxon group;

(b) they must be capable of self perpetuation, that is, not reliant on the parent stock for replacement; and

(c) they must be the product of a natural event, that is, both parents are naturally occurring and cross fertilisation was by natural means.

Wildlife Conservation Act 1950

Wildlife Conservation (Rare Flora) Notice 2008(2)

Made by the Minister for the Environment under section 23F(2) of the Act.

1. **Citation**

   This notice may be cited as the *Wildlife Conservation (Rare Flora) Notice 2008(2)*.

2. **Interpretation**

   In this notice —

   "extant" means known to be living in a wild state;

   "protected flora" means any flora belonging to the classes of flora declared by the Minister under section 6 of the Act to be protected flora by notice published in the *Gazette* 9 October 1987, at p. 3855;

   "taxon" includes any taxon that is described by a genus name and any other name or description.

   Note: The plural form of "taxon" is "taxa".

3. **Rare flora**

Subject to clause 4, protected flora —

(a) specified in Schedule 1, being taxa that are extant and considered likely to become extinct or rare and therefore in need of special protection; and

(b) specified in Schedule 2, being taxa that are presumed to be extinct in the wild and therefore in need of special protection,

are declared to be rare flora for the purposes of section 23F of the Act throughout the State.

4. **Application**

Clause 3 does not apply to those plants of a taxon of protected flora specified in Schedule 1 or 2 that have been planted for any purpose other than such plants that have been planted for the purpose of conservation of that taxon and in accordance with approval given by the Director General.

5. **Revocation**

The *Wildlife Conservation (Rare Flora) Notice 2008* is revoked.

Schedule 1 — Extant taxa

[cl. 3(a)]

Division 1 — Spermatophyta (flowering plants, conifers and cycads)

1. *Acacia anomala*
2. *Acacia aphylla*
3. *Acacia aprica*
4. *Acacia aristulata*
5. *Acacia ataxiphylla* subsp. *magna*
6. *Acacia auratiflora*
7. *Acacia awestoniana*
8. *Acacia brachypoda*
9. *Acacia caesariata*
10. *Acacia chapmanii* subsp. *australis*
11. *Acacia cochlocarpa* subsp. *cochlocarpa*
12. *Acacia cochlocarpa* subsp. *velutinosa*
13. *Acacia denticulosa*
14. *Acacia depressa*
15. *Acacia forrestiana*
16. *Acacia imitans*
17. *Acacia insolita* subsp. *recurva*
18. *Acacia lanuginophylla*
19. *Acacia leptalea*
20. *Acacia lobulata*
21. *Acacia pharangites*
22. *Acacia pygmaea*
23. *Acacia recurvata*

137. *Darwinia* sp. Stirling Range (G. J. Keighery 5732)
168. *Eremophila koobabiensis* ms

(i) The species occurs naturally in Western Australia, is well defined and represented by a voucher specimen in a State or National Herbarium. While it need not necessarily be formally described under conventions in the International Code of Botanical Nomenclature, such a description is preferred and should be undertaken as soon as possible after listing on the schedule.

Schedule 1 — Extant taxa

[cl. 3(a)]

Division 1 — Spermatophyta (flowering plants, conifers and cycads)

1. *Acacia anomala*
2. *Acacia aphylla*
3. *Acacia aprica*
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6. *Acacia auratiflora*
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8. *Acacia brachypoda*
9. *Acacia caesariata*
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Wildlife Conservation Act 1950 - 1979

'Protected Flora' is all W.A. native flora in:

Spermatophyta	(flowering, conifers, cycads)
Pteridophyta	(ferns, fern allies)
Bryophyta	(mosses, liverworts)
Thallophyta	(algae, fungi, lichens)

Wildlife Conservation (Rare Flora) Notice 2008(2)

Division 2 — Pteridophyta (ferns and fern allies)

390. *Asplenium obtusatum* subsp. *northlandicum*

Division 3 — Bryophyta (mosses and liverworts)

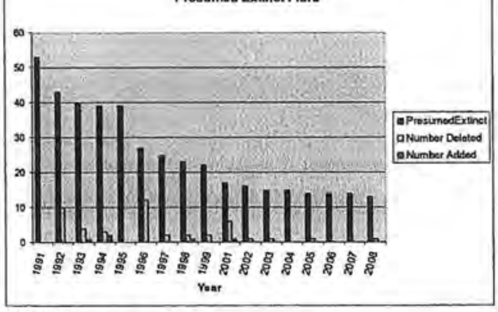
391. *Rhacocarpus rehmannianus* var. *webbianus*

Schedule 2 — Taxa presumed to be extinct

[cl. 3(b)]

Spermatophyta (flowering plants, conifers and cycads)

1. *Acacia kingiana*
2. *Acacia prismifolia*
3. *Coleanthera virgata*
4. *Frankenia decurrens*
5. *Lepidium drummondii*
6. *Leptomeria dielsiana*
7. *Leucopogon cryptanthus*
8. *Opercularia acolytantha*
9. *Ptilotus caespitulosus*
10. *Ptilotus pyramidatus*
11. *Taraxacum cygnorum*
12. *Tetratheca fasciculata*
13. *Thomasia gardneri*



DELETIONS:
26 Rediscovered in the field
8 Recent collections discovered in Herbarium collection (curatorial discoveries)
11 Deleted due to taxonomic revision

Calothamnus accedens
Piawanning Clawflower

- First discovered in 1980

- Presumed extinct in 1989
- Rediscovered in 2004 (1993)
- Added to Schedule 1 (extant) in 2005 (CR – 30 plants)
- Listed as Priority 4 in 2008 (6/14 pops, 25,000, NP)

DECLARED RARE FLORA

Ministerial Permission to 'Take' (*s* 23F(4))

Binding on the Crown

Application Process for Permit to Take :

1. Species and Communities Branch
2. Director Nature Conservation
3. Minister for the Environment

ISSUES REGARDING APPLICATIONS TO TAKE:
eg with fire

Timing - flowering period
- seeders/reshooters
- annuals/orchids

Frequency - seeders

Intensity - patchiness
- % of population
- local/regional representation

Conservation Status - ranking
- recovery plans

ISSUES REGARDING APPLICATIONS TO TAKE:
eg with clearing

Conservation Status - ranking

Local impact

Regional impact

Statewide impact

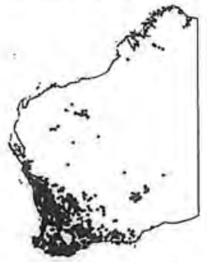
Regeneration capacity

Secondary impacts – eg disease

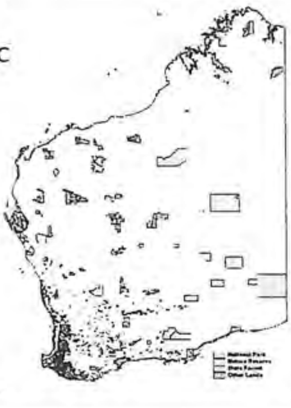
DECLARED RARE FLORA IN W. AUST

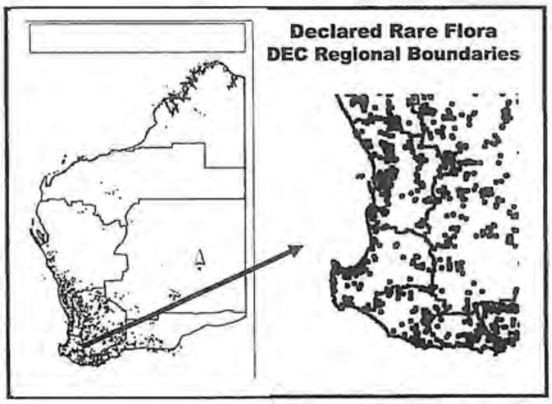
- 391 extant taxa (5/8/08)
- 30% of Aust Threatened Flora
- 6.8% of World Threatened Flora

Distribution of Declared Rare Flora in WA



Lands managed by DEC





Declared Rare Flora, 2001 by Tenure

TENURE	% POPS	% PLANTS	Av. POPN. SIZE (467)
Conservation Reserves	27.5	44.9	763
State Forest	4. 3	1. 5	159
Local Government	24.3	12.0	230
Main Roads	4.8	1.1	111
Railway Reserves	3.0	0.4	61
Other Vested Crown Land	3.3	2.5	354
Unvested Crown Land	11.9	28.2	1106
Private	20.0	9.5	222

IUCN RANKING:

- Presumed Extinct
- Threatened
  - Critically Endangered
  - Endangered
  - Vulnerable
- Conservation Dependent
- Data Deficient

IUCN Red List Guidelines

Table 2.1. Summary of the five criteria (A-E) used to evaluate if a taxon belongs in a threatened category (Critically Endangered, Endangered or Vulnerable).

Use any of the criteria A-E	Critically Endangered	Endangered	Vulnerable
A. Population reduction	Declines measured over the longer of 10 years or 3 generations		
A1	≥ 90%	≥ 70%	≥ 50%
A2, A3 & A4	≥ 80%	≥ 50%	≥ 30%

A1. Population reduction observed, estimated, inferred, or suspected in the past where the causes of the reduction are clearly reversible AND understood AND ceased based on and specifying any of the following:

(a) direct observation

(b) an index of abundance appropriate to the taxon

(c) a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality

(d) actual or potential levels of exploitation

(e) effects of introduced taxa, hybridisation, pathogens, pollutants, competitors or parasites.

A2. Population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible, based on any of (a) to (e) under A1

A3. Population reduction projected or suspected to be met in the future (up to a maximum of 100 years) based on any of (b) to (e) under A1

A4. An observed, estimated, inferred, projected or suspected population reduction (up to a maximum of 100 years) where the time period must include both the past and the future, and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible, based on any of (a) to (e) under A1

B. Geographic range in the form of either B1 (extent of occurrence) OR B2 (area of occupancy)			
B1 Either extent of occurrence	< 100 km^2	< 5,000 km^2	< 20,000 km^2
B2 or area of occupancy	< 10 km^2	< 500 km^2	< 2,000 km^2
and 2 of the following 3:			
(a) severely fragmented or # locations	= 1	≤ 5	≤ 10

(b) continuing decline in (i) extent of occurrence (ii) area of occupancy, (iii) area, extent and/or quality of habitat, (iv) number of locations or subpopulations and (v) number of mature individuals.

(c) extreme fluctuations in any of (i) extent of occurrence, (ii) area of occupancy, (iii) number of locations or subpopulations and (iv) number of mature individuals.

C. Small population size and decline			
Number of mature individuals	< 250	< 2,500	< 10,000
and either C1 or C2:			
C1 An estimated continuing decline of at least up to a maximum of 100 years	25% in 3 years or 1 generation	20% in 5 years or 2 generations	10% in 10 years or 3 generations
C2. A continuing decline and (a) and/or (b):			
(a i) # mature individuals in largest subpopulation	≤ 50	≤ 250	≤ 1,000
(a ii) or % mature individuals in one subpopulation =	90-100%	95-100%	100%
(b) extreme fluctuations in the number of mature individuals			
D. Very small or restricted population			
Either (1) number of mature individuals	< 50	< 250	< 1,000
or (2) restricted area of occupancy	na	na	typically AOO < 20km² or # locations ≤ 5
E. Quantitative Analysis			
Indicating the probability of extinction in the wild to be at least	50% in 10 years or 3 generations (100 years max)	20% in 20 years or 5 generations (100 years max)	10% in 100 years

BASIC INFO REQUIRED

\# locations

\# plants per location

spatial arrangement

Area of popn

Condition of site

change in plant numbers, locations or condition of site.

Use any of the criteria A-E	Critically Endangered	Endangered	Vulnerable
B. Geographic range in the form of either B1 (extent of occurrence) OR B2 (area of occupancy)			
B1 Either extent of occurrence	< 100 km^2	< 5,000 km^2	< 20,000 km^2
B2 or area of occupancy	< 10 km^2	< 500 km^2	< 2,000 km^2
and 2 of the following 3:			
(a) severely fragmented or # locations	= 1	≤ 5	≤ 10

(b) continuing decline in (i) extent of occurrence (ii) area of occupancy, (iii) area, extent and/or quality of habitat, (iv) number of locations or subpopulations and (v) number of mature individuals.

(c) extreme fluctuations in any of (i) extent of occurrence, (ii) area of occupancy, (iii) number of locations or subpopulations and (iv) number of mature individuals.

EXAMPLE

A species found over an area of 50km by 40km, under **B1** it has an extent of occurrence of 200km² which complies with **Endangered** and **Vulnerable**, but not **Critically Endangered**. You need to know the actual area covered by plants to determine **B2**, which can often comply with **Critically Endangered** if the populations are not spread out.

(a) can usually be used as we should know the number of populations if the species has been adequately surveyed.

(b) is more commonly used than **(c)** and requires some monitoring data to show the changes (decline) observed or predicted in the conservation status of the species, either due to reduction in the species or its habitat.

Using the example above, with four occurrences and a reduction in the number of plants noted, the species would be ranked as **Endangered B1** or **B2 (a) (b) (v)**

Use any of the criteria A-E	Critically Endangered	Endangered	Vulnerable
C. Small population size and decline			
Number of mature individuals	< 250	< 2,500	< 10,000
and either C1 or C2:			
C1. An estimated continuing decline of at least up to a maximum of 100 years	25% in 3 years or 1 generation	20% in 5 years or 2 generations	10% in 10 years or 3 generations
C2. A continuing decline and (a) and/or (b)			
(a i) # mature individuals in largest subpopulation	< 50	< 250	< 1,000
(a ii) or % mature individuals in one subpopulation =	90-100%	95-100%	100%
(b) extreme fluctuations in the number of mature individuals			

EXAMPLE

C can be used where we know the number of plants (usually) and **(1)** we have sufficient monitoring data to give a quantitative estimate to a decline in the number, or where this is not possible, **(2)** the population structure or dynamics indicates a degree of risk.

For example, a species with 200 plants, that are declining (with not adequate quantitative data on the rate of decline), but one occurrence has 150 plants would be ranked as **Endangered** even though it has less than 250 plants because not all populations are less than 50 plants and the single largest population is 75% of the total:

i.e. **Endangered C (2) (a) (i)**

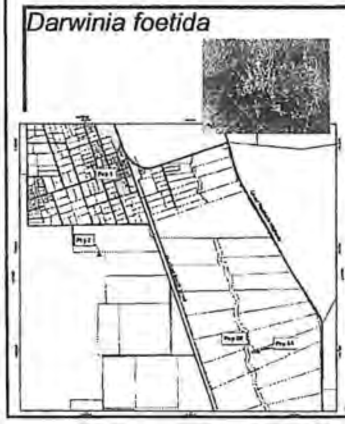
Use any of the criteria A-E	Critically Endangered	Endangered	Vulnerable
D. Very small or restricted population			
Either (1) number of mature individuals	< 50	< 250	< 1,000
or (2) restricted area of occupancy	na	na	typically: AOO < 20km² or # locations ≤5

EXAMPLE

D is the most straight forward criterion as it revolves around the number of plants – but it is reliant on a recent and reliable plant count. Note – only applies to mature plants.

Species can be ranked as **Vulnerable** under **D(2)** if they have larger numbers of plants (over 1000), but these are either in a relatively small area or number of locations, which makes the species vulnerable to threatening processes that could result in the species becoming **Critically Endangered**.

Darwinia foetida



- 3 populations
- 1300 plants
- Extent of occurrence = 1.2 km²
- Area of occupancy ~ < 1km²
- Historical collection north of Muchea thought to be cleared
- Threats: weeds, grazing by rabbits, inappropriate fire regimes and changes to hydrology
- Regenerates from seed after fire

IUCN RANKING: 2008(2)

Presumed Extinct	13
Threatened	
Critically Endangered	136
Endangered	119
Vulnerable	136
Conservation Dependent	
Data Deficient	

POORLY KNOWN FLORA IN W. AUST

- 2213 taxa (August 2009)
- 76% of Aust in 1995
- cf. British flora of ~1200
- Rich and endemic flora / habitat loss
- Good Herbarium processes
- Also 342 rare but not threatened
- Need to prioritise => Priority Flora List

PRIORITY FLORA

The need for further survey of poorly known taxa is prioritised into three categories depending on the perceived urgency for determining the conservation status of those taxa, as indicated by the apparent degree of threat to the taxa based on the current information.

1 – 3: Poorly known taxa

4: Rare but not threatened

Priority One - Poorly known Taxa

Taxa which are known from one or a few (generally <5) populations which are under threat, either due to small population size, or being on lands under immediate threat, e.g. road verges, urban areas, farmland, active mineral leases, etc., or the plants are under threat, e.g. from disease, grazing by feral animals, etc. May include taxa with threatened populations on protected lands. Such taxa are under consideration for declaration as 'rare flora', but are in urgent need of further survey.

Priority Two - Poorly Known Taxa

Taxa which are known from one or a few (generally <5) populations, at least some of which are not believed to be under immediate threat (i.e. not currently endangered). Such taxa are under consideration for declaration as 'rare flora', but are in urgent need of further survey.

Priority Three - Poorly Known Taxa

Taxa which are known from several populations, and the taxa are not believed to be under immediate threat (i.e. not currently endangered), either due to the number of known populations (generally >5), or known populations being large, and either widespread or protected. Such taxa are under consideration for declaration as 'rare flora' but are in need of further survey.

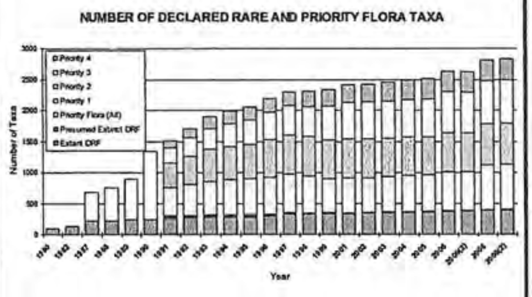
Priority Four - Rare Taxa

Taxa which are considered to have been adequately surveyed and which, whilst being rare (in Australia), are not currently threatened by any identifiable factors. These taxa require monitoring every 5-10 years.

SUMMARY OF PLANT TAXA WITH PRIORITY FOR CONSERVATION BY DEC ADMINISTRATIVE REGIONS

20 August 2009

	DECLARED RARE FLORA		PRIORITY CODES				TOTAL NO. OF TAXA
REGION	R	X	1	2	3	4	
Kimberley	4	0	69	55	48	6	182
Pilbara	2	0	71	37	88	13	211
Goldfields	13	0	101	40	89	23	266
Midwest	117	1	210	183	258	75	844
Swan	61	0	61	64	89	75	350
South West	46	1	33	36	71	49	236
Warren	24	0	15	49	58	36	182
Wheatbelt	117	3	152	143	202	85	702
South Coast	96	5	236	207	201	143	888
Unknown	-	3	3	-	-	-	6
STATE*	391	13	766	695	852	342	3059



TAKING PRIORITY FLORA

cf. DRF – Minister/Director Nature Conservation

Priority 1 & 2 – Species & Communities Branch

Priority 3 & 4 – Regional/District Manager

29/07/2008 DEPARTMENT OF ENVIRONMENT AND CONSERVATION Page 1

DECLARED RARE AND PRIORITY FLORA LIST

SPECIES / TAXON	CONS CODE	DEC REGION	DISTRIBUTION	FLOWER PERIOD
Adinctus sp. Walpole (JR Wheeler 3756)	3	WA,SR	Granite Peak, Walpole-Nornalup NP, Big Brook, Whichcliffe, Milleyannup	Jan
Alexgeorgea ganopoda	3	WA	Bow River, Mt Frankland, Kent River	
Amperea protensa	3	WA,SR,SC	Walpole, Scott River, Albany, Gardner Lake	Jan
Andersonia amabile ms	3	WA,SR	Black Point, Denbarker, Broke Inlet, Collis, Pingerup, Nornalup	Nov,Dec
Andersonia annelsii	R	WA	Perup, Manjimup	Oct
Andersonia auriculata	3	WA	Quarram, Bow River, West of Denmark, Walpole	Jul
Andersonia barbata	2	SR,WA	Busselton, Whicher Range, Nannup, Windy Harbour	Aug-Nov
Andersonia hammersleyana	2	WA	Mt Lindesay, Denmark	Sep
Andersonia jamesii	1	SC,WA	Narrikup, Sheepwash, Albany, Porongurup	Jun-Jul
Andersonia redolens	1	WA	Walpole, Nornalup Road, Mt Frankland NP	Sep

FLORA CONSERVATION

Species level:
- survey/inspection
- site management, e.g. markers
- recovery plans

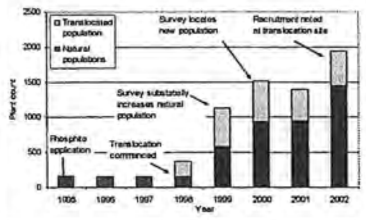
Habitat:
- impact on/of associated species
- regional processes, e.g. linkages

Threatening processes, e.g. salinity, dieback

FLORA RECOVERY

- Flora recovery teams
- Interim Recovery Plans
- Research, experimental management
- Full Recovery Plans
- Regional Management Programs
- Species & Communities Branch
- Threatened Flora Seed Centre
- Other agencies – BGPA

Lambertia orbifolia subsp. *orbifolia* recovery



Recovery Planning

REGIONAL FLORA MANAGEMENT PROGRAMS

- Geographic area basis – focus on south west
- Preceded by survey program
- One/two page summary of each taxon
- Highlight threatening processes
- Set priorities for management and research
- 12 plans in place (two plans in Swan and 'Merredin')

INTERIM RECOVERY PLANS

- Policy to prepare within 12 months for Critically Endangered. As resources available for other.
- 5 year time frame, then review
- Detailed costed actions & responsibility
- Research, experimental management
- Aim to maintain or improve status

Recovery Implementation

RECOVERY TEAMS

- Responsible for coordinating and driving program implementation
- Recovery teams – broad membership of land managers/owners, government, local government, community
- Departmental role in implementation
- Recovery Team may include specialist agencies – BGPA / Zoo
- Threatened Flora Seed Centre

RECOVERY TEAMS (2)

- 10 regional/district teams in place
- Threatened Flora Conservation Officers in place for each regional program (10)
- Regional Recovery Team will usually also incorporate species-based flora recovery plans
- Fauna recovery teams

ASSIGNMENT
questions?

— PART 1 —

CONSERVATION

CO301*

Wildlife Conservation Act 1950

Wildlife Conservation (Rare Flora) Notice 2008(2)

Made by the Minister for the Environment under section 23F(2) of the Act.

1. Citation

This notice may be cited as the *Wildlife Conservation (Rare Flora) Notice 2008(2)*.

2. Interpretation

In this notice—

"extant" means known to be living in a wild state;

"protected flora" means any flora belonging to the classes of flora declared by the Minister under section 6 of the Act to be protected flora by notice published in the *Gazette* 9 October 1987, at p. 3855;

"taxon" includes any taxon that is described by a genus name and any other name or description.

Note: The plural form of "taxon" is "taxa".

3. Rare flora

Subject to clause 4, protected flora—

(a) specified in Schedule 1, being taxa that are extant and considered likely to become extinct or rare and therefore in need of special protection; and

(b) specified in Schedule 2, being taxa that are presumed to be extinct in the wild and therefore in need of special protection,

are declared to be rare flora for the purposes of section 23F of the Act throughout the State.

4. Application

Clause 3 does not apply to those plants of a taxon of protected flora specified in Schedule 1 or 2 that have been planted for any purpose other than such plants that have been planted for the purpose of conservation of that taxon and in accordance with approval given by the Director General.

5. Revocation

The *Wildlife Conservation (Rare Flora) Notice 2008* is revoked.

Schedule 1 — Extant taxa

[cl. 3(a)]

Division 1 — Spermatophyta (flowering plants, conifers and cycads)

1. *Acacia anomala*
2. *Acacia aphylla*
3. *Acacia aprica*
4. *Acacia aristulata*
5. *Acacia ataxiphylla* subsp. *magna*
6. *Acacia auratiflora*
7. *Acacia awestoniana*
8. *Acacia brachypoda*
9. *Acacia caesariata*
10. *Acacia chapmanii* subsp. *australis*
11. *Acacia cochlocarpa* subsp. *cochlocarpa*
12. *Acacia cochlocarpa* subsp. *velutinosa*
13. *Acacia denticulosa*
14. *Acacia depressa*
15. *Acacia forrestiana*
16. *Acacia imitans*
17. *Acacia insolita* subsp. *recurva*
18. *Acacia lanuginophylla*
19. *Acacia leptalea*
20. *Acacia lobulata*
21. *Acacia pharangites*
22. *Acacia pygmaea*
23. *Acacia recurvata*
24. *Acacia rhamphophylla*
25. *Acacia sciophanes*
26. *Acacia splendens*
27. *Acacia subflexuosa* subsp. *capillata*
28. *Acacia trulliformis*
29. *Acacia unguicula*
30. *Acacia vassalii*
31. *Acacia volubilis*
32. *Acacia wilsonii*
33. *Acacia woodmaniorum*
34. *Adenanthos dobagii*
35. *Adenanthos ellipticus*
36. *Adenanthos eyrei*
37. *Adenanthos pungens* subsp. *effusus*
38. *Adenanthos pungens* subsp. *pungens*
39. *Adenanthos velutinus*
40. *Allocasuarina fibrosa*
41. *Allocasuarina tortiramula*
42. *Andersonia annelsii*
43. *Andersonia axilliflora*
44. *Andersonia gracilis*
45. *Andersonia pinaster*
46. *Anigozanthos bicolor* subsp. *minor*
47. *Anigozanthos viridis* subsp. *terraspectans*
48. *Anthocercis gracilis*
49. *Apium prostratum* subsp. *phillipii* ms
50. *Asterolasia nivea*
51. *Banksia anatona*
52. *Banksia aurantia*
53. *Banksia brownii*
54. *Banksia cuneata*
55. *Banksia fuscobractea*
56. *Banksia goodii*
57. *Banksia ionthocarpa* subsp. *chrysophoenix*
58. *Banksia ionthocarpa* subsp. *ionthocarpa*
59. *Banksia mimica*
60. *Banksia montana*
61. *Banksia mucronulata* subsp. *retrorsa*
62. *Banksia nivea* subsp. *uliginosa*

63. *Banksia oligantha*
64. *Banksia pseudoplumosa*
65. *Banksia serratuloides* subsp. *perissa*
66. *Banksia serratuloides* subsp. *serratuloides*
67. *Banksia sphaerocarpa* var. *dolichostyla*
68. *Banksia squarrosa* subsp. *argillacea*
69. *Banksia verticillata*
70. *Beyeria lepidopetala*
71. *Beyeria* sp. Bandalup Hill (G. Cockerton 7553)
72. *Boronia adamsiana*
73. *Boronia capitata* subsp. *capitata*
74. *Boronia clavata*
75. *Boronia exilis*
76. *Boronia revoluta*
77. *Brachyscias verecundus*
78. *Caladenia barbarella*
79. *Caladenia bryceana* subsp. *bryceana*
80. *Caladenia bryceana* subsp. *cracens*
81. *Caladenia busselliana*
82. *Caladenia caesarea* subsp. *maritima*
83. *Caladenia christineae*
84. *Caladenia dorrienii*
85. *Caladenia drakeoides*
86. *Caladenia elegans*
87. *Caladenia excelsa*
88. *Caladenia graniticola*
89. *Caladenia harringtoniae*
90. *Caladenia hoffmanii*
91. *Caladenia huegelii*
92. *Caladenia melanema*
93. *Caladenia procera*
94. *Caladenia viridescens*
95. *Caladenia wanosa*
96. *Caladenia williamsiae*
97. *Caladenia winfieldii*
98. *Calectasia cyanea*
99. *Calectasia pignattiana*
100. *Calytrix breviseta* subsp. *breviseta*
101. *Chamelaucium griffinii* ms
102. *Chamelaucium lullfitzii* ms
103. *Chamelaucium roycei* ms
104. *Chordifex abortivus*
105. *Chorizema humile*
106. *Chorizema varium*
107. *Commersonia* sp. Mt Groper (R. Cranfield & D. Kabay 9157)
108. *Conospermum densiflorum* subsp. *unicephalatum*
109. *Conospermum toddii*
110. *Conospermum undulatum*
111. *Conostylis dielsii* subsp. *teres*
112. *Conostylis drummondii*
113. *Conostylis lepidospermoides*
114. *Conostylis micrantha*
115. *Conostylis misera*
116. *Conostylis rogeri*
117. *Conostylis seorsiflora* subsp. *trichophylla*
118. *Conostylis setigera* subsp. *dasys*
119. *Conostylis wonganensis*
120. *Coopernookia georgei*
121. *Cyphanthera odgersii* subsp. *occidentalis*
122. *Cryptandra congesta*
123. *Darwinia acerosa*
124. *Darwinia apiculata*
125. *Darwinia calothamnoides* ms
126. *Darwinia carnea*
127. *Darwinia chapmaniana* ms
128. *Darwinia collina*
129. *Darwinia ferricola* ms
130. *Darwinia foetida* ms
131. *Darwinia masonii*
132. *Darwinia meeboldii*
133. *Darwinia oxylepis*
134. *Darwinia squarrosa*
135. *Darwinia wittwerorum*
136. *Darwinia* sp. Carnamah (J.Coleby-Williams 148)
137. *Darwinia* sp. Stirling Range (G.J.Keighery 5732)
138. *Darwinia* sp. Williamson (G.J.Keighery 12717)
139. *Daviesia bursarioides*
140. *Daviesia cunderdin*
141. *Daviesia dielsii*
142. *Daviesia elongata* subsp. *elongata*
143. *Daviesia euphorbioides*
144. *Daviesia glossosema*
145. *Daviesia megacalyx*
146. *Daviesia microcarpa*
147. *Daviesia obovata*
148. *Daviesia ovata*
149. *Daviesia pseudaphylla*
150. *Daviesia speciosa*
151. *Deyeuxia drummondii*
152. *Diuris drummondii*
153. *Diuris micrantha*
154. *Diuris purdiei*
155. *Drakaea concolor*
156. *Drakaea confluens*

157. *Drakaea elastica*
158. *Drakaea isolata*
159. *Drakaea micrantha*
160. *Drummondita ericoides*
161. *Drummondita longifolia*
162. *Eleocharis keigheryi*
163. *Epiblema grandiflorum* var. *cyaneum* ms
164. *Eremophila ciliata*
165. *Eremophila denticulata* subsp. *denticulata*
166. *Eremophila denticulata* subsp. *trisulcata*
167. *Eremophila glabra* subsp. *chlorella*
168. *Eremophila koobabbiensis* ms
169. *Eremophila lactea*
170. *Eremophila nivea*
171. *Eremophila pinnatifida*
172. *Eremophila resinosa*
173. *Eremophila rostrata* subsp. *rostrata*
174. *Eremophila rostrata* subsp. *trifida*
175. *Eremophila scaberula*
176. *Eremophila subteretifolia*
177. *Eremophila ternifolia*
178. *Eremophila vernicosa*
179. *Eremophila verticillata*
180. *Eremophila virens*
181. *Eremophila viscida*
182. *Eucalyptus absita*
183. *Eucalyptus argutifolia*
184. *Eucalyptus articulata*
185. *Eucalyptus balanites*
186. *Eucalyptus beardiana*
187. *Eucalyptus blaxellii*
188. *Eucalyptus brevipes*
189. *Eucalyptus burdettiana*
190. *Eucalyptus ceracea*
191. *Eucalyptus coronata*
192. *Eucalyptus crispata*
193. *Eucalyptus crucis* subsp. *crucis*
194. *Eucalyptus crucis* subsp. *praecipua*
195. *Eucalyptus cuprea*
196. *Eucalyptus dolorosa*
197. *Eucalyptus impensa*
198. *Eucalyptus insularis*
199. *Eucalyptus johnsoniana*
200. *Eucalyptus lateritica*
201. *Eucalyptus leprophloia*
202. *Eucalyptus merrickiae*
203. *Eucalyptus mooreana*
204. *Eucalyptus nutans*
205. *Eucalyptus phylacis*
206. *Eucalyptus platydisca*
207. *Eucalyptus pruiniramis*
208. *Eucalyptus purpurata*
209. *Eucalyptus recta*
210. *Eucalyptus rhodantha* var. *rhodantha*
211. *Eucalyptus steedmanii*
212. *Eucalyptus suberea*
213. *Eucalyptus synandra*
214. *Frankenia conferta*
215. *Frankenia parvula*
216. *Gastrolobium appressum*
217. *Gastrolobium diabolophyllum*
218. *Gastrolobium glaucum*
219. *Gastrolobium graniticum*
220. *Gastrolobium hamulosum*
221. *Gastrolobium lehmannii*
222. *Gastrolobium luteifolium*
223. *Gastrolobium modestum*
224. *Gastrolobium papilio*
225. *Glyceria drummondii*
226. *Goodenia arthrotricha*
227. *Goodenia integerrima*
228. *Grevillea acropogon*
229. *Grevillea althoferorum* subsp. *althoferorum* ms
230. *Grevillea althoferorum* subsp. *fragilis* ms
231. *Grevillea batrachioides*
232. *Grevillea brachystylis* subsp. *australis*
233. *Grevillea brachystylis* subsp. Busselton (G.J. Keighery s.n. 28/8/1985)
234. *Grevillea bracteosa* subsp. *bracteosa* ms
235. *Grevillea bracteosa* subsp. *howatharra* ms
236. *Grevillea calliantha*
237. *Grevillea christineae*
238. *Grevillea curviloba* subsp. *curviloba*
239. *Grevillea curviloba* subsp. *incurva*
240. *Grevillea dryandroides* subsp. *dryandroides*
241. *Grevillea dryandroides* subsp. *hirsuta*
242. *Grevillea elongata*
243. *Grevillea flexuosa*
244. *Grevillea fuscolutea*
245. *Grevillea humifusa*
246. *Grevillea infundibularis*
247. *Grevillea involucrata*
248. *Grevillea maccutcheonii*

249. *Grevillea maxwellii*
250. *Grevillea murex*
251. *Grevillea phanerophlebia*
252. *Grevillea pythara*
253. *Grevillea rara*
254. *Grevillea scapigera*
255. *Guichenotia seorsiflora*
256. *Gyrostemon reticulatus*
257. *Hakea aculeata*
258. *Hakea megalosperma*
259. *Haloragis platycarpa*
260. *Hemiandra gardneri*
261. *Hemiandra rutilans*
262. *Hemigenia ramosissima*
263. *Hensmania chapmanii*
264. *Hibbertia priceana*
265. *Hybanthus cymulosus*
266. *Hydatella dioica*
267. *Hydatella leptogyne*
268. *Hypocalymma longifolium*
269. *Isopogon robustus*
270. *Isopogon uncinatus*
271. *Jacksonia pungens* ms
272. *Jacksonia quairading* ms
273. *Jacksonia velveta* ms
274. *Kennedia glabrata*
275. *Kennedia macrophylla*
276. *Keraudrenia exastia*
277. *Kunzea similis* subsp. *mediterranea*
278. *Kunzea similis* subsp. *similis*
279. *Lambertia echinata* subsp. *echinata*
280. *Lambertia echinata* subsp. *occidentalis*
281. *Lambertia fairallii*
282. *Lambertia orbifolia* subsp. *orbifolia* ms
283. *Lambertia orbifolia* subsp. Scott River Plains (L.W.Sage 684)
284. *Lasiopetalum pterocarpum*
285. *Lasiopetalum rotundifolium*
286. *Latrobea colophona*
287. *Laxmannia grandiflora* subsp. *brendae*
288. *Lechenaultia chlorantha*
289. *Lechenaultia laricina*
290. *Lepidium aschersonii*
291. *Lepidium catapycnon*
292. *Lepidosperma rostratum*
293. *Lepidosperma gibsonii*
294. *Leucopogon gnaphalioides*
295. *Leucopogon marginatus*
296. *Leucopogon obtectus*
297. *Leucopogon spectabilis*
298. *Leucopogon* sp. ciliate Eneabba (F. Obbens & C. Godden s.n. 3/7/2003)
299. *Lysiosepalum abollatum*
300. *Macarthuria keigheryi*
301. *Marianthus mollis*
302. *Marianthus paralius*
303. *Marianthus* sp. Bremer (N. Gibson & M. Lyons 1776)
304. *Melaleuca sciotostyla*
305. *Meziella trifida*
306. *Microcorys eremophiloides*
307. *Microtis globula*
308. *Muehlenbeckia horrida* subsp. *abdita*
309. *Muelleranthus crenulatus*
310. *Myoporum cordifolium*
311. *Myoporum turbinatum*
312. *Myriophyllum lapidicola*
313. *Orthrosanthus muelleri*
314. *Pandanus spiralis* var. *flammeus*
315. *Paracaleana dixonii*
316. *Patersonia spirifolia*
317. *Persoonia micranthera*
318. *Petrophile latericola* ms
319. *Philotheca basistyla*
320. *Philotheca falcata*
321. *Philotheca wonganensis*
322. *Pityrodia augustensis*
323. *Pityrodia axillaris*
324. *Pityrodia scabra*
325. *Pterostylis* sp. Northampton (S.D.Hopper 3349)
326. *Ptilotus fasciculatus*
327. *Ptychosema pusillum*
328. *Pultenaea pauciflora*
329. *Reedia spathacea*
330. *Rhagodia acicularis*
331. *Rhizanthella gardneri*
332. *Ricinocarpos brevis*
333. *Ricinocarpos trichophorus*
334. *Roycea pycnophylloides*
335. *Rulingia* sp. Trigwell Bridge (R.Smith s.n. 20.6.89)
336. *Scaevola macrophylla*
337. *Schoenia filifolia* subsp. *subulifolia*
338. *Sphenotoma drummondii*
339. *Spirogardnera rubescens*
340. *Stachystemon nematophorus*
341. *Stylidium amabile*
342. *Stylidium coroniforme* subsp. *coroniforme*
343. *Stylidium galioides*
344. *Stylidium merrallii*
345. *Stylidium semaphorum*

346. *Symonanthus bancroftii*
347. *Synaphea quartzitica*
348. *Synaphea stenoloba*
349. *Synaphea* sp. Fairbridge Farm (D. Papenfus 696)
350. *Synaphea* sp. Pinjarra (R.Davis 6578)
351. *Tecticornia bulbosa*
352. *Tetraria australiensis*
353. *Tetratheca deltoidea*
354. *Tetratheca erubescens*
355. *Tetratheca harperi*
356. *Tetratheca nephelioides*
357. *Tetratheca aphylla* subsp. *aphylla*
358. *Tetratheca aphylla* subsp. *megacarpa*
359. *Tetratheca paynterae* subsp. *cremnobata*
360. *Tetratheca paynterae* subsp. *paynterae*
361. *Thelymitra dedmaniarum*
362. *Thelymitra psammophila*
363. *Thelymitra stellata*
364. *Thomasia glabripetala*
365. *Thomasia montana*
366. *Thomasia* sp. Green Hill (S.Paust 1322)
367. *Thryptomene wittweri*
368. *Tribonanthes purpurea*
369. *Verticordia albida*
370. *Verticordia apecta*
371. *Verticordia carinata*
372. *Verticordia crebra*
373. *Verticordia densiflora* var. *pedunculata*
374. *Verticordia fimbrilepis* subsp. *australis*
375. *Verticordia fimbrilepis* subsp. *fimbrilepis*
376. *Verticordia helichrysantha*
377. *Verticordia hughanii*
378. *Verticordia pityrhops*
379. *Verticordia plumosa* var. *ananeotes*
380. *Verticordia plumosa* var. *pleiobotrya*
381. *Verticordia plumosa* var. *vassensis*
382. *Verticordia spicata* subsp. *squamosa*
383. *Verticordia staminosa* subsp. *cylindracea* var. *cylindracea*
384. *Verticordia staminosa* subsp. *cylindracea* var. *erecta*
385. *Verticordia staminosa* subsp. *staminosa*
386. *Villarsia calthifolia*
387. *Wurmbea calcicola*
388. *Wurmbea tubulosa*
389. *Xyris exilis*

Division 2 — Pteridophyta (ferns and fern allies)

390. *Asplenium obtusatum* subsp. *northlandicum*

Division 3 — Bryophyta (mosses and liverworts)

391. *Rhacocarpus rehmannianus* var. *webbianus*

Schedule 2 — Taxa presumed to be extinct

[cl. 3(b)]

Spermatophyta (flowering plants, conifers and cycads)

1. *Acacia kingiana*
2. *Acacia prismifolia*
3. *Coleanthera virgata*
4. *Frankenia decurrens*
5. *Lepidium drummondii*
6. *Leptomeria dielsiana*
7. *Leucopogon cryptanthus*
8. *Opercularia acolytantha*
9. *Ptilotus caespitulosus*
10. *Ptilotus pyramidatus*

Taraxacum cygnorum
Tetratheca fasciculata
Thomasia gardneri

DAVID TEMPLEMAN, Minister for the Environment.

2*

Wildlife Conservation Act 1950

Wildlife Conservation (Specially Protected Fauna) Notice 2008(2)

Made by the Minister for the Environment under section 14(2)(ba) of the Act.

1. Citation

This notice may be cited as the *Wildlife Conservation (Specially Protected Fauna) Notice 2008(2)*.

2. Interpretation

In this notice —

"taxon" includes any taxon that is described by a family name or a genus name or any other name or description.

Note: The plural form of "taxon" is "taxa".

3. Declaration of specially protected fauna

For the purposes of the Act, all taxa of the fauna —

(a) specified in Schedule 1, being fauna that is rare or likely to become extinct, are declared to be fauna that is in need of special protection;

(b) specified in Schedule 2, being fauna that is presumed to be extinct, are declared to be fauna that is in need of special protection;

(c) specified in Schedule 3, being birds that are subject to an agreement between the governments of Australia and Japan relating to the protection of migratory birds and birds in danger of extinction, are declared to be fauna that is in need of special protection; and

(d) specified in Schedule 4, are declared to be fauna that is in need of special protection, otherwise than for the reasons mentioned in paragraphs (a), (b) and (c).

— PART 1 —

CONSERVATION

CO301*

Wildlife Conservation Act 1950

Wildlife Conservation (Rare Flora) Notice 2008(2)

Made by the Minister for the Environment under section 23F(2) of the Act.

1. Citation

This notice may be cited as the *Wildlife Conservation (Rare Flora) Notice 2008(2)*.

2. Interpretation

In this notice—

"extant" means known to be living in a wild state;

"protected flora" means any flora belonging to the classes of flora declared by the Minister under section 6 of the Act to be protected flora by notice published in the *Gazette* 9 October 1987, at p. 3855;

"taxon" includes any taxon that is described by a genus name and any other name or description.

Note: The plural form of "taxon" is "taxa".

3. Rare flora

Subject to clause 4, protected flora—

(a) specified in Schedule 1, being taxa that are extant and considered likely to become extinct or rare and therefore in need of special protection; and

(b) specified in Schedule 2, being taxa that are presumed to be extinct in the wild and therefore in need of special protection,

are declared to be rare flora for the purposes of section 23F of the Act throughout the State.

4. Application

Clause 3 does not apply to those plants of a taxon of protected flora specified in Schedule 1 or 2 that have been planted for any purpose other than such plants that have been planted for the purpose of conservation of that taxon and in accordance with approval given by the Director General.

5. Revocation

The *Wildlife Conservation (Rare Flora) Notice 2008* is revoked.

Schedule 1 — Extant taxa

[cl. 3(a)]

Division 1 — Spermatophyta (flowering plants, conifers and cycads)

1. *Acacia anomala*
2. *Acacia aphylla*
3. *Acacia aprica*
4. *Acacia aristulata*
5. *Acacia ataxiphylla* subsp. *magna*
6. *Acacia auratiflora*
7. *Acacia awestoniana*
8. *Acacia brachypoda*
9. *Acacia caesariata*
10. *Acacia chapmanii* subsp. *australis*
11. *Acacia cochlocarpa* subsp. *cochlocarpa*
12. *Acacia cochlocarpa* subsp. *velutinosa*
13. *Acacia denticulosa*
14. *Acacia depressa*
15. *Acacia forrestiana*
16. *Acacia imitans*
17. *Acacia insolita* subsp. *recurva*
18. *Acacia lanuginophylla*
19. *Acacia leptalea*
20. *Acacia lobulata*
21. *Acacia pharangites*
22. *Acacia pygmaea*
23. *Acacia recurvata*
24. *Acacia rhamphophylla*
25. *Acacia sciophanes*
26. *Acacia splendens*
27. *Acacia subflexuosa* subsp. *capillata*
28. *Acacia trulliformis*
29. *Acacia unguicula*
30. *Acacia vassalii*
31. *Acacia volubilis*
32. *Acacia wilsonii*
33. *Acacia woodmaniorum*
34. *Adenanthos dobagii*
35. *Adenanthos ellipticus*
36. *Adenanthos eyrei*
37. *Adenanthos pungens* subsp. *effusus*
38. *Adenanthos pungens* subsp. *pungens*
39. *Adenanthos velutinus*
40. *Allocasuarina fibrosa*
41. *Allocasuarina tortiramula*
42. *Andersonia annelsii*
43. *Andersonia axilliflora*
44. *Andersonia gracilis*
45. *Andersonia pinaster*
46. *Anigozanthos bicolor* subsp. *minor*
47. *Anigozanthos viridis* subsp. *terraspectans*
48. *Anthocercis gracilis*
49. *Apium prostratum* subsp. *phillipii* ms
50. *Asterolasia nivea*
51. *Banksia anatona*
52. *Banksia aurantia*
53. *Banksia brownii*
54. *Banksia cuneata*
55. *Banksia fuscobractea*
56. *Banksia goodii*
57. *Banksia ionthocarpa* subsp. *chrysophoenix*
58. *Banksia ionthocarpa* subsp. *ionthocarpa*
59. *Banksia mimica*
60. *Banksia montana*
61. *Banksia mucronulata* subsp. *retrorsa*
62. *Banksia nivea* subsp. *uliginosa*

63. *Banksia oligantha*
64. *Banksia pseudoplumosa*
65. *Banksia serratuloides* subsp. *perissa*
66. *Banksia serratuloides* subsp. *serratuloides*
67. *Banksia sphaerocarpa* var. *dolichostyla*
68. *Banksia squarrosa* subsp. *argillacea*
69. *Banksia verticillata*
70. *Beyeria lepidopetala*
71. *Beyeria* sp. Bandalup Hill (G. Cockerton 7553)
72. *Boronia adamsiana*
73. *Boronia capitata* subsp. *capitata*
74. *Boronia clavata*
75. *Boronia exilis*
76. *Boronia revoluta*
77. *Brachyscias verecundus*
78. *Caladenia barbarella*
79. *Caladenia bryceana* subsp. *bryceana*
80. *Caladenia bryceana* subsp. *cracens*
81. *Caladenia busselliana*
82. *Caladenia caesarea* subsp. *maritima*
83. *Caladenia christineae*
84. *Caladenia dorrienii*
85. *Caladenia drakeoides*
86. *Caladenia elegans*
87. *Caladenia excelsa*
88. *Caladenia graniticola*
89. *Caladenia harringtoniae*
90. *Caladenia hoffmanii*
91. *Caladenia huegelii*
92. *Caladenia melanema*
93. *Caladenia procera*
94. *Caladenia viridescens*
95. *Caladenia wanosa*
96. *Caladenia williamsiae*
97. *Caladenia winfieldii*
98. *Calectasia cyanea*
99. *Calectasia pignattiana*
100. *Calytrix breviseta* subsp. *breviseta*
101. *Chamelaucium griffinii* ms
102. *Chamelaucium lullfitzii* ms
103. *Chamelaucium roycei* ms
104. *Chordifex abortivus*
105. *Chorizema humile*
106. *Chorizema varium*
107. *Commersonia* sp. Mt Groper (R. Cranfield & D. Kabay 9157)
108. *Conospermum densiflorum* subsp. *unicephalatum*
109. *Conospermum toddii*
110. *Conospermum undulatum*
111. *Conostylis dielsii* subsp. *teres*
112. *Conostylis drummondii*
113. *Conostylis lepidospermoides*
114. *Conostylis micrantha*
115. *Conostylis misera*
116. *Conostylis rogeri*
117. *Conostylis seorsiflora* subsp. *trichophylla*
118. *Conostylis setigera* subsp. *dasys*
119. *Conostylis wonganensis*
120. *Coopernookia georgei*
121. *Cyphanthera odgersii* subsp. *occidentalis*
122. *Cryptandra congesta*
123. *Darwinia acerosa*
124. *Darwinia apiculata*
125. *Darwinia calothamnoides* ms
126. *Darwinia carnea*
127. *Darwinia chapmaniana* ms
128. *Darwinia collina*
129. *Darwinia ferricola* ms
130. *Darwinia foetida* ms
131. *Darwinia masonii*
132. *Darwinia meeboldii*
133. *Darwinia oxylepis*
134. *Darwinia squarrosa*
135. *Darwinia wittwerorum*
136. *Darwinia* sp. Carnamah (J.Coleby-Williams 148)
137. *Darwinia* sp. Stirling Range (G.J.Keighery 5732)
138. *Darwinia* sp. Williamson (G.J.Keighery 12717)
139. *Daviesia bursarioides*
140. *Daviesia cunderdin*
141. *Daviesia dielsii*
142. *Daviesia elongata* subsp. *elongata*
143. *Daviesia euphorbioides*
144. *Daviesia glossosema*
145. *Daviesia megacalyx*
146. *Daviesia microcarpa*
147. *Daviesia obovata*
148. *Daviesia ovata*
149. *Daviesia pseudaphylla*
150. *Daviesia speciosa*
151. *Deyeuxia drummondii*
152. *Diuris drummondii*
153. *Diuris micrantha*
154. *Diuris purdiei*
155. *Drakaea concolor*
156. *Drakaea confluens*

157. *Drakaea elastica*
158. *Drakaea isolata*
159. *Drakaea micrantha*
160. *Drummondita ericoides*
161. *Drummondita longifolia*
162. *Eleocharis keigheryi*
163. *Epiblema grandiflorum* var. *cyaneum* ms
164. *Eremophila ciliata*
165. *Eremophila denticulata* subsp. *denticulata*
166. *Eremophila denticulata* subsp. *trisulcata*
167. *Eremophila glabra* subsp. *chlorella*
168. *Eremophila koobabbiensis* ms
169. *Eremophila lactea*
170. *Eremophila nivea*
171. *Eremophila pinnatifida*
172. *Eremophila resinosa*
173. *Eremophila rostrata* subsp. *rostrata*
174. *Eremophila rostrata* subsp. *trifida*
175. *Eremophila scaberula*
176. *Eremophila subteretifolia*
177. *Eremophila ternifolia*
178. *Eremophila vernicosa*
179. *Eremophila verticillata*
180. *Eremophila virens*
181. *Eremophila viscida*
182. *Eucalyptus absita*
183. *Eucalyptus argutifolia*
184. *Eucalyptus articulata*
185. *Eucalyptus balanites*
186. *Eucalyptus beardiana*
187. *Eucalyptus blaxellii*
188. *Eucalyptus brevipes*
189. *Eucalyptus burdettiana*
190. *Eucalyptus ceracea*
191. *Eucalyptus coronata*
192. *Eucalyptus crispata*
193. *Eucalyptus crucis* subsp. *crucis*
194. *Eucalyptus crucis* subsp. *praecipua*
195. *Eucalyptus cuprea*
196. *Eucalyptus dolorosa*
197. *Eucalyptus impensa*
198. *Eucalyptus insularis*
199. *Eucalyptus johnsoniana*
200. *Eucalyptus lateritica*
201. *Eucalyptus leprophloia*
202. *Eucalyptus merrickiae*
203. *Eucalyptus mooreana*
204. *Eucalyptus nutans*
205. *Eucalyptus phylacis*
206. *Eucalyptus platydisca*
207. *Eucalyptus pruiniramis*
208. *Eucalyptus purpurata*
209. *Eucalyptus recta*
210. *Eucalyptus rhodantha* var. *rhodantha*
211. *Eucalyptus steedmanii*
212. *Eucalyptus suberea*
213. *Eucalyptus synandra*
214. *Frankenia conferta*
215. *Frankenia parvula*
216. *Gastrolobium appressum*
217. *Gastrolobium diabolophyllum*
218. *Gastrolobium glaucum*
219. *Gastrolobium graniticum*
220. *Gastrolobium hamulosum*
221. *Gastrolobium lehmannii*
222. *Gastrolobium luteifolium*
223. *Gastrolobium modestum*
224. *Gastrolobium papilio*
225. *Glyceria drummondii*
226. *Goodenia arthrotricha*
227. *Goodenia integerrima*
228. *Grevillea acropogon*
229. *Grevillea althoferorum* subsp. *althoferorum* ms
230. *Grevillea althoferorum* subsp. *fragilis* ms
231. *Grevillea batrachioides*
232. *Grevillea brachystylis* subsp. *australis*
233. *Grevillea brachystylis* subsp. Busselton (G.J. Keighery s.n. 28/8/1985)
234. *Grevillea bracteosa* subsp. *bracteosa* ms
235. *Grevillea bracteosa* subsp. *howatharra* ms
236. *Grevillea calliantha*
237. *Grevillea christineae*
238. *Grevillea curviloba* subsp. *curviloba*
239. *Grevillea curviloba* subsp. *incurva*
240. *Grevillea dryandroides* subsp. *dryandroides*
241. *Grevillea dryandroides* subsp. *hirsuta*
242. *Grevillea elongata*
243. *Grevillea flexuosa*
244. *Grevillea fuscolutea*
245. *Grevillea humifusa*
246. *Grevillea infundibularis*
247. *Grevillea involucrata*
248. *Grevillea maccutcheonii*

249. *Grevillea maxwellii*
250. *Grevillea murex*
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268. *Hypocalymma longifolium*
269. *Isopogon robustus*
270. *Isopogon uncinatus*
271. *Jacksonia pungens* ms
272. *Jacksonia quairading* ms
273. *Jacksonia velveta* ms
274. *Kennedia glabrata*
275. *Kennedia macrophylla*
276. *Keraudrenia exastia*
277. *Kunzea similis* subsp. *mediterranea*
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280. *Lambertia echinata* subsp. *occidentalis*
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283. *Lambertia orbifolia* subsp. Scott River Plains (L.W.Sage 684)
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295. *Leucopogon marginatus*
296. *Leucopogon obtectus*
297. *Leucopogon spectabilis*
298. *Leucopogon* sp. ciliate Eneabba (F. Obbens & C. Godden s.n. 3/7/2003)
299. *Lysiosepalum abollatum*
300. *Macarthuria keigheryi*
301. *Marianthus mollis*
302. *Marianthus paralius*
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305. *Meziella trifida*
306. *Microcorys eremophiloides*
307. *Microtis globula*
308. *Muehlenbeckia horrida* subsp. *abdita*
309. *Muelleranthus crenulatus*
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311. *Myoporum turbinatum*
312. *Myriophyllum lapidicola*
313. *Orthrosanthus muelleri*
314. *Pandanus spiralis* var. *flammeus*
315. *Paracaleana dixonii*
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333. *Ricinocarpos trichophorus*
334. *Roycea pycnophylloides*
335. *Rulingia* sp. Trigwell Bridge (R.Smith s.n. 20.6.89)
336. *Scaevola macrophylla*
337. *Schoenia filifolia* subsp. *subulifolia*
338. *Sphenotoma drummondii*
339. *Spirogardnera rubescens*
340. *Stachystemon nematophorus*
341. *Stylidium amabile*
342. *Stylidium coroniforme* subsp. *coroniforme*
343. *Stylidium galioides*
344. *Stylidium merrallii*
345. *Stylidium semaphorum*

346. *Symonanthus bancroftii*
347. *Synaphea quartzitica*
348. *Synaphea stenoloba*
349. *Synaphea* sp. Fairbridge Farm (D. Papenfus 696)
350. *Synaphea* sp. Pinjarra (R.Davis 6578)
351. *Tecticornia bulbosa*
352. *Tetraria australiensis*
353. *Tetratheca deltoidea*
354. *Tetratheca erubescens*
355. *Tetratheca harperi*
356. *Tetratheca nephelioides*
357. *Tetratheca aphylla* subsp. *aphylla*
358. *Tetratheca aphylla* subsp. *megacarpa*
359. *Tetratheca paynterae* subsp. *cremnobata*
360. *Tetratheca paynterae* subsp. *paynterae*
361. *Thelymitra dedmaniarum*
362. *Thelymitra psammophila*
363. *Thelymitra stellata*
364. *Thomasia glabripetala*
365. *Thomasia montana*
366. *Thomasia* sp. Green Hill (S.Paust 1322)
367. *Thryptomene wittweri*
368. *Tribonanthes purpurea*
369. *Verticordia albida*
370. *Verticordia apecta*
371. *Verticordia carinata*
372. *Verticordia crebra*
373. *Verticordia densiflora* var. *pedunculata*
374. *Verticordia fimbrilepis* subsp. *australis*
375. *Verticordia fimbrilepis* subsp. *fimbrilepis*
376. *Verticordia helichrysantha*
377. *Verticordia hughanii*
378. *Verticordia pityrhops*
379. *Verticordia plumosa* var. *ananeotes*
380. *Verticordia plumosa* var. *pleiobotrya*
381. *Verticordia plumosa* var. *vassensis*
382. *Verticordia spicata* subsp. *squamosa*
383. *Verticordia staminosa* subsp. *cylindracea* var. *cylindracea*
384. *Verticordia staminosa* subsp. *cylindracea* var. *erecta*
385. *Verticordia staminosa* subsp. *staminosa*
386. *Villarsia calthifolia*
387. *Wurmbea calcicola*
388. *Wurmbea tubulosa*
389. *Xyris exilis*

Division 2 — Pteridophyta (ferns and fern allies)

390. *Asplenium obtusatum* subsp. *northlandicum*

Division 3 — Bryophyta (mosses and liverworts)

391. *Rhacocarpus rehmannianus* var. *webbianus*

Schedule 2 — Taxa presumed to be extinct

[cl. 3(b)]

Spermatophyta (flowering plants, conifers and cycads)

1. *Acacia kingiana*
2. *Acacia prismifolia*
3. *Coleanthera virgata*
4. *Frankenia decurrens*
5. *Lepidium drummondii*
6. *Leptomeria dielsiana*
7. *Leucopogon cryptanthus*
8. *Opercularia acolytantha*
9. *Ptilotus caespitulosus*
10. *Ptilotus pyramidatus*

11. *Taraxacum cygnorum*
12. *Tetratheca fasciculata*
13. *Thomasia gardneri*

DAVID TEMPLEMAN, Minister for the Environment.

CO302*

Wildlife Conservation Act 1950

Wildlife Conservation (Specially Protected Fauna) Notice 2008(2)

Made by the Minister for the Environment under section 14(2)(ba) of the Act.

1. Citation

This notice may be cited as the *Wildlife Conservation (Specially Protected Fauna) Notice 2008(2)*.

2. Interpretation

In this notice —

"taxon" includes any taxon that is described by a family name or a genus name or any other name or description.

Note: The plural form of "taxon" is "taxa".

3. Declaration of specially protected fauna

For the purposes of the Act, all taxa of the fauna —

(a) specified in Schedule 1, being fauna that is rare or likely to become extinct, are declared to be fauna that is in need of special protection;

(b) specified in Schedule 2, being fauna that is presumed to be extinct, are declared to be fauna that is in need of special protection;

(c) specified in Schedule 3, being birds that are subject to an agreement between the governments of Australia and Japan relating to the protection of migratory birds and birds in danger of extinction, are declared to be fauna that is in need of special protection; and

(d) specified in Schedule 4, are declared to be fauna that is in need of special protection, otherwise than for the reasons mentioned in paragraphs (a), (b) and (c).

Department of
Environment and Conservation

Our environment, our future

Flora Conservation Course

Monitoring

Prepared by:

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Prepared for:

Flora Conservation Course

Version 1.0 (September 2007)

1 Monitoring

Monitoring is the repeated measurement of a factor or range of factors over time to determine change.

Evaluation is the analysis of the "raw information" collected during monitoring to enable conclusions to be drawn and the effectiveness of management actions to be assessed.

2 Why monitor?

There are several triggers which lead to the initiation of monitoring programs. One is when there are legislative and/or statutory requirements to start monitoring. These may be required on a "permit to take", or as part of an ethics committee condition.
Another trigger is when there is a management plan or recovery plan and the monitoring forms part of management considerations. This can sometime happen in controlled fire burn prescription, or in en other disturbance operations, such as Interim management guidelines (IMGs) NC management.

Another reason to start monitoring is to address gaps in biological knowledge. For management it is often useful to understand the regeneration biology for a species, for example whether it reseeds or re-sprouts after fire. Baseline data and improved currency are two other reasons to monitor. The quality and comprehensiveness of knowledge can be improved with collection of monitoring data. Another use is to determine and measure impacts of key threats and to ascertain ecological patterns and processes.

Other reasons to monitor are to support operations and improve management. It is sometimes a way to engage stakeholders on the local, state or federal level. Monitoring is also done to inform government and the public.

To be sure that the monitoring is carried out well, there are a series of criteria to be met:

- Have clear objectives
- Design the monitoring to meet the objectives
- Collect the data in a rigorous repeatable way
- Check that the data can be readily accessed analysed and queried by district and regional staff
- Look at ways of getting more value from the monitoring effort
- Use the data to improve management decisions.

3 What to monitor?

- Biological data, such as changes to biodiversity condition, the structure and composition of the community; this information can be examined at individual, population or species level.
- Ecosystem process and function data, such as pollination vectors, nutrient distributions, or hydrological patterns (at a larger scale)
- Behavioural impacts, such as the regeneration mechanism used in response to varied intensity of fire
- Disturbance processes, including fire behaviour, site conditions, soil moisture, groundwater levels, grazing impact, dust and other pollution
- Objectives/ strategy implementation, such as whether the project was successful and cost effective

4 Tools and Techniques of Monitoring for a Range of Results

- Opportunistic or ad hoc, as in DOB observation
- Qualitative, such as photo points
- Repeated measurements, including
  - baseline survey
  - presence, absence, condition, RFFRF
  - Change or trend
  - permanent quadrats and transects
  - hypothesis testing
  - relational determining causative factors
- Different spatial and temporal scales, such as point data versus area data
- Differences between auditing, monitoring and research
- Monitor the impact rather than the cause, which requires knowledge of a direct dependency relationship

5 Examples of Methods

5.1 Rare Flora Field Report Form (RFRF)

Rare Flora Field Report Form (RFFRF)
The RFFRF provides a snapshot of all or part of a population at one point in time.
The minimum requirements recorded on the form are the species name, the Department's population number, whether it is a new or known population, accurate location info (GPS coordinates and a description), the number of adult and seedling plants, their reproductive state, the condition of the population, and what the existing or potential threats are.

Other information which can be included is the landform, the soil type, the vegetation type using Muir's classification, associated species, fire history, pollinators, specimen collection information.

This data is entered in the Declared Endangered Flora Listing (DEFL) administered by the Species and Communities Branch of DEC.

The database and the report forms are being revised in 2008.

5.2 Photographic Monitoring

This is the simplest and most convenient method. The benefits are that it provides information over a long period if there is adequate standardization, and it visually communicates the nature of changes over time. The shortfalls are that it is difficult to explain changes interpreted from the photographs, and it does not readily produce quantitative data for entry into a database.

5.3 Quadrats and Transects

Quadrats and transects are used to ascertain long term natural dynamics of populations. Also they can show the effect of threatening processes, the effect of active management recovery work. These also provide information on threats and trends. The samples are only a subset of the population or its occurrence.

It is essential that the sites are permanently marked so that *repeatability* is ensured. The marking is done on a north-south or east-west aspect, using a compass. The size of the quadrat or transect is determined by the size and density of the plants being monitored. Nested quadrats of 1 to 2 metres make it easier to record presence-absence data.

Count mature flowering plants and seedlings separately.
Make note of:

- The reproductive state (flowering, fruiting or vegetative)
- The reproductive method (seed, vegetative)
- The method of seed storage (on plant, in soil)
- The level of seed produced (an indication of suitable pollinators being active or absent)
- The health of each plant
- The height and width measured
- The active growth or dormancy stage recorded

NB: this data is used to determine the reproductive potential of the population and to provide information for ranking when using IUCN criteria

Other useful data to record with quadrats and transects is:
Associated plants should be noted with the 10 most dominant being listed from the most common to least common. ***System cards*** can be used to show an example of each associated species found.

Canopy cover should be noted as it may impact on the health of the threatened species, i.e. many species are opportunists that appear after fire and soil disturbance. They are often short-lived and are crowded or shaded out by other species over time.

Transects are most **useful for larger species** that are scattered over a wide area in the landscape.
Transects **vary in length and width** but are commonly 30 metres by 1 metre or 30 m x 2 m in size.

Normally a transect is positioned from **just outside the edge** through a dense part of the population being monitored.

6 When to monitor

It is common to monitor on the day of a disturbance, such as a burn. Or it may be done within a few days of the disturbance.

The time for monitoring is determined by a biological response, such as when germination occurs, when green pick grazing occurs, when there is a recovery of the closure of the canopy biomass, at the time of phenological reproduction age, or breeding success.

6.1 Frequency

Monitoring can be carried out at a once off, or intermittently. I t can be done cyclically, such as by season or annually, or every 5 years.

7 Monitoring emphasis

Those species which are Critically endangered **(CR)** are of highest priority should be monitored at least annually.

Those species which are Endangered **(EN)** are the next highest priority and should be monitored at least bi-annually.

The species which are Vulnerable **(VU)** are the next highest priority and should be monitored at least every three years (preferably more frequently).

7.1 Where to monitor

On site versus Off site

Displacement effects
- Brushtail vs. ringtail possum
- Water abstraction vs local effects
- Riparian habitat vs feral pigs

Impact of transported matter
- Sediment
- Nutrient
- Water quality

Implemented on both departmental and other lands

8 Who monitors?

- Nature Conservation staff
- Specialists--local and non-regional
- Assisted by other District staff
- Volunteers and community groups
- Tertiary students
- Other agencies

8.1 Funded how

It is proposed that a species is identified in a Recovery Plan, or Interim Recovery Plan or Wildlife Management Plan or Area Management Plan. The species is identified in an annual OPP Process. The species is identified in annual Region/District strategic operational plans/action plans.

External funding from the Commonwealth's NHT, Bio prospect and the State Salinity Strategy.

8.2 Storage of information

Regional and corporate databases
New DEFL proposed to store additional population, threat and management information obtained from future monitoring
A monitoring form will be developed as part of this process

8.3 Reporting

- Routine reporting should included post-burn reporting associated with the prescription;
- annual Threatened Species/ Recovery Team Reports;
- Corporate datasets-DEFL, WAHERB, TEC
- Permit to take reporting conditions
- External funding sources report (NRM, NHT)
- Office of PP Annual Report on achievements
- External funding from the Commonwealth's NHT,
- Occasional reporting will include EPBC Act referral conditions reporting, advisory committees and the Conservation Commission

9 Summary

Monitoring is the repeated measurement of a factor or range of factors over time to determine change. Objectives must be clear, relevant and achievable. It is important to choose the correct monitoring "tool" to achieve the objective.

- Rare Flora Report Forms are used to obtain the population data (number of plants, reproductive state, threats, general conditions)
- Photo points are used to illustrate change over medium to long time periods but don't produce "hard" quantitative data
- Transects and quadrats are useful when monitoring individual plants and threatening processes
- Information storage is essential—Corporate (DEFL, TEC, WAHERB) and local databases.

Dept Environment & Conservation

Threatened Flora Management Course Sept 2000

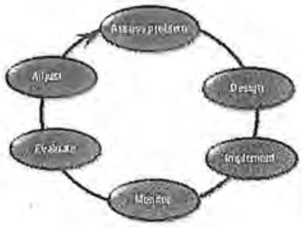
Monitoring – What is it ?

- Monitoring is the **repeated measurement** of a factor or range of factors at one or more locations over time to **determine change**.
- Evaluation is the **analysis** of the "raw information" collected during monitoring and **interpretation** of this analysis to enable **conclusions** to be drawn and the **effectiveness** of management actions to be assessed.
- Hint: monitoring is **more than** data collection.

Monitoring – What is it ?

- To be effective monitoring programs need to be designed so that they can identify the cause(s) of detected change. - it needs **diagnostic power**.
- Ecological monitoring should be part of an adaptive management framework - **Adaptive Management** is;
  - *"a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs."*

The adaptive management cycle:



Why Monitor ?

"Triggers" to initiate a monitoring program

- **Legislative/Statutory requirements:** "permit to take" / ethics committee conditions
- **Mgt Plan/Recovery Plan, mgt considerations:** identified in a burn prescription, disturbance operations, IMG's etc, Environmental Checklists.
- **Address gaps in biological knowledge :** identify regeneration biology/mechanism (reseeder, resprouter), baseline data, improve currency, quality & comprehensiveness of knowledge,

  determine & measure impacts of key threats, ascertain ecological patterns & processes.

Why Monitor ?

- **To support operations & improve management:** info to formulate policy, to determine conservation status, optimal mgt methods & priorities,
- **Politics** - local, state and federal
- **To inform government and public**

Monitoring Quality

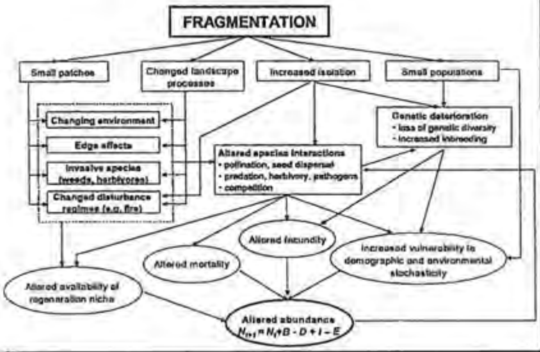
- Do we have clear objectives?
- Is the monitoring designed to meet the objectives?
- Is the data collected in a rigorous, repeatable way?
- Can the data be readily accessed, analysed and queried by district and regional staff?
- Can we get more value from the monitoring effort?
- Is the data being used to improve management decisions?
- Hint: Your district or region should have a **monitoring plan**

What to Monitor ?

Data types

- **Biological** - changes to biodiversity condition, structure & composition. At individual, population or species level.
- **Ecosystem processes & functions** – pollination vectors, nutrient distributions, hydrological patterns (larger scale).
- **Life History impacts** – regeneration mechanism (reseed/resprout) in response to intensity of fire.
- **Disturbance Processes** - fire behaviour & site conditions, soil moisture & ground water levels, grazing impact, soil sedimentation/erosion, salinity, dust & other pollution.
- **Objectives/Strategy implementation** - successful & cost effective ?

Effects of fragmentation on plant population viability



Monitoring -

variety of tools/techniques for a range of results

Monitoring Methods

- **Opportunistic or ad hoc,** ie: DOB observations
- **Qualitative** ie: photo points
- **Repeated Measurements;**
  - baseline survey - presence/absence, condition: RFFRF
  - change or trend : Permanent quadrats & transects
  - hypothesis testing - relational: determining causative factors
- **Different spatial & temporal scales** - point data vs area data, remote sensing
- **Differences between auditing, monitoring & research**
- **Monitor the impact rather than the cause** - requires knowledge of a direct dependency relationship

Methods

Rare Flora Field Report Form

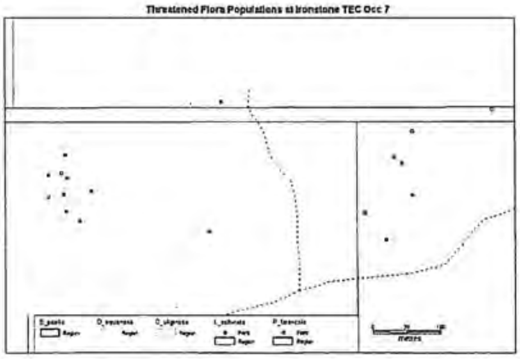
- Provides a **"Snap shot"** of all or part of a population at one point in time.
- **Minimum Requirements:**
  - Species name
  - DEFL population number
  - New or known population
  - Accurate location info (GPS + description)
  - Survey Effort (full, partial, area)
  - # of Adult, Juvenile, Seedling's
  - Reproductive state
  - Condition of the population, habitat
  - Existing or potential threatening processes

Methods

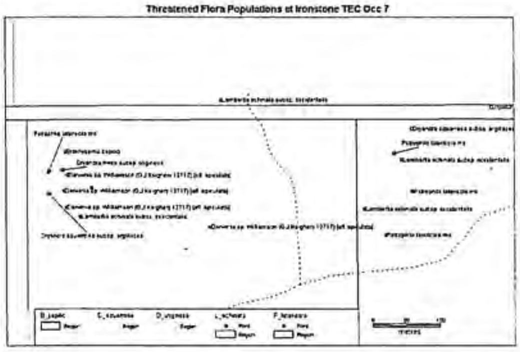
RFRF

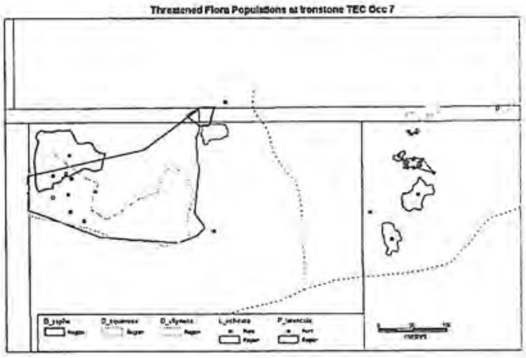
- Other information that can be included;
  - Landform
  - Soil type
  - Vegetation type (using Muir's classification)
  - Associated species
  - Fire history
  - Pollinators
  - Specimen collection information
- Information is entered into **(DEFL),** the Declared Endangered Flora Listing database administered by Species and Communities Branch.
- Vouchers sent to Herbarium and entered into **WAHerb & Florabase.**

Threatened Flora Populations at Ironstone TEC Occ 7



Threatened Flora Populations at Ironstone TEC Occ 7





Methods

Photographic Monitoring

Is the simplest and most convenient method;

Benefits

- Provides information over a long period if there is adequate standardisation.
- Visually communicates the nature of changes over time.

Shortfalls

- Difficulty in explaining changes interpreted from photographs.
- Does not readily produce quantitative data for entry into a database.

1998

1999

2001

CR Eucalypt

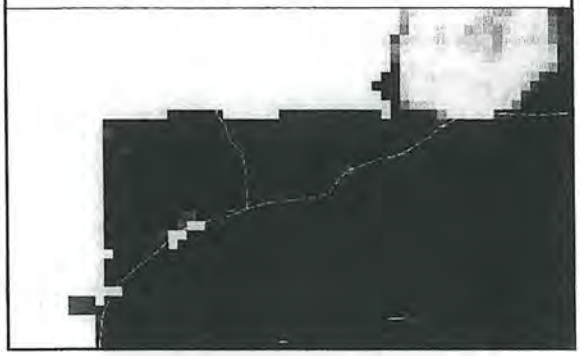
Photopoints

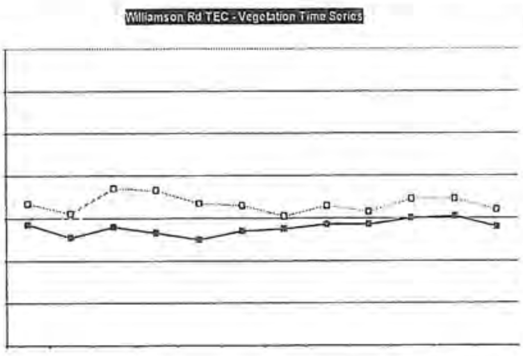
Photopoint location:	Date:	Time:
Location details:	Compass bearing:	GPS: S E
Direction of photo:	Negative number:	
Lens type/other camera settings:	Photographers name:	
Purpose of photo/site observations:		

Attach photograph here

Keep records and where you can find them in future - file pathway

"Veg Machine" - Cumulative Vegetation Trend

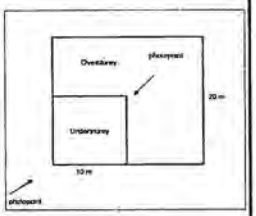




Methods

Monitoring Quadrats & Transects

- Ascertain
  - long term natural dynamics of populations
  - effect of threatening processes
  - effect of active management or recovery work
- Provide information on threats & trends
- Samples only a "subset" of the population / occurrence



mudmap diagram of markers as well as GPS.

Methods

Monitoring Quadrats & Transects

- **Repeatability is essential** - sites to be permanently marked. (in a north-south, east-west aspect using a compass)
- **Quadrat/transect size** determined by the size and density of the plants being monitored. nested quadrats of 1 - 2 metres make it easier to record presence/absence data.
- **Describe quadrat/transect using:**

Precise location	Aspect
Soil type	Water relations ?
Vegetation type	Dominant Species
Salinity	Pathogens

- **Rainfall & temperature** data useful to prevent experimental error.

Methods

Monitoring Quadrats & Transects

Count mature flowering plants and seedlings separately

- The reproductive state (flowering, fruiting, vegetative)
- The reproductive method (seed, vegetative)
- Method of seed storage (plant, soil)
- Level of seed produced (indication of suitable pollinators being active or absent)
  The health of each plant
- The height and width measured
- Active growth or dormancy stage recorded

NB: used to determine the **reproductive potential** of the population & to provide **information for ranking** when using IUCN criteria

Methods

Monitoring Quadrats & Transects

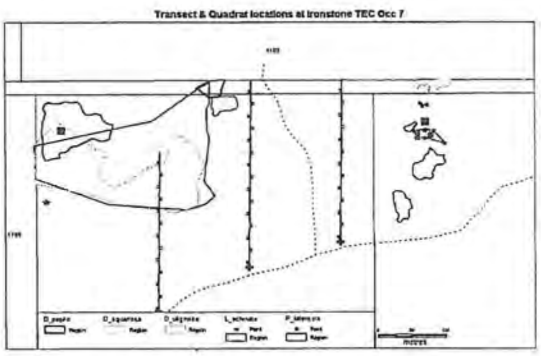
- **Associated plants** should be noted with the 10 most dominant being listed from the most to least common

- **System cards** can be used to show an example of each associated species found

Methods

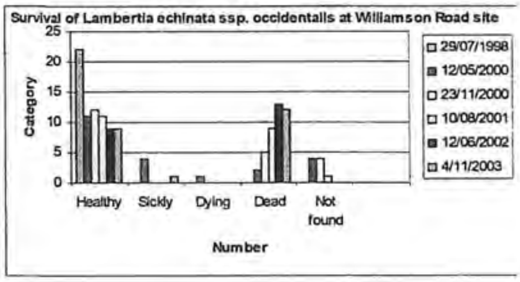
Monitoring Quadrats & Transects

- **Canopy cover should be noted** - may impact on the health of the threatened species. Ie: many species are **opportunists** that appear after fire and soil disturbance. They are often short-lived and are crowded or shaded out by other species over time.
- **Transects are most useful for larger species** that are scattered over a wide area in the landscape.
- **Vary in length and width** but are commonly 30m x 1m or 30m x 2m in size.
- Normally positioned from just **outside the edge**, through a dense part of the population being monitored.



TRANSECT	DISTANCE (m)	TAG NO	TAXON	PHENOLOGY	STEMS	HT (cm)	LONG AXIS (cm)	SHORT AXIS (cm)	NOTES
1	[illegible]	31	[illegible]	8,9	4	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	8,9	1	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	33	[illegible]	8,9	1	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	36	[illegible]	[illegible]	1	[illegible]			[illegible]
1	82	37	[illegible]	3,9	1	[illegible]	20	[illegible]	[illegible]
1	[illegible]	38	[illegible]	[illegible]	1	[illegible]			[illegible]
1	[illegible]	39	[illegible]	8,9	4	[illegible]	[illegible]	25	[illegible]
1	[illegible]	40	[illegible]	7,8	1	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	12	[illegible]	3,9	3	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	13	[illegible]	3,9	1	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	16	[illegible]	8,9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	17	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	21	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	122.4	22	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	24	[illegible]	2	1	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	25	[illegible]	2	1	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	26	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	27	[illegible]	[illegible]	2	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

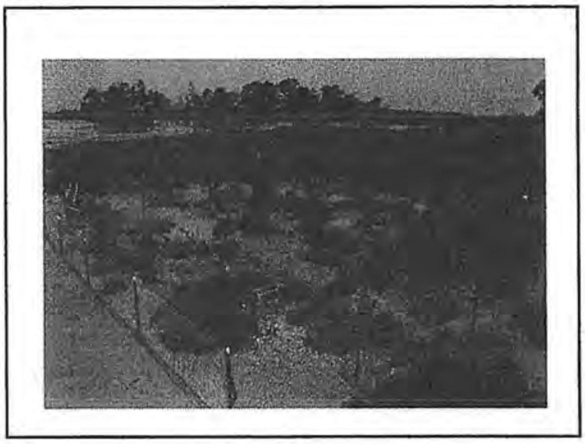
Operational Threatened Flora Management

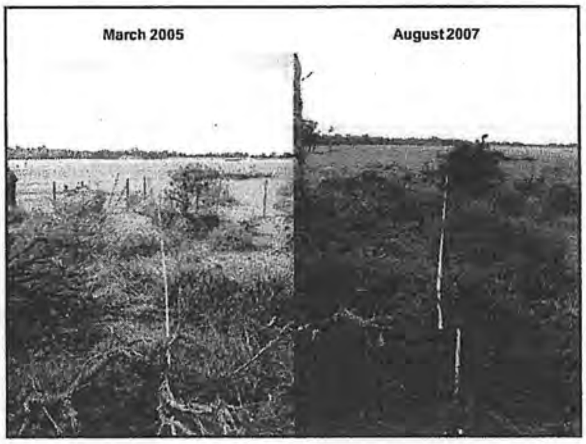


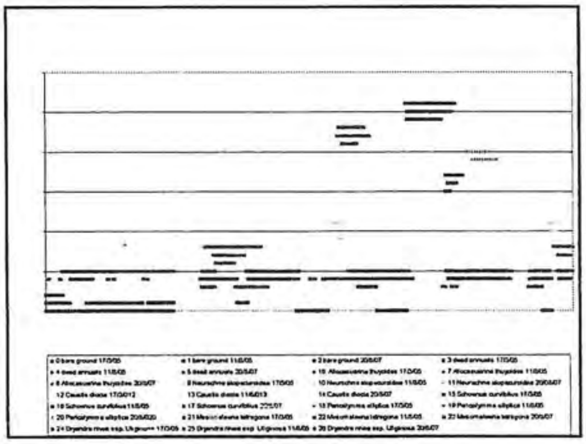
Tissue analysis phosphite concentrations of 3 Ironstone species, 2002

	Marks	Phosphite	*		
		mg/kg	Confirmed		
Species	Site	as received	*	mean (s.e.)	2001 levels
Dryandra squarrosa ssp. argillaceae	Wornerup Road	260			
Dryandra squarrosa ssp. argillaceae	Wornerup Road	230			
Dryandra squarrosa ssp. argillaceae	Wornerup Road	400			
Dryandra squarrosa ssp. argillaceae	Wornerup Road	69	*	240 (68)	
Dryandra nivea ssp. uliginosa	Williamson Road - west	8.5			
Dryandra nivea ssp. uliginosa	Williamson Road - west	4.6			
Dryandra nivea ssp. uliginosa	Williamson Road - west	4.2			
Dryandra nivea ssp. uliginosa	Williamson Road - west	3.0	*	5.0 (1.2)	
Lambertia echinata ssp. occidentalis	Williamson Road - west	130			140
Lambertia echinata ssp. occidentalis	Williamson Road - west	170	*		190
Lambertia echinata ssp. occidentalis	Williamson Road - west	25			310
Lambertia echinata ssp. occidentalis	Williamson Road - west	120		111 (31)	220
					215 (36)

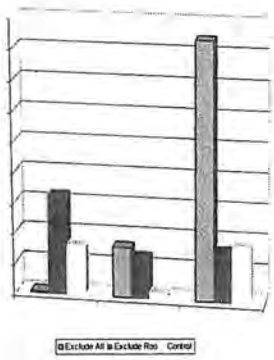
Grazing Impacts




March 2005
August 2007



Exclude All transect			
Name	**2005**	**2007**	**Change %**
Herbs			
Bare ground	516	44	91% decrease
Annuals	455	906	99% increase
Neurachne alopecuroidea	9	40	344% increase
	980	990	1% increase in herbs
Sedges			
Caustis dioica	348	395	13% increase
Lepidosperma squamatum	0	30	Recruitment
Mesomelaena tetragona	41	70	71% increase
Schoenus curvifolius	14	45	221% increase
Tremulina tremula	33	40	21% increase
	436	580	33% increase in sedges
Shrubs			
Allocasuarina thuyoides	51	200	292% increase
Dryandra nivea subsp. uliginosa	92	130	41% increase
Pericalymma ellipticum	0	55	Recruitment
	143	385	169% increase in shrubs



When to Monitor ?

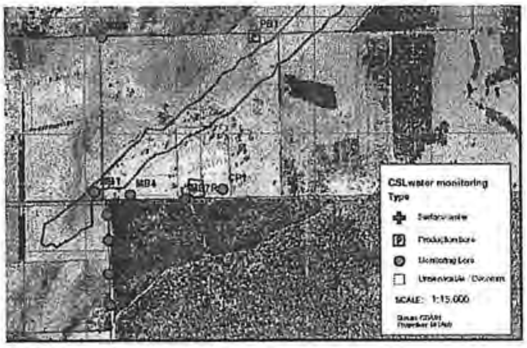
- **Day of disturbance** (eg: burn)
- **Within a few days** of disturbance
- Time **determined by Biological Response** (germination, green pick grazing, canopy closure/biomass recovery, phenological reproduction age & breeding success)
- **Frequency** - once off, intermittent or cyclic - seasonal, annual, 5yr etc

Monitoring Emphasis

- Critically endangered (CR) - highest priority and should be monitored at least annually
- Endangered (EN) - next highest priority and should be monitored at least bi-annually
- Vulnerable (VU) – next highest priority and should be monitored at least every three years (preferably more frequent)

Where to Monitor ?

- On site Vs Off site
- Displacement effects
- Point Source Vs Dispersed Nutrient Loads
  Water Abstraction Vs Local impacts
- Riparian habitat Vs feral pigs
- Impact of transported matter (sediment, nutrient, water quality).
- Implemented on both departmental and other lands.



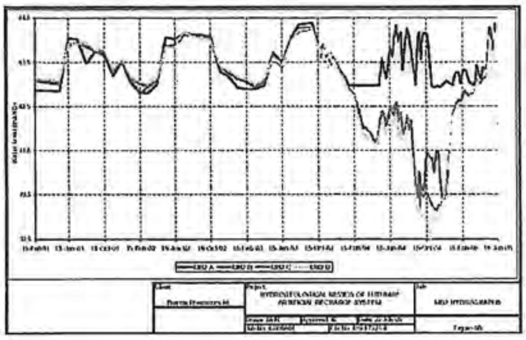
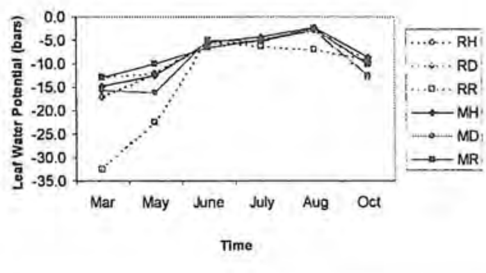
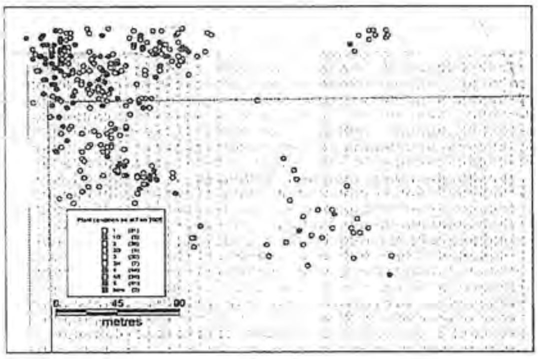


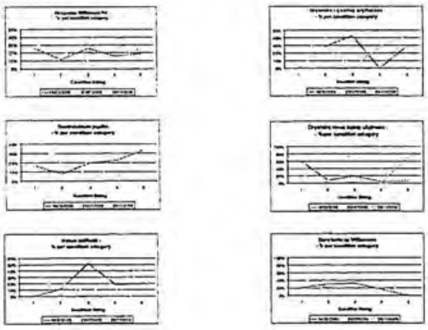
Figure 1. Pre-dawn leaf water potentials (bars) for three endangered species growing within ironstone communities.



CR flora deaths within a CR TEC – Busselton Ironstone



Condition Monitoring charts



Who Monitors ?

- NC Staff
- Specialists - local and non regional
- Assisted by other District staff
- Volunteers/Community Groups
- Tertiary Students
- Other Agencies

Funded How ?

- Identified in Recovery Plan, Interim Recovery Plan, Wildlife Mgt Plan, Area Mgt Plan.
- Identified in Annual Budgeting Process.
- Id in annual Region/District strategic operational plans / action plans.
- Externally funded by the Commonwealth's Natural Heritage Trust, Bio-prospecting and the State Salinity Strategy.
- offset funding.

Storage of Information

- **Regional & corporate databases.**
- **New DEFL proposed** to store additional population, threat and management information obtained from future monitoring
- A **monitoring form** has been developed as part of this process

Reporting

Routine

- Post burn reporting associated with the prescription.
- Annual Threatened Species / Recovery Team Rpts.
- Corporate Datasets - DEFL, WAHERB, TEC
- Permit to take reporting conditions.
- External funding source rpt (NRM, NHT).
- OPP Ann Report on achievements.

Occasional

- EPBC Act referral conditions reporting.
- Advisory Committees.
- Conservation Commission.

Summary

- Monitoring is the **repeated measurement** of a factor or range of factors over time to **determine change**.
- Evaluation is the **analysis** of monitoring data to enable **conclusions** to be formulated and management **effectiveness** assessed.
- **Objectives** – must be clear, relevant and achievable.
- Use the **correct monitoring tool** to achieve the objective.

Summary

- **Rare Flora Report Forms** – Used to obtain population data (number of plants, reproductive state, threats, general condition etc.)
- **Photo Points** – Used to illustrate change over medium to long time periods but don't produce "hard" (quantitative data).
- **Transects and Quadrats** - Useful when monitoring individual plants and threatening processes.
- **Information Storage** is essential– Corporate (DEFL, TEC, WAHerb) and Local databases.

End

Big thankyou to Erica Shedley, Andrew Brown, Russell Smith, Colin Yates for allowing parts of their presentations to be "borrowed".

Plant Disease Diagnosis and Management for South-western Australian Flora

Bryan Shearer, Colin Crane and Chris Dunne

Science Division DEC

Department of Environment and Conservation

Aims:

- Understand and recognise the major diseases affecting south-west Australian flora
- Diagnose the cause of poor plant health
- Application of appropriate management options

Disease Diagnosis

Proper diagnosis essential :

- Accurate diagnosis extremely important in preventing problem on other plants and preventing the problem in the future
- Management options depend on proper diagnosis of disease and the causal agents
- Misidentification of disease leads to wastage of time and money and further plant losses – e.g *Omphalotus* misidentified as *Armillaria* – control measure a waste of money

How does one go about diagnosing plant problems?

- Must have good observation skills;
- Be a good detective
- Keep an open mind until all the facts related to the problem have been collected – use recording sheets for a structured approach
- The possibility of multiple causal factors must be considered

7 Basics steps of disease diagnosis:

1. KNOW WHAT IS NORMAL
2. CHECK FOR SIGNS & SYMPTOMS
3. KNOW THE MAJOR DISEASES
4. OBSERVE PATTERNS
5. ASK QUESTIONS
6. LABORATORY TESTS
7. FINAL DIAGNOSIS

1. KNOW WHAT IS NORMAL

Proper plant identification:

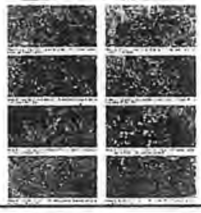
- Obvious first step covered in this course
- Needed when checking with lists of susceptibility to the disease later in the diagnosis

1. KNOW WHAT IS NORMAL

Proper plant identification:

Recognise healthy plant appearance:

- If you do not know what to expect of the plant you cannot recognise when something is wrong.
- Understand the growth habits, colours, growth rates and habitats of the plants of interest. e.g. many plants undergo colour changes associated with dry conditions in summer



Gastrolobium calycinum (York road Poison)

SUMMER WINTER

---

1. KNOW WHAT IS NORMAL

Proper plant identification:

Recognise healthy plant appearance:

- If you do not know what to expect of the plant you cannot recognise when something is wrong
- Understand the growth habits, colours, growth rates and habitats of the plants of interest. e.g. many plants undergo colour changes associated with dry conditions in summer.
- Healthy plants have background damage from environment, low level insect and fungal attack
- Complicated by declines such as Wandoo and Tuart decline. Not associated with a particular pathogen or cause – often a combination of environmental, and insect interactions

2. CHECK FOR SIGNS AND SYMPTOMS OF DISEASE

What is disease?

- Using a strict definition:

Result of an infectious organism (pathogen) that can multiply and spread to other nearby plants and interact with the environment and host plant to produce plant damage and characteristic symptoms

2. CHECK FOR SIGNS AND SYMPTOMS OF DISEASE

What is disease?

- Using the strict definition:
  Result of an infectious organism (pathogen) that can multiply and spread to other nearby plants and interact with the environment and host plant to produce plant damage and characteristic symptoms

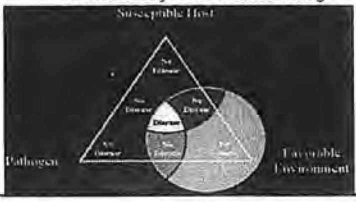
- Most pathogens are microscopic and include bacteria, fungi, nematodes, viruses, mollicutes, protozoa and parasitic plants

2. CHECK FOR SIGNS AND SYMPTOMS OF DISEASE

- Three conditions must be met for biotic plant disease to occur:
  - the host must be susceptible
  - a pathogen must be present
  - the environment must be favourable

2. CHECK FOR SIGNS AND SYMPTOMS OF DISEASE

- **Conditions necessary for disease?**
- Three conditions must be met for biotic plant disease to occur:
  - » the host must be susceptible
  - » a pathogen must be present
  - » the environment must be favourable
  - » All three of these factors must occur simultaneously – The Disease Triangle



2. CHECK FOR SIGNS AND SYMPTOMS OF DISEASE

- Signs
  - Physical evidence of the pathogen causing disease such as fruiting bodies (see display)
  - mycelium, mushrooms and spore bodies

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- Signs
  - Physical evidence of the pathogen causing disease such as fruiting bodies (see display)
  - mycelium, mushrooms and spore bodies

- *Phytophthora* is problematic in that pathogen structures are microscopic – depend on symptoms, sampling and laboratory tests

2. CHECK FOR SIGNS AND SYMPTOMS OF DISEASE

- The visible effects of disease such as:
  - plant death, lesions, wood decay

3. KNOW THE MAJOR DISEASES OF SOUTH-WESTERN FLORA

- Major pathogens are fungi – 3 main groups

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  - Diseases caused by species of *Phytophthora*

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  - Disease caused by *Armillaria luteobubalina*

3. KNOW THE MAJOR DISEASES OF SOUTH-WESTERN FLORA

- Major pathogens are fungi – 3 main groups
  - Diseases caused by species of *Phytophthora*
  - Disease caused by *Armillaria luteobubalina*
  - Diseases caused by canker fungi

Web page - Pathogen of the Month provided by Australasian Plant Pathology Society

http://www.australasianplantpathologysociety.org.au/

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

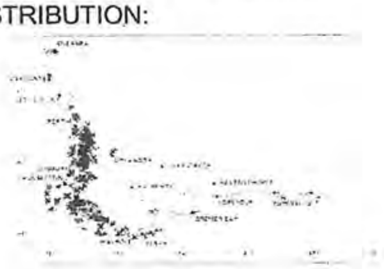
CAUSAL ORGANISM(s):

- *P. aspargi*
- *P. boehmeriae*
- *P. cinnamomi* (introduced)
- *P. citricola*
- *P. cryptogea*
- *P. cambivora*
- *P. drechsleri*
- *P. gonapodyides*
- *P. inundata*
- *P. multivora*
- *P. megasperma*
- *P. nicotianae*
- *P. niederhauserii*

+ 9 other species undetermined

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

DISTRIBUTION:



Eneabba to Cape Arid, old inner dunes to W edge of wheatbelt – mainly on leached laterites and sands.

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

DAMAGE:

Pc - W of Eneabba

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

DAMAGE:

Pm - Badgigarra National Park

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

DAMAGE:

Pc - jarrah forest

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

DAMAGE:

Pc - jarrah forest

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

DAMAGE:

Pc - *Banksia brownii* - South Coast

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

DAMAGE:

Pc – *Lambertia* - *Banksia* shrubland, Bell Track FRNP

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

DAMAGE:

Pc - *Banksia occidentalis* Cape Arid National Park

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

DETECTION & DIAGNOSIS:

Crown symptoms

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

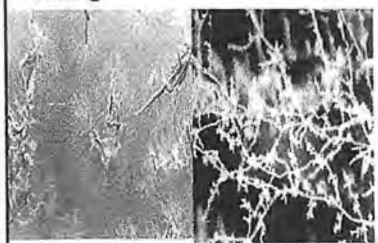
DETECTION & DIAGNOSIS:

Crown symptoms

Basal symptoms

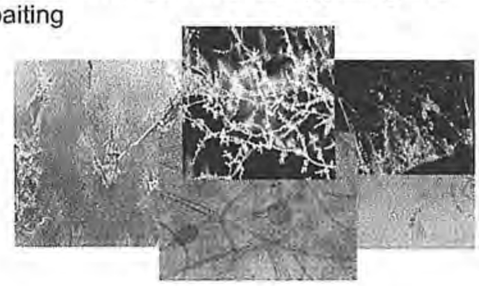
MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

Signs: determined in the lab by plating and baiting



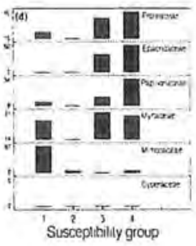
MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

Signs: determined in the lab by plating and baiting



MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

Hosts: wide host range (e.g.) threatened flora



MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

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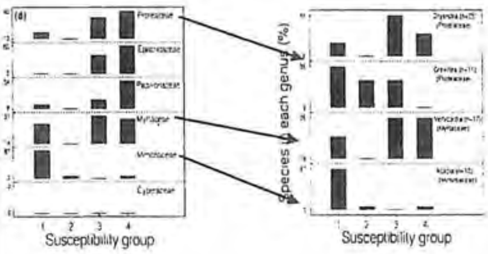


MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

Hosts: wide host range

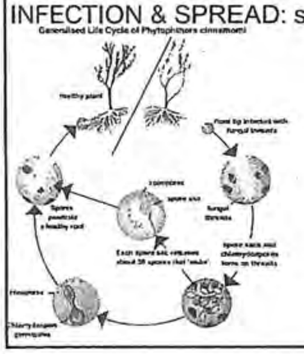
Susceptibility of South-western flora to *Phytophthora cinnamomi*

Database	Infection	Susceptible (%)	Highly susceptible (%)
Jarrah forest	natural	44	12
Banksia woodland	natural	33	15
Stirling Range NP	natural	36	10
Threatened flora	artificial	49	21
Mean		40 ± 4 [A]	14 ± 2 [B]

[A] 2300 species of the 5710 species in the South-west Botanical Province
[B] 800 species of the 5710 species in the South-west Botanical Province

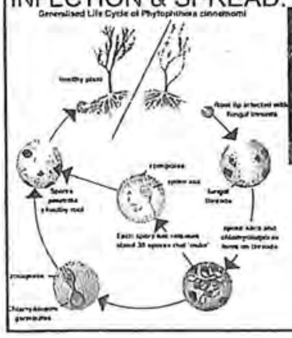
MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

INFECTION & SPREAD: soil, water, roots



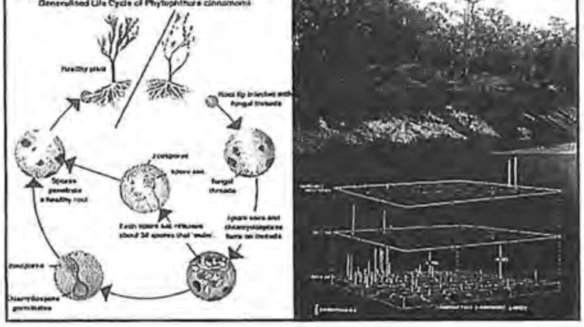
MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

INFECTION & SPREAD: soil, water, roots



MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

INFECTION & SPREAD: soil, water, roots



MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

MANAGEMENT: Hygiene, translocation, phosphite

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Phytophthora*

MANAGEMENT: Hygiene, translocation, phosphite

Dieback Working Group

A very useful contacts point for all things Phytophthora in Western Australia

http://www.dwg.org.au/

http://www.dieback.org.au/

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

CAUSAL ORGANISM:

Armillaria luteobubalina (native)

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

DISTRIBUTION:

Cervantes to Cape Arid, coastal dunes to W edge of wheatbelt – on wide range of soil types

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

DAMAGE:

Armillaria - coastal dune Cervantes

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

DAMAGE:

Armillaria - gardens metropolitan area

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

DAMAGE:

Armillaria - coastal dune Yalgorup National Park

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

DAMAGE:

Armillaria - jarrah forest

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

DAMAGE:

Armillaria - wandoo forest

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

DAMAGE:

Armillaria - karri forest

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

DAMAGE:

Armillaria - coastal dune Hopetoun, south coast

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

DETECTION & DIAGNOSIS:

Crown symptoms

Basal symptoms

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

DETECTION & DIAGNOSIS:

Crown symptoms

Basal symptoms

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

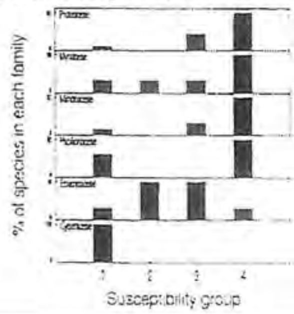
Signs: mycelial sheaths, fruiting (unreliable)

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

Signs: mycelial sheaths, fruiting (unreliable)

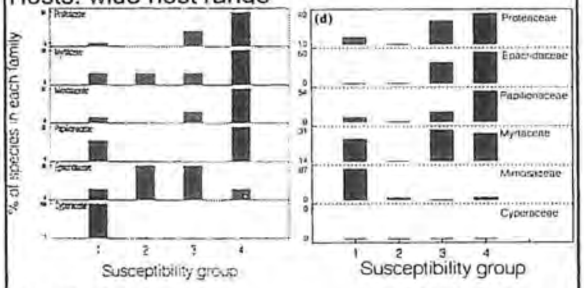
MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

Hosts: wide host range - few threatened flora



MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

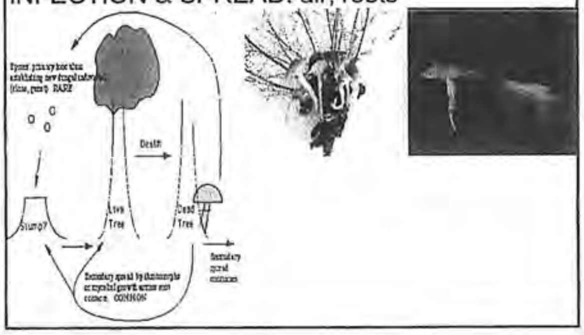
Hosts: wide host range



Armillaria *Phytophthora*

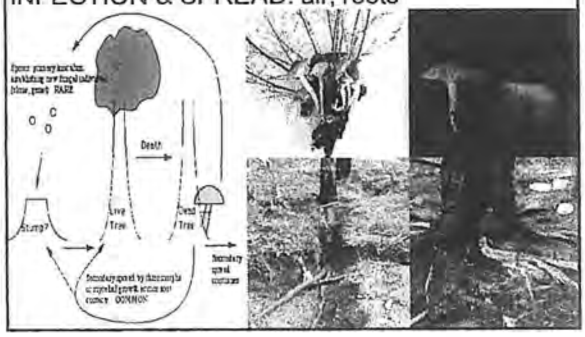
MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

INFECTION & SPREAD: air, roots



MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

INFECTION & SPREAD: air, roots



MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Armillaria*

MANAGEMENT:

Hygiene - no movement of infected roots

Prevent stress

MAJOR DISEASES OF SOUTH-WESTERN FLORA - Canker

CAUSAL ORGANISM(s): (most native)

Cryptodiaporthe
Halocryphia, Quamballaria
Botryosphaeria
Zythiostroma

MAJOR DISEASES OF SOUTH-WESTERN FLORA - Canker

DISTRIBUTION:

Very widespread – on wide range of soil types

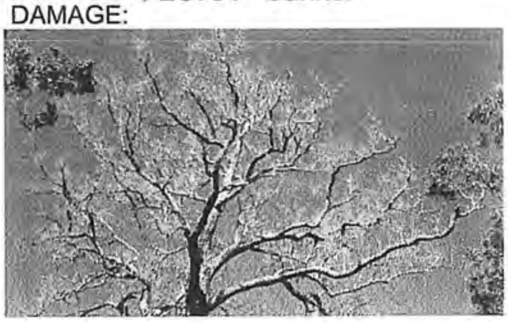
MAJOR DISEASES OF SOUTH-WESTERN FLORA - Canker

DAMAGE:

Canker - Tuart Mandurah

MAJOR DISEASES OF SOUTH-WESTERN FLORA - Canker

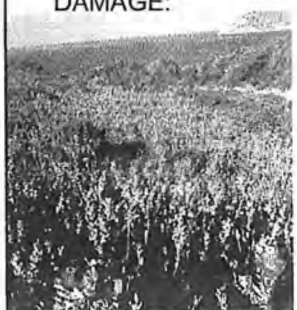
DAMAGE:



Canker - Marri throughout the south-west

MAJOR DISEASES OF SOUTH-WESTERN FLORA - Canker

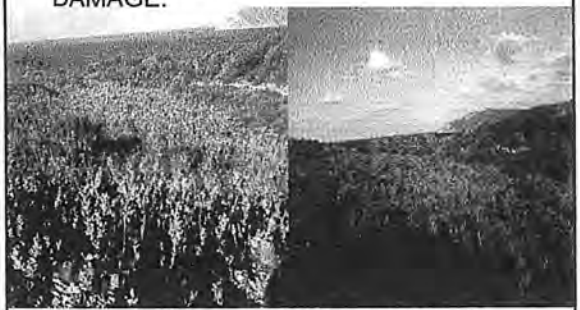
DAMAGE:



Canker - *Banksia coccinea* Bald Island 1989

MAJOR DISEASES OF SOUTH-WESTERN FLORA - Canker

DAMAGE:



Canker - *Banksia coccinea* Bald Island 1989, 1995

MAJOR DISEASES OF SOUTH-WESTERN FLORA - Canker

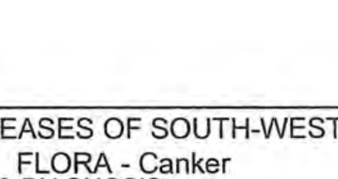
DETECTION & DIAGNOSIS:

Crown symptoms

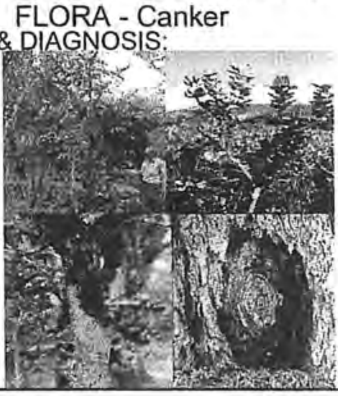
MAJOR DISEASES OF SOUTH-WESTERN FLORA - Canker

DETECTION & DIAGNOSIS:

Crown symptoms



Stem cankers
diffuse
perennial



MAJOR DISEASES OF SOUTH-WESTERN FLORA - Canker

Signs: often determined in the lab by plating

MAJOR DISEASES OF SOUTH-WESTERN FLORA - Canker

Hosts:

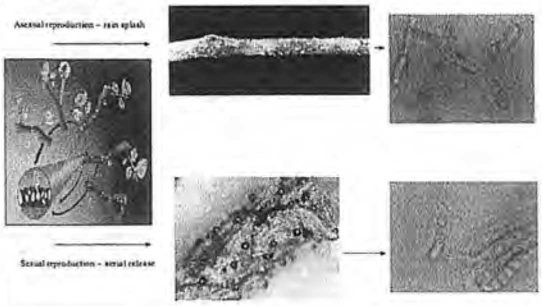
- Wide host range
- Many proteaceae - threatened *Banksia* susceptible to *Zythiostroma*
- Eucalypts resistant to *Phytophthora* susceptible to canker

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Canker*

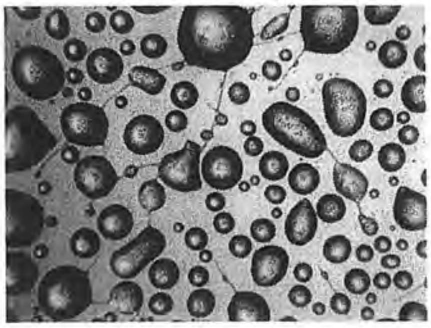
INFECTION & SPREAD: air, water splash

MAJOR DISEASES OF SOUTH-WESTERN FLORA - *Canker*

INFECTION & SPREAD: air,rain



Ascospores germinating in sub millimeter size condensation droplets



MAJOR DISEASES OF SOUTH-WESTERN FLORA - Canker

MANAGEMENT: Hygiene, destroy affected stems
Prevent stress

MAJOR DISEASES OF SOUTH-WESTERN FLORA - Other

CAUSAL ORGANISM(s):

Rusts
Leaf spots

MAJOR DISEASES OF SOUTH-WESTERN FLORA - Rusts

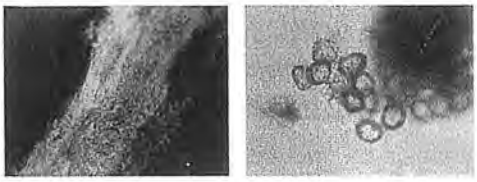
DISTRIBUTION:

Very widespread, especially wheatbelt and goldfields

MAJOR DISEASES OF SOUTH-WESTERN FLORA - Rusts

MAJOR DISEASES OF SOUTH-WESTERN FLORA - Rusts

Uromycladium tepperianum



MAJOR DISEASES OF SOUTH-WESTERN FLORA - Leaf Spots

MAJOR DISEASES OF SOUTH-WESTERN FLORA - Other

Sooty molds

MAJOR DISEASES OF SOUTH-WESTERN FLORA - Rusts and Leafspots

Hosts:
- Wide host range
- Threatened flora
- Hosts resistant to *Phytophthora* susceptible to rust or leafspot

IN SUMMARY

- Plant diseases of south-western Australia mediate plant community distribution and dynamics
- Plant diseases significantly affect biodiversity
- Plant diseases differ in their responses to host and site
- Site management must ensure that changes made do not favour disease

4. OBSERVE PATTERNS

- Timing of symptoms
  - Sickness or death occurred once – more often abiotic (associated with drought, waterlogging, herbicide) than biotic
  - Symptoms occur over time – biotic
  - Can the outbreak be related to a specific event e.g death due to *P. megasperma* often associated with summer flooding
  - Symptoms linked to discreet community succesional stages ie. expressed at senescence only

4. OBSERVE PATTERNS

- Check for host specificity
  - Plants highly resistant to *Phytophthora cinnamomi* such as most *Acacia* and *Eucalyptus wandoo* are highly susceptible to *Armillaria luteobubalina*

4. OBSERVE PATTERNS

- Are symptoms and signs associated with specific plant parts?
  - *Phytophthora* and *Armillaria* kill from the roots up.
  - Cankers kill from the tops down.
- Are symptoms associated with particular soil types?

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  - *Phytophthora* and *Armillaria* kill from the roots up.
  - Cankers kill from the tops down
- Are symptoms associated with particular soil types?
  - *Phytophthora* highest impact on infertile acidic sandy soils, low impact on loamy and calcareous soils
  - *Armillaria* tends not to occur on acidic sands and will have high impact on loamy and calcareous soils
  - Cankers can occur everywhere

4. OBSERVE PATTERNS

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    - Individual dead or sick plants– can occur with all 3 diseases

  - No indicator species present
    - Old infections of *P. cinnamomi* – may be difficult to interpret because the pathogen has removed susceptible hosts e.g. the lack of *B. grandis* in John Forest National Park – botanists tend to call these new communities!
    - Communities dominated by resistant species – uninterpretable for *P. cinnamomi*

5. ASK QUESTIONS

- What is the history of symptom expression?

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- What is the history of symptom expression?
- What are predisposing factors?
  - Site characteristics
  - Host susceptibility
- Any inciting factors?
  - What is the disturbance history of the area (altered drainage, roading, herbicide etc)
  - Changes in weather and climate patterns
  - Insect attack

6. LABORATORY TESTS

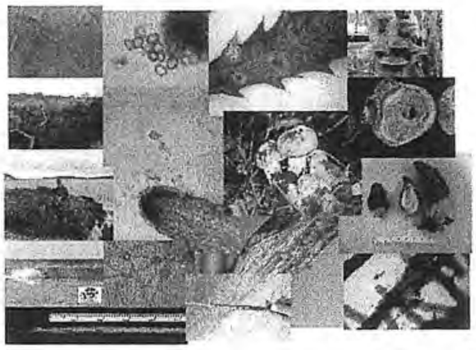
- Role of the Vegetation Health Service

- Sampling
- Baiting

- Plating (see examples)

7. FINAL DIAGNOSIS

- Sample results
- Summary table of major pathogens
- REMEMBER to
  - Be a good detective
  - Keep an open mind until all the facts related to the problem have been collected – recording sheets to help this
  - The possibility of multiple causal factors must also be considered e.g may have *Phytophthora* in wet area but deaths of *Banksia* on sandy upland – may be drought rather than disease
  - Go for help – Disease contacts
    - Chris Dunne, Colin Crane, Richard Robinson – Research
    - Mike Stukely – Vegetation Health Service
    - Mike Pez - DEC interpreters for Phytophthora interpretation & mapping



DIEBACK SIGNAGE FOR ALL

Government of Western Australia

Australian Government

WHERE IS PHYTOPHTHORA DIEBACK?

One Signage System for All

WA's Project Dieback Team with the State Dieback Consultative Council, Dieback Working Group and Department of Environment & Conservation have developed a unified dieback signage system.

Humans are the greatest culprit for spreading Phytophthora Dieback, WA's biggest killer of biodiversity. Many people are unaware they could be carrying this soil-borne pathogen into dieback free places. New signage will help people protect these areas.

Dieback Protection Areas

Special value areas have signs indicating dieback status, access restrictions and hygiene requirements.

For the first time in WA an integrated signage system has been endorsed for all lands. The aim is to raise dieback awareness and to assist in protecting special areas still free from the disease.

The system is based on the following dieback status symbols:

DIEBACK FREE | **DIEBACK INFESTED** | **DIEBACK UNKNOWN**

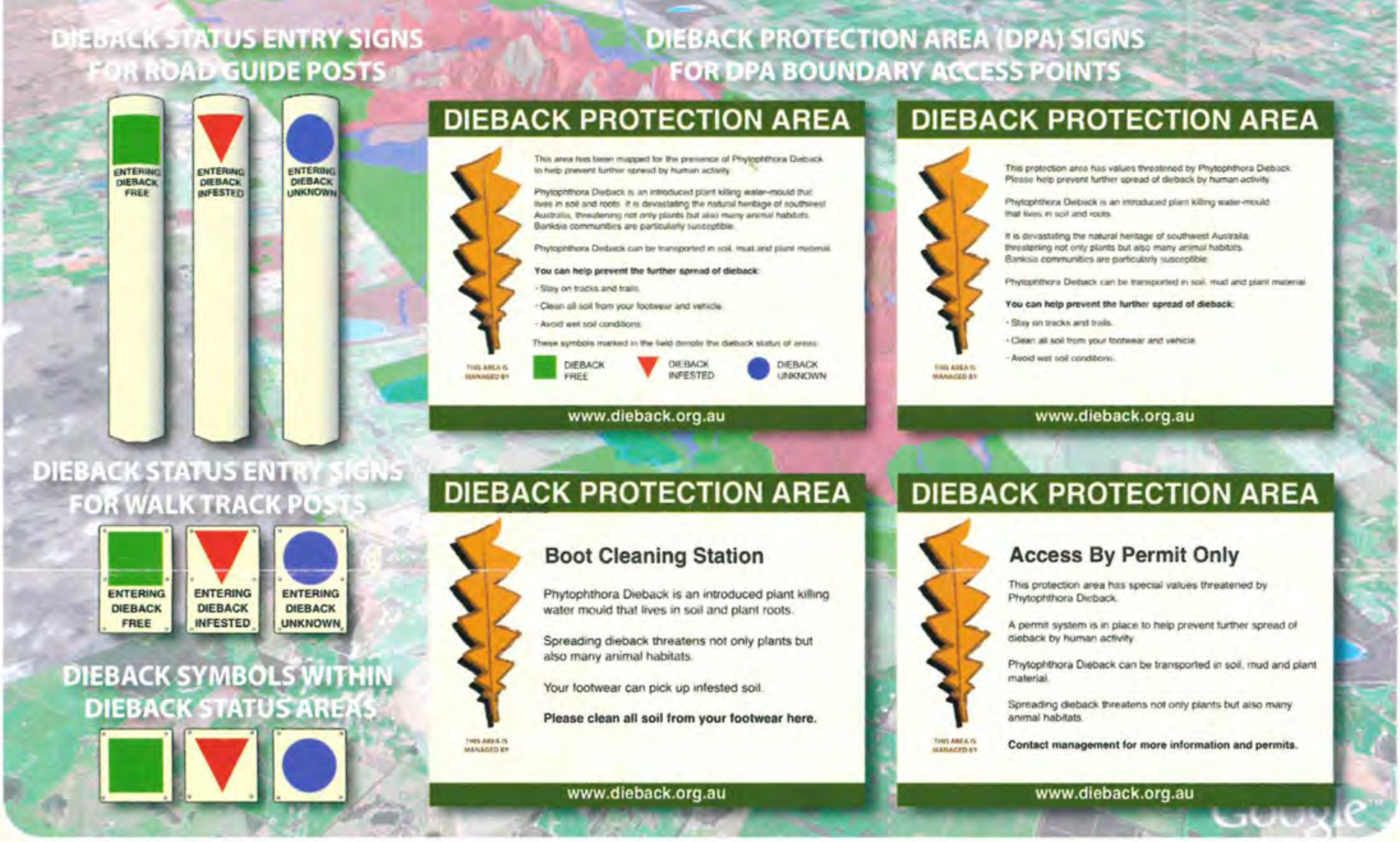
Dieback Protection Areas are currently being sign posted with these status markers across the southwest of WA.

With industry, government and community cooperation dieback free areas can be protected for future generations.

Find out more about Phytophthora Dieback

www.dieback.org.au

WA STANDARD DIEBACK SIGNAGE SYSTEM



DON'T SPREAD THE RED

People can carry Phytophthora Dieback from infested areas in many ways. Often by mud on footwear or vehicles, shifting infested soil or gravel, grading roads or moving infected plant material.

Management may include restricting access, cleaning vehicles or sterilising equipment. Dieback Protection Areas need special attention by all. These areas have special values threatened by dieback and have strict hygiene and management requirements.

BE CLEAN IN THE GREEN

HYGIENE AND SIGNS	DIEBACK FREE	DIEBACK INFESTED	DIEBACK UNKNOWN
	Cleandown stations should be used to remove or sterilise mud and soil from footwear, equipment and vehicles when **entering** Dieback Free. Avoid moist soil conditions. Access may be restricted.	An effective hygiene cleandown must be carried out when **leaving** a Dieback Infested area into Dieback Free. Ensure no infested soil or gravel, or infected plant material crosses the dieback boundary.	Areas are unknown if they have not been mapped or do not have indicators that identify the presence of Phytophthora Dieback. Areas may still have hygiene and access restrictions.

Project DIEBACK
Protecting biodiversity from Phytophthora Dieback
NATURAL RESOURCE MANAGEMENT WESTERN AUSTRALIA

SOUTHCOAST NATURAL RESOURCE MANAGEMENT | swan catchment council | AVON CATCHMENT COUNCIL | nacc | SOUTH WEST CATCHMENTS COUNCIL

Funding provided by the Australian and Western Australian Governments through the joint National Action Plan for Salinity and Water Quality programme and the Natural Heritage Trust.

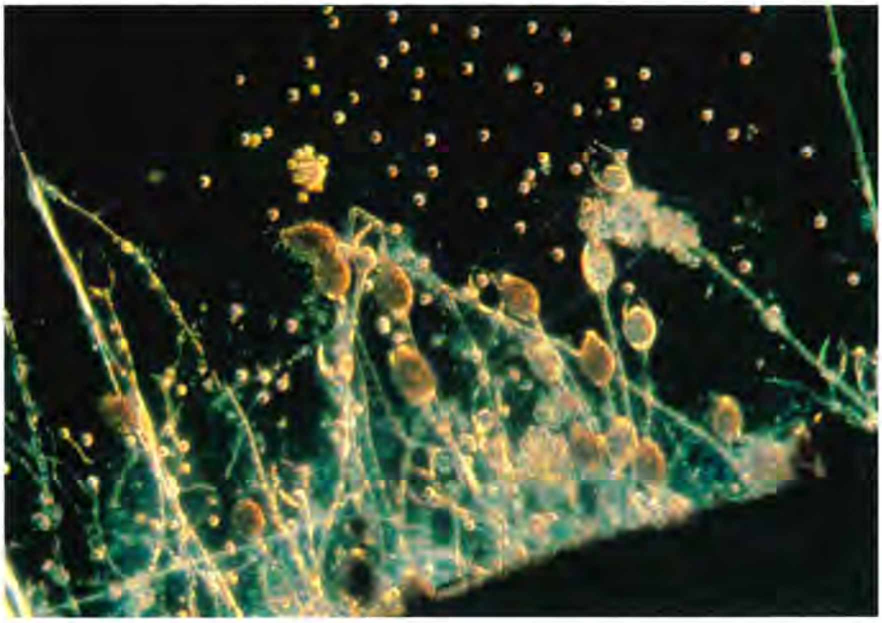
Australia's Natural Resource Management Regions working together to ensure ongoing environmental, social and economic wellbeing.

WILDFLOWER KILLERS

by Bryan Shearer, Ray Wills and Mike Stukely

Western Australia's unique wildflowers evolved in response to environmental stresses brought about by ice ages, earthquakes, flooding, fire and drought. Now they face one of the greatest threats to their existence, from seemingly insignificant, microscopic fungi belonging to a group called *Phytophthora* - the wildflower killers.

DEPARTMENT OF CONSERVATION AND LAND MANAGEMENT



Previous page:
Wild honeysuckle (*Lambertia ericifolia*) and golden dryandra (*Dryandra nobilis*).
Photo - Jiri Lochman

Spore sacs of *P. cinnamomi* release zoospores that swim in free water and infect nearby roots.
Photo - B.L. Shearer

Dieback-stricken banksia woodland in Cape Arid National Park.
Photo - Jiri Lochman ▲

For decades after foresters first noticed the deaths of jarrah trees in the early 1920s, the cause of 'jarrah dieback' escaped scientists. Only in the mid 1960s was the destroyer of jarrah finally identified by Dr Frank Podger as the soil-borne fungus, *Phytophthora cinnamomi* (see *LANDSCOPE*, Spring 1989). Dr Podger described the effects of the killer fungus in the jarrah forest, and in banksias and other wildflower communities throughout the South West. However, most of the attention and subsequent research focussed on the jarrah forest. This changed in 1985 when the departments of Forests, National Parks and Wildlife amalgamated to form the Department of Conservation and Land Management (CALM). Since then, a lot more attention has been given to the problem of infections in wildflower communities outside the forest.

We can now identify which wildflower communities are vulnerable to dieback disease, and use hygiene methods developed in the jarrah forest to help protect these communities. We also know that dieback disease is caused by seven species of soil-borne *Phytophthora*. *Phytophthora cinnamomi* is the most common and destructive, but *Phytophthora citricola*, *P. cryptogea*, *P. drechsleri*, *P. megasperma* var. *megasperma*, *P. megasperma* var. *sojae* and *P. nicotianae* also kill wildflowers.

FOREIGN INVADERS

The seven *Phytophthora* species attacking wildflower communities are not native to WA. They were probably introduced to the State with imported plants around 1900, before quarantine procedures were in place. *Phytophthora* species are now spread around the world, but the killer fungi probably originated in the sub-tropics.

During the 40 years before it was recognised that *P. cinnamomi* killed jarrah, the fungus was unwittingly spread throughout the South West by off-road vehicle activity and in infected gravel used in road construction. The fungi are also spread in soil clinging to the boots of bushwalkers, and on the feet of animals. They have also been widely distributed by people moving infected plants.

Within diseased areas, the fungi spread by growing in the root systems of infected plants, and can even spread uphill in this manner. Downhill spread is mainly by infectious spores carried by water; many of our soils contain a hard pan below the surface which causes water to pond and flow across it, carrying spores of the fungi with it. So, as well as being found in water running over the top of the soil, fungi spores may survive and spread up to five metres below the soil surface.

VULNERABLE COMMUNITIES

From the initial small dead patches of forest, dieback disease infected an estimated 280 000 ha of Crown land by 1977. Today, *Phytophthora cinnamomi* threatens diverse wildflower communities from Eneabba in the north, to the eastern edge of the jarrah forest and along the south coast to Cape Arid.

The killer fungus dramatically changes the wildflower-rich jarrah forest understorey. Wildflowers of the banksia, pea and heath families are commonly killed, causing an irreversible decline in the diversity of infected areas. Surviving trees in the forest often mask the full impact of the disease, but its effects can be as severe as those in shrubland and woodland on the coastal plain and south coast.

Dieback disease is destroying banksia communities on coastal sandplains around Perth and on the south coast. North of Perth, it is threatening the geographically restricted rose banksia (*Banksia laricina*) in the Moore River National Park. In banksia woodlands near Perth the dominant candle, holly leaf and firewood banksias (*B. attenuata*, *B. ilicifolia* and *B. menziesii*) are killed. In affected areas, no overstorey remains. Many understorey wildflower species are similarly affected: the number of species in 64-square-metre quadrats decreased from 56 in healthy woodland to 41 in diseased woodland.

On the south coast, the rare and dieback-susceptible feather-leaved banksia (*B. brownii*) is threatened with extinction; all of its few known locations are infected. The rich flora of the Stirling Range National Park is also under threat. The fungus was probably spread throughout the park by off-road vehicles and the construction of firebreaks and roads during the 1940s to 1960s. Walk trails are also infected. Grassy areas of low diversity replace wildflower-rich shrublands and woodlands in the infested areas of the park. Vegetation in Cape

Arid and Cape Le Grand National Parks is also suffering considerable damage.

The Fitzgerald National Park is one of the richest wildflower areas in WA, with 20 per cent of the State's described plant species. *Phytophthora cinnamomi* infects a narrow six-kilometre strip along Bell track, illegally built in 1971 in the northern-central part of the park. Bird's nest banksia (*B. baxteri*) and Lambertia thicket is being destroyed within the infected area. The spectacular royal hakea (*Hakea victoreae*) survives for a time in infected areas, but eventually dies. The protection of the healthy vegetation that still covers most of the park is a high priority.

The other wildflower killers are also causing concern. *Phytophthora citricola* is the most widespread, mainly killing individual plants in the area bordered by Kalbarri in the north, Boyagin Rock to the east and along the south coast to Cape Arid. *Phytophthora megasperma* kills banksia communities in seasonally waterlogged areas on the Northern Sandplains and south coast. *Phytophthora cryptogea* and *P. drechsleri* are associated with water bodies and *P. nicotianae* occasionally kills banksias.

Large areas of wildflower-rich shrublands are still disease-free, but vulnerable to infection. It is essential to prevent further losses by protecting healthy wildflower communities from disease.

LOSSES TO THE COMMUNITY

In 1989, government and industry spent at least $3.5 million dollars on dieback disease detection, mapping, prevention and research. These costs will probably increase in the future as the fight against the disease intensifies.

The loss of wildflowers directly affects multi-million dollar industries such as tourism and honey production. The wildflower areas north of Perth and on the south coast are vulnerable to infection, while popular tourist areas such as the Stirling Range National Park and Two Peoples Bay Nature Reserve are severely affected.

The death of wildflowers also affects the species that depend on them for food and shelter. Wildflower communities are varied and complex. The firewood banksia and the woollybush (*Adenanthos cygnorum*), for instance, are keystone species in the banksia woodlands around Perth.

Firewood banksia flowers in winter and is an important source of pollen and nectar for many birds and insects, at a time when few other species flower. Insect larvae that use the flower heads are an important food for cockatoos, while in autumn the nutritious seed and seedlings are eaten by many animals. Woollybush flowers from spring to autumn, and complements firewood banksia as a nectar source for birds and insects. It also has special glands that provide nectar for ants, wasps and other insects all year round. Woollybush fruits provide

The rich flora of the Stirling Range National Park is threatened by dieback disease, especially along walktrails.
Photo - Cliff Winfield ▶

Royal hakea survives for a time in infected areas but eventually succumbs to dieback.
Photo - Marie Lochman ▼

food for birds, rodents and ants, while the leaves are eaten by a specialised moth, the larvae of which are preyed upon by a wasp. The death of just these two plants has great consequences for these dependent animals.

Similar interactions occur in many other wildflower communities. About 15 per cent of South West plant species are pollinated by birds and mammals. Banksias and related wildflowers have large flowers pollinated by nectar-eating animals such as the western pygmy possum and honey possum. Seed-eating parrots might also be affected by the loss of favoured seed-producing species such as banksias or hakeas.

Populations of bird or mammal pollinators may dwindle as the plants on which they depend are eliminated. If only a few plants remain, there may not be enough food to sustain the pollinators. If the pollinators disappear, the few remaining plants may never set seed, despite having survived the killer fungi. In this way, death of susceptible species may reduce the numbers of pollinators essential to the survival of more resistant plants such as the endangered rose mallee (*Eucalyptus rhodantha*), and can thus affect neighbouring communities as well. However, we still have to learn a lot more about the interactions within wildflower communities in order to determine the true cost of dieback disease.

WHY SO VULNERABLE?

The *Phytophthora* fungi can attack at least 1 000 plant species throughout the world. Because the killer fungi were only recently introduced to WA, the State's wildflowers have little resistance to infection. Our wildflowers have adapted to poor soils and drought by developing extensive specialised root systems for maximum intake of nutrients and water, but that is precisely what makes them vulnerable to the killer fungi.

Western Australian climate and soils provide many favourable environments for the fungi. *Phytophthora* species thrive in warm, moist conditions during autumn and spring. Rainy winters create wet conditions that allow infectious spores to survive and spread in moist soil picked up by vehicles and in flowing water. Moist conditions are created for most of the year above hard pans deep in the soil. Thus, even though the surface soil may be dry, millions of infectious spores may be produced and distributed deep in the soil. Warm temperatures in summer also favour rapid fungal growth along the root systems of infected plants and result in the infection of new hosts through root-to-root contact.

MANAGING THE DISEASE

Dieback disease is everybody's problem. Effective control depends on the combined efforts of the public, assorted industries, and federal, state and local government. The more people know about the disease, the more they can do to prevent its spread. Rotary International District 9460 and a newly formed Northern Sandplains Dieback Working Party are helping the government increase public awareness and training.

Mapping the extent of the disease is an essential first step in effective prevention. The dieback mapping system developed by CALM staff for the jarrah forest is one of the most effective disease detection techniques in the world. This system is based on the interpretation of colour aerial photographs and is now also used to map dieback distribution in wildflower communities.

Quarantine and hygiene procedures have been developed in areas managed by CALM. Roads and tracks in national parks, reserves and forest have been closed to stop the infection from being introduced into healthy areas with susceptible and endangered wildflowers. Everyone can apply their own quarantine by keeping to all-weather roads, especially during wet weather.

Clean work practices also help to prevent the movement of infected soil, plant material and water into healthy areas. A package of hygienic procedures is used to minimise the consequences

Above:
A CALM officer injects an acorn banksia (*B. prionotes*) with phosphorous acid.
Photo - Bryan Shearer

Far left (above):
Animal species such as honey possums that use susceptible plants for food are also affected by dieback.
Photo - Michael Morcombe

Far left (below):
The rare rose mallee is fairly resistant to the disease.
Photo - Jiri Lochman

Left (above):
Flowering understorey of the jarrah forest - honeybush dies out, leaving only the resistant wattle, prickly moses.
Photo - Marie Lochman

Left (below):
Fox banksia (*Banksia sphaerocarpa*) is susceptible.
Photo - Michael Morcombe

should any one procedure accidentally fail. These include cleaning machinery, vehicles and footwear; controlling the movement of soil and road-making materials; minimising activities when soils are wet and sticky; disinfecting water used from streams and dams; paying attention to drainage; and carrying out essential activities only.

These methods of disease management help protect large areas of healthy bush from dieback disease, but are regarded as a holding action until better methods of controlling the disease have been developed.

FUTURE OPTIONS

At the moment, dieback fungi are usually only detected after plants have died. Remote sensing, using special detectors that sense thermal and infra-red radiation, may give early warning of infection. Trials are under way to see if healthy wildflower communities growing on soils that favour the disease can be mapped and if infected plants can be identified before they die.

Scientists now know much about how *P. cinnamomi* survives and spreads under local conditions. We need to learn more about how the other six *Phytophthora* species reproduce and survive. Determining moisture and temperature conditions that affect the ability of the fungi to produce spores, survive and infect hosts will help scientists to assess the risk of infection, and to develop hygiene maps and effective methods of control.

There may also be great potential in a host's own resistance. While many populations of susceptible species are decimated by the killer fungi, a few individuals occasionally survive. Though they often escape by chance (perhaps some subtle barrier in the soil prevented infection), some plants may have developed a genetic variation that helps them resist the fungus. If resistant individuals can be found, there is hope of replacing susceptible populations with resistant varieties. Research on resistant jarrah has shown great promise. This work will be expanded to include other key groups of plants.

Where conserving plants in the wild is not possible, tissue culture can be used to propagate and store plants at risk. This may allow us to re-establish these plants after means of controlling the killer fungi have been fully developed. Longer-term research may allow genetic engineering of the plants to include genes for resistance found in other species.

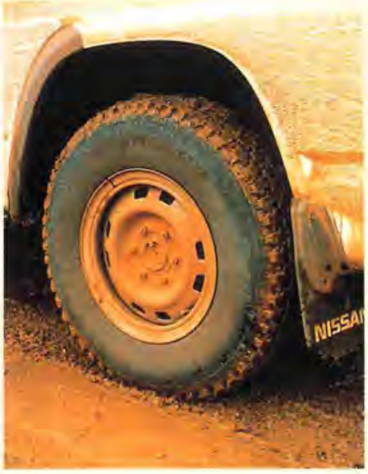
Chemotherapy is another important measure. Phosphorous acid, a cheap, biodegradable fungicide not toxic to people or animals, may be a practical way to control infection in wildflower communities. The fungicide controls all the *Phytophthora* species except *P. megasperma*. It penetrates all parts of the plant, even roots metres below the soil surface. The fungicide has a double action; it directly attacks the fungi and also boosts the plants' natural defences. Phosphorous acid protects banksias from

Photo - Jiri Lochman

WHAT YOU CAN DO

The fight against wildflower dieback must involve the whole community. You can help if you:

- Find out about the biology of the killer fungi.
- Become aware of where wildflower dieback already occurs and the effects the disease is having on plant communities.
- Take an interest in protecting your local piece of bush.
- Support the efforts aimed at containing the spread of the fungi and at finding a cure.
- Stop the spread by keeping to well-formed, well-drained roads and observe "road closed" signs.
- Make sure you are not a fungus carrier if you have to go off road.



infection for at least four years after being applied, and banksias already infected by the fungi can heal themselves after treatment. The fungicide can be applied to plants by injecting it in their trunks, and by spraying onto the foliage for large areas. It is currently being used to protect the feather-leaved banksia from infection.

Biological research offers hope of turning the fungi on themselves. Genetic engineering may be able to exploit weaknesses in the make-up of the fungi in order to help control them. However, such options are expensive and will take time to develop.

In the meantime, the whole community must combine to fight the killer fungi. The cost of protecting healthy plant communities is small compared to the loss of conservation, plant resource and aesthetic values caused by the disease.

Although there is as yet no cure for dieback disease, human ingenuity always provides hope for the future. Meanwhile, considerable advances in research and hygiene procedures provide a holding action. Until the wildflower-killing fungi are beaten, the preservation of some of WA's unique plants and animals will hang in the balance. ◘

Bryan Shearer, Ray Wills, & Mike Stukely are all research scientists within CALM's plants disease program.

THE KILLING FUNGI

The seven soil-borne *Phytophthora* species that kill our wildflowers extract their food from plant tissues by a mass of microscopic threads, or **mycelium**, which forms the body of the fungi.

Given warm, moist conditions and interaction with soil microbes, the mycelium can bud off microscopic spore sacs which release millions of tiny infectious **zoospores**. This is the main way the *Phytophthora* species infect plants and reproduce. Once released, the zoospores swim over short distances or are passively moved in moist soil through human activity and in running water.

Active zoospore production occurs mainly in spring and autumn. In winter zoospores survive in moist soil but their production is limited by low temperatures. If the soil dries out in summer the fungi usually die, but can survive in infected roots or as more resistant spore types.

The mycelium may also bud-off **chlamydospores** which are larger than zoospores and can survive in soil and plant tissue for long periods, provided conditions do not become too dry. They cannot move on their own, but can be transferred in infected roots and soil particles. When conditions are favourable the chlamydospores germinate and produce mycelium and zoospores.

Thick-walled oospores of *P. citricola*.
Photo - Bryan Shearer

Thick-walled spores called **oospores** are also produced by the mycelium under certain conditions. Oospore production by *P. cinnamomi* is infrequent because two types of mycelium must grow together before they are formed. In comparison, *P. citricola* and *P. megasperma* readily produce oospores, as the fungi form the spores from the one type of mycelium. The thick-walled oospores can survive dry conditions and probably account for the wide distribution of *P. citricola* in south-western Australia.

After infection, the fungi invade root bark and form lesions of dead tissue. The fungi kill their hosts by destroying fine roots and girdling major roots or the base of the stem, depriving the plant of access to nutrients and water.

More than 80 per cent of species in the banksia family (banksias, grevilleas, dryandras, hakeas, and so on) may be killed by the fungi. The banksia family is often the most abundant group in many areas of the South West and so provides the fundamental elements of many plant communities.

Reprint from *LANDSCOPE* magazine (Spring 1991), published by the Department of Conservation and Land Management. 0925.1291.2M
Managing editor: Ron Kawalilak. Editor: Ray Bailey. Story editor: Carolyn Thomson. Designer: Stacey Strickland.

	Plant Pathogen Group		
	Phytophthora	***Armillaria***	***Canker***
Pathogen	*P. cinnamomi* *P. citricola* *P. cryptogea* *P. drechsleri* *P. megasperma* *P. nicotianae*	*A. luteobubalina*	*Botryosphaeria* *Cryptodiaporthe* *Zythiostroma* *Quambalaria* *Endothia*
Origin	introduced	native	native some introduced?
Sporulation	• zoospore • chlamydospore • oospore	• basidiospores	• conidia • ascospores
Spread	soil/water/roots	roots/air	air
Activity	roots up	roots up	top down
Host Range	• wide • many threatened flora	• wide • hosts resistant to Phytophthora, susceptible to Armillaria • few threatened flora	• wide • hosts resistant to Phytophthora, susceptible to canker • some threatened flora
Impact • ***Forest:***			
jarrah	low-high	low-high	low-intermediate
karri	low	low-high	low-intermediate
tuart	low	low-high	high
wandoo	low	high	high
• ***Coastal dunes***	low	high	low-intermediate
• ***Banksia woodland, shrubland***	high	low-high	low-high

DISEASE DIAGNOSIS CHECKLIST

SITE: LAT/LON:

IMAGES: SAMPLE # Branches / Stem / Soil / Root collar / Roots

ASSOCIATED VEGETATION: Forest / Woodland / Scrub / Shrubland / Heath / Herbland / Grassland / Sedgeland

IMPACT: None / Low-few deaths (clumped) / Intermediate (scattered deaths) / Int-high / High (most susceptible hosts dead)

AGE OF INFECTION: Recent (most deaths with leaves) / Mixed (old & recent) / Old

SYMPTOMS: Crown / Branches / Stem / Root collar / Roots

PREDISPOSING FACTORS

TOPOGRAPHPY: Plain / Valley / Hillside /Ridge / Dune / Creek / Wetland / Salt lake

UNDERLYING ROCK: Granite / Laterite / Limestone / Sandstone / Other

SOIL COLOUR: White / Yellow / Grey / Red / Brown / Black / Other

SOIL TYPE: Laterite / Clay / Sandy clay / Clayey sand / Sand / Other

AGE OF COMMUNITY: Young / Middle / Climax / Senescent

INCITING FACTORS:

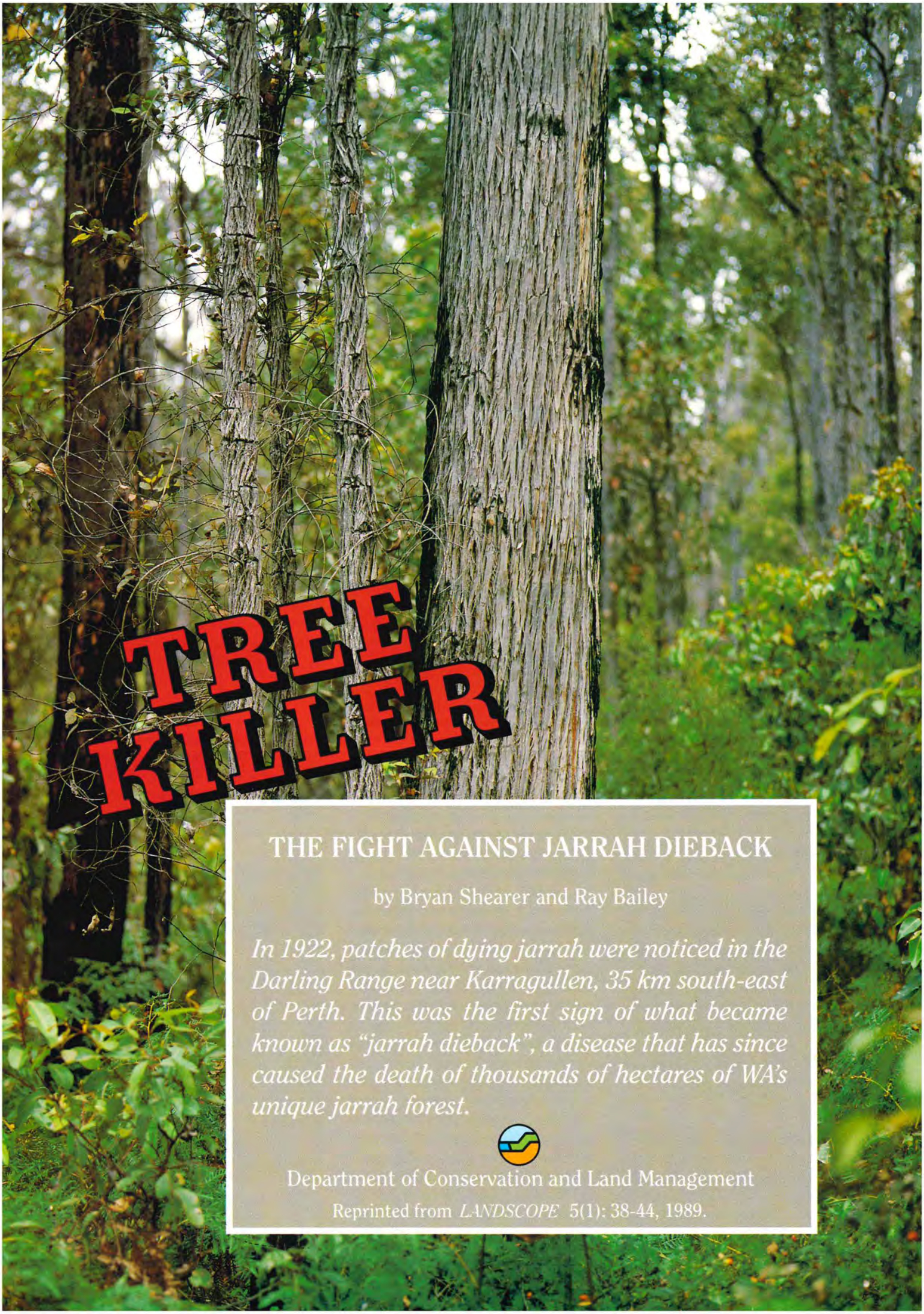
Drought / Waterlogging/ Frost / Disturbance / Insect

Fill in for main species

Species	Disease impact 1. All alive 2. <30% dead 3 ,30-90% dead 4. All dead	Regen. & recovery 1. Seedling regen 2. Adults responding to reduced competition 3. No regeneration	Abundance 1. Occasional 2. Frequent 3 .Abundant 4. Dominant	Pathogen present 1. Phytop 2. Arm 3. Canker

SAMPLE RESULTS: ....

DIAGNOSIS: ....



TREE KILLER

THE FIGHT AGAINST JARRAH DIEBACK

by Bryan Shearer and Ray Bailey

In 1922, patches of dying jarrah were noticed in the Darling Range near Karragullen, 35 km south-east of Perth. This was the first sign of what became known as "jarrah dieback", a disease that has since caused the death of thousands of hectares of WA's unique jarrah forest.

Department of Conservation and Land Management

Reprinted from *LANDSCOPE* 5(1): 38-44, 1989.

FOR half a century, the confusing behaviour of jarrah dieback was a big frustration for researchers. Susceptible understorey plants in affected areas died every year, yet jarrah died only sporadically. Then, for no apparent reason, swathes of forest would suddenly collapse. A forester would note the limits of a patch of dead jarrah, only to return in a fortnight to find the devastation advanced by as much as 50 m.

The destroyer was finally identified in 1965 by Dr Frank Podger as a killer fungus, *Phytophthora cinnamomi*. The disease is incurable, and has laid waste to large areas of trees, shrubs and plants in other parts of the world. Massive research was needed if the problem was to be curbed. The questions facing researchers were: How do we stop the fungus spreading? How do we detect it in the soil? How do we manage it, or even cure it? And how does it kill?

STOPPING THE SPREAD

Quite unknowingly, people spread the fungus throughout the South-West by moving infected soil. For example, before the fungus was identified, gravel from dieback areas was used in road construction. From the original small dead patches, the impact of the disease increased in range and severity. An estimated 280 000 ha of Crown land were infected by 1977.

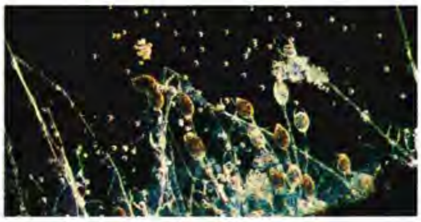
QUARANTINE

A comprehensive hygiene management program was developed in the late 1960s and large areas of forest were quarantined. Vehicle access was controlled by closing roads and restricting entry when damp soil was likely to stick to wheels and machinery. Washing down equipment became standard practice.

By preventing new infections and allowing existing ones to run their course, quarantine also aided the accurate mapping of disease distribution.

MAPPING

In the late 1970s, the development of 70 mm shadowless colour aerial photography greatly increased the accuracy of detecting and mapping disease distribution. Disease boundaries could be accurately plotted onto 1:25 000 maps,



Mass collapse of jarrah occurred in the 1960s, 1970s and 1980s after summer rainfall fell in certain sites.
Photo - Bryan Shearer ▲▲

Spore sacs of *P. cinnamomi* release zoospores that swim in free water and infect nearby roots. ▲

not only by sightings and by recovering *P. cinnamomi* from soil and plant samples, but also by identifying the deaths of susceptible trees and plants (indicator species) from the air. CALM staff were trained to interpret the photographs, and quickly became expert at mapping the patterns of death. By photographing the jarrah forest every few years, interpreters could identify every infection in the forest and locate areas for quarantine. Mapping further progressed with the development of 230 mm shadowless colour aerial photography.

The mapping system developed by CALM staff for the jarrah forest is arguably the most sophisticated forest disease detection technique in the world.

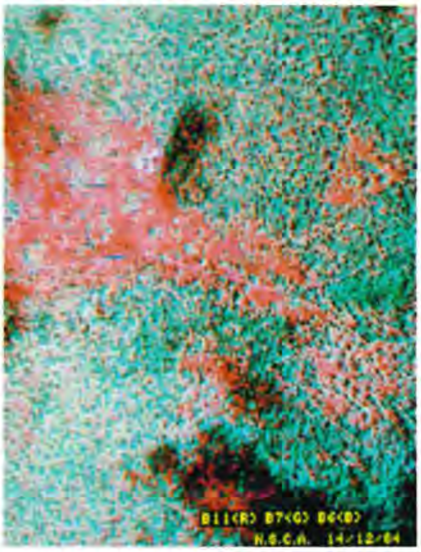
HYGIENIC FOREST OPERATIONS

Once the cause of the disease was known and its distribution mapped, all operations could be carried out hygienically to prevent the disease spreading.

Although various hygienic logging techniques were developed early in the 1970s, increased knowledge made a new system possible late in the decade. It was applied to all operations, including fire control, road construction and maintenance, and timber regeneration. Hygienic procedures were aimed at minimising the consequences if any one element in the system accidentally failed. The system has three main components: planning, exclusion and training.

In the planning phase, maps of disease distribution are used to plan the areas of operation and to determine the best hygiene methods to use. During the exclusion phase, roads are isolated and vehicle cleaning points established. Activities are confined to periods of least risk to minimise the spread of the fungus. Finally, staff are taught the biology of the fungus during their training in protective procedures.

Hygiene methods developed in State forests are now being adapted to mining and recreation areas as well as to national parks and nature reserves in the South-West.



False-colour imagery of jarrah forest. A large infected area shows up in red, while green represents healthy forest.

AN EARLY WARNING SYSTEM

Bull banksia (*Banksia grandis*) is widely distributed in the understorey of the jarrah forest. It provides a foodbase for the dieback fungus and is usually the first species to die in infected forest. This gives dramatic warning that the fungus is present. The extensive root system of bull banksia provides a "freeway" along which the growing fungus drives through the soil in summer - as much as one centimetre a day - when the surface soil is too dry and hostile for the fungus to survive. Reducing bull banksia therefore inhibits development of *P. cinnamomi*, exposing it to the withering summers. One of the aims of the Forest Improvement and Rehabilitation Scheme (FIRS), begun in 1978, is the reduction of bull banksia in the understorey. This treatment, planned by CALM and funded by ALCOA, is now being applied to forest adjacent to areas being mined for bauxite.

CAUGHT IN THE ACT

At first, researchers could not account for the long periods of apparent inactivity before and after the dieback fungus struck, the sudden ferocity of its onslaught when it did, and its neglect of some areas of jarrah compared with others.

What gave researchers the answer was rain - rain in the middle of summer. In January 1982, continuous rain soaked parts of the jarrah forest for two days. The conditions for the fungus to produce spores and grow were ideal: midsummer warmth combined with saturated soil. Nothing happened at that time; but between one and two years later, jarrah stands in that area collapsed. The fungus had struck.

Researchers and field workers redoubled their efforts, sampling roots, soil and plant material. Still they found no sign of the fungus until, almost as a last resort, they disregarded the accepted belief that the fungus was only active in the topsoil and dug deeper into the ground. With a jarrah tree excavated to reveal the tops of its vertical tap roots, the diseased tissues caused by *P. cinnamomi* were at last found - two metres below the surface along the top of a layer of solid subsoil (caprock). Other freshly killed jarrah was excavated, with similar results. The killer was finally caught in the act.

Bull banksia is one of the jarrah forest species most susceptible to dieback, and is the first to die in infected areas.
Photo - Cliff Winfield ▲

HOW DOES IT KILL?

The fungus was being spread in three ways: at surface level by human activity; through the laterally spreading roots of bull banksia; and several metres below ground, by water flowing through the soil on top of the caprock layer. Every time it rained the fungus was spread further, though not necessarily to every jarrah site. Once spread it lay dormant in the roots of trees and plants, ready to become active only when warmth and moisture occurred at the same time - rare conditions which applied during the major outbreaks of jarrah dieback observed during the fifties, sixties, seventies and early eighties. When a period of hot weather was followed by sudden rain, the fungus pounced, attacking the major vertical roots of the jarrah and almost choking off their water. Once the hot weather returned, the trees, massively needing water yet suddenly unable to receive it, died within days or even hours.

INTERIM FOUNDATION FOR JARRAH DIEBACK RESEARCH

The discovery of P. cinnamomi *in 1965 led to a research offensive through the 1960s and 1970s which had far-reaching effects on forest management. Joint Commonwealth-State ventures funded research into the biology of the fungus by the Forests Department, the CSIRO and the universities. In 1978, the aluminium and timber industries complemented government funding through a research foundation whose work was to last for nearly a decade. The role of the foundation, chaired by the Conservator of Forests with representatives from industry, universities and government departments, was to fund new and existing research. The foundation supported studies in jarrah forest ecology, understorey manipulation, host response to infection, tissue culture of jarrah, and the activity of the fungus in the soil.*

Contributors to the Dieback Research Fund

- *Alcoa of Australia*
- *Worsley Alumina*
- *Forest Products Association*
- *Wesfi*

Research Funded

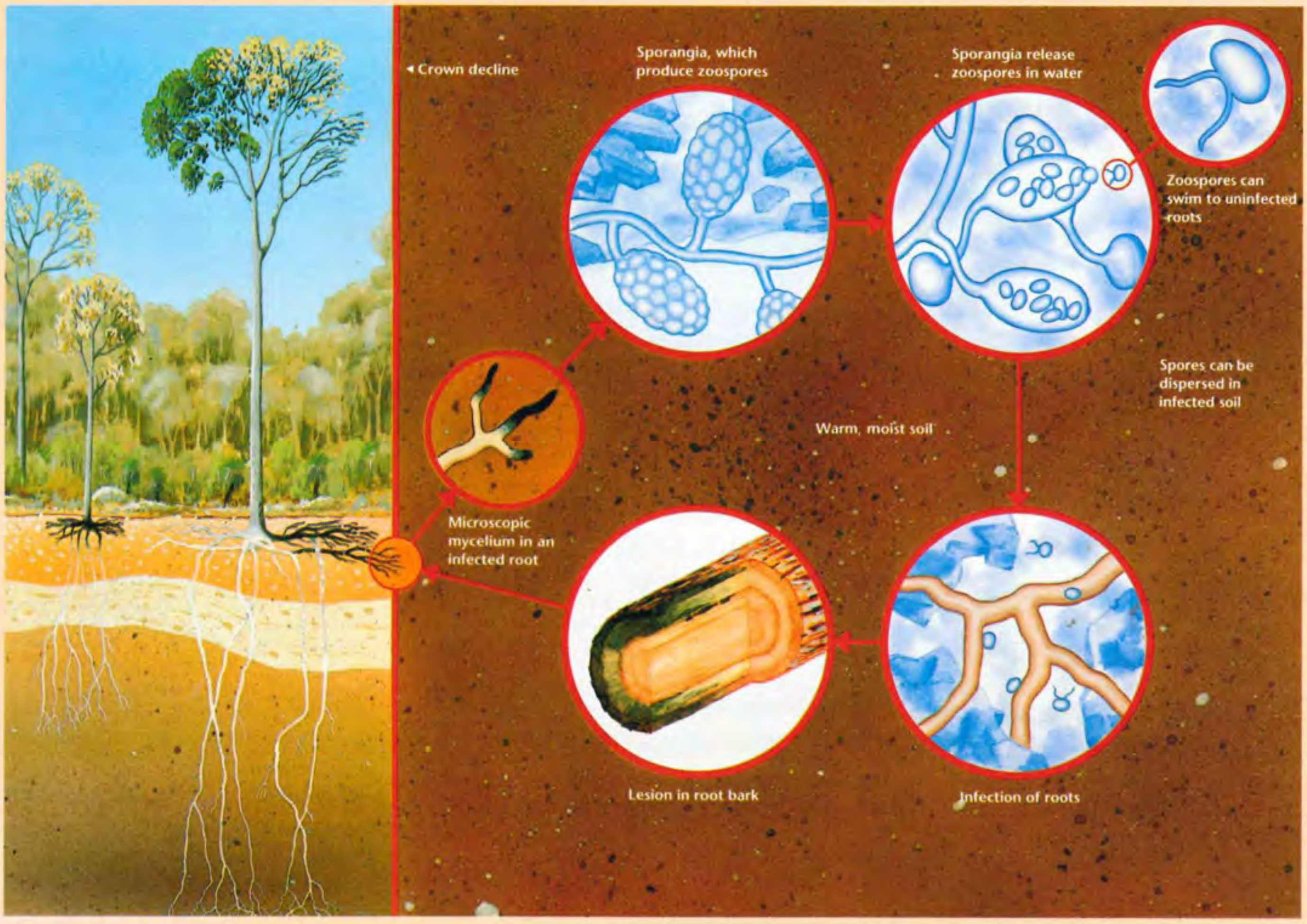
Forest ecology
(CALM, CSIRO, University of Western Australia and Curtin University)

Understorey manipulation
(CALM, CSIRO, Curtin University)

Host response to infection
(CALM, Melbourne and Murdoch Universities)

Tissue culture of jarrah
(Murdoch University)

Factors affecting activity of the fungus in the soil
(CALM)



THE KILLER FUNGUS

It was not until 1965, after years of research by many scientists, that Dr Frank Podger identified the cause of jarrah dieback as Phytophthora cinnamomi. *This pathogen was first described by a Dutch expert on plant disease in 1922 - ironically, the same year as the discovery of dieback in Western Australia.*

An introduced, soil-borne fungus, P. cinnamomi *is believed to have evolved in South-East Asia. The word* Phytophthora *comes from Greek* phyton *(plant) and* phthora *(destruction). Even though it grows best in tropical conditions, the fungus attacks nearly 1000 plant species throughout the world and is one of the most widespread plant pathogens known to man. It was probably introduced to Western Australia before the early 1900s when quarantine procedures were not in place.*

Phytophthora cinnamomi *has only relatively recently been introduced into the plant communities of south-western Australia, so they have not had the chance to evolve much resistance to the disease. South-West plant species have adapted to poor soils and drought by developing specialised root systems for maximum intake of nutrients and water, but that is precisely what makes them vulnerable to the fungus.*


Photo - L. Harman

The life cycle of P. cinnamomi *depends on moist conditions. The fungus is parasitic, and requires a living host on which to feed. The main body of a fungus - the* ***mycelium*** *- is a mass of threads, capable of producing the millions of tiny spores which reproduce the fungus.*

There are two main kinds of spores. One, the ***zoospore****, is small and spreads rapidly through water and moist soil. As they move through the soil zoospores lodge on plant roots, infect them, and, in susceptible plants, produce mycelium. The mycelium grows, feeding on the host, rotting the roots and cutting off the plant's water supply. The other type of spore, the* ***chlamydospore****, is larger than the zoospore, and can survive in the soil for long periods, provided conditions do not become too dry. They cannot move on their own, but can be transferred in particles of infected soil. When conditions are favourable the fungus again becomes active: the chlamydospores produce mycelium and zoospores.*

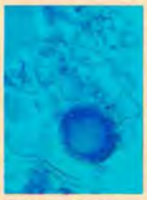


Photo - J. Tippett

After infection, the fungus invades root bark and forms ***lesions*** *which may extend into the tree collar. Infection of roots and collar results in death of host and crown decline.*


Photo - J. Tippett

PROGRESS IN THE FOREST

Forest pathology is a complex research area, needing a considerable commitment of resources. That is where the support of a foundation for jarrah dieback research was so vital (see p.41). Large trees are difficult to work with, and the soils on which they grow often have layers that resist penetration. Extremes of scale must be contended with. Jarrah trees over 30 m tall can live for centuries, with years between reproductive cycles; and a fungus that lives in microscopic soil pores and intercellular spaces has a life span of weeks to months, with a reproductive cycle of hours to days. The forest occupies a large area with a great diversity of microclimates affecting host and pathogen. The techniques needed for inoculation, excavation and assessment are therefore labour-intensive and expensive. Because trees are long-lived, factors affecting disease and attempted controls cannot be adequately tested within a few years.

Nevertheless, recent research has covered all this ground. Some of the results:

Natural Barriers: When *P. cinnamomi* infects jarrah, growth of the fungus in the outer bark can be limited by the tree's natural defences. However, these barriers are least effective when warm, moist conditions favour rapid fungal growth. Moisture level within the bark is affected by water availability within a site and the occurrence of summer rains. Once the jarrah's susceptibility is defined, the effect on the disease of different management options, under a range of site and climatic conditions, can be properly assessed.

Using Host Resistance: Testing the response of jarrah to infection has shown that some trees are genetically more resistant to the dieback fungus than others. Considerable progress in the tissue propagation of jarrah has meant that a small piece of plant material, like a bud or stamen, can be used to produce a new plant. Thus tissue culture can be used to propagate resistant plants and help re-establish jarrah on infected and mined areas.

Research has shown that changing jarrah forest understorey to favour prickly moses *(Acacia pulchella)* helps to inhibit the spread of the fungus.
Photo - Syd Shea ▲

Scientists washed down and exposed jarrah roots to study how they were infected by the dieback fungus.
Photo - Bryan Shearer ▲

Experimental burning of bull banksia, a strategy which may help reduce the spread of the fungus.
Photo - L. Harman ▼

Firing the Banksia: Research suggests that replacing susceptible species, such as banksias, with resistant legumes, such as prickly moses (*Acacia pulchella*), reduces dieback survival. Changing the understorey to one dominated by wattles alters the physical, chemical and microbiological environment of the soil to disfavour the fungus.

Burning the bull banksia-dominated understorey can result in one dominated by acacias. The use of fire to change the understorey offers a management strategy to reduce disease development over large areas, but practical application has not been as straightforward as initially hoped. More information is needed on fire ecology, acacia ecology and follow-up methods of bull banksia suppression.

Enemies in the Soil: The fungus is food for microbes in the soil. In some areas of the forest, such as under legume stands, these microbes help to suppress dieback. At present there is no practical way of applying such biological control to the forest on a wide scale. However, selected microbes could be used during rehabilitation of degraded areas.

Forest Floor Mosaics: Before the discovery that *P. cinnamomi* caused mass death of jarrah by attacking its vertical roots deep in the soil, it was thought that the whole jarrah forest could be at risk. After 1983, it was recognised that the site conditions that make jarrah vulnerable to dieback do not occur throughout the forest. These conditions include the impeding, water-spreading layer beneath the soil surface, enabling the fungus to

THE JARRAH FOREST

The jarrah forest is the most widespread forest type in the South-West of WA.
It grows predominantly on the infertile lateritic soil of the Darling Plateau. Lateritic soils are deep clays overlain by gravel. They were formed millions of years ago by chemical weathering of the eroded surface of the far more ancient granite basement rock.
The forest's dominant tree, jarrah, is a tall, straight eucalypt with dark grey fibrous bark. Its timber is renowned throughout the world for its red colour, durability and quality finish.

jarrah bark

However, many other tree and plant species, including marri, blackbutt and sheoak, make up the jarrah forest ecosystem, each growing where soil type and soil water best suits their needs. Not all of them are susceptible to the dieback fungus, while others, such as bull banksia, quickly succumb to the disease.

fringed lily

Over the forest's range, 300 species of colourful wildflowers grow in identifiable plant communities. These make up the complex shrub layer. The jarrah forest is the only place

Western Spinebill

in the world where many of the species are found.
Some of the most spectacular are members of the Protaeceae group; the banksias, dryandras, grevilleas and hakeas. Many have large flowers which attract numerous nectar-seeking birds, such as the

Acacia drumondii

Western Spinebill. The forest also provides habitat for a variety of animals.
Dieback is present in about 14 per cent of the State's jarrah forest. The disease is not randomly distributed and its intensity varies with site and vegetation type. Jarrah forest growing on the fertile, red, loamy soils in the young, dissected river valleys on the western edge of the Darling Scarp appears to be particularly resistant to the disease. Forest growing on the laterite soils of the upland areas and the silty or sandy soils in the shallow valleys is susceptible but to different degrees.

native cat

release spores, disperse, and infect the jarrah at depth. There are many jarrah sites where different conditions apply. This finding brought a much greater appreciation that the jarrah forest is comprised of a mosaic of site types with different drainage characteristics. Jarrah death ranges from high to low, depending on site characteristics and management. Time and further study of the mosaic nature of the forest floor will show whether the killer fungus is likely to erupt in any future mass killings of jarrah.

Systems have now been developed to rate uninfected areas according to the likely hazard of jarrah mortality, should the fungus be introduced. This will assist planning by determining the proportion of the uninfected landscape occupied by low, intermediate and high hazard sites.

Risk of Infection: More and more is being learnt about how conditions within the forest influence the activity of the fungus in the soil. The dispersal of spores in water seeping below the soil surface is being monitored and related to the type of forest and the climatic conditions. Determining moisture and temperature conditions that affect the dieback fungus's release of spores and even survival will help to assess the risk of infection.

Assessing Damage: Because jarrah trees die from lack of water after the dieback fungus destroys their roots, the damage being done to a living tree can be estimated by measuring the rate at which the tree uses water. This information can now be obtained by processes which no longer require the tree to be dug up.

Measuring the amount of water loss from living trees in infected areas shows how healthy the root systems are. Monitoring water loss from plants in different parts of the forest under different conditions will reveal how long some plant species are vulnerable to infection as the result of disturbance or climate.

Dieback is threatening the remnant populations of *Banksia brownii*, a rare species of the South Coast.
Photo - Greg Keighery ▲

Vehicles are washed down in all important natural areas, as a precaution against spread of dieback disease.
Photo - John Green ▼

Chemotherapy: The systemic fungicide Phosphorous acid has arrested lesion extension in bull banksia. This finding offers the first possible practical application of chemotherapy to infected plants in the forest. Promising results have been obtained in the use of chemicals to eradicate *P. cinnamomi* from the soil in spot infections. Evaluation of these control methods is continuing.

PROGNOSIS

CALM has developed hygiene methods that restrict the spread of the killer fungus, and methods that reduce its development in existing areas of infection. However, rate-reducing methods (such as using resistant biotypes and enhancing host resistance, altering the understorey, stimulating antagonistic microflora, modifying forest floor drainage, and chemical control), need further development and testing before practical application.

Phytophthora cinnamomi is a major problem in the jarrah forest. However, there is now a far better understanding of the conditions that favour pathogen dispersal and host infection; there is in particular a greater knowledge of the type of site and environment that may favour either the disease or the forest. This information, together with methods to prevent introduction and minimise spread, has shown that the cost of maintaining healthy forest is small compared to the irreversible loss in conservation, aesthetic and production values if forest is affected by disease.

The effects of the dieback fungus on plant communities other than the jarrah forest are not being ignored. Although *P. cinnamomi* has mainly been associated with jarrah dieback, it also threatens woodlands and heaths that have a high proportion of susceptible species. Hygiene methods have been applied to prevent introduction and minimise spread, and research into dieback in these communities continues.

About 75 per cent of the known plant species of the South-West are unique to the region, and many are susceptible to the dieback fungus. Introduction of the fungus threatens some plant species, such as *Banksia brownii*, with extinction. The co-operative efforts that have fuelled the fight against jarrah dieback must be maintained to help keep our unique flora free from disease. ▣

The major plant pathogens occurring in native ecosystems of south-western Australia

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Abstract

Objective assessment of the relative importance of pathogens on conservation and production values in native plant communities of south-western Australia is impeded by the lack of systematic disease surveys. The occurrence of diseases and pathogens on Western Australian native plants was compiled from published information, other reports and personal databases. Pathogens were databased according to name, host name and family, disease group and Botanical Province, giving a total of 936 entries that did not include reports of pathogens on hosts in nurseries. Ninety-one per cent of the pathogen reports were from the South-West Botanical Province and 2% from each of the Eremaean and Northern Botanical Provinces. Bacterial diseases, galls, downy and black mildews, ergot and leaf moulds were infrequently reported on native plants. Pathogens were infrequently reported on species within the families: Aizoaceae, Amaranthaceae, Amaryllidaceae, Annonaceae, Anthericaceae, Apocynaceae, Arecaceae, Asphodelaceae, Cupressaceae, Cyperaceae, Dennstaedtiaceae, Geraniaceae, Juncaceae, Lamiaceae, Linaceae, Loganiaceae, Olacaceae, Onagraceae, Phormiaceae, Pittosporaceae, Podocarpaceae, Polygonaceae, Portulacaceae, Rubiaceae, Solanaceae, Stylidiaceae, Tremandraceae, Verbenaceae and Zamiaceae. Pythiacious root rots, rusts, *Armillaria* root rots, stem cankers, and leaf spots and blights were frequently reported on native plants. Families most affected by disease were: Proteaceae, Myrtaceae, Mimosaceae, Papilionaceae, Haemodoraceae, Goodeniaceae, Epacridaceae, Poaceae and Chenopodiaceae. Families mostly affected by rusts were least affected by the root rots, stem cankers and leaf spots and blights. The biology, distribution and disease expression of *Phytophthora cinnamomi*, rust fungi, *Armillaria luteobubalina* and *Cryptodiaporthe* canker of Proteaceae in native plant communities are described. Conservation of plant taxa requires a much better inventory, than is available at present, of the incidence and status of the various plant pathogens that occur in native communities of south-western Australia. Prediction of the likely long-term effects of pathogens on native plant communities requires a much better understanding of their life cycles and biology in the south-western Australian environment.

Introduction

The lack of systematic disease surveys in native plant communities of south-western Australia impedes objective assessment of the relative importance of the impacts of pathogens on conservation and production values (Shearer & Hill 1989; Shearer 1992a). There have been no coordinated regional surveys of disease occurrence in native communities of south-western Australia, similar to the regular assessment of disease and pest conditions in Canadian forests (Forestry Canada 1993). This is somewhat surprising considering the exceptional species richness and high degree of endemicity of the flora of south-western Australia. At least 7000 species of described native vascular plants occur within the state (Green 1985), of which over 3000 are endemic to the area (Keighery 1992). Knowledge of the diseases of native plant taxa is important for maintenance of long-term conservation and production values, especially in the case of rare and endangered taxa.

Current knowledge of the occurrence, biology and impact of pathogens in Western Australia has mainly accumulated from research initiated in response to potential disease threats to wood production, such as early research on wood rots and jarrah dieback (Shearer 1992b), or from opportunistic individual curiosity and observation. Since the mid 1980's, there has been a growing appreciation of the threat of disease to conservation values (Shearer 1992b).

This paper assesses the relative occurrence of pathogens on native plant species from published information and personal databases and then describes the biology, distribution and disease expression of the major pathogens affecting Western Australian native plant communities.

Diseases and pathogens of Western Australian native plants

Occurrence of diseases and pathogens on Western Australia native plants was compiled from published information and reports (Brandis *et al.* 1984; Brittain 1989; Hill 1990; Shearer 1992a; Shivas 1989; Wills 1993) and from survey and isolation databases of my own and those of S Bellgard, F Bunny and the Plant Health Service, Department Conservation and Land Management. Pathogens were databased

Symposium on Plant Diseases in Ecosystems: Threats and impacts in south-western Australia.
Held on April 16, 1994, at Murdoch University, by the Royal Society of Western Australia and the Ecological Society of Australia.

according to name, host name and family, disease group (*e.g.* Pythiacious root rots, *Armillaria* root rots, rust, mildew, *etc*) and Botanical Province. Nomenclature of plant taxa follows that of Green (1985). The database consisted of a total of 936 entries, and did not include reports of pathogens on hosts in nurseries. Because of the lack of comprehensive surveys, the current information is incomplete and the database represents an indication of the occurrence of a pathogen on a particular host species rather than the intrinsic frequency of its occurrence. The number of occurrences within families can give some measure of the pathogens relative importance. The analysis will, however, favour pathogens and plant taxa most studied. The analysis will also favour pathogens with wide host range, and disfavour those with high impact but narrow host range.

Ninety-one per cent of the pathogen reports were from the South-West Botanical Province and 2% from each of the Eremaean and Northern Botanical Provinces. This partly reflects the greater concentration of research activity that has occurred in the South-West Botanical Province.

Disease groups occurring in three or more families and families within which there was three or more occurrences of a pathogen are shown in Table 1. Bacterial diseases, galls, downy and black mildews, ergot, and leaf moulds were infrequently reported on native plants. Pathogens were infrequently reported on species within the families: Aizoaceae, Amaranthaceae, Amaryllidaceae, Annonaceae, Anthericaceae, Apocynaceae, Arecaceae, Asphodelaceae, Cupressaceae, Cyperaceae, Dennstaedtiaceae, Geraniaceae, Juncaceae, Lamiaceae, Linaceae, Loganiaceae, Olacaceae, Onagraceae, Phormiaceae, Pittosporaceae, Podocarpaceae, Polygonaceae, Portulacaceae, Rubiaceae, Solanaceae, Stylidiaceae, Tremandraceae, Verbenaceae and Zamiaceae. This list of families with infrequent disease does not simply reflect families with few species, as only 25% of the families have 5 or less species and just over a third have more than 40 species (Green 1985). The list may represent families that are relatively disease free, but plant taxa may also be included because of limited investigation of disease occurrence.

Pythiacious root rots, rusts, *Armillaria* root rots, stem cankers, and leaf spots and blights were frequently reported on native plants (Table 1). Families most affected by disease were: Proteaceae, Myrtaceae, Mimosaceae, Papilionaceae, Haemodoraceae, Goodeniaceae, Epacridaceae, Poaceae and

Table 1

Frequency of occurrence of pathogens within disease groups and families for which there was three or more records; less frequently occurring groups and families not included are listed in the text. Totals are for all entries in the database and do not necessarily match the row or column totals.

Family	Disease group										Total for all disease groups
	Pythiacious root rots	Rusts	Armillaria root rot	Stem cankers	Leaf spots and blights	Smuts	Wood rots	Powdery mildews	Crown rot	White rust	
Proteaceae	136	3	39	53	27						258
Myrtaceae	55		25	33	17		22	7			161
Mimosaceae	5	73	13		7						98
Papilionaceae	29	7	18		6						61
Haemodoraceae	5	27	1		6				3		42
Goodeniaceae	2	37	1							1	41
Epacridaceae	24		14		1						39
Poaceae		14			1	17					35
Chenopodiaceae		13		4	5						22
Dilleniaceae	12		4		1						17
Asteraceae		11	1					2			15
Rutaceae	7	2	2								11
Colchicaceae		10									10
Orchidaceae		9						1			10
Xanthorrhoeaceae	6		2		1						9
Casuarinaceae	4		3				1				8
Iridaceae	6		1		1						8
Rhamnaceae	1	3	2								6
Apiaceae	1	2	1		1						5
Dasypogonaceae	4		1								5
Euphorbiaceae	2		3								5
Restionaceae			2			3					5
Santalaceae			2		3						5
Sterculiaceae	3	1	1								5
Thymelaeaceae	2		3								5
Ranunculaceae		2	1					1			4
Myoporaceae		1	1								3
Zygophyllaceae		3									3
Total for all families	310	232	147	91	79	25	23	12	4	3	936

Chenopodiaceae. Frequency of occurrence of Pythiacious root rots, *Armillaria* root rots, stem cankers and leaf spots and blights were similar between families, although there was a more frequent occurrence of *Armillaria* root rot in the Mimosaceae than for the other disease groups. In contrast, frequency of occurrence of rusts between families was the inverse of that for the previously mentioned disease groups. Families mostly affected by rusts were least affected by the root rots, stem cankers and leaf spots and blights (Table 1). This is especially the case with the Colchicaceae and Orchidaceae which seem to be little affected by diseases other than rust, although this may also be due to limited research on the diseases of these plant taxa.

Within the most frequently occurring Pythiacious root rots (Table 1), *Phytophthora cinnamomi* Rands accounted for 54% of reports, *P. megasperma* Drechsler for 21% and *P. citricola* Sawada for 13%. Within the rusts, 53% were *Puccinia* sp. and 32% *Uromycladium tepperianum* (Sacc) McAlpine gall rust of *Acacia* species. Only one confirmed *Armillaria* species, *A. luteobubalina* Watling & Kile, is known to cause Armillaria root rot in Western Australia (Kile *et al.* 1983). Of the 17 stem canker pathogens recorded, *Botryosphaeria* sp. was the most frequent (45% of reports) followed by *Zythiostroma* sp. (14%) and *Cryptodiaporthe* sp. (11%). Of the 46 leaf spot and blight pathogens recorded, three species were the most frequently recorded, with each only 6% of reports.

Biology of major pathogens

Knowledge of the life cycle and biology of *P. cinnamomi* in native communities of south-western Australia is derived mainly from research conducted in the northern *Eucalyptus marginata* Donn ex Smith forest (Dell & Malajczuk 1989; Shearer & Tippett 1989), but relatively little specific information is known of the biology of *P. cinnamomi* in non-forest communities. In addition, little specific information is known of the factors affecting spore production, infection and host susceptibility to infection for *Phytophthora* species other than *P. cinnamomi*, rusts, *A. luteobubalina* and stem cankers in the south-western Australian environment.

Phytophthora root rots

Phytophthora spp. are introduced soil-borne pathogens belonging to the class Oomycota, a relative primitive group of fungi having a number of morphological, physiological and biochemical characteristics found in certain protozoa and bacteria and an ancestral affiliation with heterokont algae (Barr 1983). In evolutionary development, *Phytophthora* belongs to a transitional group between entirely aquatic and completely terrestrial fungi. This is reflected in their complex life cycles dependent on moist conditions for survival, sporulation, dispersal and infection, and in the initiation of various adaptation strategies to cope with the fluctuating soil environment.

Phytophthora cinnamomi is a major pathogen in the alternating temperature and moisture mediterranean climate of south-western Australia, despite the fact it is an introduced, moisture-dependent microorganism. This has occurred because movement of infected soil by human activity has spread the pathogen throughout the region (see below). In addition, the soils and topography in conjunction with the hydrological cycle and susceptible plant communities have provided niches within the soil profile whereby *P. cinnamomi* can survive adverse conditions, and be spread in water or by root-to-root contact to infect the roots of a wide range of hosts. The interactions that have created the diversity of microenvironments and conditions favourable for sporulation, survival, dispersal and infection are detailed in Shearer & Tippett (1989) and can only briefly be described here.

Phytophthora cinnamomi takes advantage of favourable warm and moist soil conditions in autumn and spring, and presence of susceptible tissue, by rapidly producing various spore types in an expanding phase of population growth. During unfavourable conditions of low soil moisture, absence of susceptible tissue, and high microbial activity, the fungal hyphae are lysed and disintegrate, releasing resistant spores specialised for survival. Vegetative reproduction is by sporangia that release infectious motile zoospores in water. This is the main way the *Phytophthora* species reproduce and infect plants. Spherical, sedentary chlamydospores may also be vegetatively produced, but their role in infection and survival in south-western Australia is poorly understood. Under certain conditions, sexual reproduction by thick-walled oospores occurs. Oospore production by *P. cinnamomi* is probably infrequent in south-western Australia as two mating types are required for spore induction but only one mating type predominates in the region. In comparison, *P. citricola* and *P. megasperma* readily produce oospores from the one mating type. Reproduction by oospores is probably an important survival mechanism for *P. citricola* and *P. megasperma* as the thick walled spores are more resistant to drying than are zoospores.

Once *Phytophthora* species have entered the roots of susceptible hosts, primary symptoms of infection are evident as advancing fronts of necrosis (lesions) in the inner bark of roots and stems. Lesions are most evident in fleshy primary roots as a root rot. The fungi kill their hosts by destroying the roots and girdling the base of the stem, depriving the plant of access to nutrients and water. Host plant species occur mainly in the Proteaceae, Myrtaceae, Papilionaceae, Epacridaceae and Dilleniaceae (Table 1).

Rusts

Although rusts are the second most frequent pathogens on native plant taxa in south-western Australia (Table 1), research on their biology in the region is limited to only three studies (Goodwin 1963; Verhoogt & Sivasithamparam 1985; Nichol 1986). Rust fungi are of the order Uredinales of the class Basidiomycota and are destructive pathogens to many agriculture and forest crops. In contrast to *Phytophthora*, rust pathogens on native plants are probably endemic, they complete their life cycles on the above ground plant parts and they are mainly dispersed as air borne spores. Also, unlike root rots and stem cankers which can live and reproduce on dead tissue, the rust fungi are obligatory parasitic, requiring living hosts for normal development.

The life cycles of rusts are more complex than those found in any other group of fungi, and typically consist of four or five reproductive stages in a regular sequence. Details of the stages can be found elsewhere (Agrios 1978) and are briefly described as follows. Pycniospores and receptive hyphae are produced in pycnia. Pycniospores serve as spermatia and are transferred to other pycnia by insects and fuse to form binucleate hyphae. Aeciospores formed from the binucleate hyphae are wind-dispersed to infect hosts other than the one on which they are produced. Uredospores are produced from binucleate mycelium from a germinating aeciospore or a uredospore. Uredospores are generally the main repeating stage of rusts and can withstand adverse conditions of long-range dispersal from plant to plant by wind. Sexual reproduction is by teleutospores, which are not dispersed but germinate to produce basidiospores. The basidiospores are temperature and moisture sensitive, and dispersed by wind over short distances. Within this life cycle pattern, long-cycled rusts produce at least one type of binucleate spore in addition to the teleutospore, while for short-cycled rusts the teleutospore is the only binucleate spore produced. The life cycle may be completed on the one host (autoecious) or on two distinct hosts (heteroecious).

In Western Australia, gall rust (*Uromycladium tepperianum*) is a short-cycled autoecious rust producing pycniospores, teleutospores and basidiospores mainly on Acacia species (Goodwin 1963). Some rust taxa on orchids are long-cycled as they produce aeciospores, uredospores and teleutospores (Nichol *et al.* 1988). It is not known whether the life cycle of rusts on plant taxa other than the Mimosaceae (Table 1) are autoecious or heteroecious.

Host plant species occur mainly in the Mimosaceae, Goodeniaceae, Haemodoraceae, Poaceae, Chenopodiaceae, Asteraceae, Orchidaceae and Colchicaceae (Table 1). *Uromycladium tepperianum* infection stimulates the *Acacia* host to form galls and / or 'witches brooms' (Goodwin 1963). Infection of the growing point results in a witches broom caused by reduction of the growing axis and a proliferation of lateral buds. Galls may be globose or elongated and can form on different plant organs, although formation on a particular plant part is consistent within an *Acacia* sp. (Goodwin 1963). Gall formation on inflorescences reduces fertilisation and fruit development. Uredospore production by leaf rusts rupture the leaf epidermis, reducing photosynthetic and transpiration processes. In Orchidaceae, leaves infected with rust senesce earlier than healthy leaves and rusted plants produce fewer flowers than healthy plants (Nichol 1986).

Armillaria root rot

Research on *A. luteobubalina* in south-western Australia has mainly concentrated on the impact of the pathogen in forested areas (Pearce *et al.* 1986; Shearer & Tippett 1988; Pearce & Malajczuk 1990a), and the potential for biocontrol with wood decay fungi (Pearce & Malajczuk 1990b). The impact of the pathogen on shrubland and heathland communities has only recently been recognised (Shearer *et al.* 1994). Specific details are lacking on the mechanisms of infection and host colonisation of *A. luteobubalina* in Western Australia and factors affecting host susceptibility to infection (Shearer 1992a). Details of the life cycle of *Armillaria* species are reviewed in Shaw & Kile (1991).

Armillaria luteobubalina is an indigenous species of mushroom-producing primary pathogen of the order Agaricales, class Basidiomycota. Infection from *A. luteobubalina* occurs from aerial dispersed basidiospores or through mycelial transfer at root contacts. Growth through the soil by rhizomorphs is not an important mechanism of spread in south-western Australia (Pearce *et al.* 1986; Shearer & Tippett 1988) as the seasonal pattern of temperature and moisture associated with the mediterranean climate of the region, is not conducive for rhizomorph growth (Pearce & Malajczuk 1990c). Basidiospores, formed by sexual recombination of gametes, are shed in autumn-winter from annual fruiting bodies that develop on decayed roots and stems of dead and living trees. Fruiting bodies of *A. luteobubalina* are mainly produced in June and July (Pearce *et al.* 1986; Shearer & Tippett 1988). How basidiospores infect woody tissue is poorly understood and is probably an infrequent event (Kile 1983). The distribution of infection points and aerial dispersed sexually produced basidiospores results in a discontinuous, discrete distribution of infections of different genotypes. The number and distribution of different genotypes can provide an estimate of the frequency of infection from basidiospores (Kile 1983), but no analysis of this type has been done for south-western Australia. The pathogen spreads within disease centres by mycelial growth through roots. In susceptible *E. wandoo* Blakely, the mean rate of disease extension over a 8 year period was 2.04 ± 1.05 m yr^{-1} (Shearer *unpub. obs.*). This is comparable to mean maximum rates of 0.7-1.6 m yr^{-1} found by Kile (1983) for Victorian forest. New infections are established by contact between roots and stems, and dead roots and stumps increase the inoculum level. In mixed eucalypt forests in the highlands of west-central Victoria, the pathogen can survive in stumps for up to 30 years (Kile 1981).

Armillaria luteobubalina establishes in the bark and causes columns of decay within roots and stems of host species. The pathogen spreads tangentially in the inner bark of susceptible hosts, often resulting in girdling of the stem collar and host death (Pearce *et al.* 1986; Shearer & Tippett 1988). Host plant species occur mainly in the Proteaceae, Myrtaceae, Papilionaceae, Epacridaceae and Mimosaceae (Table 1).

Stem cankers

The contribution of canker fungi to stem and branch death in south-western Australia has largely been ignored (Davison & Tay 1983; Shearer 1992a). Mortality and decline of marri and red flowering gum were associated with stem cankers in the mid 1930's (Smith 1970). Davison & Tay (1983) identified a number of pathogenic fungi associated with stem and branch cankers of forest trees in south-western Australia. In 1989, a species of *Diplodina* (sexual stage *Cryptodiaporthe*) was found killing *Banksia coccinea* R. Brown on the south coast of the state (Shearer & Fairman 1991). Interpretation of the cause of stem cankering can be complicated as some fungi are frequently isolated from cankers but they are secondary invaders of the diseased tissue. *Cytospora eucalypticola* van der Westhuizen is an example of a frequently isolated fungus that pathogenicity tests have shown to be a nonagressive facultative parasite (Davison & Tay 1983; Shearer *et al.* 1987).

The origins of stem canker fungi in south-western Australia are uncertain. *Botryosphaeria ribis* Gossenb. & Dugg. is possibly an introduced pathogen (Davison & Tay 1983) and it is widely distributed on a diverse range of hosts in the tropical and temperate regions of the world. The *Cryptodiaporthe* pathogen of *B. coccinea* is possibly endemic as-it is a new species (Bathgate *et al.* 1994) and has a very limited host range within the Proteaceae (see below).

How the canker-causing fungi complete their life cycles in south-western Australia requires further research. This is complicated by uncertainties in the identity of the various spore stages of canker fungi on native plants in this state. For example, the asexual stage of *Endothia* isolated from Myrtaceae in Western Australia has been identified as *En. gyrosa* (Schw. Fr.) Fr. by isozyme analysis against voucher specimens (Davison & Coates 1991). Even though the sexual ascospore stage occurs in eastern Australia (Walker *et al.* 1985), it has yet to be recorded in Western Australia.

Canker fungi kill the aerial parts of plants. This is in comparison to disease caused by *Phytophthora* and *Armillaria* that kill plants from the roots up. Hosts affected by canker fungi occur mainly in the Proteaceae and Myrtaceae (Table 1). The fungi sporulate in dead bark and are dispersed as sexually produced ascospores in wind currents or asexually produced pycnidiospores in rain splash. The mode of entry of germinating spores is either direct or gained through lenticels or wounds from branch stubs, broken branches and insect damage. Phloem and sapwood invasion results in sunken cracked areas on the stem that may expose the xylem and exude kino. Cankers thus formed can be annual, perennial or diffuse. In annual cankers, lesion development is contained by host defense mechanisms within the first year's invasion. *Botryosphaeria ribis* generally forms annual cankers unless stress factors affect the host-pathogen interaction, as described in the next section. Perennial cankers denoted by concentric rings are formed when invasion by the pathogen is walled off, but the pathogen survives on dead tissue to re-invade healthy tissue in the following years. Large 'target'-like cankers occur on *E. calophylla* Lindley and *E. gomphocephala* DC, but the causal pathogen has yet to be determined. Diffuse cankers occur when lesions rapidly progress along the stem, resulting in gradual decline from death of twigs and lateral branches to rapid death of leaders in a few years. Diffuse canker development by *Cryptodiaporthe* sp. leads to death of infected *B. coccinea*, and destruction of diseased stands in a few years (Shearer & Fairman 1991; see below). The effect of death of canker-infected stems and branches on leaf area and host plant functioning has not been determined.

Disease caused by canker fungi can be aggravated by transient stress factors (Schoeneweiss 1975). Trees planted outside the normal range may experience environmental stress with an associated decline in resistance to infection by canker organisms (Shearer *et al.* 1987). Stress from two days of above 40 °C and high winds in February 1991, was associated with rapid extension of *Bo. ribis* lesions in stems of *B. speciosa* R Brown near Hopetoun. The stand was severely debilitated by the infection and trees died. Twelve months later, many of the surviving *B. speciosa* trees had again contained the *Bo. ribis* lesions and formed new epicormics below the walled-off lesion margin.

Distribution

Phytophthora cinnamomi

Phytophthora cinnamomi is the most common and destructive of the *Phytophthora* species found in native communities of the south-west. It occurs in the area bounded by Eneabba north of Perth, east of Dryandra near Popanyinning, and Cape Arid east of Esperance on the south coast (Fig 1).

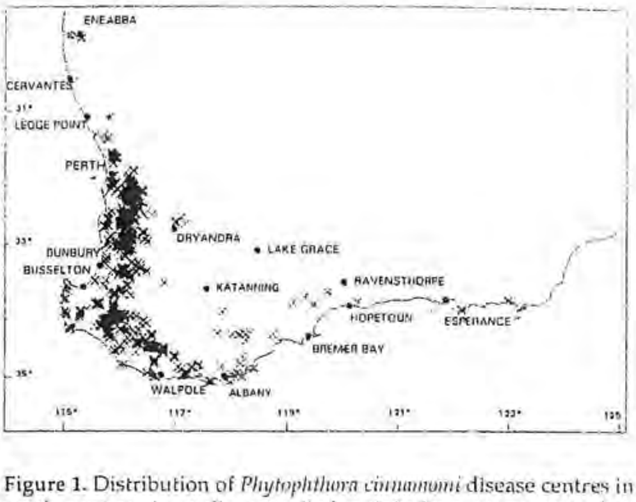

Figure 1. Distribution of *Phytophthora cinnamomi* disease centres in south-western Australia, compiled mainly from assessment plots and mapping, and supplemented by isolation records.

Greatest incidence of *P. cinnamomi* occurs in the northern and southern *E. marginata* forest (Fig 1). This is partly due to environment and partly to historical factors related to human activity (Shearer & Tippett 1989; Shearer 1992a). The pathogen frequently occurs on the acidic leached sands of the Bassendean Dune System of the Swan Coastal Plain, Gavin Sands of the Leeuwin-Naturaliste Ridge, laterite soils and winter wet flats of the d'Entrecasteaux and Walpole-Nornalup National Parks and the Keystone and Gardner geomorphic units in areas on the south coast such as West Cape Howe and Two Peoples Bay. Incidence is high in the sandy deposits of the Stirling Range National Park (the rectangle of occurrences north of Albany, Fig 1). Infections fringe the Fitzgerald River National Park east of Bremer Bay, but a 6 km long infection occurs within the park.

A transect from the coast, inland between 31.5° and 33.5° S, shows that *P. cinnamomi* disease centres are absent from coastal dunes, but increase in frequency in the Bassendean Dune System and Pinjarra Plain to the west of the Darling Scarp (Fig 2). Frequency of occurrence is greatest in the northern *E. marginata* forest on the western edge of the Darling Scarp, decreasing rapidly to the drier eastern edge of the *E. marginata* forest (Fig 2).

Rusts

Rusts are widely distributed on native plant taxa throughout the south-west (Fig 3). This is especially so for *U. tepperianum*, which occurs relatively frequently on *Acacia* spp. in coastal areas and in the eastern wheatbelt and goldfields. *Uromycladium tepperianum* is probably the most widely distributed pathogen in native communities in south-western Australia (compare Fig 3 with Figs 1 and 4-6). However, because of the limited research on rusts of native plants of Western Australia, many more surveys are needed for a more accurate picture of the distribution of rusts in native communities of the state.

Armillaria luteobubalina

Armillaria luteobubalina disease centres mainly occur in coastal dune vegetation and forested areas (Fig 4). In vegeta-

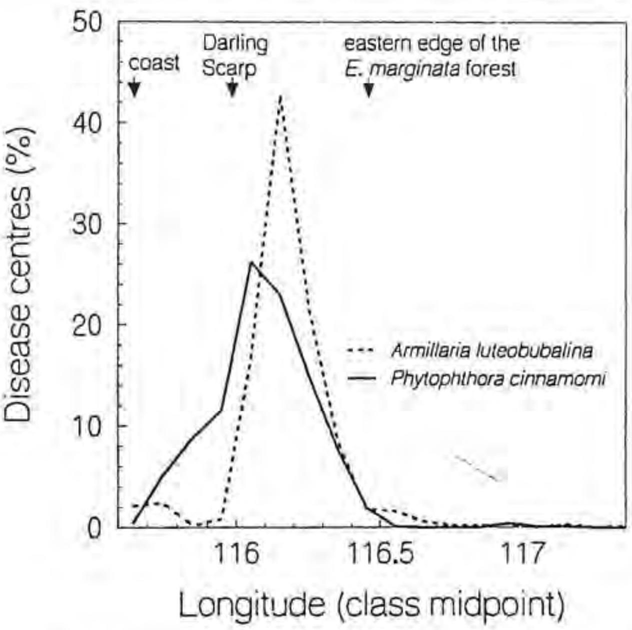

Figure 2. Occurrence of disease centres of *Armillaria luteobubalina* and *Phytophthora cinnamomi* in a transect between 31.5° and 33.5° S and from the coast (115.6° E) inland to 117.4° E. The plot is percentage of occurrence of disease centres in longitude classes of one tenth of a degree.

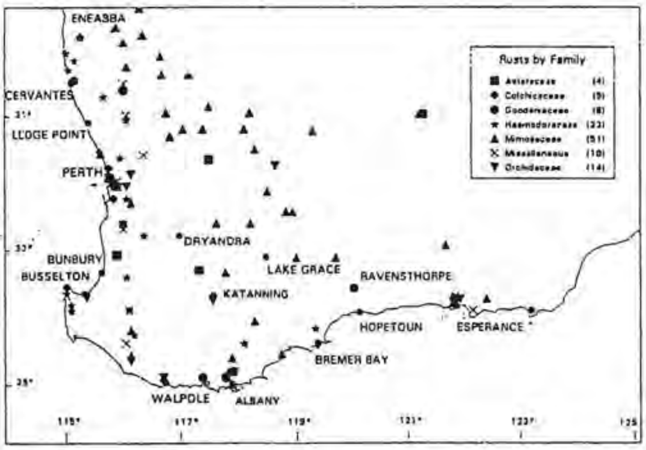

Figure 3. Distribution of rusts on native plants in south-western Australia, compiled from reports in Shivas (1989) and Nichol(1986). Rust taxa were: *Puccinia* for Haemodoraceae, *Uromycladium* for Mimosaceae, *Aecidium* and *Puccinia* for Asteraceae and Colchicaceae, and *Puccinia* and *Uromyces* for Goodeniaceae and Orchidaceae.

tion on the non-podsol sands of the coastal dunes, *A. luteobubalina* occurs as far north as Cervantes and around the coast to Cape Arid (Fig 4). The pathogen also occurs in *E. gomphocephala* forest and *Banksia* woodland of the Spearwood Dune System and equivalents, just inland from coastal dunes but rarely occurs in communities on the acid sands of the Bassendean Dune System. The pathogen frequently occurs in the northern and southern *E. marginata* forest, the *E. diversicolor* F. Muell. forest in the south, and in *E. wandoo* forest to the east.

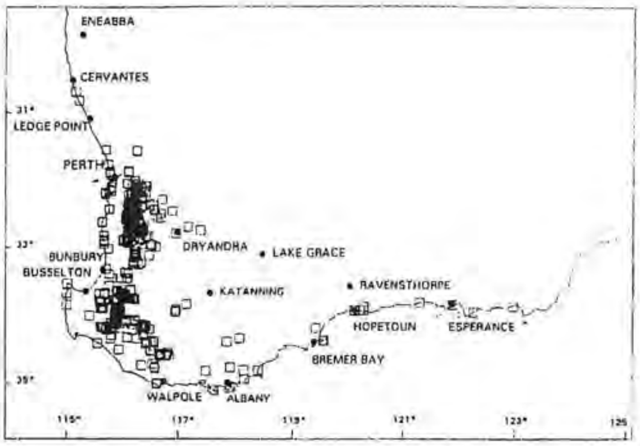

Figure 4. Distribution of *Armillaria luteobubalina* disease centres in south-western Australia, compiled from isolation records, assessment plots and mapping.

In comparison to *P. cinnamomi*, *A. luteobubalina* occurs on the coast and rarely occurs in the Bassendean Dune system to the west of the Darling scarp (Fig 2). Distribution within the northern forest tends to be more skewed to the east, than for *P. cinnamomi*, and there is a greater frequency of occurrence in the *E. wandoo* forest east of the *E. marginata* forest (Fig 2).

Stem canker pathogens

Various canker pathogens, mainly on Myrtaceae and Proteaceae, are widely distributed throughout the south-western Australian region (Fig 5). The distribution map is incomplete, however, as there has been inadequate sampling in the eastern wheatbelt and goldfields.

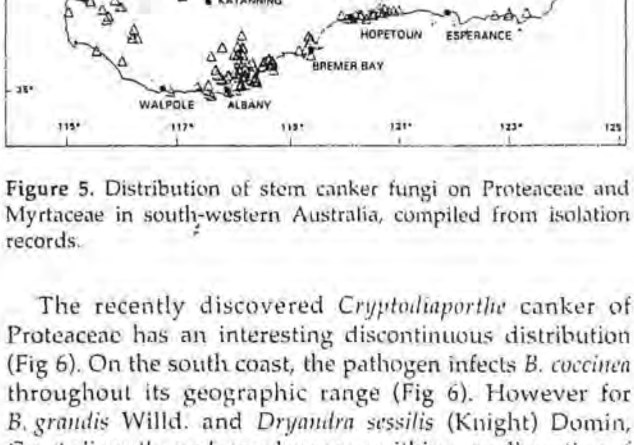

Figure 5. Distribution of stem canker fungi on Proteaceae and Myrtaceae in south-western Australia, compiled from isolation records.

The recently discovered *Cryptodiaporthe* canker of Proteaceae has an interesting discontinuous distribution (Fig 6). On the south coast, the pathogen infects *B. coccinea* throughout its geographic range (Fig 6). However for *B. grandis* Willd. and *Dryandra sessilis* (Knight) Domin, *Cryptodiaporthe* canker only occurs within a small portion of the geographic range of these two hosts. The pathogen has not been found in an area between the south coast and west coast (Fig 6), even though the area has been sampled (Fig 5). On the west coast, *Cryptodiaporthe* is an aggressive canker of *D. sessilis* north of Perth and on *B. grandis* south of Perth (Fig 6). Curiously, it has been infrequently isolated from these two hosts in other areas, even though these species occur and have been sampled throughout the south-west. Possible causes of this distribution are currently under investigation.

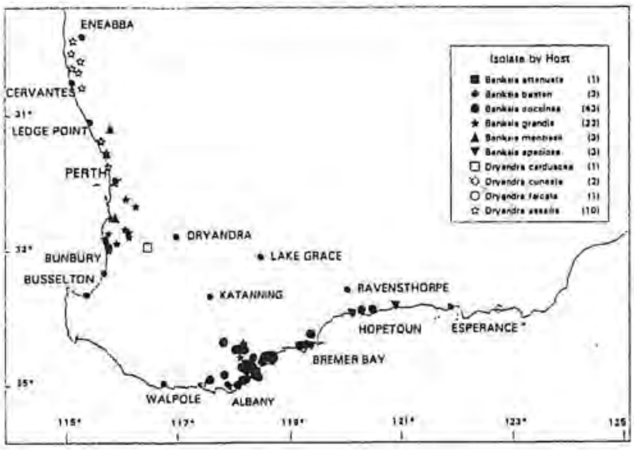

Figure 6. Distribution of *Cryptodiaporthe* stem canker of Proteaceae in south-western Australia, compiled from isolation records.

Communities affected

Phytophthora cinnamomi

Death of the susceptible understorey species of the Proteaceae, Myrtaceae, Papilionaceae and Epacridaceae (Table 1) is the first indication that *P. cinnamomi* has spread into a new area. On sites favourable to disease development, a line of dead and dying understorey marks the 'infection front' at the boundary of infested and uninfested areas (Fig 7). Disease impact is more subtle on less favourable, free draining sites, and there is often no clear demarcation between infested and uninfested areas.

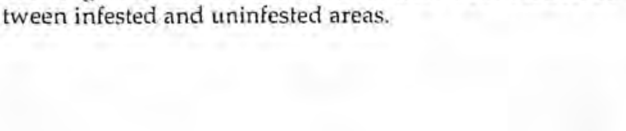

Figure 7. High impact of *Phytophthora cinnamomi* in *Banksia* woodland on the Bassendean Dune System of the Swan Coastal Plain. Most of the overstorey of *Banksia attenuata* R Brown, *B. ilicifolia* R Brown and *B. menziesii* R Brown has died in the infested area. Death of dominant key overstorey and understorey species result in reduction of vegetation biomass in the diseased area and the disease front being delineated by a sharp boundary of dying plants.

Shearer (1990) described the impact of *P. cinnamomi* according to a grouping of vegetation systems of Beard (1981). Impact of *P. cinnamomi* tends to be lowest in coastal communities on coastal limestone and forest communities on relatively fertile red earths associated with major valleys. Impact of *P. cinnamomi* is also low in inland woodlands and shrublands. However, low disease expression in inland areas is probably due to low rainfall unfavourable for pathogen survival and sporulation, rather than a lack of susceptible vegetation or soil profile characteristics favourable for pathogen development (Shearer 1990). This is illustrated by the recently observed infection of rare and endangered *B. cuneata* A S George, located east of Dryandra on the western edge of the wheatbelt (Fig 1).

Impact of *P. cinnamomi* is highest in the *E. marginata* forest understorey on laterites and *Banksia* woodlands associated with leached sands and laterites of the Northern and Southern Sandplains and the Swan Coastal Plain. Within these vulnerable communities, the impact of *P. cinnamomi* results more in changes in community structure and function than in total number of species. For example, infestation of *Banksia* woodland on the Swan Coastal Plain resulted in an average of 7 fewer species in infested than non-infested woodland (Shearer & Dillon 1994). However, the loss of these species often resulted from the almost complete death of the dominant susceptible overstorey and understorey vegetation with a substantial reduction of the vegetation biomass in the diseased area (Shearer & Dillon 1994; Fig 7). Thus in communities dominated by rare and endangered plant taxa, such as *B. brownii* Baxter ex R Brown in the Albany region, infestation is resulting in elimination of the threatened taxa. Keighery (1992) lists 6 species (2 *Andersonia* spp., *B. brownii*, 2 *Dryandra* spp. and *Lambertia orbifolia* C Gardner) that are currently threatened with extinction from *P. cinnamomi* infestation. All of these species of Proteaceae occur in the Southern Sandplains, in areas of high impact of *P. cinnamomi*. Within areas where *P. cinnamomi* has caused significant damage to susceptible communities, such as on the Swan Coastal Plain, the *E. marginata* forest and a number of reserves and national parks on the south coast such as Stirling Range National Park, Cape Arid National Park and Two Peoples Bay Nature Reserve, the main challenge is the development of suitable management strategies for communities irreversibly changed by impact of the pathogen.

Rusts

There is little information available on the impact of rusts in native plant communities of south-western Australia. The impact of rust on native communities of the state cannot accurately be assessed from the current information. Severe infection of *U. tepperianum* ultimately results in death of the host (Goodwin 1963) and the pathogen has been used in biological control of *Acacia saligna* (Labill) H L Wendl, a weed in South Africa (Morris 1991). In Orchidaceae, rust infection reduced the capacity of *Thelymitra crinita* Lindley to produce flowers (Nichol 1986). Thus, rust found on rare and endangered *T. macmillanii* F Muell would need to be considered in conservation plans, as seed production may be reduced by infection (Nichol 1986).

Armillaria luteobubalina

The impact of *A. luteobubalina* disease centres can be expressed as: 1) an expanding patch of dead and dying hosts;

2) dead hosts occurring frequently, but at random, in patches; 3) dead hosts occurring infrequently, but individually, or at random in patches; and 4) small patches of dead and dying hosts occurring in young stands, but the patches of mortality fail to expand as the stand ages. The first and second impact type mainly occur in coastal dune vegetation (Fig 8) and *E. wandoo* forest (Fig 9). The disease centres can be quite large, averaging 1.7 ± 0.2 ha (range 0.02 - 6.5 ha) for coastal dune vegetation (Shearer *et al.* 1994) and 1.2 ± 0.3 ha (range 0.01 - 8 ha) for *E. wandoo* forest (Shearer *unpub. obs.*). Most of the susceptible hosts are killed within the disease centres of coastal dune and *E. wandoo* communities, leaving open denuded areas which encourage severe wind erosion of coastal dunes (Fig 8A). In coastal dunes, geographically restricted *Callitris preisii* Miq (Fig 8B) and rare and endangered *B. brownii* and *B. occidentalis* R Brown *formosa* Hopper are threatened by infection. In the *E. wandoo* forest of the Stirling Range National Park, *A. luteobubalina* infestation is killing *Choretrum glomeratum* R Brown, the only food plant for the larvae of the rare brown azure butterfly (Wills & Kinnear 1993). The third and fourth impact type mainly occur in *E. diversicolor*, *E. gomphocephala* and *E. marginata* forests.

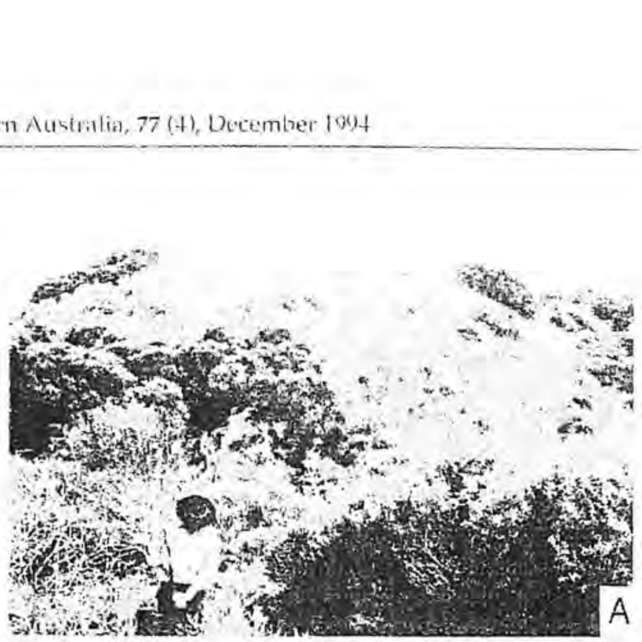

Figure 8. High impact of *Armillaria luteobubalina* in coastal dune vegetation. A, Death of dune vegetation in an infested area has resulted in denuded areas subject to wind erosion in Yalgorup National Park; B, Most *Callitris preisii* have died in a disease centre on Garden Island.

Stem canker pathogens

Stem canker pathogens are having considerable impact in communities dominated by Proteaceae and Myrtaceae in south-western Australia. *Cryptodiaporthe* stem canker is causing high mortality of *B. coccinea* (Fig 10) throughout the Banksia's geographic range on the south coast (Fig 6). In one monitored site, plant death increased from 40% to 98% in 2.7 years. The pathogen is also causing severe branch and stem cankering of *D. sessilis* north of Perth and *B. grandis*, south of Perth. On the south coast, a *Zythiostroma* sp. causes stem cankers of *B. baxteri* and *Bo. ribis* infection has debilitated stands of *B. speciosa* in association with climatic stress.

In eucalypt forest communities, stem canker fungi are associated with crown decline, stem cankering and mortality of *E. ficifolia* F Muell, *E. calophylla* and *E. gomphocephala*. In each case, the causal pathogen has yet to be identified, although *En. gyrosa* and *Bo. ribis* have been isolated from dying *E. gomphocephala* (Shearer *unpub. obs.*). Canker fungi have been associated with the complex of factors causing crown decline in *E. wandoo* (Albone 1989). Cankers are also having an impact on myrtacious dominated communities, other than forest. For example, a *Phomopsis* sp. was isolated from dying branches of *Calothamnus quadrifidus* R Brown showing severe canopy decline throughout the northern sandplain in 1993 (Shearer *unpub. obs.*).

Figure 9. High mortality of hosts in an *Armillaria luteobubalina* disease centre in *Eucalyptus wandoo* forest near Kojonup.

Conclusions

Functional diversity and dynamic balance in native ecosystems result in explosive epidemics of disease being uncommon and limited in space and time (Zadoks & Schein 1979). Why then are such explosive epidemics of *Phytophthora* species, *A. luteobubalina* and *Cryptodiaporthe* canker of Proteaceae currently occurring in plant communities of south-western Australia? *Phytophthora* species are human introduced pathogens to native plant ecosystems of south-western Australia and their impact is related to the intensity of human activity, occurrence of sub-surface soil moisture and temperature conditions that favour survival, multiplication and spread of the pathogen and large numbers of susceptible key plant taxa that have not co-evolved with the pathogens. Research has elucidated many of these interactions for *P. cinnamomi* (Shearer & Tippett 1989), but a greater understanding is required for other *Phytophthora* species such as *P. citricola* and *P. megasperma*. In contrast to *Phytophthora*, the situation for *A. luteobubalina* and *Cryptodiaporthe* canker of Proteaceae is different, as they are probably native patho-

Figure 10. A stand of *Banksia coccinea* at Cheyne Beach, east of Albany, killed by *Cryptodiaporthe* canker. Mortality within this stand increased from 40% in 1989 to 98% in 1992.

gens and presumably have co-evolved with the existing vegetation communities. Current knowledge is inadequate to determine whether the prevailing impacts observed relate to a periodic change in disease intensity, or whether they represent more permanent long-term changes.

Conservation of plant taxa requires a much better inventory, than is available at present, of the incidence and status of the various pathogens that occur in native communities of south-western Australia. As noted in this paper, the recording of most pathogen occurrences on native plants in this state is the result of opportunistic research, and comprehensive surveys have yet to be attempted. Pathological research of native plant taxa has tended to be dominated by *P. cinnamomi* to the exclusion of other pathogens. Comprehensive surveys would ensure objective assessment of the importance of hitherto ignored pathogens or pathogen/community interactions. This is illustrated by the recent recognition of the high impact of *A. luteobubalina* in coastal communities (Shearer *et al.* 1994) and *Cryptodiaporthe* canker of Proteaceae (Shearer & Fairman 1991; Bathgate *et al.* 1994). Presumably, these pathogens have been impacting on the respective communities well before their recent recognition. Biogeographical surveys of fauna and flora in communities or National Parks need to include a census of fungi occurring within the areas.

Uncertainties in the taxonomy of fungi in this state complicate inventory of the occurrence and importance of pathogens on native plants (Shearer 1992a). A number of pathogens are undescribed species. This is further complicated by the occurrence of biological species within species complexes, such as may be occurring in *P. megasperma* (Bellgard *et al.* 1994). Fungal taxonomic studies are fundamental to assessment of the relative importance of pathogens.

Prediction of the likely long-term effects of pathogens on native plant communities requires a much better understanding of their life cycles and biology in the south-western Australian environment than is available at present. By their impact, pathogens are undeniably affecting the evolution of plant communities of the state. However there is only a conceptual understanding of the selection pressures pathogens are placing on community composition and functioning, and in turn, the selection pressures environment and community composition are placing on the pathogens. Information on the biology and ecology of pathogens in native communities is needed to determine whether current impacts of endemic pathogens are short term perturbations or part of long term cycles in pathogen-community-environment interactions. Such information is also essential to the determination of the likely consequences of disease, and the application of appropriate control strategies.

Acknowledgments: My thanks to interpreters of the Forest Management Branch and South Coast Region for locations of *P. cinnamomi* and *A. luteobubalina* disease centres, and Colin Crane and John Dodd for help in preparing the disease centre co-ordinates for mapping.

References

Agrios G N 1978 Plant Pathology. Academic Press, London.

Albone P 1989 Wandoo dieback. In: Insect and Rural Tree Decline: In Search of Solutions (ed B Schur) Denmark Environment Centre, Denmark, Western Australia, 17-18.

Barr D J S 1983 The zoosporic grouping of plant pathogens. Entity or non-entity? In: Zoosporic Plant Pathogens. A Modern Perspective (ed S T Buczacki) Academic Press, London, 43-83.

Bathgate J, Shearer B & Rohl L 1994 *Cryptodiaporthe* sp: a new canker pathogen threatening *Banksia coccinea*. In: Handbook of the Symposium on Plant Diseases in Ecosystems: threats and impacts in south-western Australia (eds R T Wills & W A Cowling) Royal Society of Western Australia and the Ecological Society of Australia, Perth, 19.

Beard J S 1981 Vegetation Survey of Western Australia. The Vegetation of the Swan Area. University of Western Australia Press, Nedlands.

Bellgard S E, Shearer B L, Crane C E & Smith B J 1994 Morphological variability exhibited by *Phytophthora megasperma* retrieved from diseased areas of Western Australian bushland. In: Handbook of the Symposium on Plant Diseases in Ecosystems: threats and impacts in south-western Australia (eds R T Wills & W A Cowling) Royal Society of Western Australia and the Ecological Society of Australia, Perth, 20.

Brandis A, Hill T, Keighery G & Tippett J 1984 Dieback in the Cape Arid National Park and other areas of concern. Department Conservation and Land Management, Como, unpublished report.

Brittain T 1989 A survey of dieback disease due to *Phytophthora cinnamomi* in Two Peoples Bay Nature Reserve. Department Conservation and Land Management, Como, unpublished report.

Davison E M & Coates D J 1991 Identification of *Cryphonectria cubensis* and *Endothia gyrosa* from eucalypts in Western Australia using isozyme analysis. Australasian Plant Pathology 20:157-160.

Davison E M & Tay F C S 1983 Twig, branch and upper trunk cankers of *Eucalyptus marginata*. Plant Disease 67:1285-1287.

Dell B & Malajczuk N 1989 Jarrah dieback - a disease caused by *Phytophthora cinnamomi*. In: The Jarrah Forest. A Complex Mediterranean Ecosystem (eds B Dell, J J Havel & N Malajczuk) Kluwer Academic Publishers, Dordrecht, 67-87.

Forestry Canada 1993 Forest Insect and Disease Conditions in Canada 1990. (Compiled by B H Moody). Forest Insect and Disease Survey, Ontario.

Goodwin J 1963 A study of the Acacia rust *Uromycladium tepperianum* (Sacc.) McAlpine. University of Western Australia, Perth, Honours Thesis.

Green J W 1985 Census of the Vascular Plants of Western Australia, 2nd Ed. Western Australian Herbarium, Perth.

Hill T C J 1990 Dieback disease and other *Phytophthora* species in the Northern Kwongan. In: Nature Conservation, Landscape and Recreation Values of the Lesueur Area (eds A A Burbidge, S D Hopper & S van Leeuwen) Bulletin 424, Environment Protection Authority, Perth, 89-97.

Keighery G 1992 The impact of *Phytophthora* species on rare plants. In: Dieback - What is the Future? (Compiled by M J Freeman, R Hart & M Ryall) The Northern Sandplains Dieback Working Party. Perth, 29-36.

Kile G A 1981 *Armillaria luteobubalina*: a primary cause of decline and death of trees in mixed species eucalypt forests in central Victoria. Australian Forest Research 11:63-77.

Kile G A 1983 Identification of genotypes and the clonal development of *Armillaria luteobubalina* Watling & Kile in eucalypt forests. Australian Journal of Botany 31:657-671.

Kile G A, Watling R, Malajczuk N & Shearer B L 1983 Occurrence of *Armillaria luteobubalina* Watling and Kile in Western Australia. Australasian Plant Pathology 12:18-20.

Morris M J 1991 The use of plant pathogens for biological weed control in South Africa. Agriculture, Ecosystems and Environment 37:239-255.

Nichol A M 1986 Rust diseases of native orchids of the south-west of Western Australia. University of Western Australia, Perth, Honours Thesis.

Nichol A, Sivasithamparam K & Dixon K W 1988 Rust infections of Western Australian orchids. Lindleyana 3:1-8.

Pearce M H & Malajczuk N 1990a Stump colonization by *Armillaria luteobubalina* and other wood decay fungi in an age series of cut-over stumps in karri (*Eucalyptus diversicolor*) regrowth forests in south-western Australia. New Phytologist 115:129-138.

Pearce M H & Malajczuk N 1990b Inoculation of *Eucalyptus diversicolor* thinning stumps with wood decay fungi for control of *Armillaria luteobubalina*. Mycological Research 94:32-37.

Pearce M H & Malajczuk N 1990c Factors affecting growth of *Armillaria luteobubalina* rhizomorphs in soil. Mycological Research 94:38-48.

Pearce M H, Malajczuk N & Kile G A 1986 The occurrence and effects of *Armillaria luteobubalina* in the karri (*Eucalyptus diversicolor* F. Muell.) forests of Western Australia. Australian Forest Research 16:243-259.

Schoeneweiss D F 1975 Predisposition, stress, and plant disease. Annual Review of Phytopathology 13:193-211.

Shaw C G & Kile G A 1991 Armillaria root disease. Agriculture Handbook Number 691. Forest Service, United States Department of Agriculture, Washington, D.C.

Shearer B L 1990 Dieback of native plant communities caused by *Phytophthora* species - A major factor affecting land use in south-western Australia. Land and Water Research News No. 5:15-26.

Shearer B L 1992a The ecological implications of disease in the southern forest of south-western Australia. In: Research on the Impact of Forest Management in South-West Western Australia (ed M Lewis) CALM Occasional Paper Number 2/92. Department Conservation and Land Management, Como, 99-113.

Shearer B L 1992b Plant disease research in the Department Conservation and Land Management. In: Dieback - What is the Future? (ed M J Freeman, R Hart & M Ryall) The Northern Sandplains Dieback Working Party, Perth, 7-13.

Shearer B L & Dillon M 1994 Impact of *Phytophthora cinnamomi* infestation in Banksia woodlands on the Swan Coastal Plain south of Perth. In: Handbook of the Symposium on Plant Diseases in Ecosystems: threats and impacts in south-western Australia (eds R T Wills & W A Cowling) Royal Society of Western Australia and the Ecological Society of Australia, Perth, 36.

Shearer B L & Fairman R G 1991 Aerial canker fungi threaten *Banksia coccinea*. Abstract 85. C In: Proceedings of the Conservation Biology in Australia and Oceania Conference. University of Queensland.

Shearer B L & Hill T C 1989 Diseases of *Banksia* woodlands on the Bassendean and Spearwood Dune Systems. Journal of the Royal Society of Western Australia 71:113-114.

Shearer B L & Tippett J T 1988 Distribution and impact of *Armillaria luteobubalina* in the *Eucalyptus marginata* forest of south-western Australia. Australian Journal of Botany 36:433-445.

Shearer B L & Tippett J T 1989 Jarrah dieback. The dynamics and management of *Phytophthora cinnamomi* in the jarrah (*Eucalyptus marginata*) forest of south-western Australia. Department of Conservation and Land Management, Research Bulletin 3.

Shearer B L, Tippett J T & Bartle J R 1987 *Botryosphaeria ribis* infection associated with death of *Eucalyptus radiata* in species selection trials. Plant Disease 71:140-145.

Shearer B L, Fairman R, Crane C & Grant M 1994 Impact of *Armillaria luteobubalina* infestation in coastal dune communities of south-western Australia. In: Handbook of the Symposium on Plant Diseases in Ecosystems: threats and impacts in south-western Australia (eds R T Wills & W A Cowling) Royal Society of Western Australia and the Ecological Society of Australia, Perth, 33.

Shivas R G 1989 Fungal and bacterial diseases of plants in Western Australia. Journal of the Royal Society of Western Australia 72:1-62.

Smith W P C 1970 Stem canker disease of red flowering gums. The Journal of Agriculture of Western Australia 11:33-39.

Verhoogt M M & Sivasithamparam K 1985 Rust disease of Kangaroo Paws *Anigozanthos* Labill and *Macropidia* Drumm ex. Harve. in Western Australia. Australasian Plant Pathology 14:40-42.

Walker J, Old K M & Murray D I L 1985 *Endothia gyrosa* on *Eucalyptus* in Australia with notes on some other species of *Endothia* and *Cryphonectria*. Mycotaxon 23:353-370.

Wills R T 1993 The ecological impact of *Phytophthora cinnamomi* in the Stirling Range National Park, Western Australia. Australian Journal of Ecology 18:145-159.

Wills R & Kinnear J 1993 Threats to the Stirling Range. In: Mountains of Mystery. A Natural History of the Stirling Range (eds C Thomson, G Hall & G Friend). Department of Conservation and Land Management, Como, 135-141.

Zadoks J C & Schein R D 1979 Epidemiology and Plant Disease Management. Oxford University Press, New York.

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www.publish.csiro.au/journals/ajb *Australian Journal of Botany*, 2007, **55**, 225–238

Phytophthora cinnamomi invasion, a major threatening process to conservation of flora diversity in the South-west Botanical Province of Western Australia

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Abstract. The invasive soilborne plant pathogen *Phytophthora cinnamomi* Rands is a major threatening process in the South-west Botanical Province of Western Australia, an internationally recognised biodiversity hotspot. Comparatively recent introduction of *P. cinnamomi* into native plant communities of the South-west Botanical Province of Western Australia since the early 1900s has caused great irreversible damage and altered successional change to a wide range of unique, diverse and mainly susceptible plant communities. The cost of *P. cinnamomi* infestation to community values is illustrated by examination of direct (mortality curves, changes in vegetation cover) and indirect impacts on biodiversity and ecosystem dynamics, the proportion of *Threatened Ecological Communities* infested, *Declared Rare Flora* either directly or indirectly threatened by infestation and estimates of the proportion of the native flora of the South-west Botanical Province susceptible to the pathogen. While direct impacts of *P. cinnamomi* have been poorly documented in the South-west Botanical Province, even less attention has been given to indirect impact where destruction of the habitat by the pathogen affects taxa not directly affected by infection. Current poor understanding and quantification of indirect impacts of *P. cinnamomi* through habitat destruction results in an underestimation of the true impact of the pathogen on the flora of the South-west Botanical Province. Considerable variation of susceptibility to *P. cinnamomi* among and within families of threatened flora and responses of taxa within the genus *Lambertia* show how classification within family and genus are poor predictors of species susceptibility. Within apparently susceptible plant species, individuals are resistant to *P. cinnamomi* infection. Intra-specific variation in susceptibility can be utilised in the long-term management of threatened flora populations and needs to be a high research priority. Current control strategies for conservation of flora threatened by *P. cinnamomi* integrate hygiene and *ex situ* conservation with disease control using fungicide. Application of the fungicide phosphite has proven effective in slowing progress of *P. cinnamomi* in infested, threatened communities. However, variation in plant species responses to phosphite application is a major factor influencing effective control of *P. cinnamomi* in native communities. A greater understanding of the mechanisms of action of phosphite in plant species showing different responses to the fungicide may provide options for prescription modification to increase phosphite effectiveness in a range of plant species. The range of responses to *P. cinnamomi* infection and phosphite application described for *Lambertia* taxa suggests that the genus would make an ideal model system to elucidate the mechanisms of resistance to *P. cinnamomi* and the effectiveness of phosphite against the pathogen.

Introduction

The South-west Botanical Province of Western Australia is an internationally recognised biodiversity hotspot (Myers *et al.* 2000) within which the invasive soilborne plant pathogen *Phytophthora cinnamomi* Rands is a major threatening process (Commonwealth of Australia 2005). Inadvertent human-mediated introduction of *P. cinnamomi* from the pathogen's normal region of origin in the South-east Asian tropics has resulted in irreversibly altered plant communities of the South-west Botanical Province of Western Australia (Shearer and Smith 2000). Reduction of biodiversity caused by invasive species is a continuing, serious, wide-ranging global problem (Vitousek *et al.* 1997; Simberloff *et al.* 2005).

The first association of *P. cinnamomi* with death of *Eucalyptus marginata* Donn ex Smith and the understorey in forests of south-western Australia (Podger *et al.* 1965) stimulated much of the research that forms the current understanding of the epidemiology, impact and options for the control of the pathogen in native plant communities (Shearer and Tippett 1989; Shearer and Smith 2000; Shearer 2003). This presentation summarises the threat that *P. cinnamomi* poses to conservation values in the South-west Botanical Province of Western Australia and options aimed at conserving communities and taxa threatened by the pathogen.

Pathogen introduction, distribution and life cycle

Evidence from clonal lineage data (Dobrowolski *et al.* 2003), the patterns of disease distribution in association with human activity (Shearer and Tippett 1989; Grant and Barrett 2003) and the susceptibility of major floristic components of the native

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vegetation (Shearer *et al.* 2004*a*) indicate that *P. cinnamomi* is a comparative recent introduction into native plant communities of the South-west Botanical Province. Human settlement probably introduced the pathogen into proteaceaous heathland in Cape Arid National Park in the early 1900s (Grant and Barrett 2003), *E. marginata* forest by the 1920s (Hopkins 1973) and *Banksia* woodland by the early 1940s (Hill *et al.* 1994).

Once introduced, *P. cinnamomi* was mainly disseminated over large distances in infested soil moved by human activity. Off-road activity and infested gravel unsuspectingly used in road construction in the 1920s to 1960s (Shearer and Tippett 1989) distributed *P. cinnamomi* throughout the South-west Botanical Province of Western Australia (Fig. 1). Infested soil of potted plants has been associated with the establishment of outlying disease centres. Old remnants of an illegal *Cannabis sativa* L. plantation established from potted plants was found with the most northerly disease centre west of Eneabba (B. L. Shearer, unpubl. data). Potted plant stock brought in by human settlement probably originated the most easterly infections in the Cape Arid National Park (Grant and Barrett 2003). Natural dispersal occurs by propagules in water flowing in surface and near-surface drainage systems and by growth through root systems. The distribution of *P. cinnamomi* is related to availability of moisture, with the incidence of the pathogen being greatest in areas that are water-gaining or receiving more than 600 mm of rainfall. *P. cinnamomi* causes high visual impact in native communities at the extreme of the pathogen's geographic range. Whether isolates of *P. cinnamomi* have been selected for fitness to extreme environments at the geographic limits of the pathogen's distribution needs to be determined. Current distribution of *P. cinnamomi* (Fig. 1) seems to be a legacy of past dissemination of the pathogen, rather than recently established infestation. Qualitative observations suggest that new infestations have not occurred recently to the same extent as they have in the past. Future planning requires determination of whether the apparent current level of new infections is related to either a long lag time between establishment and expression, the result of a drying climate (Hope *et al.* 2006) or applied hygiene procedures (Shearer and Tippett 1989).

Once established, *P. cinnamomi* forms a disease centre (Fig. 2). In native vegetation mainly composed of susceptible taxa, the disease centre is characterised by 'an area of disease expression around the point of initial inoculum introduction, with the outer perimeter usually delimited by a disease front of dead and dying vegetation' (Shearer *et al.* 2004*a*). An 'old' infection zone surrounds the area of initial introduction where most of the susceptible taxa have been killed (Fig. 2), followed by the 'front' (Fig. 2) evident by recently killed vegetation that ingresses into 'healthy' diverse vegetation beyond the front (Fig. 2). The pathogen is most evident by the recently killed plants at the front, but can extend beyond the front in infected roots that grow into apparently healthy vegetation. In the South-west Botanical Province of Western Australia, disease fronts of dead and dying plants can extend into healthy vegetation at the rate of 0.7–2 m $year^{-1}$, depending on climate, site and susceptibility of vegetation (Hill *et al.* 1994; Grant and Barrett 2003; Shearer *et al.* 2004*b*). Grant and Barrett (2003) estimated that 1.5 m of disease extension per year results in 1.5 ha of native vegetation infested and changed for every 10 km of front. As a result, 14% of *E. marginata* forest (Davison and Shearer 1989), more than 60% of the Stirling Range National Park and most of Cape le Grand National Park are now affected (Grant and Barrett 2003).

The widespread distribution (Fig. 1) and high visual impact (Fig. 2) of *P. cinnamomi* in the South-west Botanical Province is intimately related to the occurrence of niches favourable to the pathogen within the region. The water mould *P. cinnamomi* is a soilborne opportunist, whose life cycle is characteristically dependent on moisture and warm temperatures for sporulation and infection. The soils, topography and the Mediterranean climate, in conjunction with the hydrological cycle and susceptible plant communities of the region, provide favourable niches within the soil profile whereby *P. cinnamomi* can survive adverse conditions and be spread in soil, water and by root-

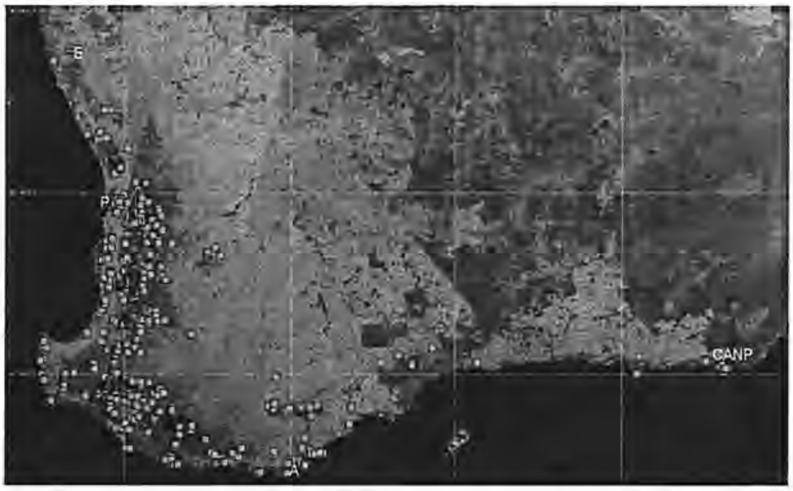


Fig. 1. Distribution of *Phytophthora cinnamomi* disease centres (□) in south-western Western Australia, compiled from assessment plots, mapping and isolation records. A = Albany; CANP = Cape Arid National Park; E = Enneabba; P = Perth.

Fig. 2. Active disease extension of *Phytophthora cinnamomi* in *Banksia* woodland on the Bassendean Dune System. The view is towards healthy woodland (H) from the old diseased area (O), where most of the susceptible hosts have been killed, with resultant high visual impact of the pathogen. The disease front (F) is demarcated by dying and recently killed hosts.

to root contact to infect roots of a wide range of susceptible hosts. Shearer and Tippett (1989) and Shearer and Smith (2000) detailed the various interactions that have created the diversity of warm, moist within-soil microenvironments that are favourable for sporulation, survival, dispersal and infection within the South-west Botanical Province. Most favourable conditions for epidemic development of *P. cinnamomi* occur in plant communities on infertile soils of poor drainage, namely laterites and leached sands of the Geraldton Sandplains, Jarrah Forest, Swan Coastal Plain, Warren and Esperance Plains bioregions (Shearer 1994). Several of these regions are botanical hotspots of plant species richness (Hopper and Gioia 2004). The population dynamics of *P. cinnamomi* have been determined for soils of *E. marginata* forest (Shearer and Shea 1987), but not for other bioregions of the province. A much greater understanding of *P. cinnamomi* population dynamics in soils of bioregions other than forest is required in order to determine changes of disease impact with time and between locations and the efficacy of control strategies within the South-west Botanical Province of Western Australia.

Cost of disease

Despite the threat that *P. cinnamomi* poses to biodiversity of the South-west Botanical Province, determination of the cost of disease to conservation values has received little attention (Shearer and Smith 2000; Shearer *et al.* 2004*a*). The cost of *P. cinnamomi* to community values can be determined in various ways (Shearer *et al.* 2004*a*). In this presentation, an examination of direct and indirect impacts on biodiversity and ecosystem dynamics, the proportion of *Threatened Ecological Communities* infested, *Declared Rare Flora* either directly or indirectly threatened by infestation and estimates of the proportion of the native flora of the South-west Botanical Province susceptible illustrate the cost of *P. cinnamomi* infestation on community values.

Direct impacts—mortality curves

Even though the impact of *P. cinnamomi* on plant communities is characterised by death of susceptible hosts, mortality curves have been rarely used to quantify direct impact of the pathogen.

In the substantial literature on *P. cinnamomi*, illustrated in Fig. 2 of Shearer and Tippett (1989), only 21 publications report on the use of mortality curves for disease assessment caused by the pathogen. Five of these publications used mortality curves to evaluate fungicide control (Englander *et al.* 1980; Shearer and Fairman 1997*a*, 1997*b*; Barrett 2003; Shearer *et al.* 2006), two for biological control (D'Souza *et al.* 2004, 2005), two for assessment of pathogenic variability (Podger 1989; Dudzinski *et al.* 1993), 10 for the assessment of resistance (Cho 1983; Butcher *et al.* 1984; Harris *et al.* 1985; McCredie *et al.*1985; Stukely and Crane 1994; Barker and Wardlaw 1995; Hüberli *et al.* 2002; Frampton and Benson 2004; Reiter *et al.* 2004; Shearer *et al.* 2004*a*) and two for the assessment of impact (Kenerley and Bruck 1987; Wills 1993).

Figure 3 presents a compilation of all known mortality curves for *P. cinnamomi* disease centres in the South-west Botanical Province of Western Australia. Common flora in disease centres in the Esperance Plains bioregion mainly reached 50% mortality in less than 5 years, compared with >6 years for the two common susceptible hosts on the Swan Coastal Plain (Fig. 3*a*, Table 1). *P. cinnamomi* caused local extinction in three or less years of most of the assessed *Declared Rare Flora* in the Esperance Plains bioregion (Fig. 3*b*). Apparent mortality rates for *Declared Rare Flora* were faster, with associated year to 50% mortality

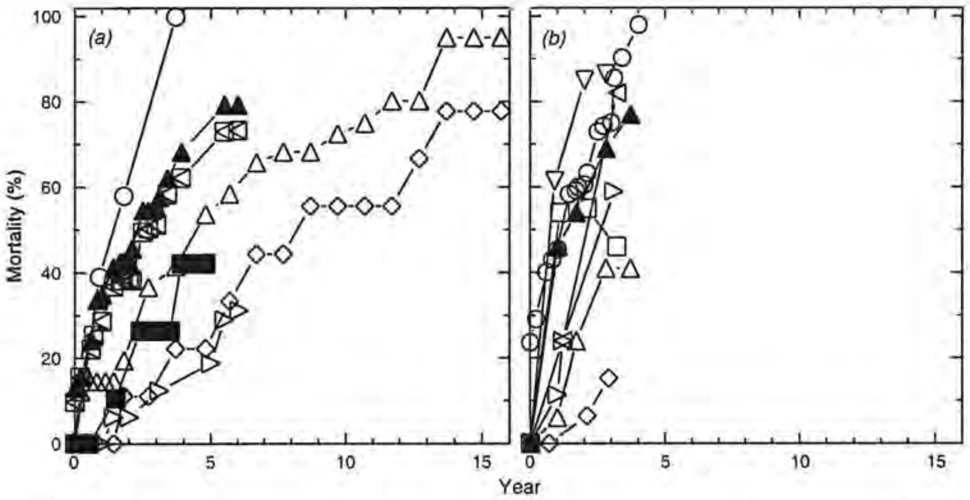


Fig. 3. Mortality curves recorded in *Phytophthora cinnamomi* disease centres for (*a*) commonly occurring flora in the Swan Coastal Plain (SWA) and Esperance Plains bioregions and (*b*) *Declared Rare Flora* in the Esperance Plains bioregion of Western Australia. Mortality was either recorded in 25-m^2 permanent quadrats or permanent lengths of 10–30 m along fronts. (*a*) Common flora: *Banksia attenuata*, SWA (△) and Stirling Range National Park (SRNP) (▲); *B. baxteri*, Waychinnicup National Park (□) and Fitzgerald River National Park (FRNP) (■); *B. coccinea*, Two Peoples Bay Nature Reserve (◁, ▷) and Gull Rock Reserve (▽); *B. grandis*, SWA (◇); *Lambertia inermis* var. *inermis*, FRNP (○). (*b*) *Declared Rare Flora*: *Andersonia axilliflora*, SRNP (▽); *B. brownii*, Millbrook Reserve (○); *Daviesia glossosema*, SRNP (◁), *D. pseudaphylla*, SRNP (▷); *Dryandra anatona*, SRNP (△, ▲); *Persoonia micranthera*, SRNP (◇); *Sphenotoma* sp. Stirling Range, SRNP (□).

less than that for most of the common flora (Table 1). No other estimates of apparent mortality rates or time to 50% mortality have been found in the literature for *P. cinnamomi*. A much greater understanding of *P. cinnamomi* disease-progress curves and the consequence of epidemic thresholds is required for the assessment of changes of disease impact with time and between locations, host susceptibility and determination of the efficacy of control strategies.

Direct impacts—changes in canopy and ground cover

Vegetation cover drives a range of different processes, including heat and mass transfer, temperature and moisture of soils (Shearer and Tippett 1989), quantity and quality of light reaching the ground (Jennings *et al.* 1999) and understorey regeneration (Lowman and Nadkarni 1995). Even though *P. cinnamomi* mainly affects community values by killing susceptible hosts, measurement of altered vegetation cover has been rarely used to monitor community changes associated with *P. cinnamomi* infestation. Ground cover has been used by Weste's group (Weste and Taylor 1971; Weste *et al.* 1973; Kennedy and Weste 1986; Weste 1986; Weste and Kennedy 1997) and canopy cover by Newell (1998) to assess changes in impact of *P. cinnamomi* in disease centres in Victoria.

Phytophthora cinnamomi infestation caused significant changes in ground and canopy cover for disease centres in three biomes of the South-west Botanical Province of Western Australia (Table 2). The greatest ground cover occurred in the shrubland biome, with the changes smallest between areas of different disease status (Table 2). In contrast, in forest and woodland biomes the ground cover in the old infested area was reduced by 27–28% compared with adjoining healthy vegetation (Table 2). Changes in canopy cover caused by *P. cinnamomi* infestation between biomes differed from that described for ground cover (Table 2). The greatest canopy cover occurred in the forest biome. *P. cinnamomi* infestation reduced canopy cover by 20–30% (Table 2), with the greatest canopy reduction resulting from disease occurring in shrubland. How these substantial changes in ground and canopy cover resulting from *P. cinnamomi* infestation affect changes in stand productivity, energy balance, microclimate, nutrient cycling and flora regeneration and diversity have yet to be quantified.

Direct impacts—species number and cover

The substantial changes in ground and canopy cover associated with *P. cinnamomi* infestation of plant communities reported in the previous section result from the dynamic interactions among host, pathogen and environment. Outcomes of many of the interactions in terms of changes in plant species number and cover are poorly documented for South-west Botanical Province (Shearer and Hill 1989; Shearer and Tippett 1989; McDougall *et al.* 2002). There has been no long-term monitoring of changes in understorey composition following *P. cinnamomi* infestation of plant communities of the South-west Botanical Province of Western Australia, comparable to that undertaken in Victoria by Weste (2003). Some different responses of vegetation to *P. cinnamomi* infestation are illustrated in Table 3.

Species richness was lower in an old infested area of *E. marginata* forest than that in the infection front and adjoining healthy forest (Table 3). In contrast McDougall *et al.* (2002) found no differences in species richness between infested and healthy forest. Most of the plant species occurring in at least two areas (Table 3) were susceptible to infection (Shearer and

Dillon 1995) and cover of the species was lower in the old infested area than in the adjoining healthy forest. *Thysanotus dichotomus* (Labill.) R.Br. showed no response and *Bossiaea ornata* (Lindley) Benth. and *E. marginata* showed a variable response to infection (Table 3).

Table 1. Apparent mortality rate (unit^{-1} year^{-1}) and year to 50% mortality from mortality curves recorded for commonly occurring and *Declared Rare Flora* (Fig. 3) in communities of the South-west Botanical Province of Western Australia infested with *Phytophthora cinnamomi*

Mortality was either recorded in 25-m^2 permanent quadrats or permanent lengths of 10–30 m along fronts. SWA, Swan Coastal Plain; FRNP, Fitzgerald River National Park; GRR, Gull Rock Reserve; MBNR, Millbrook Nature Reserve; SRNP, Stirling Range National Park; TPBNR, Two Peoples Bay Nature Reserve; WNP, Waychinnicup National Park. Apparent mortality rate was calculated from the regression of the logit of mortality against year after first assessment (Zadoks and Schein 1979). Year to 50% mortality was determined by dividing the constant by the slope coefficient (Shearer and Wilcoxson 1980)

Host	Location	Apparent mortality rate	Year to 50% mortality
Common flora			
Banksia attenuata	SWA	0.34	6.4
	SRNP	0.92	3.4
B. baxteri	WNP	0.50	2.6
	FRNP	3.27	1.8
B. coccinea	GRR	1.28	4.3
	TPBNR	0.49	3.1
	TPBNR	0.81	6.5
B. grandis	SWA	0.35	10.0
Lambertia inermis var. *inermis*	FRNP	3.46	1.6
Declared Rare Flora			
Andersonia axilliflora	SRNP	2.90	1.7
B. brownii	MBNR	1.01	1.3
Daviesia glossosema	SRNP	2.50	2.3
D. pseudaphylla	SRNP	2.11	2.5
Dryandra anatona	SRNP	1.67	3.2
	SRNP	1.86	2.4
Persoonia micranthera	SRNP	2.44	3.4
Sphenotoma sp. Stirling Range	SRNP	1.92	2.5

Table 2. Percentage (mean ± s.e. of the mean) ground and canopy cover in old and front areas of *Phytophthora cinnamomi* disease centres and in adjoining healthy areas for centres in *Eucalyptus marginata* forest, *Banksia* woodland and *Banksia* shrubland biomes of South-west Botanical Province of Western Australia

Ground cover was assessed by visual estimate of the percentage of ground covered by vegetation (Kennedy and Weste 1986). Canopy cover was assessed from hemispherical photographs and gap light analyser software (Frazer *et al.* 1999). Means are of three replicates for 22 disease centres in forest, 25 centres in woodland and 21 centres in shrubland biomes

Cover	Biome	Area			Difference
		Old	Front	Healthy	Healthy–Old
Ground	Forest	33 ± 2	47 ± 2	60 ± 2	27
	Woodland	40 ± 2	58 ± 2	68 ± 2	28
	Shrubland	74 ± 2	84 ± 2	89 ± 2	15
Canopy	Forest	47 ± 21	58 ± 1	68 ± 1	21
	Woodland	25 ± 2	37 ± 2	48 ± 2	23
	Shrubland	15 ± 1	26 ± 1	47 ± 2	32

Species richness was lower in an old infested area of *Banksia* woodland than that in the infection front and adjoining healthy woodland (Table 3). Shearer and Hill (1989), Keighery *et al.* (1994), Shearer and Dillon (1996*a*) and Shearer *et al.* (2004*b*) also reported a decrease in species numbers following infestion of *Banksia* communities by *P. cinnamomi*. Only two of the plant species occurring in at least two areas (Table 3) were susceptible to infection (Shearer and Dillon 1996*b*) and cover of the species was lower in the old infested area than in the adjoining healthy woodland. In contrast, most of the species

Table 3. Number of perennial plant species and percentage cover of plant species (mean ± s.e. of the mean of three replicates for both) recorded in 25-m^2 quadrats in old and front areas of a *Phytophthora cinnamomi* disease centre and in an adjoining healthy area for one centre in *Eucalyptus marginata* forest, *Banksia* woodland and *Banksia* shrubland biomes of South-west Botanical Province of Western Australia

High visual impact of *P. cinnamomi* in each disease centre in the three biomes. Plant species occurred in at least two areas. The site in the forest biome was a P Havel site-vegetation type (Havel 1975), the site in the woodland biome a *Banksia* woodland on Bassendean Dune sand (Shearer and Dillon 1996*a*) and the site in the shrubland biome a *Banksia* shrubland on leached sand at Cape Riche

Biome	Parameter	Area		
		Old	Front	Healthy
Forest	Number of species	14 ± 1	17 ± 1	24 ± 1
	Percentage cover			
	Adenanthos barbiger	1 ± 1	4 ± 3	7 ± 1
	Allocasuarina fraseriana	1 ± 1	2 ± 2	25 ± 9
	Banksia grandis	0	11 ± 2	37 ± 12
	Hibbertia quadricolor	0	2 ± 1	5 ± 3
	Leucopogon nutans	1 ± 1	3 ± 1	6 ± 2
	Xanthorrhoea preissii	5 ± 5	13 ± 7	17 ± 3
	Thysanotus dichotomus	3 ± 2	3 ± 2	3 ± 1
	Bossiaea ornata	4 ± 2	30 ± 17	5 ± 2
	Eucalyptus marginata	22 ± 6	41 ± 19	11 ± 3
Woodland	Number of species	9 ± 2	13 ± 2	14 ± 1
	Percentage cover			
	B. attenuata	7 ± 7	47 ± 26	23 ± 7
	H. hypericoides	0	37 ± 7	47 ± 4
	Acacia pulchella	25 ± 11	5 ± 4	3 ± 2
	Calytrix flavescens	20 ± 6	7 ± 2	3 ± 1
	Lyginia imberbis	10 ± 1	1 ± 1	1 ± 1
	Melaleuca thymoides	14 ± 8	5 ± 5	2 ± 2
	Dasypogon bromeliifolius	1 ± 1	1 ± 1	2 ± 1
	Hypocalymma robustum	2 ± 2	4 ± 1	5 ± 1
Shrubland	Number of species	12 ± 1	16 ± 2	14 ± 1
	Percentage cover			
	B. attenuata	1 ± 1	2 ± 1	25 ± 13
	B. baxteri	0	27 ± 10	67 ± 3
	D. bromeliifolius	4 ± 1	17 ± 8	15 ± 8
	Lepidosperma angustatum	22 ± 4	72 ± 9	82 ± 7
	A. cuneatus	20 ± 5	22 ± 2	12 ± 2
	B. nutans	10 ± 10	15 ± 10	12 ± 3
	Beaufortia micrantha	25 ± 13	17 ± 7	47 ± 7
	M. striata	25 ± 3	25 ± 5	25 ± 8
	Taxandria spathulata	40 ± 17	63 ± 9	43 ± 20

were comparatively resistant (Shearer and Dillon 1996*b*) and had greater cover in the old infested area than in adjoining healthy woodland (Table 3). *Dasypogon bromeliifolius* R.Br. and *Hypocalymma robustum* (Endl.) Lindl. showed no response to infection.

No differences in species richness occurred between the infested and healthy shrubland (Table 3). This was probably reflected in the lack of response to infection of most of the shrubland plant species (Table 3). Infection significantly reduced the cover of susceptible overstorey of *B. attenuata* R.Br and *B. baxteri* R.Br. (Table 3). Even though *Lepidosperma angustatum* R.Br. is resistant to *P. cinnamomi* infection (Shearer and Dillon 1996*b*), cover of the species was lower in the old infested area than that in the adjoining healthy shrubland. The response of *L. angustatum* to *P. cinnamomi* infestation was possibly due to indirect effects caused by habitat change, rather than a direct result of infection by the pathogen.

Indirect impact

While direct impacts of *P. cinnamomi* have been poorly documented in the South-west Botanical Province, even less attention has been given to the indirect impact of the pathogen. This is despite the fact that the indirect impact following infestation by plant pathogens can be greater than the direct impact of killed plants (Hansen 1999). The indirect impact of *P. cinnamomi* can lead to resistant species increasing in infested areas, as occurred in the woodland disease centre (Table 3). Presumably, factors such as reduced competition allowed better exploitation of old infested areas by resistant hosts, following removal of susceptible hosts killed by infection. Alternately, taxa not directly affected by infection may decline because of habitat destruction by the pathogen.

The response of the fern *Lindsaea linearis* SW to *P. cinnamomi* infestation in *Banksia* woodland is an example of an indirect impact of the pathogen on a canopy-dependant species. Controlled soil-inoculation tests (Shearer *et al.* 2004*a*, 2005) have shown that *L. linearis* resists *P. cinnamomi* infection and does not harbour the pathogen on roots. However, $19 \pm 12\%$ cover of the fern in an old area of a disease centre in *Banksia* woodland was significantly lower than the cover of $52 \pm 12\%$ at the front and $55 \pm 7\%$ in the adjoining healthy woodland. The reduced cover by the fern was significantly related to the reduced canopy cover resulting from killing of susceptible hosts by *P. cinnamomi*, as follows:

$$\text{Fern Cover} = -104.8 + 2.4\ \text{Canopy Cover}\,(r = 0.78,\ P < 0.05).$$

The decreased cover of the fern in the infested area was probably due to the changed habitat caused by canopy reduction resulting from *P. cinnamomi* killing susceptible hosts, rather than a direct effect of infection on the fern by the pathogen.

In one of the few reports of the indirect impact of *P. cinnamomi*, Wills (1993) suggested that reduced occurrence of apparently resistant *Stylidium scandens* R.Br. in disease centres in the Stirling Range National Park was due to reduced canopy resulting from *P. cinnamomi* killing susceptible hosts, rather than the direct effects of infection on *S. scandens*. McDougall *et al.* (2005) observed in *E. marginata* forest that several apparently resistant understorey species persisted only where canopy survived the infestation. Current poor understanding and quantification of indirect impacts of *P. cinnamomi* through habitat destruction results in an underestimation of the true impact of the pathogen on the flora of the South-west Botanical Province.

Threatened Ecological Communities

Phytophthora cinnamomi is a significant threat to the survival of *Threatened Ecological Communities* in the South-west Botanical Province of Western Australia. Of the 55 *Threatened Ecological Communities* in the region (Commonwealth of Australia 2005), 24 are infested with *P. cinnamomi* (Table 4). *Threatened Ecological Communities* infested with the pathogen incorporate a range of vegetation types and mainly occur in hot spots of flora diversity (Hopper and Gioia 2004) on the Swan Coastal Plain and Esperance Plains bioregions. Of the 24 *Threatened Ecological Communities* infested, 58% are endangered or critically endangered (Table 4).

Threatened Declared Rare Flora

Of the current 340 *Declared Rare Flora* in the South-west Botanical Province of Western Australia, 86 are threatened by either direct or indirect impact by *P. cinnamomi* (Table 5). Taxa are almost equally divided between those either directly or indirectly threatened by *P. cinnamomi*, 56% compared with 44%, respectively. Of those threatened by direct impact of *P. cinnamomi*, 52% are Proteaceae and 19% Myrtaceae (Table 5). In comparison, *Declared Rare Flora* indirectly threatened are mainly Orchidaceae (37%) followed by Myrtaceae (29%). A third of the *Declared Rare Flora* threatened by either direct or indirect impact of *P. cinnamomi* occur in the Esperance Plains bioregion followed by 26% in the Swan Coastal Plain and 23% in Jarrah Forest bioregions.

Table 6 illustrates the precarious existence of several rare flora threatened by *P. cinnamomi*. Although *B. brownii* occurs in 27 populations, 96% are infested with *P. cinnamomi* and 67% have less than 10 mature plants. Ten populations are now presumed extinct. All the few known populations of susceptible *Dryandra anatona* A.S.George, *D. montana* A.S.George and *Persoonia micranthera* P.H.Weston are infested, with the majority of populations having less than 10 mature plants (Table 6). The continued existence of susceptible *Lambertia fairallii* Keighery, first sketched by Ferdinand Bauer in the early 1800s (Pignatti-Wikus *et al.* 2000) and only recently described (Keighery 1983), is immediately threatened by *P. cinnamomi*. *Lambetia orbifolia* C.A.Gardner subsp. *orbifolia* ms occurs in only three locations, one of which is in significant decline from *P. cinnamomi* infestation.

Susceptible species

Shearer *et al.* (2004*a*) estimated from four databases that 2284 species of the 5710 described plant species in the South-west Botanical Province are susceptible to *P. cinnamomi* and 800 of these 2284 species are highly susceptible to the pathogen. Many of the highly susceptible species tend to occur frequently and be structurally dominant in the communities in which they occur and their inevitable death following *P. cinnamomi* infestation leads to an irreversible and conspicuous decline in biomass, with

Table 4. *Threatened Ecological Communities* of the South-west Botanical Province of Western Australia infested with *Phytophthora cinnamomi*
Bioregions (Western Australia Herbarium 1998): AW, Avon Wheatland; ESP, Esperance Plains; GS, Geraldton Sandplains; JF, Jarrah Forest; SWA, Swan Coastal Plain; WAR, Warren. Endorsed, endorsed by the Minister for Environment: Y, yes; N, no

Community	No. of sites	Type	Bioregion	Critically endangered	Endangered	Vulnerable	Priority	Endorsed
Gp200–170	3	*Petrophile* heath	GS				Y	N
Ferricrete	2	Tall shrubland	GS		Y			N
Lesueur-Coomallo D1	1	*Allocasuarina* heath	GS	Y				Y
Lesueur-Coomallo M2	1	*Allocasuarina* heath	GS		Y			N
Mound Springs	2	Wetland	SWA		Y			Y
SCP20a	25	*Banksia* woodland	SWA		Y			Y
SCP10b	8	Shrubland	SWA		Y			Y
SCP14	1	Wetland	SWA				Y	N
SCP30a	50	*Callitris* woodland	SWA			Y		Y
SCP02	2	Wet shrubland	SWA		Y			Y
SCP3a	3	*Eucalyptus* woodland	SWA	Y				Y
SCP20b	18	*Banksia* woodland	SWA		Y			Y
SCP1b	9	*Eucalyptus* woodland	SWA			Y		Y
SCP3b	11	*Eucalyptus* woodland	SWA			Y		Y
Mottlecah	1	Mottlecah heath	AW				Y	N
Meelup Granites	7	*Calothamnus* heath	JF			Y		Y
Scott Ironstone	14	Woodland	JF		Y			N
Mt Lindesay	1	Heath–woodland	WAR		Y			N
Esperance sandplain	2	Scrub heath	ESP				Y	N
Bandalup Hill	2	*Eucalyptus* woodland	ESP		Y			N
E. acies mallee	3	*Eucalyptus* heath	ESP			Y		Y
Montane mallee	12	Montane thicket	ESP		Y			N
Coyanarup Wetland Ranges	1	Wetland	ESP			Y		N
Montane	4	Montane thicket	ESP	Y				Y
Total = 24	183			3	11	6	4	

associated reduced floristic diversity and capacity of infested sites to support dependent biota (Wills 1993; Shearer and Dillon 1995, 1996*a*, 1996*b*). Shearer *et al.* (2004*a*) concluded that '*P. cinnamomi* in south-western Australia is an unparalleled example of an introduced pathogen with wide host range causing great irreversible damage to a range of unique, diverse but mainly susceptible plant communities'.

Variation in host susceptibility

The diversity of susceptible hosts is one of the main reasons why *P. cinnamomi* is such a successful pathogen in the South-west Botanical Province of Western Australia. Despite this, a greater understanding of the variation in host response is required to elucidate mechanisms of resistance, survival of taxa threatened by *P. cinnamomi* in different environments and utilisation of resistant individuals for long-term management of infested communities (Shearer and Dillon 1996*b*; Shearer *et al.* 2004*a*, 2005). Patterns of variation among and within families have been illustrated for threatened flora tested in a shadehouse environment (Shearer *et al.* 2004*a*, 2005). Relative susceptibilities determined in controlled environments reflect those found in natural environments (Butcher *et al.* 1984; McCredie *et al.* 1985; Stukely and Crane 1994; Barker and Wardlaw 1995; Hüberli *et al.* 2002; Shearer *et al.* 2004*a*).

Susceptibility between families

Threatened flora show considerable variation among and within families (Fig. 4). Taxa within Mimosaceae are mainly resistant, with few individuals within a species killed by infection. Although Myrtaceae taxa are mainly resistant, the distribution tails off to a few susceptible species for which most individuals are killed by infection. Papilionaceae represents a transitional family where there is a flat distribution of species between resistant and susceptible taxa. At the other extreme, taxa within Proteaceae are biased towards susceptible species, although considerable variation in response to *P. cinnamomi* exists within the family.

Susceptibility within families

Variation in susceptibility within a family is illustrated for Proteaceae (Fig. 5). Species of *Grevillea* are mainly resistant. *Hakea* represents a transitional genus where there is a flat distribution of species between resistant and susceptible taxa. Taxa within *Dryandra* and *Banksia* are biased towards susceptible species, although a few resistant species occur within these genera.

Thus, the illustrated considerable variation of susceptibility to *P. cinnamomi* within supposed susceptible families, such as Proteaceae, show how classification within families can be a poor predictor of species susceptibility. This is further illustrated by the responses to *P. cinnamomi* of all the described taxa within the genus *Lambertia*.

Susceptibility within Lambertia

The susceptibility of *Lambertia* taxa to *P. cinnamomi* is poorly understood or documented even though the pathogen is a major

Table 5. Current *Declared Rare Flora* threatened by either direct or indirect impact of *Phytophthora cinnamomi* in the South-west Botanical Province of Western Australia

Descriptions of direct and indirect impact of *P. cinnamomi* are given in the text

Impact of *Phytophthora cinnamomi*	Family	Genus	Number of taxa	Family total
Direct	Epacridaceae	*Andersonia*	4	
		Leucopogon	1	
		Sphenotoma	1	6
	Goodeniaceae	*Lechenaultia*	1	1
	Iridaceae	*Patersonia*	1	1
	Myrtaceae	*Darwinia*	6	
		Verticordia	3	9
	Papilionaceae	*Daviesia*	3	
		Gastrolobium	1	
		Latrobea	1	
		Pultenaea	1	6
	Proteaceae	*Adenanthos*	1	
		Banksia	4	
		Conospermum	1	
		Dryandra	6	
		Grevillea	3	
		Isopogon	1	
		Lambertia	5	
		Persoonia	1	
		Petrophile	1	
		Synaphea	2	25
Total				48
Indirect	Cyperaceae	*Lepidosperma*	1	1
	Haemodoraceae	*Anigozanthos*	1	
		Conostylis	4	5
	Myrtaceae	*Calytrix*	1	
		Chamelaucium	1	
		Darwinia	1	
		Eucalyptus	3	
		Verticordia	5	11
	Orchidaceae	*Caladenia*	5	
		Diuris	2	
		Drakaea	3	
		Epiblema	1	
		Microtis	1	12
	Papilionaceae	*Gastrolobium*	1	
		Jacksonia	1	
		Kennedia	1	3
	Poaceae	*Deyeuxia*	1	1
	Proteaceae	*Banksia*	1	
		Grevillea	1	2
	Restionaceae	*Chordifex*	1	1
	Santalaceae	*Spirogardnera*	1	1
	Xyridaceae	*Xyris*	1	1
Total				38
Grand total				86

threatening process for several taxa within the genus. *Lambertia* are keystone taxa within the communities they occur. Fifteen taxa are currently recognised in Western Australia (Western Australia Herbarium 1998) and one, *L. formosa* Sm., in New South Wales (Hnatiuk 1995). Five *Lambertia* taxa are *Declared Rare Flora* and two taxa have a *Priority* conservation code (Western Australia Herbarium 1998).

Lambertia taxa show considerable variation in susceptibility to *P. cinnamomi* within a continuum (Fig. 6). Rate of colonisation ranged from 0.2 cm day^{-1} for the most resistant *L. formosa* and 0.8 cm day^{-1} for the most susceptible *L. orbifolia* subsp. *orbifolia*. Within common *Lambertia* species, *L. formosa* was the most resistant and *L. ericifolia* R.Br. the most susceptible (Fig. 6*a*). The resistance of the *L. formosa* of the eastern states, compared with the more susceptible Western Australian *Lambertia* species, parallels the situation in *Banksia*, where species in eastern Australia tend to be more resistant than those in Western Australia (Cho 1983; McCredie *et al.* 1985). Yet to be elucidated are the reasons for the greater resistance to *P. cinnamomi* in eastern Australian than in Western Australian taxa. Within threatened *Lambertia* taxa, *L. rariflora* Meisn. subsp. *rariflora* was the most resistant and *L. orbifolia* subsp. *orbifolia* the most susceptible (Fig. 6*b*). There was no significant difference in susceptibility among replicates of *L. echinata* subsp. *occidentalis* Keighery and of *L. orbifolia* subsp. Scott River Plains (L.W. Sage 684). The significant difference in susceptibility to *P. cinnamomi* between *L. orbifolia* subsp. Scott River Plains and *L. orbifolia* subsp. *orbifolia* supports the genetic evidence (Coates 2000) that the two populations are separate evolutionary lineages.

Intra-specific resistance

Within apparently susceptible plant species, individuals are resistant to *P. cinnamomi* infection (Butcher *et al.* 1984; Harris *et al.* 1985; McCredie *et al.* 1985; Stukely and Crane 1994; Frampton and Benson 2004; Shearer *et al.* 2004*a*). How intra-specific variation in susceptibility to *P. cinnamomi* can best be utilised in the long-term management of threatened flora populations, needs to be a high research priority (Shearer *et al.* 2005).

Conserving threatened flora

Hygiene and quarantine measures (Shearer and Tippett 1989), long-term *ex situ* seed conservation (Cochrane and Coates 1994), translocations (Monks and Coates 2002) and aerial application of the systemic fungicide phosphite (Barrett 2003) have been the main management strategies used to protect flora and plant communities threatened by *P. cinnamomi* in the South-west Botanical Province of Western Australia. Hygiene measures, *ex situ* seed conservation and translocations are delay tactics that work best when integrated with control measures, such as phosphite application, that also reduce the rate of *P. cinnamomi* development. Phosphite is an environment-friendly fungicide that is effective in activating host defence responses in certain plant species otherwise susceptible to *P. cinnamomi* (Guest and Grant 1991; Shearer *et al.* 2006).

Application of the fungicide phosphite has proven effective in slowing the progress of *P. cinnamomi* in infested threatened communities (Shearer and Fairman 1997*a*, 1997*b*; Barrett 2003; Shearer *et al.* 2004*b*). However, variable responses of plant species to phosphite application (Table 7) are a major factor influencing effective control of *P. cinnamomi* by phosphite in native communities.

Table 6. Populations of *Declared Rare Flora* threatened by *Phytophthora cinnamomi*

Rare flora	Populations				
	Number	Number mature plants			Percentage infested with *P. cinnamomi*
		<10	10–100	>100	
Banksia brownii	27	18	4	5	96
Dryandra anatona	5	3	1	1	100
D. montana	4	2	2		100
Lambertia fairallii	5	2	1	2	100
L. orbifolia subsp. *orbifolia*	3		2	1	67
Persoonia micranthera	5	2	1	2	100

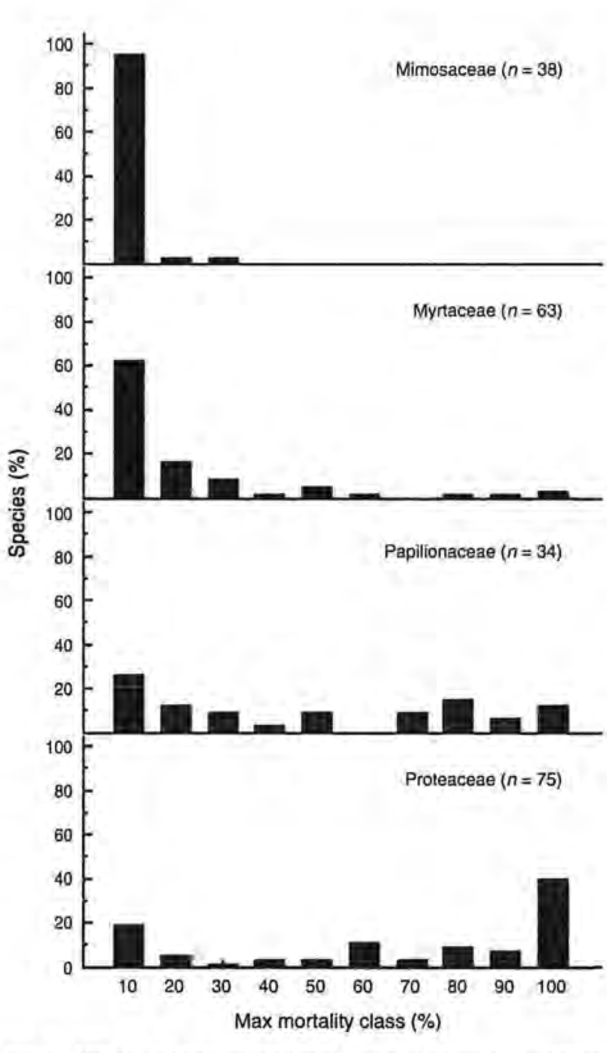


Fig. 4. Variation in host susceptibility to *Phytophthora cinnamomi* among and within four families. Percentage distribution of threatened species among percentage mortality classes following *P. cinnamomi* soil inoculation of species from four families in a shadehouse environment. Number of plant species within each family inoculated with the pathogen is indicated in parenthesis. Percentage mortality classes: 0–10, 11–20 to 91–100. Shearer *et al.* (2004*a*, 2005) detailed methods for soil inoculation and assessment of susceptibility of threatened flora to *P. cinnamomi*.

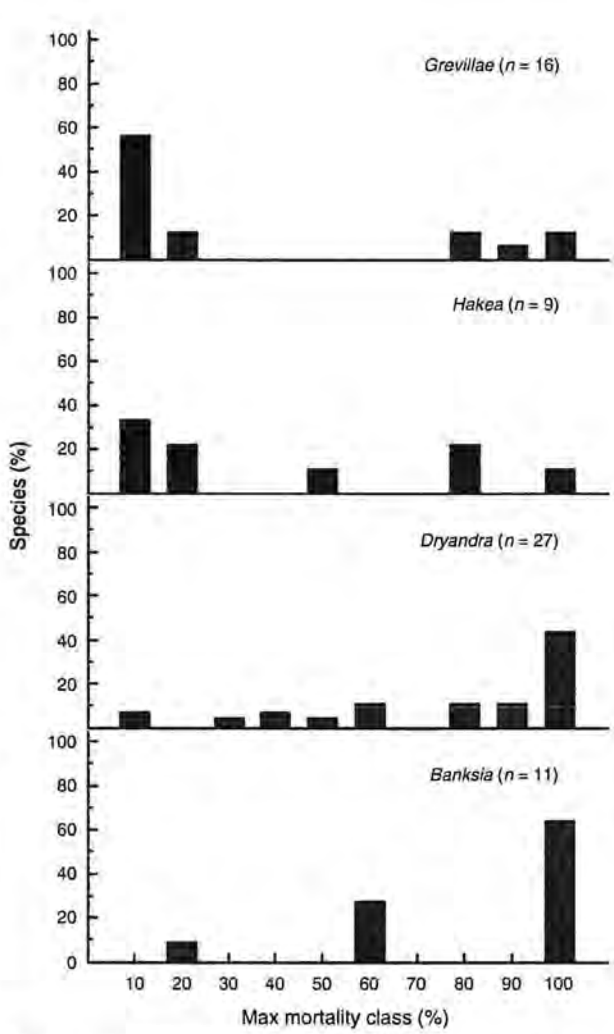


Fig. 5. Variation in host susceptibility to *Phytophthora cinnamomi* among genera within the family Proteaceae. Percentage distribution of threatened species among percentage mortality classes following *P. cinnamomi* soil inoculation of species from four genera within Proteaceae in a shadehouse environment. Number of plant species within each genera inoculated with the pathogen is indicated in parenthesis. Percentage mortality classes: 0–10, 11–20 to 91–100. Shearer *et al.* (2004*a*, 2005) detailed methods for soil inoculation and assessment of susceptibility of threatened flora to *P. cinnamomi*.

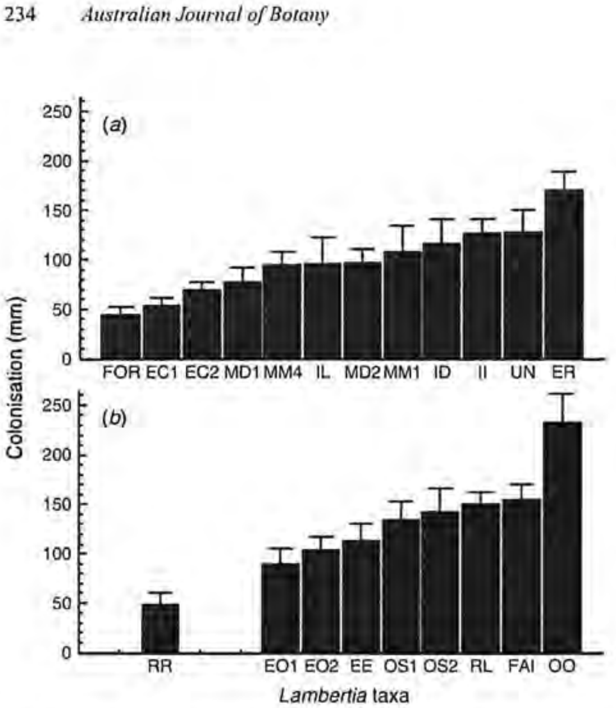


Fig. 6. Variation in susceptibility to *Phytophthora cinnamomi* within the genus *Lambertia*. Mean colonisation (±s.e. of the mean of 10 replicates) 14 days following stem inoculation of nine common and seven rare *Lambertia* taxa in a glasshouse environment. (*a*) Common *Lambertia* taxa: *L. formosa* (FOR); *L. echinata* subsp. *citrina* (EC1, EC2); *L. multiflora* var. *darlingensis* (MD1, MD2); *L. multiflora* var. *multiflora* (MM4, MM1), *L. ilicifolia* (IL); *L. inermis* var. *drumondii* (ID); *L. inermis* var. *inermis* (II); *L. uniflora* (UN); *L. ericifolia* (ER). (*b*) Rare *Lambertia* taxa: *L. rariflora* subsp. *rariflora* (RR); *L. echinata* subsp. *echinata* (EE); *L. echinata* subsp. *occidentalis* (LEO1, LEO2); *L. orbifolia* subsp. Scott River Plains (OS1, OS2); *L. rariflora* subsp. *lutea* (RL); *L. fairallii* (FAI); *L. orbifolia* subsp. *orbifolia* (OO). Stems were wound-inoculated with *P. cinnamomi* Isolate DP55 by methods previously described (Shearer *et al.* 2004*a*, 2006). *Lambertia* susceptibility was tested in stems since although *P. cinnamomi* mainly infects roots of plants, stems have the same relative susceptibility to the pathogen as roots (Dixon *et al.* 1984; Tippett *et al.* 1985) and stems are less variable than roots (Shearer *et al.* 1988, 2006). Relative susceptibilities determined in controlled environments reflect those found in natural environments (Butcher *et al.* 1984; McCredie *et al.* 1985; Stukely and Crane 1994; Barker and Wardlaw 1995; Hüberli *et al.* 2002; Shearer *et al.* 2004*a*). Daily mean maximum and minimum temperature during the 14-day inoculation period was 24.4±0.9°C and 14.8±0.5°C, respectively.

Phosphite effectiveness, the ability of the fungicide to inhibit the growth of *P. cinnamomi* in treated plant tissues, changes with application method (Table 7). Phosphite injection was the most effective treatment, with 82% of the plant species treated inhibiting the development of *P. cinnamomi* (Table 7). In contrast, low-volume phosphite spray showed the lowest effectiveness, with only 41% of the plant species treated inhibiting *P. cinnamomi*. High volume spray was intermediate, with 67% of the plant species treated inhibiting *P. cinnamomi* development (Table 7). There are few reports of the influence of different application methods on the effectiveness and levels of phosphite in the plant (Shearer *et al.* 2004*b*). Schutte *et al.* (1991) compared foliar spray with stem injection and found that although phosphite levels in the roots of 4-year-old citrus trees were greater following foliar spray than those after stem injection, the fungicide persisted longer in the roots following stem injection than foliar spray. Different methods of phosphite application should be compared in order to determine the effects of application method on phosphite uptake, redistribution and persistence within the plant and duration of effectiveness against *P. cinnamomi*.

Considerable variation in phosphite effectiveness occurred within and among plant species (Table 7). In some species, such as *B. grandis*, phosphite was consistently effective in inhibiting *P. cinnamomi* over different application methods and treatments (Table 7). In contrast, phosphite effectiveness in *L. inermis* R.Br. var. *inermis* differed considerably among different application methods and treatments (Table 7). The reasons for this variation have yet to be elucidated. Phosphite has a complex mode of action in plant tissues (Guest and Grant 1991), the mechanisms of which are poorly understood. A greater understanding of the mechanisms of action of phosphite in plant species showing different responses to the fungicide may provide options for prescription modification to increase phosphite effectiveness in a range of plant species.

Conclusions for conservation

Phytophthora cinnamomi is a human-introduced pathogen that has found favourable niches in native plant communities of South-west Botanical Province of Western Australia. Imbalance created by human activity, together with conducive climate and soils and a susceptible diverse flora that has not co-evolved with the pathogen, has been elemental to the high impact of *P. cinnamomi* on biodiversity within the region.

Community loss of diversity and functioning following gap creation by *P. cinnamomi* infestation undeniably influences the evolution of affected communities. 'Novel ecosystems' (Hobbs *et al.* 2006) are evolving following infestation. Despite this, *P. cinnamomi*-mediated changes in the diversity and functioning of the community are poorly understood and documented. Assessment of conservation options requires a much better understanding of the long-term direct and indirect effects of *P. cinnamomi* on native plant communities, than is available at present.

Management of infested communities is a major conservation dilemma. The only *P. cinnamomi* infestation in the Fitzgerald River National Park International Biome threatens flora and fauna in the rest of the park. Future spread of the pathogen is linked to the hydrology of such sites and prevention is dependant on modification of site hydrology and pathogen behaviour. However, engineering solutions cannot be simplistically applied to biological problems. Disturbance from remedial actions can favour the reproduction and survival of the pathogen, exacerbating disease development. More data are needed on the effect of site disturbance on the abiotic and biotic soil environment and interactions with pathogen sporulation and survival, and subsequent population dynamics of the pathogen in the soil profile, in order to determine changes of disease impact with time and location and the efficacy of control strategies.

Understanding host susceptibility to *P. cinnamomi* infection is fundamental to conservation options. Ranking of taxa according

Table 7. Phosphite effectiveness in south-western Australian native plant species susceptible to *Phytophthora cinnamomi* following various methods of application

Phosphite effectiveness occurred when there was a statistically significant control of *P. cinnamomi* in phosphite-treated plants in comparison with plants not treated with phosphite. Injection of phosphite at 100 g L^{-1}; high-volume spray of phosphite at 5 g L^{-1}; low-volume spray of phosphite at 24–48 kg ha^{-1}. References in parenthesis: 1 = Smith (1994); 2 = Shearer and Fairman (1997*a*); 3 = Shearer and Fairman (1997*b*); 4 = Pilbeam *et al.* (2000); 5 = Tynan *et al.* (2001); 6 = Wilkinson *et al.* (2001); 7 = Barrett (2003); 8 = Barrett *et al.* (2003); 9 = Shearer *et al.* (2006); 10 = C. E. Crane and B. L. Shearer (unpubl. data)

Application method	Phosphite effective	Phosphite not-effective
Injection	*Banksia attenuata* (3) *B. baxteri* (10) *B. coccinea* (9) *B. ilicifolia* (10) *B. grandis* (3, 9) *B. menziesii* (10) *B. verticillata* (10) *Eucalyptus marginata* (3, 9) *Lambertia inermis* var. *inermis* (10)	*B. attenuata* (10) *L. inermis* var. *inermis* (10)
High-volume spray	*Adenanthos barbiger* (4) *Astroloma xerophyllum* (5) *B. baxteri* (2) *B. brownii* (2) *B. coccinea* (2) *B. grandis* (5, 6, 10) *B. hookeriana* (6) *Daviesia decurrens* (4) *D. physodes* (5) *Dryandra sessilis* (6) *Hibbertia furfuracea* (5) *L. inermis* var. *inermis* (10) *L. multiflora* var. *multiflora* (5) *Leucopogon verticillatus* (5)	*B. attenuata* (10) *B. baxteri* (10) *Dampiera linearis* (6) *Eremaea beaufortioides* (5) *H. commutata* (6) *Verticordia grandis* (5) *Xanthorrhoea preissii* (4)
Low-volume spray	*Andersonia* sp. (7) *B. baxteri* (7, 10) *B. brownii* (1, 7, 10) *B. coccinea* (1, 10) *B. grandis* (10) *B. sphaerocarpa* var. *dolichostyla* (10) *B. verticillata* (10) *Beaufortia anisandra* (10) *Isopogon trilobus* (10) *L. inermis* var. *inermis* (7, 10) *L. fairallii* (10) *L. rariflora* subsp. *lutea* (10) *Sphenotoma* sp. (7)	*A. cuneatus* (10) *B. attenuata* (10) *Hakea ferruginea* (10) *H. pandanicarpa* (10) *Grevillea concinna* (10) *L. echinata* subsp. *citrina* (10) *L. echinata* subsp. *echinata* (10) *L. echinata* subsp. *occidentalis* (10) *L. ericifolia* (10) *L. ilicifolia* (10) *L. inermis* var. *drumondii* (10) *L. inermis* var. *inermis* (10) *L. multiflora* var. *darlingensis* (10) *L. multiflora* var. *multiflora* (10) *L. orbifolia* subsp. *orbifolia* (10) *L. orbifolia* subsp. Scott River Plains (10) *L. rariflora* subsp. *rariflora* (10) *L. uniflora* (10) *Petrophile biloba* (1)

to susceptibility to *P. cinnamomi* prioritises threatened flora according to hazard from the pathogen. Determination of the variation in susceptibility within and among families enables interpretation of differences in survival of threatened flora under different situations and assists in studies on mechanisms of resistance and identification and selection of resistant individuals within susceptible taxa. Resistance to invading *P. cinnamomi* expressed in the flora of the South-west Botanical Province is unlikely to be the result of long-term evolution of host–pathogen interactions. Thus, host defences to *P. cinnamomi* induced in the flora of the region may be favoured by selection for factors such as adaption to abiotic stress of drought and low soil fertility and to biotic stress of plant competition (Shearer *et al.* 2004*a*). Because of the range of susceptibilities in relatively few taxa, the genus *Lambertia* would make an ideal model system to elucidate the mechanisms of resistance to *P. cinnamomi*. Such studies would be further enhanced by identification and maintenance of resistant and susceptible lines within taxa.

Current strategies for conserving flora threatened by *P. cinnamomi* integrate hygiene and *ex situ* conservation with fungicide control. Requiring more attention within this integrated approach is the restoration of diseased communities with plants genetically resistant to *P. cinnamomi*. Such a strategy needs to be combined with population genetic analysis and biogeographical and ecological studies, in order to prevent potentially undesirable outcomes caused by human-mediated changes in population genetic structure (Coates 2000). Aerial application of phosphite has been successful in reducing disease development in targeted threatened plant populations. Fundamental differences in plant responses to phosphite application have important implications for conservation of threatened flora. Plant species that have low response to phosphite application pose special problems because effective control of *P. cinnamomi* will not be obtained with current prescriptions. Investigations of the mechanisms of action of phosphite will help prescription modification for effective control in low-responsive species and may indicate other chemicals that could have a synergistic action with phosphite. The range of responses to phosphite application by *Lambertia* taxa suggests that the genus would make an ideal model system to elucidate the mechanisms of phosphite effectiveness against *P. cinnamomi*.

Acknowledgements

Our thanks go to A. Crawford for germinating seed, V. English and J. Pryde for help in compiling Table 4, E. Adams, R. Carter, V. Clarke, M. Garkakalis, R. Hearn, B. Loudon, C. Page, N. Rouse, R. Smith and M. Streilein for help in compiling Table 5, R. Fairman for help with impact assessments, and C. Dunne and M. Shearer for checking the manuscript.

References

Barker PCJ, Wardlaw TJ (1995) Susceptibility of selected Tasmanian rare plants to *Phytophthora cinnamomi*. *Australian Journal of Botany* **43**, 379–386. doi: 10.1071/BT9950379

Barrett S (2003) Monitoring of aerial phosphite applications for the control of *Phytophthora cinnamomi* in the Albany district. In '*Phytophthora* in forests and natural ecosystems'. 2nd international IUFRO working party 7.02.09 meeting, Albany, WA. (Eds JA McComb, GEStJ Hardy, IC Tommerup) pp. 132–137. (Murdoch University Print: Perth)

Barrett SR, Shearer BL, Hardy GEStJ (2003) The efficacy of phosphite applied after inoculation on the colonisation of *Banksia brownii* stems by *Phytophthora cinnamomi*. *Australasian Plant Pathology* **32**, 1–7. doi: 10.1071/AP02061

Butcher TB, Stukely MJC, Chester GW (1984) Genetic variation in resistance of *Pinus radiata* to *Phytophthora cinnamomi*. *Forest Ecology and Management* **8**, 197–220. doi: 10.1016/0378-1127(84)90053-7

Cho JJ (1983) Variability in susceptibility of some *Banksia* species to *Phytophthora cinnamomi* and their distribution in Australia. *Plant Disease* **67**, 869–871.

Coates DJ (2000) Defining conservation units in a rich and fragmented flora: implications for the management of genetic resources and evolutionary processes in south-west Australian plants. *Australian Journal of Botany* **48**, 329–339. doi: 10.1071/BT99018

Cochrane A, Coates D (1994) Western Australia's Threatened Flora Seed Centre and its role in conservation of genetic diversity. *Danthonia* **3**, 4–7.

Commonwealth of Australia (2005) 'Environment Protection and Biodiversity Conservation Act 1999.' (Commonwealth Government Printer: Canberra)

Davison EM, Shearer BL (1989) *Phytophthora* spp. in indigenous forests in Australia. *New Zealand Journal of Forestry Science* **19**, 277–289.

Dixon KW, Thinlay, Sivasithamparam K (1984) Technique for rapid assessment of tolerance of *Banksia* spp. to root rot caused by *Phytophthora cinnamomi*. *Plant Disease* **68**, 1077–1080.

Dobrowolski MP, Tommerup IC, Shearer BL, O'Brien PA (2003) Three clonal lineages of *Phytophthora cinnamomi* in Australia revealed by microsatellites. *Phytopathology* **93**, 695–704.

D'Souza NK, Colqhhoun IJ, Shearer BL, Hardy GEStJ (2004) The potential of five Western Australian native *Acacia* species for biological control of *Phytophthora cinnamomi*. *Australian Journal of Botany* **52**, 267–279. doi: 10.1071/BT03089

D'Souza NK, Colqhhoun IJ, Shearer BL, Hardy GEStJ (2005) Assessing the potential for biological control of *Phytophthora cinnamomi* by fifteen native Western Australian jarrah-forest legume species. *Australasian Plant Pathology* **34**, 533–540. doi: 10.1071/AP05067

Dudzinski MJ, Old KM, Gibbs RJ (1993) Pathogenic variability in Australian isolates of *Phytophthora cinnamomi*. *Australian Journal of Botany* **41**, 721–732. doi: 10.1071/BT9930721

Englander L, Merlino JA, McGuire JJ (1980) Efficacy of two new systemic fungicides and ethazole for control of phytophthora root rot of rhododendron, and spread of *Phytophthora cinnamomi* in propagation benches. *Phytopathology* **70**, 1175–1179.

Frampton J, Benson DM (2004) Phytophthora root rot mortality in fraser fir seedlings. *HortScience* **39**, 1025–1026.

Frazer GW, Canham CD, Letzman KP (1999) 'Gap light analyser (GLA): imaging software to extract canopy structure and gap light transmission indices from true-colour fisheye photographs. Users manual and program documentation, Version 2.0.' (Simon Frazer University: Burnaby, British Columbia; and the Institute of Ecosystem Studies: Millbrook, New York)

Grant M, Barrett S (2003) The distribution and impact of *Phytophthora cinnamomi* Rands in the south coast region of Western Australia. In '*Phytophthora* in forests and natural ecosystems'. 2nd international IUFRO working party 7.02.09 meeting, Albany, WA. (Eds JA McComb, GEStJ Hardy, IC Tommerup) pp. 34–40. (Murdoch University Print: Perth)

Guest D, Grant B (1991) The complex action of phosphonates as antifungal agents. *Biological Review* **66**, 159–187.

Hansen EM (1999) Disease and diversity in forest ecosystems. *Australasian Plant Pathology* **28**, 313–319. doi: 10.1071/AP99050

Harris JA, Kassaby FY, Smith IW (1985) Variations in mortality in families of *Eucalyptus regnans* caused by *Phytophthora cinnamomi* up to 5 years after planting. *Australian Forest Research* **15**, 57–65.

Havel JJ (1975) Site-vegetation mapping in the northern jarrah forest (Darling Range). 1. Definition of site-vegetation types Bulletin 86. Forests Departmenty, Perth.

Hill TCJ, Tippett JT, Shearer BL (1994) Invasion of Bassendean Dune *Banksia* woodland by *Phytophthora cinnamomi*. *Australian Journal of Botany* **42**, 725–738. doi: 10.1071/BT9940725

Hobbs RJ, Arico S, Aronson J, Baron JS, Bridgewater P, Cramer VA, Epstein PR, Ewel JJ, Klink CA, Lugo AE, Norton D, Ojima D, Richardson DM, Sanderson EW, Valladares F, Vilà M, Zamora R, Zobel M (2006) Novel ecosystems: theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography* **15**, 1–7. doi: 10.1111/j.1466-822X.2006.00212.x

Hope PK, Drosdowsky W, Nicholls N (2006) Shifts in the synoptic systems influencing southwest Western Australian. *Climate Dynamics* **26**, 751–764. doi: 10.1007/s00382-006-0115-y

Hopkins ER (1973) Crown dieback in eucalypt forest. In 'Eucalypt dieback in Australia'. Proceedings of the Lakes Entrance seminar. (Eds GC Marks, RM Idczak) pp. 1–16. (Forests Commission: Melbourne)

Hopper SD, Gioia P (2004) The southwest Australian floristic region: evolution and conservation of a global hot spot of biodiversity. *Annual Review of Ecology and Evolutionary Systematics* **35**, 623–650. doi: 10.1146/annurev.ecolsys.35.112202.130201

Hnatiuk RJ (1995) 40. Lambertia. In 'Flora of Australia. Volume 16, Elaeagraceae, Proteaceae 1'. pp. 425–436. (CSIRO Publishing: Melbourne)

Hüberli D, Tommerup IC, Calver MC, Colqhhoun IJ, Hardy GEStJ (2002) Temperature and inoculation method influence disease phenotypes and mortality of *Eucalyptus marginata* clonal lines inoculated with *Phytophthora cinnamomi*. *Australasian Plant Pathology* **31**, 107–118. doi: 10.1071/AP01078

Jennings SB, Brown ND, Sheil D (1999) Assessing forest canopies and understorey illumination: canopy closure, canopy cover and other measures. *Forestry* **72**, 59–73. doi: 10.1093/forestry/72.1.59

Keighery GJ (1983) New species from the Stirling Range of Western Australia. *Botanische Jahrbücher für Systematik, Pflanzengeschichte und Pflanzengeographie* **104**, 177–182.

Keighery GJ, Coates DJ, Gibson N (1994) Future ecosystems—ecological balance (ecological impact of disease causing fungi in south-western Australia). *Journal of the Royal Society of Western Australia* **77**, 181–184.

Kenerley CM, Bruck RI (1987) Distribution and disease progress of phytophthora root rot of fraser fir seedlings. *Phytopathology* **77**, 520–526.

Kennedy J, Weste G (1986) Vegetation changes associated with invasion by *Phytophthora cinnamomi* on monitored sites in the Grampians, Western Victoria. *Australian Journal of Botany* **34**, 251–279. doi: 10.1071/BT9860251

Lowman MD, Nadkarni NM (1995) 'Forest canopies.' (Academic Press: San Diego, CA)

McCredie TA, Dixon KW, Sivasithamparam K (1985) Variability in the resistance of *Banksia* L.f. species to *Phytophthora cinnamomi* Rands. *Australian Journal of Botany* **33**, 629–637. doi: 10.1071/BT9850629

McDougall KL, Hobbs RJ, Hardy GEStJ (2002) Vegetation of *Phytophthora cinnamomi*-infested and adjoining uninfested sites in the northern jarrah (*Eucalyptus marginata*) forest of Western Australia. *Australian Journal of Botany* **50**, 277–288. doi: 10.1071/BT01096

McDougall KL, Hobbs RJ, Hardy GEStJ (2005) Distribution of understorey species in forest affected by *Phytophthora cinnamomi* in south-western Western Australia. *Australian Journal of Botany* **53**, 813–819. doi: 10.1071/BT04203

Monks L, Coates D (2002) The translocation of two critically endangered *Acacia* species. *Conservation Science Western Australia* **4**, 54–61.

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. *Nature* **403**, 853–858. doi: 10.1038/35002501

Newell GR (1998) Characterization of vegetation in an Australian open forest community affected by cinnamon fungus (*Phytophthora cinnamomi*): implications for faunal habitat quality. *Plant Ecology* **137**, 55–70. doi: 10.1023/A:1008056432001

Pignatti-Wikus E, Riedl-Dorn C, Mabberly DJ (2000) Ferdinand Bauer's field drawings of endemic Western Australian plants made at King George Sound and Lucky Bay, December 1801–January 1802. Part II. *Rendiconti Lincei. Scienze Fisiche e Naturali* **11**, 201–244.

Pilbeam RA, Colquhoun IJ, Shearer B, Hardy GEStJ (2000) Phosphite concentration: its effect on phytotoxicity symptoms and colonisation by *Phytophthora cinnamomi* in three understorey species of *Eucalyptus marginata* forest. *Australasian Plant Pathology* **29**, 86–95. doi: 10.1071/AP00016

Podger FD (1989) Comparative pathogenicity of fourteen Australian isolates of *Phytophthora cinnamomi* determined on transplants of Tasmanian temperate heathland. *Australian Journal of Botany* **37**, 491–500.

Podger FD, Doepel RF, Zentmyer GA (1965) Association of *Phytophthora cinnamomi* with a disease of *Eucalyptus marginata* forest in Western Australia. *Plant Disease Reporter* **49**, 943–947.

Reiter N, Weste G, Guest D (2004) The risk of extinction resulting from disease caused by *Phytophthora cinnamomi* to endangered, vulnerable or rare plant species endemic to the Grampians, western Victoria. *Australian Journal of Botany* **52**, 425–433. doi: 10.1071/BT03130

Schutte GC, Bezuidenhout JJ, Kotze JM (1991) Timing of application of phosphonate fungicides using different application methods as determined by means of gas–liquid–chromatography for *Phytophthora* root rot control of citrus. *Phytophylactica* **23**, 69–71.

Shearer BL (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 BL (2003) The contribution of research in the Forest Department and the Department of Conservation and Land Management to the fight against *Phytophthora* species in native vegetation of south-western Australia over the last two decades. In '*Phytophthora* in forests and natural ecosystems'. 2nd international IUFRO working party 7.02.09 meeting, Albany, WA. (Eds JA McComb, GEStJ Hardy, IC Tommerup) pp. 235–242. (Murdoch University Print: Perth)

Shearer BL, Dillon M (1995) Susceptibility of plant species in *Eucalyptus marginata* forest to infection by *Phytophthora cinnamomi*. *Australian Journal of Botany* **43**, 113–134. doi: 10.1071/BT9950113

Shearer BL, Dillon M (1996*a*) Impact and disease centre characteristics of *Phytophthora cinnamomi* infestations of *Banksia* woodlands on the Swan Coastal Plain, Western Australia. *Australian Journal of Botany* **44**, 79–90. doi: 10.1071/BT9960079

Shearer BL, Dillon M (1996*b*) Susceptibility of plant species in *Banksia* woodlands on the Swan Coastal Plain, Western Australia, to infection by *Phytophthora cinnamomi*. *Australian Journal of Botany* **44**, 433–445. doi: 10.1071/BT9960433

Shearer BL, Fairman RG (1997*a*) Foliar application of phosphite delays and reduces the rate of mortality of three *Banksia* species in communities infested with *Phytophthora cinnamomi*. In 'Proceedings of the 11th biennial conference of the Australasian Plant Pathology Society'. p. 180. (Australasian Plant Pathology Society: Perth)

Shearer BL, Fairman RG (1997*b*) Phosphite inhibits lesion development of *Phytophthora cinnamomi* for at least four years following trunk injection of *Banksia* species and *Eucalyptus marginata*. In 'Proceedings of the 11th biennial conference of the Australasian Plant Pathology Society'. p. 181. (Australasian Plant Pathology Society: Perth)

Shearer BL, Hill TC (1989) Diseases of *Banksia* woodlands on the Bassendean and Spearwood dune systems. *Journal of the Royal Society of Western Australia* **71**, 113–114.

Shearer BL, Shea SR (1987) Variation in seasonal population fluctuations of *Phytophthora cinnamomi* within and between infected *Eucalyptus marginata* sites of southwestern Australia. *Forest Ecology and Management* **21**, 209–230. doi: 10.1016/0378-1127(87)90044-2

Shearer BL, Smith IW (2000) Disease of eucalypts caused by soilborne species of *Phytophthora* and *Pythium*. In 'Diseases and pathogens of eucalypts'. (Eds PJ Keane, GA Kile, FD Podger, BN Brown) pp. 259–291. (CSIRO Publishing: Melbourne)

Shearer BL, Tippett JT (1989) Jarrah dieback: the dynamics and management of *Phytophthora cinnamomi* in the jarrah (*Eucalyptus marginata*) forest of south-western Australia. Research Bulletin 3. Department of Conservation and Land Management, Perth.

Shearer BL, Wilcoxson RD (1980) Sporulation of *Septoria* species on wheat and barley in Minnesota. Agricultural Experimental Station Technical Bulletin 323. University of Minnesota, St Paul, MN.

Shearer BL, Michaelsen BJ, Somerford PJ (1988) Effects of isolate and time of inoculation on invasion of secondary phloem of *Eucalyptus* spp. and *Banksia grandis* by *Phytophthora* spp. *Plant Disease* **72**, 121–126.

Shearer BL, Crane CE, Cochrane A (2004*a*) 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. doi: 10.1071/BT03131

Shearer BL, Crane CE, Fairman RG (2004*b*) Phosphite reduces disease extension of a *Phytophthora cinnamomi* front in *Banksia* woodland, even after fire. *Australasian Plant Pathology* **33**, 249–254. doi: 10.1071/AP04002

Shearer B, Crane C, Cochrane A (2005) A thief of time: *Phytophthora cinnamomi* and threatened flora. *Australian Plant Conservation* **13**(4), 14–15.

Shearer BL, Fairman RG, Grant MJ (2006) Effective concentration of phosphite in controlling *Phytophthora cinnamomi* following stem injection of *Banksia* species and *Eucalyptus marginata*. *Forest Pathology* **36**, 119–135. doi: 10.1111/j.1439-0329.2006.00440.x

Simberloff D, Parker IM, Windle PN (2005) Introduced species policy, management, and future research needs. *Frontiers in Ecology and Environment* **3**, 12–20.

Smith BJ (1994) Effects of phosphonic acid and sodium silicate on lesion development of *Phytophthora cinnamomi* and histological responses in host species endemic to Western Australia. BSc(Honours) Thesis, University of Western Australia, Perth.

Stukely MJC, Crane CE (1994) Genetically based resistance of *Eucalyptus marginata* to *Phytophthora cinnamomi*. *Phytopathology* **84**, 650–656. doi: 10.1094/Phyto-84-650

Tippett JT, Hill TC, Shearer BL (1985) Resistance of *Eucalyptus* species to invasion by *Phytophthora cinnamomi*. *Australian Journal of Botany* **33**, 409–418.

Tippett JT, McGrath JF, Hill TC (1989) Site and seasonal effects on susceptibility of *Eucalyptus marginata* to *Phytophthora cinnamomi*. *Australian Journal of Botany* **37**, 481–490. doi: 10.1071/BT9890481

Tynan KM, Wilkinson CJ, Holmes JM, Dell B, Colquhoun IJ, McComb JA, Hardy GEStJ (2001) The long-term ability of phosphite to control *Phytophthora innamomi* in two native plant communities of Western Australia. *Australian Journal of Botany* **49**, 761–770. doi: 10.1071/BT00062

Vitousek PM, D'Antonio CM, Loope LL, Rejmanek M, Westbrooks R (1997) Introduced species: a significant component of human-caused global change. *New Zealand Journal of Ecology* **21**, 1–16.

Weste G (1986) Vegetation changes associated with invasion by *Phytophthora cinnamomi* of defined plots in the Brisbane Ranges, Victoria, 1975–1985. *Australian Journal of Botany* **34**, 633–648. doi: 10.1071/BT9860633

Weste G (2003) The dieback cycle in Victorian forests: a 30-year study of changes caused by *Phytophthora cinnamomi* in Victorian open forests, woodlands and heathlands. *Australasian Plant Pathology* **32**, 247–256. doi: 10.1071/AP03013

Weste G, Kennedy J (1997) Regeneration of susceptible native species following decline of *Phytophthora cinnamomi* over a period of 20 years on defined plots in the Grampians, Western Victoria. *Australian Journal of Botany* **45**, 167–190. doi: 10.1071/BT96048

Weste GM, Taylor P (1971) The invasion of native forest by *Phytophthora cinnamomi* I. Brisbane Ranges, Victoria. *Australian Journal of Botany* **19**, 281–294. doi: 10.1071/BT9710281

Weste G, Cooke D, Taylor P (1973) The invasion of native forest by *Phytophthora cinnamomi* II. Post-infection vegetation patterns, regeneration, decline in inoculum, and attempted control. *Australian Journal of Botany* **21**, 13–29. doi: 10.1071/BT9730013

Western Australian Herbarium (1998) 'FloraBase—The Western Australia flora.' (Department of Environment and Conservation) http://florabase.calm.wa.gov.au/

Wilkinson CJ, Holmes JM, Tynan KM, Colquhoun IJ, McComb JA, Hardy GEStJ, Dell B (2001) Ability of phosphite applied in a glasshouse trial to control *Phytophthora cinnamomi* in five plant species native to Western Australia. *Australasian Plant Pathology* **30**, 343–351. doi: 10.1071/AP01055

Wills RT (1993) The ecological impact of *Phytophthora cinnamomi* in the Stirling Range National Park, Western Australia. *Australian Journal of Ecology* **18**, 145–159. doi: 10.1111/j.1442-9993.1993.tb00439.x

Zadoks JC, Schein RD (1979) 'Epidemiology and plant disease management.' (Oxford University Press: New York)

Manuscript received 3 February 2006, accepted 28 November 2006

VEGETATION HEALTH SERVICE - PHYTOPHTHORA SAMPLE INFORMATION SHEET

SEND TO: Vegetation Health Service, Science Division – D.E.C, 17 Dick Perry Ave KENSINGTON 6152 **Phone**: (08) 9334 0317 **Fax:** (08) 9334 0114

CONTACT DETAILS

Name____

Fax No.______________________Phone No.____________________

Region/District_______________________________________

MGA ZONE

Tick if 50____

Tick if 51____

Job Type (Please indicate)

D.E.C. (C)	Alcoa (A)
Recoup (R)	FPC
Private (P)	Other_____

VHS USE ONLY

Date received
Date faxed

VHS Identification Number (VHS USE ONLY)	Sample Date	Sample label (Forest block, Sample number etc.)	Plant species sampled	Site Impact (1)	GDA (2)	Map Reference (3)	Land Tenure (4)	Result s/s root (5)	Result bait (5)
						E _ _ _ _ _ _ N _ _ _ _ _ _ _			
						E _ _ _ _ _ _ N _ _ _ _ _ _ _			
						E _ _ _ _ _ _ N _ _ _ _ _ _ _			
						E _ _ _ _ _ _ N _ _ _ _ _ _ _			
						E _ _ _ _ _ _ N _ _ _ _ _ _ _			
						E _ _ _ _ _ _ N _ _ _ _ _ _ _			
						E _ _ _ _ _ _ N _ _ _ _ _ _ _			
						E _ _ _ _ _ _ N _ _ _ _ _ _ _			

NOTES:

1. Site impact - Low, Moderate, High or Very High (as in the Dieback Interpreter's Manual).
2. Please tick this column if your map references are supplied in the new **GDA 94** standard. If not, please specify the datum used.
3. An MGA map reference with prefixes **must** be supplied for all samples.
4. Land Tenure - State Forest (SF), National Park (NP), Reserve (R), Westrail (W), Private (P), Gravel Pit (GP), or other. (other - describe in comments below).
5. Result codes used - CIN= *Phytophthora cinnamomi*, MUL=*P.multivora*, CRY= *P.cryptogea*, PI=*P.inundata*, PM= *P.megasperma*, PN= *P.nicotianae*, NEG = negative, SUB = subcultured.

COMMENTS:

Ex Situ Seed Conservation

Flora Conservation Course
2009

Andrew Crawford & Anne Cochrane

Threatened Flora Seed Centre
Science Division

Department of
Environment and Conservation

Course Content

Ex situ conservation
- DEC's Threatened Flora Seed Centre
- Millennium Seed Bank Project

Seedbanking strategies
- Provenance, timing of seed collection, fruit ripeness & seed predation
- Documentation
- Seed handling & storage

Assessment (multi-choice)

Course Aim

To provide an understanding of the importance of seed collection for conservation purposes and to provide knowledge of basic seed identification, collection and processing

Ex situ conservation

... maintenance of samples of organisms away from their natural habitat

- seed
- pollen
- vegetative propagules = "germplasm"
- tissue or cell culture
- living plants
- DNA

Opposite of *in situ* (on site) conservation

Ex situ conservation

.... used as an interim solution to prevent loss of genetic diversity due to threatening processes such as salinity, disease, weed invasion and habitat loss.

A strategy that can be used as a last resort in preventing the species extinction

Neither a substitute for in situ *conservation nor mandate for destruction of habitat*

Habitat fragmentation threatens the survival of many species in the agricultural zone of Western Australia

Many species threatened with extinction found only in fresh or naturally saline lowlands, directly threatened by rising ground water and salinity

Phytophthora cinnamomi - dieback

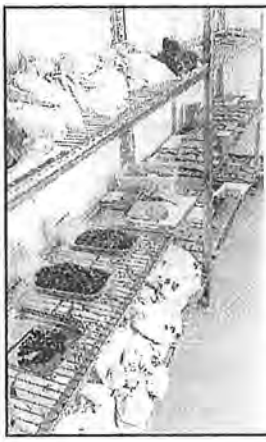
"Unparalleled example of an introduced pathogen with a wide host range causing immense irreversible damage to unique and diverse plant communities"

Climate Change - geographic range shifts, drought, more fire, decoupling of biotic relationships, shift in seasonal activities

Seed Conservation

- Plants can produce seed in quantity
- Seeds are small & naturally dispersed
- Seeds are mostly desiccant tolerant
- Potentially long storage life
- Useful for propagation in the future
- Wide species applicability
- Technology is easy & cost effective

Seed banking is a cheap insurance policy



Seed Longevity

Seeds of many flowering plants can be stored under low temperature and low moisture conditions for long periods of time without significantly reducing viability

Seed Conservation

Allows access to biodiversity material for recovery and research both in- and out of-season, removing pressure off wild populations.

Seed Conservation

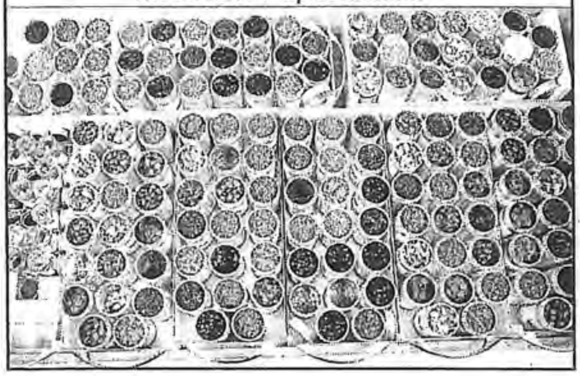
.. may represent the only option available if the remaining natural populations are to be conserved in the face of destruction of their habitat

In some cases material may be held in storage from now extinct populations .....

Banksia anatona (1 pop)

Banksia brownii (at least 3 pops)

...is this the last option for conservation of threatened species.......?



Alternative methods

If plants do not produce viable seed

Vegetative propagation

1. Cuttings
2. Tissue culture

–More expensive, technology

Drawback *- use of clonal material requires many individuals to conserve diversity*

Threatened Flora Seed Centre (TFSC)

- Established at CALM in 1992
- Initial commonwealth funding (ANCA)
- *Phytophthora* susceptible rare and threatened species
- Principle long term seed storage facility in Western Australia
- Additional funding – state, commonwealth & international

Objective

....to ensure the maintenance of genetically representative seed collections of Western Australian threatened flora under long term storage conditions as an interim solution to the prevention of genetic degradation or local extinction of threatened flora populations.....

Natural Resource Management in Western Australia – The Salinity Strategy (2000)

Section 4.4.1 *Seed collection, storage and databasing*

...CALM will establish and maintain a long term storage facility for seed of rare and threatened plant species located in saline environments...

National Strategy for the Conservation of Australia's Biological Diversity (1996)

Objective 1.9: *Ex-Situ Conservation*

...to complement *in situ* measures, establish and maintain facilities for *ex situ* research into and conservation of plants, animals and micro-organisms...

Global Strategy for Plant Conservation (2002)

Target: *Conserving Plant Diversity*

... 60 per cent of threatened plant species in accessible *ex situ* collections, preferably in the country of origin, and 10 % of them included in recovery and restoration programmes...

Millennium Seed Bank Project

Conceived, developed and managed by the Seed Conservation Department of the Royal Botanic Gardens Kew United Kingdom

Aim is to collect and conserve 10% of the world's dryland flora by 2010 as part of Global Strategy for Plant Conservation

---

Western Australian seed banking efforts have been facilitated through generous MSB financial and technological inputs

DEC's Threatened Flora Seed Centre has been in partnership with the MSB since 2001

Seed Collection Strategy

- What species will be collected?
- How many populations sampled?
- How many plants sampled?
- How much seed to collect per plant?
- Multi-year sampling may be required

Seed Collection Strategy

- What species will be collected?
- How many populations sampled?
- How many plants sampled?
- How much seed to collect per plant?
- Multi-year sampling may be required

What Species?

- Degree of threat
- Geographic range of the species
- Number of individuals and populations
- Conservation status of the species
- Intended purpose of the collection

TFSC Collecting Priorities

- Declared Rare & Priority Flora
- Species associated with Threatened Ecological Communities & Recovery Catchments
- Biodiversity Hotspots

Purpose of Collection

- Reintroduction and restoration
- Long term storage (insurance policy)
- Research - Disease susceptibility
  - Salinity tolerance
  - Seed biology
  - Genetic
- Display and Education
  - Botanic Gardens
  - Schools

Seed Collection Strategy

- What species will be collected?
- How many populations sampled?
- How many plants sampled?
- How much seed to collect per plant?
- Multi-year sampling may be required

Sampling Populations

- Sample all populations if possible to maximise diversity of collection
- Variation between pops may reflect reproductive & physiological differences
- Keep seed from different pops separate
- Local pops possibly most suitable for site rehab (long term survival & ecological processes) due to evolution & adaptation to local conditions

Seed Collection Strategy

- What species will be collected?
- How many populations sampled?
- How many plants sampled?
- How much seed to collect per plant?
- Multi-year sampling may be required

Sampling Plants

- Sample ≥50 plants per population to increase genetic variation
- Random stratified sampling with equal proportions of seed from each plant
- Sample from range of sizes, shapes etc including from range of ecotypes
- Ideally, keep seed from separate plants in separate bags

Seed Collection Strategy

- What species will be collected?
- How many populations sampled?
- How many plants sampled?
- How much seed to collect per plant?
- Multi-year sampling may be required

- Take no more than 10-20 % of seed from each plant unless that plant & immediate habitat to be destroyed eg clearing, road maintenance etc.
- Remaining seed will allow natural regeneration to occur & provide material for the soil seed bank

Objective: *collect genetically representative sample of the population without damaging any plants prospects for survival in the wild.*

Seed Collection Strategy

- What species will be collected?
- How many populations sampled?
- How many plants sampled?
- How much seed to collect per plant?
- Multi-year sampling may be required

Repeat Sampling

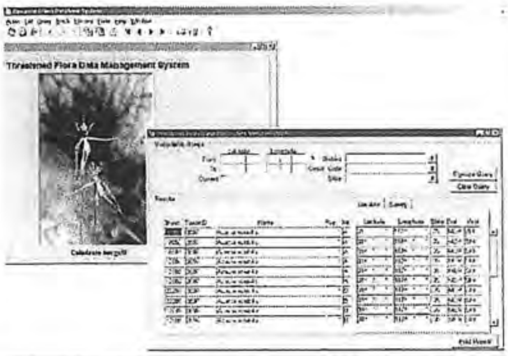
It is not always possible to collect sufficient seed for the desired purpose all in one go without affecting the demography and/or reproductive capacity of the population.

Multi-season or multi-year sampling may be required.

Planning a Collecting Trip

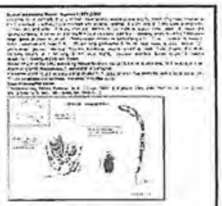
- Florabase records
- DEFL Records
- RFRF
- Mud maps
- Species information
- Herbarium specimens
- Topographic maps
- ARCVIEW tool to collate

DEFL database



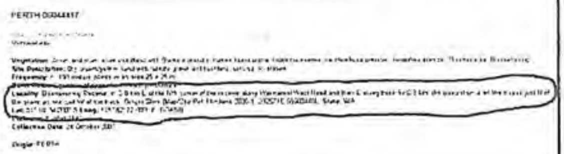
Paper Files (RFRF & mud maps)

Species Information

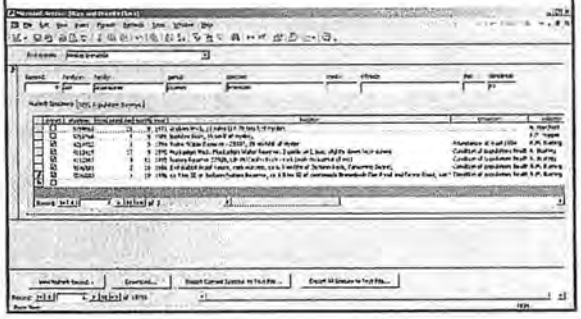


Data Gathering

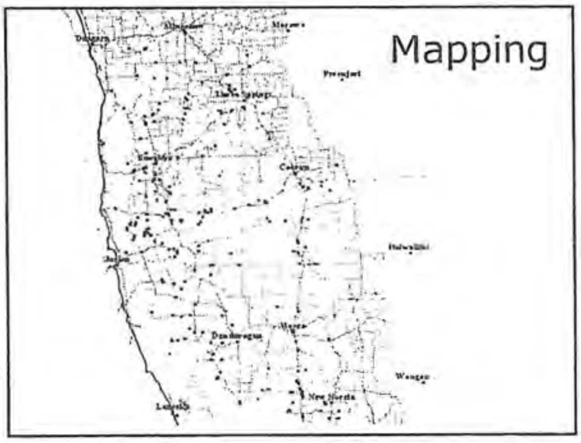
- Good location information
- Recent record
- Good site/habitat description
- Information on plant numbers

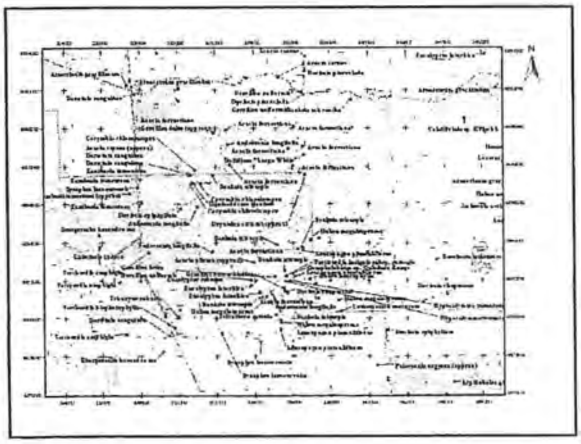


Collating Information
(TFSC collecting database)



Mapping





Collecting gear: secateurs, bags (calico & paper), notebook, plant press, maps, GPS.........

Seed Collection Considerations

- Fruit/seed comes various shapes & sizes
- Seed storage & dispersal mechanisms vary
- Seed collection techniques vary depending on fruit/seed type & storage/dispersal
- Timing of seed collection vary according to species & environmental conditions

Fruit/seed comes in all shapes & sizes

Seed Collection Techniques

- Hand picking (individual seed/ fruits)
- Pruning with secateurs
- Bags (eg stockings/ muslin)
- Extended pole pruners
- Stripping
- Shaking branches
- Collecting from ground
- Seed traps

Using stocking / muslin bags over *Grevillea* fruits

Hand cutting using secateurs

Grovelling!.....

Timing of Collections

- Take into account natural seed storage and dispersal mechanisms
- Sample at point of natural dispersal when fruits/seed are mature
- Time to maturity varies from species to species, from site to site and is dependant on environmental factors
- Recollect over several weeks if necessary

Info on reproductive biology helps decide collection time

Serotiny or canopy seed storage

Seed dispersal: wind, animal, passive (gravity), water…

There is very little known about the interval between flowering and fruiting

Firm white endosperm, not watery or milky.

Fruit Ripeness

- changes in fruit colour
- changes in seed coat colour
- fruit splitting or breaking open
- fruit that are hard and dry
- seed rattling
- some seed already dispersed
- fleshy fruits going soft

There are always exceptions!

Green not usually ripe.

black or brown usually ripe

often first fruits shed have been aborted or insect damage.

ACACIA Daviesia

Synaphea

Some plants fruit and flower over a long period of time. Be careful to only collect mature fruits.

Some plants flower in response to fire & some may only seed 1-2 years post-fire

Check valves or capsules are closed & seed not released

Seeds releasing from dry woody capsules

Check fruits/seeds are not damaged by insects

Sure signs of insect activity-

- frass (looks like sawdust)
- holes
- webbing

Check that fruit you are collecting are filled.

Darwinia acerosa
fruit on left empty; fruit on right full

Seed Quality
is partly determined by:

- the stage at which seeds were collected
- how seeds were handled after collection

Seed quality affects seed longevity & germination

Collection Information

- Genus, species, subspecies
- Exact location (GPS if possible)
- Collector, date & collecting number
- Number of plants sampled
- Additional information (eg pollinators, health, ecology, associated species, soils, phenology)

Information is almost as important as the seed itself

Herbarium specimens

Gastrolobium congestum

Eremophila flower, fruit, seed and germinant

Eremophila nivea

Adenanthos flower, fruit and seed

Good seed

Aborted seed

Verticordia albida flower, fruit with seed and germinant

with verticordia you are collecting old flowers.

Give bush a gentle shake to catch seed.

Darwinia flower and fruit with seed

Darwinia lejostyla

Darwinia chapmanniana

Acacia fruits, seed and germinant

Hints for Seed Collection

- Know your species
- Examine pop. Is there a mixture of species?
- Examine seed carefully - collect ripe seed only
- Random & equal sampling
- Clean equipment - **don't introduce disease**
- Collect sufficient seed but don't over collect
- Collect herbarium specimen(s)
- Collect in dry weather if possible
- Reduce risk of herbivory/fungal growth
- Use breathable containers - paper & calico bags
- Label containers and do not damage seed

Remember!

Illustration from Bonney, N. B. 1994. *What Seed is That?* Adelaide, S.A., Greening Australia

It is illegal to collect any plant material (seed, herbarium specimens, cuttings etc) in Western Australia without a licence.

What makes a good collection?

- Priority species, accurately identified
- Single species – no hybrids or mixed pops
- Good quality seed
- Genetically representative of species/pop
- Plants & pops not damaged or over collected
- Sufficient size for needs (consider predation, low seed set, aborted & immature seed)
- Adequate data (incl herb spec)

Remember!

- Plants may not seed all year round so allow time to plan & execute collections
- More than one visit may be required to collect sufficient seed for intended use
- Consider costs associated with collections – eg vehicle, time in field...

Seed handling & storage

- Handle seed gently
- Keep seed cool & dry
- Store seed in calico/paper not plastic
- Well sealed & labelled bags

Store seed temporarily under conditions which will maintain maximum viability until incorporation into long term storage facilities.

Don't let time in the field be wasted

After the field work....

1. Seed cleaning
2. Seed quality assessment
3. Seed quantification
4. Seed germination

Then seed is ready for packing, storage & viability monitoring

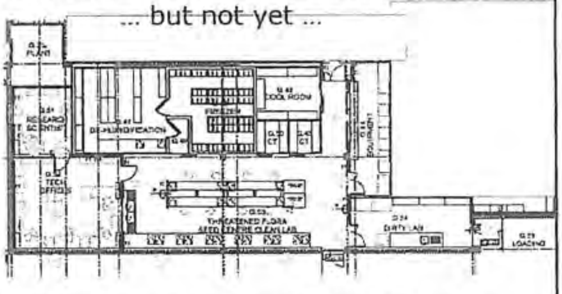
Good seed can last 50+ years in storage

We can provide advice on:

- Seed collection
- Seed germination/ viability testing
- Seed storage

Come visit us in our new seed store

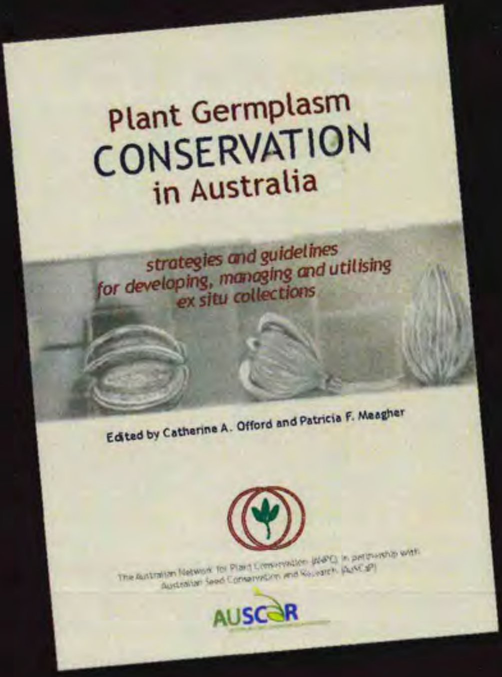
... but not yet ...



Threatened Flora Seed Centre

This book provides a mine of information on recent advances in plant germplasm conservation in Australia and beyond ... I cannot think of a better text to recommend on this subject.

Professor Stephen D. Hopper
Director, Royal Botanic Gardens, Kew



Australian Network for Plant Conservation Inc

Plant Germplasm Conservation Guidelines

ORDER FORM

Price each AUD $39.95

Postage and handling: Australia $7.00 ea or International $AUD14.00 ea

Price	Postage	Subtotal	Qty	TOTAL	
$39.95 +	$7.00 =	$46.95	x ___	= ________	In Australia
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Email: anpc@anpc.asn.au Web: www.anpc.asn.au

ABN 70 861 480 818

Good conservation strategies

As global threats to biodiversity escalate, the most judicious conservation strategies will be ones that combine available resources to provide the highest possible degree of protection. Banked seeds are available irrespective of season and can be used immediately to support a species' survival in the wild. The collection of data associated with the species or population from which the seeds are taken is a potentially vital contribution to knowledge about these plants and should always be obtained at the time of seed collection.

Quality collections

Good quality seed collections with a broad genetic base are required to reinforce and benefit species survival. Storage conditions that minimise deterioration of seeds will maximise the quality and quantity of seeds available for future use.

Species at risk

Species targeted for conservation are those most at risk in the wild. Species with low plant numbers, few populations or limited geographic range, or those highly threatened by human and other influences (for example disease, salinity, weed invasion and grazing) may all warrant priority for seed conservation. Other priorities include those experiencing a rapid decline in conservation status or health and those thought to be genetically or taxonomically different from more common species. Where habitats are in immediate danger of destruction, and where on ground actions cannot guarantee species survival, the collection and maintenance of plant material from the wild becomes necessary, acting as insurance.

Seed conservation directly and indirectly assists species' survival in the wild. It is an integral part of the Western Australian Department of Environment and Conservation's Flora Conservation and Herbarium Program and is supported by national and international conservation strategies.

Enquiries

If you would like to know more about seed conservation please contact the Seedbank Manager on 93340500.

You can also write to:

The Seedbank Manager
Threatened Flora Seed Centre
Department of Environment and Conservation
Locked Bag 104
Bentley Delivery Centre
Western Australia 6983

www.naturebase.wa.gov.au

Natural Heritage Trust
Helping Communities Helping Australia

SCRIPT
South Coast Regional Initiative Planning Team

MILLENNIUM SEED BANK PROJECT Kew

Department of Environment and Conservation

2006374-10-1M

Seed conservation

Supporting the survival of plant diversity in Western Australia

Department of Environment and Conservation

Conserving life on Earth

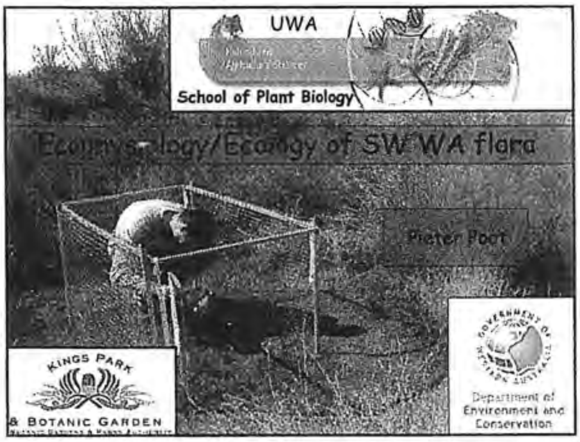
Plants are the basis of life on Earth. They trap the sun's energy, generate oxygen and provide nourishment and habitat for almost all life forms. The tremendous diversity of life on Earth is largely dependent on the diversity of plant species. Any loss of species diversity has irreversible negative impacts on ecosystem processes.

Nature's genetic storehouse

Seeds are nature's genetic storehouse and seed collections provide a ready source of plant material. Seeds can be used to help restore degraded lands, reintroduce species into the wild and restock depleted populations. In these ways they help to conserve natural habitats and ecosystems. Seeds are used in scientific research to understand seed biology, conservation genetics and disease susceptibility – information that helps our efforts for on-ground conservation and management.

Helping on-ground conservation

Collecting seeds for conservation is a complementary approach to on-ground actions and has some useful advantages. Seed conservation is an efficient and cost-effective way to conserve the variation within and between individual species. Seeds occupy little space and require little attention over long periods of time. Seeds are portable and can be stored at a number of sites, reducing their vulnerability to loss. Seeds can produce whole plants using minimal technology.



Outline of presentation

- Adaptations of species confined to a Threatened Ecological Community

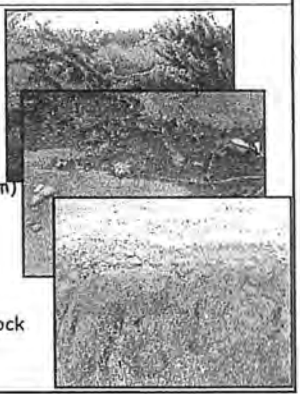
Ironstone communities:

- Consequences of a Threatening process to a widespread community

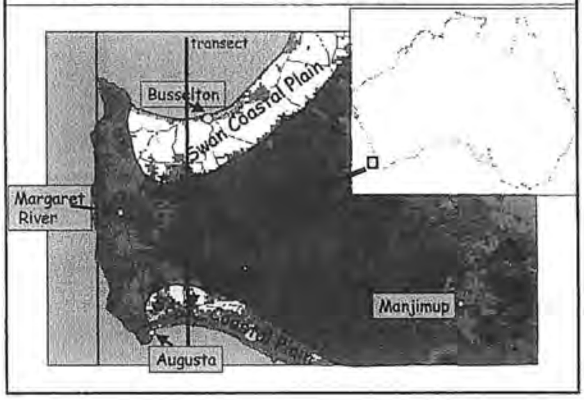
Wandoo woodland decline:
is climate change responsible?

Ironstone communities: what are they ?

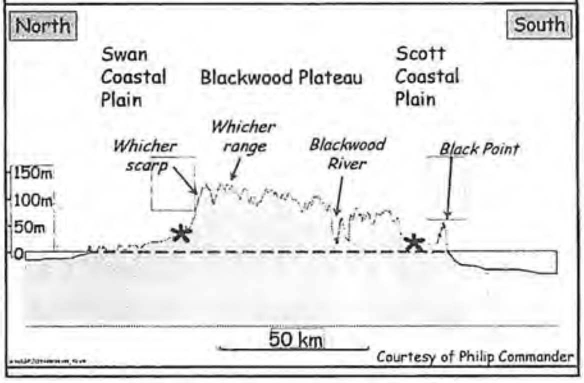
- Winter-wet shrublands
- Skeletal red soils (0-15 cm) (sandy loams)
- Over massive ironstone rock (up to 4m deep)



Where are they? → Geography



Where are they ? → Topography



How were they formed?

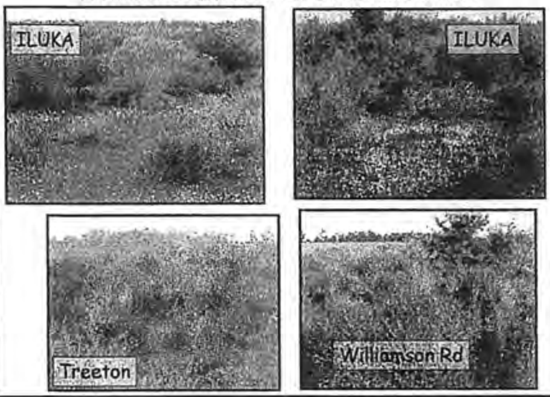
- could have been forming since ± 1.5 million years ago
  - → run-off of Fe rich water from scarp laterites
  - → precipitation of Fe oxides/Fe hydroxides in zone of water table fluctuation (winter)

↓

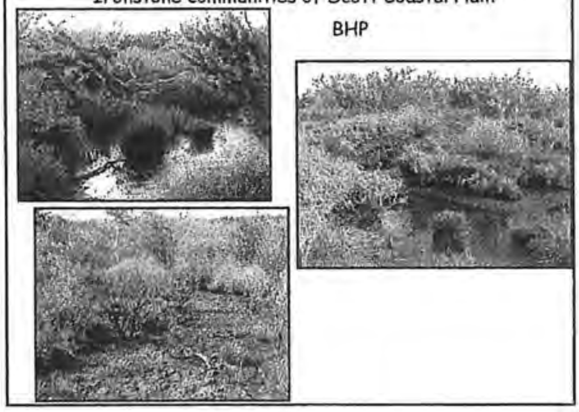
coffee rock formation

- iron rich impeding layers are common on coastal plain but at much greater depth !
  - → <u>ironstone communities</u>: "islands" in a "sea" of much deeper Quaternary sand deposits

Ironstone communities of Swan Coastal Plain



Ironstone communities of Scott Coastal Plain



What is so special about them?

- They are almost gone (438 of 3,910 ha left: TEC)
  (Gibson, Keighery, Keighery 2000)
- Discovered only in the 1990's
- High number (23) of endemic taxa

- Extremely stressful environment

- Oxygen deprivation

↓

Fe, Mn toxicity ?

Highly stressful environment

- Drought/dessication

Main question

- Why are ironstone endemics so restricted in their distribution ?

→ Maybe: they are too specialised !

↓

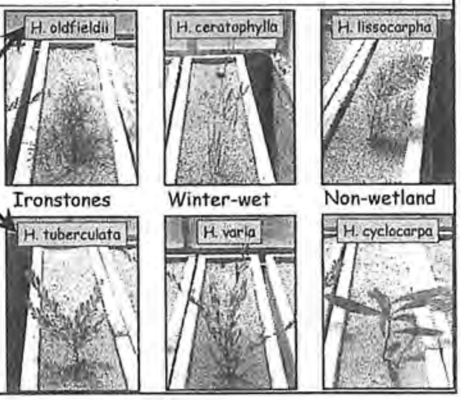
Adaptations needed to be successful in their own highly stressful habitat

are not very useful (or too extreme) in other environments...

↘ 'kind of handy' to know also in terms of TEC management...

A congeneric comparison: Hakea (Proteaceae)

both produce plenty of viable seeds



First 'growth analysis' experiments

Are ironstone species in <u>any way</u> different from their common congeners ?

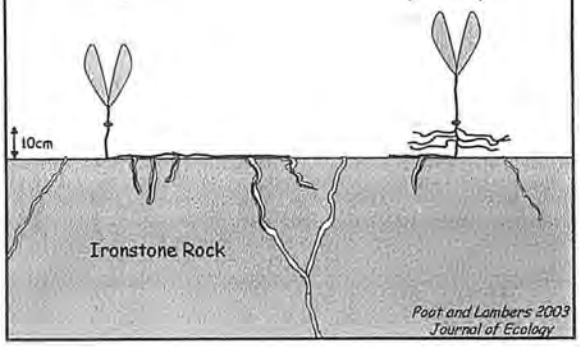
↓

It's all in the roots...

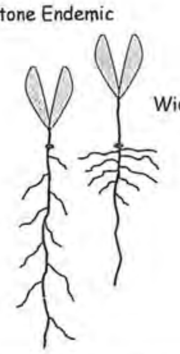
Ironstone endemics:

- initially invest more in roots
- initially have thinner roots
- main root axis does not respond to bottom of pots
- much more roots in bottom of pot

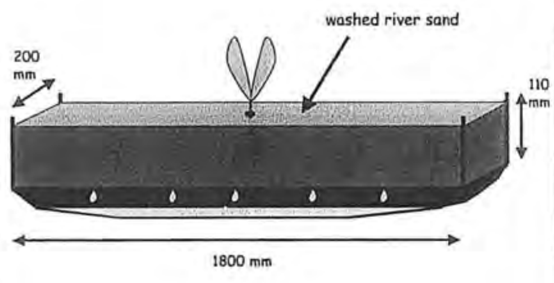
Model: a shallow ironstone habitat

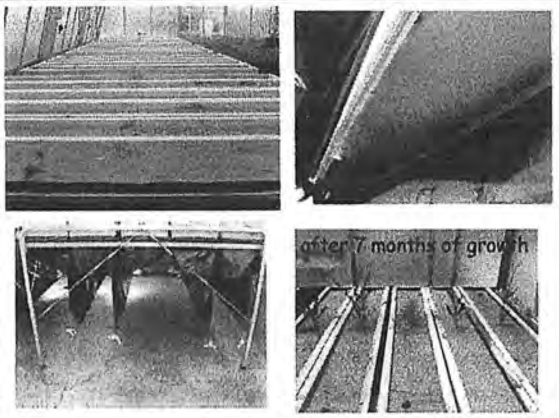


Model: a deeper soil

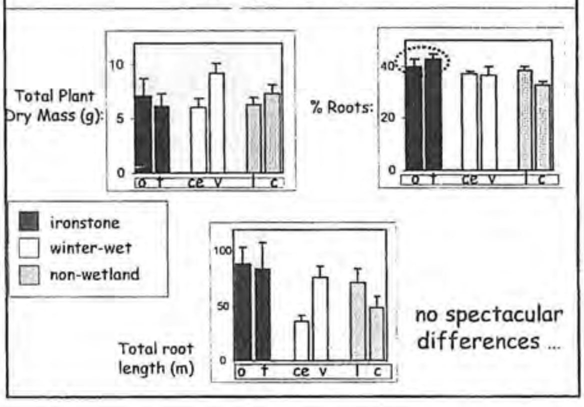


A more realistic pot design





Overall plant growth

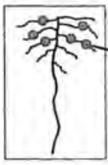


Detailed look at root systems:

1. Spatially: <u>where</u> did they put their roots?

2. Temporally: <u>when</u> did they put them there?

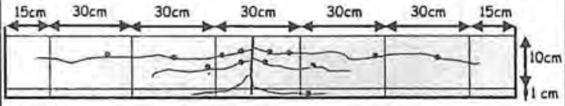
3. Functional: <u>what</u> type of roots did they put where? (cluster versus non-cluster)

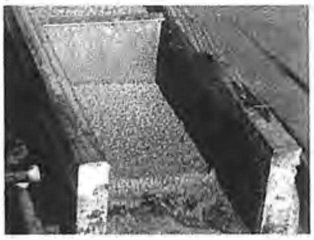


clusters: dense outgrowth of lateral rootlets

(involved in nutrient acquisition: mainly P and micronutrients)

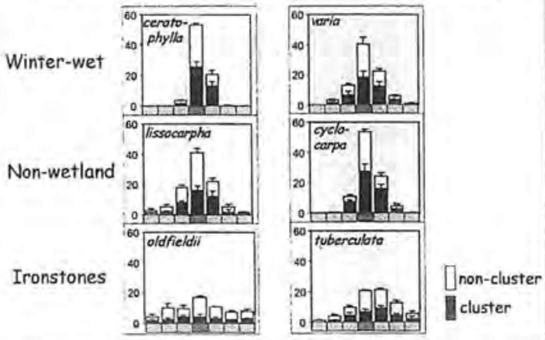
14 root compartments





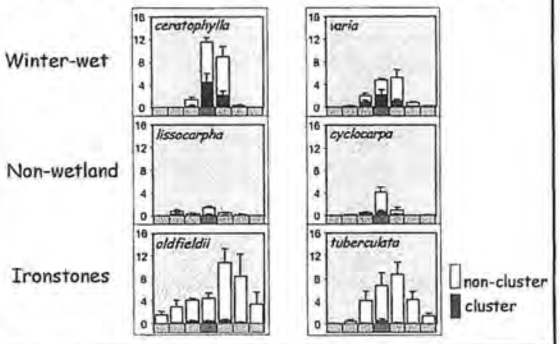
Spatially: where did they put their roots (superficial)?

Relative allocation of root fresh mass: 0-10 cm depth (% of total)

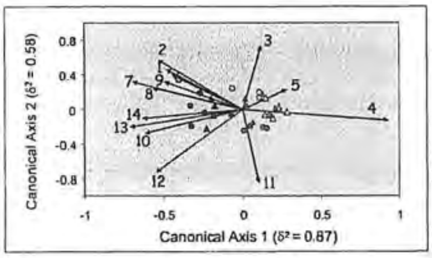


Spatially: where did they put their roots (deep)?

Relative allocation of root fresh mass: 10-11 cm depth (% of total)

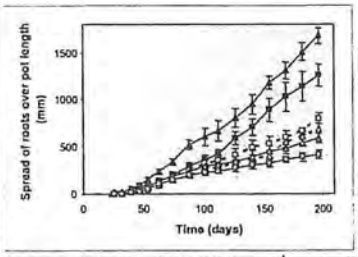


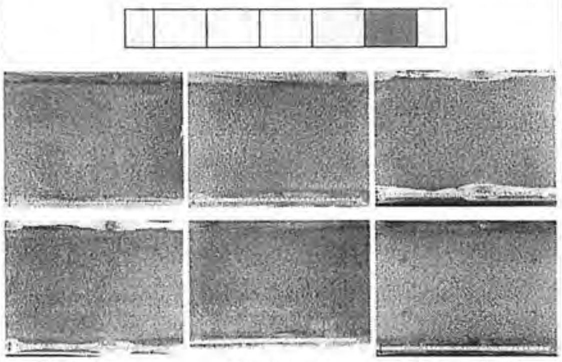
Similarities in root distribution pattern: Multivariate analysis (CAP)



Temporally: when did they put them there (deep)?

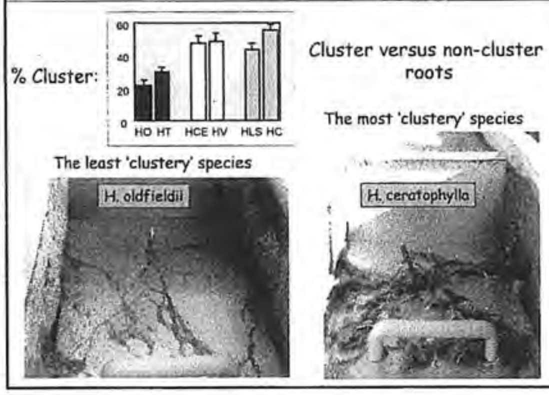
Temporal spread of roots (mm) over the bottom of the pots:





Ironstone species | Winter-wet species | Non-wetland species

Functionally: different types of roots



Can these differences really explain:

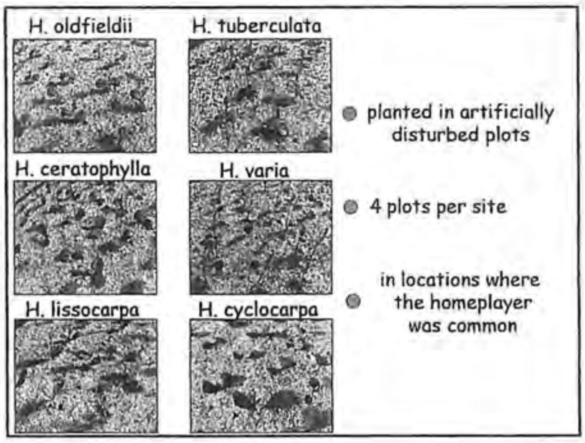
a) their success in their own habitat

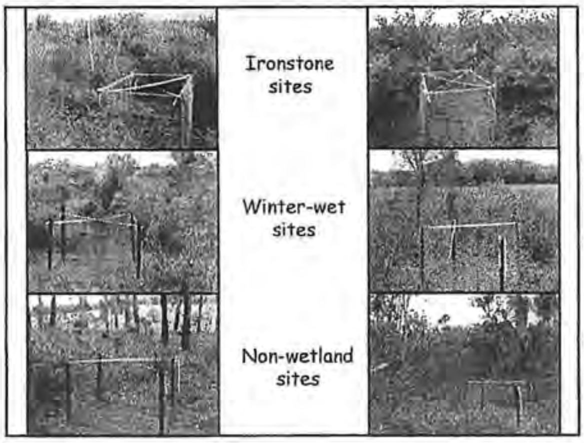
b) their failure in most others

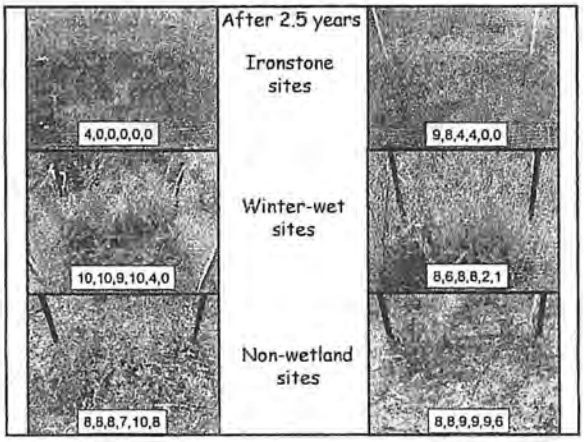
Back to the field: a reciprocal transplant experiment

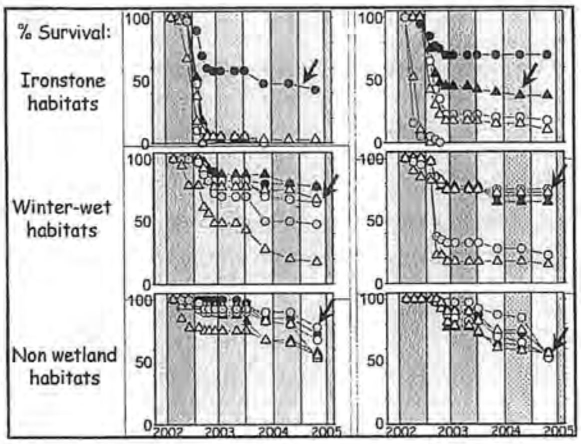
- collect seeds of the 6 Hakea species
- germinate species in glasshouse
- transplant young seedlings to kangaroo-proof plots in field

Each site has 1 'homeplaying' species


H. oldfieldii
H. tuberculata
H. ceratophylla
H. varia
H. lissocarpa
H. cyclocarpa
planted in artificially disturbed plots
4 plots per site
in locations where the homeplayer was common


Ironstone sites
Winter-wet sites
Non-wetland sites


After 2.5 years
Ironstone sites
4,0,0,0,0,0
9,8,4,4,0,0
Winter-wet sites
10,10,9,10,4,0
8,6,8,8,2,1
Non-wetland sites
8,8,8,7,10,8
8,8,9,9,9,6



Conclusions ironstone communities

- ironstone Hakea's have a specialised root system morphology

SPECIALISTS!

↓

increased chance of finding a crack

↓

increased chance of surviving summer drought in their own habitat

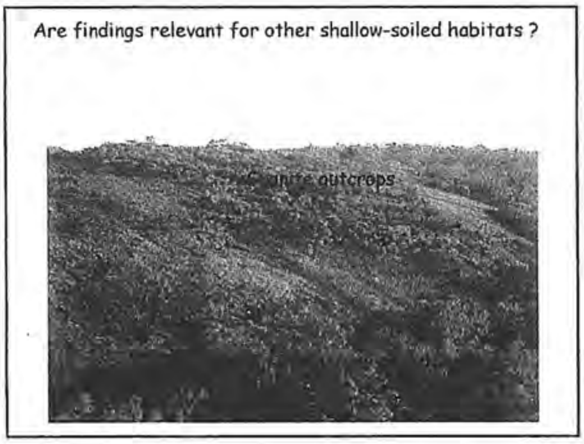
decreased competitive ability in habitats on deeper soils ???

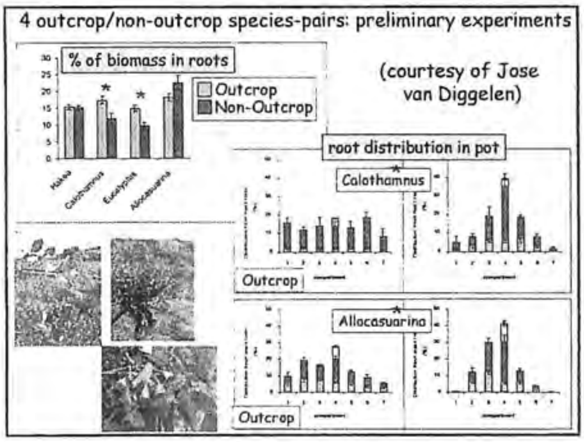
NOT SHOWN YET...

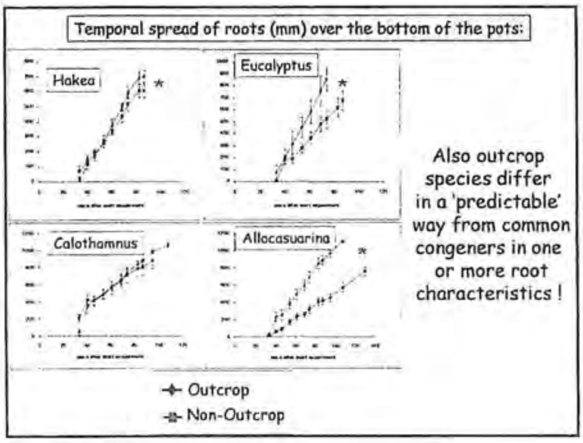
WHY?

Apparently no disadvantage in other habitats... why?

- time...?
- climate change ?
- setup of transplant experiment ?
  - real regeneration: fire (nutrients) ?
  - start with seeds ?
  - cages/kangaroos ?
  - initial weeding ?
- local herbivores not 'trained' for rare species ?
- there is no disadvantage ?


Are findings relevant for other shallow-soiled habitats ?
Granite outcrops


4 outcrop/non-outcrop species-pairs: preliminary experiments
% of biomass in roots
Outcrop
Non-Outcrop
Hakea
Calothamnus
Eucalyptus
Allocasuarina
(courtesy of Jose van Diggelen)
root distribution in pot
Calothamnus
Outcrop
Allocasuarina
Outcrop


Temporal spread of roots (mm) over the bottom of the pots:
Hakea
Eucalyptus
Calothamnus
Allocasuarina
Also outcrop species differ in a 'predictable' way from common congeners in one or more root characteristics !
Outcrop
Non-Outcrop

Conclusions shallow-soiled communities (1)

shallow-soil habitats: very drought-prone environments

↓

strong selection for drought avoidance (tolerance)

↓

root specialization

↓

root system characteristics are more rigid

↓

loss in phenotypically plasticity

local specialisation traded off against flexibility to adapt to other environments (commonness versus rareness)

What works best?

- adapt locally (specialisation: ecotypes) ↘ costs?
- just be flexible ! (increased phenotypic plasticity)! ↓ limit/costs?

Models evaluating costs and benefits of plasticity:

- variable/unpredictable high resource environment ↘ phenotypic plasticity
- predictable stressfull environment ↘ specialisation

↙ shallow-soil environments ↘ many rare species worldwide !

Management implications ?

- revegetation/replanting or perennial vegetation can only be successful when there are 'available cracks'
  - after fire
  - after death of adults
  - open, less dense areas are like that for a reason !
- since it's all in the roots: using pot plants or cuttings with altered shoot-root ratio's may be problematic
- young seedlings need enough time to grow their roots (plant early winter, irrigate with unseasonal drought)
- prevent competition with weeds or non-target species
- climate change (drought) may decrease recruitment

Outline of presentation

- Adaptations of species confined to a <u>Threatened</u> Ecological Community

  Ironstone communities:

- Consequences of a <u>Threatening</u> process to a widespread community

  Wandoo woodland decline: is climate change responsible?

What many wandoos currently look like ...

reports of crown decline, from 1970's onward, becoming widespread in 1990's

What is causing the decline ? → Drought ?

SW Australia has experienced a 'sudden' drop in rainfall since the mid 1970's (2002, Indian Ocean Climate Initiative)

Last quarter century winter rain as % of previous 75 years

Other co-occurring eucalypt species seem less affected

↓

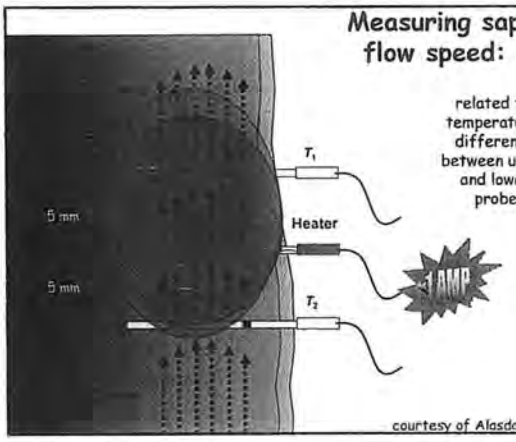
is Wandoo more vulnerable to drought ?

→ compare wandoo's daily and seasonal water relations with that of co-occurring eucalypts

Marri	Jarrah	Powderbark	Wandoo
variety of soils	*variety of soils*	*lateritic breakaways*	*often clay flats*

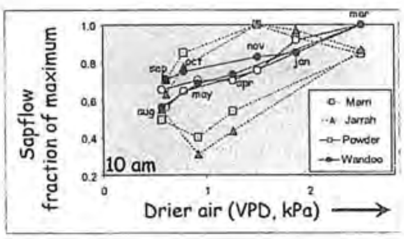
Measuring sap flow speed:

related to temperature difference between upper and lower probe



courtesy of Alasdair Grigg

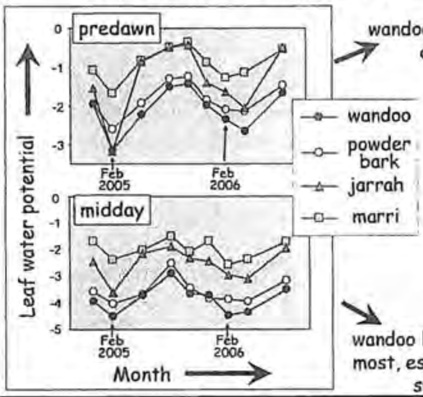
Relative sapflow velocity over the seasons:



Powderbark + Wandoo:
tight coupling between 'dryness' of air and water loss (sapflow)

Marri + Jarrah:
coupling lost after Nov, greatly reduced sapflow rates in autumn

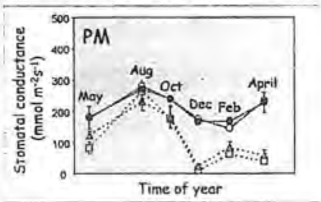
Leaf water status during course of the year



wandoo has it roots in drier soils

wandoo leaves 'dry out' most, especially during summer !

Leaf stomatal conductance during course of the year



Jarrah and Marri show much more stomatal closure during drier part of the year

Conclusions of ecophysiology work:
Wandoo + Powderbark differ from Jarrah and Marri

→ Stay more 'active' during the day
→ Stay more 'active' during dry season

↓

Loose more water

↓

Have more negative leaf water potential

↓

Larger water potential gradient (leaf-soil)

↓

Better able to extract water from dry soil

↓

have a more inland (drier regions) distribution

Period of biggest drought stress (Feb/March)

↓

wandoo has most negative pre-dawn midday water potentials of all species

best in obtaining water from driest soil + most superficial root system

in trouble ?

↓

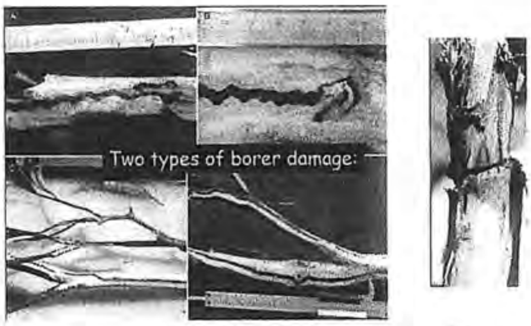
least conservative water user ?

↓

water spender relying on its ability to still obtain water from a very dry soil (but with least control)?

most stressed → most susceptible to pests???

Involvement of pests
(Ryan Hooper - Phytopathology - UWA)



Type-1 Jewel Beetle larvae Type-2

General conclusions

- no clear indications about cause of the decline yet

↓

beetle larvae and fungi seem involved indirectly

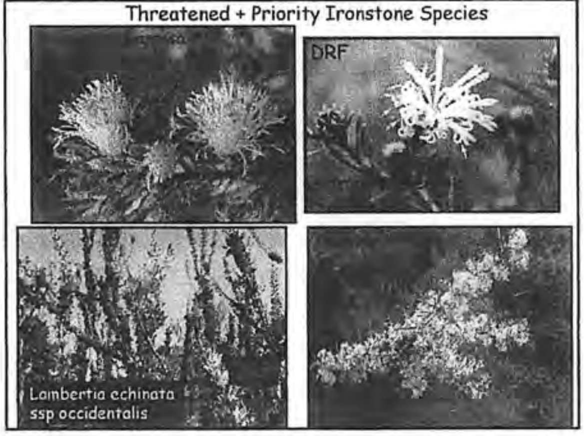
→ Why now?

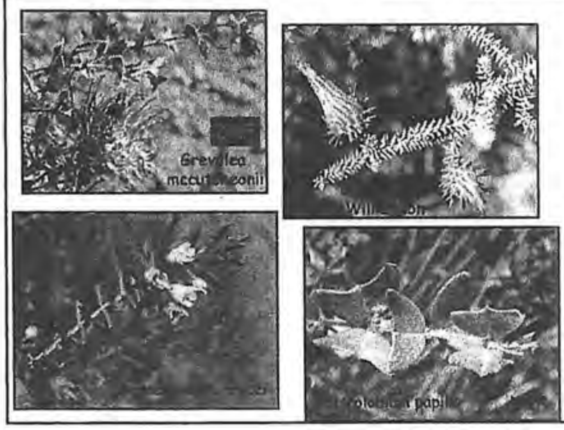
Increased stress:
- climate change
- salinity (clearing)

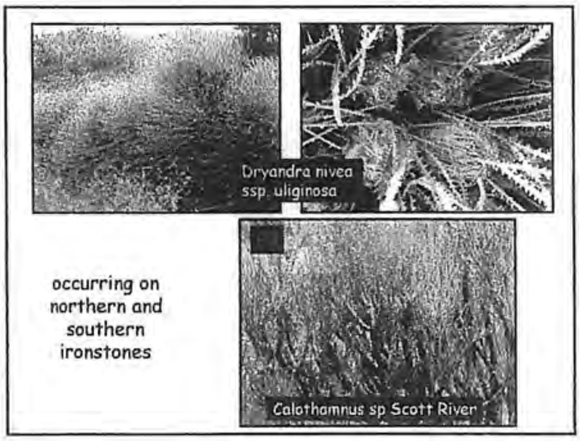
Future work (funds allowing...)

- Leaf physiology: what mechanism enables wandoo and powderbark to 'sustain such dry leaves'
- Start digging: get more insight in location and functioning of root systems
- Link between drought stress and pest/disease susceptibility

Threatened + Priority Ironstone Species






Dryandra nivea
ssp. uliginosa
occurring on
northern and
southern
ironstones
Calothamnus sp Scott River

Department of
Environment and Conservation

Our environment, our future

Flora Conservation Course

Threatened Ecological Communities

Prepared by:

Val English, Principal Ecologist, Species and Comm Branch, Kensington

Prepared for:

Flora Conservation Course

Version 1.0 (September 2008)

1 Overview

- Elements of biodiversity
- Plans, policies and Legislation
- Identifying TECs
- Recovery Process
- Examples

2 Levels of Biodiversity

Ecosystems

Communities

Species

Populations

Individuals

Genes

3 Legislation that is used to protect Threatened Ecological Communities.

- The Environmental Protection Act, Wildlife Conservation Act (1950)-no mention of TECs
- Notices of I under the Soil and Land Conservation Act (1948)
- Non-statutory process of listing in new CALM Policy no. 9
- As of 2004 New Legislation is Environmental Protection (Clearing of Native Vegetation) Regulations Under the EP Act of 1986 Clearing of native vegetation requires a permit except for exempt purpose
- There are 16 TECs from Western Australia listed on the Commonwealth EPBC Act

re are four different types of translocations. These are:

4 Threatened Ecological Communities

A Threatened Ecological Community is defined as an ESA (Environmentally Sensitive Area)

- ESA cannot be cleared without a permit, not even day-to-day, routine clearing activities

5 DEC's Corporate Plan

Objectives and strategies
1st Objective Protect biodiversity
4th strategy Identify, Protect
Prepare and implement Recovery Plans for the most threatened

4th strategy under first objective:
To recover threatened flora, fauna and ECs.

- Identify and specially protect TSCs
- Priority rank them for conservation
- Prepare and implement RPs for the most threatened TSCs

6 Draft Policy #9

'*Conserving threatened species and ecological communities*'

- Describes process of TEC conservation ('Recovery Process')
- Objective 'No listed threatened species or ecological community to be lost through human action or inaction'

Preserving threatened species and ecological communities.
Establishes scientific committee which makes recommendations to Director of Nature Conservation, which have to be endorsed by Minister

TEC must meet these criteria
Presumed "totally destroyed", "critically endangered", "endangered" or "vulnerable"

- Describes constitution of TEC Scientific Committee
- Recommendations of TECSC sent to Director Nature Conservation
- Endorsement of Minister required

7 Definition of an Ecological Community

A naturally occurring biological assemblage that occurs in a particular type of habitat.

*A **threatened ecological community** (TEC): is one that meets the criteria as;*

- *'presumed totally destroyed',*
- *'critically endangered',*
- *'endangered' or*
- *'vulnerable'.*

***A Priority Ecological Community (PEC):** A possible threatened ecological community*

- *does not meet survey criteria or is not adequately defined,*
- *is adequately known and rare but not threatened, has recently been removed from threatened list and requires regular monitoring,*
- *or is conservation dependent (high priority for further work to clarify status).*
- *P1-5 (indicates urgency for further work to clarify status)*

7.1 Identifying TECs

- *Defined based on Regional Vegetation survey (eg Beard, SCP survey, Kimberley Rainforest survey, South Coast mountain top survey)*
- *Some defined from smaller scale surveys (eg PhDs, consultants reports, reports on caves, mound springs), put into regional context*

Information requirements:

- *Community well described/defined*
- *Distribution known*
- *Know when it is considered 'destroyed'*
- *Can allocate to a threat category*
- *Nominated to TECSC as 'threatened' or Priority by Regions/Project Officers*
- *If accepted, endorsement (of TECs) of listing by DNC, Minister*
- *Deemed to be a TEC in WA (69 to date)*

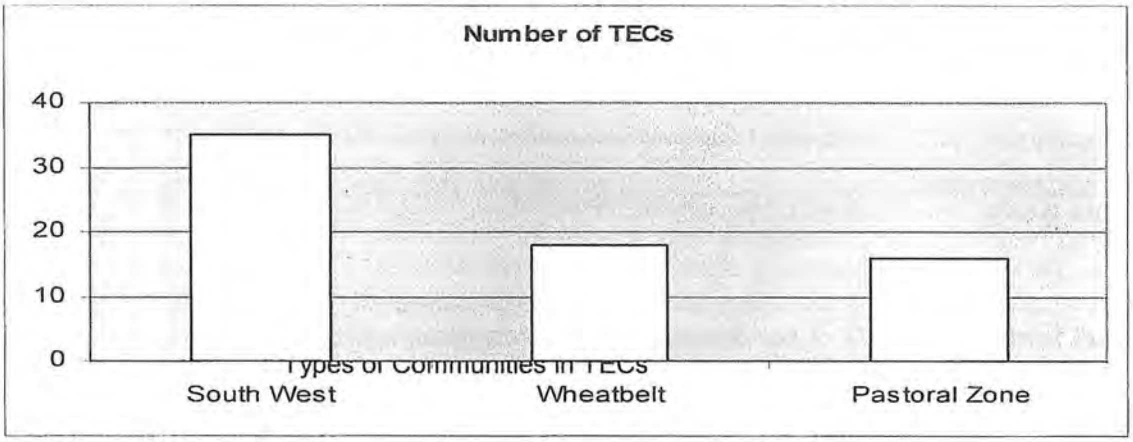
7.2 TEC Database

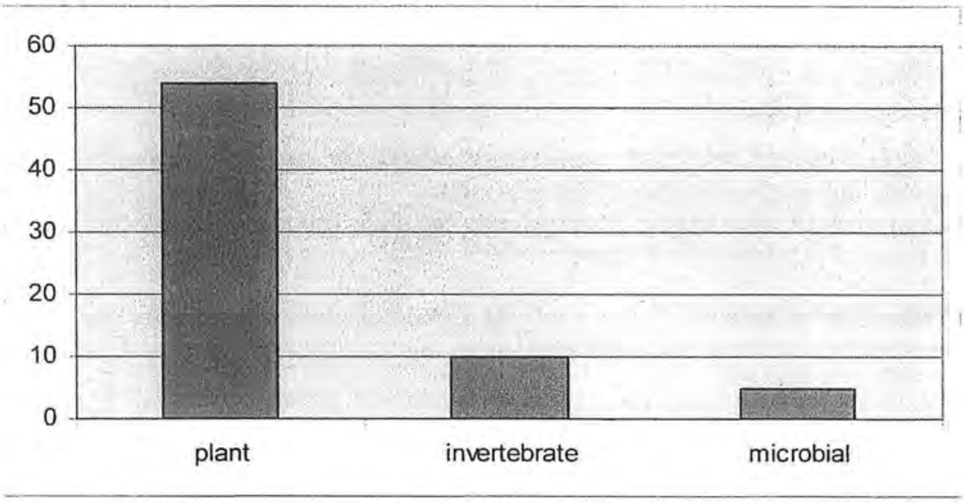
- *Database of TECs resides at Kensington*
- *Consists of Access tables and Arcview spatial components*
- *Contains location and boundary data for occurrences*
- *Includes description, category, threats, recommendations and actions*

- *Is distributed regularly to many users (DEC users too!)*

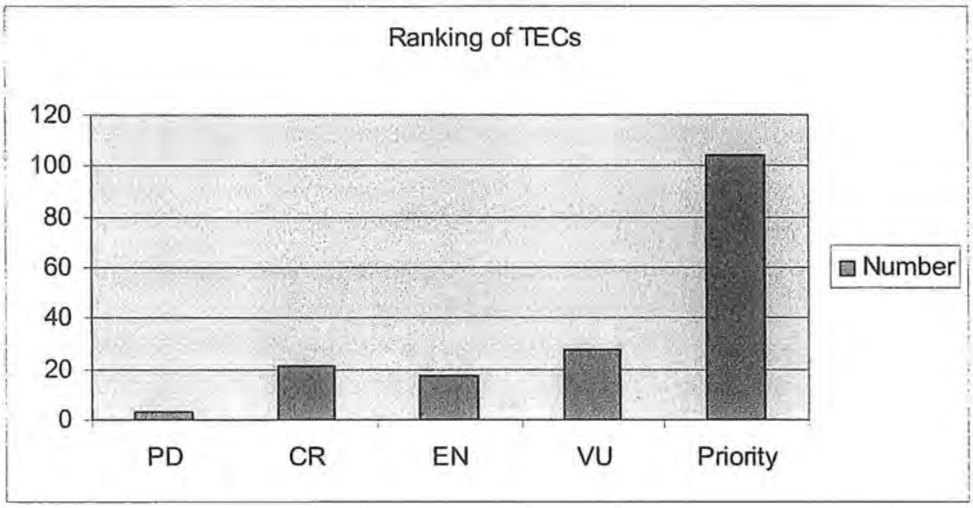
7.3 TEC Hotspots

- Wetlands in young coastal dunes
- Claypans
- Soils on eastern side SCP (eg Pinjarra Plain, Ridge Hill Shelf, Dandaragan Plateau)
- Wetlands on the eastern side of the SCP
- Limestone ridges
- Vegetation on Muchea Limestone (E side SCP)
- Coastal vegetation with *Callitris preissii (*Rottnest Tea tree*)* or *Melaleuca lanceolata (*moonah*)*
- Unusual substrates eg Chert, *ironstone*
- Caves (especially wet caves)
- Microbial formations
- Springs (permanently wet areas)
- Ironstone hills
- Hills with remnant vegetation in largely cleared landscapes (W'belt)
- Mountains, larger hills in the South West (outside of jarrah forest)





Types of Communities in TECs

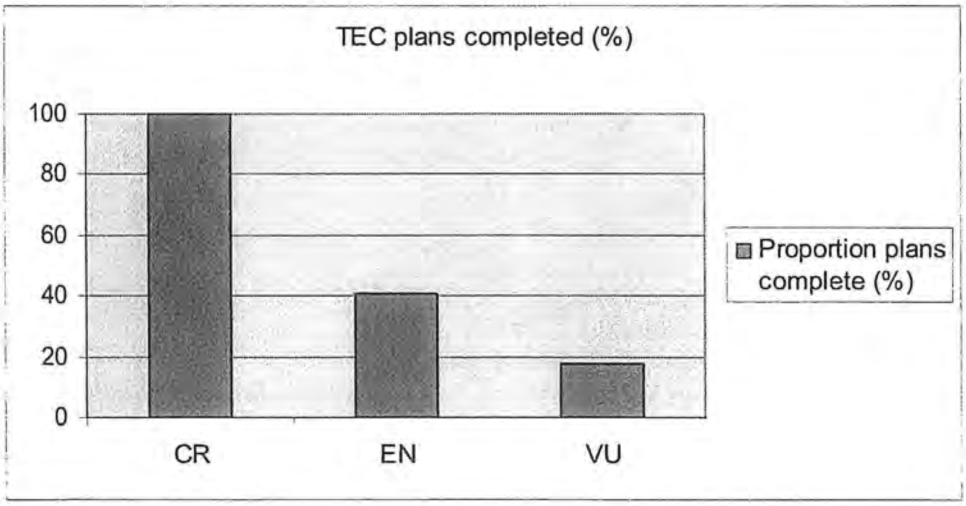


8 TEC Recovery Plans

- Formalises recovery processes including Recovery Teams and Recovery Plans (as for flora)

Recovery plans

- Policy 9 formalises recovery processes including Recovery Teams and Recovery Plans (as for flora)
- RPs developed for Critically Endangered TECs first (highest priority for recovery)
- Usually written by Recovery Teams
- Are a management plan for a threatened community



Implementation of Recovery

- Coordination of recovery of TECs through Nature Conservation Division
- Primarily through Species and Communities Branch and Recovery Teams
- On-ground recovery work → Districts/Regions, Science Division, community etc.

9 Examples of TECs

Lake Richmond

- Formed by complex community of microbes
- EPBC listed (EN), CR in WA
- Threats include changed water quality, trampling, weed invasion, sediment (fire)
- Managed by Naragebup Environment Centre and Shire
- Actions include monitoring, education, liaison, boardwalks, fire management, weed control.
- Mound Springs
-
- Continuous groundwater discharge in raised areas of peat: created unique permanently moist habitats
- Unusual invertebrate fauna – described by Jasinska
- Four remaining vegetated springs
- Mound Springs
-
- Continuous groundwater discharge in raised areas of peat: created unique permanently moist habitats
- Unusual invertebrate fauna – described by Jasinska
- Four remaining vegetated springs

Koolanooka Hills

- Identified by Dr John Beard as unique vegetation system on ironstone hills
- Vulnerable in WA, not EPBC listed
- Total hill system covers about 5,500 ha
- Under threat from mining, weeds
- Recovery Plan in place
- Actions include seeking to acquire for conservation, liaison re mining, fencing, monitoring, weed control

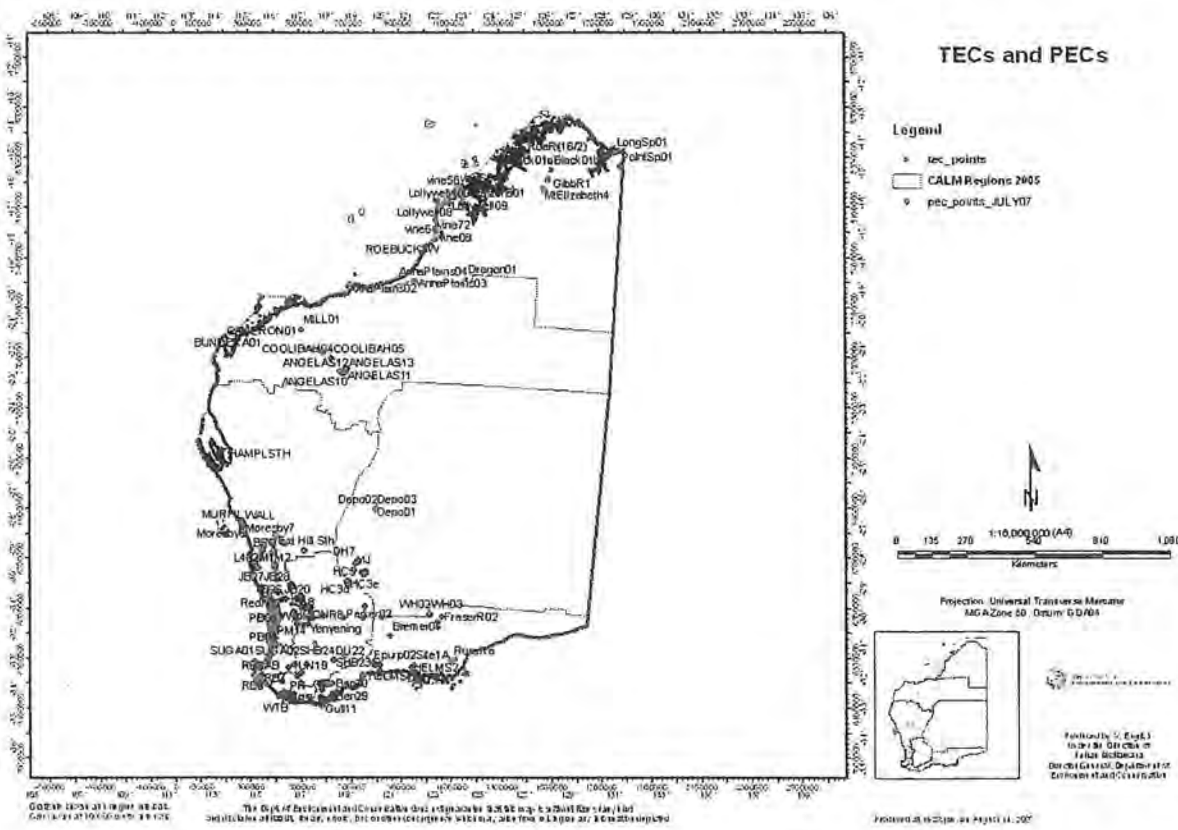
Busselton ironstone

- Described by Gibson *et al.* (1994)
- Listed as CR in WA, EN under EPBC
- 15 occurrences remaining; area ~140 ha
- 11 DRF and 6 Priority taxa (many endemic to TEC
- Threats – dieback, fire, hydrological change.
- Recovery Plan drafted 1999, update 2005
- Recovery implemented by SW Region Recovery Team
- Actions include monitoring, phosphite treatment, translocations, fire management

Toolibin Lake

- Listed as CR in WA, EN under EPBC Act
- One of last remaining 'Perched wetlands of the Wheatbelt region with extensive stands of *Casuarina obesa* and *Melaleuca strobophylla*'
- Under threat from altered hydrology
- Recovery Team working to recover/ maintain hydrology, including engineering solutions

- **Under threat from changed hydrology, weeds, fire**
- **EPBC listed (EN), CR in WA**
- **Recovery Plan in place**
- **Actions include investigating, monitoring hydrology, weed control, fire management**



10 Summary of some important ideas from the case studies

Conclusion

- The Department places a high priority on conservation of TECs, many staff, other scientists, volunteers involved
- Various legislation and policies are used to conserve TECs in Western Australia
- Better ways to manage them are being developed with Recovery Teams

Threatened Ecological Communities

Val English

Species and Communities Branch

To be covered

- Elements of biodiversity
- Policies and Legislation
- Identifying TECs
- Examples of the 'Recovery Process'

Levels of biodiversity

- Ecosystems/landscapes
- Communities
- Species
- Populations
- Individuals
- Genes

Legislation and Policies

EPBC Act

16 WA TECs listed:

- 10 - Swan Coastal Plain
- 4 - Leeuwin-Naturaliste Ridge
- 1 - Wheatbelt
- 1 - South Coast Region

EPBC Act

- Any proposal likely to have a significant impact on listed TECs must be referred to Commonwealth Minister for Environment.
- An offence to undertake such actions without prior approval from Commonwealth Minister.
- Minister will decide whether the action requires EPBC Act approval.
- Requirement for Conservation Advices / Recovery Plans

$5 million penalties for non-referral by corporations.

Legislation and Policies

- *Wildlife Conservation Act 1950*
- Does not provide for listing TECs
- New Biodiversity Bill – planned
- Non-statutory listing process developed in WA (new draft Policy 9 describes)




Legislation and Policies

EP ACT CLEARING REGULATIONS

- July 2004 *Environmental Protection (Clearing of Native Vegetation) Regulations 2004* made under the *Environmental Protection Act 1986* came into operation.
- Clearing of vegetation requires a permit, unless for exempt purpose

Legislation and Policies

EP ACT CLEARING REGULATIONS

- TECs are defined as Environmentally Sensitive Areas (ESAs)
- Routine day-to-day activities of vegetation clearing allowed with no permit do not apply to ESAs
- Any clearing proposals for ESAs to be under a specific permit

New Draft Policy 9

'Conserving threatened species and ecological communities'

- Describes process of TEC conservation ('Recovery Process')
- Objective 'No listed threatened species or ecological community to be lost through human action or inaction'
- Defines operation of TEC Scientific Committee
- Requirement for Recovery Plans - background information, recommend and cost recovery actions, allocate responsibilities (*most threatened first*)

Ecological Community defns 1

Ecological Community:

A naturally occurring biological assemblage that occurs in a particular type of habitat.

Ecological Community defns 2

A threatened ecological community (TEC): one that meets the criteria as:

- 'presumed totally destroyed'
- 'critically endangered'
- 'endangered'
- 'vulnerable'

Ecological Community defns 3

Priority EcologicalCommunity (PEC):

- A possible threatened ecological community
- Does not meet survey criteria or is not adequately defined,
- Is adequately known and rare but not threatened, has recently been removed from threatened list and requires regular monitoring,
- Or is conservation dependent (high priority for further work to clarify status).
- P1-5 (indicates urgency for further work to clarify status)

Identifying TECs 1

Information requirements outlined in definitions:

eg to meet Critically Endangered (CR):

- A) The estimated geographic range, and/or total area occupied, and/or number of discrete occurrences since European settlement have been reduced by at least 90% and either or both of the following apply (i or ii):
  - i) geographic range, and/or total area occupied and/or number of discrete occurrences continuing to decline - total destruction of the community imminent (within approximately 10 years);
  - B) Current distribution is limited, and ii) very few occurrences, each of which is small and/or isolated and extremely vulnerable to known threatening processes

Identifying TECs 2

Information requirements:

- Description of the community sufficient to distinguish it from all others
- Number and location of remaining occurrences
- Current extent of community (area and geographic range)
- Publications or other data that support the description of the community

Identifying TECs 3

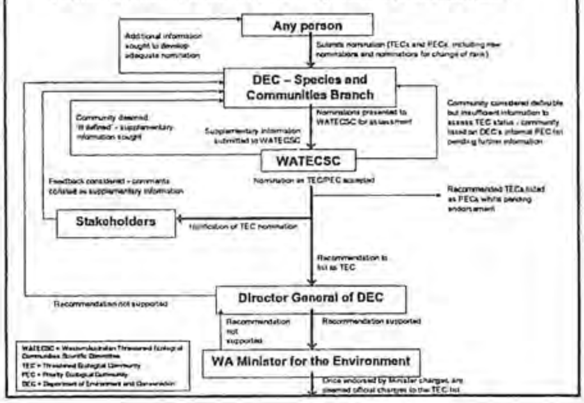
Information requirements:

- The threatening processes acting on occurrence
- History of decline of the community (if possible)
- The tenure, level of modification, land use, of the remaining occurrences
- Know when occurrences are considered 'destroyed'
- Can unambiguously allocate the community to a threat category

Identifying TECs 4

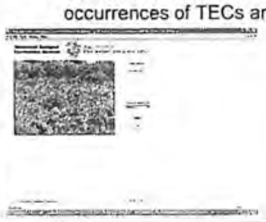
- Defined based on Regional Vegetation survey (eg Beard, SCP survey, Kimberley Rainforest survey, South Coast mountain top survey)
- Some defined from smaller scale surveys (eg PhDs, consultants reports, reports on caves, mound springs), put into regional context

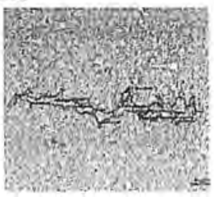
Western Australian TEC and PEC Listing Process ('Horrendogram')



TEC database 1

- Database of TECs resides at Kensington
- Consists of Access tables and Arcview spatial components
- Contains location and boundary data for all known occurrences of TECs and PECs

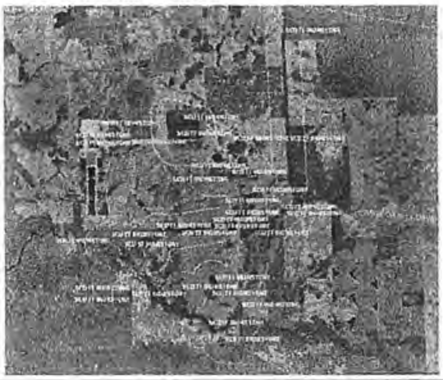




TEC database 2

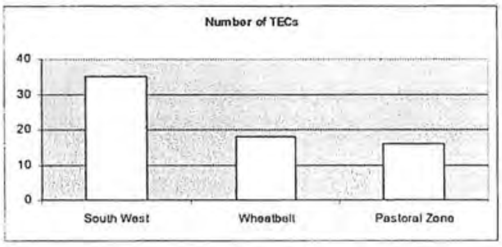
- Includes description, category, threats, species present, survey data, recommendations and actions
- Is distributed regularly to many users (DEC, other govt depts, NRM groups etc)

TEC Database - buffers

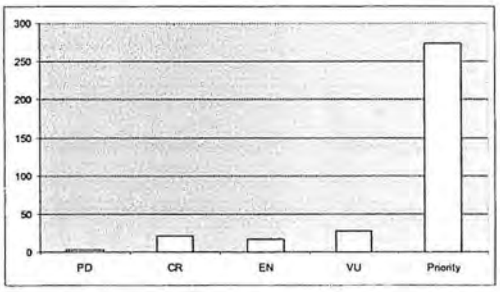


TECs and PECs

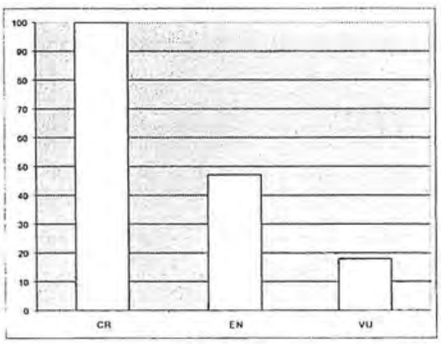
TEC Numbers



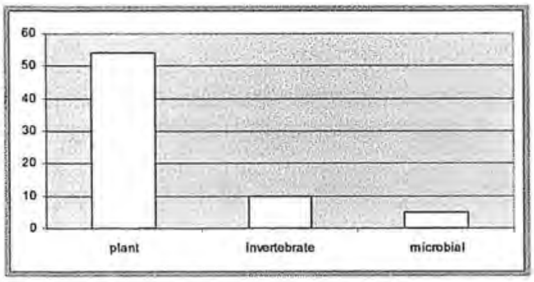
Rankings



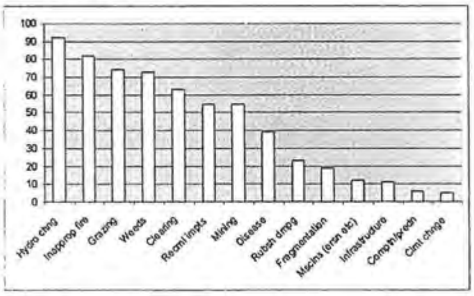
Proportion with Recovery Plans



TECs based on different biota



Number TECs/PECs subject to threat



TEC LISTING AND RECOVERY RESPONSIBILITIES

Nominations TECs and PECs - SCB, Regions, Districts, Science Division

↓

Listings of TECs and PECs - SCB

↓

Recovery Planning - usually SCB (in consultation with others), Regions, Districts

↓

On ground recovery – Recovery Teams, Districts, Regions, Science Division, community groups, landholders, NRM groups.

↓

Review of effectiveness of recovery, review, update of plans - SCB, Districts, Regions, Recovery Teams

(C'wealth funding important)

EXAMPLE 1

Yate dominated alluvial claypan

Yate dominated alluvial claypan

- On hard setting loamy soils with yellow clayey subsoils of the Jingalup soil system. Claypan on a flood plain - low lying, seasonally inundated with fresh water.
- Dominated by *Eucalyptus occidentalis* (flat-topped yate) with occasional *Eucalyplus wandoq* many herbs and geophytes.
- Described in Gibson, N., Keighery, G.J., Lyons, M.N. and Keighery, B.J. (2005) Threatened plant communities of Western Australia. 2 The seasonal clay-based wetland commonalities of the South West. Pacific Conservation Biology Vol. 11: 287-301.

Yate dominated alluvial claypan

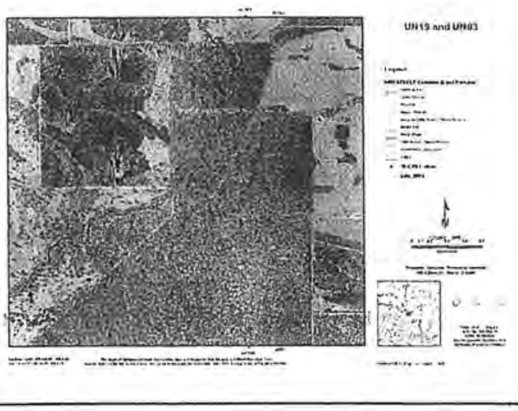
- Sixty nine 10 x 10m quadrants established in 37 clay-based wetlands (claypans) across the South West Botanical Province.
- 39 quadrats established on Swan Coastal Plain 1991 - 1993 and 30 on coastal plain and the adjacent plateau 1997 - 2002.
- Despite extensive effort only one occurrence located, within a single nature reserve !

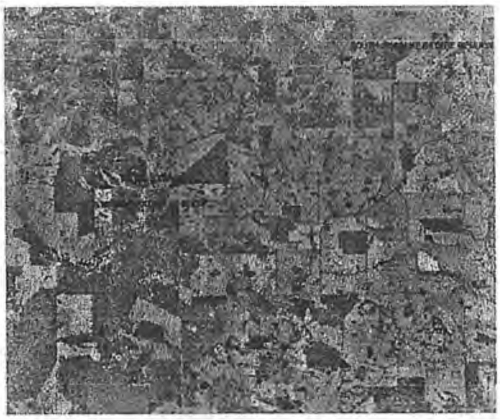
Yate dominated alluvial claypan

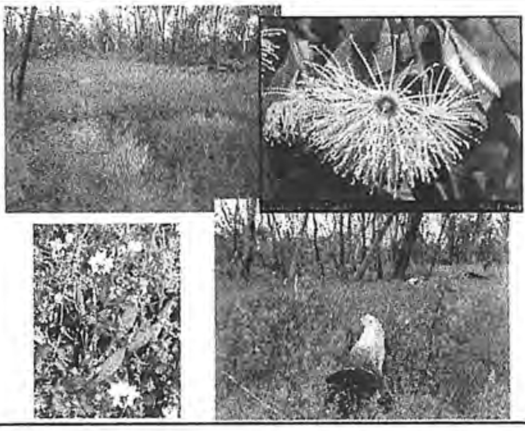
- Community recommended as EN B ii) 2006. (Not yet endorsed through State processes):

B) Current distribution is limited, and

ii) there are few occurrences, each of which is small and/or isolated and all or most occurrences are very vulnerable to known threatening processes;







Yate dominated alluvial claypan

Threats:
- Altered hydrology
- Disease
- Weeds
- Altered fire regimes

Recovery actions:
- Field site – to be discussed!

EXAMPLE 2

***Melaleuca huegelii* – *M. systena* shrublands of limestone ridges (FCT 26a)**

Melaleuca huegelii – *M. systena* shrublands of limestone ridges (FCT 26a)

Defined by Gibson *et al.* 1994 "A Floristic Survey of the southern SCP" (Gibson *et al.* 1994)

Distinctive unit in analysis of floristics of 500 plots

Ranked as Endangered B(iii) in 2001

B) Current distribution is limited, and

iii) there may be many occurrences but total area is very small and each occurrence is small and/or isolated and extremely vulnerable to known threatening processes.

Limestone ridges (FCT 26a)

- Series of distinctive plant communities on limestone-rich soils of Swan Coastal Plain.
- Particularly restricted one '*Melaleuca huegeli* – *M. systena* shrublands of limestone ridges' near Perth on shallow soils over limestone or massive Tamala Limestone ridges.
- Occurs from near Yanchep in the north, to Lake Clifton in the south.
- Community is a species-rich shrubland of *Melaleuca huegeli* (chenille honeymyrtle), and *Melaleuca systena* (coastal honeymyrtle) often over limestone heath species including *Banksia sessilis* (parrot bush) and *Grevillea preissii* (spider net grevillea).

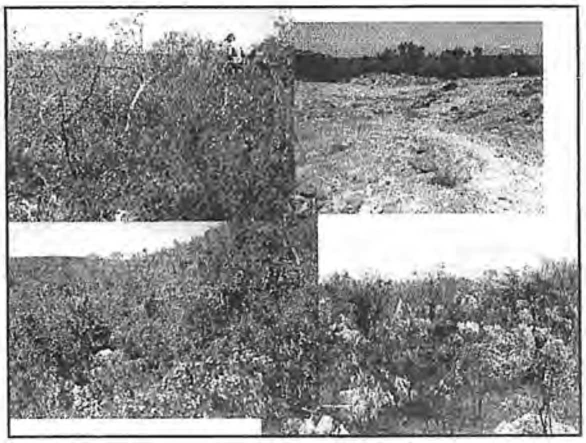
Limestone ridges (FCT 26a)

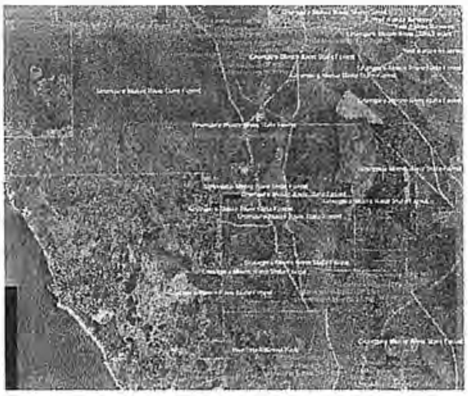
- 79 occurrences totaling ~146ha
- <25% of this area is within secure conservation reserves.
- Similar but more common plant community is found on lower slopes or in pockets with deeper soil, dominated by different group of species including trees or mallees
- Ridges of Tamala Limestone roughly parallel to the coast on the Swan Coastal Plain.
- On Aeolianite (wind deposited) limestone mainly composed of shell fossils and quartz sands that formed ancient dune systems.

Limestone ridges (FCT 26a)

Major threats

- Limestone is a source of road-making material and has many other uses, and quarrying is main threat to the community.
- Frequency of fires, impact of recreational uses and illegal rubbish dumping are generally increasing as urban areas expand.
- Can all lead to degradation of this community through causing changes to its composition, and increasing weed invasion .





Limestone Ridges Recovery

Actions recommended in a Recovery Plan

- seeking to increase area of community in secure reserves,
- minimising further clearing, incl. clearing for quarrying
- improving management of fire,
- increasing the awareness of conservation of community

EXAMPLE 3

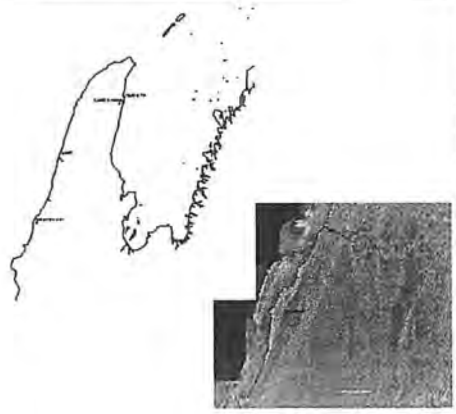
Cape Range Remipede Community (Bundera Sinkhole)

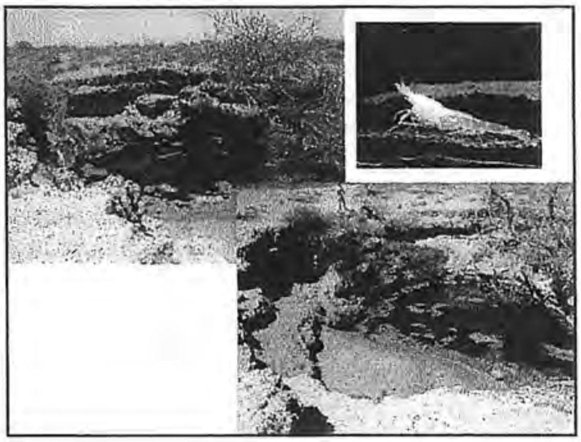
Bundera Sinkhole

- Ranked Critically EndangeredB(ii) - 1996
- B) Current distribution is limited, and
- ii) there are very few occurrences, each of which is small and/or isolated and extemely vulnerable to known threatening processes
- Recovery Plan 2001
- Nominated under EPBC

Bundera Sinkhole

- Fauna mainly relicts from Tethyan Sea
- Sea separated southern continents between 65 and 225 million years ago (the 'Mesozoic era').
- 'Cape Range remipede community' includes only member of crustacean Class 'Remipedia' in Southern Hemisphere





Bundera Sinkhole

- Very sharply defined layers of water
- Differ vastly in oxygen levels, salinity, levels of various nitrogen and sulphur compounds, temperature.
- Layering thought to be vital to the survival of the animals that live in the sinkhole
- Only Australian example of this layering of water in a cave system.

Bundera Sinkhole

Major threats:
- bombs!
- dumping of waste
- disturbance of the layering of the water
- introduction of feral fish
- nutrient enrichment (feral goats)

Recovery actions:
- protecting the site from dumping of rubbish /introduction of feral fish
- prohibiting unauthorised diving
- feral goat control
- ...care with bombing targets!

Bundera Sinkhole

- North West Cape Karst Management Advisory Committee oversees plan implementation
- Team - WA Museum, DEC, Shire of Exmouth, Defence Estates Organisaion, WA Speleological Group (Exmouth).

Conclusion

- TEC conservation is integral to biodiversity conservation at the ecosystem level
- Various legislation and policies are used to conserve TECs
- Better knowledge, and ways to manage TECs are being developed through Recovery Planning and Recovery Teams

Threatened plant communities of Western Australia. 2 The seasonal clay-based wetland communities of the South West

N. GIBSON[1], G. J. KEIGHERY[1], M. N. LYONS[1] and B. J. KEIGHERY[2]

The communities of seasonal clay-based wetlands of south-west Australia are described. They are amongst the most threatened in Western Australia. It is estimated that >90% of the original extent of these communities has been cleared for agriculture, and the remaining areas, despite largely occurring in conservation reserves, are threatened by weed invasion and rising saline groundwater. Thirty-six taxa are identified as claypan specialists occurring in six floristic communities. Composition was strongly correlated with rainfall and edaphic factors. The most consistent attribute shared between the seasonal clay-based wetlands of south-west Australia, and the analogous vernal pools systems of California, Chile, and South Africa was the widespread conversion of these wetlands to agricultural systems. The south-west Australia wetlands had a richer flora, different lifeform composition, higher species richness but fewer claypan specialists than the vernal pools of California. The dissimilarity in the regional floras and vegetation types from which the pool floras were recruited explain these differences.

Key words: Threatened community; Vegetation clearance; Remnant; Salinity; Weeds; Vernal pools; Claypans.

INTRODUCTION

THE South West Botanical Province (SWBP) of Western Australia covers some 347 000 km² and largely coincides with the area of Mediterranean climate in south-west Australia. It has an estimated flora of some 8 000 taxa of which 75% are believed to be endemic (Hopper 1992). It has been divided into seven major bioregions largely defined by climate, soils and major structural vegetation units (Fig. 1, Thackway and Creswell 1995). The seasonal wetlands of the SWBP are both extensive and compositionally diverse. They are most commonly found along the Swan Coastal Plain and in the higher rainfall Warren bioregion but also occur widely across the SWBP (Fig. 1). In a quadrat based study covering 7 500 km² of the southern Swan Coastal Plain more than half of the 30 major vegetation units described were seasonal wetlands (Gibson *et al.* 1994). Similar levels of compositional diversity are also found along the south coast (Wardell-Johnson and Williams 1996). Most of these wetlands are seasonally waterlogged or seasonally inundated in response to winter rainfall recharge of shallow unconfined groundwater systems (Froend *et al.* 1993). They can be dominated by woodlands, shrublands, or sedgelands communities. In the extensively cleared areas (primarily for cereal cropping) many of the remaining seasonal wetlands are becoming more saline or permanently inundated due to rising saline groundwaters (George *et al.* 1995).

Shepherd *et al.* (2001) estimates that 57.3% of the SWBP has been cleared. The most heavily cleared bioregions are the Avon Wheatbelt (83.6%) and the Swan Coastal Plain (61.6%), and within these regions clearance has been biased toward the agriculturally desirable soils. While no precise figures are available for the extent of wetlands across the SWBP, more than 362 000 ha of wetlands have been mapped across the Swan Coastal Plain south of Lanclin (Hill *et al.* 1996). These wetlands occupy 25% of the plain and it has been estimated that some 70% have been drained, filled in or otherwise altered (Rigget 1969; Halse 1989; Davis and Froend 1999). Loss has been greatest for the seasonal wetlands (88% of total area of wetlands) and can exceed 94% on some parts of the plain, primarily as a result of conversion for agriculture (Rigget 1969; Hill *et al.* 1996).

While most seasonal wetlands are connected to the regional groundwater, a series of wetlands are found on clay substrates that rely solely on rainfall to fill and then dry to impervious pans in summer. These wetlands fit Keeley and Zedler's (1998) definition of a vernal pool habitat — *"precipitation-filled seasonal wetlands inundated during periods when temperature is sufficient for plant growth, followed by a brief waterlogged-terrestrial stage and culminating in extreme desiccating soil conditions of extended duration"*. In addition to these seasonal clay-based wetlands (locally referred to as ephemeral claypans or clay flats), the seasonal pools of granite rocks that occur extensively across southwestern Australia (Withers 2000) would also fit Keeley and Zedler's (1998) concept of a vernal pool, but our discussion here is restricted to seasonal wetlands occurring on clay substrates.

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PACIFIC CONSERVATION BIOLOGY Vol. 11: 287–301. Surrey Beatty & Sons, Sydney 2005

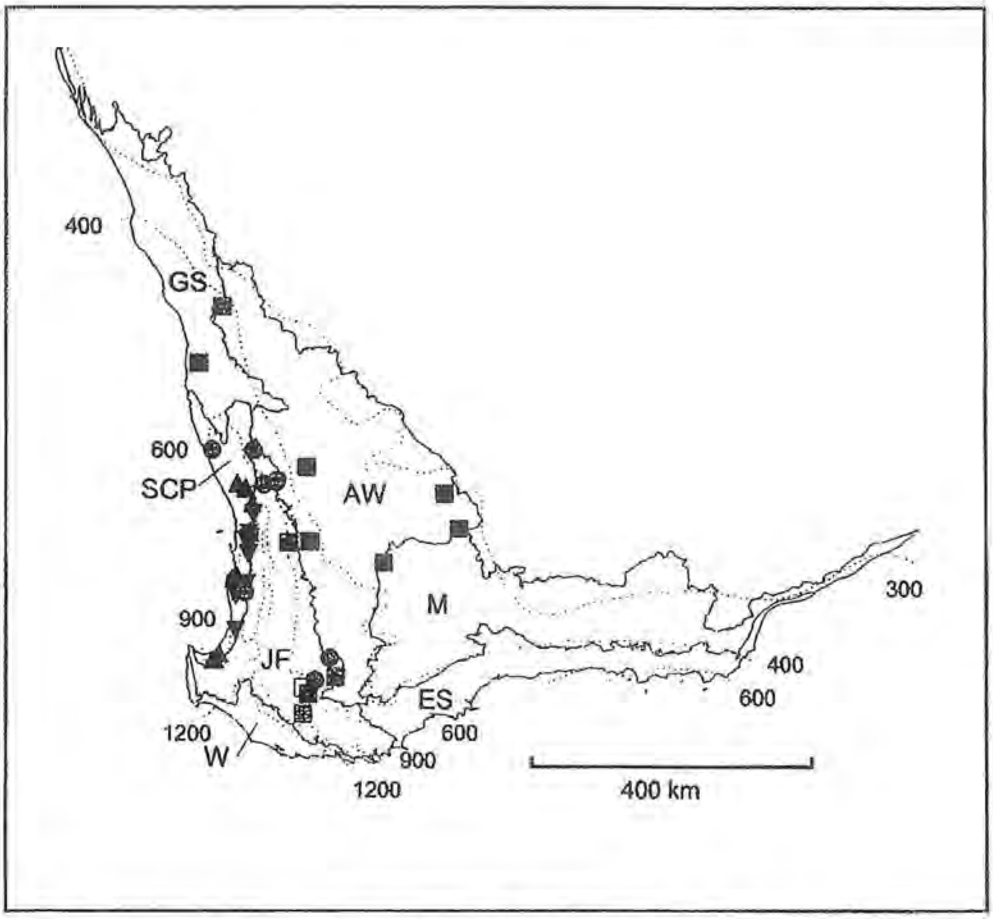


Fig. 1. Distribution of 69 quadrats sampled (symbols can indicate more than one quadrat) showing six group classification, rainfall isohyets (mm) and major bioregions of the SWBP of south-west Australia. Bioregion code: AW, Avon Wheatbelt; ES, Esperance Sandplain; GS, Geraldton Sandplain; JF, Jarrah Forest; M, Mallee; SCP, Swan Coastal Plain; W, Warren. Quadrat group code: group 1, triangle; group 2, inverted triangle; group 3, circle; group 4, open square; group 5, grey square; group 6 dark square.

Compositionally distinct, these wetlands are characterized by a temporally overlapping suites of annual taxa that germinate and flower as the wetland dries (Gibson *et al.* 1994). While no estimate of the extent of this type of wetland is available across the SWBP, on the southern coastal plain only some 240 ha remains (CALM, Threatened Ecological Communities database, May 2004), representing *ca.* 0.25% of the remaining vegetated seasonal wetlands on this part of the plain. Given the general pattern of clearance biased to agriculturally desirable soils across the SWBP, it is likely that in total <10% of the original extent of these wetlands remain. Known examples occur from 28°30'S to 34°30'S and inland for 300 km, receiving between 300 and 900 mm annual rainfall. The landscape in the SWBP is subdued rarely reaching above 300 m.

Recently three small seasonal clay-based wetlands were located in the heavily cleared agricultural area of South Australia which experiences a Mediterranean climate similar to south-west Australia. They appear to represent the last remnants of these seasonal clay-based wetlands on the Northern Adelaide Plains (P. Coleman, pers. comm., 2002, botanical consultant).

While no other examples of this wetland type are known from Australia (Jacobs and Brock 1993; Benson and Jacobs 1994), vernal pools have been reported from many areas with Mediterranean climates including South Africa (Stephens 1929; Campbell *et al.* 1980), Chile (Bliss *et al.* 1998) and on the west coast of North America centered on California (hereafter referred to as "Californian"; Purer 1939; Keeley and Zedler 1998). They have been studied in considerable detail in California where 169 taxa have been recorded from vernal pools and *ca.* 100 of these are restricted or largely restricted to the pools (Holland and Jain 1977). This flora is predominately annual (*ca.* 80%) and comprises two elements; a widespread cosmopolitan group of aquatic taxa, and 69 Californian endemics (Stone 1990; Zedler 1990). Nineteen of these taxa are currently listed as threatened or endangered. Generally between 15 and 25 taxa occur in any individual pool and different pool species can dominate in different years depending on climatic variation (Holland and Jain 1981; Holland and Dains 1990; Keeley and Zedler 1998).

Californian vernal pools occur on three major geomorphic units, the coastal terraces of southern California and baja California, the alluvial terraces of the Central Valley, and on eroded lava flows. The pools are of variable size and depth and are characterized by an impervious duripan layer which may result from pedogenic hardpans, rock, volcanic deposits or clay lenses (Zedler 1987; Keeley and Zedler 1998). Most occur at low altitudes but do extend to 1 900 m and over a range of 1 800 km from eastern Washington (47°N) to Baja California (31°N) (Sawyer and Keeler-Wolf 1995; Keeley and Zedler 1998). The majority receive between 125 to 1 500 mm annual rainfall. A classification of eight vernal pool ecosystem types based on geography and geomorphology has been proposed (Sawyer and Keeler-Wolf 1995). It is estimated that 90% of the vernal pools in California have been destroyed since the 1800s (Holland 1978, quoted in Keeley and Zedler 1998).

Recent work in Chile (Bliss *et al.* 1998) has reported vernal pools occurring extensively over 1 000 km (between 31°23'S to 38°36'S), covering a rainfall range of from 95 to 1 400 mm, all occurring within 130 km of the coast and from 25 to 2 400 m above sea level. One hundred and forty species were recorded from 30 pool complexes, 70% of the common species being annual. The flora was largely derived from wetland generalists or upland taxa with some inundation tolerance. There is a surprising lack of representation of local vernal pool specialists, but four amphitropical genera are shared with the vernal pools of California. Land use practices are having a significant impact on the pools with very little pristine habitat remaining (Bliss *et al.* 1998).

The seasonal claypans of South Africa remain little studied but appear to be restricted to a small area on the Cape Flats near Cape Town (Stephens 1929; Campbell *et al.* 1980) with an annual rainfall of *ca.* 500 mm.

The aim of the present research was to characterize the clay-based seasonal wetlands of south-west Australia in terms of distribution, geomorphology, flora, vegetation patterning, and conservation status, and provide a comparison with analogous wetlands (vernal pools) of other Mediterranean regions.

METHODS

Sixty-nine 10 × 10 m quadrats were established in 37 seasonal clay-based wetlands (hereafter referred to as claypans) across the SWBP. Thirty-nine of the quadrats were established on the Swan Coastal Plain between 1991 and 1993 and a further 30 quadrats were established on the coastal plain and the adjacent plateau between 1997 and 2002 (Fig. 1). Survey effort was more intensive on the Swan Coastal Plain, but there has also been significant survey effort for such claypans in the other areas across the South West. The claypans on the plateau were located during the course of a major regional survey which sampled over 1 500 quadrats across the South West (Keighery *et al.* 2002; Lyons *et al.* 2004). Consequently the broad pattern of distribution of the claypans is considered to be accurate. Given the very high level of clearance of the claypans sampling was not stratified, rather it was as comprehensive as possible.

All quadrats were sampled at least twice with some quadrats on the plain being revisited up to four occasions to ensure that the entire phenological procession in spring and early summer was sampled (Lin 1970). In each quadrat presence/absence data for all vascular plants were recorded as were notes on vegetation structure, and site geomorphology (inundated flat claypan or basin claypan). Quadrats were permanently marked with four galvanized pegs and GPS position taken to aid re-sampling. Quadrats were positioned parallel to the edge of claypans with the entire quadrat below maximal water level.

A stratified bulked soil sample from the top 10 cm was collected from 67 of the 69 quadrats and pH, electrical conductivity, total N, total P, percentage sand, silt and clay, exchangeable Ca, Mg, K and Na were measured using standard methods (McArthur 1991). Mean annual rainfall and mean annual temperature were estimated for each quadrat using the BIOCLIM model (Busby 1986).

Quadrats were classified according to similarities in species composition (presence/absence data) using the Bray-Curtis coefficient and "unweighted pair-group mean average" fusion method (UPGMA module in PATN, Belbin 1995, beta value -0.1; Sneath and Sokal 1973). Classification results are presented at the 6 group level (referred to as communities), and the methods of Dufrene and Legendre (1997) based on a constancy and fidelity statistic were used to determine best indicator species for each group at this level (PC-ORD v 4.24, McCune and Mefford 1999). Quadrats were ordinated using semi-strong hybrid routine (SSH in PATN, cut level 0.9), correlations of environmental vectors were determined by the PCC routine in

PATN (Belbin 1995) and significance tested by monte-carlo simulation (MCAO in PATN).

Differences in the edaphic and climatic parameters of the different community types were investigated using Kruskal-Wallis one-way analysis of variance as these data were highly skewed. Statistical analysis of species richness patterns in relation to community types could not logically be undertaken as these data were used in generating the classification. Species richness was analysed in relation to pool geomorphology (inundated flat claypan vs basin claypan), and rainfall (re-coded into 3 classes; 300–600 mm, 601–900 mm, >901 mm) using two-way analysis of variance and regression analysis after preliminary analysis confirmed its normal distribution (Statistica V6, StatSoft 2001).

In addition to taxa recorded in quadrats, a search was made of the Western Australian Herbarium for any further species recorded from claypans of the SWBP. For the combined lists, each taxon was allocated to a lifeform group, one of three distributional classes (endemic to claypans, centered on claypans, or with a wider distributions) and to one of four functional groups (a submerged group that do not tolerate drying; an amphibious group that do tolerate both flooding and drying; and damp and dry terrestrial group that do not tolerate flooding) following the system of Brock and Casanova (1997).

Beta-diversity (the changeover in species between quadrats) was calculated by dividing total flora from the 69 quadrats (an estimate of gamma-diversity) by the species richness at each quadrat (alpha-diversity). Patterns in beta-diversity were further examined by plotting Bray-Curtis similarity scores against geographical separation for each quadrat pair.

Nomenclature generally follows Paczkowska and Chapman (2000).

RESULTS

Distribution and geomorphology

The distribution of the 69 quadrats sampled in relation to rainfall and the major bioregions of the SWBP is shown in Figure 1. Claypans are almost completely absent from the Geraldton and Esperance Sandplains. They are also absent from the high rainfall areas of the Jarrah Forest and Warren bioregions. In addition, few were found where rainfall fell below 400 mm.

Two geomorphological types of claypans were encountered, one on low lying areas of seasonally inundated/waterlogged flats (62%) ranging in size from a few square meters to hundreds of square meters, and the other as small basin claypans (38%) from *ca.* 0.5 ha to 10 ha in size that dried completely over summer. These basin claypans were generally surrounded by lunettes carrying *Banksia* or eucalypt woodlands. Shrubs (1 m, occasionally to 3 m) were common in both claypan types with trees occurring on the flats sometimes closely associated with the claypan systems. The claypans of SWBP are never associated with grasslands, a vegetation type completely lacking from the SWBP (Diels 1906; Beard 1981).

Flora

A flora of 609 taxa (including 98 introduced taxa) in 268 genera from 83 families has been recorded for the claypans of the SWBP, with 71.4% of these taxa recorded from just 17

Table 1. Species richness of the plant families recorded in the claypans of the SWBP of Western Australia, includes both quadrat data and further records from the Western Australian Herbarium.

Family	Total	Native	Introduced
Asteraceae	57	46	11
Cyperaceae	56	52	4
Poaceae	51	22	29
Orchidaceae	36	35	1
Myrtaceae	35	35	–
Stylidiaceae	25	25	–
Fabaceae	25	14	11
Anthericaceae	22	22	–
Apiaceae	21	21	–
Restionaceae	18	18	–
Droseraceae	18	18	–
Centrolepidaceae	13	13	–
Haemodoraceae	12	12	–
Goodeniaceae	12	12	–
Juncaginaceae	12	12	–
Iridaceae	11	2	9
Proteaceae	11	11	–
TOTAL	435	370	65

families (Table 1). The most diverse genera were *Stylidium* (24 taxa), *Schoenus* (21), *Drosera* (18), *Melaleuca* (13), *Isolepis* (13), *Triglochin* (12), *Centrolepis* (9), and *Thysanotus* (8).

Introduced taxa were most often recorded in the Poaceae (29 taxa), Asteraceae, Fabaceae (11 taxa each), and Iridaceae (9 taxa). The genus *Trifolium* was represented by seven taxa, all introduced. Introduced taxa represent some 16.1% of the flora for the claypans and this is a higher than the 9% recorded for the entire Western Australian flora (Keighery 1995; Paczkowska and Chapman 2000).

Of the 609 taxa, 281 could be considered wetland taxa (i.e., those typical of seasonally wet habitats including the submerged, amphibious and terrestrial damp functional groups) and 328 taxa more typical of uplands (the terrestrial dry functional group, Table 1). For native wetland taxa 17 of the 101 genera are shared with Californian vernal pools, and eight of 17 introduced genera are also shared (Thorne 1984).

South-west Australian claypans are rich in annual herbs and geophytes, with perennial herbs and shrubs contributing to a smaller degree. When just wetland taxa are considered this pattern is stronger (Table 2). The proportion of geophytes is 2–3 times greater than that recorded for the flora of the SWBP as a whole (Parsons and Hopper 2003). Of the 29 most common taxa (found in >25% of quadrats sampled), 23 were annuals or geophytes, and 9 of these were introduced taxa.

Table 2. Life forms of the total native and exotic flora recorded for claypans of the SWBP and of the typical wetland taxa (includes submerged, amphibious and terrestrial damp functional groups). The data are from both survey and herbarium records.

Lifeform	% total flora (n = 609)	% wetland taxa (n =281)
fern allies	0.7	0.7
fern	1.2	2.5
arboresent monocot	0.2	–
annual grass	4.6	1.1
annual sedge	5.1	10.7
annual herb	32.8	34.5
parasitic annual herb	0.7	–
geophyte	18.1	21.0
perennial climber	0.2	–
perennial grass	3.6	0.7
perennial restiad	3.0	4.6
perennial sedge	5.1	5.7
perennial herb	10.2	6.4
parasitic perennial herb	0.2	–
shrub	12.8	10.3
mallee	0.2	–
tree	1.6	1.8

Thirty-six taxa were found to be endemic to, or have distributions centered on, claypans in the SWBP (Table 3 and 4, hereafter referred to as claypan specialists). The genera *Eryngium* and *Schoenus* were the richest. Most of the claypan specialists were annuals or geophytes and, unsurprisingly, were more strongly represented by the submerged and amphibious functional groups than were the 573 taxa with wider distributions (Table 3).

Vegetation patterning

A total of 561 taxa were recorded from the 69 sampled quadrats and species richness ranged from seven to 81 taxa per quadrat. Mean species richness was 41.7 taxa per quadrat. Of the 561 taxa recorded, 203 (36.2%) were recorded in only a single quadrat. These taxa had little effect on the quadrat classification and are not discussed further. All groups are characterized by high cover of annual herbs in spring and early summer and lacking annuals by mid to late summer as the claypans dry.

At the six group level, the classification of the 69 quadrats showed strong correlation with both climatic and edaphic factors (Table 5, Fig. 2). Diagnostic taxa of each quadrat group was identified using Dufrene and Legendre's (1997) INDVAL routine (Table 6). A brief description of each of the six quadrat groups is given below.

Groups 1 to 4 are confined to the higher rainfall zone of the study area and all have high species richness (Fig. 1, Table 5).

Group 1 occurred on the coastal plain and at one claypan (3 quadrats) on the plateau, and is characterized by a series of annual taxa common in the damp terrestrial phase of the pool cycle (e.g., *Blennospora doliiformis, Angianthus preissianus*; Table 6). Quadrats in this group had highest mean electrical conductivity reflecting proximity to coast (Table 5). Structurally these claypans are quite variable ranging from woodlands to herblands, the most common overstorey taxa are *Casuarina obesa, Melaleuca viminea* and *M. cuticularis.*

Group 2 is entirely confined to the coastal plain and characterized by a series of shrubs (e.g., *Hypocalymma angustifolium, Kunzea micrantha, K. recurva* and *Viminaria juncea*; Table 6) that commonly occur in these claypans. Seasonally inundated flats are the most common claypan type in groups 1 and 2 and these types are predominately found in high rainfall areas (Table 5).

Group 3 are predominately deeper basin claypans occurring both on the coastal plain and the adjacent plateau, these claypans are

Table 3. Distribution of 609 native and exotic taxa recorded in the claypans of the SWBP (from survey and herbarium records) by functional group (after Brock and Casanova 1997) and distribution. Claypan specialists were defined as taxa endemic to, or with distributions centred on the claypans.

	Functional groups				
Distributions	Submerged	Amphibious	Terrestrial — damp	Terrestrial — dry	Total
Endemic to claypans	5	8	3	–	16
Centered on claypans	2	9	9	–	20
Wider	5	53	187	328	573
Total	12	70	199	328	609

Table 4. Claypan specialists (taxa endemic to, or with distributions centered on claypans) of the SWBP. The data are from both survey and herbarium records.

Family	Taxon	Distribution	Lifeform
Anthericaceae	*Chamaescilla gibsonii*	centered on pools	geophyte
Apiaceae	*Eryngium ferox*	endemic	geophyte
	Eryngium pinnatifidum subsp. *palustre*	endemic	geophyte
	Eryngium sp. (E. Wittwer 2293)	endemic	geophyte
	Eryngium subdecumbens	endemic	geophyte
	Hydrocotyle lemnoides	endemic	annual herb
Aponogetonaceae	*Aponogeton hexatepalus*	endemic	annual herb
Asteraceae	*Angianthus drummondii*	endemic	annual herb
	Angianthus platycephalus	centered on pools	annual herb
	Blennospora doliiformis	centered on pools	annual herb
	Craspedia argillicola	endemic	geophyte
	Rhodanthe pyrethrum	centered on pools	annual herb
Centrolepidaceae	*Centrolepis caespitosa*	centered on pools	annual herb
Colchicaceae	*Wurmbea* aff. *dioica* (GJK 6681)	endemic	geophyte
Cyperaceae	*Eleocharis keigheryi*	centered on pools	annual sedge
	Schoenus capillifolius	endemic	annual sedge
	Schoenus loliaceus	centered on pools	annual sedge
	Schoenus natans	endemic	annual sedge
	Schoenus sp. (GJK12235)	centered on pools	annual sedge
	Schoenus sp. (GJK 6291)	endemic	annual sedge
Haemodoraceae	*Tribonanthes* sp. (GJK and NG 2134)	endemic	geophyte
	Tribonanthes sp. (GJK sn 8-9-94)	endemic	geophyte
Hydatellaceae	*Hydatella australis*	centered on pools	annual herb
	Hydatella dioica	endemic+	annual herb
	Hydatella leptogyne	centered on pools	annual herb
	Trithuria bibracteata	centered on pools	annual herb
	Trithuria submersa	centered on pools	annual herb
Isoetaceae	*Isoetes drummondii*	centered on pools	fern allies
Marsileaceae	*Pilularia novae-hollandiae*	centered on pools	fern
Menyanthaceae	*Villarsia submersa*	centered on pools	geophyte
Myrtaceae	*Baeckea tenuifolia*	centered on pools	shrub
	Verticordia plumosa var. *pleiobotrya*	centered on pools	shrub
Papilionaceae	*Isotropis cuneifolia* subsp. *glabra*	centered on pools	perennial herb
Poaceae	*Amphibromus nervosus*	centered on pools	perennial grass
Stylidiaceae	*Stylidium* sp. (GJK 15491)	endemic	annual herb
Thymelaeaceae	*Pimelea imbricata* var. *major*	centered on pools	shrub

characterized by aquatic (*Hydrocotyle lemnoides*) and amphibious taxa (e.g., *Glossostigma diandrum*, *Villarsia capitata* and *Eleocharis keigheryi*; Table 6). Species richness was still high but lower than the previous two groups (Table 5). The quadrats in this group were generally shrublands dominated by *Melaleuca lateritia*.

Group 4 comprises two quadrats from a claypan on a floodplain under *Eucalyptus wandoo* – *E. occidentalis* woodland, a vegetation type that has largely been cleared for agriculture.

Groups 5 and 6 tend to occur on drier areas, with surface soils being more alkaline and having higher levels of total P and exchangeable cations than the other groups, with the exception of group 4 which has similar levels of exchangeable Ca and Mg (Table 5).

Group 5 represents relatively species poor quadrats, primarily basin claypans, largely confined to the Jarrah Forest. This group represents more marginal claypan habitat than quadrats in group 3, and is characterized by two

Table 5. Quadrat group means and standard errors for species richness, climatic and edaphic variables. Species richness calculations were based on 100 m^2 quadrats and exclude taxa recorded from one quadrat. Significant differences between group means for climatic and edaphic variables tested by Kruskal-Wallis one-way ANOVA, group 4 was excluded as it was represented by only two quadrats. Soil data were available for only 67 of 69 quadrats, means were calculated with these two quadrats excluded as indicated at bottom of table.

	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		
	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	Sign level
Species richness	42.9	2.0	50.5	2.9	34.9	1.9	52.5	7.5	13.4	2.0	25.4	3.3	
Annual rainfall (mm)	818	31.4	935	19.5	683	51.1	586	0.0	548	46.8	391	32.3	<0.0001
Annual temperature (°C)	17.6	0.2	17.7	0.1	17.3	0.3	14.8	0.0	15.5	0.7	17.6	0.5	<0.05
pH	5.9	0.1	5.4	0.1	5.5	0.1	5.7	0.0	6.4	0.2	7.1	0.3	<0.0001
Electrical conductivity (1:5 mS m^{-1})	176.6	66.8	22.3	2.9	16.5	4.1	11.0	2.0	21.6	6.7	22.6	5.8	ns
Total N (%)	0.057	0.007	0.078	0.007	0.064	0.012	0.172	0.001	0.133	0.054	0.087	0.010	<0.05
Total P (mg kg^{-1})	39.6	5.8	63.7	5.4	54.0	5.7	98.0	2.0	100.4	28.3	163.6	40.9	<0.001
% sand	89.9	1.5	75.6	3.6	85.4	2.6	74.2	3.6	81.1	1.5	81.4	2.5	<0.01
% silt	4.9	1.0	10.9	2.1	6.6	0.9	9.2	1.7	6.1	1.1	8.9	1.4	<0.05
% clay	5.2	0.7	13.5	2.5	7.9	1.7	16.6	1.9	12.8	1.3	9.7	1.8	<0.05
Exchangeable Ca (me%)	0.84	0.15	1.35	0.19	1.58	0.28	5.33	0.30	3.04	0.59	5.27	1.00	<0.0001
Exchangeable Mg (me%)	1.76	0.33	1.75	0.38	1.30	0.39	4.12	0.00	5.37	1.63	2.74	0.48	<0.05
Exchangeable K (me%)	0.20	0.04	0.22	0.02	0.20	0.04	0.42	0.01	1.09	0.45	1.22	0.28	<0.001
Exchangeable Na (me%)	0.98	0.21	0.71	0.07	0.41	0.08	0.70	0.03	2.08	0.72	1.24	0.31	<0.05
No. quadrats — soil data available	20		18		13		2		7		7		
No. quadrats — total	21		18		13		2		7		8		

orchid species. Quadrats in this group are structurally variable ranging from woodland to herblands with few faithful taxa.

Group 6 occurs in lower rainfall regions outside the Jarrah Forest and is characterized by a series of taxa (often introduced) not present in claypans of the higher rainfall zone (Table 6) and appear to represent a transition to the more arid intermittently filled claypan types (M. Lyons, unpubl. data; Gibson *et al.* 2000b; Fig. 1). Quadrats in this group were generally woodlands dominated by *Casuarina obesa*, *Melaleuca strobophylla* or occasionally *Eucalyptus loxophleba*.

The most strongly correlated environmental parameters with the three dimensional ordination (stress level 0.21) were rainfall and exchangeable Ca, however mean annual temperature and most edaphic variables also showed significant correlations (Fig. 2). While not strongly correlated with the ordination, the means for percentage sand, silt and clay showed significant differences between quadrat groups (Table 5). In all claypans examined, clay content was found to increase with depth (Gibson, unpubl. data).

A plot of species richness of the 69 quadrats against mean annual rainfall annotated by claypan type shows the strong correlation between richness and rainfall (species richness = 9.0074+0.0441*rainfall; r^2 = 0.3535; $P < 0.0001$) and the predominance of basin claypans in the lower rainfall areas (Fig. 3). A two-way analysis of variance of species richness by rainfall and claypan type, showed a significant increase in species richness with rainfall class ($F_{2,63}$ = 6.64, $P < 0.01$), and significantly higher species richness in claypans on flats compared to basins ($F_{1,63}$ = 4.37, $P < 0.05$). There was no significant interaction between rainfall class and claypan type.

Beta-diversity was both high and highly variable (range 6.9 to 80.1) with a mean of 16.9 (sd = 11.5), indicating *ca.* 17 additional taxa were recorded for each additional quadrat sampled. This implies an average turnover in taxa between quadrats of *ca.* 40% (mean beta diversity/mean quadrat richness). When similarity in species composition between quadrats was examined as a function of distance, the trend showed moderate levels of similarity at close geographical distances, decreasing to *ca.* 0.1 at distances of more than 300 km (Fig. 4). There was however a large amount of variation in the data especially at very close distances. Similarity coefficients of between 0.07 and 0.77 were recorded at separation distances of <3.5 km, implying there was no simple relationship between species composition and the inter-quadrat distance.

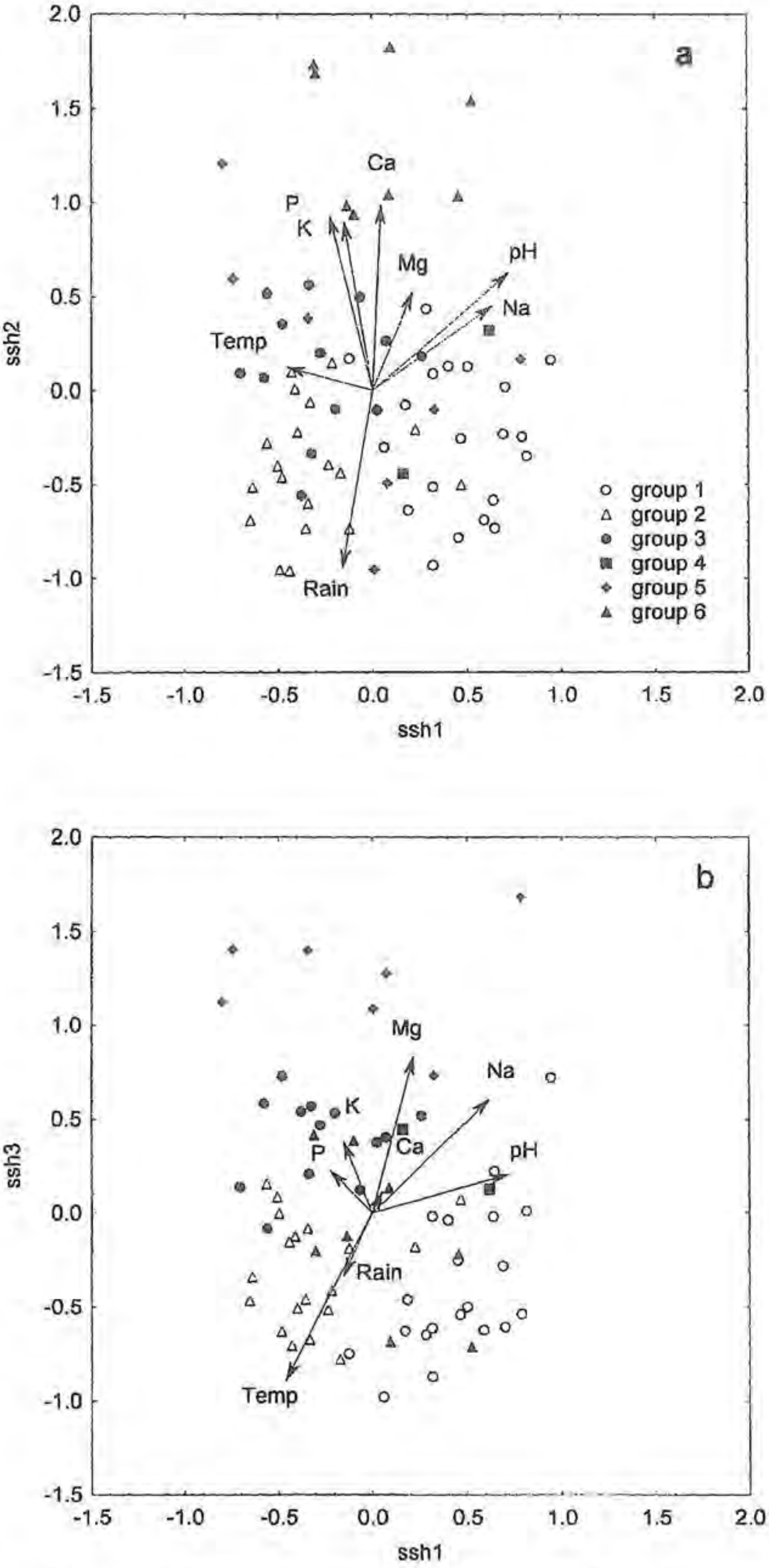


Fig. 2. Ordination of claypan quadrats coded by quadrat group. Arrows show the direction of the best fit linear correlations for the environmental parameters significant at P < 0.001. (a) Axis 1 vs 2. (b) Axis 1 vs 3.

Table 6. Diagnostic taxa of the six group classification of the claypans of the SWBP. Columns represent quadrat groups with INDVAL (%) shown for 6 group level following methods of Dufrene and Legendre (1997). Only taxa that were significant at $P < 0.05$ tested by Monte-Carlo simulation are included. Boxing indicates high INDVAL scores. The large number of indicator taxa identified in group 4 results, in part, from poor sampling of this quadrat group (represented by only 2 quadrats). Number of quadrats in each quadrat group indicated at the bottom of the table, * indicates an introduced taxon.

Taxon	1	2	3	4	5	6
Angianthus preissianus	28	1	1	0	0	0
Blennospora doliiformis	33	0	0	0	0	0
Samolus junceus	32	0	0	0	4	0
Triglochin calcitrapa	34	2	0	0	0	0
Pogonolepis stricta	33	0	1	0	0	2
Calandrinia granulifera	33	0	0	0	0	0
Drosera gigantea	26	2	1	0	0	0
Drosera menziesii	30	36	0	0	0	0
* *Briza maxima*	22	43	9	0	1	0
Centrolepis aristata	25	30	16	8	0	0
* *Briza minor*	16	24	3	27	1	7
* *Romulea rosea*	8	48	8	0	1	0
Cyathochaeta avenacea	0	44	0	0	3	0
Viminaria juncea	0	65	1	0	0	0
* *Parentucellia viscosa*	1	75	0	0	0	0
Borya scirpoidea	2	42	0	0	0	0
Hypocalymma angustifolium	1	47	0	0	0	0
Xanthorrhoea preissii	0	39	0	0	0	0
Kunzea micrantha	2	31	0	0	0	0
Kunzea recurva	1	29	0	0	0	0
Eutaxia virgata	0	35	1	0	0	0
Verticordia huegelii	0	33	0	0	0	0
Opercularia vaginata	0	44	0	0	0	0
* *Cicendia filiformis*	12	30	37	0	0	0
Eleocharis keigheryi	0	0	37	0	0	8
Myriocephalus appendiculatus	0	0	30	0	0	9
Hydrocotyle lemnoides	0	0	36	0	0	3
Glossostigma diandrum	1	0	50	0	2	1
Villarsia capitata	1	1	42	0	0	5
Lachnagrostis plebeia	0	2	34	0	0	0
Tribonanthes longipetala	3	1	55	0	2	0
Gratiola pubescens	0	0	20	53	0	1
Neurachne alopecuroidea	0	27	1	22	0	0
* *Cyperus tenellus*	3	30	7	34	0	2
Schoenus plumosus	11	4	0	50	0	3
Aphelia nutans	12	1	0	26	0	0
Tribonanthes australis	4	17	0	54	0	0
Hyalosperma cotula	0	14	3	56	0	0
Acacia lasiocarpa	0	1	0	45	0	0
Isolepis cernua	7	8	3	50	0	0
Schoenolaena juncea	5	5	1	47	4	0*
* *Anagallis arvensis*	4	1	1	54	0	3
Hydrocotyle callicarpa	4	0	0	73	0	0
Thysanotus manglesianus	7	5	0	62	0	0
Siloxerus multiflorus	2	2	2	66	0	0
Dichopogon preissii	2	1	2	69	0	0
Utricularia inaequalis	2	0	0	78	0	0
Drosera rosulata	4	3	0	62	1	0
Hypoxis occidentalis	1	3	3	63	0	0
* *Parentucellia latifolia*	3	3	0	31	0	0
Stylidium ecorne	4	3	2	25	0	0
Chamaescilla gibsonii	0	1	0	73	1	0
Eucalyptus wandoo	0	1	2	79	0	0
Schoenus capillifolius	0	1	2	72	0	1
Trichocline sp. (BJK& NG 564)	0	0	0	95	0	0
Ptilotus manglesii	0	1	0	45	0	0
Carex inversa	0	0	0	40	0	3
Stylidium guttatum	0	0	0	46	0	0
Wurmbea dioica	0	0	0	61	20	0
Eucalyptus occidentalis	0	0	0	87	2	0
Lagenophora huegelii	0	0	0	95	0	0
Tetraria capillaris	0	0	0	95	0	0
Dichopogon capillipes	0	1	0	41	0	0
Levenhookia pusilla	2	0	0	42	0	0
Pterostylis aff. *nana*	3	0	0	39	0	0

Table 6 — *continued*

Taxon	1	2	3	4	5	6
Drosera erythrorhiza	1	0	0	38	0	0
Stylidium emarginatum	0	1	0	41	0	0
Thysanotus tenellus	2	0	0	87	0	0
Trachymene pilosa	3	0	0	84	0	0
Schoenus bifidus	0	4	0	38	0	0
Craspedia variabilis	0	0	0	100	0	0
Eryngium pinnatifidum subsp. *minus* ms	0	0	0	100	0	0
Stylidium uniflorum	0	0	0	100	0	0
Microtis orbicularis	0	0	9	0	48	0
Prasophyllum gracile	0	0	1	0	33	0
* *Crassula natans*	0	0	16	0	2	29
* *Arctotheca calendula*	1	0	9	0	0	38
Centipeda crateriformis subsp. *crateriformis*	0	0	0	0	0	50
* *Erodium cicutarium*	0	0	0	0	0	38
* *Bromus rubens*	0	0	0	0	0	50
* *Crassula decumbens*	0	0	0	0	0	63
Melaleuca strobophylla	0	0	0	0	0	50
* *Trifolium arvense* var. *arvense*	0	0	0	0	0	38
* *Trifolium tomentosum*	0	0	0	0	0	63
* *Cotula bipinnata*	0	0	1	0	0	56
Isolepis congrua	0	0	1	0	0	43
Marsilea drummondii	0	0	1	0	3	35
Crassula colorata	0	0	0	0	0	46
Number of quadrats	21	18	13	2	7	8

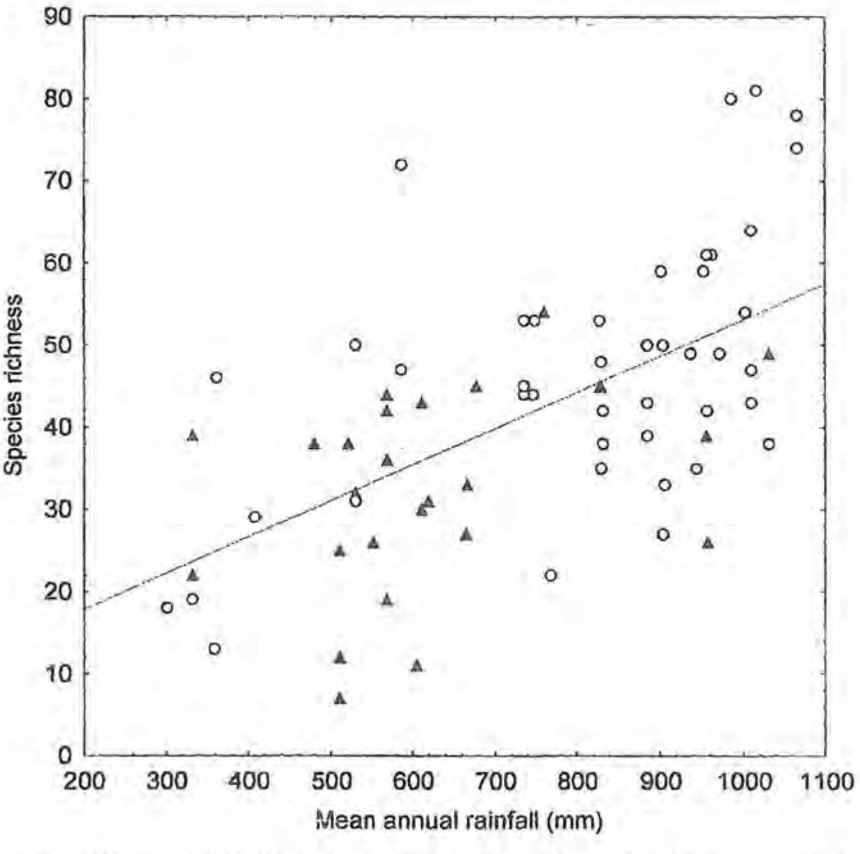


Fig. 3. Linear plot of relationship between mean annual rainfall with species richness of 69 quadrats annotated by claypan type (open circle, inundated flats; closed triangle, basin claypans).

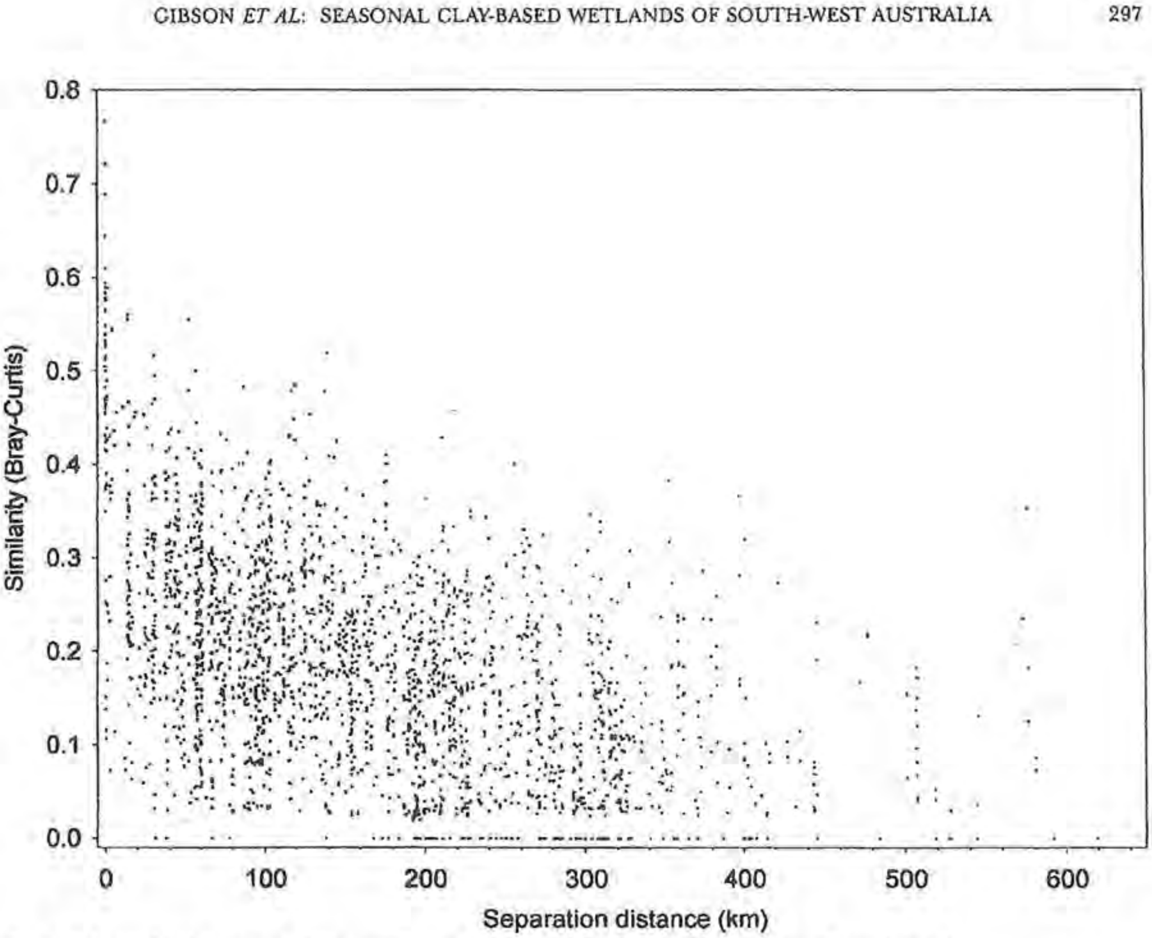


Fig. 4. Relationship between similarity coefficient (Bray-Curtis) and distance separating all quadrat pairs.

DISCUSSION

Distribution and geomorphology

Two geomorphological types of claypans were encountered (inundated flat claypans and basin claypans). Neither type was restricted to either the old Tertiary Plateau or the younger Swan Coastal Plain (early Pleistocene, McArthur and Bettenay 1960). Claypans on inundated flats are more common on the Swan Coastal Plain where floodplains are common. The dominance of basin claypans in lower rainfall areas (<750 mm) reflects the lack of broad floodplains in these areas (Fig. 1). Where rainfall fell below 400 mm the seasonal claypans are largely replaced by other intermittently flooded claypan types (Gibson *et al.* 2000b; Lyons *et al.* 2004).

The lack of claypans on the Geraldton and Esperance Sandplains bioregions (Fig. 1) is explained by the lack of suitable substrates in these areas. Similarly the massive laterite cap rock, which is the major landform in the Jarrah Forest, offers few sites for claypan development. However, in the low lying areas in the Warren bioregion where rainfall exceeds 1 200 mm, extensive areas of perennial sedgelands and wet heath communities commonly occur on clay substrates. No claypans have been found in this region and it is possible that the summer drought period is too short to allow for the development of claypans.

Some of the claypans on the Swan Coastal Plain showed further pediological development of duripan at shallow depths. These duripans can occasionally develop into massive ferricretes where the claypan communities are replaced by shrub rich communities with high levels of endemism (Gibson *et al.* 2000a).

Flora and vegetation

The flora of claypans in south-west Australia is both rich and highly variable and appears to have been recruited from a widespread cosmopolitan wetland element (*Isoetes, Myriophyllum, Cotula, Eryngium* and others), a generally southern Australian seasonal wetland element (*Schoenus, Isolepis, Melaleuca*), and largely south-west Australian seasonal wetland element (*Stylidium, Tribonanthes, Drosera, Centrolepis*). Added to this, many typical upland taxa occur in the claypans.

The cursory nature of our knowledge of claypans in the SWBP is highlighted by the fact that seven of 36 claypan specialists are still awaiting formal descriptions, a further five have only been described in the last six years, two were believed to be extinct until recent recollections (Keighery and Keighery 1996), and one taxa has not been collected since its discovery 20 years ago. Four of these 36 taxa are formally listed as threatened under State and Federal legislation and a further 18 are currently being considered for listing (K. Atkins, pers. comm. 2004, Principal Botanist, Department of Conservation and Land Management).

Within the 69 quadrats sampled, the higher species richness of the flats compared with the basin claypans is likely to result from a shorter period of inundation and hence an earlier and potentially longer wet terrestrial phase. Neither pool depth nor period of inundation has been quantified but both claypan types are typically completely dry by mid-summer. The possible reasons for higher species richness in the higher rainfall areas have not been investigated but may reflect differences in physiological tolerance of taxa along the climatic gradient (with fewer taxa being able to contend with short and/or less frequent periods of inundation), or differences in resources (total P is negatively correlated with rainfall).

Vegetation patterning showed strong correlation with both climatic and edaphic factors, however the analysis of both beta-diversity, and the plots of the similarity coefficient of quadrats pairs against geographic separation (Fig. 4) showed the pattern of high variability in species composition at all geographic scales. The source of this variability is unclear but is a common feature of seasonal wetlands of all types on the coastal plain (Gibson *et al.* 1994). Possible causal factors include the highly fragmented nature of seasonal wetlands that may result in highly stochastic recruitment of the individual wetland floras. Seasonal fluctuations in water levels or period of inundation may also play a significant role.

Comparisons with other Mediterranean regions

The outstanding differences between the claypans of the SWBP and the vernal pools of California are:

- the much richer claypan flora recorded in the SWBP (281 wetland taxa and 328 upland taxa) compared with the California vernal pool flora (169 taxa, Holland and Jain 1977)
- the very high species richness of the claypans of the high rainfall areas (up to 81 taxa in 100 m^2 quadrat) of the SWBP compared with 15–25 taxa per pool in California
- the lower number of claypan specialists identified in the SWBP (36 taxa) compared to *ca.* 100 vernal pool specialists that have been recorded in California, and
- the higher proportion of geophytes (28.6% v 3%) and the lower proportion of annual taxa (51.4% v >70%) and perennial herbaceous taxa (5.7% v 17%) recorded in the claypan specialists of the SWBP compared to the vernal pool specialists of California (Table 7).

The Mediterranean climates of south-west Australia and California are believed to date from the Pliocene (Stone 1990; Dodson and Kershaw 1994) although large climatic oscillations swept across both landscapes during the Quaternary. The altitudinal range and annual rainfall experienced by the claypans in the SWBP are a subset of those reported for the vernal pools of California, so it is unlikely that the floristic dissimilarities could be related to differences in seasonality or in the period of inundation. Zedler and Black (2004) recently documented the invasion of vernal pools in California by an amphibious annual grass native to southern Australia and common in the claypans of the SWBP, suggesting similar growing conditions are found in both regions.

Table 7. Comparison of a lifeforms between the vernal pool specialists of California (data from Holland and Jain 1977), the claypan specialists SWBP (data from survey and herbarium records), and the typical wetland taxa recorded in claypans of the SWBP.

Lifeform	% vernal pool specialists California (n = 101)	% claypan specialists SWBP (n = 36)	% wetland taxa of the claypans SWBP (n = 281)
Native annuals	>70	51.4	40.2
Introduced annuals	<7	–	6.0
Fern and fern allies	3	5.7	3.2
Native perennial herbs	17	5.7	16.4
Introduced perennial herbs	2	–	0.7
Native geophytes	3	28.6	20.3
Introduced geophytes	–	–	0.7
Native shrubs	–	8.6	10.3
Native trees	–	–	1.8

The major differences between the vernal pools of California and the claypans of south-west Australia are probably related to the regional floras and vegetation types from which these wetland floras were recruited. South-west Australia lacks the grasslands common in California which are largely coincident with the vernal pools of the Central Valley (Heady 1977; Holland and Jain 1977). The SWBP was instead covered by a complex mosaic of woodlands, shrublands and wetlands (Beard 1990). This is likely to explain the richer flora seen in the claypans of the SWBP. Elements that are limited in the Californian vernal pool specialists such as geophytes, shrubs, trees, annual sedges, and perennial restiads are common in the widespread wetlands of the SWBP and have been recruited into the flora of the claypans (Table 7). This diversity of lifeforms and hence diversity in resource requirements and utilization patterns could allow the much higher species packing (up to three times) than seen in Californian pools. The much lower proportion of claypan specialists in the SWBP also probably reflects the much more widespread distribution of other seasonal wetland types across the South West compared with California. It is not clear why the vernal pool flora of the coastal terraces of southern and baja California are not richer in other lifeforms since these are associated with more diverse vegetation types (Zedler 1987) than those of the Central Valley.

Comparative data from Chile are as yet scant but it is noted that extensive grasslands are also lacking in Mediterranean Chile and that the latitudinal and altitudinal extent of vernal pools would imply that the vernal pool flora of this area has been recruited from wide variety of vegetation types. How widespread other types of seasonal wetlands are in this part of Chile is not known.

Conservation status

Sadly the most consistent feature of the vernal pools of California, Chile, South Africa and the south-west Australia is the massive clearance of these ecosystems, primarily for agriculture. It is estimated that *ca.* 90% of the vernal pools of California have been destroyed since the 1800s (Holland 1978 quoted in Keeley and Zedler 1998). Recent work from Chile (Bliss *et al.* 1998) indicates little pristine habitat is left. South African vernal pools are largely unstudied, but Stephens (1929) warned that the clay-based seasonal wetlands in the Cape Town area were already rapidly disappearing in the 1920s.

The distribution of the claypans of the SWBP is coincident with the most heavily cleared areas of the south-west Australia. It is estimated that <10% of the original distribution of these claypans remain on the coastal plain. The situation is likely to be similar throughout the heavily cleared landscapes of the Avon Wheatbelt and parts of the Jarrah Forest bioregions.

The Western Australian Government maintains a list of threatened communities but as yet this listing has no legislative requirement for protection. The two claypan communities from the coastal plain (types 1 and 2) are currently listed as Vulnerable and available data suggests that only *ca.* 240 ha of these communities remain in less than 40 locations. None of the inland claypan communities are currently listed, nor are accurate area figures available. Community types 3 and 4 are likely to meet criteria for listing. Community 5 needs further study but may represent depauperate examples of community type 3, perhaps in response to deeper or longer inundation, while community type 6 appears transitional in nature. Most of the claypans in the SWBP occur in conservation reserves but these reserves tend to be small and highly fragmented in a matrix of agricultural or urban lands. None of the claypan communities are yet listed under Federal legislation.

In addition to the widespread clearance of the past, many of the remaining claypans are threatened in the short term by weed invasion, and in the medium term by inundation from rising saline groundwater due to the widespread clearance of the native perennial vegetation and its replacement with annual cropping regimes.

Brown and Brooks (2003a,b) detail the invasion and control of *Sparaxis bulbifera* and *Tribolium uniolae* in one of the most significant claypan remaining in the Perth metropllitan area. Plots in this claypan were classified as community type 2 which is listed as Vulnerable on the Western Australian threatened communities list. There is an urgent need for this type of active management in many of the claypans since their small and highly fragmented nature makes them highly susceptible to weed invasion.

In the medium term an even more serious threat to these communities is rising saline groundwater that pays no heed to tenure boundaries (George *et al.* 1995). When salinity risk maps are overlain with remnant vegetation mapping it is clear that almost all of the known claypans occur on susceptible land systems (NLWRA 2001). Protection of these land systems may require replanting of 30–70% of the cleared lands across the landscape and involve lag periods of up to 30 years (NLWRA 2001). Ground water management plans and resources will be needed to mitigate this threat.

These ecosystems represent a significant repository of biodiversity in all the Mediterranean regions studied and warrant protection. Such actions will not be simple to implement, and in southwestern Australia, may prove to be particularly intractable given the forecasts for saline groundwater impacts over the next 20 years (NLWRA 2001).

ACKNOWLEDGEMENTS

The Chemistry Centre (Western Australia) carried out the soil analyses. Three anonymous referees are thanked for their detailed comments on an earlier draft of the manuscript. Funding was provided by the Australian Heritage Commission and the Western Australian Department of Conservation and Land Management.

REFERENCES

Beard, J. S., 1981. Vegetation Survey of Western Australia: Swan 1:1 000 000 Series. University of Western Australia Press, Nedlands.

Beard, J. S., 1990. Plant Life of Western Australia. Kangaroo Press, Kenthurst, New South Wales.

Belbin, L., 1995. PATN Technical Reference. CSIRO Division of Wildlife and Ecology, Canberra.

Benson, J. S. and Jacobs, S. W. L., 1994. Plant communities of the Monaro lakes. *Cunninghamia* **3**: 651–76.

Bliss, S. A., Zedler, P. H., Keeley, J. E. and Arroyo, M. T. K., 1998. A floristic survey of the temporary wetlands in the mediterranean-climate region of Chile. Pp. 219–28 *in* Wetlands for the Future. Contributions from INTECOL's V International Wetlands Conference ed by A. J. McComb and J. A. Davis. Gleneagles Publishing, Glen Osmond.

Brock, M. A. and Casanova, M. T., 1997. Plant life at the edge of wetlands: ecological responses to wetting and drying patterns. Pp. 181–92 *in* Frontiers in Ecology: Building the Links ed by N. Klomp and I. Lunt. Elsevier Science, Oxford.

Brown, K. and Brooks, K., 2003a. Controlling *Sparaxis bulbifera* (L.) Ker Gawl. Invading a clay based wetland. *Plant Prot. Quart.* **18**: 26–30.

Brown, K. and Brooks, K., 2003b. Management of the South African grass *Tribolium uniolae* (L.f.) Renvoize invading threatened plant communities in the Brixton Street Wetlands. *Plant Protec. Quart.* **18**: 99–101.

Busby, J. R., 1986. A bioclimatic analysis of *Nothofagus cunninghamii* (Hook.) Oerst. in south eastern Australia. *Aust. J. Ecol.* **11**: 1–7.

Campbell, B., Grubb, A. and Moll, E., 1980. The vegetation of the Edith Stephens Cape Flats Flora Reserve. *J. Sth. Afr. Bot.* **46**: 435–44.

Davis, J. A. and Froend, R., 1999. Loss and degradation of wetlands in southwestern Australia: underlying causes, consequences and solutions. *Wetl. Ecol. Man.* **7**: 13–23.

Diels, L., 1906. Die Pflanzenwelt von West Australien südlich des Wendekreises. Vegetation der Erde VII. Leipzig.

Dodson, J. R. and Kershaw, A. P., 1994. Evolution and history of Mediterranean vegetation types in Australia. Pp. 21–40 *in* Ecology and Biogeography of Mediterranean Ecosystems in Chile, California and Australia ed by M. T. K. Arroyo, P. H. Zedler and M. D. Fox. Springer-Verlag, New York.

Dufrene, M. and Legendre, P., 1997. Species assemblages and indicator species: The need for a flexible asymmetrical approach. *Ecol. Mono.* **67**: 345–66.

Froend, R. H., Farrell, R. C. C., Wilkins, C. F., Wilson, C. C. and McComb, A. J., 1993. Wetlands of the Swan Coastal Plain. Volume 4. The effects of altered water regimes on wetland plants. Water Authority of Western Australia and EPA, Perth.

George, R. J., McFarlane, D. J. and Speed, R. J., 1995. The consequences of a changing hydrologic environment for native vegetation in Western Australia. Pp. 9–22 *in* Nature Conservation 4: The Role of Networks ed by D. A. Saunders, J. L. Craig and E. M. Mattiske. Surrey Beatty & Sons, Chipping Norton.

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 to Heritage Council of Western Australia and Australian Heritage Commission. Department of Conservation and Land Management, Western Australia.

Gibson, N., Keighery, G. J. and Keighery, B. J., 2000a. Threatened plant communities of Western Australia. 1. The ironstone communities of the Swan and Scott Coastal Plains. *J. Roy. Soc. WA.* **83**: 1–12.

Gibson, N., Keighery, G. J. and Lyons, M. N., 2000b. The flora and vegetation of the seasonal perennial wetlands of the southern Carnarvon Basin, Western Australia. *Rec. WA. Mus.* **61**: 175–216.

Halse, S. A., 1989. Wetlands of the Swan Coastal Plain — past and present. Pp. 105–12 *in* Proceedings of the Swan Coastal Plain groundwater management conference ed by E. Lowe. WA Water Resources Council, Perth.

Heady, H. F., 1977. Valley Grassland Pp. 491–514 *in* Terrestrial Vegetation of California ed by M. G. Barbour and J. Major. John Wiley and Sons, New York.

Hill, A. L., Semeniuk, C. A., Semeniuk, V. and Del Marco, A., 1996. Wetlands of the Swan Coastal Plain. (Volume 2A) Wetland mapping, classification and evaluation. Waters and Rivers Commission and Department of Environmental Protection, Perth.

Holland, R. F., 1978. The geomorphic and edaphic distribution of vernal pools in the great Central Valley, California. California Native Plant Society, Special Publication No. 4, Sacramento, CA.

Holland, R. F. and Dains, V. I., 1990. The edaphic factor in vernal pool vegetation. Pp. 31–48 *in* Vernal Pool Plants — Their Habitat and Biology ed by D. H. Ikeda and R. A. Schlising. Studies from the Herbarium, Number 8, California State University, Chico, CA.

Holland, R. and Jain, S., 1977. Vernal pools. Pp. 515–33 *in* Terrestrial Vegetation of California ed by M. G. Barbour and J. Major. John Wiley and Sons, New York.

Holland, R. F. and Jain, S. K., 1981. Insular biogeography of vernal pools in the Central Valley of California. *Amer. Nat.* **117**: 24–37.

Hopper, S. D., 1992. Patterns of plant diversity at the population and species levels in south-west Australian mediterranean ecosystems Pp. 27–46 *in* Biodiversity of Mediterranean Ecosystems in Australia ed by R. J. Hobbs. Surrey Beatty & Sons, Chipping Norton.

Jacobs, S. W. L. and Brock, M. A., 1993. Wetlands of Australia: Southern (temperate) Australia. Pp. 244–304 *in* Wetlands of the World I: Inventory, ecology and management ed by D. F. Whigham, D. Dykyjova and S. Hejny. Kluwer Academic Publishers, The Netherlands.

Keeley, J. E. and Zedler, P. H., 1998. Characterization and global distribution of vernal pools. Pp. 1–14 *in* Ecology, Conservation and Management of Vernal Pool Ecosystems ed by C. W. Witham, E. T. Bauder, D. Belk, W. R. Ferren Jr. and R. Ornduff. Proceedings from the 1996 Conference. California Native Plant Society, Sacramento, CA.

Keighery, G. J., 1995. How many weeds? An annotated list of the naturalised vascular plants of Western Australia. Pp. 71–101 *in* Invasive Weeds and Regenerating Ecosystems in Western Australia: Proceedings of the Conference held at Murdoch University, July 1994 ed by G. Burke. Institute for Science and Technology Policy, Murdoch University, Perth.

Keighery, G., Halse, S. and McKenzie, N., 2002. Why wheatbelt valleys are valuable and vulnerable: the ecology of wheatbelt valleys and threats to their survival. Pp. 55–65 *in* Dealing With Salinity in Wheatbelt Valleys: Processes, Prospects and Practical Options: Papers, Proceedings and Outcomes of the Field Tour/Conference/Workshop, July 30–August 01, 2001, Merredin, Western Australia. Water and Rivers Commission, Perth.

Keighery, G. J. and Keighery, B. J., 1996. Re-discovery of *Schoenus natans* (Cyperaceae). *WA. Nat.* 21: 65–67.

Lin, J., 1970. The Floristics and Plant Succession in Vernal Pool Vegetation. M. A. thesis, San Francisco State College, San Francisco, CA.

Lyons, M. N., Gibson, N., Keighery, G. J. and Lyons, S. D., 2004. Wetland flora and vegetation of the Western Australian wheatbelt. *Rec. WA. Mus. Supp.* 67: 33–83.

McArthur, W. M., 1991. Reference Soils of South-western Australia. Department of Agriculture, Perth.

McCune, B. and Mefford, M. J., 1999. PC-ORD. Multivariate Analysis of Ecological Data, Version 4. MjM Software Design, Gleneden Beach, Oregon, USA.

National Land and Water Resources Audit, 2001. Australian Dryland Salinity Assessment 2000. Extent, impacts, processes, monitoring and management options. NLWRA, Canberra.

Paczkowska, G. and Chapman, A. R., 2000. The Western Australian Flora. A Descriptive Catalogue. The Wildflower Society of Western Australia Inc., Western Australian Herbarium, and Botanic Gardens and Parks Authority, Perth.

Parsons, R. F. and Hopper, S. D., 2003. Monocotyledonous geophytes: comparison of south-western Australia with other areas of mediterranean climate. *Aust. J. Bot.* 51: 129–33.

Purer, E. A., 1939. Ecological study of vernal pools, San Diego County. *Ecology* 20: 217–29.

Rigget, T. L., 1969. A Study of the Wetlands of the Swan Coastal Plain. Western Australian Department of Fisheries and Fauna, Perth.

Sawyer, J. and Keeler-Wolf, T., 1995. A Manual of California Vegetation. California Native Plant Society, Sacramento, CA.

Shepherd, D. P., Beeston, G. R. and Hopkins, A. J. M., 2001. Native Vegetation in Western Australia: Extent, Type and Status. *Dep. Agricul. Res. Man. Tech. Rep.* 249.

Sneath, P. H. A. and Sokal, R. R., 1973. Numerical Taxonomy. The Principals and Practice of Numerical Classification. W. H. Freeman, San Francisco.

StatSoft, Inc., 2001. STATISTICA (data analysis software system), version 6. (www.statsoft.com).

Stephens, E. L., 1929. Fresh water aquatic vegetation of the south-west districts. Pp. 81–95 *in* The Botanical Features of the South Western Cape Province. The Specialty Press of South Africa Ltd., Cape Town.

Stone, R. D., 1990. California's endemic vernal pool plants: Some factors influencing their rarity and endangerment. Pp. 89–108 *in* Vernal Pool Plants. Their Habitat And Biology ed by D. H. Ikeda and R. A. Schlising. Studies from the Herbarium, Number 8, California State University, Chico, CA.

Thackway, R. and Creswell, I. D., 1995. An Interim Biogeographic Regionalisation For Australia: A Framework For Setting Priorities In The National Reserves System Cooperative Program. Version 4.0. Australian Nature Conservation Agency, Canberra.

Thorne, R. F., 1984. Are California's Vernal Pools Unique? Pp. 1–8 *in* Vernal Pools and Intermittent Streams ed by S. Jain and P. Moyle. Institute of Ecology, University of California, Davis, CA.

Wardell-Johnson, G. and Williams, M., 1996. A floristic survey of the Tingle mosaic, south-western Australia: applications in land use planning and management. *J. Roy. Soc. WA.* 79: 241–76.

Withers, P. C., 2000. Overview of granite outcrops in Western Australia. *J. Roy. Soc. WA.* 83: 103–08.

Zedler, P. H., 1987. The ecology of southern California vernal pools: A community profile. *U.S. Fish Wildl. Service Biol. Rep.* 85(7.11): 1–136.

Zedler, P. H., 1990. Life histories of vernal pool vascular plants. Pp. 123–46 *in* Vernal Pool Plants. Their Habitat and Biology ed by D. H. Ikeda and R. A. Schlising. Studies from the Herbarium, Number 8, California State University, Chico, CA.

Zedler, P. H. and Black, C., 2004. Exotic plant invasions in an endemic-rich habitat: The spread of an introduced Australian grass, *Agrostis avenacea* J. F. Gmel., in California vernal pools. *Austral Ecol.* 29: 537–46.

For more information about the EPBC Act and the responsibilities of landowners and managers in relation to TECs, contact the Commonwealth Department of the Environment, Water, Heritage, and the Arts on (02) 6274 1111 or visit **www.environment.gov.au/biodiversity/threatened.**

Possible impacts to threatened ecological communities are taken into account by State assessment bodies when applications to develop or clear land are evaluated during land use planning and environmental impact assessment processes. TECs are also indirectly protected under Western Australian legislation through the *Environmental Protection Act 1986* and Environmental Protection (Clearing of Native Vegetation) Regulations 2004. Under the Environmental Protection Act, any clearing of native vegetation requires a permit, unless done for an exempt purpose. A number of exemptions for day-to-day management purposes are prescribed under the Regulations, but these exemptions do not apply in environmentally sensitive areas. TECs have been defined under the regulations as environmentally sensitive areas so the exemptions from requiring a clearing permit do not apply in these areas. Any such clearing proposals must therefore be undertaken under a specific permit and be assessed for any environmental impact. Under the Act, the assessment of the impact of an application to clear native vegetation must take into account a number of clearing principles, one of which is the impact on TECs.

Anyone considering the possibility of clearing within a threatened ecological community should contact DEC's Native Vegetation Protection section on 1800 061 025 or visit the 'land' section of **www.dec.wa.gov.au** for more information on permit requirements.

Conservation categories for threatened ecological communities

Critically Endangered (CR)

Subject to major contraction in area or was already of limited distribution, and is in danger of severe modification or destruction in the immediate future.

Endangered (EN)

Subject to major contraction in area or was already of limited distribution, and is in danger of significant modification or destruction in the near future.

Vulnerable (VU)

Declining or declined in distribution and/or condition and whose ultimate security has not been secured or still widespread but will become CR, EN or PD in the near future if threatening processes continue or begin to operate.

Presumed Destroyed (PD)

No examples are left or has been extensively modified such that it is unlikely to recover in the foreseeable future.

Priority Ecological Communities

Possible threatened ecological communities that do not meet the stringent survey criteria for the assessment of TECs are added to DEC's Priority Ecological Community Lists under Priorities 1, 2 and 3. Ecological Communities that are adequately known, are rare but not considered to be threatened, or meet criteria for Near Threatened, or that have been recently removed from the threatened list, are placed in Priority 4. These ecological communities require regular monitoring. Conservation Dependent ecological communities are placed in Priority 5.

More information

The Department of Environment and Conservation's (DEC's) Species and Communities Branch within the Nature Conservation Division is responsible for coordinating threatened species and ecological community conservation.

For more information, including advice about managing a TEC, or to obtain or provide other information on TECs or possible TECs, contact the TEC Database Coordinator on (08) 9334 0116.

Information on TECs and examples of recovery plans are available at **www.naturebase.net/plantsandanimals.**

This information is accurate at March 2008.

Conserving threatened ecological communities

ACT NOW FOR THE FUTURE

Department of Environment and Conservation

Our environment, our future

About threatened ecological communities

The Department of Environment and Conservation (DEC) is responsible for conserving Western Australia's biological diversity. This responsibility includes identifying elements of biodiversity that are under threat of extinction and seeking to ensure that they do not become extinct. In the past this has mainly involved plant and animal species but now DEC has developed a process for identifying and conserving threatened ecological communities.

What is a threatened ecological community?

An 'ecological community' is a naturally occurring biological assemblage or group of plants and/or animals (or other living things such as microbes) that occurs in a particular type of habitat. Together with their habitat, ecological communities form ecosystems.

A threatened ecological community (TEC) is one that has been endorsed by Western Australia's Environment Minister as being subject to processes that threaten to destroy or significantly modify it across much of its range. It must also fit into one of the categories 'presumed totally destroyed', 'critically endangered', 'endangered' or 'vulnerable'. TECs may be at risk from threatening processes including land clearing, inappropriate fire regimes, inappropriate grazing, trampling, pollution, competition or predation from introduced animals, weed invasion, hydrological changes, salinity and diseases. Most TECs are either naturally restricted in distribution, or were once widespread but now occur only as remnants in cleared landscapes. However, a widespread ecological community may be listed as a TEC if information indicates that significant and widespread threats are active across its range. To be eligible for assessment as a TEC, an ecological community must be described so that all variations of it clearly fit the description and it is clear that it is distinct from all other communities. The distribution of the community must be known and it must have been searched for adequately to be confident that no significant areas of it remain undiscovered.

CONSERVING THREATENED ECOLOGICAL COMMUNITIES

Proposed TECs are referred to the WA Threatened Ecological Communities Scientific Committee (WATECSC) for assessment. WATECSC is comprised of experts in the field of ecological community identification and conservation and includes representatives from DEC, tertiary institutions, the Western Australian Museum and other organisations and individuals. If WATECSC is satisfied that an ecological community is appropriately described, has been adequately surveyed and meets the criteria for listing as threatened, a recommendation for it to be listed as a TEC will be made through the DEC to the Environment Minister.

To date, listed TECs have primarily been identified through three types of information – regional surveys; expert knowledge in specific areas (primarily caves and microbial assemblages); and local surveys that have been verified in a regional context.

Conserving threatened ecological communities

DEC approaches the conservation and management of TECs in cooperation with other landowners and managers. Many recovery actions are implemented with the involvement of recovery teams, catchment or Natural Resource Management groups, wildlife enthusiasts, school groups and the owners and managers of land on which the TECs occur.

DEC develops TEC recovery plans to detail actions that will be taken to ensure the long-term conservation of the communities. Where TECs occur on land that is privately owned or managed by other agencies, DEC seeks the support of these bodies or individuals and develops the plan in consultation with them. The plans require that DEC must obtain agreement from the appropriate landowners and managers before recovery actions are undertaken on their land. This may include seeking resources for research and on-ground works.

Recovery teams advise, develop and oversee implementation of recovery plans for TECs. Recovery team members include DEC district staff, Species and Communities Branch staff and relevant representatives from other State Government agencies, local government authorities and catchment councils, including landowners, and members of non-government conservation groups.

Funding assistance for landowners and land managers may be available through the plans for conservation projects on TECs such as flora monitoring surveys, fencing, weed control or other necessary management. Potential funding sources include various State Government or non-government organisation programs or programs run through regional Natural Resource Management groups including under the Commonwealth's Natural Heritage Trust or equivalent.

Legislation

There is currently no Western Australian legislation that deals specifically with TECs. However, TECs that occur in Western Australia may be listed as nationally threatened under the Commonwealth Government's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Any person or organisation may nominate communities for listing. A number of State-listed TECs have been referred to the Commonwealth Government and have been listed under the EPBC Act following review at that level. There is a legal requirement that land managers who wish to undertake actions that are likely to damage communities that are listed under the EPBC Act refer the proposal to the Commonwealth Environment Minister.

Department of Environment and Conservation
2007

DEFINITIONS, CATEGORIES AND CRITERIA FOR THREATENED AND PRIORITY ECOLOGICAL COMMUNITIES

1. GENERAL DEFINITIONS

Ecological Community
A naturally occurring biological assemblage that occurs in a particular type of habitat.

Note: The scale at which ecological communities are defined will often depend on the level of detail in the information source, therefore no particular scale is specified.

A **threatened ecological community** (TEC) is one which is found to fit into one of the following categories; "presumed totally destroyed", "critically endangered", "endangered" or "vulnerable".

Possible threatened ecological communities that do not meet survey criteria are added to DEC's Priority Ecological Community Lists under Priorities 1, 2 and 3. Ecological Communities that are adequately known, are rare but not threatened, or meet criteria for Near Threatened, or that have been recently removed from the threatened list, are placed in Priority 4. These ecological communities require regular monitoring. Conservation Dependent ecological communities are placed in Priority 5.

An **assemblage** is a defined group of biological entities.

Habitat is defined as the areas in which an organism and/or assemblage of organisms lives. It includes the abiotic factors (eg. substrate and topography), and the biotic factors.

Occurrence: a discrete example of an ecological community, separated from other examples of the same community by more than 20 metres of a different ecological community, an artificial surface or a totally destroyed community.

By ensuring that every discrete occurrence is recognised and recorded future changes in status can be readily monitored.

Adequately Surveyed is defined as follows:
"An ecological community that has been searched for thoroughly in most likely habitats, by relevant experts."

Community structure is defined as follows:
"The spatial organisation, construction and arrangement of the biological elements comprising a biological assemblage" (eg. *Eucalyptus salmonophloia* woodland over scattered small shrubs over dense herbs; structure in a faunal assemblage could refer to trophic structure, eg. dominance by feeders on detritus as distinct from feeders on live plants).

Definitions of Modification and Destruction of an ecological community:

Modification: "changes to some or all of ecological processes (including abiotic processes such as hydrology), species composition and community structure as a direct or indirect result of human activities. The level of damage involved could be ameliorated naturally or by human intervention."

Destruction: "modification such that reestablishment of ecological processes, species composition and community structure within the range of variability exhibited by the original community is unlikely within the foreseeable future even with positive human intervention."

Note: Modification and destruction are difficult concepts to quantify, and their application will be determined by scientific judgement. Examples of modification and total destruction are cited below:

Modification of ecological processes: The hydrology of Toolibin Lake has been altered by clearing of the catchment such that death of some of the original flora has occurred due to dependence on fresh water. The system may be bought back to a semblance of the original state by redirecting saline runoff and pumping waters of the rising underground watertable away to restore the hydrological balance. Total destruction of downstream lakes has occurred due to hydrology being altered to the point that few of the original flora or fauna species are able to tolerate the level of salinity and/or water logging.

Modification of structure: The understorey of a plant community may be altered by weed invasion due to nutrient enrichment by addition of fertiliser. Should the additional nutrients be removed from the system the balance may be restored, and the original plant species better able to compete. Total destruction may occur if additional nutrients continue to be added to the system causing the understorey to be completely replaced by weed species, and death of overstorey species due to inability to tolerate high nutrient levels.

Modification of species composition: Pollution may cause alteration of the invertebrate species present in a freshwater lake. Removal of pollutants may allow the return of the original inhabitant species. Addition of residual highly toxic substances may cause permanent changes to water quality, and total destruction of the community.

Threatening processes are defined as follows:
"Any process or activity that threatens to destroy or significantly modify the ecological community and/or affect the continuing evolutionary processes within any ecological community."

Examples of some of the continuing threatening processes in Western Australia include: general pollution; competition, predation and change induced in ecological communities as a result of introduced animals; competition and displacement of native plants by introduced species; hydrological changes; inappropriate fire regimes; diseases resulting from introduced microorganisms; direct human exploitation and disturbance of ecological communities.

Restoration is defined as returning an ecological community to its pre-disturbance or natural state in terms of abiotic conditions, community structure and species composition.

Rehabilitation is defined as the re-establishment of ecological attributes in a damaged ecological community although the community will remain modified.

2. DEFINITIONS AND CRITERIA FOR PRESUMED TOTALLY DESTROYED, CRITICALLY ENDANGERED, ENDANGERED AND VULNERABLE ECOLOGICAL COMMUNITIES

Presumed Totally Destroyed (PD)
An ecological community that has been adequately searched for but for which no representative occurrences have been located. The community has been found to be totally destroyed or so extensively modified throughout its range that no occurrence of it is likely to recover its species composition and/or structure in the foreseeable future.

An ecological community will be listed as presumed totally destroyed if there are no recent records of the community being extant **and either** of the following applies (A or B):

A) Records within the last 50 years have not been confirmed despite thorough searches of known or likely habitats **or**

B) All occurrences recorded within the last 50 years have since been destroyed

Critically Endangered (CR)
An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or that was originally of limited distribution and is facing severe modification or destruction throughout its range in the immediate future, or is already severely degraded throughout its range but capable of being substantially restored or rehabilitated.

An ecological community will be listed as **Critically Endangered** when it has been adequately surveyed and is found to be facing an extremely high risk of total destruction in the immediate future. This will be determined on the basis of the best available information, by it meeting **any one or more of** the following criteria (A, B or C):

A) The estimated geographic range, and/or total area occupied, and/or number of discrete occurrences since European settlement have been reduced by at least 90% **and either or both** of the following apply (i or ii):

i) geographic range, and/or total area occupied and/or number of discrete occurrences are continuing to decline such that total destruction of the community is imminent (within approximately 10 years);

ii) modification throughout its range is continuing such that in the immediate future (within approximately 10 years) the community is unlikely to be capable of being substantially rehabilitated.

B) Current distribution is limited, **and one or more** of the following apply (i, ii or iii):

i) geographic range and/or number of discrete occurrences, and/or area occupied is highly restricted and the community is currently subject to known threatening processes which are likely to result in total destruction throughout its range in the immediate future (within approximately 10 years);

ii) there are very few occurrences, each of which is small and/or isolated and extremely vulnerable to known threatening processes;

iii) there may be many occurrences but total area is very small and each occurrence is small and/or isolated and extremely vulnerable to known threatening processes.

C) The ecological community exists only as highly modified occurrences that may be capable of being rehabilitated if such work begins in the immediate future (within approximately 10 years).

Endangered (EN)
An ecological community that has been adequately surveyed and found to have been subject to a major contraction in area and/or was originally of limited distribution and is in danger of significant modification throughout its range or severe modification or destruction over most of its range in the near future.

An ecological community will be listed as **Endangered** when it has been adequately surveyed and is not Critically Endangered but is facing a very high risk of total destruction in the near future. This will be determined on the basis of the best available information by it meeting **any one or more of** the following criteria (A, B, or C):

A) The geographic range, and/or total area occupied, and/or number of discrete occurrences have been reduced by at least 70% since European settlement **and either or both** of the following apply (i or ii):

i) the estimated geographic range, and/or total area occupied and/or number of discrete occurrences are continuing to decline such that total destruction of the community is likely in the short term future (within approximately 20 years);

ii) modification throughout its range is continuing such that in the short term future (within approximately 20 years) the community is unlikely to be capable of being substantially restored or rehabilitated.

B) Current distribution is limited, **and one or more** of the following apply (i, ii or iii):

i) geographic range and/or number of discrete occurrences, and/or area occupied is highly restricted and the community is currently subject to known threatening processes which are likely to result in total destruction throughout its range in the short term future (within approximately 20 years);

ii) there are few occurrences, each of which is small and/or isolated and all or most occurrences are very vulnerable to known threatening processes;

iii) there may be many occurrences but total area is small and all or most occurrences are small and/or isolated and very vulnerable to known threatening processes.

C) The ecological community exists only as very modified occurrences that may be capable of being substantially restored or rehabilitated if such work begins in the short-term future (within approximately 20 years).

Vulnerable (VU)
An ecological community that has been adequately surveyed and is found to be declining and/or has declined in distribution and/or condition and whose ultimate security has not yet been assured and/or a community that is still widespread but is believed likely to move into a category of higher threat in the near future if threatening processes continue or begin operating throughout its range.

An ecological community will be listed as **Vulnerable** when it has been adequately surveyed and is not Critically Endangered or Endangered but is facing a high risk of total destruction or significant modification in the medium to long-term future. This will be determined on the basis of the best available information by it meeting **any one or more of** the following criteria (A, B or C):

A) The ecological community exists largely as modified occurrences that are likely to be capable of being substantially restored or rehabilitated.

B) The ecological community may already be modified and would be vulnerable to threatening processes, is restricted in area and/or range and/or is only found at a few locations.

C) The ecological community may be still widespread but is believed likely to move into a category of higher threat in the medium to long term future because of existing or impending threatening processes.

3. DEFINITIONS AND CRITERIA FOR PRIORITY ECOLOGICAL COMMUNITIES

PRIORITY ECOLOGICAL COMMUNITY LIST

Possible threatened ecological communities that do not meet survey criteria or that are not adequately defined are added to the Priority Ecological Community Lists under Priorities 1, 2 and 3. These three categories are ranked in order of priority for survey and/or definition of the community, and evaluation of conservation status, so that consideration can be given to their declaration as threatened ecological communities. Ecological Communities that are adequately known, and are rare but not threatened or meet criteria for Near Threatened, or that have been recently removed from the threatened list, are placed in Priority 4. These ecological communities require regular monitoring. Conservation Dependent ecological communities are placed in Priority 5.

Priority One: Poorly-known ecological communities

Ecological communities with apparently few, small occurrences, all or most not actively managed for conservation (e.g. within agricultural or pastoral lands, urban areas, active mineral leases) and for which current threats exist. Communities may be included if they are comparatively well-known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under immediate threat from known threatening processes across their range.

Priority Two: Poorly-known ecological communities

Communities that are known from few small occurrences, all or most of which are actively managed for conservation (e.g. within national parks, conservation parks, nature reserves, State forest, unallocated Crown land, water reserves, etc.) and not under imminent threat of destruction or degradation. Communities may be included if they are comparatively well known from one or more localities but do not meet adequacy of survey requirements, and/or are not well defined, and appear to be under threat from known threatening processes.

Priority Three: Poorly known ecological communities

(i) Communities that are known from several to many occurrences, a significant number or area of which are not under threat of habitat destruction or degradation or:

(ii) communities known from a few widespread occurrences, which are either large or within significant remaining areas of habitat in which other occurrences may occur, much of it not under imminent threat, or;

(iii) communities made up of large, and/or widespread occurrences, that may or not be represented in the reserve system, but are under threat of modification across much of their range from processes such as grazing by domestic and/or feral stock, and inappropriate fire regimes.

Communities may be included if they are comparatively well known from several localities but do not meet adequacy of survey requirements and/or are not well defined, and known threatening processes exist that could affect them.

Priority Four: Ecological communities that are adequately known, rare but not threatened or meet criteria for Near Threatened, or that have been recently removed from the threatened list. These communities require regular monitoring.

(a) Rare. Ecological communities known from few occurrences that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These communities are usually represented on conservation lands.

(b) Near Threatened. Ecological communities that are considered to have been adequately surveyed and that do not qualify for Conservation Dependent, but that are close to qualifying for Vulnerable.

(c) Ecological communities that have been removed from the list of threatened communities during the past five years.

Priority Five: Conservation Dependent ecological communities

Ecological communities that are not threatened but are subject to a specific conservation program, the cessation of which would result in the community becoming threatened within five years.

PRIORITY ECOLOGICAL COMMUNITIES FOR WESTERN AUSTRALIA

27 August 2008

Note:
i) Nothing in this table may be construed as a nomination for listing under the Commonwealth *EPBC Act 1999*.
ii) The inclusion in this table of a community type does not necessarily imply any status as a threatened ecological community.
iii) Regions eg Pilbara are based on Department of Environment and Conservation regional boundaries.
iv) For definitions of categories (Priority 1 etc.) refer document entitled 'Definitions and Categories'.

	Community name	Category
	PILBARA	
1	**West Angelas Cracking-Clays** Open tussock grasslands of *Astrebla pectinata, A. elymoides, Aristida latifolia*, in combination with *Astrebla squarrosa* and low scattered shrubs of *Sida fibulifera*, on cracking-clay loam depressions and flowlines. Threats: Disturbance footprints increasing from mine, future infrastructure development, possible weed invasion and changes in fire regime.	Priority 1
2	**Weeli Wolli Spring community** Weeli Wolli Spring's riparian woodland and forest associations are unusual as a consequence of the composition of the understorey. The sedge and herbfield communities that fringe many of the pools and associated water bodies along the main channels of Weeli Wolli Creek have not been recorded from any other wetland site in the Pilbara. The spring and creekline are also noted for their relatively high diversity of stygofauna and this is probably attributed to the large-scale calcrete and alluvial aquifer system associated with the creek. Threat: dewatering and re-watering altering patterns of inundation.	Priority 1
3	**Burrup Peninsula rock pool communities** Calcareous tufa deposits. Interesting aquatic snails. Threats: recreational impacts, and potential development; NOX and SOX emissions.	Priority 1
4	**Burrup Peninsula rock pile communities** Comprise a mixture of Pilbara and Kimberley species, communities are different from those of the Hamersley and Chichester Ranges. Threats: mining	Priority 1
5	**Roebourne Plains coastal grasslands** The Roebourne Plains coastal grasslands with gilgai micro-relief of deep cracking clays are self mulching cracking clays that emerge on depositional surfaces. The Roebourne Plains gilgai grasslands occur on microrelief of deep cracking clays, surrounded by clay plains/flats and sandy coastal and alluvial plains. The gilgai depressions supports ephemeral and perennial tussock grasslands dominated by *Sorghum* sp. and *Eragrostis xerophila* (Roebourne Plains grass) along with other native species including *Astrebla pectinata* (barley mitchell grass), *Eriachne benthamii* (swamp wanderrie grass), *Chrysopogon fallax* (golden beard grass) and *Panicum decompositum* (native millet). It differs from the surrounding clay flats of the Horseflat land system which are dominated by *Eragrostis xerophila* and other perennial tussock grass species (*Eragrostis* mostly). Threats: Grazing, clearing for mining and infrastructure	Priority 1
6	**Stony Chenopod association of the Roebourne Plains area** Roebourne Common and airport. Not a very common community. Threats: Preferentially grazed by stock.	Priority 1
7	**Barrow Island subterranean fauna** Barrow Island stygofauna and troglofauna. Threats: Mining	Priority 1
8	**Subterranean invertebrate communities of mesas in the Robe Valley region** A series of isolated mesas occur in the Robe Valley in the state's Pilbara Region. The mesas are remnants of old valley infill deposits of the palaeo Robe River. The troglobitic faunal communities occur in an extremely specialised habitat and appear to require the particular structure and hydrogeology associated with mesas to provide a suitable humid habitat. Short range endemism is common in the fauna. The habitat is the humidified pisolitic strata. Threats: Mining	Priority 1
9	**Subterranean invertebrate community of pisolitic hills in the Robe Valley** A series of isolated mesas and low undulating hills occur in the Robe Valley in the state's Pilbara region. The troglofauna have very short range distributions, generally with each species appearing to be restricted to its individual mesa or hills. Threats: mining	Priority 1
10	**Peedamulla Marsh vegetation complex** Peedamulla (Cane River) Swamp Cyperaceae community, near mouth of Cane River. Plants are unusual. Threats: grazing	Priority 1
11	**Barrow Island creekline vegetation** General cover of *Triodia angusta* with shrubs principally *Hakea suberea, Petalostylis labicheoides, Acacia bivenosa*, and *Gossypium robinsonii*. Mangrove thickets (*Avicennia marina*) at the creek mouths.	Priority 1
12	***Astrebla lappacea* grasslands** On boundary of Hamersley and Brockman Stations	Priority 1

	Threats: Heavily grazed.	
13	**Sand Sheet vegetation (Robe Valley)** *Corymbia zygophylla* scattered low trees over *Acacia tumida* var. *pilbarensis*, *Grevillea eriostachya* high shrubland over *Triodia schinzii* hummock grassland. Other associated species include *Cleome uncifera*, *Heliotropium transforme*, *Indigofera boviperda* subsp *boviperda*, and *Ptilotus arthrolasius*. Most northern example/expression of vegetation of Carnarvon Basin. Community is poorly represented type in the Pilbara Region, and not represented in the reserve system. Community contains many plant species that are at their northern limits or exist as disjunct populations. Vulnerable to invasion by weeds (particularly buffel grass) Threats: mining, weed invasion	Priority 1
14	**Mingah Springs calcrete groundwater assemblage type on Gascoyne palaeodrainage on Mingah Spring Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
15	**Plant assemblages of the Wona Land System** A system of basalt upland gilgai plains with tussock grasslands, in Chichester National Park and in pastoral leases. Threats: preferential grazing by stock and kangaroos. High level erosion.	Priority 3 (iii)
16	**Coolabah-lignum flats: *Eucalyptus victrix* over *Muehlenbeckia* community** Woodland or forest of *Eucalyptus victrix* (coolibah) over thicket of *Muehlenbeckia florulenta* (lignum) on red clays in run-on zones. Associated species include *Eriachne benthamii, Themeda triandra, Aristida latifolia, Eulalia aurea* and *Acacia aneura*. Threats: dewatering and grazing.	Priority 3(i)
17	**Invertebrate assemblages (Errawallana Spring type) Coolawanya Station** Geologically distinct. Sherlock River system. Permanent spring-fed creek. Has atypical invertebrate community. Threats: grazing.	Priority 4 (b)
18	**Invertebrate assemblages (Nyeetberry Pool type)** Jimmawurrada Creek. Nyeetberry pool, Robe River. Permanent River Pool in the Pilbara (groundwater fed). Blind isopod collected from this site. Threats: mining and feral animals	Priority 4 (b)
19	**Stygofaunal communities of the Millstream Freshwater Aquifer** A unique assemblage of subterranean invertebrate fauna. Threats: Groundwater drawdown and salinisation.	Priority 4(b)
	KIMBERLEY	
1	**Perched spring-fed peat-based swamps on hillslopes of the Durack Range area** Assemblages of spring-fed wetlands on organic substrates perched on sandstone hill-slopes in the Central Kimberley bioregion. Drainage lines are vegetated with a forest of *Corymbia ptychocarpa* (swamp bloodwood), *Grevillea pteridifolia, Melaleuca* spp, *Pandanus spiralis*, and some *Livistona* spp. over the fern *Cyclosorus interruptus* and the climbing fern *Lygodium microphyllum*. Sedges occur in the understorey and clumps of Reed Grass *Arundinella nepalensis* are dominant in the understorey where the canopy is more open. Also associated with the drainage lines are swamps vegetated by dense sedgelands with grasses and herbs. Threats: Cattle grazing and weeds.	Priority 1
2	**Assemblages of Point Spring and Long Spring rainforest swamps** Closed canopy rainforest on freshwater swamps on alluvial floodplain soils in the east Kimberley. Two occurrences are known, these are Point Spring and Long Swamp. At Point Spring the canopy is 17m high and the dominant tree species include *Canarium australianum, Carallia brachiata, Euodia elleryana, Ficus racemosa, F. virens* and *Terminalia sericocarpa*. The rainforest canopy height at Long Swamp is 30m, and the dominant tree species include *Nauclea orientalis, Terminalia sericocarpa* and *Euodia elleryana*. The periphery of the patch is permanently moist and supports a *Melaleuca leucadendra* forest. Threats: Invasion by feral fish, impacts of stock, climate change and rising sea levels.	Priority 1
3	**Assemblages of the wetlands associated with the organic mound springs on the tidal mudflats of the Victoria-Bonaparte Bioregion** East Kimberley (i.e. Brolga Spring, King Gordon Spring, Attack Spring etc on Carlton Hill Station). Large wetlands with Melaleuca forest with small patches of rainforest on central mounds. Rainforest and paperbark forest associated with mound springs and seepage areas of the Victoria Bonaparte coastal lands.	Priority 1
4	**Monsoon vine thickets of limestone ranges** Nimbing Range, Napier Range, and Jeremiah hills.	Priority 1
5	***Oryza australiensis* (wild rice) grasslands on alluvial flats of the Ord River** West side of Weaber Hills, Weaber Plain, Mantini Flats, Knox Creek.	Priority 1
6	**Inland Mangrove (*Avicennia marina*) community of Salt Creek** Anna Plains Station, Mandora.	Priority 1
7	**Plant assemblages on vertical sandstone surfaces** Eg. Two undescribed spinifex spp. at Bungles and Molly Spring, foxtail spinifex at Cathedral Gorge and Thompsons Spring. Fire sensitive plants, fire regimes a threat.	Priority 1
8	**Invertebrate community of Napier Range Cave** On Old Napier Downs, Karst No. KNI. Threats: Mine close by and tourist visitation.	Priority 1

9	**Invertebrate assemblages of the cliff foot springs around Devonian reef system** Black soils. Threats: Springs drying up due to dewatering of karst systems.	Priority 1
10	**Dwarf pindan heath community of Broome coast** Occurs between the racecourse and Gantheame Point lighthouse. Insufficient survey outside of Broome townsite area to determine full extent.	Priority 1
11	***Corymbia paractia* dominated community on dunes** *Corymbia paractia* behind dunes, Broome township area, Dampier Peninsula. Transition zone where coastal dunes (with vine thickets) merge with Pindan (desert) vegetation. Also, port north of Broome.	Priority 1
12	**Invertebrate community of Tunnel Creek** Has unique fauna and has high visitation but not enough data available yet to describe - currently only has one sample site (neighbouring sample areas eg Windjana Gorge have different genera).	Priority 2
13	**Assemblages of Disaster Bay organic mound springs** Organic mound springs on tidal flat with *Melaleuca acacioides, Timonius timon, Pandanus spiralis, Melaleuca viridiflora, Acacia neurocarpa* and *Lumnitzera racemosa* (mangrove) woodland with *Typha domingensis* and sedges, including *Schoenoplectus litoralis.*	Priority 3 (iii)
14	**Assemblages of Lolly Well Springs wetland complex** Wetland complex containing numerous low organic mound springs with moats.	Priority 3 (ii)
15	**Nimalaica clay pan community.** Inland from Willie Creek.	Priority 4 (b)
	MID-WEST	
1	**Mount Gibson Range vegetation complexes (banded ironstone formation).** Threats: mining	Priority 1
2	**Blue Hills (Mt Karara/Mungada Ridge/Blue Hills) vegetation complexes (banded ironstone formation).** Threats: mining	Priority 1
3	**Jack Hills vegetation complexes (banded ironstone formation).** Threats: mining	Priority 1
4	**Lake Austin vegetation complexes (banded ironstone formation).** Threats: mining	Priority 1
5	**Mt Dimer vegetation complexes (banded ironstone formation).** Threats: mining	Priority 1
6	**New Forest vegetation complexes (banded ironstone formation).** Threats: mining	Priority 1
7	**Robinson Range vegetation complexes (banded ironstone formation).** Threats: mining	Priority 1
8	**Twin Peaks vegetation complexes (banded ironstone formation).** Threats: mining	Priority 1
9	**Weld Range vegetation complexes (banded ironstone formation).** Threats: mining	Priority 1
10	**Wolla Wolla (Gullewa) vegetation complexes (banded ironstone formation).** Threats: mining	Priority 1
11	**Yalgoo vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
12	**Moresby Range vegetation association** *Melaleuca megacephala* and *Hakea pycnoneura* thicket on stony slopes of Moresby Range.	Priority 1
13	**Mt Dugel/Mt Nairn vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
14	**Minjar/Gnows Nest vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
15	**Warriedar Hill/Pinyalling vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
16	**Mt Magnet vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
17	**Tallering Peak vegetation complexes** Tallering Peak in the northwest is a massif of banded ironstone and jaspilite, with outcropping masses or rock along the spine. Vegetation is sparse and includes shrubs of only 1.2m of *Acacia quadrimarginea, A ?coolgardiensis, Eremophila leucophylla, Thryptomene johnsonii*, a smaller Baeckea or Thryptomene sp. and *Ptilotus obovatus.*	Priority 1
18	**Lesueur-Coomallo Floristic Community M2 (*Melaleuca preissiana* woodland)** Woodland dominated by *Melaleuca preissiana* along sandy drainage lines, with faithful species of *Anigozanthos pulcherrimus* and constant species of *Chamaescilla corymbosa, Petrophile brevifolia* and *Xanthorrhoea reflexa.*	Priority 1
19	**Lesueur-Coomallo Floristic Community DFGH** Mixed species-rich heath on lateritic gravel with *Hakea erinacea, Melaleuca platycalyx* and *Petrophile seminuda:* a fine scale mixture of four floristically-defined communities occurring on lateritic slopes.	Priority 1
20	**Kalbarri ironstone community** Winter wet, mallee/melaleuca over herbs. Dense shrubland when burnt. Surrounded by sandplain. Yerina	Priority 1

	springs and north Eurardy Station. Z-bend loop, Junga Dam. The Declared Rare Flora taxon *Eremophila microtheca* occurs in community.	
22	**Shrublands of the Northampton Area, dominated by Melaleuca species over exposed Kockatea Shale** Heath on breakaways located in Port Gregory, west of Northampton. Community includes priority taxa; *Ptilotus chortophytum* (P1), *Leucopogon* sp. Port Gregory, *Ozothamnus* sp. Northampton, *Gastrolobium propinquum* (P1), outlier of *Ptilotus helichrysoides*. Unusual geology (Kockatea Shale) outcropping at surface.	Priority 1
23	**Badja calcrete groundwater assemblage type on Moore palaeodrainage on Badja Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
24	**Belele calcrete groundwater assemblage type on Murchison palaeodrainage on Belele Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
25	**Beringarra calcrete groundwater assemblage type on Murchison palaeodrainage on Beringarra Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
26	**Black Range south groundwater calcrete assemblage type on Raeside palaeodrainage on Lake Mason Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
27	**Bunnawarra calcrete groundwater assemblage type on Moore palaeodrainage on Bunnawarra Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
28	**Byro Central and Byro HS calcrete groundwater assemblage types on Murchison palaeodrainage on Byro Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
29	**Challa and Challa North calcrete groundwater assemblage type on Murchison palaeodrainage on Challa Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
30	**Cogla Downs calcrete groundwater assemblage type on Murchison palaeodrainage on Yarrabubba Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
31	**Curbur calcrete groundwater assemblage type on Gascoyne palaeodrainage on Curbur Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
32	**Dalgety Downs calcrete groundwater assemblage type on Gascoyne palaeodrainage on Dalgety Downs Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
33	**Doolgunna calcrete groundwater assemblage type on Gascoyne palaeodrainage on Doolgunna Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
34	**Gabyon calcrete groundwater assemblage type on Moore palaeodrainage on Gabyon Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
35	**Gifford Creek calcrete groundwater assemblage type on Lyons palaeodrainage on Gifford Creek Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
36	**Hillview calcrete groundwater assemblage type on Murchison palaeodrainage on Hillview Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
37	**Innouendy calcrete groundwater assemblage type on Murchison palaeodrainage on Innouendy Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
38	**Karalundi calcrete groundwater assemblage type on Murchison palaeodrainage on Karalundi Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
39	**Killara and Killara North calcrete groundwater assemblage types on Murchison palaeodrainage on Killara Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
40	**Kirkalocka calcrete groundwater assemblage type on Moore palaeodrainage on Kirkalocka Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes.	Priority 1

	Threats: mining	
41	**Lake Austin calcrete groundwater assemblage type on Murchison palaeodrainage on Austin Downs Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
42	**Landor calcrete groundwater assemblage type on Gascoyne palaeodrainage on Landor Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
43	**Mangaroon calcrete groundwater assemblage type on Lyons palaeodrainage on Lyons Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
44	**Maranalgo west calcrete assemblage type on Moore palaeodrainage on Maranalgo Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
45	**Meeberrie calcrete groundwater assemblage type on Murchison palaeodrainage on Meeberrie Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
46	**Meka calcrete groundwater assemblage type on Murchison palaeodrainage on Meka Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
47	**Mellenbye calcrete groundwater assemblage type on Moore palaeodrainage on Mellenbye Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
48	**Milgun central and Milgun south calcrete groundwater assemblage types on Gascoyne palaeodrainage on Milgun Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
49	**Milly Milly calcrete groundwater assemblage type on Murchison palaeodrainage on Milly Milly Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
50	**Mt Augustus calcrete groundwater assemblage type on Lyons palaeodrainage on Mt Augustus Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
51	**Mt Clere calcrete groundwater assemblage type on Gascoyne palaeodrainage on Mt Clere Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
52	**Mt Narryer calcrete groundwater assemblage type on Murchison palaeodrainage on Mt Narryer Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
53	**Mt Padbury calcrete groundwater assemblage type on Murchison palaeodrainage on Mt Padbury Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
54	**Munarra calcrete groundwater assemblage type on Murchison palaeodrainage on Munarra Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
55	**Muralgarra calcrete groundwater assemblage type on Murchison palaeodrainage on Muralgarra Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
56	**Murchison Downs calcrete groundwater assemblage type on Murchison palaeodrainage on Murchison Downs Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
57	**Ninghan calcrete groundwater assemblage type on Moore palaeodrainage on Ninghan Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
58	**Nowthanna Hill calcrete groundwater assemblage type on Murchison palaeodrainage on Yarrabubba Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
59	**Paroo calcrete groundwater assemblage type on Carey palaeodrainage on Paroo Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
60	**Polelle calcrete groundwater assemblage type on Murchison palaeodrainage on Polelle Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes.	Priority 1

	Threats: mining	
61	**Taincrow calcrete groundwater assemblage type on Murchison palaeodrainage on Taincrow Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
62	**Three Rivers and Three Rivers Plutonic calcrete groundwater assemblage types on Gascoyne palaeodrainage on Three Rivers Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
63	**Wagga Wagga calcrete groundwater assemblage type on Yalgoo palaeodrainage on Wagga Wagga Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
64	**Wanna calcrete groundwater assemblage type on Lyons palaeodrainage on Wanna Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
65	**Windimurra calcrete groundwater assemblage type on Murchison palaeodrainage on Windimurra Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
66	**Windsor calcrete groundwater assemblage type on Murchison palaeodrainage on Windsor Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
67	**Wondinong calcrete groundwater assemblage type on Murchison palaeodrainage on Wondinong Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
68	**Wooramel calcrete groundwater assemblage type on Wooramel palaeodrainage on Innouendy Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
69	**Yalgoo calcrete groundwater assemblage type on Moore palaeodrainage on Bunnawarra Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
70	**Yarrabubba east and west calcrete groundwater assemblage types on Murchison palaeodrainage on Yarrabubba Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining.	Priority 1
71	**Yoweragabbie calcrete groundwater assemblage type on Moore palaeodrainage on Yoweragabbie Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
72	***Petrophile chrysantha* low heath on Lesueur dissected uplands (Gp200-170)** Low heath dominated by *Petrophile chrysantha* on Lesueur Dissected Uplands. Associated species include *Dryandra armata* and *Hakea undulata.*	Priority 2
73	***Claypans with mid dense shrublands of *Melaleuca lateritia* over herbs** Claypans (predominantly basins) usually dominated by a shrubland of *Melaleuca lateritia* occurring both on the coastal plain and the adjacent plateau. These claypans are characterized by aquatic (*Hydrocotyle lemnoides* – Priority 4) and amphibious taxa (e.g. *Glossostigma diandrum*, *Villarsia capitata* and *Eleocharis keigheryi* - DRF)	Priority 2
74	**Coolabah-lignum swamps** Widely distributed, would need to clarify composition of herbs and extent of specific plant assemblage. Similar assemblage occurs in the Pilbara.	Priority 3(iii)
75	**Hypersaline community number 2. Stromatolites of Hamelin Pool** Hypersaline tidal stromatolite aragonite community formed by trapping and binding by a variety of cyanobacteria and eukaryotes.	Priority 4 (a)
76	**Plant assemblages (spinifex dominated) of sand dune mesa topping the Kennedy Range National Park**	Priority 4 (a)
77	**Invertebrate assemblages of Edithana Pool** High quality river pool on the Lyons River. High invertebrate diversity. Threats: cattle and Tilapia	Priority 4 (b)
78	**Invertebrate assemblages of Mooka Springs** Spring in the Kennedy Range. Has rich representative invertebrate community. Threats: feral goats and mining.	Priority 4 (b)
79	**Invertebrate assemblages of Cattle Pool** High quality river pool on the Lyons River adjacent to Mt Augustus National Park. High invertebrate diversity. Threats: cattle and Tilapia	Priority 4 (b)
80	**Invertebrate assemblages of Yinnetharra Cattle Pool** Permanent freshwater pool on the middle Gascoyne. Threats: cattle	Priority 4 (b)

81	**Invertebrate assemblages of Mibbley pool** Large relatively undisturbed freshwater pool on the upper Gascoyne River (therefore unusual). Until recently protected from stock by thick riparian vegetation. A track has been cleared to the pool which has allowed stock access.	Priority 4 (b)
82	**Invertebrate assemblages of Erong Springs** High aquatic invertebrate diversity site in the Gascoyne area. Threats: stock and goats.	Priority 4 (b)
83	**Invertebrate assemblages of Callytharra Spring, Wooramel River** Permanent Spring on the Wooramel river. High aquatic invertebrate diversity Threats: cattle.	Priority 4 (b)
84	**Lake Macleod invertebrate assemblages** Saline aquatic community with strong marine affinities with particularly rich copepod elements is effectively a well developed, very rich birrida community with strong marine and terrestrial components with especially rich hypactacoid community. Distinctive but lacks threats.	Priority 4 (b)
	GOLDFIELDS	
1	**Koolyanobbing vegetation complexes (banded ironstone formation)** Threats: Subject to mining	Priority 1
2	**Die Hardy Range/Diemels vegetation complex (banded ironstone formation)** Threats: iron ore mining.	Priority 1
3	**Mount Jackson Range vegetation complex (banded ironstone formation)** Threats: iron ore mining.	Priority 1
4	**Windarling Ranges vegetation complex (banded ironstone formation)** Threats: mining	Priority 1
5	**Booylgoo Range vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
6	**Bulga Downs vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
7	**Cashmere Downs vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
8	**Finnerty Range vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
9	**Perinvale/Walling Range vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
10	**Wiluna West vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
11	**Lake Giles vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
12	**Lake Mason vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
13	**Montague Range vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
14	**Lee Steere Range vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
15	**Violet Range vegetation complexes (banded ironstone formation)** Threats: mining	Priority 1
16	**Albion Downs calcrete groundwater assemblage type on Carey palaeodrainage on Albion Downs Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
17	**Banjawarn calcrete groundwater assemblage type on Carey palaeodrainage on Banjawarn Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
18	**Barwidgee calcrete groundwater assemblage type on Carey palaeodrainage on Barwidgee Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
19	**Black Range North calcrete groundwater assemblage type on Raeside palaeodrainage on Lake Mason Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
20	**Bubble Well calcrete groundwater assemblage type on Carey palaeodrainage on Millbillillie Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
21	**Carnegie Downs calcrete groundwater assemblage type on Burnside palaeodrainage on Carnegie Downs Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
22	**Cunyu SBF and Cunyu Sweetwater calcrete groundwater assemblage types on Nabberu palaeodrainage on Cunyu Station**	Priority 1

	Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	
23	**Dandaraga calcrete groundwater assemblage type on Raeside palaeodrainage on Dandaraga Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
24	**Depot Springs calcrete groundwater assemblage type on Raeside palaeodrainage on Depot Springs Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
25	**Glenayle calcrete groundwater assemblage type on Burnside palaeodrainage on Glenayle Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
26	**Hinkler Well calcrete groundwater assemblage type on Carey palaeodrainage on Lake Way Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
27	**Lake Way South calcrete groundwater assemblage type on Carey palaeodrainage on Lake Way Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
28	**Jundee Homestead and Jundee South Hill calcrete groundwater assemblage type on Carnegie palaeodrainage on Jundee Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
29	**Kaluwiri calcrete groundwater assemblage type on Raeside palaeodrainage on Kaluwiri Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
30	**Lake Mason calcrete groundwater assemblage type on Raeside palaeodrainage on Lake Mason Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
31	**Lake Miranda east and Lake Miranda west calcrete groundwater assemblage types on Carey palaeodrainage on Yakabindie Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
32	**Lake Violet south and Lake Violet calcrete groundwater assemblage types on Carey palaeodrainage on Millbillillie Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
33	**Laverton Downs calcrete groundwater assemblage type on Carey palaeodrainage on Laverton Downs Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
34	**Lorna Glen calcrete groundwater assemblage type on Carnegie palaeodrainage on Lorna Glen Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
35	**Melrose Station (Lake Darlot) calcrete groundwater assemblage type on Carey palaeodrainage on Melrose Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
36	**Melita calcrete groundwater assemblage type on Raeside palaeodrainage on Melita (Sons of Gwalia) Station)** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
37	**Millbillillie: Bubble calcrete groundwater assemblage type on Carey palaeodrainage on Millbillillie Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
38	**Mt Morgan calcrete groundwater assemblage type on Carey palaeodrainage on Mt Weld Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
39	**Nambi calcrete groundwater assemblage type on Carey palaeodrainage on Nambi Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
40	**Old Cunya calcrete groundwater assemblage type on Nabberu palaeodrainage on Cunya Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
41	**Perrinvale calcrete groundwater assemblage type on Raeside palaeodrainage on Perrinvale Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1

42	**Pinnacles calcrete groundwater assemblage type on Raeside palaeodrainage on Pinnacles Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
43	**Sturt Meadows calcrete groundwater assemblage type on Raeside palaeodrainage on Sturt Meadows Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
44	**Uramurdah Lake calcrete groundwater assemblage type on Carey palaeodrainage on Millbillillie Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
45	**Wiluna BF calcrete groundwater assemblage type on Carey palaeodrainage on Millbillillie Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
46	**Windidda calcrete groundwater assemblage type on Carnegie palaeodrainage on Windidda Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
47	**Yakabindie calcrete groundwater assemblage type on Carey palaeodrainage on Yakabindie Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
48	**Yandal calcrete groundwater assemblage type on Carey palaeodrainage on Yandal Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
49	**Yeelirrie calcrete groundwater assemblage type on Carey palaeodrainage on Yeelirrie Stration** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
50	**Yuinmery north and south calcrete groundwater assemblage types on Raeside palaeodrainage on Yuinmery Station** Unique assemblages of invertebrates have been identified in the groundwater calcretes. Threats: mining	Priority 1
51	**Helena and Aurora Range vegetation complexes (banded ironstone formation)** Threats: iron ore mining.	Priority 1
52	**Mount Manning Range vegetation complex (banded ironstone formation)** Threats: iron ore mining.	Priority 3 (i)
53	**Yellow sandplain communities of the Great Victoria Desert** Very diverse mammalian and reptile fauna, distinctive plant communities. Threats: mining	Priority 3 (ii)
54	**Yilgarn Hills vegetation complex** Threats: mining	Priority 3 (iii)
55	**Mt Belches *Acacia quadrimarginea* / *Ptilotus obovatus* banded ironstone community** On Randall River Timber Reserve. Threats: Has grazing coexistence with the reserve.	Priority 3 (iii)
56	**Banded Ironstone Hills with *Dryandra arborea*** On Unallocated Crown Land in excellent condition north-west Menzies area. Threats: mining	Priority 3 (iii)
57	**Duladgin Ridge vegetation complex**	Priority 3 (iii)
58	**Mount Jumbo Range vegetation complex** Laverton area, northeast goldfields	Priority 3 (iii)
59	**Mount Linden Range banded ironstone ridge vegetation complex**	Priority 3 (iii)
	SOUTH WEST	
1	***Reedia spathacea - Empodisma gracillimum – Sporadanthus rivularis* dominated floodplains and paluslopes of the Blackwood Plateau** Diverse closed sedges and rushes to 1.5 m in height of *Reedia spathacea/Empodisma gracillimum/Sporadanthus rivularis* with open low shrubs to open scrub of *Taxandria linearifolia.*	Priority 1
2	**Granite community dominated by the shrubs *Calothamnus graniticus* subsp. *graniticus, Acacia cyclops, A. saligna, Hakea oleifolia, H. prostrata and Jacksonia furcellata* (Sugar Loaf Rock)** Shrubland (0.5-2 m) growing on shallow soils derived from granite gneiss on the Cowaramup and Gracetown (Willyabrup Exposed Rocky Slopes land unit) soil landscape systems. The dominant species include: *Allocasuarina humilis, Acacia cyclops, A. littorea, A. pulchella, A. rostellifera, Calothamnus graniticus, Darwinia citriodora, Corymbia calophylla, Daviesia horrida, D. preissii, Dryandra lindleyana, D. erinacea, Hakea prostrata, H. trifurcata, Spyridium globulosum, Pimelea ferruginea,* and *Xanthorrhoea preissi.*	Priority 1
3	***Melaleuca rhaphiophylla-M. preissiana-Banksia littoralis* low forest on seasonally waterlogged soils of the Dunsborough-Eagle Bay area** A low forest dominated by *Melaleuca rhaphiophylla, M. preissiana, Banksia littoralis* and *Agonis flexuosa* with occasional emergent *Corymbia calophylla* over *Boronia molloyae, Astartea scoparia, Viminaria juncea, Hakea varia, Pteridium esculentum, Jacksonia furcellata, Aotus cordifolia* (P3), *Hibbertia perfoliata, Cyathochaeta clandestina,* and *Empodisma gracillimum* on seasonally waterlogged light grey sands and grey brown sandy loams of the Abba Plain and Willyabrup Valleys soil-landscape systems.	Priority 1

4	**Tall closed sedgeland on shallow soils derived from granite gneiss on the Leeuwin Naturaliste Ridge ('Sedgelands of the Cape Leeuwin Spring')** Tall closed sedgeland of *Juncus krausii, Baumea juncea, and Schoenoplectus validus;* tall closed sedgeland of *Typha orientalis,* over *S. validus, Lepidosperma gladiatum* and *Muehlenbeckia adpressa;* low closed sedgeland of *Ficina nodosa and Baumea juncea* on shallow soils derived from granite gneiss on the Leeuwin Naturaliste Ridge.	Priority 1
5	***Eucalyptus gomphocephala* (tuart), *Eucalyptus decipiens, Eucalyptus cornuta* (yate) woodlands (near Busselton)**	Priority 1
6	***Eucalyptus rudis, Corymbia calophylla, Agonis flexuosa* Closed Low Forest (near Busselton)** A low lying Spearwood Dune plant community associated with shallow sandy soils over Tamala limestone that in places is exposed at the surface. The plant community on these soils supports a unique mixture of wetland and upland flora. Typically low forest dominated by *Eucalyptus rudis, Eucalyptus calophylla, Agonis flexuosa* over a diverse understorey including *Hibbertia hypericoides, Logania vaginalis, Conospermum caeruleum, Agrostocrinum hirsutum* and *Lomandra micrantha.* Other associated species include *Eucalyptus decipiens, Melaleuca rhaphiophylla, Banksia littoralis, Hakea varia* and the sedge species *Baumea juncea* and *Gahnia trifida.*	Priority 1
7	***Eucalyptus patens, Corymbia calophylla, Agonis flexuosa* Closed Low Forest (near Busselton)** *Eucalyptus patens* on loamy brown sands over limestone. Species present include *Eucalyptus patens, Corymbia calophylla* and *Agonis flexuosa* over understorey species including *Bossiaea linophylla, Hibbertia hypericoides, Gastrolobium praemorsum, Leucopogon propinquus, Phyllanthus calycinus, Lomandra micrantha, Lepidosperma longitudinale, Mesomelaena tetragona, Cyathochaeta avenacea* and *Tetraria octandra.* The community is likely to have similarities to community type 1b 'Southern *Corymbia calophylla* woodlands on heavy soils'.	Priority 1
8	**Central Whicher Scarp Mountain Marri woodland (Whicher Scarp woodlands of grey/whites sands community A1)** Located on Whicher Scarp mid slopes. The taxa that identify the group include: *Ricinocarpus* aff. *cyanescens, Hibbertia ferruginea, Platysace filiformis, Conospermum capitatum* subsp. *glabratum, Thysanotus arbuscular, Schoenus brevisetis, Phlebocarya filifolia, Leucopogon glabellus, Pimelea rosea* subsp. *rosea, Adenanthos obovatus, Stylidium carnosum* and *Gompholobium capitatum*.	Priority 1
9	**West Whicher Scarp *Banksia attenuata* woodland (Swan Coastal Plain centred woodlands of grey/white sands community B2)** This community type occurs in grey sand in the West Whicher Scarp. It is similar to the open *Banksia attenuata* woodlands with Peppermint (*Agonis flexuosa*) from the grey sands of the West Whicher Scarp. The type is species poor. Taxa include: *Allocasuarina fraseriana, Banksia attenuata, Xylomellum occidentale, Bossiaea praetermissa, Calytrix flavescens, Gompholobium tomentosum, Hibbertia hypericoides, Hovea stricta, Hypocalymma robustum, Kunzea rostrata, Petrophile linearis* and a suite of grasses, herbs and sedges.	Priority 1
10	**Central Whicher Scarp Jarrah woodland (Whicher Scarp woodlands of coloured sands and laterites community C1)** Occurs on coloured sands on moderate to gentle slopes of the Central Whicher Scarp. The community has strong representation of a less common group of southern taxa including: *Podocarpus drouyianus, Loxocarya cinerea, Allocasuarina fraseriana, Drosera stolonifera, Amperea ericoides, Thysanotus triandrus, Cyathochaeta equitans, Hibbertia quadricolor, Comesperma calymega, Lepidosperma pubisquameum, Conospermum paniculatum, Acacia preissiana* and *Hybanthus debissimus.*	Priority 1
11	**Whicher Scarp Jarrah woodland of deep coloured sands (Whicher Scarp woodlands of coloured sands and laterites community C2)** Community is found scattered through the Central and North Whicher Scarp on midslopes on deep, generally coloured sands rarely associated with laterites. Community has a strongest representation of common sand taxa especially *Hypolaena exsulca, Dasypogon bromeliifolius, Stirlingia latifolia, Petropile linearis, Melaleuca thymoides* and *Adenanthos meisneri.*	Priority 1
12	**Dardanup Jarrah and Mountain Marri woodland on laterite (Whicher Scarp woodlands of coloured sands and laterites community C5)** Community located on unusual surface of quartzite and laterite in Dardanup forest which is an area where the Whicher Scarp, Blackwood Plateau and Darling Scarp interface. It is notable in the presence of uncommonly encountered laterite taxa including: *Lomandra* sp. Dardanup, *Lomandra spartea, Olax benthamiana, Andersonia heterophylla, Hemigenia incana, Acacia varia* var. *varia, Daviesia angulata, Pimelea preissii,* and also *Lomandra brittanii, Xanthorrhoea acanthostachya, Dryandra armata* var. *armata, Hakea stenocarpa, Stachystemon vermicularis, Lambertia multiflora* var *darlingensis, Petrophile striata* and *Pimelea sulphurea.*	Priority 1
13	**Sabina River Jarrah and Marri woodland (Whicher Scarp community F1)** Community in Sabina River alluvial fan where the Sabina River meets the Swan Coastal Plain. It is characterised by a suite of wetland taxa of restricted occurrence in the Whicher Scarp: *Mirbelia dilatata, Lomandra pauciflora, Tremandra diffusa, Tremandra stelligera, Trymalium floribundum* subsp. *trifidum* and *Clematis aristata* var. *occidentalis.* Other significant taxa in the community are: *Hovea elliptica, Leucopogon verticillatus,* and *Darwinia citriodora.*	Priority 1
14	**Shrublands of near permanent wetlands in creeklines of the Whicher Scarp (Whicher Scarp community G2)** Community is species poor and included the following taxa: *Astartea scoparia, Homalospermum firmum, Taxandria fragrans* MS, **Anthoxanthum odoratum, Baumea rubingosa, Cyathochaeta teretifolia, Isolepis*	Priority 1

	cernua, Taraxis grossa.	
15	**Swan Coastal Plain Paluslope Wetlands** These wetlands are very wet all year round and are associated with areas of groundwater seepage from the sandy low hills at the base of the Whicher Scarp. At times these wetlands are contiguous with areas of Pinjarra Plain wetlands, and the wetlands of the two landforms merge. Combinations of the following species are typically found in the type: *Melaleuca preissiana, Taxandria linearifolia, Taxandria fragrans, Melaleuca incana,* and *Cyathochaeta teretifolia*. Other species include: *Eucalyptus patens, Homalospermum firmum, Gahnia decomposita, Callistachys lanceolata, Hakea linearis, Melanostachya ustulata, Evandra aristata, Beaufortia sparsa, Calistemon glaucus* and *Pultenaea pinifolia.*	Priority 1
16	**Low shrublands on acidic grey-brown sands of the Gracetown soil-landscape system** A low shrubland or heath occurring on grey brown sand with a bleached surface derived from granite gneiss near the west coast of the Leeuwin-Naturaliste Ridge. Dominant or characteristic shrub species include; *Calothamnus sanguineus, Darwinia citriodora, Hakea prostrata, Hakea trifurcata, Jacksonia horrida, Kunzea ciliata, Pimelea ferruginea, Pimelea rosea, Spyridium globulosum, Verticordia plumosa* var. *plumosa, Xanthorrhoea brunonis*. Common herbs, grasses and sedges include; *Asteridea pulverulenta, Austrodanthonia setacea, Austrostipa compressa, Brachyscome iberidifolia, Lepidosperma squamatum, Platysace haplosciadia, Trichocline spathulata* and *Velleia trinervis.*	Priority 2
17	***Melaleuca lanceolata* forests, Leeuwin Naturaliste Ridge** Low Closed Forest to Closed Forest of *Melaleuca lanceolata* ("moonah") occurring near the coastline of the Leeuwin-Naturaliste Ridge adjacent to limestone cliffs and down steeply sloping rock slopes on dark-grey, brown or, less commonly, pale-grey sands, often with outcropping limestone. The Moonah varies from 2 to 15 metres, reflecting depth of soil and wind pruning. Typical understorey shrubs are *Tetragonia implexicoma, Rhagodia baccata, Leucopogon propinquus,* and *Suaeda australis.*	Priority 2
18	**Blackwood Alluvial Flats** Woodlands and shrublands of the alluvial soils of the upper Blackwood River (Condinup and Darkan 5f soil-landscape sub-systems). Vegetation associations identified to date: Wet shrublands on alluvial clay flats, Jarrah-Marri woodlands on alluvial grey-brown loams, Wandoo woodlands on alluvial grey-brown clay-loams (includes vernal pools), Flooded Gum-Wandoo woodland on alluvial grey clays (includes vernal pools), Wandoo woodlands on grey sandy loams	Priority 2
19	***Epiphytic Cryptogams of the karri forest** Cryptogams associated with *Trymalium floribundum* and *Chorilaena quercifolia* in the karri forests of south-west WA. Comprises liverworts, mosses and lichens found on the bark of mature (plants greater than 15 years old and prior to senescence at about age 50) *Trymalium floribundum* and *Chorilaena quercifolia* in the karri forest of south-west Western Australia.	Priority 3 (i)
	SWAN	
1	***Avon Pools** Deep pools and natural braided sections of fresh to brackish rivers of the Avon Botanical District.	Priority 1
2	**Fairbridge Ironstone community** (Cemetery – Fairbridge Farm).	Priority 1
3	**Mt Saddleback heath communities**	Priority 1
4	***Casuarina obesa* association** Thomas Rd to Serpentine River, Swan Coastal Plain. No detailed information to assess if distinct community.	Priority 1
5	**Leschenault White Mangrove Community** May not be considered a separate community type as is possibly a geographic outlier.	Priority 1
6	**Elongate fluviatile delta system** Peel Harvey system, the site appears to contain common vegetation types on an unusual substrate, may not meet the criteria for TECs.	Priority 1
7	**Hypersaline microbial community 1** Extant coastal hypersaline lakes microbialite community formed by *Apanothecae halophitica, Oscillatoria* sp./ *Spirulina* sp., *Botrycoccus* and diatoms (Government House Lake, Rottnest).	Priority 2
8	**Wandoo woodland over dense low sedges of *Mesomelaena preisii* on clay flats** Wandoo woodland on clay flats in valleys over dense low sedges of *Mesomelaena preisii.*	Priority 2
9	**Banksia woodland of the Gingin area restricted to soils dominated by yellow to orange sands** Species rich Banksia woodlands on deep yellow-red sands that appear restricted to the western Dandaragan Plateau. The vegetation is described as scattered *Eucalyptus todtiana* and *Eucalyptus calophylla* over *Banksia menziesii* and *Banksia attenuata* low open woodland over *Jacksonia sternbergiana* and *Adenanthos cygnorum* high open shrubland over *Allocasuarina humilis* and *Chamelaucium lullfitzii* (DRF) open shrubland over *Eremaea pauciflora* and *Astroloma xerophyllum* low shrubland over *Mesomelaena pseudostygia* open sedgeland.	Priority 2
10	**Living microbial mats in hypersaline ponds** Extant hypersaline pond stromatolitic 'Conophyton' like unlithified communities formed with little sediment incorporation by (?) *Phormidium hypersalinum* (Pamelup Pond, Lake Preston, Yalgorup).	Priority 2
11	**Wooded wetlands which support colonial waterbird nesting areas** Chandala, Booragoon Lake, unnamed wetland near Pinjarra, McCarleys Swamp. This type differs from the listed 'Perched wetlands of the Wheatbelt region with extensive stands of *Casuarina obesa* and *Melaleuca strobophylia*' ('Toolibin-type' wetlands) in that the Wheatbelt type is Casuarina, rather than Melaleuca dominated. Also, Toolobin Lake type is now brackish-saline (formerly fresh-brackish), whereas this type are currently fresh-brackish.	Priority 2

12	**Litter Dependent Invertebrate Community of the northern Jarrah Forest** Chandler Block, Northern Jarrah Forest, insufficient evidence that this is a discrete community type.	Priority 2
13	***Banksia ilicifolia* woodlands, southern Swan Coastal Plain ('community type 22')** Low lying sites generally consisting of *Banksia ilicifolia – B. attenuata* woodlands, but *Melaleuca preissiana* woodlands and scrubs are also recorded. Occurs on Bassendean and Spearwood systems in the central Swan Coastal Plain north of Rockingham. Typically has very open understorey, and sites are likely to be seasonally waterlogged.	Priority 2
14	***Claypans with mid dense shrublands of *Melaleuca lateritia* over herbs** Claypans (predominantly basins) usually dominated by a shrubland of *Melaleuca lateritia* occurring both on the coastal plain and the adjacent plateau. These claypans are characterized by aquatic (*Hydrocotyle lemnoides* – Priority 4) and amphibious taxa (e.g. *Glossostigma diandrum, Villarsia capitata* and *Eleocharis keigheryi* - DRF).	Priority 2
15	**Coastal shrublands on shallow sands, southern Swan Coastal Plain ('community type 29a')** Mostly heaths on shallow sands over limestone close to the coast. No single dominant but important species include *Spyridium globulosum, Rhagodia baccata*, and *Olearia axillaris.*	Priority 3
16	**Granite communities of the northern Jarrah Forest** Jarrahdale area - Monadnocks, Blue Rock; insufficient information to distinguish discrete community type/s.	Priority 3
17	**Swan Coastal Plain *Banksia attenuata - Banksia menziesii* woodlands ('community type 23b')** These woodlands occur in the Bassendean system, from Melaleuca Park to Gingin. Occurs in reasonably extensive Banksia woodlands north of Perth.	Priority 3
18	***Eucalyptus haematoxylon - Eucalyptus marginata* woodlands on Whicher foothills ('community type 1a')** Community occurs along the northern edge of State Forest along the base of the Whicher Range and is composed of *Eucalyptus haematoxylon – Corymbia calophylla - Eucalyptus marginata* forests and woodlands. Taxa virtually restricted to the type include *Acacia varia* subsp. *varia, Agonis grandiflora* and *Xanthosia pusilla.*	Priority 3
19	**Southern Swan Coastal Plain *Eucalyptus gomphocephala - Agonis flexuosa* woodlands (type 25)** Woodlands of *Eucalyptus gomphocephala - Agonis flexuosa* south of Woodman Point. Recorded from the Karrakatta, Cottesloe and Vasse units. Dominants other than tuart were occasionally recorded, including *Corymbia calophylla* at Paganoni block and *Eucalyptus decipiens* at Kemerton. Tuart formed the overstorey nearby however.	Priority 3
20	**Quindalup *Eucalyptus gomphocephala* and / or *Agonis flexuosa* woodlands ('community type 30b')** This community is dominated by either Tuart or *Agonis flexuosa.* The presence of *Hibbertia cuneiformis, Geranium retrorsum* and *Dichondra repens* differentiate this group from other Quindalup community types. The type is found from the Leschenault Peninsular south to Busselton.	Priority 3
21	**Southern *Banksia attenuata* woodlands ('community type 21b')** This community is restricted to sand sheets at the base of the Whicher Scarp, the sand sheets on elevated ridges or the sand plain south of Bunbury. Structurally, this community type is normally *Banksia attenuata* or *Eucalyptus marginata – B. attenuata* woodlands. Common taxa include *Acacia extensa, Jacksonia* sp. Busselton, *Laxmannia sessiliflora, Lysinema ciliatum* and *Johnsonia acaulis.*	Priority 3
22	**Low lying *Banksia attenuata* woodlands or shrublands ('community type 21c')** This type occurs sporadically between Gingin and Bunbury, and is largely restricted to the Bassendean system. The type tends to occupy lower lying wetter sites and is variously dominated by *Melaleuca preissiana, Banksia attenuata, B. menziesii, Regelia ciliata, Eucalyptus marginata* or *Corymbia calophylla.* Structurally, this community type may be either a woodland or occasionally shrubland.	Priority 3
23	**Northern Spearwood shrublands and woodlands ('community type 24')** Heaths with scattered *Eucalyptus gomphocephala* occurring on deeper soils north from Woodman Point. Most sites occur on the Cottesloe unit of the Spearwood system. The heathlands in this group typically include *Dryandra sessilis, Calothamnus quadrifidus*, and *Schoenus grandiflorus.*	Priority 3
24	**Acacia shrublands on taller dunes, southern Swan Coastal Plain ('community type 29b')** Community is dominated by Acacia shrublands or mixed heaths on the larger dunes. This community stretches from Seabird to south of Mandurah. No consistent dominant but species such as *Acacia rostellifera, Acacia lasiocarpa*, and *Melaleuca acerosa* were important.	Priority 3(i)
25	**Central Northern Darling Scarp Granite Shrubland Community** Shrublands and heath on deeper loams and red earths on fragmented granite/quartzite. Heath species typically consist of the taller shrubs *Xanthorrhoea acanthostachya* and *Allocasuarina humilis* over smaller proteaceous and myrtaceous shrubs, namely *Melaleuca* aff. *scabra, Baeckea camphorosmae* and to a lesser extent, the proteaceous shrubs *Dryandra armata, Hakea incrassata and Hakea undulata.* Located in central region of the Northern Darling Scarp near Perth.	Priority 4 (a)
	WARREN	
1	***Reedia spathacea - Empodisma gracillimum - Schoenus multiglumis* dominated peat paluslopes and sandy mud floodplains of the Warren Biogeographical Region** Sedges/ rushes to about 1.5m in height of *Reedia spathacea/Empodisma gracillimum/ Schoenus multiglumis* with *Homalospermum firmum* low open shrubs to scrub.	Priority 1
2	**Relictual peat community** Lake Surprise.	Priority 1
3	**Southwest Coastal Grassland** Southwest coastal grassland dominated by *Austrostipa flavescens, Poa porphyroclados* and *Desmocladus flexuosus.*	Priority 2

4	**Sphagnum communities of the Tingle Forest** Only 3 known occurrences - Walpole area.	Priority 2
5	**Basalt association of the Warren Region** Black Point - near Augusta.	Priority 2
6	**Saprolite association of the Warren Region** Walpole Inlet. 'Palusmont wetland communities'.	Priority 2
7	**Flat wetlands Rocky Gully to Denmark** Threats: dieback and fire.	Priority 2
8	**Southern Granite community (Muirillup Rock, Northcliffe)** Subset of wheatbelt granites; insufficient information to distinguish discrete community type/s.	Priority 2
9	**Aquatic invertebrate communities of peat swamps**	Priority 2
10	***Epiphytic Cryptogams of the karri forest** Cryptogams associated with *Trymalium floribundum* and *Chorilaena quercifolia* in the karri forests of south-west WA. Comprises liverworts, mosses and lichens found on the bark of mature (plants greater than 15 years old and prior to senescence at about age 50) *Trymalium floribundum* and *Chorilaena quercifolia* in the karri forest of south-west Western Australia.	Priority 3
	WHEATBELT	
1	**Highclere Hills (Mayfield) vegetation complex (banded ironstone formation)** Threats: iron ore mining.	Priority 1
2	**Red Morrel Woodland of the Wheatbelt** Tall open woodlands of *Eucalyptus longicornis* (red morrell) found in the Wheatbelt on lateritic, ironstone or granitic soil types. Sometimes found with *Eucalyptus salmonophloia* (Salmon Gum), or *E. loxophleba* (York Gum) woodlands and has very little understorey. It is also found directly above lake systems in the central and eastern Wheatbelt. The landscape unit in which it is found is valley floors, usually adjacent to saline areas.	Priority 1
3	***Avon Pools** Deep pools and natural braided sections of fresh to brackish rivers of the Avon Botanical District.	Priority 1
4	**Canegrass perched clay wetlands of the wheatbelt dominated by *Eragrostis australasica* and *Melaleuca strobophylla* across the lake floor**	Priority 1
5	**Mottlecah dominated heathland on deep white sands** Wheatbelt Mottlecah *(Eucalyptus macrocarpa* subsp. *macrocarpa)* dominated heathland on deep white sands. *Eucalyptus macrocarpa* over proteaceous sandplain community.	Priority 1
6	**Natural organic saline seeps of the Avon Botanical District** The known occurrence of this community is characterised by vegetation in a series of bands from the upland to the saline seep. 1) Dunes and sandplain, 2) Saline seep and 3). Adjacent flats and flow lines.	Priority 1
7	**Dense Melaleuca thickets with emergent mallee *Eucalyptus erythronema* var. *marginata* and *Eucalyptus transcontinentalis* of the Wheatbelt Region**	Priority 1
8	**Tamma-Dryandra-Eremaea shrubland** Tamma-Dryandra-Eremaea shrubland on cream sands of the Ulva Landform Unit. *Acacia lasiocalyx* and *Allocasuarina campestris* over *Eremaea pauciflora, Dryandra armata, Hakea aculeata* and *Dryandra erythrocephala* open heath over *Neurachne alopecuroidea* very open grassland over cream sands of the Ulva Landform Unit.	Priority 1
9	***Banksia prionotes* and *Xylomelum angustifolium* low woodlands on transported yellow sand** *Banksia prionotes* and *Xylomelum angustifolium* Low Woodlands on large yellow sands dunes (formed from sheets of transported sand in the valleys) on the Ulva Landform Unit. The community has a species rich understorey of *Grevillea eriostachya, Melaleuca leptospermoides, Verticordia roei, Calytrix leschenaultii, Dampiera* spp., *Baeckea preissiana* and *Borya constricta.*	Priority 1
10	**Salt Flats Plant Assemblages of the Mortlock River (East Branch)** The habitat comprises braided channels (up to 2 km wide), flats, wash-lines and sandy rises (up to 2m high) stretching 39 km along the Mortlock River (East) from Meckering eastwards to 8 km west of Tammin. A mosaic of plant communities assorted by elevation occurs on the river flats. The area represents the most extensive braided saline drainage line in this part of the SW agricultural zone. The plant community comprises mixed shrubs (*Scholtzia capitata, Melaleuca* aff. *uncinata*) over species rich herbs on sandy rises, with *Melaleuca thyoides* on margins, dwarf scrub and species rich herbs on washlines and saline wetlands.	Priority 1
11	**Brown mallet *Eucalyptus astringens* communities in the western Wheatbelt on alluvial flats (previously 'Beaufort River Flats')** Near York and on the Arthur River on grey clays the understorey is dominated by *Melaleuca viminea* over sedges (*Gahnia trifida*) and bunch grasses. At Kojunup and near Tambellup on brown clays sparse shrubs and succulent shrubs (*Disphyma crassifolium*) dominate the understorey.	Priority 1
12	**Yate (*Eucalyptus occidentalis*) dominated alluvial claypans of the Jingalup Soil System**	Priority 2
13	**Gypsum Dunes (Lake Chinocup)** *Eucalyptus* aff. *incrassata* mallee over low scrub on gypsum dunes.	Priority 2
14	**Wheatbelt *Allocasuarina huegeliana* over *Pteridium esculentum* fernland community** Tall emergent *Eucalyptus salmonophloia* over *Allocasuarina huegeliana* tall closed forest over *Acacia acuminata* mid-high isolated trees over *Alyxia buxifolia* tall sparse shrubland over *Pteridium esculentum* very tall closed fernland over various sparse forbland. Occurs in a drainage line near the base of a granite inselberg.	Priority 2
15	***Claypans with mid dense shrublands of *Melaleuca lateritia* over herbs**	Priority 2

	Claypans (predominantly basins) usually dominated by a shrubland of *Melaleuca lateritia* occurring both on the coastal plain and the adjacent plateau. These claypans are characterized by aquatic (*Hydrocotyle lemnoides* – Priority 4) and amphibious taxa (e.g. *Glossostigma diandrum*, *Villarsia capitata* and *Eleocharis keigheryi* - DRF).	
16	***Allocasuarina huegeliana* and *Lepdiosperma tuberculatum* growing on the south-western side of granite outcrops adjacent to laterite on the eastern slopes of the Darling Scarp**	Priority 2
17	**Parker Range vegetation complexes** *Hakea pendula* Tall Shrubland is of particular significance. *Eucalyptus sheathiana* with *E. transcontinentalis* and/or *E. eremophila* woodland on sandy soils at the base of ridges and low rises; *E. longicornis* with *E. corrugata* and *E. salubris* or *E. myriadena* woodland on broad flats; *E. salmonophloia* and *E. salubris* woodland on broad flats; *Allocasuarina acutivalvis* and *A. corniculata* on deeper sandy soils of lateritic ridges; *E. capillosa* subsp. *polyclada* and/or *E. loxophleba* over *Hakea pendens* thicket on skeletal soils on ridges (laterites, breakaways and massive gossanous caps); and *Callitris glaucophylla* low open woodland on massive greenstone ridges.	Priority 3(iii)
18	**Plant assemblages of the Wongan Hills System** Mallee over *Petrophile shuttleworthiana/Allocasuarina campestris* thicket on shallow gravely soils over ironstone on summit and slopes; Shrub mallee on slopes of lateritic hills; Mallee over *Allocasuarina campestris* thicket on the slopes of the laterite plateaus; Mallee over Melaleuca thicket on red brown loam over gravel on slopes below the plateau; Mallee over *Melaleuca coronicarpa* heath on shallow red soil on scarp slopes; *A. campestris/Calothamnus asper* thicket over red-brown clay/ironstone/greenstone on scree slopes; and in lower areas: *Eucalyptus longicornis/ E. salubris* woodland, *E. salmonophloia* and *E. loxophleba* woodlands; *Acacia acuminata* low forest; *E. ebbanoensis* mallee over scrub; and open mallee of *E. drummondii.*	Priority 4(a)
	SOUTH COAST	
1	**Species rich shrublands and thickets with scattered eucalypt emergents on yellow sandy loam** *Eucalyptus flocktoniae* (syn. *E. urna*) low woodland.	Priority 1
2	**Stromatolite like microbialite community of a Coastal Hypersaline Lake (Pink Lake)** Microbial, invertebrate and plant assemblages of natural saline seeps. Well-laminated stromatolites consisting of alternations of egg-shell-like layers of inorganic aragonite precipitate and calcified microbial layers dominated by coccoid cyanobacteria and photosynthetic bacteria. These structures probably record seasonal alternations of the growth of a benthic microbial community and aragonite precipitation.	Priority 1
3	**Ridge Road Quartzite community** Open Jarrah forest and woodland developed on young exposed quartzite with an understorey dominated by *Taxandria parviceps* on the western interface of the Yilgarn craton and the Albany-Frazer orogen.	Priority 1
4	**Bremer Range vegetation complexes** Mt Day, Round Top Hill, Honman Ridge. *Eucalyptus rhomboidea* ms and *E. eremophila* woodland on the side slopes of low ridges; *E. flocktoniae* woodland (with *E. salubris*, *E. salmonophloia*, *E. dundasii* and *E. tenuis*) on broad flat ridges and side slopes; *E. flocktoniae* and/or *E. longicornis* woodland on saline soils on ridges and flats adjacent to large salt lake systems; *E. longicornis* and/or *E. salmonophloia* or, *E. georgei* subsp *georgei* or, *E. dundasii* woodland, on low areas; *E. livida* woodland on lateritic tops or Allocasuarina thickets on greenstone ridges of lateritic breakaways; *Acacia duriuscula*, *Allocasuarina globosa*, *E. georgei* subsp. *georgei* and *E. oleosa* thickets on greenstone ridges with skeletal soils. Proposed Nature Reserve. Threats: exploration and mining	Priority 1
5	**Fraser Range vegetation complex** Plant assemblages of the Fraser Range Vegetation Complex: *Allocasuarina huegeliana* and *Pittosporum phylliraeoides* open woodland over *Beyeria lechenaultia* and *Dodonaea microzyga* Scrub and *Aristida contorta* bunch grasses (granite complex), on the slopes and summits of hills; *Acacia acuminata* Tall Shrubland dominated by *Melaleuca uncinata* and *Triodia scariosa* on uplands with shallow loamy sands; *Eucalyptus* aff. *uncinata* (KRN 7854) over *Senna artemisioides* subsp. *helmsii*, *Cryptandra miliaris*, *Dodonaea boroniifolia*, *D. stenozyga* and *Triodia scariosa* (*Eucalyptus effusa* Mallee) on colluvial flats with loamy clay sands, and; *E. oleosa*, *E. transcontinentalis*, *E. flocktoniae* Woodland on flats.	Priority 1
6	**Plant assemblages of the Southern Hills Vegetation Complex** Complex of woodland *(E. oleosa, E. transcontinentalis, E. flocktoniae)* on flats with open stony ridges carrying mainly mallee and spinifex *(Eucalyptus effusa* Mallee: *Eucalyptus* aff. *uncinata* (KRN 7854) *over Cassia helmsii, Cryptandra miliaris, Dodonaea boroniifolia, D. stenozyga* and *Triodia scariosa).* Includes patches of grassland, wattle thicket and mallee.	Priority 1

7	**Green Range granite hill heath and woodland community** Heath and woodland dominated by *Acacia heteroclita, Anthocercis viscosa, Thryptomene saxicola, Darwinia citriodora, Prostanthera verticillata, Platysace compressa, Gastrolobium bilobum, Hakea oleifolia, Leucopogon verticillaris, Agonis flexuosa, Eucalyptus cornuta*, and *Acacia drummondii* ssp. *elegans* on red clay-loam over granite.	Priority 1
8	**Wet ironstone heath community (Albany District)** The habitat for the community is winter-wet ironstone in valley floors. The heath community is dominated by *Kunzea recurva, K. preissiana, K. micrantha, Hakea lasiocarpha, H. tuberculata, H. oldfieldii, H. cucullata, H. sulcata, Petrophile squamata, Dryandra tenuifolia* ssp. *tenuifolia, Adenanthos apiculatus, Melaleuca suberosa, M. violacea, Gastrolobium spinosum*. North Porongurup.	Priority 1
9	**Porongurup Range Karri Forest** Occurs on granite, red clay-loam on the mid-upper slopes of the Porongurup Range. Dominants include *Eucalyptus diversicolor, Corymbia calophylla, Trymalium floribundum, Hydrocotyle ?hirta, Tetrarrhena laevis, Clematis pubescens, Lepidosperma effusum* and *Pteridium esculentum*. Other associated species include; *Apium prostratum* subsp. *phillipii* (DRF), *Ranunculus colonorum, Adiantum aethiopicum, Asplenium flabellifolium, A. aethiopicum* (P4), *Veronica plebeia, Poa porphyroclados* and *Oxalis corniculata*.	Priority 1
10	**Cheynes 1 Tree Mallee** *Eucalyptus acies, E. lehmanii, E. goniantha* Tree Mallee Tall Open Shrubland and Open Sedgeland on loam on steep slopes of spongelite breakaway. Common shrub species include *Gastrolobium bilobum, Rhadinothamnus rudis, Melaleuca blaeriifolia, Hakea elliptica, Spyridium majoranifolium* and *Agonis theiformis*. Common sedges include *Desmocladus flexuosus* and *Tetraria capillaris*. Priority taxa other than *E. acies* (P4) and *E. goniantha* (P4) include *Dryandra serra* (P4, at the eastern limit of its range) and *Calothamnus robustus* (P3).	Priority 1
11	**Cheynes 2 Open Tree Mallee** *Eucalyptus acies* (P4), *E. doratoxylon* Tree Mallee over Mixed Tall Open Shrubland, Open Shrubland and Open Sedgeland on loam on gentle to moderate slopes and crests of spongelite outcropping. Common tall shrub species include *Allocasuarina trichodon, Hakea cucullata* and *H. lasiantha*; however the tall shrub stratum may be absent. Common shrubs include *Calothamnus robustus* (P3), *Beaufortia empetrifolia, Dryandra mucronulata, Melaleuca striata* and *Taxandria spathulata*. Common sedges include *Mesomelaena stygia, M. tetragona, Cyathochaeta avenacea, Anarthria scabra* and *Chordifex leucoblepharus*.	Priority 1
12	**Heath on Komatiite at Bandalup Hill** Dense heath on alkaline red clay over komatiite (ultra-mafic rock) and associated carbonates. Note: very open tree mallee over heath B in Hale Bopp occurrence. Dominant species: *Beyeria* sp. Bandalup, *Acacia ophiolithica, Hakea verrucosa, Grevillea fastigiata, Melaleuca* sp. Gorse, *Allocasuarina* sp. Bandalup, *Verticordia oxylepis, Grevillea oligantha, Hybanthus floribundus, Pomaderris brevifolia* ssp. *brevifolia, Pultenaea wudjariensis, Melaleuca pomphostoma, Nematolepis phebalioides, Philotheca gardneri* Bandalup form, *Gyrostemon* sp. Ravensthorpe, *Calothamnus quadrifidus, Calytrix tetragona, Halgania anagalloides, Coleanthera myrtoides*. *Beyeria* sp., *Pultenaea wudjariensis, Grevillea fastigiata* and *Gyrostemon* sp. Ravensthorpe are narrow range endemics.	Priority 1
13	***Melaleuca* sp. Kundip Heath** Very open mallee over *Melaleuca* sp. Kundip (Collection number GF Craig 6020) dense heath. Open mallee over dense shrub heath (1.0-1.5) dominated by *Melaleuca* sp. Kundip on pale grey loamy sand with quartz rubble, occupies hill slopes. Associated species include *Melaleuca* sp. Kundip (GF Craig 6020) (P1) (dominant), *M. haplantha, M. stramentosa* (P1), *M rigidifolia, M. bracteosa, Melaleuca* sp. Gorse, *Pultenaea* sp. Kundip (GF Craig 6008) (P1), *Eucalyptus cernua, E. phaenophylla, E. pileata, Dodonaea trifida* (P3), *Acacia durabilis* (P3), *Leucopogon infuscatus and Hibbertia psilocarpa* ms. On its eastern boundary, the community abuts *Eucalyptus astringens* open low woodland and in this area there is an intergrade community.	Priority 1
14	**Montane mallee of the Stirling Ranges** Thicket, mallee-thicket and heath community on mid to upper slopes of Stirling Range mountains and hills east of Red Gum Pass.	Priority 1
15	**Coyanarup Wetland Suite** Microscale paluslopes associated with seepage and creeks in the area between Coyanarup Peak and Bluff Knoll in the Stirling Ranges.	Priority 1
16	***Eucalyptus purpurata* woodlands (Bandalup Hill)** *Eucalyptus purpurata* woodlands on magnesite soils of the ridge-tops and upper slopes of Bandalup Hill	Priority 1
17	**Open Low *Allocasuarina fraseriana – Eucalyptus staeri* woodland in association with *Banksia coccinea* thicket** The community occurs on the Dempster Landform Unit. This plant community occurs where the distribution of *A. fraseriana* and *B. coccinea* overlap within this landform unit. Associated species include *Jacksonia spinosa, Phyllota barbata, Daviesia flexuosa, Melaleuca thymoides, Agonis theiformis, Hypocalymma strictum, Adenanthos cuneatus, Adenanthos obovatus, Petrophile rigida, Andersonia caerulea, A. depressa, Leucopogon* spp., *Lysinema ciliatum, Needhamiella pumilio, Dasypogon bromeliifolius, Anarthria scabra, A. prolifera, Lyginia barbata, Hypolaena* sp., *Mesomelaena gracilipes, Lomandra* ssp., *Conostylis serrulata,*	Priority 1

	and Amperea ericoides.	
18	***Banksia laevigata – Banksia lemanniana* proteaceous thicket** This community occurs on laterised ridges and breakaways. Associated species generally include *Eucalyptus pleurocarpa, Adenanthos oreophilus, Leptospermum maxwellii, Beaufortia orbifolia, Taxandria spathulata* and *Stylidium albomontis.*	Priority 1
19	***Eucalyptus megacornuta* mallet woodland** Associated species include the shrubs *Hovea acanthoclada, Lasiopetalum compactum, Melaleuca thapsina.* This community typically grows on rock piles and breakaways of laterised banded ironstone and pyrite formations. A vegetation study noted that *E. megacornuta* is almost confined to the Ravensthorpe Range and was considered rare (less than 1,000 plants known in conservation reserves, or few populations).	Priority 1
20	**Albany Blackbutt (*Eucalyptus staeri*) mallee heath on lateritic ridges and seasonally-waterlogged laterite** Regionally very limited and very poorly reserved.	Priority 1
21	**Albany Blackbutt (*Eucalyptus staeri*) mallee-heath on deep sand** Appears to have been very extensive and common throughout the region although it has been comprehensively cleared and degraded (mainly due to grazing).	Priority 1
22	**Tallerack (*Eucalyptus pleurocarpa*) mallee-heath on heavy soils** May have been common prior to clearing for agriculture, and the remaining occurrences of this vegetation are of high conservation significance.	Priority 1
23	**Swamp Yate (*Eucalyptus occidentalis*) woodlands in seasonally inundated clay basins** Yate woodlands with intact understory and fringing vegetation are poorly conserved in the region.	Priority 1
24	**Microbial mantles of Nullabor caves (especially Weebubbie Cave)** Significant microbial communities in underwater sections of caves. Threats: uncontrolled access	Priority 1
25	**Rich troglobite and tree root habitats of Nullarbor caves (Nurina Cave, Olwolgin Cave, Burnabbie Cave, N327, N1327)** The caves contain rich communities of invertebrates and sensitive habitats, especially tree roots. Threats: uncontrolled access	Priority 1
25	**Scrub heath on deep sand with Banksia and Lambertia, and Banksia scrub heath on Esperance Sandplain** The scrub heath forms part of Beard's Esperance System and comprises two very closely related vegetation units (bSZc & blSZc) on sand of varying depths overlying clay: Scrub heath dominated by *Banksia speciosa* and *Lambertia inermis* and other proteaceous species such as *B. media* and *Hakea* spp. (with occasional *Nuytsia floribunda* and mallee species) over herbs on deep sand (to 1m) over clay over ironstone. The scrub heath may share a number of species in common with the Mallee heath vegetation unit (e26SZc) of the Esperance System: *Eucalyptus tetragona* and. *E decipiens* with occasional *E. incrassata, E. redunca* over *Lambertia inermis* and *Hakea* spp. on lateritic soil over ironstone.	Priority 3(iii)
26	**Woodline Hills vegetation complexes (*Baeckea recurva* shrubland)** Ridge communities unique but unless a mine is proposed are currently not threatened.	Priority 4 (a)
27	**Stirling Range Upland Yate community** Low woodland of *Eucalyptus cornuta* over a sparse shrub layer of *Gastrolobium velutinum, Chamelaucium pauciflorum* and *Thomasia foliosa* over open herbs of *Tetrarrhena laevis, Poa porphyroclados, Billardiera heterophylla, Clematis pubescens, Senecio* sp., *Hydrocotyle hirta, Cheilanthes austrotenuifolia* and *Asplenium flabellifolium.*	Priority 4(b)

* Community type occurs in more than one region

BUSHLAND PLANT SURVEY

A Guide to Plant Community Survey for the Community

by Bronwen Keighery

A Wildflower Society of WA (Inc.) Publication
September 1994

FIELD GUIDE TO BUSHLAND SURVEY RECORDING SHEET Use pencil for recording p1

RECORDING SHEET 1

• **Bushland Area**
Name your bushland area.
• **Site Number**
Each site must be coded and numbered as all plant specimens will need to be labelled with this information. The first four letters of the name should be used.
• **Date**
At least two visits should be made to each site so it is important to record the date of each visit.
• **Recorders**
Two people to four people should work on each site. Do not assume the same people will visit the site, record all people involved.

FIVE categories of descriptive information are collected.

1. LOCATION of the SITE

The position of the site is marked with four pegs which are positioned using the ropes as shown in Figure 17, page 23.
Detailed location information for each site is required, to revisit the site for the subsequent sampling and in the longer term. This information must be recorded as the pegs may be removed or relocated, a fire may occur in the area and other person will need to locate the site.
• **Mud Map**
Orientate your clipboard with the N arrow facing north. Draw a sketch of the location of the site. Indicate distance to firebreaks, roads and any other prominent land mark. Indicate the location of your site in relation to these using a 'marker' in and adjacent to your site. Your 'marker' should be a combination of plants, rock etc that will not be taken out by fire and is unique to your site. Look around your site make sure that the 'large' Jarrah you have indicated is not one of several in the area.
• **Road Location**
Give the nearest road and distance to the nearest intersection.
• **Geographic Location (optional)**
Locate your sites on a topographic map and determine latitude, longitude and altitude.
• **Photograph**
Take a photo of the site and record the point from which the photograph was taken on your site diagram with **P**. Any subsequent photos will be taken from this point.
• **Topographic position**
Locate your site on the transect and circle the position. Modify the diagram if this is necessary.

2. SITE DATA

• **Slope and Aspect**
An approximate measure of the degree of slope and the direction the slope faces is made. Circle the appropriate response.
• **Soil**
Surface soil can be observed by scrapping back the litter. Sub-surface soil is brought to the surface by ants and the best way to observe this is to find an ants nest in or near the site. Refer to laterite, clay, sandy clay, clayey sand or sand. Circle the appropriate response.
Rocks will be present in some areas and when present the percentage of exposed rock in the site should be recorded as well as the nature of the rock type.
• **Drainage**
The ability of site to drain after rain. To be recorded as well drained, moderate or poorly drained. This relates to soil type as well as topography. Circle the appropriate response.
• **Wetland status**
This records the duration through the year of free water. Recorded as; permanent - all year OR temporary - winter/spring. Circle the appropriate response and record the depth of the free water.
• **Litter**
A visual estimate (percentage range) of the litter cover, **disregarding the vegetation cover** will be made using the same scale (Table 1) to be used for recording the vegetation cover. Indicate the depth of the litter in centimetres or as a single layer of debris.
• **Bare ground**
The amount of the site with **no litter cover** over it. A visual estimate (percentage range) is made using the same scale (Table 1) to be used for recording vegetation cover.

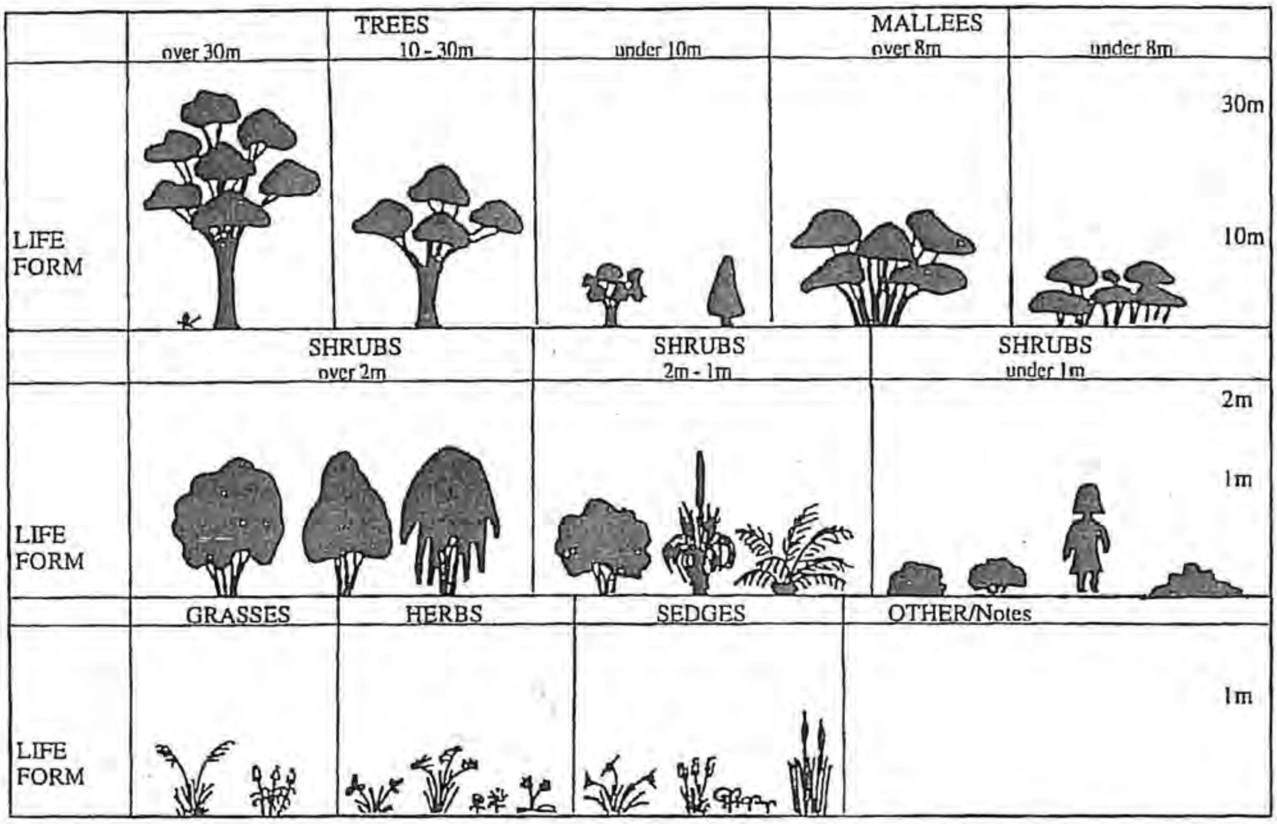
RECORDING SHEET 2

3. VEGETATION STRUCTURE AND COVER

Each layer of vegetation in the plant community is described according to life form, height, cover.and dominant species.

- **Life Form/Height**

Each layer in the community can be selected from the pictorial representations as shown below.



For each layer observed, working from the tallest to the shortest stratum, determine:

- **Cover**

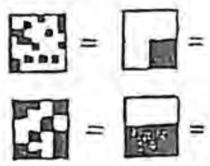
What is referred to as"crown cover"is used to record plant cover. This is the <u>total</u> area under an imaginary line bounding the extremities of all the plants.in each group described. The group may be a layer in the community, an individual species, litter or bare ground.

Crown cover

Individual clump

Crown cover area

Take crown cover of all plants concerned and mentally clump them into a corner of the site. This area gives the percentage cover.



To simplify the estimation of cover in this section cover 'classes' are used rather than trying to estimate an exact percentage .

Cover Classes	2-10%	10-30%	30 - 70%	over 70%

Not all layers will be present in a site.

- **Dominant Species**

Record the principal species, according to cover, in each layer. Label each plant as described in the section below. If there are more than three dominant species describe the layer as mixed.

Complete RECORDING SHEET 3 before doing section 4 below

4.VEGETATION CONDITION

• This category of **information** is collected **last** as you will need to be familiar with the vegetation and flora information for your bushland area to assess condition.

• You will **select a rating from the six vegetation condition ratings listed in Table 2.** The condition rating is related to the vegetation structure; that is the impact of disturbance on each of these layers and consequently on the ability of the community to regenerate.

• Make notes on the factors that contribute to the condition class determined.

Table 2: Vegetation Condition Scale
Modified from Trudgen, 1991 by B. J. Keighery for the Swan Coastal Plain Survey, 1993.

1 = 'Pristine'
Pristine or nearly so, no obvious signs disturbance.

2 = Excellent
Vegetation structure intact, disturbance affecting individual species and weeds are non-aggressive species
For example damage to trees caused by fire, the presence of non-aggressive weeds and occasional vehicle tracks.

3 = Very Good
Vegetation structure altered, obvious signs of disturbance.
For example disturbance to vegetation structure caused by repeated fires, the presence of some more aggressive weeds, dieback, logging and grazing.

4 = Good
Vegetation structure significantly altered by very obvious signs of multiple disturbance.
Retains basic vegetation structure or ability to regenerate to it.
For example disturbance to vegetation structure caused by very frequent fires, the presence of some very aggressive weeds at high density, partial clearing, dieback and grazing.

5 = Degraded
Basic vegetation structure severely impacted by disturbance. Scope for regeneration but not to a state approaching good condition without intensive management.
For example disturbance to vegetation structure caused by very frequent fires, the presence of very aggressive weeds, partial clearing, dieback and grazing.

6 = Completely Degraded
The structure of the vegetation is no longer intact and the area is completely or almost completely without native species.
These areas are often described as 'parkland cleared' with the flora composing weed or crop species with isolated native trees or shrubs.

RECORDING SHEET 3

5. SPECIES PRESENCE (floristic data)

In this section **every species present** in the study site is be recorded. It is best to
- start with the tallest stratum, i.e. trees or shrubs, working through each stratum to work on sedges last
- within each layer record the most common species first and the most uncommon last.
- systematically collect a small sample of each of each plant species.

• **Label** each plant with a watch makers tag bearing the following information
- **plants number** • **site code**
- **date** • plant's name or working name if required

• **Record matching information on RECORDING SHEET 3**
- **Column 1** - **Plant name** - if known record in the bushland otherwise leave blank.
- **Column 2** - **Plant number**
- **Column 3** - **Flowering** - TICK if species flowering
- **Column 4** - **Identification Check** - all specimens need to be identified and the identification checked.

All labelled specimens should be placed in the plastic collecting bag for pressing at the conclusion of the study site work.

Adjacent plants - Plants not found in your site but observed adjacent to the site can be collected but record them on the recording sheet with clear indication that they are adjacent.

BUSHLAND PLANT SURVEY RECORDING SHEET 1- use pencil only

BUSHLAND AREA ______________________ **SITE NUMBER** ____________

DATE TRIP ____________ **RECORDERS** ______________________

DATE TRIP ____________ **RECORDERS** ______________________

DATE TRIP ____________ **RECORDERS** ______________________

BOTANIST ______________________

From '*Bushland Plant Survey*' written by B. Keighery (1994) and published by the Wildflower Society of WA (Inc.), PO Box 64 Nedlands WA 6008.

1. LOCATION of the QUADRAT

Mud Map Draw a sketch of the location of the site below.

N

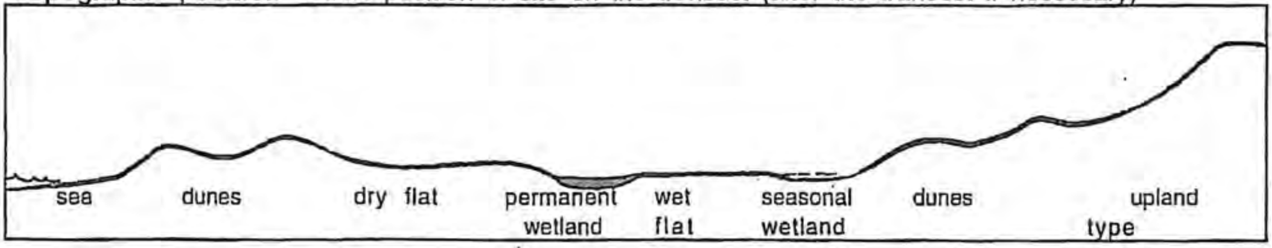
Road Location

Geographic Location **Latitude** **S** **Longitude** **E** **Altitude**

Reference Map

Photograph Photographer's Name Photo No

Topographic position Circle position of site on the transect (alter the transect if necessary)



2. SITE DATA Circle the correct response.

Slope flat gentle steep	***Aspect*** N NE E SE S SW W NW

Surface Soil	***Colour***
Exposed rock ***type***	% surface

Sub-surface Soil	***Colour***
Rock ***type***	depth to rock

Drainage well mod poor depth water cm	***Wet*** all year winter/spring

Litter % cover	***Bare Ground*** %cover
Depth cm	

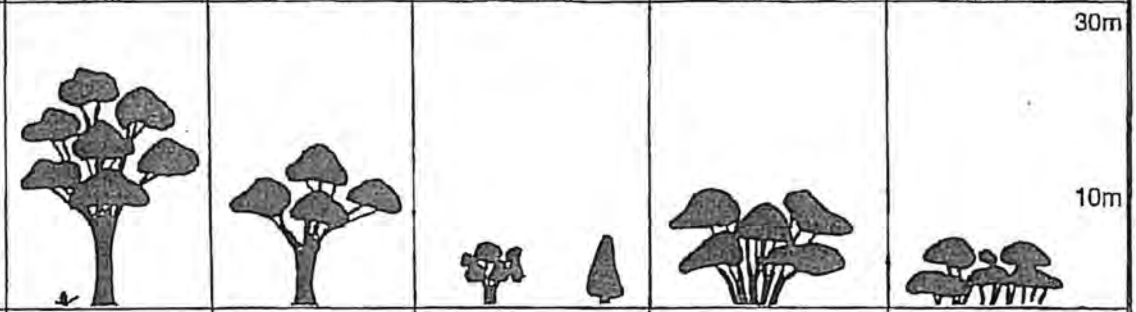
BUSHLAND PLANT SURVEY RECORDING SHEET 2 - use pencil only

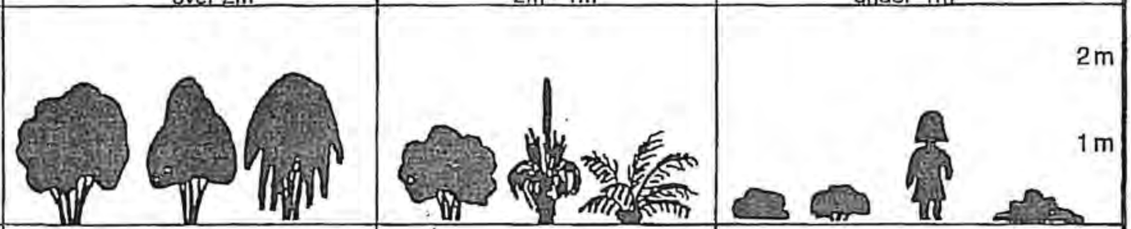
3. VEGETATION STRUCTURE AND COVER

From '*Bushland Plant Survey*' written by B. Keighery (1994) and published by the Wildflower Society of WA (Inc.), PO Box 64 Nedlands WA 6008.

For each layer record - appropriate **life form**, **cover class** (see below).and **dominant species** in each layer.

Cover Class	2-10%	10-30%	30 - 70%	over 70%

	TREES			MALLEES	
	over 30m	10 - 30m	under 10m	over 8m	under 8m
LIFE FORM					
COVER CLASS (%)					
DOMINANT SPECIES					

	SHRUBS		SHRUBS
	over 2m	2m - 1m	under 1m
LIFE FORM			
COVER CLASS (%)			
DOMINANT SPECIES			

	GRASSES	HERBS	SEDGES	OTHER
LIFE FORM				
COVER CLASS (%)				
DOMINANT SPECIES				

4. VEGETATION CONDITION

			COMMENTS
1	'PRISTINE'		
2	EXCELLENT		
3	VERY GOOD		
4	GOOD		
5	DEGRADED		

BUSHLAND PLANT SURVEY RECORDING SHEET 3 - use pencil only

5. SPECIES PRESCENCE

SITE No	
Date	

Label each plant with plants number, site code, date and plant's name or working name if required

Record on Sheet
- Column 1 plant name-
- Column 2 plant number
- Column 3 flowering time- TICK if species flowering
- Column 4 identification check

From *'Bushland Plant Survey'* written by B. Keighery (1994) and published by the Wildflower Society of WA (Inc.), PO Box 64 Nedlands WA 6008.

TREES	No	FI	ID	SHRUBS (cont.)	No	FI	ID	HERBS (cont.)	No	FI	ID
MALLEES											
				GRASSES							
SHRUBS											
								SEDGES			
				HERBS							

Appendix 2

Western Australian Department of Agriculture Technote No. 4/83
Reproduced with permission from the Department of Agriculture.

Soil texture classification

By R. Pepper, Research Officer, Resource Management Division
For a more complete description of soil texturing, refer to 'Australian Soil and Land Survey handbook', compiled and edited by R.C. McDonald, R.F. Isbell and J.G. Speight, from which most of these notes were prepared.

Soil texture indicates the relative proportions of sand, silt, and clay-sized particles in a soil. These proportions govern the amount of water a soil can store and how much is available for plant growth. Texture determines the speed at which water drains through a soil profile which is important for crop growth or for storing water in earth dams.

Soil texture should not be confused with the consistency properties of soil such as 'heavy' or 'light' which refer to its ease of cultivation.

Soil texture can be assessed readily in the field by hand. The method is a short-cut to the more exact technique of mechanical analysis used in the laboratory in which the various proportions of sand, silt and clay in the soil are measured.

If moist soil is hand-textured, it can be placed into textural classes as shown in Figure 1, and compared with others.

Soil rarely consists of only one particle size. The basic classes, in increasing proportions of the fine fractions (silt and clay) are:

Increasing clay content →

- sand, loamy sand
- sand loam, loam, silt loam
- sandy clay loam, clay loam, silty clay loam
- sandy clay, silty clay and clay

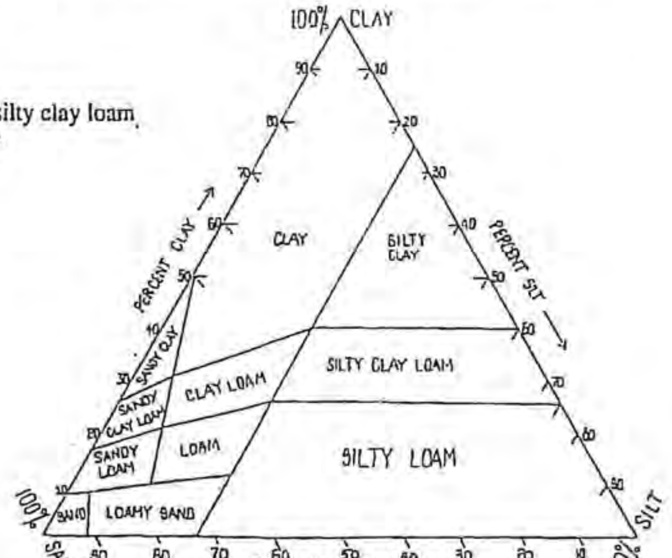


Figure 1: Texture diagram. (Based on international fractions with effective diameters 0.002, 0.02 and 2mm for the upper limits of clay, silt and sand fractions respectively.)

Method

Soil texture is determined on soil which passes a 2mm sieve. Particles greater than 2mm are classed as gravel or stones and modify the textural classes, such as gravelly sandy loam, or stoney loam.

Texture cannot be assessed on a handful of dry soil. A hand texture test is done by placing enough sieved soil to fit comfortably in the palm of the hand. Water is added, a little at a time and the moistened soil kneaded to form a ball. When the ball just fails to stick to the fingers, no more water is added but kneading is continued for about one minute to produce a soil ball uniformly wet throughout.

The behaviour of this moist soil and the flat ribbon produced when it is squeezed between the thumb and forefinger, characterises the soil texture. The squeezed soil forms a flat ribbon between 2 to 3mm thick. The length of this ribbon indicates the soil texture.

The textural classes defined by this method are:

Sand - no coherence when moist or dry. Individual particles easily seen.

Loamy sand - slight coherence when moist. Can be squeezed into a ribbon about 5mm long.

Sandy loam - moist soil just coherent, very sandy to touch, will form a ribbon 15 - 25mm long, sand grains are readily seen

Loam - moist soil coherent and rather spongy, some plasticity, smooth feel with no obvious sandiness. Will form a ribbon about 25mm long

Silty Loam - moist soil quite coherent, feels very smooth to silky. Forms a ribbon 25mm long.

Sandy clay loam - strongly coherent, sandy to touch, with sand grains visible in fine matrix. Will form a ribbon 25 - 40mm long.

Clay loam - moist soil coherent and plastic, smooth to manipulate. Will form a ribbon 40 - 50mm long.

Silty clay loam - coherent smooth, plastic and silky to touch. Will form a ribbon 40-50mm long.

Sandy clay - plastic, sands seen and felt in clayey matrix. Will form a ribbon 50-75mm long.

Silty Clay - very plastic, smooth and silky to manipulate. Will form a ribbon 50 - 70mm long.

Clay - very smooth to touch, highly plastic. Will form a ribbon 60 - 75mm long.

Other properties affecting texture

Although texture is strongly influenced by clay content, other properties can affect soil texture:

• Type of clay mineral - Montmorillonite makes the soil resist deformation, so is stiffer to squeeze into a ribbon. Therefore a longer ribbon may be produced indication more clay than is present. Kaolinite makes the soil appear less clayey, and easily squeezed into shorter ribbons.

• Silt Particles - Silt particles give the soil a silky smoothness, typical of the many pallid zone materials in the south-west of Western Australia.

• Organic matter - Organic matter confers cohesion to sandy soils and a greasiness to clayey soils. Therefore soils that have a high clay content and enough organic matter may texture as clay loams instead of clays.

• Iron and aluminium oxides - Iron and aluminium oxides, present in pink and red soils, may need more water to form a plastic soil ball. When squeezed, the ball only produces a short ribbon, indicating a less clayey texture. This is because the iron and aluminium oxides cement clay particles together.

• Calcium and magnesium carbonates - If calcium and magnesium carbonates are present, moist soil feels spongy. For sandy and loamy textures, carbonates make the soil appear more clayey. However the carbonates may make clay textures appear less clayey because they cement clay particles together.

• Cation capacity and exchangeable cations - Calcium saturated clays are usually easier to wet and knead and give a smooth texture. Sodium and magnesium saturated clays are more difficult to wet. They produce a soil that sticks to the fingers and is stiff and hard to ribbon, thus appearing more clayey than they are.

• Strong structural aggregation - Clay content will be under-estimated if the soil is strongly aggregated. Usually prolonged and vigorous kneading will break down the aggregates and texture will be closer to true clay content.

Since the above properties vary in the soils, specific allowance cannot be made for them and hand texturing must remain a subjective measure of the properties of sand , silt and clay in a soil.

However, despite limitations, soil texturing is a useful field guide to a soil's water holding characteristics and clay content and indicates how well water may move through it. Soil texture probably provides the most complete assessment of the overall behaviour of soil and its agricultural usefulness.

Table 12: Vegetation Condition Scales commonly used in the Perth Metropolitan Region

Condition scale used in BUSH FOREVER, VOL 2, from Keighery B J (1994)	Condition scale used to derive Keighery B J (1994) and Connell (1995) after Trudgen (1991)	Condition scale used in PEP MAPPING after Connell (1995)
Pristine (1) Pristine or nearly so, no obvious signs of disturbance	Excellent (E) Pristine or nearly so, no obvious signs of damage caused by the activities of European man.	No equivalent unit
Excellent (2) Vegetation structure intact, disturbance affecting individual species and weeds are non-aggressive species.	Very Good (VG) Some relatively slight signs of damage caused by the activities of European man. For example, some signs of damage to tree trunks caused by repeated fires and the presence of some relatively non-aggressive weeds such as *Ursinia anthemoides* or *Briza* species, or occasional vehicle tracks.	Very Good (vg) Evidence of localised low level damage to otherwise healthy bush. Seedling recruitment and generally healthy population size (age/stage) structure apparent. Weed and grazing damage is confined (<20% of area). Some modification to vegetation structure due to changes in fire regimes may be apparent. Evidence of logging or fire wood collection may be found. High likelihood that vegetation structure and species richness can be maintained.
Very Good (3) Vegetation structure altered, obvious signs of disturbance. For example, disturbance to vegetation structure caused by repeated fires, the presence of some more aggressive weeds, dieback, logging and grazing.	Good (G) More obvious signs of damage caused by the activities of European man, including some obvious impact on the vegetation structure such as caused by low levels of grazing or by selective logging. Weeds as above, possibly plus some more aggressive ones.	Good (g) Evidence of localised high level damage to otherwise low level damaged bush. Recruitment is localised and the populations of some species may be senescent. Weed and grazing damage is apparent in 20–50% of the area. Modification to vegetation structure due to changes in fire regimes may be apparent. Localised gall and parasitic plant damage may be apparent. Evidence of logging or firewood collection. Moderate likelihood that vegetation structure and species richness can be maintained.
Good (4) Vegetation structure significantly altered by very obvious signs of multiple disturbance. Retains basic vegetation structure or ability to regenerate it. For example, disturbance to vegetation structure caused by very frequent fires, the presence of some very aggressive weeds at high density, partial clearing, dieback and grazing	Poor (P) Still retains basic vegetation structure or ability to regenerate to it after very obvious impacts of activities of European man such as grazing or partial clearing (chaining) or very frequent fires. Weeds as above, probably plus some more aggressive ones such as *Ehrharta* species.	Poor (p) Widespread high level damage. Recruitment is disrupted and most woody species appear senescent. Weed and grazing damage may be apparent throughout >50% of the area. Modification to vegetation structure due to changes in fire regimes may be apparent. Locally some vertical strata are absent. Gall and mistletoe damage apparent. Evidence of logging or firewood collection. Low likelihood that vegetation structure and species richness can be maintained or re-established.
Degraded (5) Basic vegetation structure severely impacted by disturbance. Scope for regeneration but not to a state approaching good condition without intensive management. For example, disturbance to vegetation structure caused by very frequent fires, the presence of very aggressive weeds, partial clearing, dieback and grazing.	Very Poor (VP) Severely impacted by grazing, fire, clearing, or a combination of these activities. Scope for some regeneration but not to a state approaching good condition without intensive management. Usually with a number of weed species including aggressive species.	Very Poor (vp) Widespread high level damage. Recruitment is disrupted and most species appear senescent. Weed and grazing damage apparent throughout the area. Modification to vegetation structure due to changes in fire regimes apparent. Widespread loss of vertical strata. Gall and mistletoe damage apparent. Evidence of logging or firewood collection. Little to no likelihood that vegetation structure and species richness can be re-established.
Completely Degraded (6) The structure of the vegetation is no longer intact and the area is completely or almost completely without native species. These areas are often described as 'parkland cleared' with the flora comprising weed or crop species with isolated native trees or shrubs.	Completely Degraded (D) Areas that are completely or almost completely without native species in the structure of their vegetation i.e. areas that are cleared or 'parkland cleared' with their flora comprising weed or crop species with isolated native trees or shrubs.	Not used – does not apply to bushland.

List of Threatened Ecological Communities on the Department of Environment and Conservation's Threatened Ecological Community (TEC) Database endorsed by the Minister for the Environment

Species & Communities Branch (Correct to December 2006)

Community identifier	Community name	General Location (IBRA Regions)	Category of Threat and criteria met under WA criteria	Category under Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*
1. SCP20a	Banksia attenuata woodland over species rich dense shrublands	Swan Coastal Plain	EN B) ii)	
2. TOOLIBIN	Perched wetlands of the Wheatbelt region with extensive stands of living Swamp Sheoak (*Casuarina obesa*) and Paperbark (*Melaleuca strobophylla*) across the lake floor.	Avon Wheatbelt	CR A) i); CR A) 11); CR C)	EN
3. SCP10b	Shrublands on southern Swan Coastal Plain Ironstones (Busselton area)	Swan Coastal Plain	CR B) ii)	EN
4. SCP19	Sedgelands in Holocene dune swales of the southern Swan Coastal Plain	Swan Coastal Plain	CR B) ii)	EN
5. Clifton-microbialite	Stromatolite like freshwater microbialite community of coastal brackish lakes	Swan Coastal Plain	CR B) i), CR B) ii)	
6. Richmond-microbial	Stromatolite like microbialite community of coastal freshwater lakes	Swan Coastal Plain	CR B)i), CR B) ii)	EN
7. Mound Springs SCP	Communities of Tumulus Springs (Organic Mound Springs, Swan Coastal Plain)	Swan Coastal Plain	CR A) i), CR A) ii), CR B) i), CR B) ii)	EN
8. SCP20c	Shrublands and woodlands of the eastern side of the Swan Coastal Plain	Swan Coastal Plain	CR B) ii)	EN
10. NTHIRON	Perth to Gingin Ironstone Association	Swan Coastal Plain	CR A) ii), CR B) ii), CR C)	EN
11. MUCHEA LIMESTONE	Shrublands and woodlands on Muchea Limestone	Swan Coastal Plain	EN B) ii)	EN
12. Augusta-microbial	Rimstone Pools and Cave Structures Formed by Microbial Activity on Marine Shorelines	Warren	EN B) ii)	
13. SCP30a	Callitris preissii (or Melaleuca lanceolata) forests and woodlands, Swan Coastal Plain	Swan Coastal Plain	VN B)	
14. SCP18	Shrublands on calcareous silts of the Swan Coastal Plain	Swan Coastal Plain	VN B)	
15. SCP02	Southern wet shrublands, Swan Coastal Plain	Swan Coastal Plain	EN B) ii)	

16. SCP3a	*Eucalyptus calophylla* - *Kingia australis* woodlands on heavy soils, Swan Coastal Plain	Swan Coastal Plain	CR B) ii)	EN
17. SCP3c	*Eucalyptus calophylla* - *Xanthorrhoea preissii* woodlands and shrublands, Swan Coastal Plain	Swan Coastal Plain	CR B) ii)	EN
18. Thetis-microbialite	Stromatolite community of stratified hypersaline coastal lakes	Geraldton Sandplain	VN B)	
19. SCOTT IRONSTONE	Scott River Ironstone Association	Warren	EN B) i), EN B) ii)	
20. SCP20b	Banksia attenuata and/or *Eucalyptus marginata* woodlands of the eastern side of the Swan Coastal Plain	Swan Coastal Plain	EN B) i), EN B) ii)	
21. SCP15	Forests and woodlands of deep seasonal wetlands of the Swan Coastal Plain	Swan Coastal Plain	VN C)	
22. SCP1b	*Eucalyptus calophylla* woodlands on heavy soils of the southern Swan Coastal Plain	Swan Coastal Plain	VN B)	
23. SCP3b	*Eucalyptus calophylla* - *Eucalyptus marginata* woodlands on sandy clay soils of the southern Swan Coastal Plain	Swan Coastal Plain	VN B)	
24. CAVES SCP01	Aquatic Root Mat Community Number 1 of Caves of the Swan Coastal Plain	Swan Coastal Plain	CR B) i), CR B) ii)	EN
25. CAVES LEEUWIN01	Aquatic Root Mat Community Number 1 of Caves of the Leeuwin Naturaliste Ridge	Warren	CR B) i), CR B) ii)	EN
26. CAVES LEEUWIN02	Aquatic Root Mat Community Number 2 of Caves of the Leeuwin Naturaliste Ridge	Warren	CR B) i), CR B) ii)	EN
27. CAVES LEEUWIN03	Aquatic Root Mat Community Number 3 of Caves of the Leeuwin Naturaliste Ridge	Warren	CR B) i), CR B) ii)	EN
28. CAVES LEEUWIN04	Aquatic Root Mat Community Number 4 of Caves of the Leeuwin Naturaliste Ridge	Warren	CR B) i), CR B) ii)	EN
29. MONTANE	Montane Thicket of the eastern Stirling Range	Esperance Sandplain	CR B) ii)	EN
30. MEELUP GRANITES	*Calothamnus graniticus* heaths on south west coastal granites	Warren/Jarrah Forest	VN B)	
32. SCP07	Herb rich saline shrublands in clay pans	Swan Coastal Plain	VN B)	
33. SCP08	Herb rich shrublands in clay pans	Swan Coastal Plain	VN B)	
34. SCP09	Dense shrublands on clay flats	Swan Coastal Plain	VN B)	
35. SCP10a	Shrublands on dry clay flats	Swan Coastal Plain	EN B) ii)	
38. Morilla swamp	Perched fresh-water wetlands of the northern Wheatbelt dominated by extensive stands of living *Eucalyptus camaldulensis* (River Red Gum) across the lake floor.	Avon Wheatbelt	PD B)	

39. Camerons	Camerons Cave Troglobitic Community	Carnarvon Basin	CR B) i), CR B) ii)
40. Bryde	Unwooded freshwater wetlands of the southern Wheatbelt of Western Australia, dominated by *Muehlenbeckia horrida* subsp. *abdita* and *Tecticornia verrucosa* across the lake floor	Avon Wheatbelt	CR B) i), CR B) ii)
41. Bundera	Cape Range Remipede Community	Carnarvon Basin	CR B) ii)
42. Greenough River Flats	*Acacia rostellifera* low forest with scattered *Eucalyptus camaldulensis* on Greenough Alluvial Flats.	Geraldton Sandplain	CR C)
44. Roebuck Bay mudflats	Species-rich faunal community of the intertidal mudflats of Roebuck Bay	Kimberley	VU B)
46. Themeda Grasslands	Themeda grasslands on cracking clays (Hamersley Station, Pilbara). Grassland plains dominated by the perennial Themeda (kangaroo grass) and many annual herbs and grasses.	Pilbara	VN A)
49. Bentonite Lakes	Herbaceous plant assemblages on Bentonite Lakes	Avon Wheatbelt	EN B) iii)
55. Coomberdale chert hills	Heath dominated by one or more of *Regelia megacephala*, *Kunzea praestans* and *Allocasuarina campestris* on ridges and slopes of the chert hills of the Coomberdale floristic region.	Avon Wheatbelt	EN B) ii)
56. Billeranga System	Plant assemblages of the Billeranga System (Beard 1976): *Melaleuca filifolia – Allocasuarina campestris* thicket on clay sands over laterite on slopes and ridges; open mallee over mixed scrub on yellow sand over gravel on western slopes; *Eucalyptus loxophleba* woodland over sandy clay loam or rocky clay on lower slopes and creeklines; and mixed scrub or scrub dominated by *Dodonaea inaequifolia* over red/brown loamy soils on the slopes and ridges	Avon Wheatbelt	VN A), VN B)
59. Koolanooka System	Plant assemblages of the Koolanooka System (Beard 1976): Allocasuarina campestris scrub over red loam on hill slopes; Shrubs and emergent mallees on shallow loam red over massive ironstone on steep rocky slopes; *Eucalyptus ebbanoensis* subsp. *ebbanoensis* mallee and *Acacia* sp. scrub with scattered *Allocasuarina huegeliana* over red loam and ironstone on the upper slopes and summits; *Eucalyptus loxophleba* woodland over scrub on the footslopes; and mixed *Acacia* sp. scrub on granite	Avon Wheatbelt	VN A), VN B)

60. Moonagin System	Plant assemblages of the Moonagin System (Beard 1976): Acacia scrub on red soil on hills; Acacia scrub with scattered *Eucalyptus loxophleba* and *Eucalyptus oleosa* on red loam flats on the foothills.	Avon Wheatbelt	VN A), VN B)
62. Limestone ridges (SCP 26a)	*Melaleuca huegelii - Melaleuca acerosa* shrublands on limestone ridges (Gibson *et al*. 1994 type 26a)	Swan Coastal Plain	EN B) iii)
63. Irwin River Clay Flats	Clay flats assemblages of the Irwin River: Sedgelands and grasslands with patches of Eucalyptus loxophleba and scattered *E. camaldulensis* over *Acacia acuminata* and *A. rosellifera* shrubland on brown sand/loam over clay flats of the Irwin River.	Avon Wheatbelt	PD A), PD B)
67. Monsoon thickets	Monsoon (vine) thickets on coastal sand dunes of Dampier Peninsula	West Kimberley, Dampierland Bioregion	VU C)
70. Mt Lindesay	Mt Lindesay – Little Lindesay Vegetation Complex	Frankland District, Warren Region	EN B) ii)
71. Russell Range	Russell Range mixed thicket complexes	South Coast, Esperance Plains Bioregion	VN B), VN C)
72. Ferricrete	Ferricrete floristic community (Rocky Springs type)	Geraldton Sandplain	VU B)
74. Herblands and Bunch Grasslands	Herblands and Bunch Grasslands on gypsum lunette dunes alongside saline playa lakes	Esperance Sandplain	VU B)
75. Inering System	Plant assemblages of the Inering System (Beard 1976)	Avon Wheatbelt	VN A)
76. Lesueur-Coomallo Florstic Community D1	Lesueur-Coomallo Floristic Community D1	Geraldton Sandplain	CR B) i) CR B) ii)
77.Lesueuer-Coomallo Floristic Community A1.2	Lesueur-Coomallo Floristic Community A1.2	Geraldton Sandplain	EN B) ii)
78. Ethel Gorge	Ethel Gorge aquifer stygobiont community	Pilbara	EN B) ii)
80. Theda Soak	Assemblages of Theda Soak rainforest swamp	North Kimberley	VU A), VU B)
81. Walcott Inlet	Assemblages of Walcott Inlet rainforest swamps	North Kimberley	VU B)
82. Roe River	Assemblages of Roe River rainforest swamp	North Kimberley	VU B)
84. Dragon Tree Soak	Assemblages of Dragon Tree Soak organic mound spring	Kimberley Region, Great Sandy Desert Bioregion	EN B) i)
85. Bunda Bunda	Assemblages of Bunda Bunda organic mound spring	West Kimberley, Dampierland Bioregion	VU A), VU B)
86. Big Springs	Assemblages of Big Springs organic mound springs	West Kimberley, Dampierland Bioregion	VU A), VU B)
89. North Kimberley mounds	Organic mound spring sedgeland community of the North Kimberley Bioregion	North Kimberley	VU A), VU B)

92. Black Spring	Black Spring organic mound spring community	North Kimberley	EN B) i), EN B) ii)
95. Mandora Mounds	Assemblages of the organic springs and mound springs of the Mandora Marsh area	West Kimberley, Dampierland and Greats Sandy Desert Bioregions	EN B) iii)
96. Broomehill	Plant assemblages of the Broomehill System	Avon Wheatbelt	PD A)
97. Mound Springs (Three Springs area)	Assemblages of the organic mound springs of the Three Springs area	Avon Wheatbelt	EN B) i), EN B) ii)
99. Depot Springs	Depot Springs stygofauna community	Goldfields Region, Murchison Bioregion	VU B)
102. Eucalyptus acies mallee heath	Thumb Peak, Mid mount Barren, Woolburnup Hill (Central Barren Ranges) *Eucalyptus acies* mallee heath	Esperance Sandplain	VU B)

Total = 69 TECs in Western Australia that are endorsed by the Minister for Environment(16 of these are listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*)

Critically Endangered: 21; Endangered: 17; Vulnerable: 28; Presumed Destroyed: 3

Natural Diversity Recovery Catchments

Landscape Level Conservation

By Roger Hearn for Flora Conservation Course

Session Outline

Landscapes
Natural Diversity Recovery Catchments
Policy and management framework
Muir Unicup examples

Landscapes – Where do they fit into the conservation picture?

Individuals – a package of genes drawn from a population, conservation measures include cloning, ex situ cultivation, etc

Populations – local scale, local actions, mitigating local threats (weeds, disturbance, fire, grazing, etc), seed collection and storage, translocations, etc.

Species – poor, vague but useful concept, focus on groups of closely related populations of genes, conservation involves local actions across the individual populations as above.

Communities – assemblages of populations of different species cohabiting a patch and utilising a shared resource base, again most actions associated with their conservation are local as for populations.

Ecosystems – assemblages of communities within a landscape or spanning landscapes where landscapes are typified by geology, geomorphology, hydrology, hydrogeology, climate and ecological processes, and where conservation measures target large scale processes.

Landscapes may be contained within ecosystems, or ecosystems may be contained within landscapes – a matter of scale.

Landscape conservation actions

Reservation in 'Protected Areas'

Protection from large scale disturbance or mitigation of large scale disturbance and may include

- Feral animal management – pigs, horses, goats, foxes, cats
- Weed management – East Coast Wattles, blackberries, etc.
- Fire management – appropriate regimes for communities and species
- Restoring hydrology or managing it to mitigate effects of irreversible change
- Restoration works to recreate communities

Landscape Conservation Projects in WA – a few examples

Rangelands conservation project – lease cancellation, destocking, closure of stock water, rehabilitation and restoration, etc

Linkage corridor establishment – "Gondwanan Link", land acquisition, restoration works, covenanting private land, etc

Gnangara Strategy – groundwater management, cave water management, plantation removal and landscape restoration

Natural Diversity Recovery Catchments – wetland and valley floor community conservation in a salinising landscape

Natural Diversity Recovery Catchments

Areas where land clearing and drainage for agriculture has resulted in altered hydrology, and where this altered hydrology is threatening high value, often remnant, "Natural Diversity" assets

These assets usually include threatened species and threatened communities.

Alteration usually involves mobilization of salt in the landscape, usually with a change of water levels in wetlands, changes to depth to water tables, altering hydro-periods and hydrological cycles, and as we are increasingly understanding, acidification of the landscape.

Why Catchments?

Catchments as they are natural hydrological units – almost, as groundwater catchments don't always align with surface water catchments

Conservation measures usually have to be applied remote from the asset to be protected as threatening processes act from afar - what happens "upslope" has "down slope" consequences

To act, need to know your landscape and how it works – general principles are only a start

Research is essential to build a picture of the underlying geology (rocks and surfaces), the regolith (its varying structures and landforms with their chemical properties, hydrological properties and physical properties), surface water systems, groundwater systems, erosion and deposition (water and wind), fire and biological processes

State Policy

"the Govt will develop and implement a co-ordinated Wetlands and Natural Diversity Recovery Program.......to ensure that critical and regionally significant natural areas, particularly wetlands, are protected in perpetuity."

[Western Australian Salinity Action Plan (1996); reconfirmed in State Salinity Strategy (2000), Government Response to Salinity Taskforce Report (2002]

Key Aims

To protect high priority biodiversity assets, particularly wetlands, that are at risk from salinity, and which are regionally significant (note also physical diversity component)

To contribute to the development of technologies to combat salinity throughout the agricultural region

Catchment Selection

Three Phases of Selection

- Expert system processes
- Expert system processes with explicit criteria
- As above, plus analysis of outputs from the biological survey of the agricultural region

Phase 1 - Expert system processes

At start of SAP 3 catchments were ready to go or up and running

Phase 2 - Expert system processes with explicit criteria

Biodiversity values at risk
Biogeographic representation
Opportunities for R&D or demonstration sites
Tenure of land at risk
Representation of hazard
Potential for success
Socio-political considerations

Additional 3 Catchments added and several others tentatively identified

Phase 3 - Expert system processes with explicit criteria plus analysis of outputs from the biological survey of the agricultural region

Biodiversity values
- Irreplaceability analysis (community)
- Species analysis

Feasibility
- Biophysical threat analysis
- Knowledge and technical capacity, costs
- Socio-political will

A further suite of about 20 catchments identified

Planning & Management Processes

- Specific catchment goals
- Define biodiversity assets
- Biophysical threat analysis and feasibility
- Complete and implement management plan
- Monitor and evaluate

Hydro Management Integrates:

Biophysical components (incl. science)

- Rainfall
- Surface water – lakes, streams
- Groundwater - hydrogeology
- Evapotranspiration

Salinity Management Package

- Engineering – drains, pumps, siphons
- Enhanced storage
- Revegetation
- Agronomic change
- Remnant vegetation protection

Management aims to deliver regimes of:

- Salinity, sediments, nutrients etc. of surface water entering asset.
- Volumes and timing of surface water entering asset.
- Depth to groundwater under asset.
- Salinity, sediments, nutrients etc. of ground water entering the asset.
- Volumes and timing of ground water entering the asset.

Muir Unicup:

- Map, photo mosaic, topography
- Background
- Assets, wetlands, waterbirds, plants, invertebrates and fish
- Revegetation
- Rem Veg protection
- Plantations cropping and grazing
- Biological Surveys
- Groundwater, Geology, Hydrogeology, Acidity
- Surface water, lakes and streams
- Weeds and ferals

Muir Unicup: Outputs and outcomes

Outputs

- seedlings (about 300 ha)
- land purchase (about 250ha)
- research/investigations (, ,)
  - veg mapping
  - invertebrates
  - salinity in groundwater and soils
  - surface water hydrology
  - acid ground water
  - geology
- planning/communication (community meetings, planning)
- misc. including weed control and recreation facilities.
- engineering works in the future

Outcomes

- Positive impacts on groundwater in Yarnup.
- Research and development for broader application
- Rehabilitation for habitat as well as water

Natural Diversity Recovery Catchments

Landscape Level Conservation

Roger Hearn for Flora Conservation Course 2009

Session Outline

- Landscapes
- Natural Diversity Recovery Catchments
- Policy and management framework
- Muir Unicup examples

Landscapes – Where do they fit into the conservation picture?

- Individuals
- Populations
- Species
- Communities
- Ecosystems

Landscapes – Where do they fit into the conservation picture?

- Individuals
  - package of genes drawn from a population
  - measures include cloning
  - ex situ cultivation
  - translocations

Landscapes – Where do they fit into the conservation picture?

- Populations
  - local scale, local actions
  - mitigating local threats
  - seed collection and storage
  - translocations

Landscapes – Where do they fit into the conservation picture?

- Species
  - poor, vague but useful concept
  - focus on groups of closely related populations of genes
  - involves local actions across the individual populations

Landscapes – Where do they fit into the conservation picture?

- Communities
  - assemblages of populations of different species cohabiting a patch and utilising a shared resource base
  - most actions associated with their conservation are local as for populations
  - But not always

Landscapes – Where do they fit into the conservation picture?

- Ecosystems
  - assemblages of communities within or spanning landscapes
  - typified by geology, geomorphology, hydrology, hydrogeology, climate and ecological processes
  - measures target large scale processes

Landscapes – Where do they fit into the conservation picture?

- Landscapes may be contained within ecosystems, or ecosystems may be contained within landscapes – a matter of scale.

Landscape Conservation

- Reservation in 'Protected Areas'
- Protection from large scale disturbance
- Mitigation of large scale disturbance

Landscape Conservation – management actions

- Feral animal management
- Weed management
- Fire management
- Restoring or managing hydrology
- Restoration to recreate communities

Landscape Conservation Projects in WA

- Rangelands conservation project
  - lease cancellation
  - destocking
  - closure of stock water
  - rehabilitation and restoration

Landscape Conservation Projects in WA

- Linkage corridor establishment
  - "Gondwanan Link"
  - land acquisition
  - restoration works
  - covenanting private land

Landscape Conservation Projects in WA

- Gnangara Strategy
  - groundwater management
  - cave water management
  - plantation removal
  - landscape restoration

Landscape Conservation Projects in WA

- Natural Diversity Recovery Catchments
  - valley floor communities
  - wetland conservation
  - in a salinising landscape
  - in an acidity prone landscape

Natural Diversity Recovery Catchments

- Areas of high value, often remnant, "Natural Diversity" assets
- These assets usually include threatened species and threatened communities.
- Subject to historic land clearing and drainage for agriculture
- Resulting in altered landscape hydrology
- Altered hydrology is threatening the assets

Natural Diversity Recovery Catchments

- Altered Hydrology usually includes
  - mobilization of salt in the landscape
  - change of water levels in wetlands
  - changes to depth to water tables
  - altering hydro-periods and hydrological cycles
  - acidity

Why Catchments?

- they are natural hydrological units – almost
- groundwater catchments don't always align with surface water catchments
- actions usually have to be applied remote from the asset
- processes act from afar - what happens "upslope" has "down slope" consequences

Why Catchments?

- To act, need to know your landscape and how it works
- general principles are only a start
- underlying geology (rocks and surfaces)
- regolith (its varying structures and landforms with their chemical properties, hydrological properties and physical properties)
- surface water and groundwater systems
- erosion and deposition (water and wind)
- fire and biological processes

Policy and management framework

- State Policy
- Key Aims
- Catchment Selection
- Planning & Management Processes
- Hydro Management
- What Management aims to deliver

State Policy

- "the Govt will develop and implement a co-ordinated Wetlands and Natural Diversity Recovery Program.......to ensure that critical and regionally significant natural areas, particularly wetlands, are protected in perpetuity."

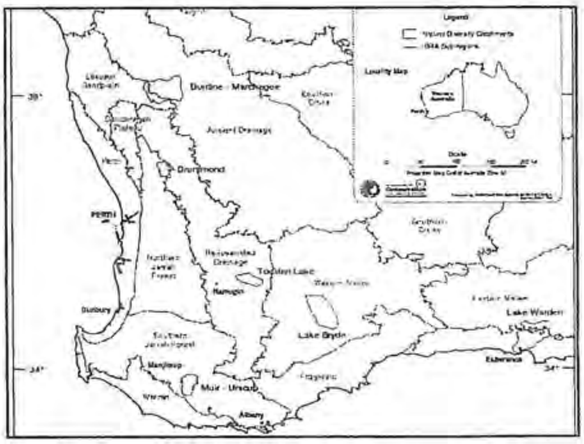
[Western Australian Salinity Action Plan (1996); reconfirmed in State Salinity Strategy (2000), Government Response to Salinity Taskforce Report (2002]

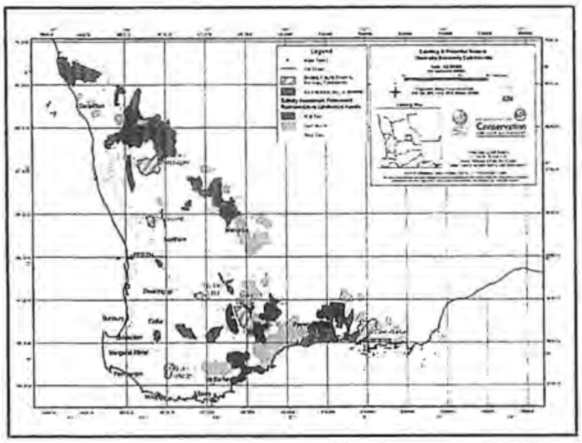
Key Aims

- To protect high priority biodiversity assets, particularly wetlands, that are at risk from salinity, and which are regionally significant (note also physical diversity component)
- To contribute to the development of technologies to combat salinity throughout the agricultural region

Catchment Selection

- Three Phases of Selection
  - Expert system processes
  - Expert system processes with explicit criteria
  - As above plus analysis of outputs from the biological survey of the agricultural region





Planning & Management Processes

- Specific catchment goals
- Define biodiversity assets
- Biophysical threat analysis and feasibility
- Complete and implement management plan
- Monitor and evaluate

Hydro Management Intigrates

Biophysical components

- Rainfall
- Surface water – lakes, streams
- Groundwater – hydrogeology, hydrogeochemistry
- Evapotranspiration

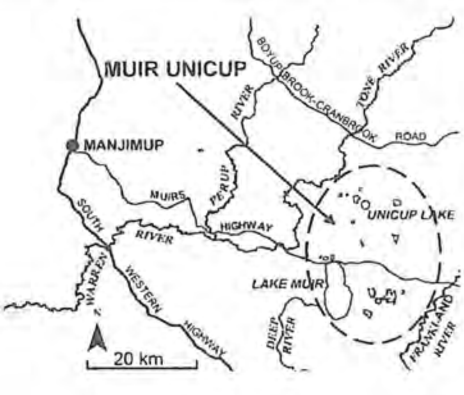
Salinity Management

- Engineering – drains, pumps, siphons
- Enhanced storage
- Revegetation
- Agronomic change
- Remnant vegetation protection

Management aims to deliver regimes of

- Salinity, sediments, nutrients etc. of surface water entering asset
- Volumes and timing of surface water entering asset
- Depth to groundwater under asset
- Salinity, sediments, nutrients etc. of ground water entering the asset
- Volumes and timing of ground water entering the asset

Muir-Unicup Natural Diversity Recovery Catchment



Muir-Unicup NDRC

Muir-Unicup Natural Diversity Recovery Catchment

Asset Goal

- To maintain existing biodiversity richness of the wetlands, sumplands, damplands, riparian zone, and other seepage areas (including mid-slopes) threatened by salinity, acidity or waterlogging
- If this achieved, then the objective will broaden to encompass the recovery of assets where they have been degraded.

Muir-Unicup Natural Diversity Recovery Catchment

Assets

Natural Values

- Birds
- Communities (based on vegetation), principally wetland and valley floor
- Plants
- Invertebrates and fish

800–900 sp. 70 km²
in catchment. 35 DRF
or priority.

7 sp fish – 3 DRF or priority.

Birds

little bittern

Australasian bittern.

Natural Communities

- Large diversity
- Freshwater wetlands and rare peat communities…
- … to primary salt lakes
- Tall open forests…
- …to low closed forests and open woodlands
- …a variety of wet and dry heaths
- …sedgelands
- …and herb fields

Yate woodlands.

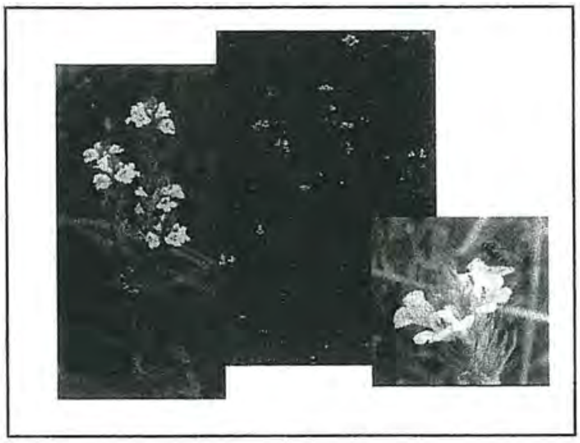
Herblands - annual or tuberous herblands.
Germination in winter

hypo saline wetland
below seawater
salt levels

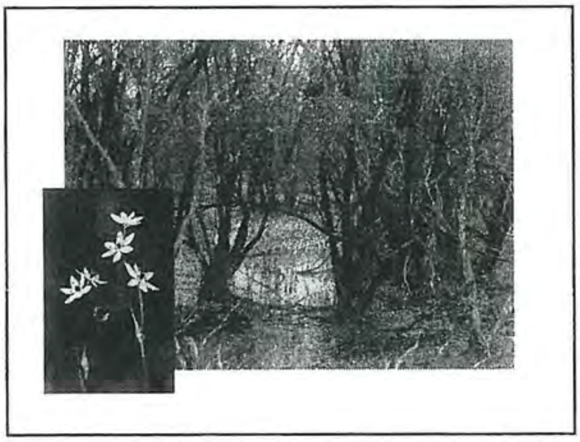
Melaleuca verticudata

Plants

- Keighery & Gibson – 976 species, 862 native
- 60% natives are wetland or valleyfloor species, possibly under threat
- Rare and Priority taxa – about 30 taxa, again their relationship to wetlands is high

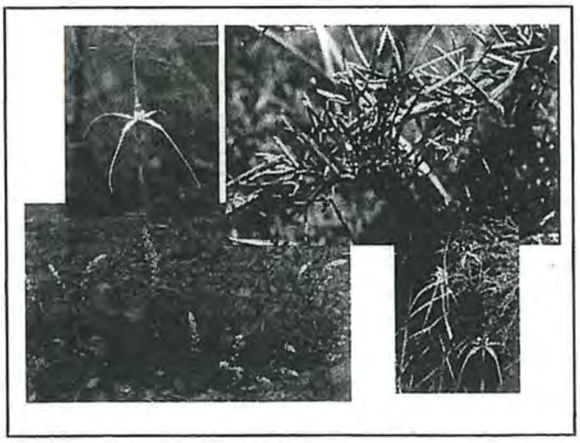


Euphrasia scabra probably will be ID as another separate sp.



Wurmbea sp. Cranbrook

relatively freshwater community

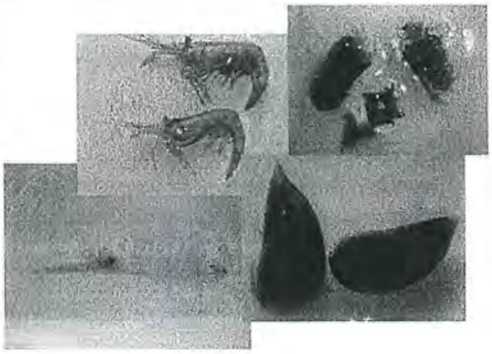


stylidium reniaium

Thitharia

Macroinvertebrates

- 2 Systematic surveys – 96/97 & 03/04
- 248 taxa recorded, 32 SW endemics, 5 Muir Unicup endemics
- Up to 94 taxa in a single wetland, highest values wetlands undergoing change
- Endemics, unusual and rare ones



invertebrates

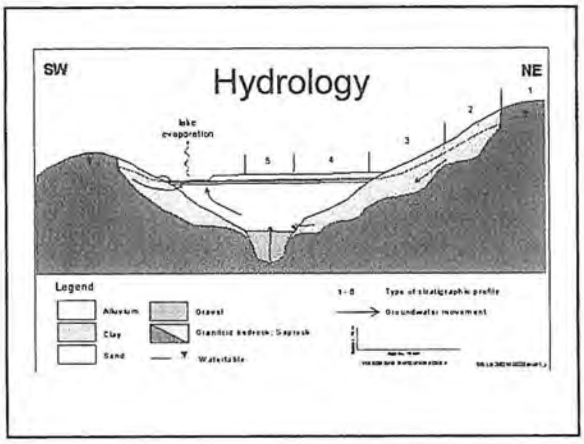
Fish

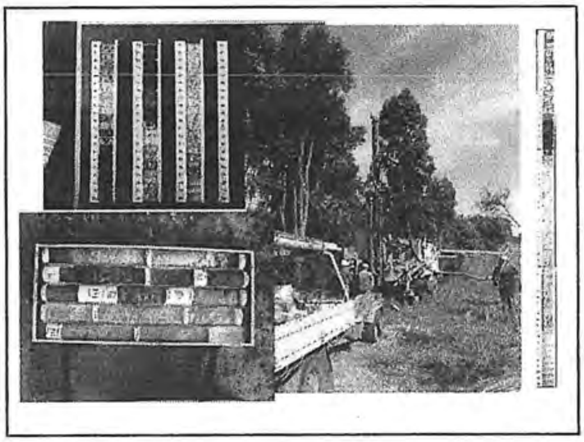
- 7 taxa recorded, 6 native
- Primarily in peat wetlands or former freshwater lakes
- Include 2 declared and 1 priority taxa
- Significant local extinctions over the drought years

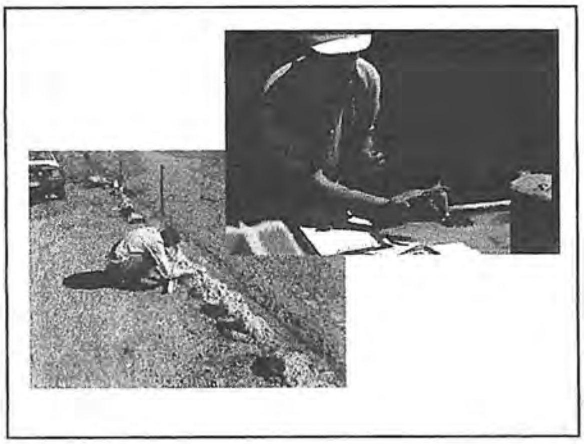
Biophysical Threat Analysis and Feasibility

- Threats:
  - Altered hydrology and hydrochemistry
  - Weeds
  - Ferals
  - Stock
  - Drought
  - Climate change
- Feasibility: still subject to analysis

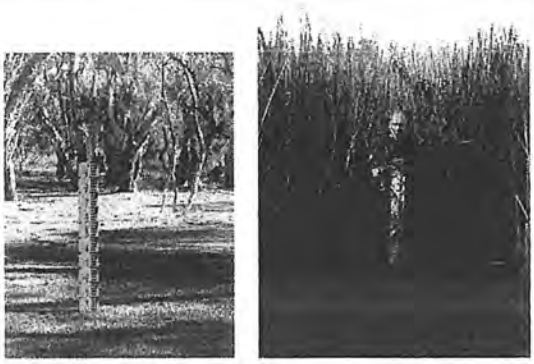
No WONS.

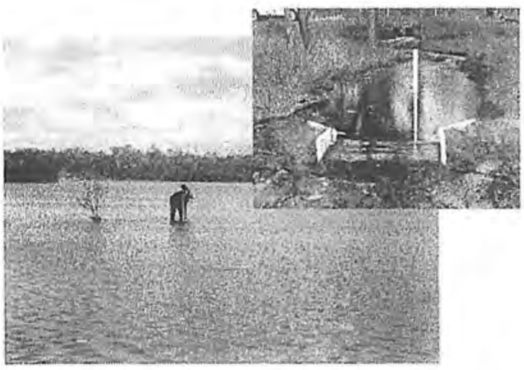

SW
Hydrology
NE
lake evaporation
1
2
3
4
5
Legend
Alluvium
Gravel
Clay
Sand
Water table
Type of stratigraphic profile
Groundwater movement

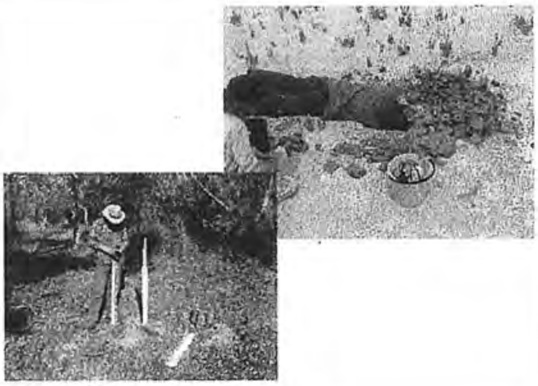


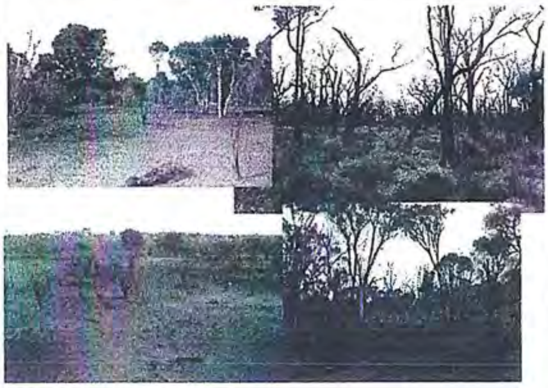



Monitoring









Acid saline groundwater coming to the surface.

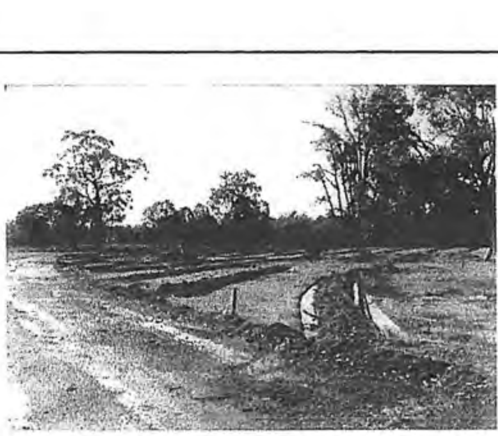
Acid Collapse Site

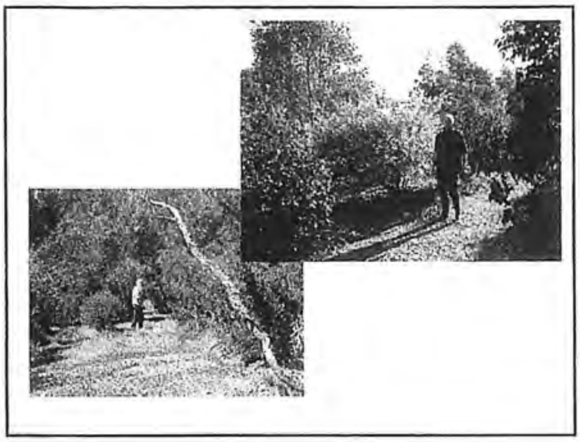
Muir-Unicup Natural Diversity Recovery Catchment

Revegetation

Revegetation

- Long term value, low risk of getting it wrong
- About 250 ha of Crown land
- A further 50 ha of private land
- For hydrological & biodiversity reasons
- Variable success





Weeds and Ferals

Muir Unicup: Outputs and outcomes

- Outputs
  - seedlings (about 300 ha)
  - land purchase (about 250ha)
  - Planning/communication (community meetings, planning)
  - misc. including weed control and recreation facilities

Muir Unicup: Outputs and outcomes

- Outputs continued:
- Research/investigations
  - veg mapping stage 1
  - invertebrates / fish / wetland baseline data
  - salinity in groundwater and soils
  - surface water hydrology
  - acid ground water
  - geology
  - data, data, data

Muir Unicup: Outputs and outcomes

- Outcomes:
  - Positive impacts on groundwater in Yarnup area
  - Research and development for broader application
  - Rehabilitation for habitat as well as water

Muir Unicup: The future

- Planning and management
- Further research and analysis
  - Surface water / groundwater / lake water / lake floor interactions
  - Further develop the hydro-geological model
  - Further mapping of the complex basins and surface water system
  - Vegetation mapping over time
  - Develop hydrological models for the complex system

Summary

- Landscapes and Conservation
- Natural Diversity Recovery Catchments as Landscape Conservation Units
- Policy and management framework for NDRC's
- Some Muir Unicup examples given

An Introduction to Fungi of Southwestern Australia

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INTRODUCTION
The Kingdom Fungi is made up of an extremely large and diverse group of organisms, second only to arthropods in numbers. It is estimated that about 1.5 million species are to be found on Earth. The majority are microscopic and unfamiliar but those referred to as macrofungi produce large fruit bodies that we can more easily recognise and relate to. The number of macrofungi in Australia is likely between 10,000 and 20,000 but the majority of them are unnamed with only about 25% of them documented.

For most of us fungi are mysterious organisms and we only notice them when they develop their large fruit bodies. Many are exquisite in their structural symmetry and colour, while others provoke feelings of fear and sometimes disgust. For centuries fungi have been a subject of fascination and are often included in fairy tales, myths and legends. Most stories, however, emphasise the dark side of fungi resulting in most of us falsely thinking that fungi are something to avoid. The truth is that fungi are amongst the most beneficial organisms to be found in our forests and woodlands, and without them much of the environment from which we gain the most benefit and pleasure simply would not exist. They are one of our most important resources, in terms of both their ecology and their biodiversity and because we have much to learn, studying and learning about fungi can be both exciting and rewarding.

ACT NOW FOR THE FUTURE
Department of Environment and Conservation
Our environment, our future

ECOLOGY

Fungi play important roles in ecosystem functioning. They are the forest recyclers, breaking down forest litter and debris to provide nutrients for plants. Fungi also form a symbiotic relationship with the fine roots of plants to form mycorrhiza that aid the uptake of these nutrients into the plants. Some of these mycorrhizal fungi also form underground truffle-like fruit bodies that provide a food source for several native mammals including the woylie and potoroo. Wood decay fungi rot trees and logs to produce the hollows that many animals and birds need for shelter and nesting. Parasitic fungi are rare, but also play an important role in natural selection and in providing dead material for wood decay fungi and other organisms such as insects to colonise. Native pathogens in healthy ecosystems are beneficial, but pathogens introduced into Australia from other countries can be devastating, and some have already caused large-scale damage to our unique ecosystems. The honey fungus, *Armillaria luteobubalina*, is one native pathogen that co-exists in the natural environment, but in disturbed or modified environments such as parks and gardens that are established on cleared bush it can be very destructive.

For the majority of their existence, fungi persist in the form of microscopic filaments called hyphae. Hyphae colonise the soil or other organic matter such as leaf litter and wood. The majority of fungi do not produce large fruit bodies and are thus referred to as microfungi and cannot be seen with the naked eye, but many species of fungi are referred to as macrofungi and at certain times of the year they develop the distinctive fruit bodies we refer to as mushrooms, toadstools and brackets. Most macrofungi fruit in autumn or winter, but a few fruit in spring.

Fungi can be found in just about every habitat available on Earth. Some of the more unusual places you will find fungi fruiting in Western Australia are in burnt forests just a couple of days after a bushfire, on the carcasses of dead animals such as kangaroos, in the desert, on *Banksia* cones and on the dung of animals such as wallabies and woylies.

Humans also use fungi in a variety of ways. The most common use is for food, beverages and medicine. In Europe and North America, truffles and morels are a prized delicacy. In China, Japan and other parts of Asia many fungi are used for food and in herbal medicines. One of the better-known uses for fungi is in making beer and wine. Yeasts have been used in the brewing industry for centuries. Another use for fungi is in traditional art and craft cultures where a number of species produce magnificent fabric dyes and others are used for making paper.

CAUTION

Some Western Australian species of fungi are edible, but it is not recommended that you eat any wild mushrooms before getting a positive identification from an expert.

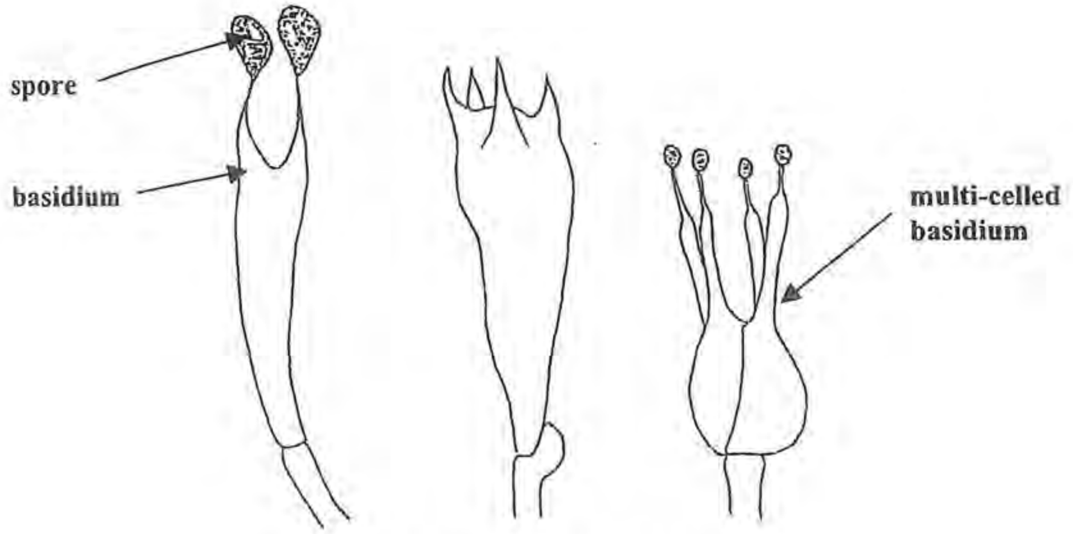
NATIVE FUNGI ARE PROTECTED

Just like our native plants and animals fungi are protected with Government Legislation. It is illegal to collect them from national parks and a permit is needed to take them from State forest. When you see them in the forest look and enjoy, but leave them there for others to enjoy and so they can complete their life cycle and continue to benefit the environment well into the future.

CLASSIFICATION

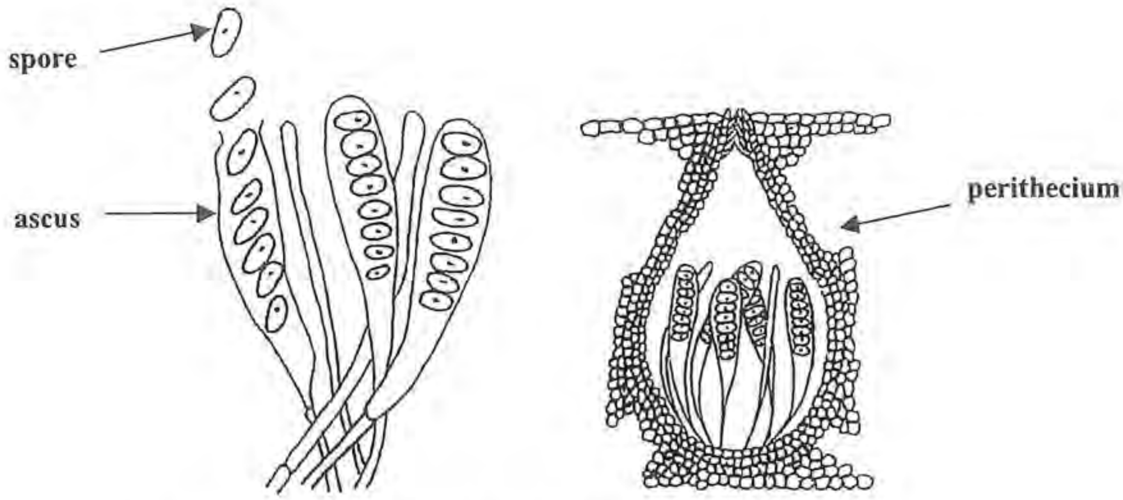
There are two main types of fungi, the Basidiomycetes and the Ascomycetes. They differ in the way they produce their spores, a feature that can only be seen microscopically.

The **BASIDIOMYCETES** include mushrooms, toadstools, coral fungi, puffballs, bracket fungi and others. They produce their **spores** on microscopic club-shaped cells called **basidia** (s. basidium). Basidia are found on the gills, on the inside surface of pores or simply on the surface of the fungus, depending on which Basidiomycete group the fungus belongs to. Basidia usually produce either 2 or 4 spores and are generally single celled, but in the jelly fungi they are multi-celled.



Highly magnified diagrams of a variety of basidia

The **ASCOMYCETES** is a diverse group and the fruit bodies can be cup-like, disc-shaped, club-like, spherical or crust-like in appearance, and their texture can be fleshy to firm or hard and carbonaceous. They produce their spores in microscopic sac-like cells called **asci** (s. ascus). Asci are found on the surface of the fruit body or contained within vessel-shaped structures called **perithecia** (s. perithecium) that are embedded in the fruit body surface. Asci are single celled and usually produce 8 ascospores. The spores are released when the ascus opens at the apex, and when inside perithecia they are released through a pore at the top of the structure.



Highly magnified diagrams of asci and a perithecium containing asci

While their diversity may at first be overwhelming, with practice, fungi can be separated into a number of groups. Despite some being very common, many still do not have names, but they can be readily identified, by the structure of their fruit body, as belonging to a common group and often to a genus within that group.

For many fungi, the colour of spores can also be used to separate similar taxa. Removing the stem and then placing the cap of the mushroom on a piece of paper (gills or pores down) for several hours will result in a **spore print**. The released spores will leave a coloured deposit of spore powder on the paper. In addition to the colour, the shape of the spores will readily identify the genus of many fungi. Spores may be smooth or ornamented and the spores of many species have distinctive shapes. But, spores can only be examined with the use of a microscope.

THE STRUCTURE OF A MUSHROOM

The main body of the fungus is made up of microscopic thread-like **hyphae** that occupy soil, or plant or animal remains. The hyphae expand and develop into a cob web-like mass called the **mycelium**. The mycelium ramifies through the chosen substrate, releasing decay-causing enzymes and absorbing nutrients. The fruit bodies are the reproductive stage formed by the mycelium. They can be equated to being the fruit of a plant, for example, just like an apple on a tree. The mushroom or fruit body produces spores and is the basic structure on which traditional taxonomy (describing and naming) of macrofungi is presently based. However, modern molecular techniques, similar to those used in forensic science, are rapidly being developed.

The basic terminology used to describe typical mushrooms is quite simple, and most mushrooms can be described in terms of the shape, colour and texture of their cap, the gills or pores under the cap, and their stem. Not all fruit bodies are mushroom- or toadstool-shaped. Many are modified but represent simplified forms of this shape.

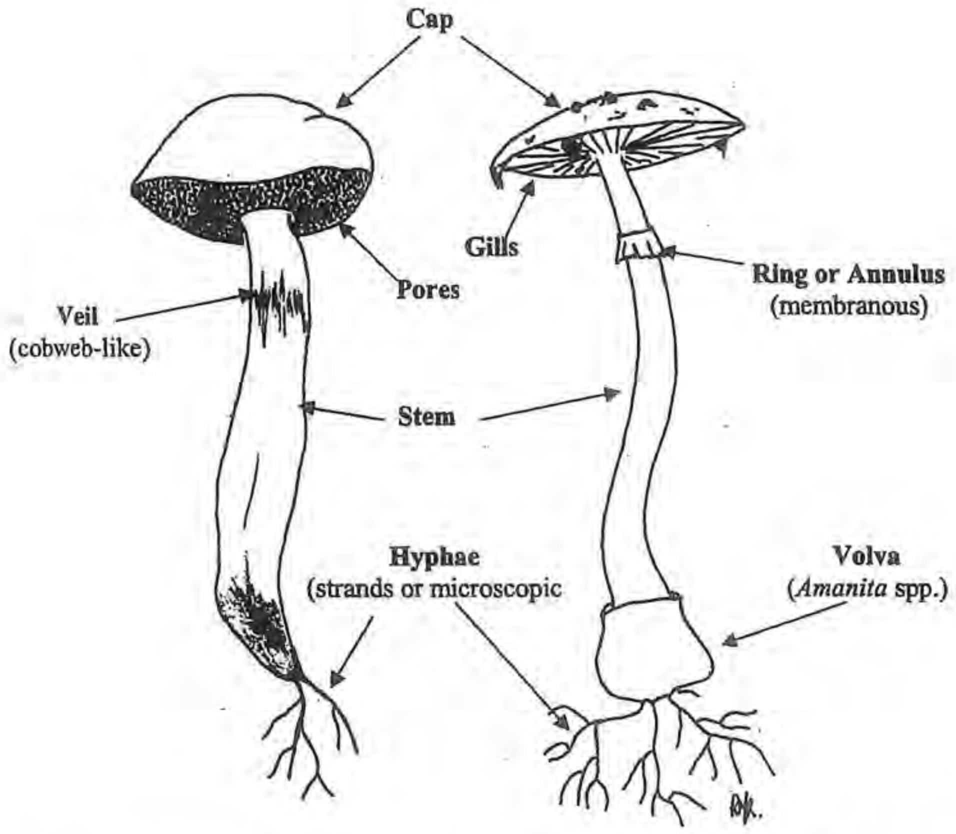


Diagram of mushrooms illustrating the important structures used for identification

In simple mushrooms the gills are exposed but in some genera the young developing gills are protected by a covering called a **partial veil** if it is membranous or by a **cortina** if it is thin and wispy or cob-web-like. As the mushroom expands the covering ruptures or tears away from the margin of the cap, leaving either a membranous ring called an **annulus** or cob-web-like veil remnants on the stem. In some other genera, *Amanita* for example, a membranous **universal veil** totally envelops the young button stage of the mushroom. As the mushroom expands, the veil ruptures leaving membranous or mealy scale-like fragments on the cap and a cup-like sheath at the base of the stem called a **volva**. In other genera the universal veil may be cob web-like or produce a slimy coating.

FUNGAL GROUPS
The structure of fungal fruit bodies can be very varied and the basic shape and structural features of them can be used to classify them into groups. The groups illustrated here do not represent formal taxonomic relationships but are simply based on what the fungus fruit body looks like.

BASIDIOMYCETES: Includes the mushrooms, toadstools, coral fungi, puffballs, bracket fungi and others. The common groups within the Basidiomycetes include:

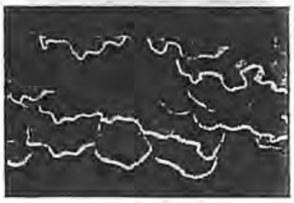
AGARICS
Mushrooms with gills

SPINE FUNGI
Mushrooms or fruit bodies with spines

BOLETES
Mushrooms with pores

TRUFFLE-LIKE FUNGI
Underground fruiting fungi

CORAL FUNGI
Fruit bodies with simple club-like or multi-branched structures



LEATHER SHELF AND CRUST FUNGI
Thin leathery shelves or sheets on sticks and wood

PUFFBALLS
Sac-like fungi

POLYPORES
Firm or hard woody bracket-like fungi on wood and trees

STINKHORNS
Delicate or firm with foul smelling slime

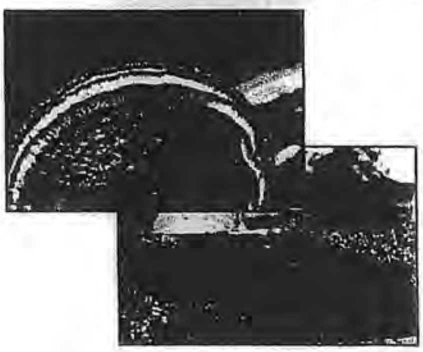
JELLY FUNGI
Soft gelatinous fungi on wood

ASCOMYCETES: This diverse group has fruit bodies that can be cup-like, disc-shaped, club-like, spherical or crust-like in appearance, and their texture can be fleshy to firm or hard and carbonaceous. Some common groups of Ascomycetes are:

CUP FUNGI
Cup- or disc-shaped fruit bodies

MORELS
Fleshy fruit bodies with an elongated honeycomb-like cap

EARTH TONGUES
Firm and fleshy with a tongue-like appearance



FLASK FUNGI
Usually hard and carbon-like

This guide only illustrates very broad groups, but is will be useful to get you started in identifying fungi. There are many publications and web sites dealing with more advanced identification techniques and keys to genera and species. A few featuring Australian fungi are listed below and suggested as a starting point.

FURTHER READING

A number of Australian books are available to help you identify the many fungi you will encounter in the bush. Most books deal with fungi from southeastern Australia, but still contain many species that you will find in the southwest.

Bougher, N.L. and Syme, K. 1998. Fungi of southern Australia. University of Western Australia Press, Perth.

Fuhrer, B.A.2001. A Field Companion to Australian Fungi (Revised Edition). Bloomings Books, Victoria, Australia.

Fuhrer, B.A.2005. A Field Guide to Australian Fungi. Bloomings Books, Victoria, Australia.

Fuhrer, B.A. and Robinson, R.M. 1992. Rainforest Fungi of South-east Australia. CSIRO, Melbourne and the Forestry Commission, Tasmania.

Grey, P and Grey, E. 2005. Fungi Down Under: the Fungimap guide to Australain fungi. Fungimap, Royal Botanic Gardens Melbourne.

Griffiths, K. 1985. A Field Guide to the Larger Fungi of the Darling Scarp and South West of Western Australia. Kevn Griffiths, Perth.

McCann, I.R. 2003. Australian Fungi Illustrated. Macdown Productions.

Robinson, R. 2002. Forest fungi: lifestyles of the little known. Landscope Vol. 18, No. 1: 10-18.

Robinson, R. 2003. Fungi of the South-West Forests. Department of Conservation and Land Management. Perth, WA.

Young, A.M. 2005. A Field Guide to the Fungi of Australia. University of NSW Press Ltd, Sydney.

WEBSITES DEVOTED TO AUSTRALIAN FUNGI AND THEIR ECOLOGY:

WA Forest and Woodland Fungi – search on: http://www.naturebase.net/
or go to http://www.dec.wa.gov.au/science-and-research/fungi-research/wa-forest-and-woodland-fungi.html

Perth Urban Bushland Fungi - http://www.fungiperth.org.au/

*fungi*map - http://www.rbg.vic.gov.au/fungimap_/welcome

Australian National Botanic Gardens: Fungi - http://www.anbg.gov.au/fungi/

*Fungi*Bank (also deals with land restoration) - http://www.fungibank.csiro.au/

Mycorrhizal associations - http://mycorrhizas.info

International Fungi and Fibre Symposium and Exhibition - an excellent site to view the use of fungi in craft – dyes, paper making and more and features activities from the 11th Symposium held in Denmark, WA in 2003 :
http://sonic.net/~dbeebee/AustralianSymposium.htm

Fungi of the South-West

Richard Robinson - Science Division, Manjimup

ACT NOW FOR THE FUTURE

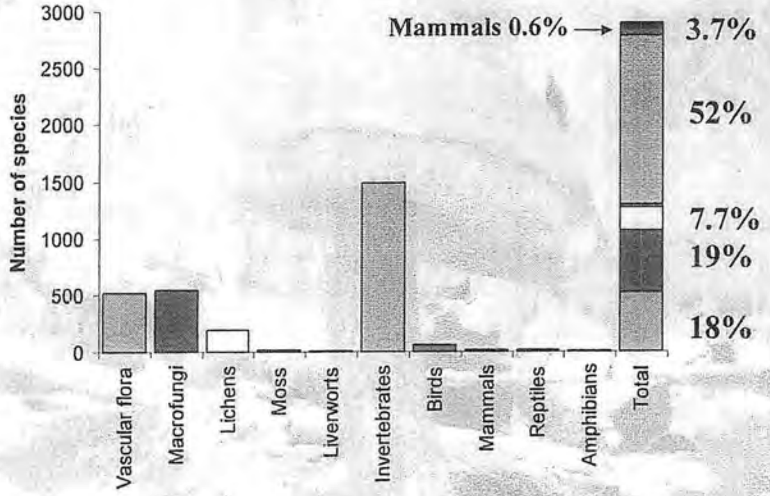
Department of Environment and Conservation

Our environment, our future

KINGDOM FUNGI

- an estimated 1.5 million species (5x that of vascular plants)
  - perhaps ~ 250,000 species in Australia
    - compared to 21,000 – 25,000 vascular plants
    - ~20,000 are macrofungi
- the Macro or Larger fungi produce visible fruit bodies
  - mushrooms, toadstools, corals, puffballs, brackets etc
    - about 25% are named
    - many with misapplied names
    - traditional views of taxonomy are changing rapidly with modern technology – DNA sequencing

Biodiversity in jarrah forest



Data from FORESTCHECK 2002-06 (total spp. = 2890)

Fungi play crucial roles in ecosystem functioning

- A small number of fungi are parasitic
- Fungi decompose litter and debris
  - capture, store, release and recycle organic nutrients
- Many fungi develop symbiotic relationships with the roots of plants and form **mycorrhiza** (fungus-root)
  - increases the area of soil the plant can exploit
  - aid directly with the uptake of nutrients (eg. P & N)
    - receive sugars from the plant in return
  - protect plants from stress and pathogens
- Truffle-like fungi are a major part of the diet of native mammals
- Fungal hyphae binds soil particles and improves soil structure

Fungi play crucial roles in ecosystem functioning

Parasites - invade and kill or accelerate the death of plants

- *Armillaria luteobubalina* is a natural thinning agent in undisturbed ecosystems

Fungi play crucial roles in ecosystem functioning

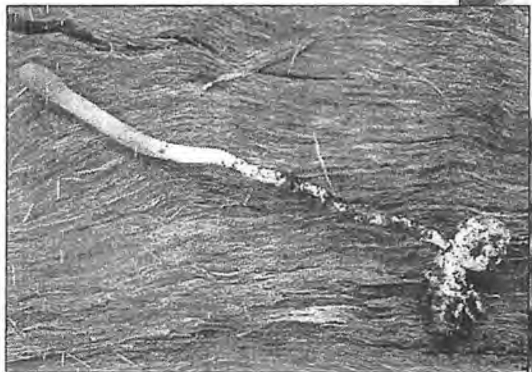
Parasites - invade and live off other fungi

- *Hypomyces chrysospermum* infects the fruitbodies of Boletes

Fungi play crucial roles in ecosystem functioning

Parasites - infect and kill insects

- *Cordyceps* spp. parasitise beetle larvae



Fungi play crucial roles in ecosystem functioning

Saprotrophs - decomposers

- wood decay fungi break down woody debris

Gymnopilus alantopus

Fungi play crucial roles in ecosystem functioning

Saprotrophs - decomposers

- heart-rot fungi produce nesting hollows

Laetiporus portentosus

Fungi play crucial roles in ecosystem functioning

Saprotrophs - decomposers

- others breakdown litter and build soil organic matter

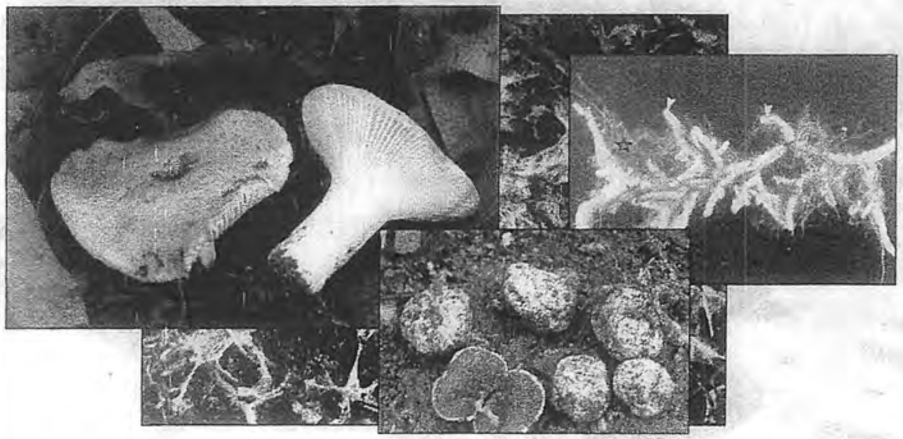
Ramaria ochraceosalmonicolor

Mycena subcapillaris

Fungi play crucial roles in ecosystem functioning

Mycorrhiza - symbiotic partnership with the roots of shrubs and trees

- enhance nutrient uptake



Mycorrhizal roots of jarrah

Fungi play crucial roles in ecosystem functioning

Mycorrhiza - symbiotic partnership with the roots of shrubs and trees

Ectomycorrhizal

Casuarinaceae
- ***Allocasuarina***

Papilionaceae
- ***Callistachys***
- ***Gastrolobium***
- ***Bossiaea***

Mimosaceae
- ***Acacia***

Myrtaceae
- ***Agonis***
- ***Eucalyptus***
- ***Leptospermum***
- ***Melaleuca***

Non-Mycorrhizal

Proteaceae
- ***Banksia***
- ***Grevillea***
- ***Persoonia***

} **proteoid roots**

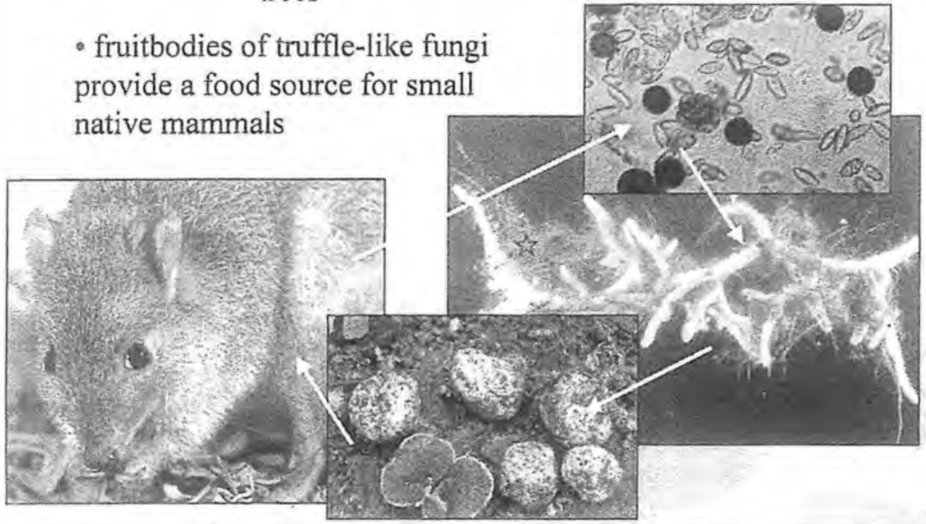
Zamiaceae

Macrozamia **spp** **- coralloid roots**

Fungi play crucial roles in ecosystem functioning

Mycorrhiza - symbiotic partnership with the roots of shrubs and trees

- fruitbodies of truffle-like fungi provide a food source for small native mammals



Healthy woodlands have an abundance of fungi

Within the fungi:

- wide range of species
- high degree of diversity within functional groups
- high abundance of fruitbodies

Trees and shrubs with:

- high number of mycorrhizal roots

Soil and litter with:

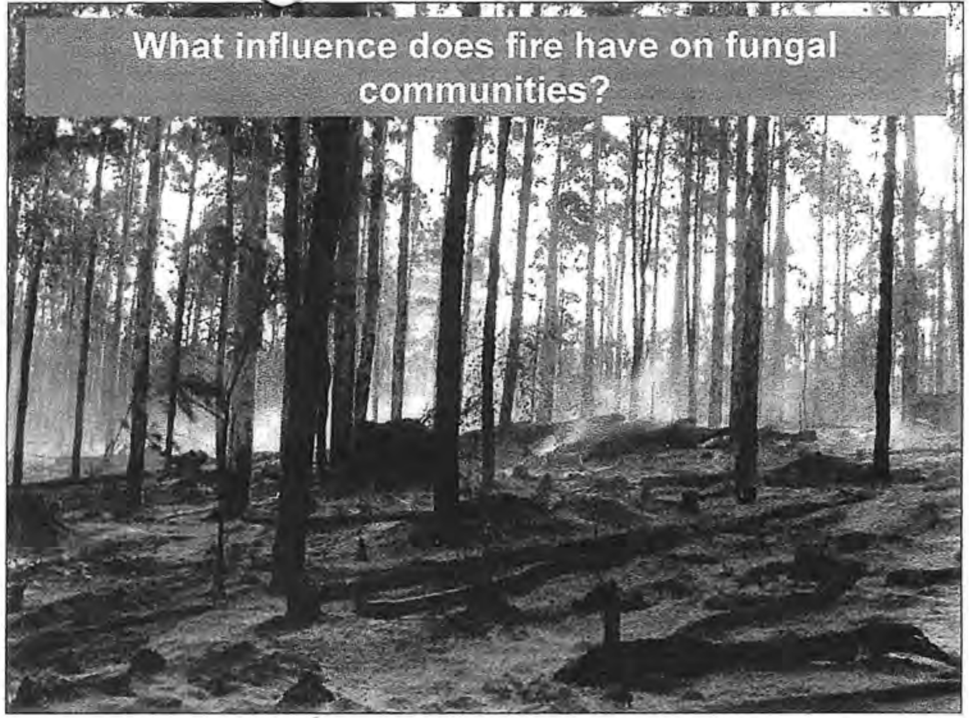
- abundant mycelium

Dead wood:

- alive with activity
    - abundant mycelium, invertebrates and active decay

Questions - discussion

Next - Response of Fungi to Fire



Response of macrofungi to fire in regrowth karri (*Eucalyptus diversicolor*) forest

- Ongoing project to gather data on the response and succession of macrofungi following a wildfire in December 1997
- Results from Jan 1998 - Dec 2002 (now have data for 2007)

Methods

- 10 sites – 5 burnt, 5 unburnt since establishment (20-25 yrs)
- 4 plots (5m x 5m) at each site
- Sites established within 2 weeks of wildfire
- Plots monitored every 2 weeks in fruiting season (April – Sept), monthly during the rest of the year
- Recorded sporophore species and abundance in each plot

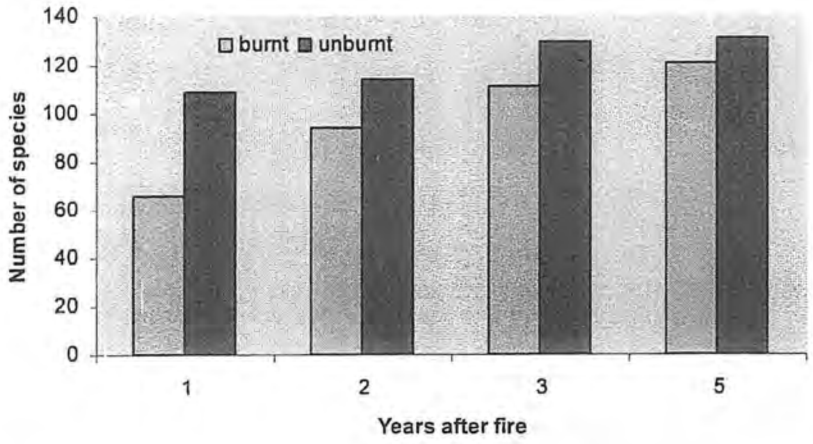
Results

After 5 years of monitoring:

- 332 spp. of macrofungi, 46,885 sporophores recorded
  - 123 identified to species
  - 1,750 voucher collections
- 236 spp. recorded on burnt sites, 209 spp. on unburnt
  - 123 spp. (37% of total) exclusive to burnt sites
    - 63 spp. (19% of total) as a direct result of fire
      - 41 spp. recorded only in the first year after fire

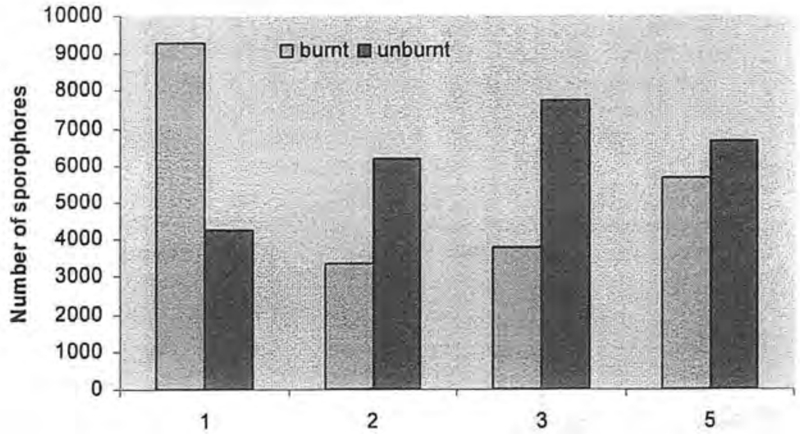
Results

- Species richness was lower on burnt sites
  - increased annually, and reached 90% of that on unburnt sites after 5 years



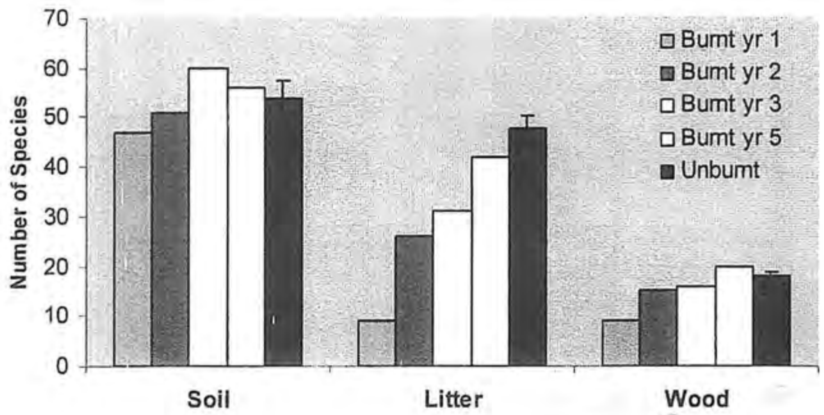
Results

- Species abundance



Results

- Number of species recorded on soil, litter and wood

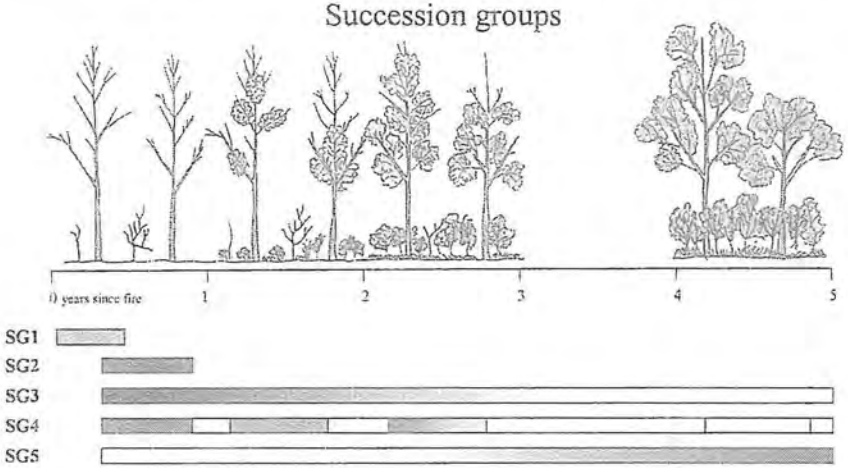


Results

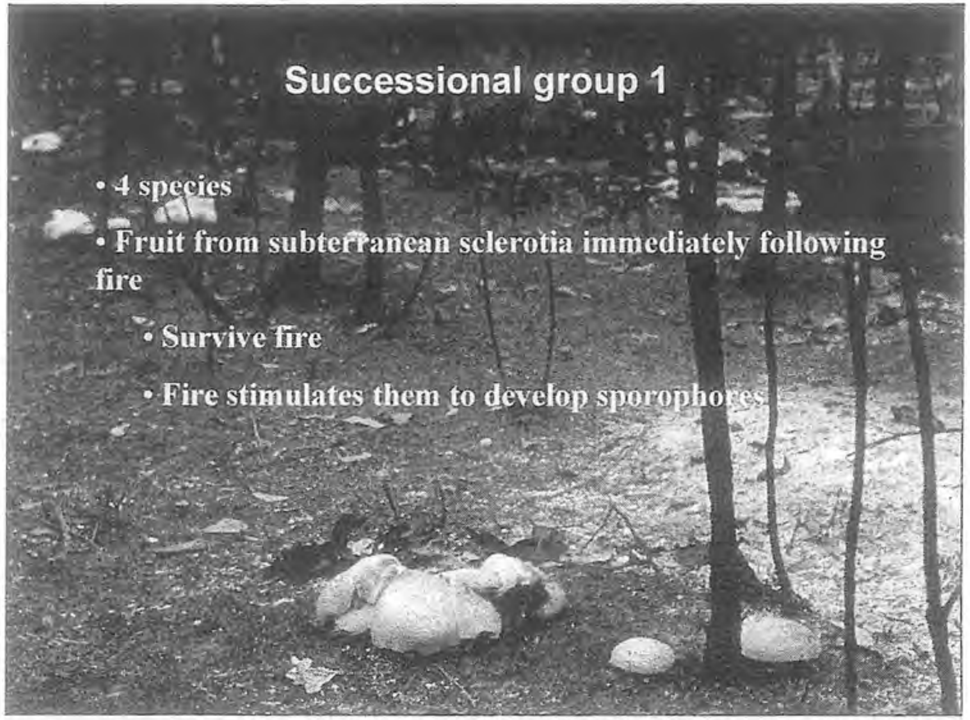
- The composition of the macrofungal community was significantly different on burnt sites each year following the fire

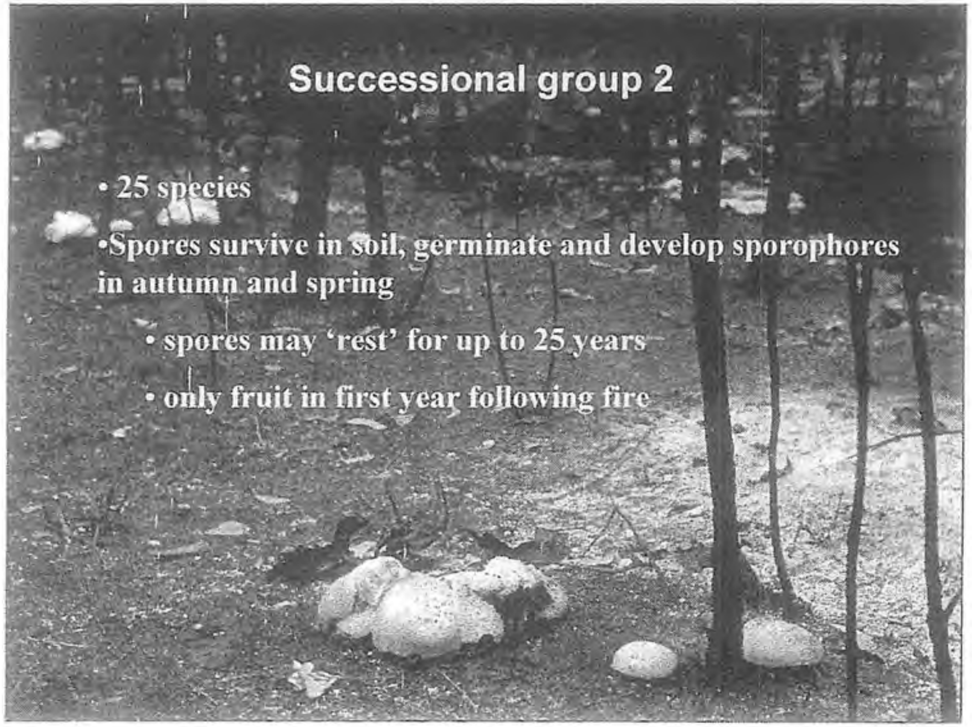
- Five distinct succession groups were recognised on burnt sites during the first 5 years following the fire

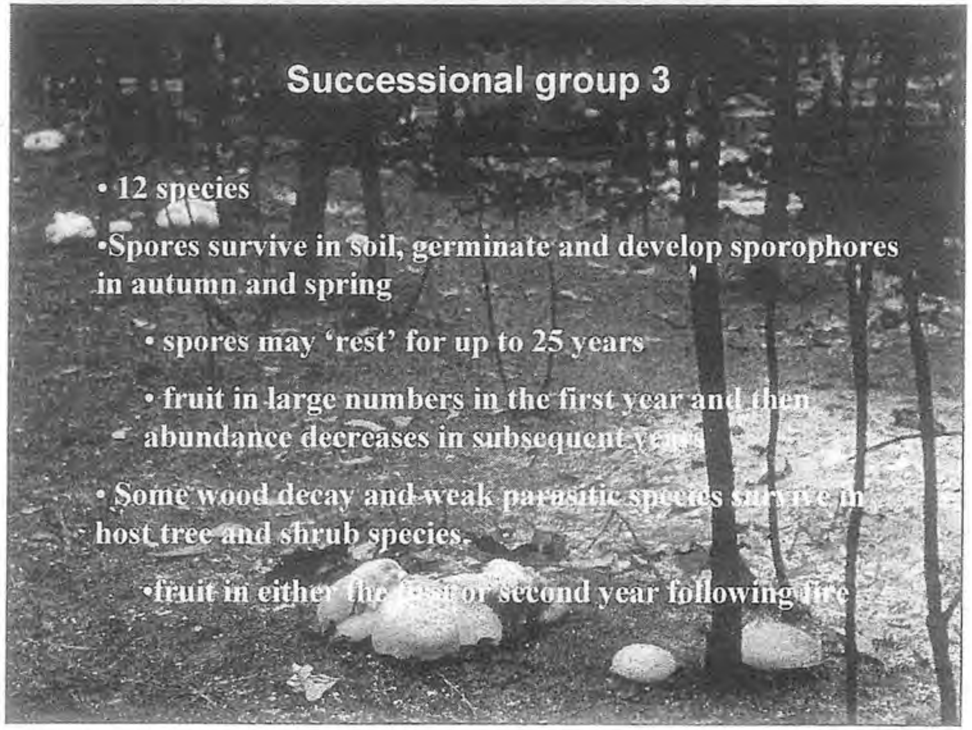
Succession groups

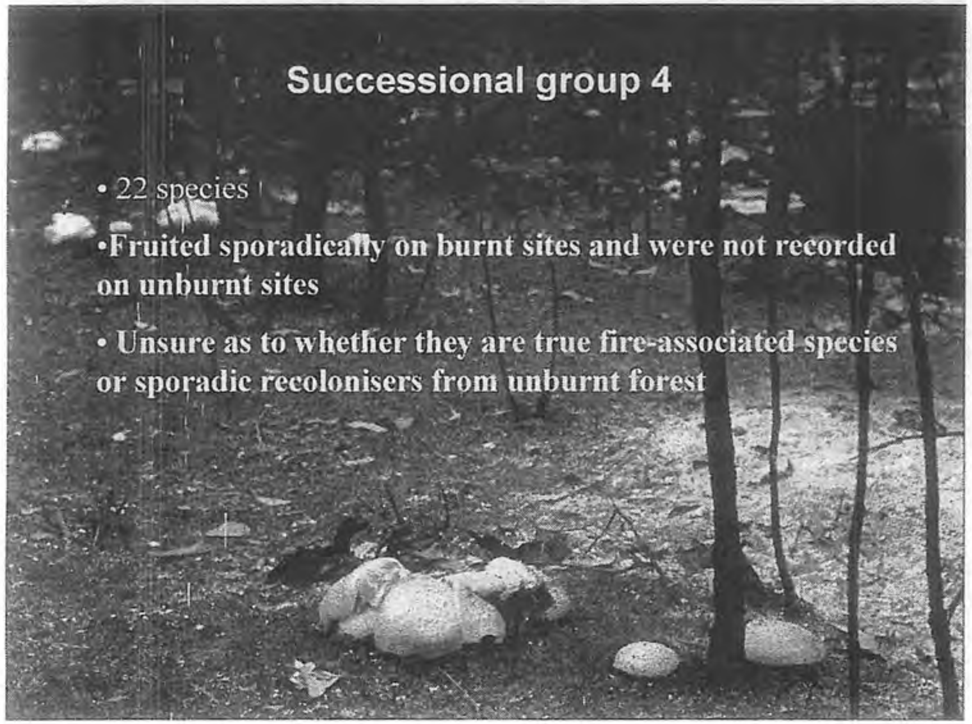


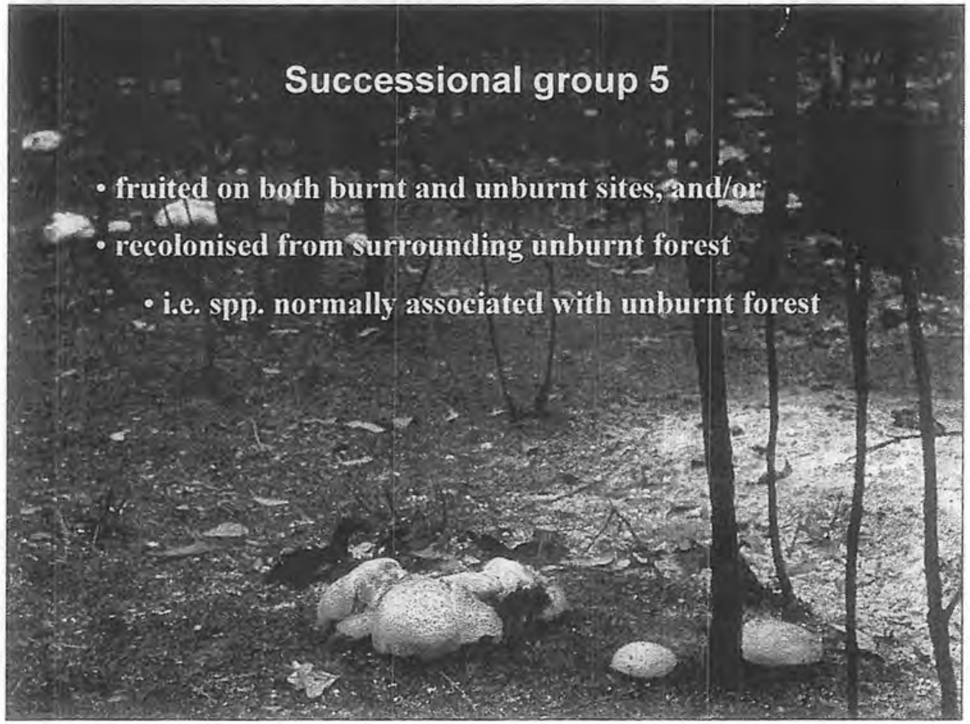
- Succession Group (SG) 1 and SG 2 contain true pyrophilous species
- SG 3 contains a mix of pyrophilous species and fire 'survivors'
- SG 4 contains species not recorded on the unburnt plots but recorded sporadically on the burnt plots (fire-associated species??)
- SG 5 contains species normally associated with unburnt forest

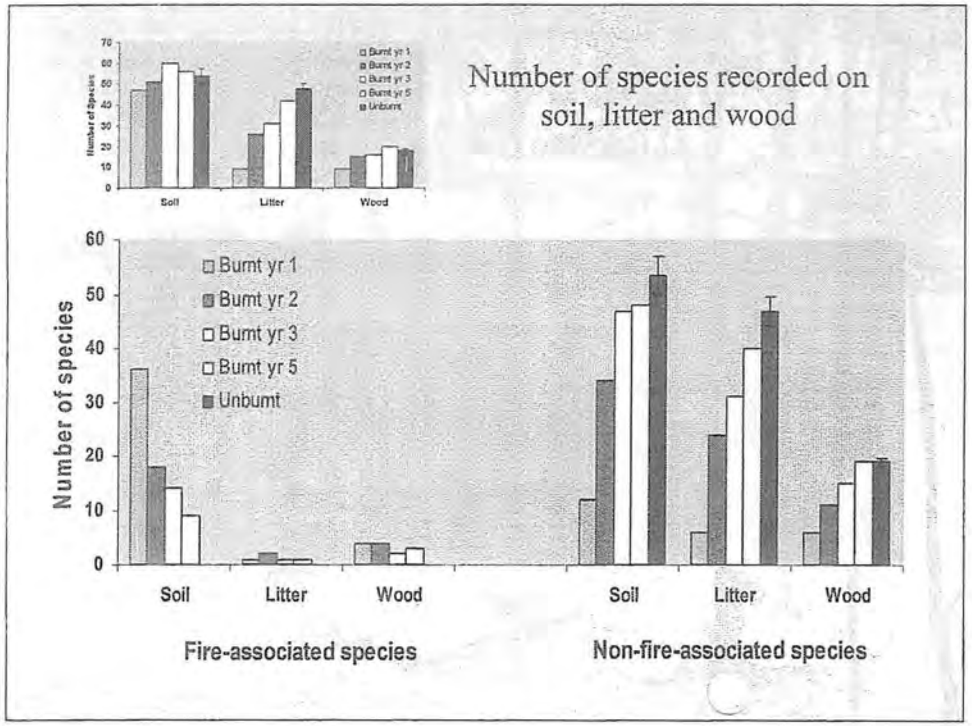


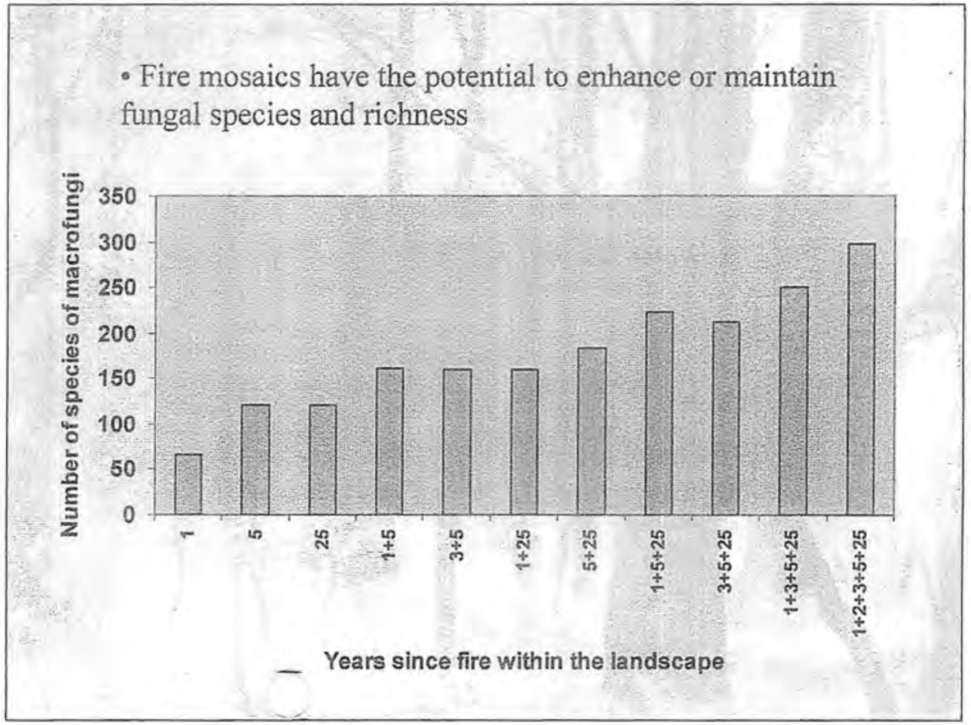





Successional group 4
• 22 species
•Fruited sporadically on burnt sites and were not recorded on unburnt sites
• Unsure as to whether they are true fire-associated species or sporadic recolonisers from unburnt forest


Successional group 5
• fruited on both burnt and unburnt sites, and/or
• recolonised from surrounding unburnt forest
• i.e. spp. normally associated with unburnt forest


Number of species recorded on soil, litter and wood
Soil
Litter
Wood
60
50
40
30
20
10
0
Number of species
Burnt yr 1
Burnt yr 2
Burnt yr 3
Burnt yr 5
Unburnt
Soil
Litter
Wood
Soil
Litter
Wood
Fire-associated species
Non-fire-associated species


• Fire mosaics have the potential to enhance or maintain fungal species and richness
Number of species of macrofungi
350
300
250
200
150
100
50
0
1
5
25
1+5
3+5
1+25
5+25
1+5+25
3+5+25
1+3+5+25
1+2+3+5+25
Years since fire within the landscape

Conclusions

- Species richness is lower on recently burnt sites
  - but very high abundance in the first year after fire
- Species composition on burnt sites is significantly different each year for at least 5 years following fire
- Some species of macrofungi are adapted to survive fire
  - Many Australian species fruit only after fire
- Species on recently burnt sites are replaced over time by species more commonly found on long unburnt sites
- Spatial and temporal separation of fires of differing intensity (a mosaic) will increase species diversity over broad regions

Questions - discussion

Identifying Fungi – the basics

FUNGAL IDENTIFICATION

Microscopic thread-like filaments (hyphae) = vegetative portion

- hyphal mass = mycelium

Mushroom or fruit body = reproductive structure

- Produce spores
- Structure on which (traditional) identification is based

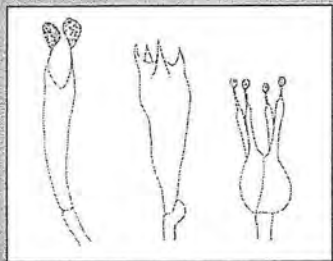
Two main types of macrofungi – based on the spore-bearing cells

BASIDIOMYCETES

ASCOMYCETES

BASIDIOMYCETES

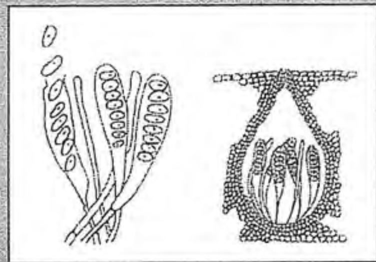
- Produce spores <u>on</u> microscopic club-shaped cells called **BASIDIA**



- Usually 2- or 4-spored structures

ASCOMYCETES

- Produce spores <u>within</u> microscopic club-shaped cells called **ASCI**



- Usually 8 spores produced per ascus

FUNGAL IDENTIFICATION

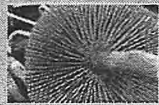
Based on the morphological characters of the fruit body, and on the colour of the spores most species of macrofungi encountered in WA can be:

- assigned to a basic group.

And with **practice**:

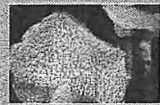
- readily identified to Genus

COMMON FUNGAL GROUPS - BASIDIOMYCETES



AGARICS

Mushrooms with gills

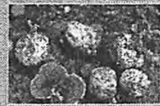


SPINE FUNGI

Mushrooms or fruit bodies with spines

BOLETES

Mushrooms with pores



TRUFFLE-LIKE FUNGI

Underground fruiting fungi

CORAL FUNGI

Fruit bodies with simple club-like or multi-branched structures

LEATHER SHELF AND CRUST FUNGI

Thin leathery shelves or sheets on sticks and wood

PUFFBALLS & EARTHBALLS

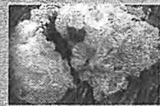
Sac-like fungi

POLYPORES

Firm or hard woody bracket-like fungi on wood and trees

STINKHORNS

Delicate or firm with foul smelling slime



JELLY FUNGI

Soft gelatinous fungi on wood

COMMON FUNGAL GROUPS - ASCOMYCETES

CUP & DISC FUNGI

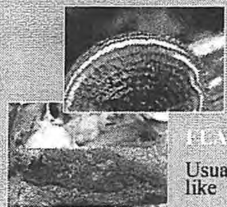
Cup- or disc-shaped fruit bodies

EARTH TONGUES

Firm and fleshy with a tongue-like appearance

MORELS

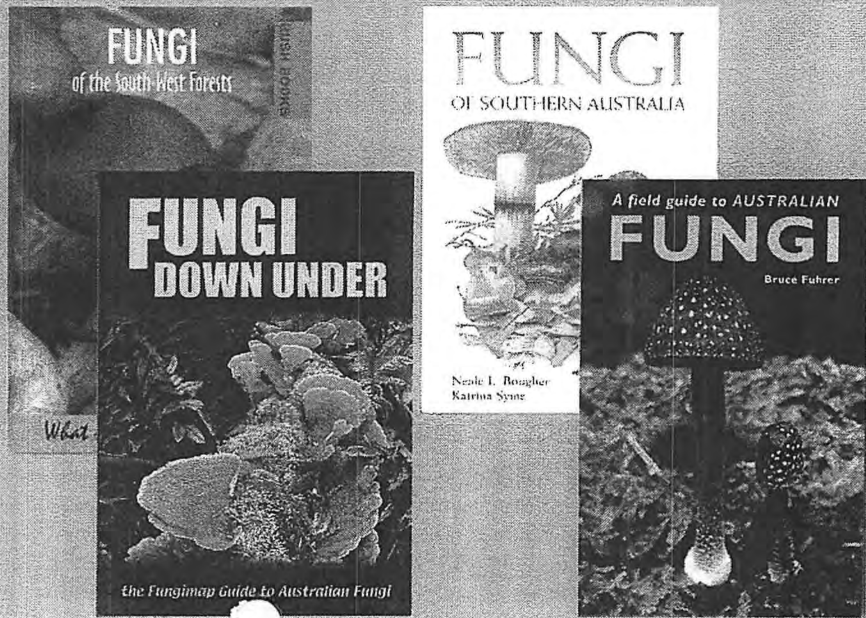
Fleshy fruit bodies with an elongated honeycomb-like cap



FLASK FUNGI

Usually hard and carbon-like

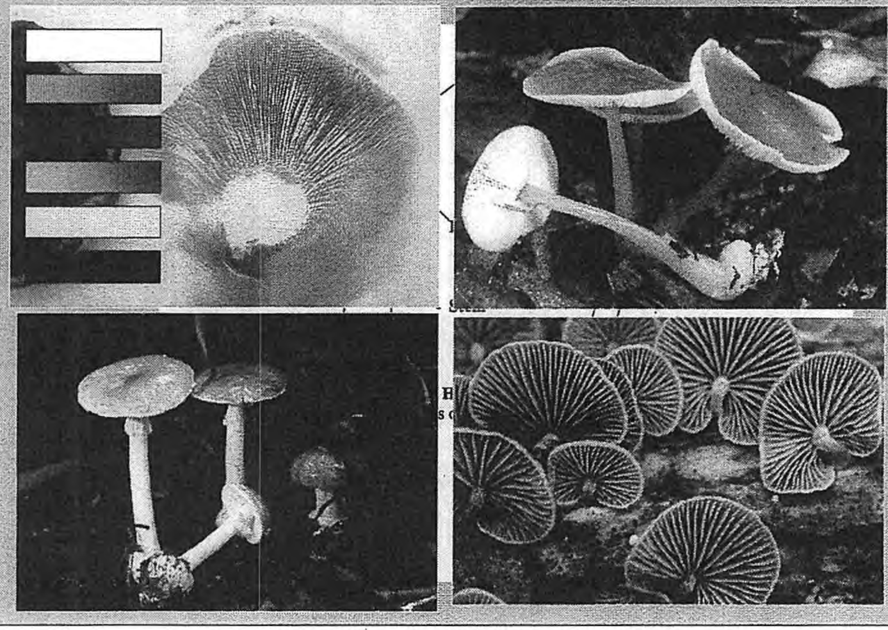
FUNGAL IDENTIFICATION – Guide Books



RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

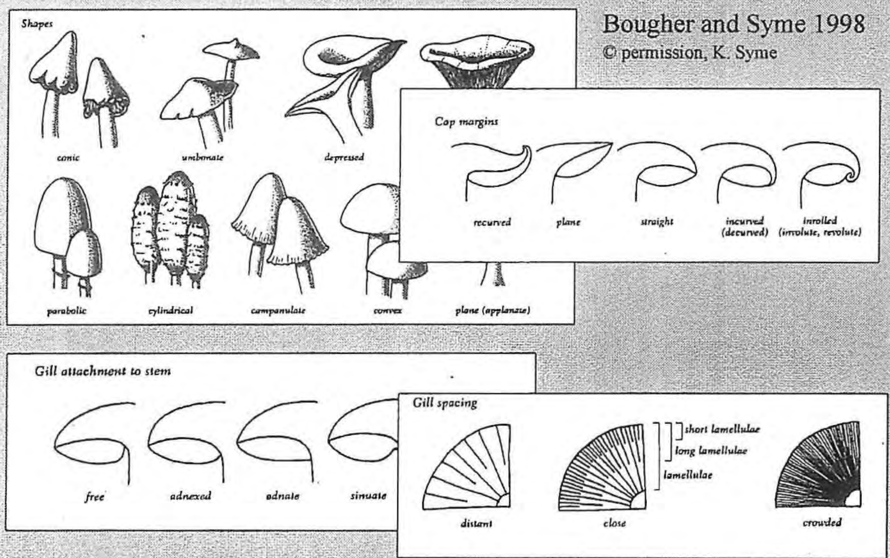
1. AGARICS – mushrooms with gills

RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS



RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

Bougher and Syme 1998
© permission, K. Syme



RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

Bougher and Syme 1998
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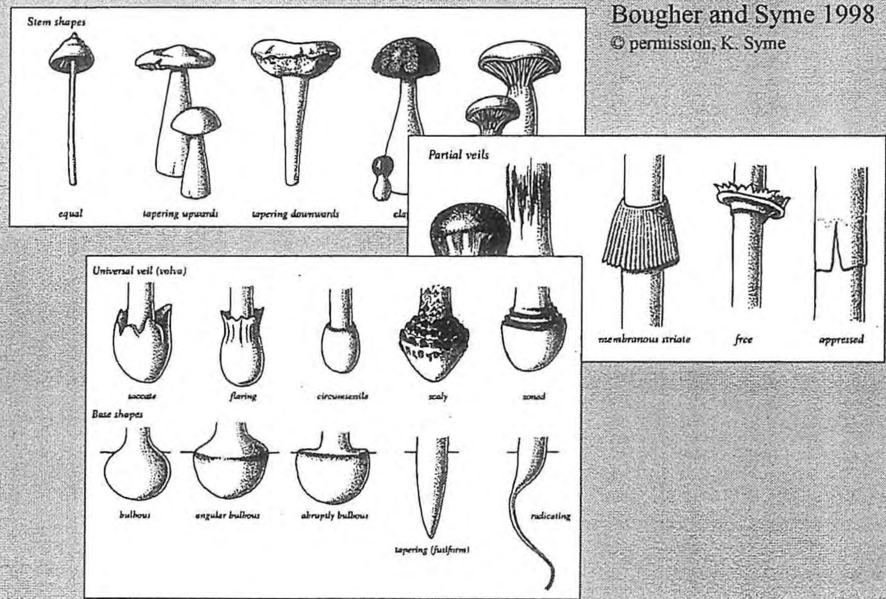
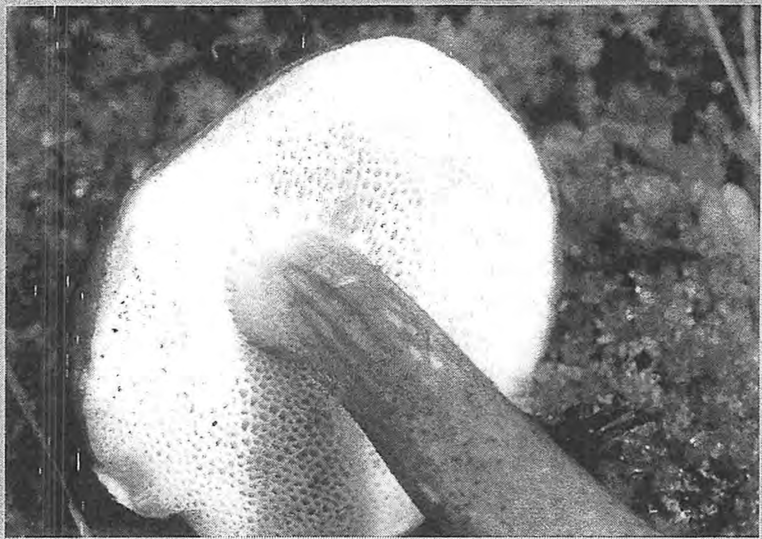


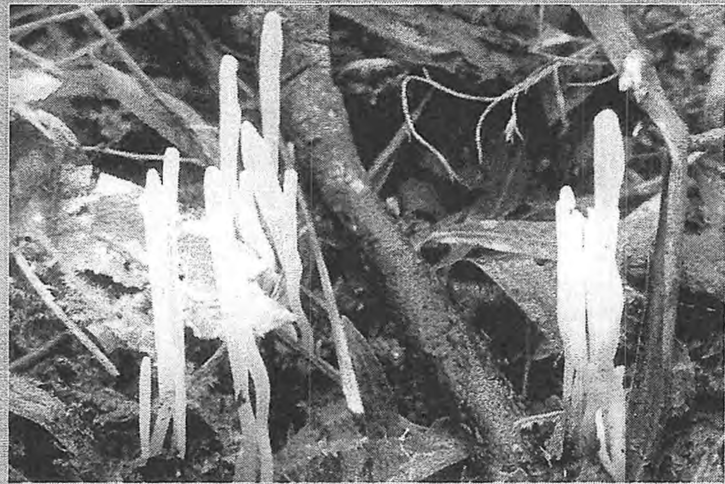
RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

2. BOLETES – mushrooms with pores



RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

3. CORAL FUNGI – fruitbodies with simple club-like or multi-branched structures



Clavulinopsis amoena

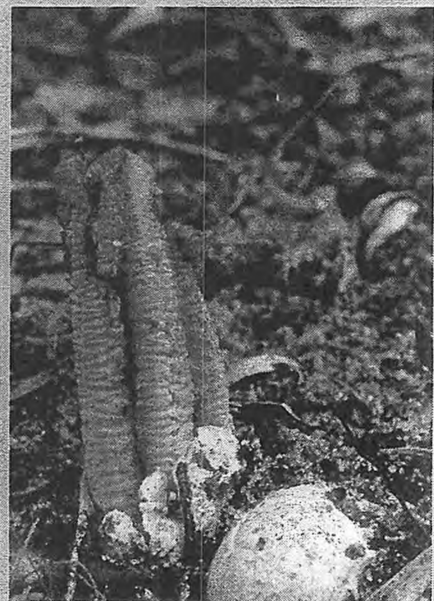
RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

4. EARTHBALLS & PUFFBALLS – sac-like fungi

Scleroderma cepa

RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

5. STINKHORNS – delicate or firm fruitbodies with foul smelling slime



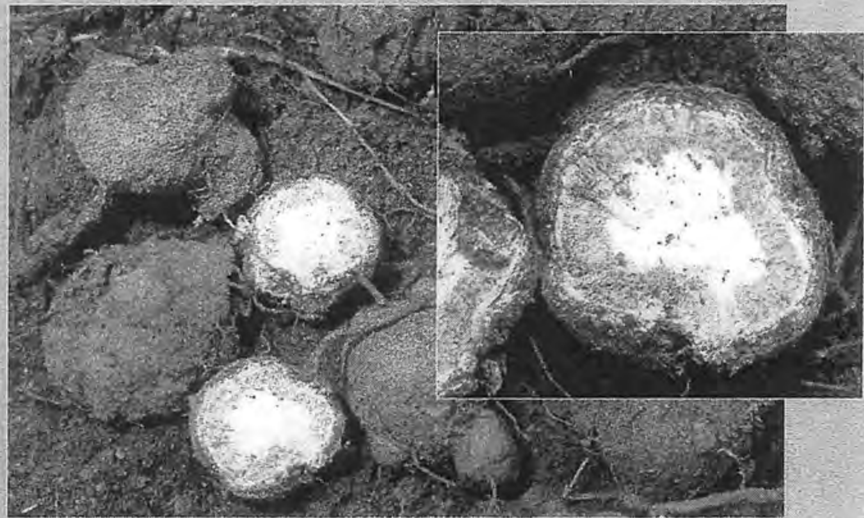
Colus pusillus

RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

6. SPINE FUNGI – mushrooms or fruitbodies with spines

RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

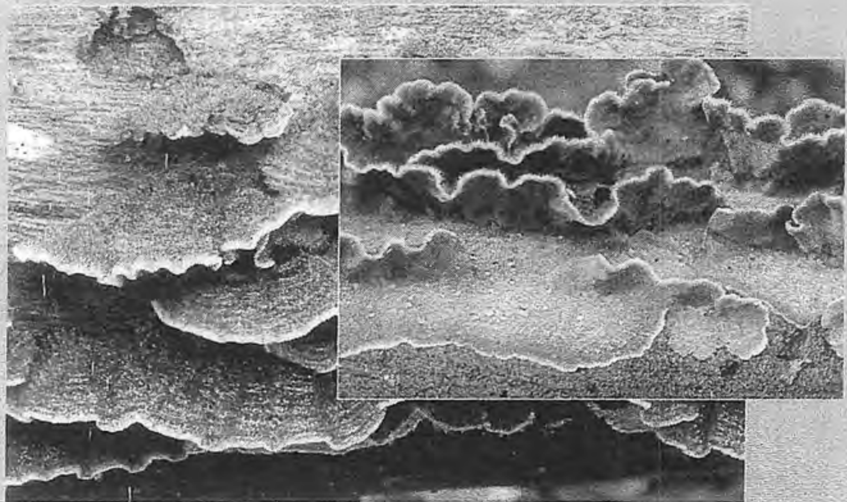
7. TRUFFLE-LIKE FUNGI – underground fruiting fungi



Mesophellia trabalis

RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

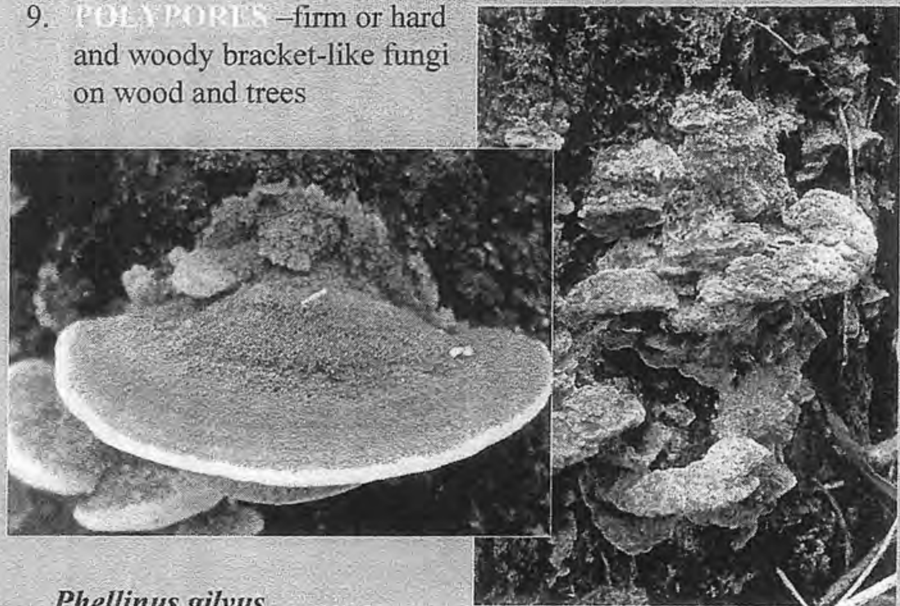
8. LEATHER SHELF AND CRUST FUNGI – thin leathery shelves or sheets on sticks and wood



Stereum illudens

RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

9. POLYPORES –firm or hard and woody bracket-like fungi on wood and trees



Phellinus gilvus

RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

10. JELLY FUNGI – soft gelatinous fungi on wood

Tremella mesenterica

RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

11. CUP & DISC FUNGI – Cup- or disc-shaped fruit bodies

Peziza tenacella

RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

12. EARTH TONGUES
Firm and fleshy with a tongue-like appearance

Trichoglossum hirsutum

RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

13. MORELS - Fleshy fruit bodies with an elongated honeycomb-like cap

Morchella el

RECOGNISING FUNGI OF THE SOUTH-WEST FORESTS

14. FLASK FUNGI - Usually hard and carbon-like

Daldinia concentrica

Department of Environment and Conservation

Our environment, our future

Flora Conservation Course

Translocation

Prepared by:

Leonie Monks, Research Scientist, Science Division, Kensington

Prepared for:

Version 1.0 (September 2008)

1 Translocation in Flora Conservation

A translocation is the deliberate transfer of plant material from one area to another for conservation purposes.

The phrase "for conservation purposes" is important, as that distinguishes it from gardening.

2 Types of Translocation

There are four different types of translocations. These are:

Re-stocking (or Augmentation or Enhancement): increase population size by adding individuals to an existing population.

Re-introduction: establishment of a population in a site where it formerly occurred.

Introduction: establishment of a population in a site where it is not known to have occurred but is within the known range and habitat.

Conservation Introduction: establishment of a population in an area that is outside the known range, but which is appropriate habitat.

A translocation aims to increase the number of individuals and populations of threatened plant taxa. This is the Biological success of the project. However you may have other goals you want to achieve from implementing a translocation. Such as encourage the local community to become involved in looking after threatened plants in their district or raise awareness about threatened species. This can be considered project success and clearly biological success should be considered the main focus of project success. For the work that is discussed in this talk one of the main goals of the project was to refine translocated methodology. With careful consideration of planting design, much information could be learnt about the species biology and how to improve survival in future translocations.

3 When to consider translocation.

Translocations are considered when:

- the species is rare and/or at a high risk of extinction AND
- threats to natural populations cannot be successfully managed on site

In addition, consideration must be given to:

- ability to actually grow plants for the translocation and
- availability of long term funding.

Funding is needed for the planning phase, the actual planting and, most importantly, the long-term monitoring program. Because a translocation is not finished after all the plants are in the ground, you must continue to go back to check to see whether the plants are surviving, growing and reproducing.

4 Steps in planning for translocation.

The steps you'll need to take in developing a translocation are as follows:

First you'll need to select the sites.

The following criteria can be used to selected a site for translocation

- Absence of threatening processes. This is particularly important as there is little point in translocating if the new site needs intensive management to control threats. You won't be improving the long term outlook of the species.
- Security of land tenure. This does not necessarily have to mean DEC managed estate, but it does mean there needs to be written agreement from the land owner/ manager that the site will be protected.
- Similarity of associated vegetation type and structure
- Similarity of soil type
- For example, in one red brown clay loam soil type with open Spinifex grasslands and open Allocasuarina, Eucalypt overstory, one threatened species, a Daviesia, occurs in the open flat area. When choosing a new site it would be important to look for these similar soil and vegetation types.

4.1 How many sites should be selected?

This will depend on several factors. If only a small number of plants are propagated then it may be sensible to concentrate effort at one site. However if a large number of plants are propagated it may be a good idea to "spread the risk" and not "put all the eggs in the one basket".

It may also be difficult to find suitable sites, which will dictate how many sites can be used. If the reason for translocation is to reduce the risk of one catastrophic event causing the extinction of a single population or the species, then you may decide to choose several sites.

Ultimately it will depend on your reasons for doing the translocation, the goals and aims of your translocation program, the amount of propagation material you have and the number of suitable sites you can find.

5 Translocation proposal

Preparing a translocation proposal is essential before any work commences on a translocation. Information that should be included is: History of taxa, the taxa's biology and ecology, yours aims, details of proposed translocation site a timetable of when each step is to take place, methodology to be used, a description of the long term monitoring plan, who is going to undertake the work, a criteria for success and failure, where the funding for the project is coming from, and this funding should cover not only the planting phase, but also the monitoring phase, endorsements from relevant land managers and owners, list any references cites and include maps of the taxas distribution and location of translocation sites.

An outline of a Translocation Proposal can be found in CALM Policy Statement 29 on the DECWeb at http://calmweb.calm.wa.gov.au/drb/edo/mab/pol.htm

The proposal must also be endorsed by all interested parties, in particular the DEC region where the work will be occurring, and any landowners or land managers of the area where the translocation site is proposed to be located.

It should then be submitted to the Species and Communities Branch for departmental approval. They will send the proposal to two independent referees and you will be asked to address any comments the referees make before the proposal is approved. You must allow at least three months from when you submit the proposal to Species and Communities Branch for proposal to be processed.

6 Plant propagation phase

A decision will need to be made as to which is the most appropriate method for propagating the plants for the translocation. Seed can either be collected fresh, specifically for the translocation, or the seed resources of the Threatened Flora Seed Centre may be utilised. Seed can then either be germinated and grown on before being planted as seedlings or direct seeding methods can be used.

If a seed based translocation is not suitable then plants grown from cutting may be planted. It is particularly important that a wide range of individuals are sampled from the natural population for a cutting based translocation to give a good genetic base to the new population. An alternative to cuttings is plants raised from tissue culture.

And remember to allow sufficient time to collect the propagation material. If seed or cutting material need to be collected specifically for the translocation there may only be a short window of opportunity to collect and you must plan ahead to ensure you are ready to collect at the appropriate time. This information can be discussed with the seed collector when you are initiating the translocation process.

6.1 Propagation Requirements

There are a few points to consider when deciding where to have plants raised for translocation. Firstly plants must be raised at an accredited nursery to ensure plants and soil are disease free.

Secondly it is essential that plants are raised at a place that keeps good records so that information about each individual plant can be traced all the way back to the point of seed or cutting material collection.

Records need to be kept of:

- the origin of the plant material,
- when it was collected
- who collected it
- how many plants the material comes from
- the method in which the plants were raised
- the parent material of each individual plant

And again you must plan ahead to allow sufficient time to grow plants on to a suitable age for planting. This information can be discussed with the plant propagator when you are initiating the translocation process.

The ultimate goal of your translocation is to create a viable population.

It is useful to know what the minimum number of plants needed for a viable population would be when determining the number of plants you need to achieve this goal. As we don't know this in many cases, we need to assess it using the characteristics of the species. In a paper by Bruce Pavlik (1996) you can score the species against nine characteristics that indicate viability. You can then make an estimate of between 50 and 2500 individuals from this. So for the characteristic of longevity you would score whether the plant is a perennial or an annual. If it is an annual it would fall closer to the 2500 end of the scale; if it is a perennial it would fall closer to the 50 end of the scale.

Some other factors to take into account are the amount of propagation material available and therefore how many plants can be grown. This depends on resources, including the funding available and the availability of facilities to undertake propagation. Also how many people can help undertake the propagation, planting and monitoring.

You will also need to take into account how many translocation sites are available and the size of the available habitat.

If you are planning any experiments, what would be the minimum number of plants needed to ensure a statistically valid experiment.

You may find that you do not have the resources to propagate sufficient plants in one year. For example, seed may be difficult to collect, in which case you should consider staggering planting over several years.

Propagation can require special techniques. At Kings Park nursery fire is used to stimulate germination of buried seed and seedlings.

6.2 Planting

When planting it is necessary to:

- Consider when is the best time for planting – i.e. not at the height of summer
- permanently tag transplants, so that each individual can be tracked during monitoring.
- consider the layout of the plants within the translocation site. This includes how far apart plants need to be planted, which will depend on the size of the adult plants. If an experimental component is included in the translocation then correct replication is needed when planning site layout. You also need to think about whether the plants need to be planted amongst other vegetation, or out in the open - have a look at the natural populations to give you clues as to where to plant.
- consider what level of care is to be given to the plants after planting. For example:
    - watering
    - mulching
    - protection against herbivores
    - protection against sun and wind
    - fertilising
    - use of soil wetting agents etc

Examples of after care

- Use of mulch,
- Setting up a watering system to water the plants over summer
- Fencing an area to protect against herbivores
- Fencing individual plants to protect against herbivores and shelter plants from sun and winds.

6.3 Monitoring

This is probably one of the most neglected steps of the translocation process; however it is one of the most important. Without detailed long term monitoring of both the new population and at least one of the natural populations there is no way of assessing whether the whole process was worthwhile. There is simply no point is spending a lot of departmental resources and using valuable propagation material if there is no long term follow up as to whether the process was a success and why. Even a failure can be valuable as long as it is known why, so that the same mistakes are not repeated.

A monitoring program should include:

- counts of survival
- measurements of growth
- counts of buds/ flowers/ fruit
- counts of naturally recruited seedlings

It should also include these same measurements for the natural populations to allow for comparison. These comparisons should be the basis for assessing success of the new population (for example if the new population has similar levels of fruit production or seed viability to the natural population).

It is essential that monitoring data be forwarded to the central database at Science Division, Kensington. This allows others to learn from previous translocations and can prevent everybody from having to reinvent the wheel every time a new translocation site is set up. It also means that there will be one central point for everyone to access translocation data and reduces the risk of data being accidentally lost. It also allows other to easily pick up your work, should you move on to another area of work or another workplace.

6.4 Assessing the success of the translocation

Deciding whether the translocation was worthwhile and successful is an extremely important component of the translocation process. It is also one of the most difficult to assess.

Success in the short term is whether the plants survive at the site, whether they grow and produce flowers and fruit and ultimately a second generation.

You also need to think of success in the long term. Many of our species are long lived and recruitment is linked to disturbance events such as fire. So you need to be able to ascertain whether the population will survive in the long term – beyond the life span of the plants you planted. Also, it is important to know whether the genetic diversity of the new population is adequate for the long-term adaptability of the population. Can the population adapt to changes in its environment? This is difficult to monitor without genetic studies.

Whatever characteristics of the translocated population you monitor you will also need to do on plants in the natural population. This will provide you with a baseline against which to assess the performance of the translocated population. Without this baseline you have no way of knowing whether the data you are collecting from the translocated plants is normal or whether the new population is performing poorly.

Another measure of success can be whether you accomplished the aims you set out to achieve. For example, you may want to get the local community involved in the planting of a threatened plant to develop a relationship with that community group. So your goal may be to plant one new population of a threatened plant species and at the same time get the local community involved with the planting and monitoring.

7 Case Studies of the DEC Projects

A range of treatments have been tested across a range of taxa to ascertain which were essential to ensure biological success. These are some of the treatments tested so far, obviously there are whole lot more that could be investigated.

- Gro-cones
- Shade
- Mulch
- Protection from herbivores
- Age of seedlings at planting
- Water
- Fire
- Smoke
- Disturbance
- Soil treatment (Terracottem)
- Seed pretreatment
- Planting location
- Mounding
- Deep ripping

8 Case Study 1

Lambertia orbifolia subsp. *orbifolia* (Round- leaf Honeysuckle) was known from 2 populations of 169 plants when translocation was begun in 1998. These populations were both located on narrow road verges where they had been accidentally graded during road maintenance and were also infected with dieback and aerial canker. We planted one new population in a nature reserve a few kilometres away from the natural populations. The site was considered suitable, because it has the same associated vegetation and soil type as the natural population, the land tenure is secure, it is free of *Phytopthora* and it is only a short distance away from the natural populations. 714 seedlings and cuttings were planted over four years between 1998 and 2005.

At the last monitoring 53% of these plants were surviving. Survival varied a between the different years planting 99% of the last plantings are surviving in 2006 but only 7% of the third plantings are surviving. This is obviously confounded by some of the experimental treatments tested but variations in years also account for some of the differences in survival. The plants have all grown taller and wider since planting, despite the treatments we have given them.

Some of the earlier graphs I showed compared the number of fruit between treatments, but the only way to understand how "normal" the level of fruit production is to compare the levels found in the translocated population to that found in the natural population. We compared the flower to fruit ratio over two years between the translocated population and three of the natural populations. In 2003 the translocated population was somewhere in the middle in terms of how many flowers it takes to produce one fruit.

We collected and tested the germinability of seed from the translocated and natural populations in 2001. The translocated population's germinability was slightly lower than that of several of the natural populations, but higher than that of the Narrikup townsite Reserve.

Naturally recruited seedlings were first found at the translocation site in 2002. Initially there were 57 seedlings recorded only around plants planted in 1998. But by 2006 there were 118 seedlings.

So in terms of the biological goals we set ourselves we have achieved them.

We have met the short term goals in that we have a population of 380 adult plants after eight years, plants have grown, viable seed produced at similar rates to natural populations and seedlings have naturally recruited at the translocation site.

For the long term we will use a mating system study and population viability modelling to make predictions about whether we may achieve long term success.

For our project goal we wanted to know whether any of these four techniques (Gro-cone, mulch, fencing and founding propagule type) increase survival, gowth and reproduction of our translocated individuals

We found fencing was worthwhile, the use of mulch and gro-cones was not worthwhile and that we should plant seedlings rather than cuttings.

So we achieve our aims for project success.

But continued monitoring is still very important and I would still recommend experimentally testing all treatments as results vary from site to site, species to species and year to year.

9 Case Study 2

Acacia cochlocarpa subsp. cochlocarpa (the spiral-fruited wattle) is known from around 115 plants in a single population north of Watheroo in the DEC Moora District. The subspecies is threatened by road verge maintenance activities, and activities such as spray drift, from the adjacent farm. Also of concern are the small population size and the lack of secure tenure. A decision was made to translocate this subspecies in 1997. In early 1998 a translocation site was found in a nature reserve 4 km away. The site is a gravel pit, which was deep ripped. The site was considered suitable, because it has associated vegetation surrounding the gravel pit and soil type that is the same as the natural population, the land tenure is secure, and it is only a short distance away from the natural population.

779 seedlings and 1500 seed were planted over four years. We currently have 65% of seedlings surviving. Only 6% of seed germinated and currently 64% of the germinated seeds survive. In terms of biological success this establishment is fairly reasonable.

Plants have grown relative to their size at planting.

The plants are producing seed at a rate similar to the natural population and seed viability is variable as is that of the natural population. There is no natural recruitment, so we haven't as yet met our short term criteria for success ten years after starting the translocation. However, we do know from ecological research done by Colin Yates that recruitment is limited to the post fire period, so we don't really expect recruitment until this happens. And this highlights the importance of knowing something about the biology and ecology of the species you are working with.

Our project goals were to investigate whether it was better to plant seedlings younger or grow them on in the nursery until they were much older. We also wanted to see how important watering over the first summer was to survival, growth and fruit production. And we looked at important protection from grazing was to translocation success.

Watering increased survival and growth, although this increase was only slight. But if you remember that more watered plants survived and they were bigger they are still probably contributing more seed to the soil seed bank than plants that were not watered.

As for age of planting, there was little difference in survival, with just slightly more one-year-old plants surviving than two-year-old plants. The two-year-old plants were larger than one-year-old plants, but I've added in the initial width data so you can see that these plants are bigger, because they started bigger. You can see the one-year-old plants are actually catching up. The biggest difference was in terms of appearance. One-year-old plants just look healthier than two-year-old plants. They have a denser canopy which is much greener than two-year-old plants.

Protection from grazing by kangaroos or rabbits turned out to be very important. Plants had a much better chance of survival and slightly better growth when they were protected from grazing.

So in summary we have met some, but not all of our short term criteria for success. And where we haven't met our criteria, we know why. We have met our project success goals in that we know that it is worth the cost and effort of watering the plants. We also now knowthat it is better to plant one-year-old plants rather than two-year-old plants because it is a shorter lead in time to translocation, they are easier to transport to site, easier to plant and they catch up to the older plants in size and seed production fairly quickly. And fencing to protect plants from grazing is very important

10 Summary of some important ideas from the case studies

These case studies show types of situations when translocations are used as part of a management program. They have highlighted how important it is to consider having an experimental component to the translocation. Several techniques were discussed and the results varied between species and between years. Without the experimental design there is simply no way of being sure what factors are having a significant impact on the outcome of the translocation. And finally you should now be aware that translocations are not a quick fix solution. They involve detailed planning and long term monitoring. Translocations should not be contemplated unless there are firm commitments given to long term monitoring.

11 Some useful references

Australian Network for Plant Conservation (2004) Guidelines for the Translocation of Threatened Plants in Australia. (Available for loan from the WA Herbarium Library and Woodvale Research Centre Library).

Department of Conservation and Land Management Policy Statement 29. Translocation of Threatened Flora and Fauna. (Available on the CALM Web).

Translocation of Threatened Flora.

Leonie Monks
Research Scientist
Science Division

Course content

- Background on translocations
- Method of translocating
- Monitoring translocations
- Case Studies

General Aim of the Presentation

To provide the participants with the basic knowledge of translocation methodology and the understanding of how translocations can be used in the conservation of threatened flora.

Learning Outcomes

1. Demonstrate an understanding of plant translocations and how they can be used as part of Threatened Species Management Programs.
2. Discuss the procedures that need to be followed when planning, setting up, and monitoring a plant translocation.

What is a translocation?

A translocation is the deliberate transfer of plant material from one area to another for conservation purposes.

(from the "Guidelines for the Translocation of Threatened Plants in Australia" by the Australian Network for Plant Conservation, 2004).

Categories of translocations.

- Re-stocking/ Augmentation/ Enhancement: increase of population size by adding individuals to an existing population.
- Re-introduction: establishment of a population in a site where it formerly occurred.

Categories of translocations

- Introduction: establishment of a population in a site where it is not known to have occurred, but is within the known range and habitat.
- Conservation Introduction: establishment of a population in an area that is outside the known range, but which is appropriate habitat.

Aims of translocation.

1. Create a viable self-sustaining population of a threatened plant taxa. (Biological)
2. Refine translocation methodology

(Project)

When to consider translocation.

Translocations are considered when:

- the species is rare and/or threatened.

AND

- threats to natural populations cannot be successfully managed on site.

When to consider translocation.

Consideration must also be given to:
- ability to grow plants.
- availability of long term funding.

Protocols used for developing a translocation.

1. Site selection

- Sites are selected based on the following criteria:
  - Absence of threatening processes
  - Security of land tenure
  - Similarity of associated vegetation type & structure
  - Similarity of soil type

- How many sites should be selected?

Protocols used for developing a translocation.

2. Translocation proposal. Includes:

- History of taxa
- Taxa's biology and ecology
- Aims
- Details of proposed translocation site
- Timetable
- Methodology
- Long term monitoring plan
- Personnel
- Criteria for success and failure
- Funding
- Endorsements from land managers & owners
- References
- Maps

Protocols used for developing a translocation.

2. Translocation proposal

- This document must be endorsed by all interested parties.
- It is then submitted to the Species and Communities Branch for departmental approval (allow at least three months for this process).

Protocols used for developing a translocation.

3. Plant propagation phase

This may utilise either:

- The seed resources of the Threatened Flora Seed Centre for
  - direct seeding
  - raising seedlings
- Cutting material
- Material raised from tissue culture techniques.

Protocols used for developing a translocation.

3.Plant propagation phase

- Sufficient time must be allowed to collect seed or cutting material ready for propagation at an appropriate time.

Protocols used for developing a translocation.

4. Raising of the plants

- plants should be raised at an accredited nursery to ensure plants and soil are disease free.
- it is **VITAL** that good records are kept of the origin of the plant material and the method in which the plants were raised.

Protocols used for developing a translocation.

4. Raising of the plants

- sufficient time must be allowed to grow propagules on to an suitable age for planting.
- how many plants?

Protocols used for developing a translocation.

5. Planting

- Consider the best time for planting.
- Permanently tag transplants
- Consider the layout of the plants within the translocation site.

look at natural popn's to determine the layout of plants at translocation

Protocols used for developing a translocation.

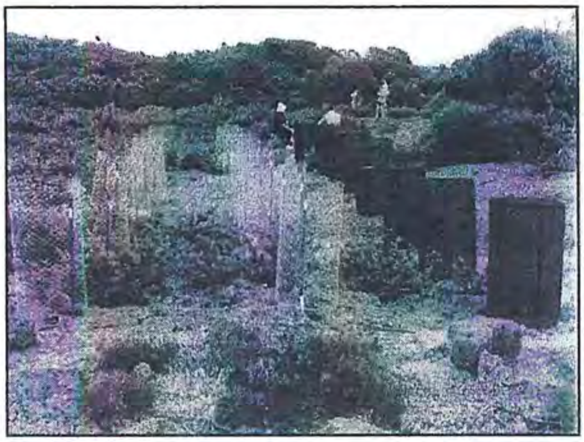
5. Planting

When planting consideration should also be given to level of after planting care.

- watering
- mulching
- protection against herbivores
- protection against sun and wind.

$1500 for box timer

herbivore exclusions



shade cloth to protect against winds.

Protocols used for developing a translocation.

6. Monitoring.

- Should include counts of:
- survival
- measurements of growth
- counts of buds, flowers, fruit.
- seedlings

Protocols used for developing a translocation.

6. Monitoring.

- Should also include these same measurements for the natural populations.
- It is essential that monitoring data is forwarded to the translocation database at Kensington.

Protocols used for developing a translocation.

7. Assessing the success of the translocation

Success can divided into 2 phases:

- Short term
  - –Survival, growth and reproduction of plants
- Long term
  - –new population able to be self sustaining
  - –maintenance of adequate level of genetic diversity.

Protocols used for developing a translocation.

7. Assessing the success of the translocation.

- Comparison with natural population.
- Whether you successfully achieved the aims of the project.

Case Studies

Project success

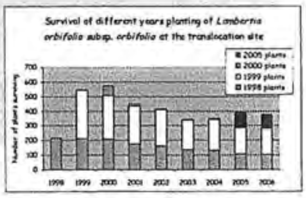
A range of treatments have been tested across a range of taxa to ascertain which were essential to ensure biological success.

- Gro-cones
- Shade
- Mulch
- Protection from herbivores
- Age of seedlings at planting
- Water
- Fire
- Smoke
- Disturbance
- Soil treatment (Terracottem)
- Seed pretreatment
- Planting location
- Mounding
- Deep ripping

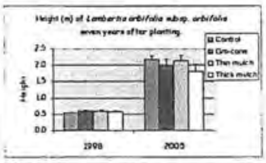
ambertia orbifolia
subsp. orbifolia.
– Narrikup.

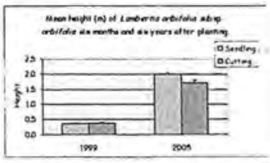
Translocation establishment

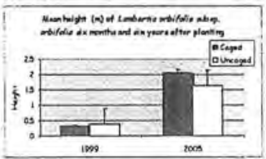
- 53% overall survival (380 of 714 plants).
- Survival of different years plantings varied from 7 to 99%.

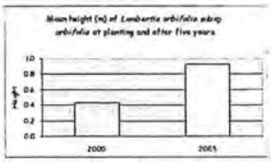


Vegetative Growth









Reproduction

Flower to fruit ratios for translocated and natural populations of *Lambertia orbifolia* subsp. *orbifolia*.

Population	2003	2004
Translocated	11:1	10:1
Spencer Road	4:1	8:1
Healy Road	15:1	2:1
Narrikup Townsite Reserve	29:1	10:1

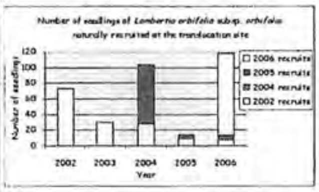
Reproduction

Seed viability in 2001 of translocated and natural populations of *Lambertia orbifolia* subsp. *orbifolia*.

Population	% seed germination
Translocated	88 ± 4
Spencer Road	95 ± 2
Healy Road	98 ± 2
Elvins Property	94 ± 3
Narrikup Townsite Reserve	70 ± 13

Recruitment

- 73 seedlings first recorded in 2002



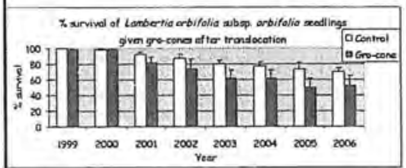
Has the aim of a viable population been achieved?

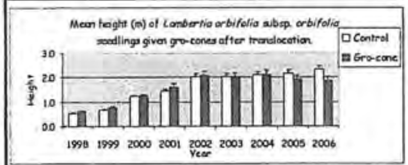
- Population of 380 adult plants after eight years.
- Plants have increased in height and width.
- Viable seed produced at similar rates to natural populations.
- Seedlings have naturally recruited at the translocation site.
- Mating system study and population viability modelling being used to predict long term success.

Lambertia orbifolia subsp. *orbifolia* - experimental treatments

- Gro-cone (1998)
- Mulch (1998)
- Fencing (1999)
- Founding propagule type (1999)

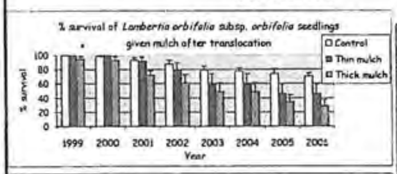
Gro-cones

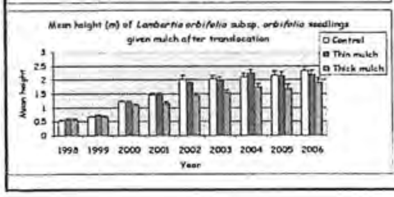




Gro-cone around *Lambertia orbifolia* subsp *orbifolia* seedling

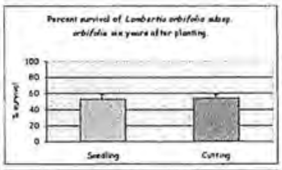
Mulch

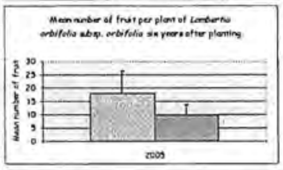




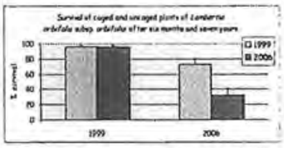
Lambertia orbifolia subsp. *orbifolia* seedling.

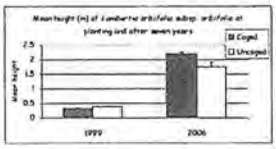
Founding propagule type.

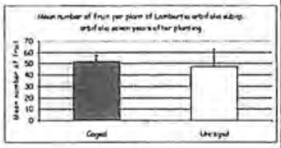




Fencing







Project Success: the conclusions so far.....

- Fencing worthwhile
- Mulch and gro-cones not worthwhile
- Seedlings performed slightly better than cuttings.

But....

- Continued monitoring very important.
- Still recommend experimentally testing all treatments, as results vary from site to site, species to species and year to year.

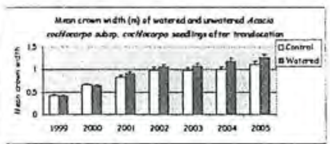
Joel Collins found more pop'n in Avon-Mortlock district recently.

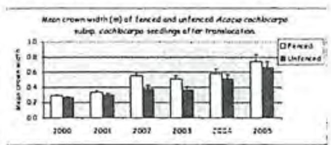
Acacia cochlocarpa subsp. *cochlocarpa*: Biological success?

- 779 seedlings and 1500 seed planted.
- 65% survival of seedlings in 2005.
- 6% of seed germinated.
- 64% of germinated seeds survive in 2005.

Seed germinated over 3 years.

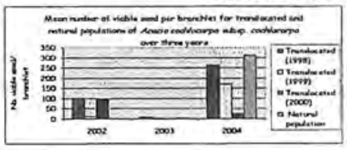
Acacia cochlocarpa subsp. *cochlocarpa*: Biological success?

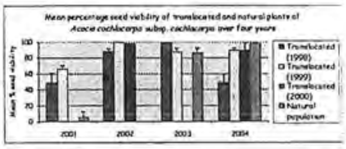




- Plants have grown relative to their starting size.

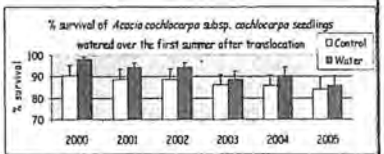
Acacia cochlocarpa subsp. *cochlocarpa*: Biological success?

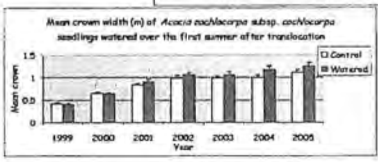




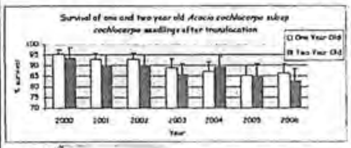
- Plants are producing viable seeds
- But no seedling recruitment due to lack of disturbance.

Water



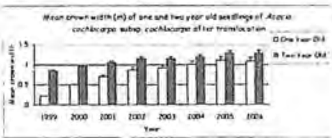


Age of seedlings at planting.

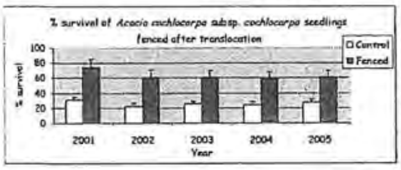


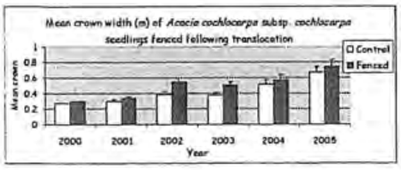
Acacia cochlocarpa subsp. *cochlocarpa* Photo: Bruce Maslin

Planting *Acacia cochlocarpa* subsp. *cochlocarpa*



Fencing





Acacia cochlocarpa subsp. cochlocarpa

Acacia cochlocarpa subsp. cochlocarpa: Biological and Project Success?

- Two new populations of 213 and 328 plants respectively.
- Plants have grown, and produced viable seed.
- No recruitment as yet.
- Watering and fencing important.
- Plant seedlings at a younger age (1 years rather than two years).

Acknowledgements

- Dept of Environment and Conservation staff.
- Kings Park nursery.
- Numerous volunteers.
- Natural Heritage Trust.
- World Wide Fund for Nature.
- Salinity Action Plan.

Scenarios

There are now some scenarios about translocations for you to discuss in small groups.

Department of Environment and Conservation

Our environment, our future

Flora Conservation Course

The Western Australian Herbarium

Prepared by:

Nicholas Lander, WA Herbarium, Kensington
Ryonen Butcher, WA Herbarium, Kensington

Prepared for:

Flora Conservation Course

Version 1.0 (September 2008)

1 The Western Australian Herbarium

The Western Australian Herbarium (PERTH) is part of the Flora Conservation and Herbarium Programme of DEC's Science Division. The herbarium's current operating staff includes 12 Scientists, 20 Technical Officers, four Administration staff and 52 Volunteers. Additionally, one Scientist and one Technical Officer are based in Manjimup. The herbarium also houses staff from the Threatened Flora Seed Centre and supports a number of DEC staff from other programmes, as well as externally managed personnel e.g. from the Perth Urban Bushland Fungi (PUBF) project, the Flora of Australia project and mining industry funded projects.

DEC is legislated under the CALM Act 1984 *"to be responsible for the permanent preservation of the plant collections of the Western Australian Herbarium and to care for and extend these collections"*, and these collections are used to describe and document Western Australia's botanical species diversity. With >680,000 specimens the herbarium is currently overflowing and will be housed in a new building—the Biodiversity Science Centre, in Kensington—in 2009. Other roles of the herbarium staff include identifying plant specimens, maintaining and developing the databases and interactive keys accessible through the herbarium's website FloraBase, maintaining and evolving FloraBase itself, coordinating a Regional Herbaria Network and running an extensive volunteer programme.

2 Herbarium Staff

The unique team of staff is located throughout the State. They gather, manage, research and communicate information about Western Australia's unique and precious flora. They have a vital place in a national and international network of herbaria and allied biodiversity conservation agencies.

Herbarium staff work closely with the Threatened Flora Seed Centre on studies of critically endangered (CR) species and also work in conjunction with Science Division's molecular genetics facility to help resolve the taxonomic boundaries of conservation-listed species. Many users consult the herbarium for baseline data.

Biodiversity data is managed using information technology, which allows for the communication of scientific results to a wide range of users involved in conservation. These information systems include the Census of Western Australian Plants, a Specimen database, a Plant descriptions database, a botanical library and database of reference materials, a plant images database, and a database of biological attributes of plants, much of which is linked to spatial data.

3 Herbarium Volunteers

The volunteer programme of the herbarium involves a wide range of people from the community. Their diverse work includes specimen processing, image capture and storage, plant identification, provision of plant information to the tourism industry and invaluable participation in regional herbaria. Volunteers also contribute to expanding the website FloraBase, and collecting, identifying and documenting invasive species. Some volunteers also have the expertise to curate and identify specialist plant groups, such as slime moulds and other non-vascular plants.

Field Surveying Methods in the field for Rare and Priority Flora

Sue Patrick

1. For recording a previously vouchered population or if trying to find a new population in a suitable plant community. Stop at location and record odometer reading and take GPS reading. If no plants are found it should be recorded that this locality has been searched (make mud map of area searched).

2. Equipment required. Carry collecting equipment in back pack or shoulder bag

   - Field notebook with collecting licence and Muirs veg system, pasted in for easy reference.
   - Jewellers tags for plant specimens.
   - Rare Flora Report Form or notes in field notebook on information to be recorded.
   - GPS
   - Camera
   - Notes on plant description, and photocopy of plant or a field herbarium card.
   - If at a site of a population previously vouchered by a herbarium specimen, notes on the site as recorded on the herbarium label, eg. plant community, soil, topography etc.
   - Hand counter, if required, for recording plant numbers.
   - Large collecting bag and small bags including paper bags for delicate specimens.
   - Handlens
   - Flagging tape
   - Secateurs (clean, use methylated spirit to clean between sites)
   - Pen knife, for removing small plants from soil.
   - Compass
   - Safety equipment, bandage for snakebite etc.

3. Check vegetation description and soil type if refinding previously recorded population, look at photocopy or field card to refresh memory of the plant.

4. Start to search in most likely area according to plant community, having read description of site where previously recorded for reference

5. When plants found:
   a. Recheck plant description, may need hand lens
   b. Establish area of population, walking transects at right angles, also
   check the other side of track, and along verges in both directions (disturbance opportunists)
   c. Count plants or estimate number.

6. Recording information.

Make records in field notebook, using a reminder of all the aspects of the Rare Flora Report Form that need to be covered. Also include plant size, habit, flower colour and any other points of note.

7. Take GPS reading, within population at nearest point to track, and recording boundaries of population if required.

8. Photographs, whole plant, close up of flowers and fruit, habitat.

9. Take voucher specimen for each population surveyed. This will ensure that a correct identification has been made, but may also be needed if future taxonomic work is required for the species, for example a split to subspecies.

10. Take specimens of the associated vegetation for identification. This is when it is useful to have an account of the vegetation in a field notebook, so that the specimens can be allotted collection numbers.

11. Tag specimens, bag them, fold over bag and put in a cool area of the vehicle. Press at end of day. May need to press at the time, eg. *Hibbertia* loses petals rapidly and needs to be pressed soon after collection, or if the day is very hot press every few hours.

Plant Identification

The WA Herbarium and its online plant information system, FloraBase

Ryonen Butcher
Research Scientist
Western Australian Herbarium
Department of Environment and Conservation

Department of Environment and Conservation
Our environment, our future

General Aim

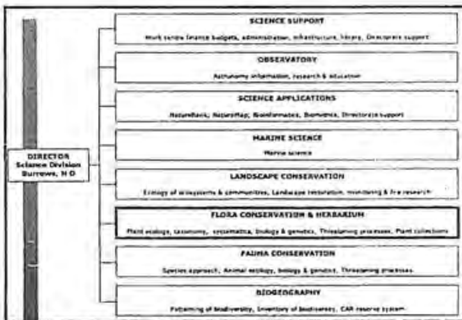
- To provide Departmental staff with an understanding and knowledge of the WA Herbarium and how it can be used to access information (particularly via FloraBase) on rare and threatened flora.

Learning Outcomes

- Have an understanding and awareness of:
  - the WA Herbarium and the work carried out by staff there
  - the facilities available for flora research
  - the Regional Herbaria Network
  - the Volunteer Programme
  - FloraBase, including the ability to use the site to retrieve information on rare and threatened flora species

Assessment

- Approximately 1 hour computer simulation assessment (Interactive Keys).
- 15 minute multi-choice theory exam.



Herbarium:
13 Scientists
17 Technical Officers
4 Administration Staff
50 Volunteers
13 Research Associates

Manjimup:
1 Scientist
1 Technical Officer

The WA Herbarium

- Unique State-wide team
- Gathers, manages, researches and communicates information on our unique and precious flora
- Vital role in a national and international network of herbaria and allied biodiversity conservation agencies

WA Herbarium - Responsibilities

- Safe-keeping and expansion of the State's plant, algae and fungi research Collections.
  - New specimens - new taxa and new records
  - Provide the core resource for knowledge of the State's flora and fungi
- Description and documentation of WA's botanical diversity.
  - Fundamental resources for accurate identification of plant and fungi specimens throughout WA

Herbarium and Staff Roles

- Biodiversity
- Biosystematics
- Conservation
- FloraBase
- Regional Herbaria Network
- Volunteer programme

Biodiversity

- Biological diversity – includes genetic diversity, species diversity and ecosystem diversity
- WA has a rich and unique flora
- SWAFR is in the world's top 20 biodiversity hotspots; *c.* 60–65% endemism
- Biodiversity documented through vouchering

Biodiversity Collections

- >706,158 vascular plant specimens - 13,213 taxa
  - 1,199 naturalised aliens + 12,014 native plants
  - 2008–2009: 22,618 collections added i.e. 3.3% increase
- >20,000 marine plant + algae specimens - *c.* 1,000 spp.
- >11,000 fungi specimens (CSIRO) - *c.* 2,600 spp.
  - Est. only 5–10% fungi known; *c.* 140,000 spp.

Biodiversity Collections

- Biological Surveys:
  - Salinity Action Plan; Swan Coastal Plain; Yilgarn and Ravensthorpe Ranges; Pilbara Biological Survey; Kimberley Heritage Assessment; Kimberley Islands
- Woodland Watch and Wetland Watch
- Decommissioning of Pilbara Regional Herbarium
- J Chappill legume collections; M & R Barrett Kimberley collections; Kings Park
- Threatened Flora Seed Centre vouchers
- DEC Regional Offices and Regional Herbaria

Reference Herbarium

- Currently has *c.* 14,000 specimens representing *c.* 11,000 taxa
- Over 3,000 visitors use this resource to identify plant specimens during any given year
- Maintained by volunteers and populated with duplicate specimens from the research collection

Biosystematics

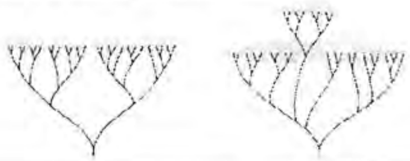
- Use of data (e.g. cytological, genetic, morphological, biochemical) to delimit and characterise species and to assess taxon relationships, especially within an evolutionary context
- Basis for understanding and ordering of taxonomic biodiversity

Biosystematics

- Identification applications and manuals
- Taxonomic journal *Nuytsia* - 1970, *c.* 100 spp./yr
- Regional Floras and field guides
- Recent and current research

Recent Research Outcomes

- *Banksia* Australia + New Guinea; *Dryandra* SW WA
- Morphological and molecular data analysed
- *Dryandra* now included in *Banksia*
  - changes in circumscription and nomenclature



Tecticornia bibenda
Top 10 species 2007

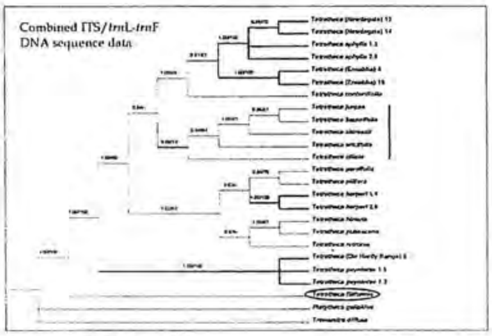
Bibendum, the Michelin Man™

Rare BIF *Tetratheca* Species

Tetratheca paynterae

Tetratheca aphylla

Tetratheca harperi



Adapted from Butcher *et al* (2007)

WA Herbarium Research

- Taxonomic studies on plants arising from biological survey; description of new plants threatened by mining
- Taxonomy of specialist vascular plant groups:
  - e.g. *Stylidium*, *Tetratheca*, *Synaphea*, *Acacia* (Pilbara, Dalwallinu, Mulga), samphires, epacrids, monocots, genera in Asteraceae, Sterculiaceae, Proteaceae, Myrtaceae (tribe Chamelaucieae), Leguminosae
- Taxonomy of marine plants and fungi (PUBF)
- Development of interactive keys

Conservation Biology

- WA Herbarium's biodiversity information complements many conservation projects:
  - Genetics & biosystematics for conservation, circumscription & management
  - Rare & threatened species seed storage
  - Weeds of WA
  - Experimental translocations of CR plants
  - Susceptibility of rare & endangered species to *Phytophthora*
  - Population ecology of CR flora
  - Causes of rarity in four *Tetratheca* taxa in the Goldfields
  - Avon Natural Diversity Programme - Baselining

Biodiversity Information Systems

- Biodiversity data is managed using sophisticated information technologies
- Allows for communication of scientific results to a multitude of users

Biodiversity Information Systems

- WA Census (>21,577 names)
- Specimen database (>706,158 specimens)
- Plant descriptions database
- Botanical library and database (>23,528 accessions)
- Plant images database (>36,083 + 6,840 on FloraBase)
- Spatial data
- Biological attributes of plants

2008–2009

- 254 names added to the Census
- A decrease (-71) in the number of manuscript names in current use, (374 to 303)
  - formal publication
  - conversion to phrase names (Australian Plant Census)
- 36 new phrase names in current use (1186 to 1222)
- Continued increase in published species, up 116 (111 native and 5 alien) to 10,724 species

FloraBase

- State-wide
- Integrates all previous datasets
- Provides lists of plants, up-to-date classification, short descriptions, range maps and a representative image
- Primary method for staff and public to access botanical information

FloraBase

http://florabase.dec.wa.gov.au/

Regional Herbaria Network

- *c.* 70 regional community groups - maintain local reference collections of duplicate specimens
- Trains volunteers to accurately record data
- Contributes new documented specimens
- Maintains accuracy of identification

Volunteer Programme

- Allows for active public participation
- Strong links with community environmental groups
- Assistance with on-ground projects reduces time, money and individual labour

Volunteer Programme

- Specimen processing
- Image capture and storage
- Plant identification
- Provision of plant information to the tourism industry
- Regional herbaria network co-ordination

Volunteer Programme

Current Projects:

- Contributions to FloraBase
- Development of interactive keys
- Collection, identification, and documentation of invasive species - Weed Information Network (WIN)
- Curation and identification in specialist plant groups e.g. slime moulds (Myxomycota)
- Compilation of historical information

Utility and reciprocity…

- Information:
  - Descriptions and names
  - FloraBase
  - Specific data
- Specimens:
  - Advice on collecting and preparing specimens
  - Identification

Assessment

Short answer and/or multi-choice - 15 mins

Assessment

1. What is is the principal responsibility of the WA Herbarium?

    1. Maintain a collection of culinary herbs
    2. Identify plants for DEC staff, consultants and the public
    3. Describe and document WA's botanical diversity
    4. Develop new plant strains for silvicultural and horticultural use
    5. Write popular guides to WA wildflowers

Assessment

2. What facilities are <u>un</u>available at the WA Herbarium?

    1. Community Reference Herbarium
    2. Research Herbarium
    3. Culinary Herbs for Sale
    4. Botanical Library
    5. Public Exhibitions

Assessment

3. Regional Herbaria Collections are…

1. Owned by the WA Herbarium
2. Duplicated at the WA Herbarium
3. Funded by DEC
4. Commercially operated
5. Managed by local councils

Assessment

4. The WA Herbarium contains plant specimens from throughout…

1. The world
2. Australasia
3. Australia
4. Western Australia
5. SW Western Australia

Assessment

5. The primary role of biosystematics is to provide a basis for…

1. Understanding of taxonomic relationships and ordering of biodiversity
2. Understanding of plant growth rates
3. Identification of plants at risk from die-back
4. Identification of potential weed threats
5. Management of rare flora

Assessment

6. Biodiversity information systems maintained by the WA Herbarium include…

1. Declared & Endangered Flora List (DEFL)
2. *Phytophthora* Database
3. NatureBase
4. Census of WA Plants (WACensus)
5. EcoBase

Assessment

7. FloraBase is…

1. A database of plant species names
2. A database of plant specimens
3. A database of plant species descriptions
4. A database of plant images
5. An information system that integrates a number of datasets concerning WA plants

Assessment

8. Regional Herbarium Network Volunteers…

1. Spray weeds in nature reserves with herbicide
2. Provide advice on poison plants to local hospitals
3. Identify marihuana & other drug plants for local police
4. Maintain and extend local plant collections
5. Collect native flora for plant nurseries

Assessment

9. The WA Herbarium is…

1. A botanic garden
2. A herb nursery
3. A library
4. A multi-faceted information system on the flora of WA
5. A branch of the WA Museum

Assessment

10. The WA Herbarium charges…

1. All clients for services
2. All non-DEC clients for services
3. Only commercial clients for services
4. Academic clients & students for services
5. Commercial clients & clients in receipt of external funding for services

Declared Rare Flora and road maintenance

What is Declared Rare Flora?

Declared Rare Flora, or DRF as they are commonly referred to, are native plant species that are rare, in danger of extinction or otherwise in need of special protection. They may also be referred to as 'Threatened Flora'.

Many DRF species are only known from a small number of mature plants and some only occur in one or two locations. Road verges often provide important habitats for rare flora, especially in shires where extensive clearing has occurred for agriculture, housing and industry. For example, a particular species of grevillea is known from only one roadside population of approximately 443 individual plants.

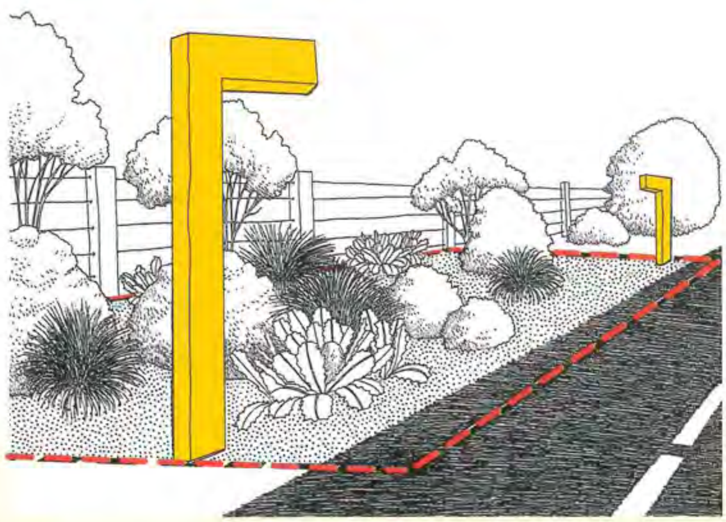
Declared Rare Flora and the law

DRF is given special protection under State and Federal legislation to prevent extinction and to maintain biodiversity. The State legislation, the *Wildlife Conservation Act 1950*, states that DRF shall not be taken unless with the written authorisation of the Minister for the Environment. For this purpose, the words 'to take' means 'to gather, pluck, cut, pull up, destroy, dig up, remove or injure the flora or to cause or permit the same to be done by any means'. For example, damage by grading or weed spraying constitutes 'taking', as does collecting seed or specimens.

Applications for permits to take DRF are arranged through the Department of Environment and Conservation (DEC). Applications are assessed on their effect on the conservation of the species at a local and regional scale, and require at least six to eight weeks to be processed, depending on their complexity and the potential impact on the DRF. A penalty of up to $10,000 applies to DRF that is taken without a permit. For more information, contact your local DEC office or DEC's Species and Communities Branch on (08) 9334 0455.

How do I know where Declared Rare Flora grows on roadsides?

To assist road managers, DRF sites on roadsides are generally marked with two standardised yellow markers at either end of a site, which are bent to face towards each other as shown in the illustration. These markers are commonly known as 'hockey sticks' or DRF markers. It is usually the road manager's (shire or Main Roads) responsibility to erect and maintain the markers in consultation with the local DEC Conservation Officer.



The markers indicate that DRF plants may occur anywhere between the markers, from the road's running surface to the fence. If work is proposed in the vicinity of, but particularly between, these markers road workers should check with their supervisor as to how the work may impact on any DRF, and change the work practice if necessary to avoid taking the DRF. Continuing road works without obtaining a permit may break the law and jeopardise a DRF population.

When new populations of DRF are found, formal notifications are sent to the appropriate landowners and managers. Road managers should maintain a register of DRF occurrences on their roadsides to ensure works are planned to avoid impacting DRF.

Everyone is responsible for protecting Declared Rare Flora for the future.

2008277-0808-1M

ACT NOW FOR THE FUTURE

Government of Western Australia Department of Environment and Conservation

Our environment, our future