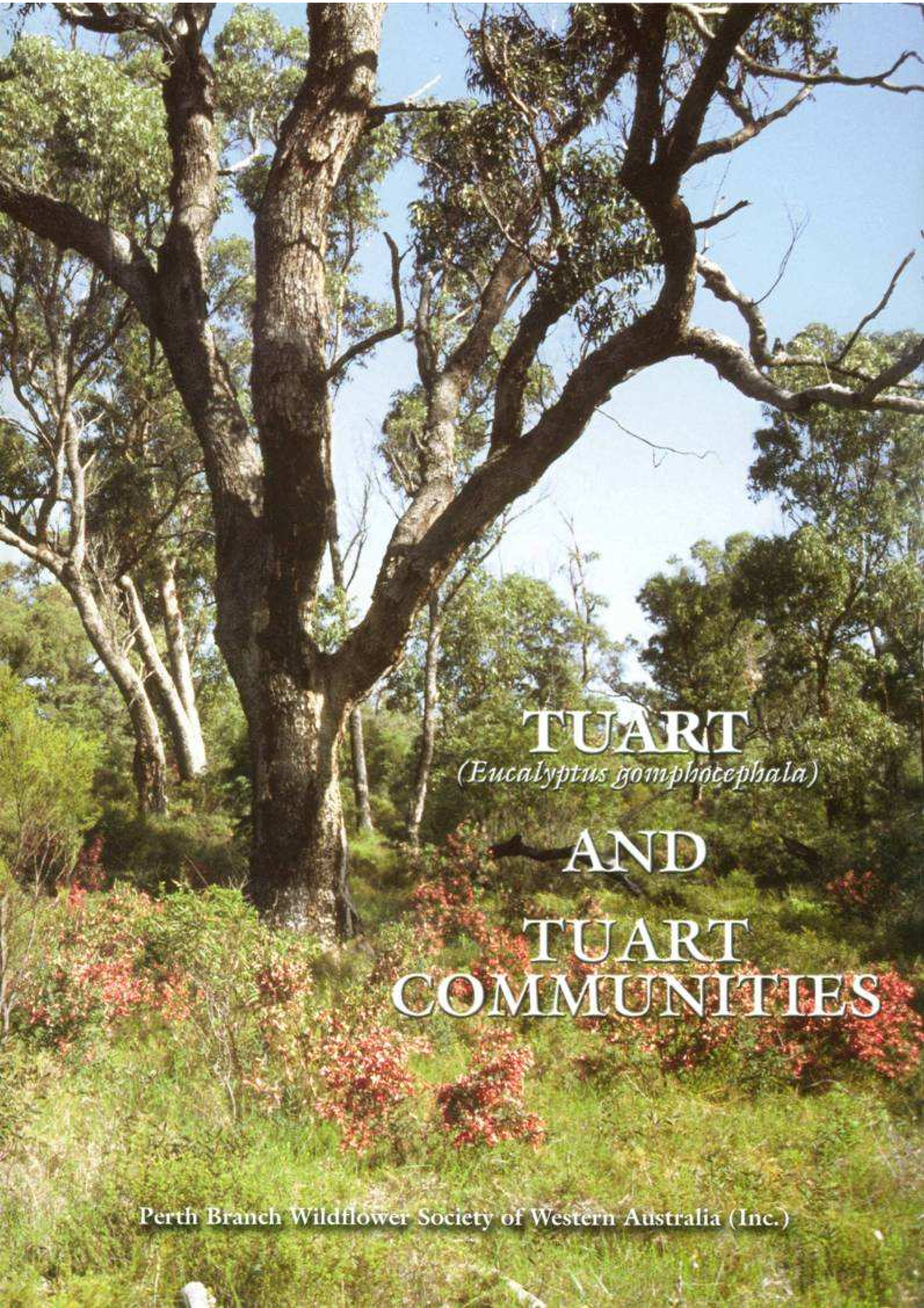

TUART
(Eucalyptus gomphocephala)
AND
TUART COMMUNITIES

Perth Branch Wildflower Society of Western Australia (Inc.)

TUART

(*Eucalyptus gomphocephala*)

AND

TUART COMMUNITIES

Edited by BJ Keighery and VM Longman
June 2002

A Perth Branch
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Publication

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Individual papers should be referenced to the individual authors in this publication.

Cover and opposite page 1: Tuart community in The Maidens (Tuart Area 73).
Photographs: Bernhard Bischoff

CONTENTS

INTRODUCTION

The Book: Tuart (*Eucalyptus gomphocephala)* and Tuart Communities

This book began as the proceedings of a workshop – **Tuart - the tree and the community with which it lives**, held in March 1998 (see below). At the Workshop the organizers gave a commitment to produce proceedings of the Workshop. Essentially it was intended that the proceedings would cover the talks and respond to the issues raised in discussion at the Workshop. It was planned that this would be done by the end of 1998.

Over the next three years, a series of unforeseen events delayed the production of the proceedings. To some extent this delay was fortuitous as it allowed a series of topics and issues to be further researched. These are outlined below.

- Work in progress at the time of the workshop could be completed and/or developed. This is particularly evident in the paper on variation in Tuart. At the time of the workshop David Coates was unable to reference specific genetic data for Tuart. Since the workshop David and Linda Broadhurst were able to begin this work and present their results in this publication. Other contributors were able to expand on their work, often in collaboration with others. An example of this is the paper by Robert Powell and Bronwen Keighery.

- A more thorough response to the topics, issues and questions raised in the open discussion session was possible. This has been done through both
  - a direct response paper: 'Tuart Issues - Responses to the Questions and Issues Raised at the Workshop' and
  - the papers: 'The Distribution and Conservation of Tuart and the Community with which it Lives' and 'Floristics of the Tuart Forest Reserve'.

- Improved integration of the written papers.

As a consequence, the publication is somewhat different than what was planned at the workshop, hence the name change.

The Workshop : Tuart (*Eucalyptus gomphocephala*) - the tree and the community with which it lives

On Saturday 21st March 1998 the Wildflower Society of Western Australia - Perth Branch, in co-operation with the Departments of Conservation and Land Management (Wildlife Research Centre) and Environmental Protection (Conservation Branch) organized a one day seminar/workshop on **Tuart - the tree and the community with which it lives**.

The topic of the Workshop arose as:
- Tuart is an endemic of the Swan Coastal Plain where most of the people in WA live;
- Tuart is typical of many of the communities growing in coastal areas from Busselton to Jurien;
- Tuart grows in a variety of communities from the forests of Busselton to scattered groves near Jurien; and
- the conservation of Tuart and its community is vital to conservation on the Swan Coastal Plain.

Several months before the Workshop, a flier was distributed to a variety of groups and state and local government bodies. This advertising was very successful and the Workshop was booked out a week in advance. Participants at the Workshop listed the following sources/contacts when they were asked how they had heard of the workshop - Ecoplan News, South West Environment Centre, WA Naturalists Club, Wildflower Society Flier, Ecoplan Workshop, Landcare Magazine, Greening WA Leaflet, Swan Catchment Centre notice board, Department of Conservation and Land Management (CALM) volunteer newsletter and personal contact. The high level of response to the limited advertising indicated that there was a high interest in Tuart.

Around seventy people registered for Workshop. These people are listed below. Several people were unable to attend on the day.

George Babarskas
Barbara Backhouse
Bob Backhouse
Jim Barrow
Lin Barrow
Bernhard Bischoff
Marion Blackwell
Charles Broadbent
Kate Brown
Norma Calcutt
Don Cameron
Cheryl Campbell
Ben Carr
Kevin Chia
David Coates
Ann Cochrane
Margaret Collins
Dianna Corbyn
Jo Darbyshire
Mitchell Davies
John Dell
Glynne Dyer
Charles Evans
Eitan Friedman
Gerry Gauntlett
Judith Gauntlett
Keryn Gear
Neil Gibson
Mary Gray
Ann Gunness
Claire Hall
John Harris
Alison Hearn
Griselda Hitchcock
Steve Hopper
Ric How
Brian James
Bronwen Keighery
Greg Keighery
Jan King
Ian Lantzke
Patricia Lantzke
Brendan Lepschi
Janice Marshall
Gary McMahon
Neil McMulkin
Karen McRoberts
Ellen Miguel
Tom Mitchell
Brian Moyle
Michael Norman
Margo O'Byrne
Dorothy Perret
Hywel Phillips
Suzanne Robertson
Robin Roe
Katinka Ruthrof
Lesley Shaw
Carolyn Switzer
Claire Thorstensen
Challis Tilbrook
Bill Tyler
Maxine Tyler
David Wake
Neil Walker
Rose Walker
Andrew Webb
Beth Weir
Nick Woolfrey
Colin Yates

Participants came from across the range of Tuart, from Jurien to Busselton. Friends Groups, landholders, local government, industry, CALM, Kings Park, the Department of Environmental Protection and Conservation and Land Management and the WA Museum were all represented at the Workshop.

The Workshop went from 10am to 3.30pm and was held in the Tuart woodland at the CALM Wildlife Research Centre at Woodvale. Before lunch, expert speakers presented papers on the nature of variation in the Tuart species, the biology of Tuart, the variety of communities in which Tuart grows and the flora and fauna of Tuart communities. After lunch Tuart reserve managers from the community and government briefly addressed Tuart management issues. A workshop discussion session followed in which the participants of the workshop were invited to comment on issues raised by the speakers, present their own issues and question any of the speakers.

Bronwen Keighery chaired the morning session and Margo O'Byrne the afternoon session.

Displays on Tuart at Mt Henry, Bunbury and Bold Park were mounted in the Wildlife Research

Centre Library.

The setting of the centre, a delightful day, delicious morning and afternoon teas and lunches, fine speakers and willing participants ensured that the workshop was a success.

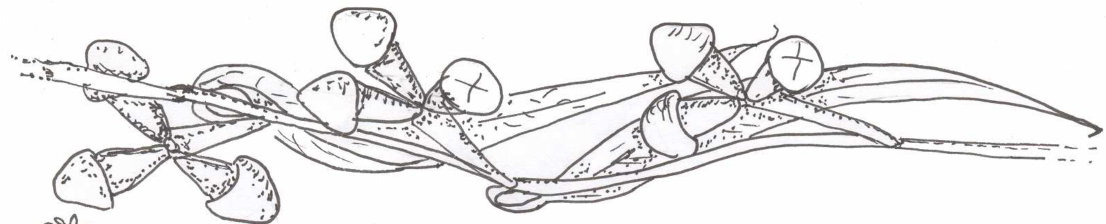
ACKNOWLEDGEMENTS

With such a long gestation, this publication has relied on the encouragement and support of many people. So, finally now that this book is published we wish to thank the following individuals and groups.

- The people who registered for, and participated in the workshop.
  These people were listed on the previous page.
- Presenters of the papers at the workshop.
  We are fortunate in this state, as there are many generous people in the community of biologists who are happy to share their areas of expertise with the interested community. All of the speakers at the Workshop enthusiastically responded to the initial request to prepare a talk and were erudite and knowledgeable on the day. The presenters are indicated on the Program over the page.
- The authors of the papers
  The authors are listed on the Contents page. The papers also contain individual acknowledgment sections.
- The Workshop Committee: Barbara and Bob Backhouse, Lin and Jim Barrow, Neil Gibson, Claire Hall, Alison Hearn, Bronwen, Greg, Kristin and Sarah Keighery, Brian Moyle and Beth Weir. A particular thanks to Barbara Backhouse who typed some of Bronwen's Workshop notes and proof read most of the papers.
- People were not involved in the workshop but have volunteered time and expertise to the project: David Longman, Kelly Rylander, Sandra Santich and Nick Casson. Special mention should be made of David Longman's invaluable computer support.
- The Departments of Conservation and Land Management and Environmental Protection who supported the workshop and the production of this book.
- The Department of Conservation and Land Management Wildlife Research Centre at Woodvale for supplying the venue for the Workshop.

We have endeavoured to list all those who have been involved in the Workshop and contributed to this publication. Some may have been missed and we apologize.

Bronwen Keighery and Vanda Longman



Tuart (Eucalyptus gomphocephala*)* – *the tree and the community with which it lives*
Workshop Saturday 21st March 1998

10 am to 10.20 am
Registration and Morning Tea

10.20 am to 1 pm
Part A- The Tree and its community *Chair Bronwen Keighery*
(Presenters are in bold)

Tuart and its variation	***David Coates*** *(CALM)*	*30 mins*
Biology of Tuart	***Colin Yates*** *(Kings Park Board and Botanic Garden)*	*30 mins*
Tuart Plant Communities	***Neil Gibson*** *and Bronwen Keighery (CALM and DEP)*	*30 mins*
Flora of Tuart Communities	***Greg Keighery*** *(CALM)*	*30 mins*
Fauna of Tuart Communities	***Ric How*** *& John Dell (WA Museum)*	*30 mins*

Lunch: *1 pm to 1.45 pm*

1.45 to 3.30 pm
Part B - Management Issues *Chair Margo O'Byrne*
This session will begin with short presentations on management issues associated with Tuart reserves presented by four community or agency representatives.

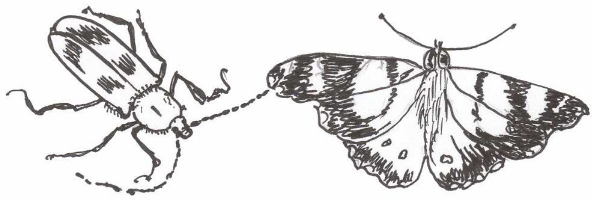
Short Presentations

Bronwen Keighery	*Tuart in the urbanised landscape*
Bernhard Bischoff	*Tuart at Bunbury*
Charles Broadbent	*Tuart Management Issues in the Ludlow Tuart Forest*
Ben Carr	*Tuart at Woodman Point*

Workshop Discussion
The following open session will consider management issues raised as a result of the morning's talks, issues raised by managers and the participants.

Groups managing bushland areas in which Tuart grows will be invited to present displays on their bushland.

Location: *CALM Wildlife Research Centre, Woodvale, Perth.*



TUART - WHERE IT GROWS

CONTENTS

THE DISTRIBUTION AND CONSERVATION OF TUART AND THE COMMUNITY WITH WHICH IT LIVES

BJ Keighery[1], GJ Keighery[2] and D Shepherd[3]

1. Perth Branch of the Wildflower Society of Western Australia (Inc.), PO Box 837, Nedlands, WA, 6909.
2. Science Division, Department of Conservation and Land Management, Wildlife Research Centre, PO Box 51, Wanneroo, WA, 6946.
3. Department of Agriculture, Locked Bag 4, Bentley Delivery Centre, WA, 6983.

ABSTRACT

Tuart (*Eucalyptus gomphocephala*) is endemic to the Swan Coastal Plain being found in a near coastal band approximately 400 kilometres in length from Jurien on the northern margin of the Plain to the Sabina River (just east of Busselton). Tuart is generally confined to the two coastal æolian dune belts, the Quindalup Dunes and the Spearwood Dunes. A series of outlying populations are known from the Moore, Swan, Canning, Murray, Serpentine and Harvey Rivers. The outlying population on the Swan was named as a separate variety but now appears to be extinct. Tuart is relatively common on the deeper soils of the Spearwood Dunes but less common on the Quindalup Dunes.

Vegetation mapping of areas of the Swan Coastal Plain began in the 1950's. Two sets of mapping are currently available in a digital format being: mapping of the broad structural units with Tuart in the overstorey; and mapping of vegetation complexes. Only the former covers the entire Plain and both map Tuart as principally occurring on the Spearwood Dunes, significantly underestimating the area on the Quindalup Dunes.

Information is also available on the regional floristic groupings (floristic community types) in which Tuart is found. As would be expected Tuart occurs in a variety of floristic community types across its range from both wetland and upland types. In only some of these is Tuart a defining species.

Current information on the distribution and abundance of typical Tuart and Tuart dominated communities indicate that there are significant numbers of individual trees and vegetated areas remaining. However, a series of issues are raised in relation to retention and protection. It appears that the Red Tuart (*Eucalyptus gomphocephala* var. *rhodoxylon*) is extinct and it is recommended that this be gazetted as Declared Rare Flora. The other issues relate to the extent and condition of Tuart dominated communities. At the level of vegetation type, the broadest level of definition of ecological communities, two vegetation types are identified as being in need of urgent action to identify their extent and condition and identify areas for retention and protection. The retention levels of the other four Tuart dominated vegetation types meet current retention targets. However, Tuart dominated communities have been significantly impacted by partial clearing, grazing, use as shelter areas, frequent fire, forestry, horticulture, weed invasion and, apparently, changes in the water table. This vegetation is generally in a more disturbed condition than surrounding vegetation. Areas of Tuart dominated vegetation in the best condition should be priorities for retention and protection. There is also a need for better understanding of Tuart and how to protect and maintain populations of Tuart and the communities in which it grows. A series of recommendations are made to address these concerns.

INTRODUCTION

Tuart has long been of interest to the people of Perth and its surrounds. However, there is some confusion as to the distribution and abundance of Tuart, which is evident both in the broader community as well as in the published literature. This confusion dates from the early descriptions of Tuart and Tuart communities, which were somewhat misleading. Hutchins (1916) stated that Tuart

> '..is of quite local distribution, being confined to small patches of nearly pure forest along the coast [in Ludlow area], on soils containing a large proportion of lime.'

Later reports by Kessell (1925) stated that Tuart grew from Lake Pinjar to the Sabina River on limestone along the coast, with the best Tuart between the Sabina River and Capel. To address these and other inconsistencies relating to the distribution and abundance of Tuart and Tuart dominated communities, this paper considers records from the published and unpublished literature, together with the authors' current field knowledge. The conservation of Tuart is discussed in relation to the various mapped sources and information on current distribution and abundance in specific bushland areas.

INFORMATION SOURCES AND THEIR USE IN DETERMINING TUART DISTRIBUTION AND ABUNDANCE

A variety of sources are used here to describe the distribution and abundance of Tuart. Each source is outlined and the information derived from each on Tuart distribution and abundance is discussed.

Herbarium Records

Type Specimens

Two named taxa, other than the named hybrids, are known for Tuart (Coates *et al.* this publication). These are described briefly below.

Typical Tuart - *Eucalyptus gomphocephala* var. *gomphocephala*
The first known collection of Tuart comes from the Baudin expedition in 1801 and was made at Geographe Bay, in what is now the area of the Ludlow Tuart Forest (Peron 1807, Keighery and Keighery this publication). The collection is held in the Paris Herbarium.

Red Tuart - *Eucalyptus gomphocephala* var. *rhodoxylon*
The type collection for this variety is held in the New South Wales National Herbarium at Sydney. The collection was made by Steedman at Guildford in November 1937 (Blakely and Steedman 1939, Coates *et al.* this publication).

WA Herbarium Collections

Twenty-nine collections are listed in Florabase (CALM 2001) in the Western Australian Herbarium. Twenty-three of these can be used to determine the distribution of Tuart (Map 1), the others being duplicates, hybrids, cultivated material or collected from imprecise localities. These collections stretch from near Cervantes to Ludlow and describe Tuart as growing on sand associated with limestone, grey sand (occasionally over yellow sand) and calcareous sands on the Swan Coastal Plain. One outlier on sand over alluvium is described from Lowlands. Paczkowska and Chapman (2000) describe the distribution for Tuart from these records as being from three

Interim Biogeograhic Regions (after Thackway and Cresswell 1995[1]), the Geraldton Sandplains, Jarrah Forest and the Swan Coastal Plain. The collections on which the presence in the other two regions are based on planted material (Geraldton) and an imprecise locality between Perth and King George's Sound in 1854 (on what probably was a boat journey).

Other Herbaria

One other Herbarium, Melbourne, has been searched for Tuart specimens. Of those sighted all but one of the collections were from natural populations, from within the known range. A specimen from north of Arrowsmith by Oldfield indicates that Tuart may extend north of the current confirmed northern localities (north of Jurien). This specimen was not dated but Oldfield collected in the 1840s and it is very unlikely the collection was from a planted tree. Also of interest was a record from Victoria of Tuart as a weed.

Vegetation Mapping

Original and Current Extent of Native Vegetation

Until 1750 Australia was covered with native vegetation. However, since the arrival of Europeans much of this vegetation has been cleared and/or altered by activities such as grazing, forestry, agriculture, changes in the water regime, mining and urbanisation and the introduction of non-indigenous species, some of which have become weeds in the native vegetation. Over the last 10 years, the extent of the remaining native vegetation has been recorded in various digital data sets[2].

In Western Australia the Spatial Resource Information Group at the Department of Agriculture has mapped the remaining native vegetation throughout the south-west of Western Australia. Three basic vegetation classes (Beeston *et al.* 1995) are mapped from visual interpretation of aerial photographs. The three classes are:

Remnant vegetation
- most closely resembles the natural state of vegetation for a given area
- most similar to identifiable remnant areas of similar vegetation types
- understorey intact
- of the greatest structural diversity/complexity in comparison to disturbed vegetation in the region
- minimal disturbance by agents of human activity;

Modified vegetation
- degraded understorey
- obvious human disturbance
- saline incursions
- high perimeter-to-area ratio
- narrow corridors of vegetation along roads, railway lines;

Scattered trees
- cleared parkland

[1] Reference to these biogeographic regions has been preferred since 1994 when the state and federal governments met to develop the boundaries of the regions across Australia. They are commonly called IBRA regions after the report edited by Thackway and Cresswell in 1995 on the Interim Biogeographic Regionalistation of Australia. WA has the highest number of IBRA regions in Australia as well as the largest number of unique IBRA regions.

[2] These are what are termed Geographic Information Systems (GIS). References for GIS datasets are annotated with a #.

- no canopy continuity
- no significant opportunity for regeneration.

Mapping for the National Land and Water Resources Audit (Beeston *et al.* 2001) used in this paper maps the first two categories. The areas mapped are based on the visual interpretation of these classes of vegetation from rectified 1997-1998 colour airphotos (DOLA 1998), or black and white orthophotos for the same period. The vegetation was digitised directly from digital orthophoto images with 0.4 to 1-metre resolution using Intergraph™ IRASC and Geomedia software.

Mapping of Native Vegetation Units

A series of maps are available that map units of vegetation containing Tuart. These sources are outlined below and the information that can be derived from each compared. When using this information, it is necessary to appreciate that these maps indicate that Tuart is likely to occur in an area; they do not identify particular bushland areas in which Tuart does occur.

<u>Vegetation Types</u>
The first comprehensive descriptions of the Swan Coastal Plain vegetation, within the context of the vegetation south-west of Western Australia, were made by Diels (1906). Diels commented on the distribution of Tuart but did not map its extent. Maps of vegetation on the Swan Coastal Plain began with the work of Speck in his Masters of Science (1952) and Doctor of Philosophy (1958) theses. Speck's 1952 map is the basis of the map of vegetation of the Perth area in Seddon (1972).

In the 1960s and '70s two other studies, Beard (1979a, b and c) and Smith (1973, 1974), built on the work of Speck to map the vegetation types of the Swan Coastal Plain. Together, the maps of Beard and Smith map the extent of Tuart dominated vegetation types on the Swan Coastal Plain (Table 1a) at a 1 : 250 000 scale. Beard mapped the Pinjarra, Perth and Hill River and Moora Sheets, and Smith mapped the Collie and Augusta and Margaret River Sheets. While the units mapped are comparable, the maps are different as Beard mapped the original extent of the vegetation types (pre-1750) and Smith mapped the current extent (that is, in 1970).

The maps of Beard (and Speck) identify an almost continuous belt of Tuart dominated vegetation as far north as the Yanchep area on the coastal limestone hills of the Spearwood Dune System. To the north of Yanchep, Beard maps pockets of Tuart dominated vegetation to Bashford Nature Reserve, still on the Spearwood Dune System. To the south, Speck and Smith map Tuart dominated vegetation in an almost continuous belt on the coastal limestone hills of the Spearwood Dune System to the Sabina River (Table 1a).

Later Beard (1981) produced a map at a 1 : 1 000 000 scale for the entire Plain. In this map, Beard distinguishes five units dominated by Tuart (Table 1b). The 'Banksia and scattered tuart' unit is not mapped at this scale. The 'tuart tall woodland' unit was not mapped previously by Beard at the 1 : 250 000 scale (see Table 1a) as it only occurred within the area mapped by Smith (1973, 1974).

In the late 1990s Beard's 1 : 250 000 maps were digitised (Hopkins *et al.* 1996, 2001). Where mapping by Beard was not available at this scale (area of Smith's studies), the mapping by Smith, the Forest Department (see below) and aerial photographs were used to develop new linework (Hopkins pers. comm.). These maps distinguish six units dominated by Tuart (Table1c). The current extent of the Tuart dominated vegetation types is shown in Map 2.

<u>Forest Department Mapping</u>
The Forest Department (and later the Department of Conservation and Land Management) has been mapping the extent of a series of forest types within state forest for many years. Maps of areas

of the Swan Coastal Plain show the distribution of Tuart dominated vegetation in state forest in the area extending from the Yanchep area to the Sabina River.

Vegetation Complexes

The vegetation complexes (Heddle *et al.* 1980) were defined in relation to the landform-soil units determined by Churchward and McArthur (1980). The delineation of vegetation complexes is based on the concept of a series of vegetation units forming regularly repeating complexes associated with a particular soil unit as identified by Churchward and McArthur (1980). In this mapping the vegetation units may occur in more than one complex but the relative proportions of units in the complex are different. The area of the study broadly matches the area of System 6 (DCE 1983), from the Moore River to Bunbury.

A total of 38 vegetation complexes are described on the Plain (including the Dandaragan Plateau, Heddle *et al.* 1980) at a scale of 1 : 250 000. Tuart is recorded in three structural formations in the vegetation complexes (see Table 3.5 in Heddle *et al.* 1980), being: tall woodland, open forest and/or woodlands (Table 2a). These three structural formations are recorded from seven of the vegetation complexes (Table 2a) with it being typical of four (Karrakatta - Central & South, Cottesloe - Central & South, Yoongarillup and Vasse). Tuart is also found in the Quindalup Complex but this is not described for this complex by Heddle *et al.* (1980). The current extent of the vegetation complexes in which Tuart dominated vegetation units occur are shown in Map 3.

However, it should be noted that the available published maps of the vegetation complexes are of the System 6 area. That is, the mapping does not extend significantly north of the Moore River or south far beyond Bunbury (see Map 3). As a consequence, there are significant areas of vegetation in which Tuart is found that are not included in this mapping.

The vegetation complexes maps were digitised initially by the Department of Conservation and Land Management and have been refined for use as part of the Perth Environmental Project (Dixon *et al.* 1994).

Use of Vegetation Mapping to Determine the Distribution of Tuart and the Area of Tuart Dominated Vegetation

Mapped information can be used to determine the areas of the different mapped vegetation units. When the original extent of the vegetation is mapped together with the remaining native vegetation, the current extent of each unit can be determined. Today, with digital data sets, intersecting the two sets of maps is relatively easy. Map 2 and Map 3 show the current extent of the vegetation types and vegetation complexes respectively. In the past this was done by physically overlaying the two maps and using a grid to determine areas.

Information from three of the mapping studies described above is presented here. One is in the published literature and the second two were generated for this paper from digitised data sets held at the Department of Agriculture by one of the authors (D. Shepherd). When using such information to consider the original and current extent of the different mapped units, it is imperative that the remnant vegetation mapping and the nature of the mapped vegetation units are understood. Such an understanding allows for a realistic use of the information (see Discussion). Information from the three sources is outlined below.

- ***Vegetation Types - Beard 1 : 1 000 000 Maps (Table 1b)***
  Beard and Sprenger (1984) used the Beard (1981) map at a 1 : 1 000 000 scale to consider the area of original vegetation and level of clearing of Tuart dominated units. Figures were only given for the two 'widespread' units dominated by Tuart: 'tuart tall woodland' and 'tuart and

tuart-jarrah woodland' (Table 1b). The 1984 study estimated that 94% of the 'tuart tall woodland' was 'cleared'. Cleared land was derived from what was termed 'Alienated land', that is all land in private ownership as:

> 'Crown land designated to be retained for a specific purpose such as conservation of flora and fauna is termed a reserve, while land available for alienation is termed vacant Crown Land. ……. With small exceptions, reserves and vacant crown land have not been cleared and it is assumed that their vegetation is still intact. By no means all alienated land has been cleared, though the portion untouched diminishes annually. However the assumption is made here that alienated means cleared as it does for practical purposes.'

- ***Vegetation Types - Beard 1 : 250 000 Maps after Hopkins et al. (Table 1c)***
  Over the late 1990s and early 2000s the maps of Beard have been digitised (Hopkins et al. 1996, 2001). By intersecting the two map sets, remnant native vegetation (Beeston et al. 2001) and vegetation type[3], these maps have then been used to again consider the original extent of the vegetation types, the area remaining of each type and the level of protection of each type (Table 1c).

- ***Vegetation Complexes – Heddle* et al. *(1980) 1 : 250 000 (Table 2)***
  By intersecting the two map sets, remnant native vegetation (Beeston *et al.* 2001) and vegetation complexes, the present occurrence of bushland in the various vegetation complexes has been determined (Table 2b).

Floristic Community Types

The regional floristic study on public lands over the southern Swan Coastal Plain (Gibson *et al.* 1994) considered the patterning of plant distribution on the Plain and related to the total flora of the Plain. The presence or absence of individual species in standard areas is used to define floristic groupings based on shared species with the aid of various multivariant analysis techniques.

Gibson *et al.* (1994) located 509 100 m^2 sites (also called plots and quadrats) across the Swan Coastal Plain. These sites were mostly on public lands and located so as to sample the geomorphological/soil units and plant community patterning identified by previous studies. Sites were placed in bushland areas to sample vegetation in the best available condition. Within each site, all vascular plants were recorded and information collected on various physical parameters, vegetation structure and vegetation. Most sites (more than 95 per cent) were visited on at least two occasions.

Analysis of the 509 sites distinguished four 'super' groups, three related to the major landform elements and a wetland group found across all the major landform elements. More detailed classification established 30 floristic community types, with a further 13 subdivisions evident, making 43 types.

Using this classification as a basis, a further 613 100 m^2 sites were analysed for the System 6 and Part System 1 Update Program (Government of WA 2000). These additional sites came from several additional sources and were located on public and private lands (DEP 1996, Keighery 1996, Griffin 1994). Classification of these sites against the Gibson *et al.* (1994) data identified a further 23 floristic community types. Greater sampling density lead to a reclassification of floristic groups 19, 20, 23 and 30 (new subgroups being distinguished in three of these groups). Fifteen supplementary groups were identified. A total of 66 floristic community types are now recognized.

[3] While the Hopkins *et al.* (1996 and 2001) mapping was used, some linework was closed and some polygons relabelled.

Tuart is recorded from 64 quadrats (Map 1), which fall into 13[4] of the 66 regional groups (Tables 3 and 4). Information on the nature and distribution of the various community types in which Tuart occurs can be used as the basis for the regional comparison of bushland areas (see Tables 3 and 4 and Maps 5 to 16) as outlined below. The floristic community types are divided into wetlands and uplands for the purposes of this discussion. These sites have been further compared in Gibson *et al.* (this publication).

Wetlands

- Tuart occurs in several floristic community types found in seasonal wetlands (FCT's 16, 17 and 19b)
- The seasonal wetland floristic community types in which Tuart occurs have not been identified south of the Perth Metropolitan Region (most southern sampled location is Tuart Area 15, Table 4b and Map 4)
- One seasonal wetland floristic community type, type 19 (Tuart Area 11 and 15, Table 4b and Map 4 and Map 7), in which Tuart occurs is a threatened ecological community (after English and Blyth 1997)

Uplands

- The majority of the floristic community types in which Tuart occur are in two major landform units, the Spearwood Dune System (FCTs 24, 25, 26b and 28) and the Quindalup Dune System (FCTs 29a, 30c2 and S11).
- Tuart rarely occurs in floristic community types that are more typical of the Bassendean Dune System (FCT 21a).
- Tuart is identified as being a dominant species in floristic community types 25 and 30b (Table 3). Type 25 typically occurs on Spearwood Dunes while type 30b occurs on the Quindalup Dunes. These two types have a predominantly southern distribution, all but two locations (25 – Tuart Area 17, Table 4c and Map 10; 30b – Tuart Area 11, Table 4b and Map 14) being south of Perth.
- Floristic community type 24 is virtually confined to the PMR (Map 9), with one atypical representation that does not contain Tuart found north of the PMR).
- Floristic community type 28 does not occur south of the PMR (Map 12).
- On the Spearwood Dunes there is a major change over in floristic community types in the Perth area.

Flora and Vegetation Survey of Bushland Areas

All of the information sources considered previous to this are regional datasets. Only two of these datasets relate to particular bushland areas, that is the Herbarium localities and the floristic site data (Map 1). Given the range of Tuart there are few such records of Tuart. However, Tuart is a distinctive tree and there are many studies of particular bushland areas and field observations that record the occurrence of Tuart.

Using a series of survey records and unpublished records, this study identifies bushland areas in which Tuart is recorded. Within each area comment is given on the abundance and distribution of Tuart, and the condition of the associated communities (Table 4 and Map 4). This is not a

[4] Gibson *et al.* (this publication) lists Tuart from 14 floristic community types. However with the additional sampling (DEP 1996) and re-analysis (Keighery *et al.* 1997) the plot from Bush Forever Site 403 (Tuart Area 68, Table 4d) from floristic community type 30a (after Gibson *et al.* 1994) was reallocated to floristic community type 30c2. Thus floristic community type 30a is not listed in Table 3.

comprehensive listing but focuses on bushland areas with some level of protection and/or recognition as conservation lands, being: National Parks, Nature Reserves, Bush Forever Sites, System 6 areas and proposed reserves. These areas are mapped on Map 4. However, in areas where there were known Tuart populations, but no known areas with some level of protection, the population is listed but not mapped.

The 'Tuart Areas' listed in Table 4 are grouped in three sectors, being:

- Northern Sector - Jurien to the Perth Metropolitan Region (PMR);
- Perth Sector - the PMR; and
- Southern Sector - PMR to the Sabina River.

When applicable, the table is split further into Quindalup and Spearwood Dune Tuart Areas. Each of the mapped Tuart Areas is allocated a Tuart Area Number and shown on Map 4.

As applicable, a series of information sets are listed against each of the Tuart areas and/or populations. These include:

- Tuart Area/Abundance score
  These 'scores' are indicative only. They were derived from field observations made by two of the authors (BJ Keighery and GJ Keighery) of the Tuart populations in the bushland areas. The purpose of these is to indicate that while Tuart may be present in an area there is considerable variation in the size and significance of the population.

Score	Tuart Area/Abundance
OUT	Significant Tuart population, generally small in area but disjunct from other more extensive populations (may be combined with other scores)
5	> 50% area Tuart dominated communities OR > 50 ha Tuart dominated community
3	< 50 - 20% area Tuart dominated communities OR < 50 ha Tuart dominated community
2	<20% area Tuart dominated communities OR <10 ha Tuart dominated community
1	Tuart patches <1 ha Tuart dominated community

- Tuart Community Condition Score
  These 'scores' are indicative only. Again they were derived from field observations made by two of the authors (BJ Keighery and GJ Keighery) of the Tuart populations in the bushland areas. The plant communities in which Tuart occurs generally show high levels of disturbance.

Score	Tuart Community
5	Tuart population over intact understorey
3	Tuart population over understorey with limited weed invasion
2	Tuart population over understorey with extensive weed invasion
1	Tuart trees only, no understorey

Table 4 also gives specific information on the quadrats located in particular bushland areas. The quadrat codes and condition scores (after DEP 1996, Gibson *et al.* 1994, Griffin 1994 and Keighery 1996) are listed together with the regional floristic groupings (floristic community types after Gibson *et al.* 1994 and DEP 1996) and the Tuart site groups (after Gibson *et al*., this publication). This information, together with Appendix 1 in Gibson *et al*. (this publication), lists the floristic information available for these quadrats.

DISCUSSION

Tuart – the tree

Natural Distribution

Tuart is endemic to the Swan Coastal Plain, being naturally found over a 400 km range from just north of Jurien to just north of the Sabina River (Maps 1, 2, 3 & 4). The current known northern and southern extents of Tuart require further comment.

- Northern extent: At this stage there are no confirmed localities of Tuart beyond the population to the north of Jurien. While the Oldfield collection of Tuart, from Arrowsmith, has been quoted frequently as indicating the northern extent of Tuart (for example Blakely 1965), this collection requires confirmation.
- Southern extent: Although Shann (1926) states that Tuart extended beyond the Sabina to the Vasse at the time of settlement, and Smith (1974) maps Tuart south of the Sabina River, there is no evidence for this. Keighery and Keighery (this publication) describe how Yate (*Eucalyptus cornuta*) replaces Tuart west of the current forest.

Within this north-south distribution, Tuart is primarily found on the near coastal dunes of the Quindalup and Spearwood Dune Systems. The vegetation mapping has generally underestimated the area of Tuart on the Quindalup Dunes (Map 2 and Map 3). However, it is clear from herbarium specimens, site records and bushland area records that Tuart is found extensively in both Dune Systems.

To the east, outlying populations are found on low sandy dunes beside the Moore (Tuart Area 8 and possibly along the river to the west of Cowalla Road), Swan (Guildford), Canning (Mt Henry, Tuart Area 68), Serpentine (Lowlands, Tuart Areas 70 and 71), Murray (Murray River Flats at Ravenswood) and Harvey (Reserve 13987, Tuart Area 89) Rivers. The population at Guildford is named as the Red Tuart *(Eucalyptus gomphocephala* var. *rhodoxylon*, see Coates *et al*. this publication).

Tuart is the largest tree on the Plain. Generally Tuart increases in stature and girth from north to south, the populations in the Tuart forest area (Keighery and Keighery this publication) containing the largest trees. However, Tuart's growth appears to be very dependant on the conditions in which it grows as trees in sheltered populations on deep soils with an ample water supply reach similar sizes to those in the forest. In exposed locations on the Quindalup Dunes, mallee forms have been recorded (north of Pipidinny Road in Tuart Area 10 and at Dalyellup, possibly in Tuart Area 74). These mallees are of particular interest as Tuart has been recorded as being unable to form a lignotuber(for example in Powell 1990)[5].

Unnatural Distribution

Tuart is very widely planted, both in Australia and overseas. Gardner (1987) states that the species is naturalized, from plantings, in Esperance. Rose (pers. com.) has noted that Tuart is self-seeding from plantings at Geraldton. There are records that Tuart is self-seeding in Victoria.

At times it is difficult to determine if a particular Tuart is planted or natural. Tuart has been planted

[5] Similar comments have been made about Tingle species; however, Grant Wardell-Johnston (pers. comm.) has reported mallees in these and comments that it is expected that most eucalypts can form a lignotuber and will do so under particular conditions.

throughout its natural range (and elsewhere) for many years; its relatively rapid growth allows for large well-established trees in 30 years. When determining if a tree is a natural or planted specimen, there is a need to look beyond size at the number and arrangement of the trees (see Powell 1990 for a guide to determining natural trees).

Conservation

Typical Tuart *(Eucalyptus gomphocephala* var. *gomphocephala)*

Keighery (1999) in a study of species conservation on the southern Swan Coastal Plain records typical Tuart from 24 reserves (National Parks, Nature Reserves or Conservation Parks). This study records Tuart from 89 areas with some level of protection (Table 4). In terms of the Keighery (1999) study, typical Tuart can be considered 'well reserved', being found in more than 15 reserves. However, if typical Tuart is considered over its entire range, there are a series of other factors that should be considered in assessing the conservation status of the species. These are listed below with comment on each as they relate to typical Tuart.

- Populations that are outside the main geographic range (disjunct populations)
  Some of the northern (Table 4a - Arrowsmith, Jurien and Cowalla Road populations) and eastern populations of Tuart (Table 4d and 4g) can be considered disjunct. While some of these have some level of protection (Table 4d Tuart Areas 67, 68, 69, 70 & 71), others have no apparent protection (Table 4a - Arrowsmith, Jurien and Cowalla Road; Table 4g - Murray River Flats at Ravenswood). There is a need for survey of the unprotected populations and some form of protection identified.

- Populations at the ends of the species geographic range (on the Swan Coastal Plain, this being north or south)
  The southern range end of Tuart is protected in the Tuart Forest National Park but the situation to the north is somewhat more complicated. The populations of Tuart become smaller and smaller towards the north and east of the species range. Smaller populations are more difficult to maintain (see below).

- Populations that represent a significant number of the known individuals of the taxon in the region and/or a population in good condition (that is, a mixture of different-aged individuals — mature adults to seedlings)
  Large populations of mixed age in relatively intact communities are the most likely to be maintained naturally. While this is generally the case (see Table 4, columns 5 and 6) there are several apparent exceptions to this. For example, the Tuart Forest Reserve has been actively managed for many years to encourage Tuart recruitment (Broadbent this publication). However, the Tuart Forest Reserve is one of the most altered of the large extant Tuart communities (Keighery and Keighery this publication) and these changes have had/have a significant impact on recruitment. One other large population of Tuart, in and around the centre and north of Yalgorup National Park, has shown a very marked decline in the last six years (see Longman and Keighery this publication). The primary cause/s of this decline is/are not yet apparent, however the Tuart communities in this location were generally in excellent condition prior to the decline.

- Population size and age structure
  Another issue that needs to be addressed in respect to the conservation of Tuart in small populations is the maintenance of the population. Information on Table 4 shows that very few Tuart populations are considered to have high ratings for this score (see Column 5, Table 4). Some of the populations are very small, especially those to the north of the range and the disjunct populations (for example Tuart Areas 68 and 70) and there is always the possibility

that the population will be lost. These populations need to be monitored and action taken to maintain the populations if there is a significant decline in recruitment. At times this may require planting but natural recruitment should be encouraged (see Longman and Keighery this publication). The decline in populations generally has been the subject of a deal of debate in the literature (see Longman and Keighery, Ruthrof *et al*., Powell and Keighery this publication). Care must be taken when assessing the population decline as there is a tendency in the literature to consider that the Tuart population densities currently observed in areas of the Tuart Forest Reserve (see Keighery and Keighery this publication) are the 'typical densities of Tuart'. This is not the case. The density of Tuart varies greatly but it most often occurs as a tall woodland/open woodland to woodland/open woodland than a forest. Management of populations to form a forest is only applicable in the extreme south of Tuart's range, and even here there is debate over the original density of Tuart in this location.

Red Tuart (*Eucalyptus gomphocephala* var. *rhodoxylon*)
The Red Tuart is presumed extinct. Despite detailed searches of the locality from which it was described, and a publicity campaign, no trees matching the type have been located.

Tuart dominated communities

Natural Distribution

Tuart is not restricted to a single plant community, being found:

- in a diverse set of structural formations, from forests to very open mallee;
- on a series of landforms such as steep sandy slopes, protected swales, seasonal wetlands and the slopes of massive limestone ridges; and
- in a series of major landform units, principally the Quindalup and Spearwood Dunes.

This diversity of communities is reflected in the different vegetation types (after Beard 1979 a, b and c; Smith 1973, 1974; Hopkins *et al*. 1996, 2001 - Map 2), vegetation complexes (after Heddle *et al.* 1980 - Map 3) and floristic community types (Gibson *et al.* 1994 and DEP 1996, Table 4 and Maps 1 and 5 - 16) from which Tuart communities are described.

Condition of Tuart Communities

The communities in which Tuart grows are generally more impacted by the activities of Europeans than the surrounding communities. Table 4 (Column 6) lists very few Tuart Areas as being considered to contain intact communities. The specific site based vegetation condition scores (Table 4, Column 8) support this general trend as no sites are considered 'Pristine'. It appears that this is related to the early, and continued, use by Europeans of the Quindalup and Spearwood Dunes for grazing. Typically, those areas dominated by Tuart that are most degraded are the protected hollows (dune swales) in more coastal locations where stock (and kangaroos) shelter. Vegetation condition generally improves in the areas where there are extensive areas dominated by Tuart. Further disturbance is associated with the selective clearing of large areas for grazing, horticulture and forestry.

Towards the north of Tuart's range, where Tuart is generally confined to areas low in the landscape, few intact areas of Tuart remain outside reserves (north of Yanchep National Park and associated State Forest). These areas have been selectively cleared for pasture. Selective clearing/grazing is also evident in the Tuart pockets within reserves. The most northern area of a Tuart vegetation type mapped (Bashford Nature Reserve, Tuart Area 5, Map 2b and Map 4c) is significantly altered. The band of Tuart Woodland around the seasonally inundated claypan dominated by Flooded Gum (*Eucalyptus rudis*) is almost completely devoid of native understorey, with the only relatively intact Tuart dominated communities being where Tuart occurs sporadically in the *Banksia* Low Woodland. The tracks in the area and the remains of fences indicate that the Tuart area was the focus for grazing.

Conservation

The mapped datasets can be used to give some indication of the remaining area of Tuart dominated vegetation types and vegetation complexes (Tables 1c and 2b). When considering these areas or percentages, the limitations of these datasets should be kept in mind. These are outlined below.

(1) General:
- the area of Tuart dominated communities on Quindalup Dunes is generally not mapped; and
- the presence of Tuart in a community does not indicate that the communities are floristically the same (see Table 4 and Gibson *et al.*, Keighery and Keighery, Keighery this publication).

(2) Remnant Vegetation mapping:
- Tuart dominated communities are relatively easy to map from aerial photography; as a consequence, the area of remnant vegetation mapped is generally overestimated as Tuart Woodland with virtually no associated understorey can appear as remnant vegetation in the photographs; and
- the condition of Tuart dominated communities is generally lower than that of surrounding vegetation (see Table 4 and Gibson *et al.,* Keighery and Keighery and Keighery, this publication).

(3) Vegetation type:
- the small northern areas of Tuart dominated communities (between Bashford Nature Reserve and Jurien) are not mapped (compare Map 2 with Maps 1 and 4).

(4) Vegetation Complexes:
- these are not mapped for entire known area of Tuart dominated communities mapped (compare Map 3 with Maps 1 and 4);
- the actual area of Tuart dominated communities is not mapped (see Table 2a); and
- Tuart dominated communities are found in other vegetation complexes.

As a consequence, the figures generated by the intersection of the remaining areas of vegetation (Beeston *et al.* 2001) with vegetation type containing Tuart (after Hopkins *et al.* 2001) as shown in Table 1c are the focus of this discussion. In recognition of the limitations identified above in 1, 2 and 3 (4 does not apply), this discussion is restricted to general trends rather than specific areas or percentages.

If the total area of the Tuart dominated vegetation types (Table 1c) are considered in relation to the *National Objectives and Targets for Biodiversity Conservation 2001-2005* (Commonwealth of Australia 2001)[6], then the current remaining area of around 35% is just (keeping in mind

[6] This target has been established for Australia through the *National Objectives and Targets for Biodiversity Conservation 2001-2005* and states specifically that:

> 'By 2003, all jurisdictions:
> - have clearing controls in place that prevent clearance of ecological communities with an extent below 30 per cent of that present pre-1750; and
> - have programs in place to assess vegetation condition.'

Ecological communities are defined as 'naturally occurring biological assemblages that occur in a particular type of habitat' (English and Blyth 1997). The scale at which ecological communities are defined will depend on the level of detail in the relevant information source. As a consequence no particular scale is specified.

limitation 2) in excess of the 30% or more of the original (pre-1750) extent of ecological communities target. However it is clear that this broad unit is not an ecological community as within this total area of Tuart dominated vegetation:

- two major landform units, Quindalup Dunes and Spearwood Dunes, are represented;
- six vegetation types are mapped (Tables 1a, b and c);
- seven vegetation complexes are mapped (Table 2);
- 13 floristic community types are identified (Table 3); and
- some of the 89 bushland areas containing Tuart (Table 4) do not correspond with the vegetation type mapping.

If vegetation type, is used as a surrogate for ecological communities[7] then both the 'Mosaic' and 'Medium open woodland; marri, tuart' units remain at levels below 30%, being 28.4% and 6.6% respectively. Both of these types are relatively restricted (original areas of 509 ha and 1213 ha respectively) and all other information (see Table 4 and related information) indicate that these areas are unreserved and very poorly known. At this level of discrimination, one other unit, 'Medium woodland; tuart, jarrah' at around 30% remaining (30.3%) is close to the minimum target. However, if the limitations outlined in point 2 are taken in to account, this type is at the lowest target level. Of the remaining three units, one unit, 'Medium woodland; tuart' at around 39% remaining, is within 10% of the targets, the other two units being shown as remaining at levels of over 50% of their original extent. That is, at this broad level of definition of ecological communities - vegetation type, only two of the six units mapped have relatively large proportions of their original extent remaining and the targets for retention can be met for three, possibly four, of the vegetation types[8].

A comparison of Map 2 and Map 4 generally indicates that the three vegetation types with >30% remaining are found is a series of protected areas or areas identified for protection. However, even at this very broad level the area between the southern PMR boundary and the north of the Mandurah area does not appear to have any protected or potentially protected Tuart areas.

While the situation as described above is encouraging, to actually determine how well each of these units is protected, or potentially protected, is not further developed here due to:

- the limitations of these data (see 1, 2 and 3 above);
- the variable condition of Tuart dominated communities (see Table 4 and related text); and
- other information on Tuart dominated communities which show that there is considerable variation within the types (as outlined previously and summarized above), indicating that there are finer levels at which ecological communities can be distinguished.

In addition, it is considered that such an analysis and discussion requires additional information on the characteristics of Tuart dominated communities, as listed below:

- area in lands subject to some level of protection or proposed protection communities. (That is, the actual areas of Tuart dominated vegetation, not those inferred from the vegetation type mapping. Many of the areas identified on Table 4 and Map 4 have specific small scale

[7] That is, in this case, Tuart dominated vegetation types are being used to identify ecological communities.

[8] This discussion has focussed on the areas and percentages of the remaining Tuart dominated vegetation types generated from the intersection of the Beeston *et al.* (2001) remnant vegetation mapping with vegetation type modified in this paper from Hopkins *et al.* (2001) as shown in Table 1c. However there are a series of other figures available on the original and remaining areas of the vegetation types (see Beard and Sprenger 1981 and Hopkins *et al.* 1996). The figures from Beard and Sprenger (1981) are listed in Table 1b. Interestingly there is little correspondence between the figures in Tables 1b and 1c, in fact the total original area of only the two units given is greater than the total original area given in Table 1c. There are also some differences between the original areas given in Hopkins *et al.* (1996) and the figures in Table 1c. This is can be accounted for by the changes in linework. As a consequence the other figures are not used here.

vegetation maps in the published and unpublished literature.)
- structural and floristic characters of the community.
- condition of the community.
- health of the Tuart population.

Three of the issues outlined above are demonstrated in a consideration of the Tuart Forest Reserve (Tuart Area 88, Map 4) described in Keighery and Keighery (this publication). The vegetation type mapping (Map 2) maps the Reserve as ‘tall woodland; tuart’ and ‘medium woodland; tuart, jarrah’. However if we look at some of the other described vegetation and flora characteristics of the Reserve as outlined in Keighery and Keighery it can be seen that the situation is complicated.

- Specific area vegetation mapping
  Five plant communities are mapped, four of these units are associated with upland areas and the other with seasonally inundated or waterlogged areas. Another two communities are not mapped. Three of the upland units are dominated by Tuart. The unmapped wetlands contain threatened species and communities.
- Floristic community types
  Two types containing Tuart are described in the Reserve: floristic community type 25 and 30b. This combination is also found in the south Bunbury area (see Table 4 for Tuart Areas 73, 85 and 86) even though only one vegetation type, ‘medium woodland; tuart, jarrah’, is mapped for the south Bunbury area (Map 2). Interestingly, this combination is apparently confined to the Bunbury-Busselton area, indicating that the community structure and floristics of the Tuart Forest Reserve should not be used as a reference area for Tuart dominated communities north of Bunbury.
- Vegetation condition
  One of the three plant communities dominated by Tuart in the Reserve is ‘Tuart Tall Woodland over pasture (Mapping unit: tW, Map 3 in Keighery and Keighery). That is, this community does not fit the mapping categories for remaining native vegetation. However, close to the entire area is mapped on Map 2.

As a consequence, the information collated in this paper, particularly Table 4 and the associated information and discussion, has begun the task but more detailed work is required to address what is considered adequate conservation of Tuart dominated communities.

CONCLUSION

The aim of this paper was to bring together the known information in relation to:
- the distribution of Tuart and Tuart dominated communities;
- the abundance of Tuart in these communities; and
- the available information sets that should be taken into account when addressing the conservation of Tuart.

This paper highlights some general problems in determining the distribution and abundance of an individual species and in determining and understanding the communities in which it occurs. It is clear that a series of sources need to be used for a comprehensive consideration of these attributes.

It is recognized that Tuart and most Tuart dominated communities have significant numbers and areas remaining, especially when compared with many other species and communities. However, there is a need for better understanding of Tuart and how to protect it and maintain populations of Tuart and the communities in which it grows. As a consequence the following recommendations are made.

RECOMMENDATIONS

- **A Tuart Atlas project should be initiated. The project should follow the principles and procedures established in the Banksia Atlas (Taylor and Hopper 1988). Specific information on Tuart health, population structure, abundance, associated communities and vegetation condition should be included in the population recording sheets.**

- **As a matter of urgency, outlying populations of Tuart should be identified and mechanisms to protect or further protect these areas be instigated where necessary. These populations fall into two main groups.**
  - **Populations north of Yanchep: particular attention should be given to mapping and protecting populations in the area of Jurien, Cowalla Road and north and south of the Moore River adjacent to Guilderton.**
  - **Populations on the Moore, Swan, Canning, Serpentine, Murray and Harvey Rivers.**

- **The Red Tuart *(Eucalyptus gomphocephala* var. *rhodoxylon*) should be listed by CALM as 'presumed extinct', that is be recognized as Declared Rare Flora.**

- **A Conservation Plan for Tuart should address the estimated percentage of Tuart vegetation units remaining as well as Tuart population structure, health, abundance, associated communities and vegetation condition. This Plan should recognize that Tuart has several forms and occurs on a variety of landforms and geomorphic units, in vegetation with a variety of structural and floristic attributes.**

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TABLES

TABLE 1a.Vegetation types containing Tuart on the Swan Coastal Plain after Beard (1979a, b & c) and Smith (1973 & 1974) at 1:250 000 scale.

Units mapped by Beard – Lancelin to Mandurah (letter/number codes in black and white)	
e4 Mi	Tuart woodland (most northern location is at Bashford Nature Reserve)
e4 Mr	Tuart open woodland
e2/4 Mi	Tuart-jarrah woodland
No code	Banksia and scattered tuart
e3/4Mr	Tuart-marri open woodland
Units mapped by Smith – Mandurah to Busselton (coloured codes)	
T (pinkish grey)	High woodland (tuart)
T (brownish grey)	Woodland (tuart)

TABLE 1b. Vegetation types containing Tuart on the Swan Coastal Plain after Beard (1981) at 1:1 000 000 scale together with area estimates from Beard and Sprenger (1984).

Units mapped	**Original Area** ha	**% alienated**	**% remaining in reserves + vacant crown land**
Tuart tall woodland (e4 Ti)	6 900	94	6
Tuart woodland (e4 Mi	-	-	-
Tuart open woodland (e4 Mr)	-	-	-
Tuart-jarrah woodland (e2/4 Mi)	103 900	-	-
Tuart-marri open woodland (e3/4Mr)	-	-	-

TABLE 1c. Remaining areas of vegetation (Beeston *et al.* 2001) in each vegetation type containing Tuart on the Swan Coastal Plain after Hopkins *et al.* (2001)[1] at 1:250 000 scale.

Key

Column 1 Vegetation type after Hopkins *et al.* (2001) and, in brackets, units and codes after Beard (1979a, b & c and 1981, Tables 1a and 1b)
Column 2 Original area of the vegetation type (pre-1750) in hectares (ha)
Column 3 Remaining area of the vegetation type in hectares (ha)
Column 4 Remaining area as the percentage of the original area of the vegetation

Vegetation Type (Hopkins *et al.* 2001) (comparable unit in Beard 1979a, b & c and 1981)	**Original Area** ha	**Remaining Area** ha	% orig.
Tall woodland; tuart (Tuart tall woodland: e4 Ti)	**3 155**	**2 212**	**70.1**
Medium woodland; tuart (Tuart woodland : e4 Mi)	**50 237**	**19 564**	**38.9**
Medium open woodland; tuart (Tuart open woodland: e4 Mr)	**1 264**	**777**	**61.5**
Medium woodland; tuart, jarrah (Tuart-jarrah woodland: e2/4 Mi)	**53 980**	**16 332**	**30.3**
Mosaic: Medium open woodland; tuart/low woodland; banksia (Banksia and scattered tuart: No code)	**509**	**145**	**28.4**
Medium open woodland; marri, tuart (Tuart-marri open woodland: e3/4Mr)	**1 213**	**80**	**6.6**
Total	**110 358**	**39 109**	**35.4**

[1] See earlier comment on changes.

TABLE 2a. Vegetation complexes (Heddle *et al*. 1980) containing Tuart on part of the Swan Coastal Plain

Key

Column 1 Tuart structural formations listed for the vegetation complexes (after Table 3.5, Heddle *et al.* 1980). Two 'levels', of occurrence are indicated, these are
- **bold** formations that should be present,
- non bold formation that should be present, but absence not critical

Column 2 Units after Heddle *et al*. (1980), % Tuart dominated estimated by BJ and GJ Keighery

Structural Formations	Vegetation Complex	% Tuart dominated vegetation
Spearwood Dunes		
Open forest	KARRAKATTA COMPLEX - NORTH: Predominantly low open forest and low woodland of *Banksia* species. *Eucalyptus todtiana,* less consistently open forest of *E. gomphocephala - E. todtiana - Banksia* species	**approx. 30%**
Open forest (with Jarrah and Marri)	KARRAKATTA COMPLEX - CENTRAL AND SOUTH: Predominantly open forest of *Eucalyptus gomphocephala - E. marginata - E. calophylla* and woodland of *E. marginata - Banksia* species	**approx. 50%**
Open forest (with Jarrah and Marri) **Woodland**	COTTESLOE COMPLEX - CENTRAL AND SOUTH: Mosaic of woodland of *Eucalyptus gomphocephala* and open forest of *E. gomphocephala - E. marginata - E. calophylla;* closed heath on the limestone outcrops.	**approx. 20%**
Combinations of Bassendean Dunes/Pinjarra Plain/Spearwood Dunes		
Open forest (with Jarrah and Marri)	CALADENIA COMPLEX: Mosaic of vegetation from adjacent vegetation complexes of Karrakatta, Yanga and Bassendean.	**approx. 5%**
Open forest (with Jarrah and Marri)	CANNINGTON COMPLEX: Mosaic of vegetation from adjacent vegetation complexes of Bassendean, Karrakatta, Southern River and Vasse.	**approx. 5 %**
Marine (lagoonal and estuarine) Deposits		
Tall woodland Open forest (with Jarrah and Marri)	YOONGARILLUP COMPLEX: Woodland to tall woodland of *Eucalyptus gomphocephala* with *Agonis flexuosa* in the second storey. Less consistently an open forest of *E. gomphocephala - E. marginata - E. calophylla.*	**approx. 50%**
Open forest (with Jarrah and Marri) **Woodland**	VASSE COMPLEX : Mixture of the closed scrub of *Melaleuca* species fringing woodland of *E. rudis - Melaleuca* species and open forest of *E. gomphocephala - E. marginata - E. calophylla*	**approx. 10%**

TABLE 2b. Remaining areas of vegetation after Beeston *et al.* (2001) in each vegetation complex (Heddle *et al*. 1980)

Key

Column 1 Vegetation complex after Heddle *et al*. 1980

Column 2 Original area of the vegetation complex (pre-1750) in hectares (ha)

Column 3 Remaining area of the vegetation complex in hectares (ha)

Column 4 Remaining area as the percentage of the original area

Vegetation Complex	**Original Area** ha	**Remaining Area** ha	 % orig.
KARRAKATTA COMPLEX - NORTH	44 273	20 040	45.3
KARRAKATTA COMPLEX - CENTRAL AND SOUTH	49 850	15 176	30.4
COTTESLOE COMPLEX - CENTRAL AND SOUTH	45 182	18 358	40.6
CALADENIA COMPLEX	9 660	5 310	55
CANNINGTON COMPLEX	16 661	1 657	10
YOONGARILLUP COMPLEX	24 795	11 372	45.9
VASSE	11 161	3 328	29.8

TABLE 3. Regional floristic groups containing Tuart on the Southern Swan Coastal Plain
(from Gov of WA 2000). Communities where Tuart dominate are in bold.

Key

Column 1 Floristic community type number code.
Codes in italics are additional groups identified in DEP (1996) and these are not listed in Gibson *et al.* (1994)

Column 2 General description of the floristic community type

Column 3 Distribution of the floristic community in relation to the Perth Metropolitan Region (PMR)

PMR	confined to PMR
PMR+	predominantly in PMR
>PMR	distribution goes well beyond the PMR
N	Northernmost location in the PMR
S	Southernmost location in the PMR
C	PMR central to distribution
blank	outside PMR
*	isolated occurrence outside normal range

Column 4 Average species richness for each floristic community type.
Average species richness per 10 m x 10 m plot, less those species only occurring in a single plot (single records). Some community types can have a high proportion of single records and these estimates of average species richness are underestimates in some cases.

FCT Code	**Floristic Community Type Name** (communities in which Tuart is a defining species are in bold)	**Distrib in relation to PMR**	**Average Species Richness**
Supergroup 2 - Seasonal Wetlands			
16	Highly saline seasonal wetlands	PMR	11.2
17	*Melaleuca rhaphiophylla - Gahnia trifida* seasonal wetlands	>PMR/N*	13.4
19b	Woodlands over sedgelands in Holocene dune swales	PMR	*26.3*
Supergroup 3 - Uplands centred on Bassendean Dunes			
21a	Central *Banksia attenuata - Eucalyptus marginata* woodlands	PMR/N	52.0
Supergroup 4 - Uplands centred on Spearwood and Quindalup Dunes			
Spearwood Dunes			
24	Northern Spearwood shrublands and woodlands	PMR*	38.9
25	**Southern *Eucalyptus gomphocephala – Agonis flexuosa* woodlands**	**>PMR/S**	**48.1**
26b	Woodlands and mallees on Limestone	PMR+	49.8
28	Spearwood *Banksia attenuata* or *Banksia attenuata - Eucalyptus* woodlands	>PMR/S	55.1
Quindalup Dunes			
29a	Coastal shrublands on shallow sands	>PMR/C	33.7
30b	**Quindalup *Eucalyptus gomphocephala* and/or *Agonis flexuosa* woodlands**	**(PMR)**	***35.0***
30c2	Woodlands and shrublands on Holocene dunes (re-allocated from 30c and 30a Gibson *et al.* 1994)	PMR	*23.9*
S11	Northern *Acacia rostellifera - Melaleuca acerosa* shrublands	PMR	*21.0*
S15	Weed group Not allied with any supergroup	n/a	n/a

TABLE 4. Attributes of bushland areas containing natural populations of Tuart

Column 1 Tuart Area Number

The areas are listed from north to south between Jurien and Busselton. Only those populations in areas with some level of protection or proposed protection are mapped and numbered. Some areas contain areas of Quindalup and Spearwood Dunes and are listed twice.

Column 2 Map 4a to 4l

Column 3 Population/Bushland Area Name

Bush Forever Site numbers (Gov of WA 2000) and System Recommendation numbers (DCE 1976 and 1983) are given in brackets when applicable. Populations containing areas of mallee are in italics.

Column 4 Source of the information on population/s

This information was derived from two principal sources being:

- Survey Reports - Outside the Perth Metropolitan Region (PMR) references are listed. Within the PMR Bush Forever Volume 2B (Gov of WA 2000) was used and should be consulted to find the specific references. The source of quadrat data is listed.
- Unpublished records by BJ Keighery (BJK), GJ Keighery (GJK) and others as indicated.

Column 5 Tuart Area/Abundance Score (estimated by BJ Keighery and GJ Keighery)

A ? indicates an uncertain score.

Score	Tuart Area/Abundance
OUT	Significant Tuart population, generally small in area but disjunct from other more extensive populations (may be combined with other scores)
5	50% area Tuart dominated communities OR > 50 ha Tuart dominated community; outliers and Quindalup Dune
3	< 50 - 20% area Tuart dominated communities OR < 50 ha Tuart dominated community
2	<20% area Tuart dominated communities OR <10 ha Tuart dominated community
1	Tuart patches <1 ha Tuart dominated community

Column 6 Tuart Community Condition Score (estimated by BJ Keighery and GJ Keighery).

A ? indicates an uncertain score.

Score	Tuart Community
5	Tuart population over intact understorey
3	Tuart population over understorey with limited weed invasion
2	Tuart population over understorey with extensive weed invasion
1	Tuart trees only, no understorey

Column 7 Quadrat Codes (see Column 3 for the source of these)

Column 8 Floristic community type (FCT, see Table 3) and vegetation condition score (after Keighery 1994, see below). Wetland FCT's are in **bold.** NA is not available.

1 Pristine Pristine or nearly so, no obvious signs of disturbance.
2 Excellent Vegetation structure intact, disturbance affecting individual species and weeds are non-aggressive species.
3 Very Good Vegetation structure altered, obvious signs of disturbance.
4 Good Vegetation structure significantly altered by very obvious signs of multiple disturbance. Retains basic vegetation structure or ability to regenerate it.
5 Degraded Basic vegetation structure severely impacted by disturbance. Scope for regeneration but not to a state approaching good condition without intensive management.
6 Completely Degraded The structure of the vegetation is no longer intact and the area is completely or almost completely without native species.

TABLE 4a. Natural populations of Tuart on the Quindalup and Spearwood Dunes north of the PMR.
The majority of these populations are on Spearwood Dunes, except for Tuart Area 8 which is on the Quindalup Dunes.

Mapped Tuart Area No	Map 4 No	Area Name (System Area Number)	Information Source	Tuart Area/Ab Score	Tuart Condition Score	Quadrats	FCT (Cond. Score)
NA		Arrowsmith (not mapped, old record in need of confirmation	Specimen (Oldfield)	?	?		
NA		Jurien population (see Map 1a, area not mapped on Map 4)	CALM file record	OUT	?3/2		
1	**a**	Southern Beekeepers Nature Reserve (3 large populations recorded)	Burbidge & Boscacci (1989)	OUT	3		
2	**a**	'Cervantes Tuart Reserve' (Reserves 39400/41008, east of Cervantes)	GJK, Griffin (1994)	OUT/2	3	CE01 CE02	3 3
3	**a/b**	Nambung National Park	GJK	?5	?3		
4	**b/c**	Wangarren Nature Reserve	GJK	?	?3		
5	**c**	Bashford Nature Reserve	GJK/BJK, AH Burbidge	3	3/1		
6	**c**	Nilgen Nature Reserve	GJK	?3	2/3		
NA		Cowalla Road (see Map 1b, area not mapped on Map 4)	GJ/BJK	?3	1/2[1]		
7	**d**	Seabird UCL	Keighery *et al.* (1996)	2	3/2		
8	**d**	Moore River Point Reserve (Reserves 21473 and 17949) and adjacent bushland (not shown on Map 4)	BJK DEP (1996), Griffin (1998)	3	3/5	Guild 09 Guild 16 Guild 07 for08	26b (3.5) NA (2) **17 (1.5)** NA (2.5)

[1] Beard (1979c) maps 'tuart–marri open woodland' in this area. Observations by BJK and GJK in spring of 2001 confirmed that Tuart occurs in this area along Cowalla Road. Only one small patch of Tuart was observed in bushland, most of the Tuart areas were Tuart woodland over pasture.

TABLE 4b. Natural populations of Tuart on the Quindalup Dune areas in the PMR (Bush Forever Sites)

Mapped Tuart Area No	Map 4 No	Bush Forever Site(s) Name (Site No/System 6 number)	Information Source	Tuart Area/Ab Score	Tuart Condition Score	Quadrat	FCT (Cond. Score)
9	**d**	Wilbinga-Caraban Bushland (406)	Gov of WA (2000), GJK/BJK	?1	5/3		
10	**d/e**	*Ningana Bushland*, Yanchep/Eglington (289)	Gov of WA (2000), GJK/BJK	3	3/2		
11	**d**	Yanchep National Park and Adjacent Bushland (288/M3)	Gov of WA (2000), Keighery (1996)	3	3/2	yan08 Pip01 yan10	30c2 30b **19b**
12	**f**	Trigg Bushland and Adjacent Coastal Reserve, Trigg/Scarborough (308/M36)	Gov of WA (2000), DEP (1996), Gibson *et al.* (1994)	5	3	TRIG02 Trigg08	29a (3) S15
13	**f**	Swanbourne Bushland, Swanbourne/City Beach (315/M46)	Gov of WA (2000), Griffin 1994	2	3	M4601 M4602	S11 S11
14	**g**	Woodman Point, Coogee/Munster (341/M90)	Gov of WA (2000), Gibson *et al.* (1994)	3	3/2	WOODP-2	30c2 (4)
15	**g/h**	Lake Cooloongup, Lake Walyungup and Adjacent Bushland, Hillman to Port Kennedy (356/M103)	Gov of WA (2000), Gibson *et al.* (1994), Keighery (1996)	5	3/2	Cool04 Cool14 Cool15 Cool03	**17** (2) **19b** **19b** 24 (3.5)
16	**h**	Port Kennedy (377/M106)	Gov of WA (2000)	1	occasional		

TABLE 4c. Natural populations of Tuart Spearwood Dune areas in the PMR (Bush Forever area)

Mapped Tuart Area No	Map 4 No	Bush Forever Site(s) Name (Site No/System 6 designation)	Information Source	Tuart Area/Ab Score	Tuart Condition Score	Quadrat	FCT (Cond. Score)
9	**d**	Wilbinga-Caraban Bushland (406)	Gov of WA (2000), DEP (1996), Gibson *et al.* (1994)	5	5/3	SHE 06 Wilb 13	26b (2.5) 26b (4)
17	**d/e**	South-West Link from Wilbinga to Yanchep National Park (284/M1)	Gov of WA (2000)	3	3	tokyu01	25 (5)
18	**d/e**	East Link from Wilbinga to Yanchep National Park (396)	Gov of WA (2000), DEP (1996)	?	?		
11	**d/e**	Yanchep National Park and Adjacent Bushland (288/M3)	Gov of WA (2000), DEP (1996)	5	5/3	YAN-1 YAN-5 YAN-10	26b (3) 26b (2) 26b (3)
19	**d/e**	Ridges and Adjacent Bushland, Yanchep/Nowergup (381/M4)	Gov of WA (2000)	5	5		
20	**d/e**	State Forest 65 — Pinjar Plantation Central Bushland, Yanchep (1, 408 -11, 414 -15)	Gov of WA (2000)	?5	?5/3		
21	**e**	Bernard Road Bushland, Carabooda (129)	Gov of WA (2000)	3	5/3		
22	**e**	Link between Yanchep and Neerabup National Parks (130)	Gov of WA (2000)	3	5/3		
23	**e**	Hopkins Road Bushland, Nowergup (290)	Gov of WA (2000)	3	5		
24	**e**	Neerabup National Park, Lake Gnowergup Nature Reserve and Adjacent Bushland, Neerabup (383/M6)	Gov of WA (2000), Gibson *et al.* (1994)	5	5/3	NEER-1 NEER-5 NEER-11 NEER-6	24 (4) 24 (3.5) 24 (2.5) 28 (3.5)
25	**e**	Burns Beach Bushland (322/M2)[2]	Gov of WA (2000)	1	3		
26	**e**	Neerabup Lake and Adjacent Bushland, Neerabup (384/M6)	Gov of WA (2000)	3	5/3		
27	**e**	Shire View Hill and Adjacent Bushland, Nowergup/Neerabup (293)	Gov of WA (2000)	5/3	5/3		
28	**e**	West Flynn Drive Bushland, Carramar (494)	Gov of WA (2000)	2	5/3		
29	**e**	Flynn Drive Bushland, Neerabup (295/M8)	Gov of WA (2000)	?	?		
30	**e/f**	Yellagonga Regional Park, Wanneroo/Woodvale/Kingsley (299/M7)	Gov of WA (2000), DEP (1996)	3	3/2	yela03	28 (5)
31	**e**	Conti Road Bushland, Wanneroo (164)	Gov of WA (2000)	3	3		

[2] The adjacent Bush Forever Site 323 contains Tuart populations. These are not listed in Government of WA (2000).

Mapped Tuart Area No	Map 4 No	Bush Forever Site(s) Name (Site No/System 6 designation)	Information Source	Tuart Area/Ab Score	Tuart Condition Score	Quadrat	FCT (Cond. Score)
32	**e**	Caporn Street Bushland, Mariginiup (469)	Gov of WA (2000)	1	2		
33	**e**	Garden Park Bushland, Wanneroo (470)	Gov of WA (2000)	1	2		
34	**e**	High Road Bushland, Wanneroo (471)	Gov of WA (2000)	1	2		
35	**e/f**	Woodvale Nature Reserve, Woodvale (407)	Gov of WA (2000), Gibson *et al.* (1994)	5	3	WOODV-1	28 (4)
36	**e/f**	Whitfords Avenue Bushland, Craigie/Padbury 303/M7)	Gov of WA (2000), DEP (1996)	5	3	Pinn03	28 (4)
37	**f**	Shepherds Bush Reserve, Kingsley (39)		2	3/2		
38	**f**	Warwick Open Space Conservation Area (202/M11)	Gov of WA (2000), Gibson *et al.* (1994)	2	3	WARI-1	28 (3.5)
39	**f**	Star Swamp Reserve and Adjacent Bushland, North Beach/Waterman (204/M35)	Gov of WA (2000), DEP (1996)	3	3/2	Star01 Star02	24 (5) 24 (5)
12	**f**	Trigg Bushland and Adjacent Coastal Reserve, Trigg/Scarborough (308/M36)	Gov of WA (2000), Gibson *et al.* (1994)			TRIG 06	24 (3.5)
40	**f**	Carine Swamps, Carine (M37)	Gov of WA (2000)	2	1		
41	**f**	Lake Gwelup Reserve, Gwelup (212/M39)	Gov of WA (2000)	2	1		
42	**f**	Bold Park and Adjacent Bushland, City Beach (312/M47)	Gov of WA (2000)	5	3/2		
43	**f**	Underwood Avenue Bushland, Shenton Park (119)	Gov of WA (2000)	2	2		
44	**f**	Shenton Bushland, Shenton Park (218)	Gov of WA (2000)	1	2		
45	**f**	Kings Park (317/M49)	Gov of WA (2000)	5	3/2		
46	**f**	Lake Claremont, Claremont/Swanbourne (220/M48)	Gov of WA (2000)	?1	?1		
47	**f**	Sir Frederick Samson Park, Samson (59/M72)	Gov of WA (2000)	2	2		
48	**g**	Manning Lake and Adjacent Bushland, Hamilton Hill/Spearwood (247/M92)	Gov of WA (2000)	1	1		
49	**g**	Market Garden Swamps, Spearwood/Munster (429, 435/M92)	Gov of WA (2000)	1	1		
50	**g**	Lake Coogee and Adjacent Bushland, Munster (261/M92)	Gov of WA (2000)	1	1		
51	**g**	Yangebup and Little Rush Lakes, Yangebup (M93)	Gov of WA (2000)	1	?2		
52	**g**	Brownman Swamp, Mt Brown Lake and Adjacent Bushland, Henderson/Naval Base (346/M91/92)	Gov of WA (2000)	5	3/2	MTB-4	24 (3)
53	**g**	Wattleup Lake and Adjacent Bushland, Wattleup/Mandogalup (393/M93)	Gov of WA (2000), Gibson *et al.* (1994)	1	?2		
NA		Fraser Road Bushland (390)	Listed as containing Tuart in Gov of WA (2000) but this appears to be an error				
54	**g**	Mandogalup Road Bushland, Mandogalup (268)	Gov of WA (2000)	2	3		
55	**g**	The Spectacles (269)	Gov of WA (2000)	2	3/5		

Mapped Tuart Area No	Map 4 No	Bush Forever Site(s) Name (Site No/System 6 designation)	Information Source	Tuart Area/Ab Score	Tuart Condition Score	Quadrat	FCT (Cond. Score)
56	**g**	Sandy Lake and Adjacent Bushland, Anketell (270)	Gov of WA (2000)	3	3/5		
57	**g**	Mandogalup Road Bushland, Hope Valley (267)	Gov of WA (2000)	3	3/5		
58	**g/h**	Parmelia Avenue Bushland, Parmelia (67)	Gov of WA (2000)	1	1		
59	**g/h**	Leda and Adjacent Bushland, Leda (349/M104)	Gov of WA (2000), DEP (1996)	5	3/2	leda01 leda03	25 (4) **16 (3)**
60	**h**	Cassia Drive Bushland, Karnup (278)		3	3/2		
15	**g/h**	Lake Cooloongup, Lake Walyungup and Adjacent Bushland, Hillman to Port Kennedy (M103) - eastern Spearwood section (356)	Gov of WA (2000), Gibson *et al.* (1994)			KERO-2	24 (3)
61	**g/h**	Baldivis Swamp and Adjacent Bushland (495)	Gov of WA (2000)	2	2		
62	**h**	Stakehill Swamp, Baldivis (275)	Gov of WA (2000)	3	5/3		
63	**h**	Churcher Swamp, Baldivis (75)	Gov of WA (2000)	?1	?2		
64	**h**	Baldivis Road Bushland, Baldivis (376)	Gov of WA (2000)	3	3/2		
65	**h**	Anstey Swamp, Karnup (379)	Gov of WA (2000)	3	3/5		
66	**h**	Paganoni Swamp and Adjacent Bushland, Karnup (395)	Gov of WA (2000), Gibson *et al.* (1994)	5	5/3	PAGA-7 PAGA-6	21a (3.5) 25 (3)

TABLE 4d. Natural populations of Tuart predominantly outside the Quindalup and Spearwood Dunes in the PMR.

Mapped Tuart Area No	Map 4 No	Bush Forever Site(s) Name (Site No/System 6 designation)	Information Source	Tuart Area/Ab Score	Tuart Condition Score	Quadrat	FCT (Cond. Score)
67	**f**	Peppermint Grove Foreshore (403)	Gov of WA (2000), Gibson *et al.* (1994)	OUT	2/3	PEPGRV-2	30c2 (2)
NA		Swan River flats Guildford	Specimen (Steedman)	Population not able to be located			
68	**f**	Mount Henry Bushland, Salter Point (227)	Gov of WA (2000), Gibson *et al.* (1994)	OUT	3/2	MTHENRY-1	30c2 (3)
69	**g/h**	Doghill Road Bushland, Baldivis (369)	Gov of WA (2000)	OUT/3	3/5		
70	**g/h**	Lowlands Bushland - Eastern Block, Peel Estate (368/M105)	Gov of WA (2000), Gibson *et al.* (1994)	OUT/1	3	low10a	21a (3)
71	**g/h**	Lowlands Bushland - Western Block (Hymus Swamp), Peel Estate (372/M105)	Gov of WA (2000)	OUT/1	1		

TABLE 4e. Natural populations of Tuart on the Quindalup Dune areas in the Mandurah to Sabina River area south of the PMR.

Mapped Tuart Area No	Map 4 No	Area Name (System 6 designation)	Information Source	Tuart Area/Ab Score	Tuart Condition Score	Quadrat	FCT (Cond. Score)
72	**k**	Leschenault Peninsular Conservation Park (C66)	Gibson *et al.* (1994)	5	5/3/2	LESCH-1 LESCH-5	30b (3.5) 30b (3.5)
73	**k/l**	The Maidens (South Bunbury Coastal Land C70)	DEP (1996)	5	3/5	Nmaid04 Gmaid02 Gmaid01	30b (2) 25 (2) 25 (4)
74	**k/l**	*Coastal Dalyellup Proposed Regional Open Space*	BJK	5	3/5		

TABLE 4f. Natural populations of Tuart predominantly on the Spearwood Dune areas in the Mandurah to Sabina River area south of the PMR.

Mapped Tuart Area No	Map 4 No	Area Name (System 6 designation)	Information Source	Tuart Area/Ab Score	Tuart Condition Score	Quadrat	FCT (Cond. Score)
75	**i**	Reserve 860 (part C51)	BJK/GJK	2	3		
76	**i**	Carrabunyup Nature Reserve (part C50)	GJK	1	3		
77	**i**	Stony Point Reserve 27528 (C51)	BJK/GJK	3	3		
78	**i**	Mealup Point Nature Reserve	Gibson *et al.* (1994)	3	3	MEAL-I	25 (3.5)
79	**i/j**	Yalgorup National Park (C54)	Gibson *et al.* (1994)	5[3]	5/3[3]	YALG-7 WHILL-5	26b (4) 26b (3)
80	**i/j**	Clifton Management Priority Area (C55)	BJK/GJK	5[3]	5/3[3]		
81	**j**	McLarty Management Priority Area (C56)	Gibson *et al.* (1994)	5[3]	5/3[3]	CORON-2	25 (3)
82	**j**	Myalup Management Priority Area/Lyons Forest Block (C57)	Gibson *et al.* (1994)	5	5/3	LYON-2 MYALUP-2	25 (3) 25 (3)
83	**j**	Crampton Nature Reserve (C61)	Gibson *et al.* (1994)	3	3	CRAMPT-1	21a (1.5)
84	**j/k**	Myalup Swamp/Mialla Lagoon (C63)	Gibson *et al.* (1994)	?1	?1/3		
85	**k/l**	'Shearwater Tuart Forest'	DEP (1996)	3	2/3	Nmaid 05	25 (4)
86	**k/l**	College Grove Bushland proposed Regional Open Space	DEP (1996)	?3[4]	3/2	bunb01	25 (4)

[3] See Longman and Keighery (this publication) for a discussion of the current condition of Tuart populations in this area.
[4] Beard (1981) maps this area as 'tuart tall woodland'.

Mapped Tuart Area No	Map 4 No	Area Name (System 6 designation)	Information Source	Tuart Area/Ab Score	Tuart Condition Score	Quadrat	FCT (Cond. Score)
87	**k/l**	Dalyellup Reserve (Reserves Near Dalyellup C71)	Gibson *et al.* (1994)	5		C71-4	25 (2.5)
88	**l**	Tuart Forest Reserve (part System recommendation 1.1 (DCE 1978))	Gibson *et al.* (1994)	5	5/3/2	MINN-1 MINN-2 MINN-3 PEPB-1	25 (4.5) 25 (4) 25 (3.5) 30b (4)

TABLE 4g. Natural populations of Tuart predominantly outside the Quindalup and Spearwood Dunes in the Mandurah to Sabina River area south of the PMR.

Mapped Tuart Area No	Map 4 No	Area Name (System 6 designation)	Information Source	Tuart Area/Ab Score	Tuart Condition Score	Quadrat	FCT (Cond. Score)
NA		Murray River flats Ravenswood – private land and road reserve (see Map 1e, not mapped on Map 4)	BJK/GJK	OUT/3	1		
89	**i**	Harvey River Reserve (Res 13987)	Gibson *et al.* (1994)	OUT/3	?3	DRAIN-1	21a (3)

MAPS

MAPS 1a to f. Tuart locations.

Key

See Map Legend for symbols (some symbols may overlap)

Tuart Plot Locations
Locations of the 10 m x 10 m plots containing Tuart used to determine the regional floristic community type groups (see Tables 3 and 4).

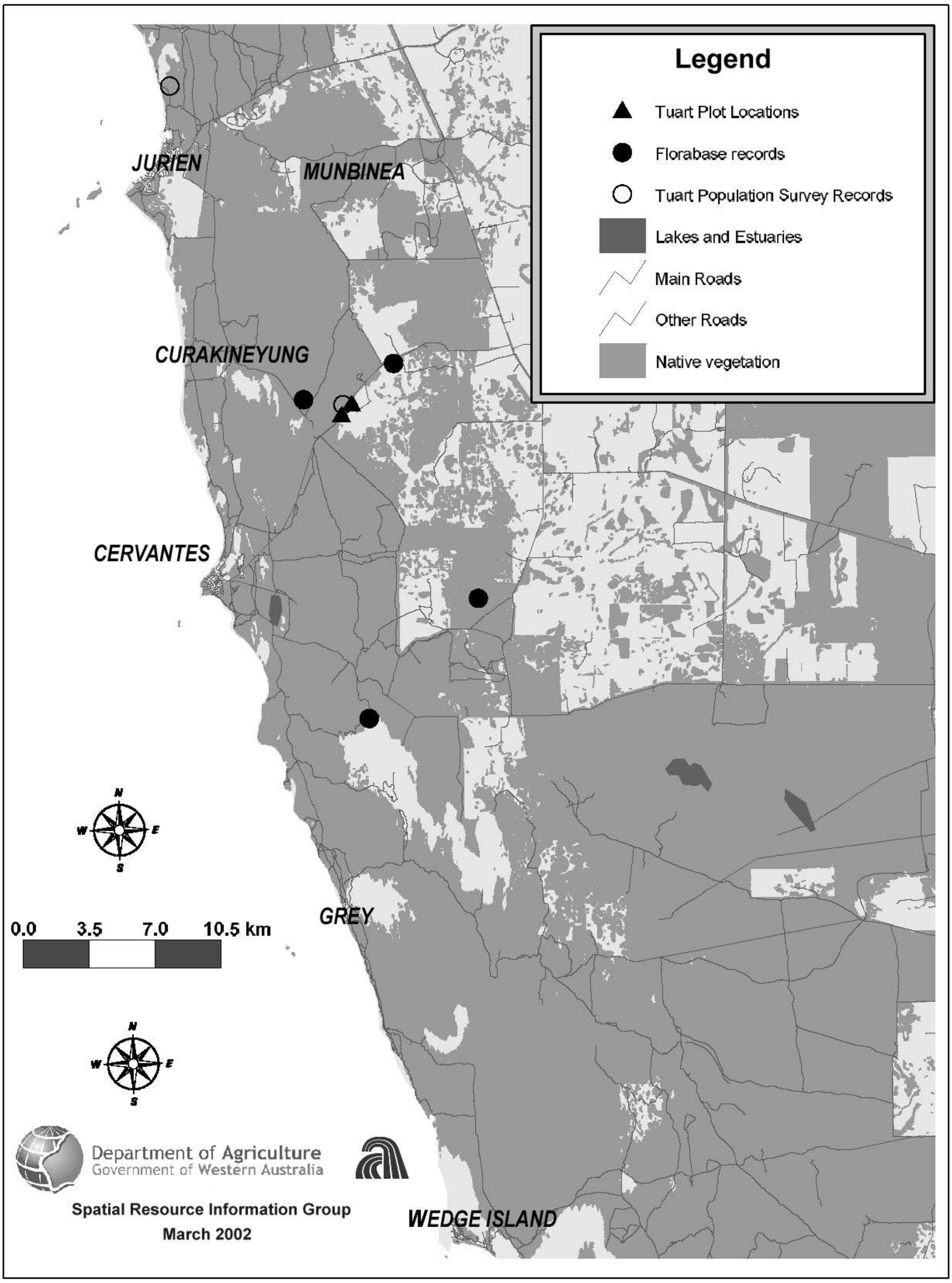
Florabase records
Selected WA Herbarium Collections as listed in Florabase (CALM 2001).

Tuart Population Survey Records
Locations of Tuart populations from field observation by BJ Keighery and GJ Keighery and a CALM file record (north of Jurien).

Lakes and Estuaries
GIS database of Lakes and Estuaries supplied by DOLA.

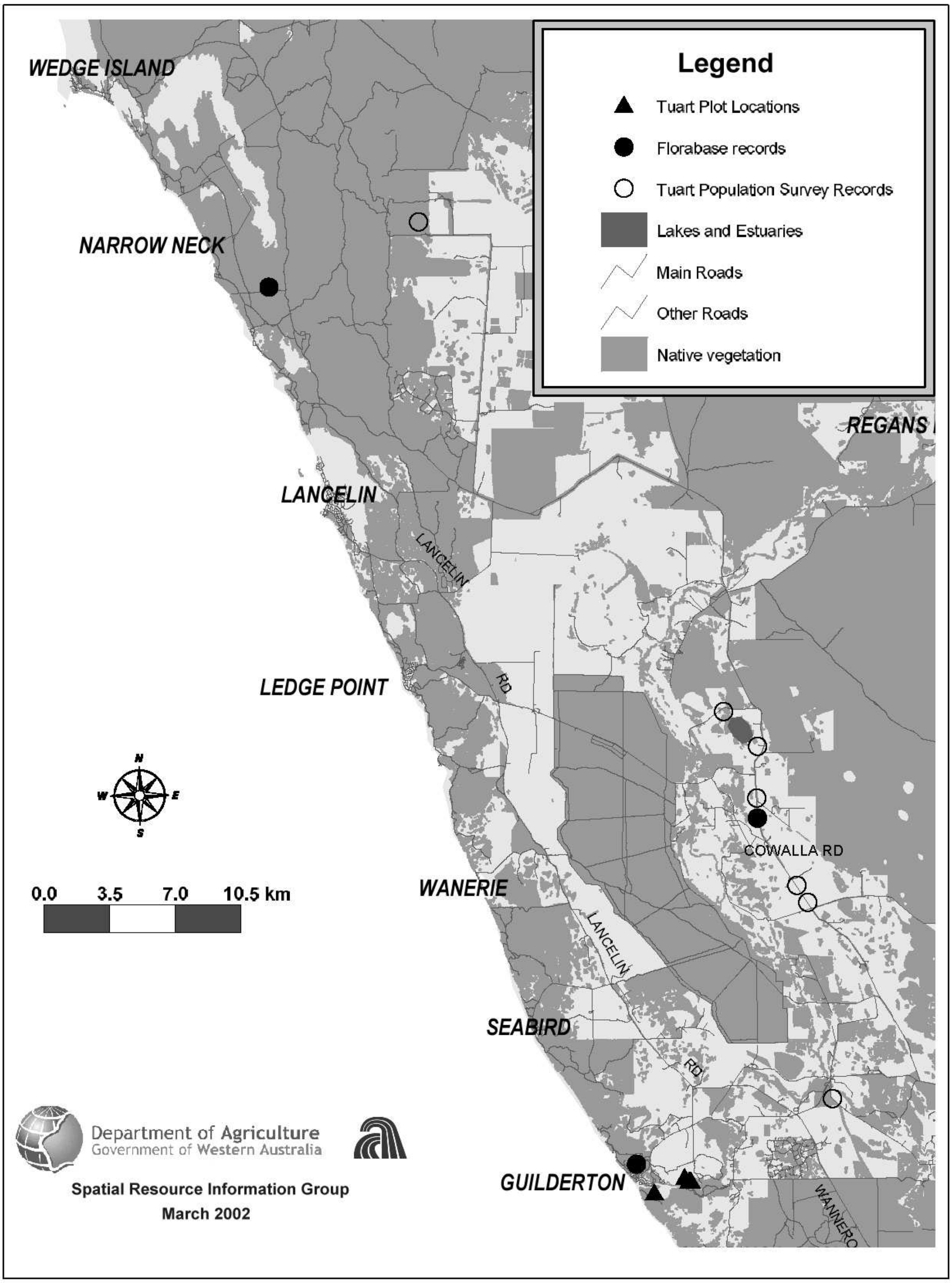
Main Roads/Other Roads
GIS database of Main Roads and Other Roads supplied by DOLA.

Native Vegetation
Native vegetation mapping after Beeston *et al*. (2001). This may include some plantations.

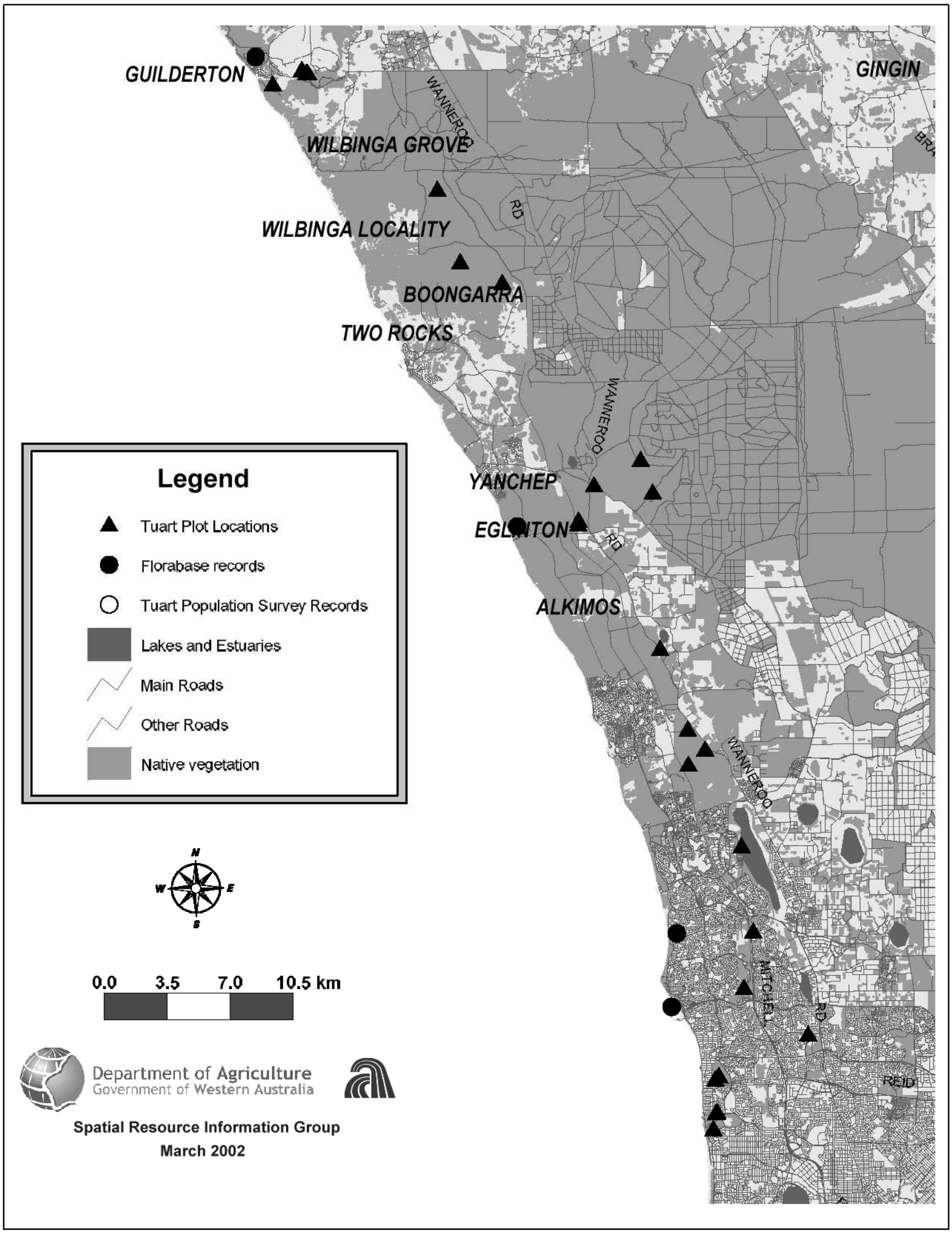


Legend
Tuart Plot Locations
Florabase records
Tuart Population Survey Records
Lakes and Estuaries
Main Roads
Other Roads
Native vegetation
JURIEN
MUNBINEA
CURAKINEYUNG
CERVANTES
GREY
WEDGE ISLAND
0.0 3.5 7.0 10.5 km
N
W
E
S
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002

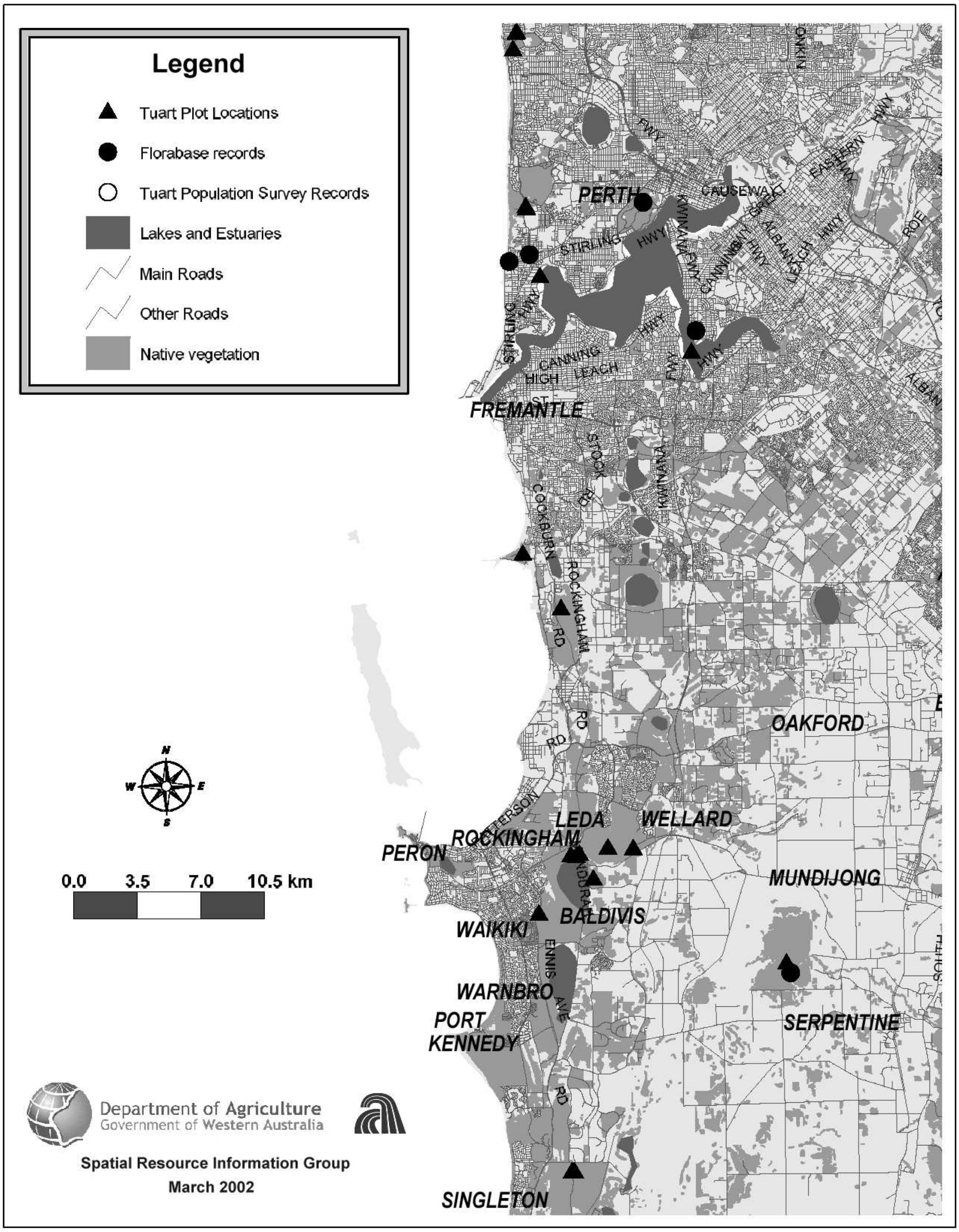
Map 1a.


Legend
Tuart Plot Locations
Florabase records
Tuart Population Survey Records
Lakes and Estuaries
Main Roads
Other Roads
Native vegetation
WEDGE ISLAND
NARROW NECK
LANCELIN
LEDGE POINT
WANERIE
SEABIRD
GUILDERTON
REGANS
LANCELIN RD
COWALLA RD
WANNERO
N
W
E
S
0.0 3.5 7.0 10.5 km
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002

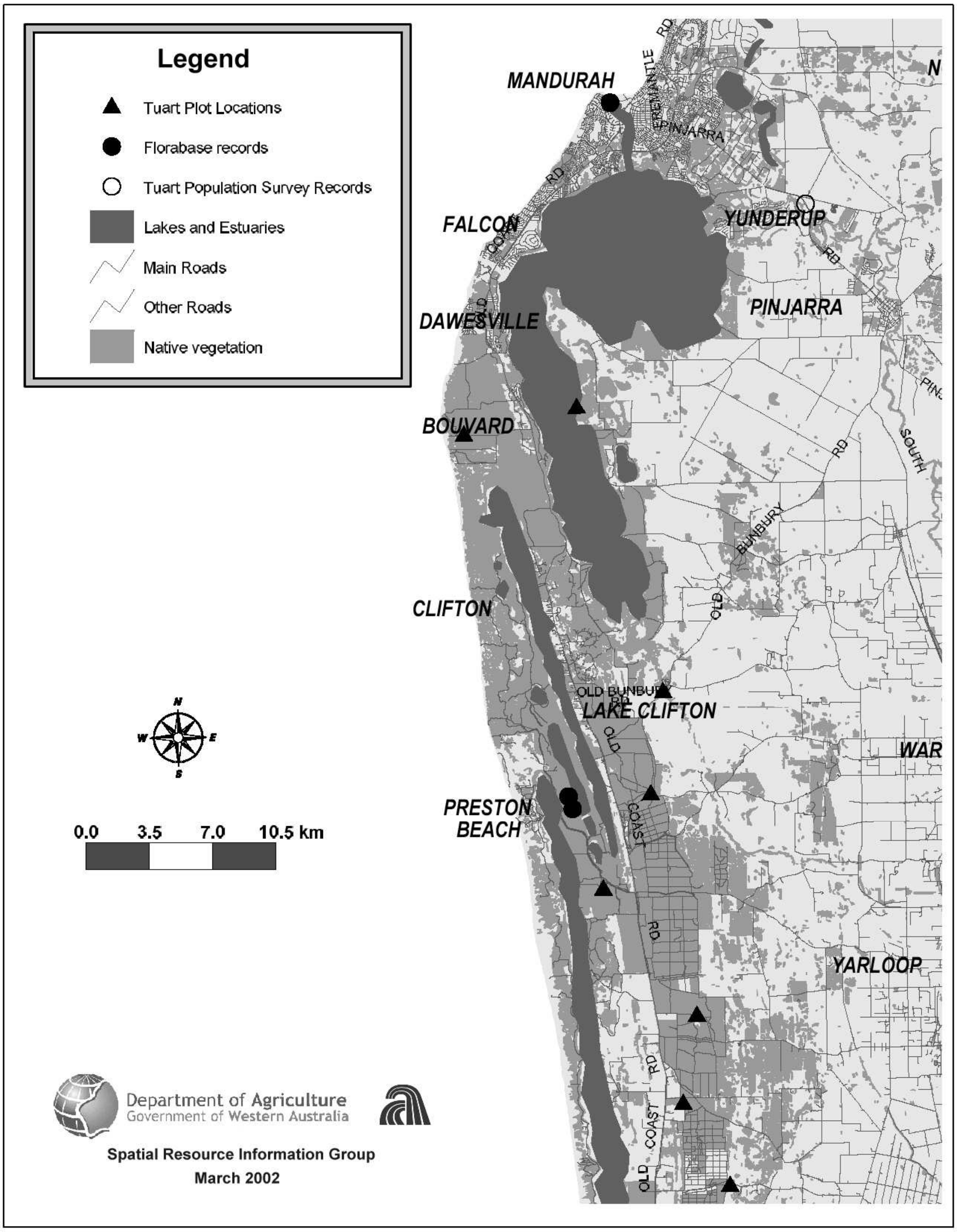
Map 1b.


GUILDERTON
GINGIN
WILBINGA GROVE
WILBINGA LOCALITY
BOONGARRA
TWO ROCKS
YANCHEP
EGLINTON
ALKIMOS
WANNEROO
RD
MITCHELL
REID
Legend
Tuart Plot Locations
Florabase records
Tuart Population Survey Records
Lakes and Estuaries
Main Roads
Other Roads
Native vegetation
N
W
E
S
0.0 3.5 7.0 10.5 km
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002

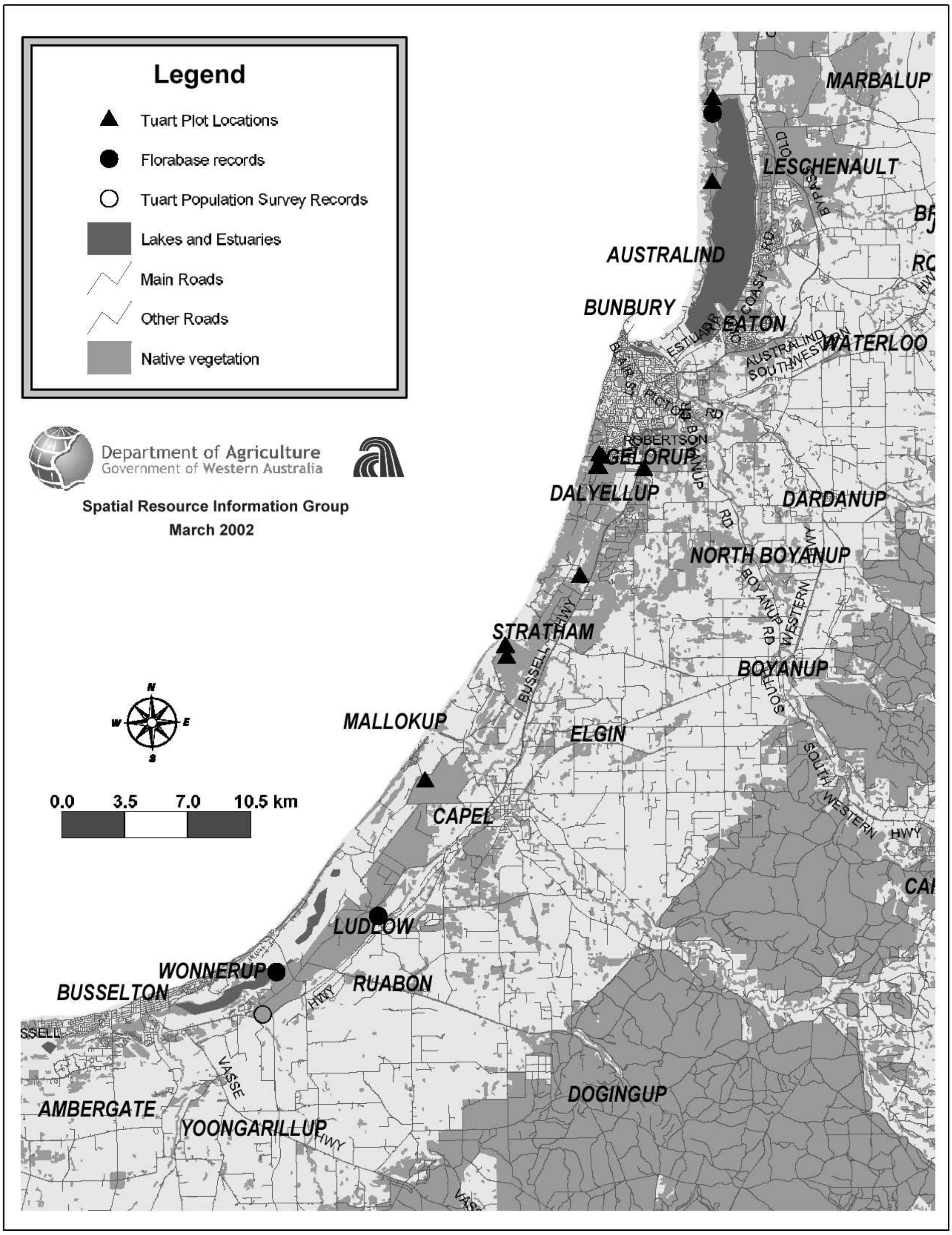
Map 1c.


Legend
Tuart Plot Locations
Florabase records
Tuart Population Survey Records
Lakes and Estuaries
Main Roads
Other Roads
Native vegetation
0.0
3.5
7.0
10.5 km
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
PERTH
FREMANTLE
OAKFORD
LEDA
WELLARD
ROCKINGHAM
PERON
MUNDIJONG
BALDIVIS
WAIKIKI
WARNBRO
PORT
KENNEDY
SERPENTINE
SINGLETON

Map 1d.


Legend
Tuart Plot Locations
Florabase records
Tuart Population Survey Records
Lakes and Estuaries
Main Roads
Other Roads
Native vegetation
0.0 3.5 7.0 10.5 km
MANDURAH
FALCON
YUNDERUP
PINJARRA
DAWESVILLE
BOUVARD
CLIFTON
LAKE CLIFTON
WAR
PRESTON BEACH
YARLOOP
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002

Map 1e.


Legend
Tuart Plot Locations
Florabase records
Tuart Population Survey Records
Lakes and Estuaries
Main Roads
Other Roads
Native vegetation
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
N
W
E
S
0.0 3.5 7.0 10.5 km
MARBALUP
LESCHENAULT
AUSTRALIND
BUNBURY
EATON
WATERLOO
GELORUP
DALYELLUP
DARDANUP
NORTH BOYANUP
STRATHAM
BOYANUP
MALLOKUP
ELGIN
CAPEL
LUDLOW
WONNERUP
RUABON
BUSSELTON
AMBERGATE
YOONGARILLUP
DOGINGUP

Map 1f.

MAPS 2a to g. Current extent of Tuart dominated vegetation types.

Key

See Map Legend for symbols

Lakes and Estuaries
GIS database of Lakes and Estuaries supplied by DOLA.

Main Roads/Other Roads
GIS database of Main Roads and Other Roads supplied by DOLA.

Vegetation types
The area of remaining native vegetation (after Beeston *et al*. 2001) in six types (after Hopkins *et al.* 2001) are mapped (see below). Plantations are generally not included.

Column 1 Word description (after Hopkins *et al.* 1996, 2001)

Column 2 Key to Codes (after Beard 1979a, b and c, 1981)

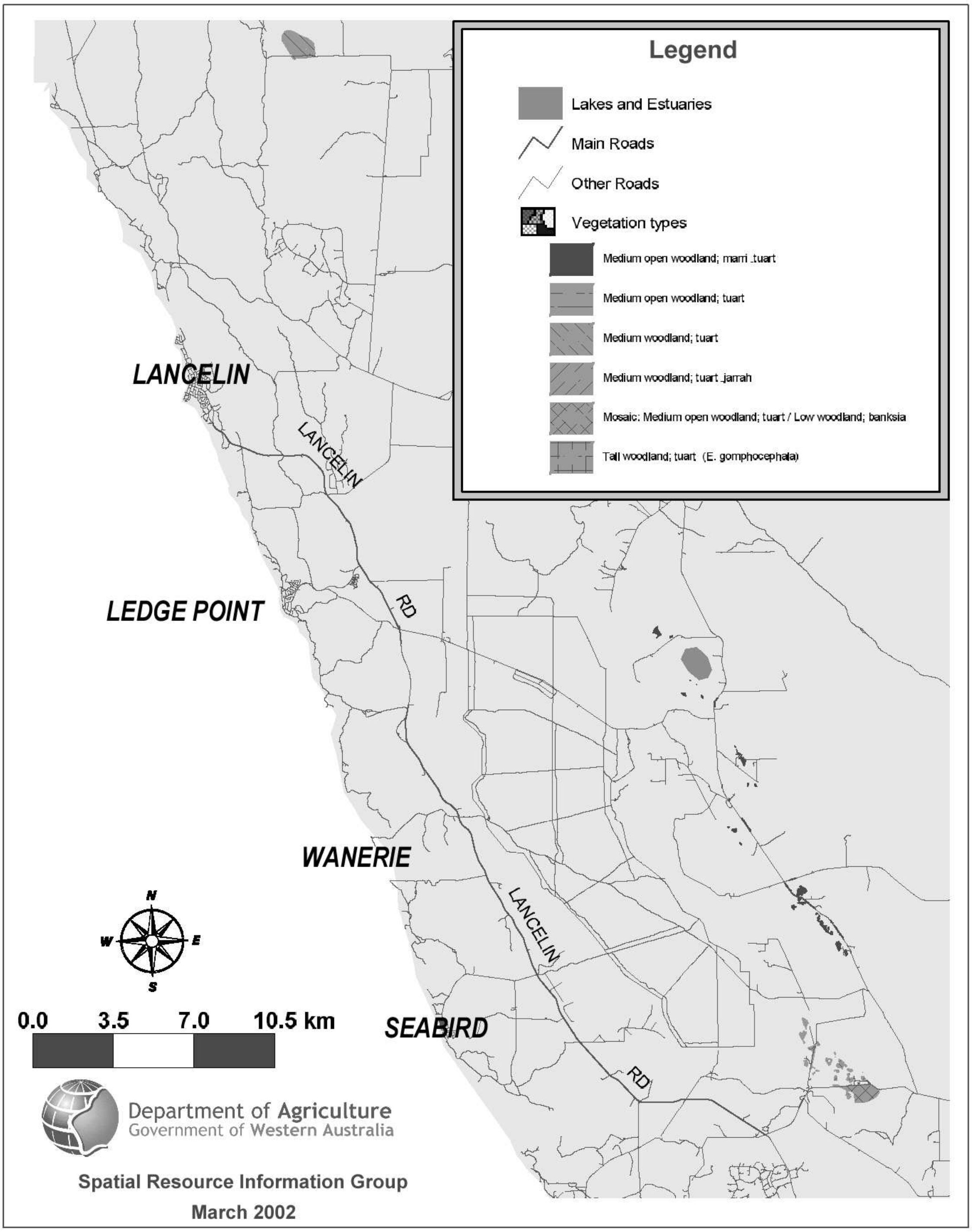
Species
e eucalypt
4 Tuart (*Eucalyptus gomphocephala*)
2 Jarrah (*Eucalyptus marginata*)
3 Marri (*Eucalyptus calophylla*)

Physiognomy of dominant stratum
T Tall trees > 25 m tall
M Medium trees 10 - 25 m tall
L Low trees < 10 m tall

Density of Canopy cover
i Woodland Incomplete canopy – open not touching. Projective foliage cover 10 - 30%.
r Open Woodland Rare but conspicuous. Projective foliage cover < 10%.

Column 3 Unit number (after Hopkins *et al.* 2001)

Unit description	Code	No
Medium open woodland; marri, tuart	e3,4 Mr	1010
Medium open woodland; tuart	e4 Mr	1011
Medium woodland; tuart	e4 Mi	998
Medium woodland; tuart, jarrah	e2, 4 Mi	6
Mosaic: Medium open woodland; tuart/low woodland; banksia	e4Mr/bLi	1012
Tall woodland; tuart	e4 Ti	2


Legend
Lakes and Estuaries
Main Roads
Other Roads
Vegetation types
Medium open woodland; marri .tuart
Medium open woodland; tuart
Medium woodland; tuart
Medium woodland; tuart .jarrah
Mosaic: Medium open woodland; tuart / Low woodland; banksia
Tall woodland; tuart (E. gomphocephala)
LANCELIN
LANCELIN
LEDGE POINT
RD
WANERIE
LANCELIN
RD
SEABIRD
N
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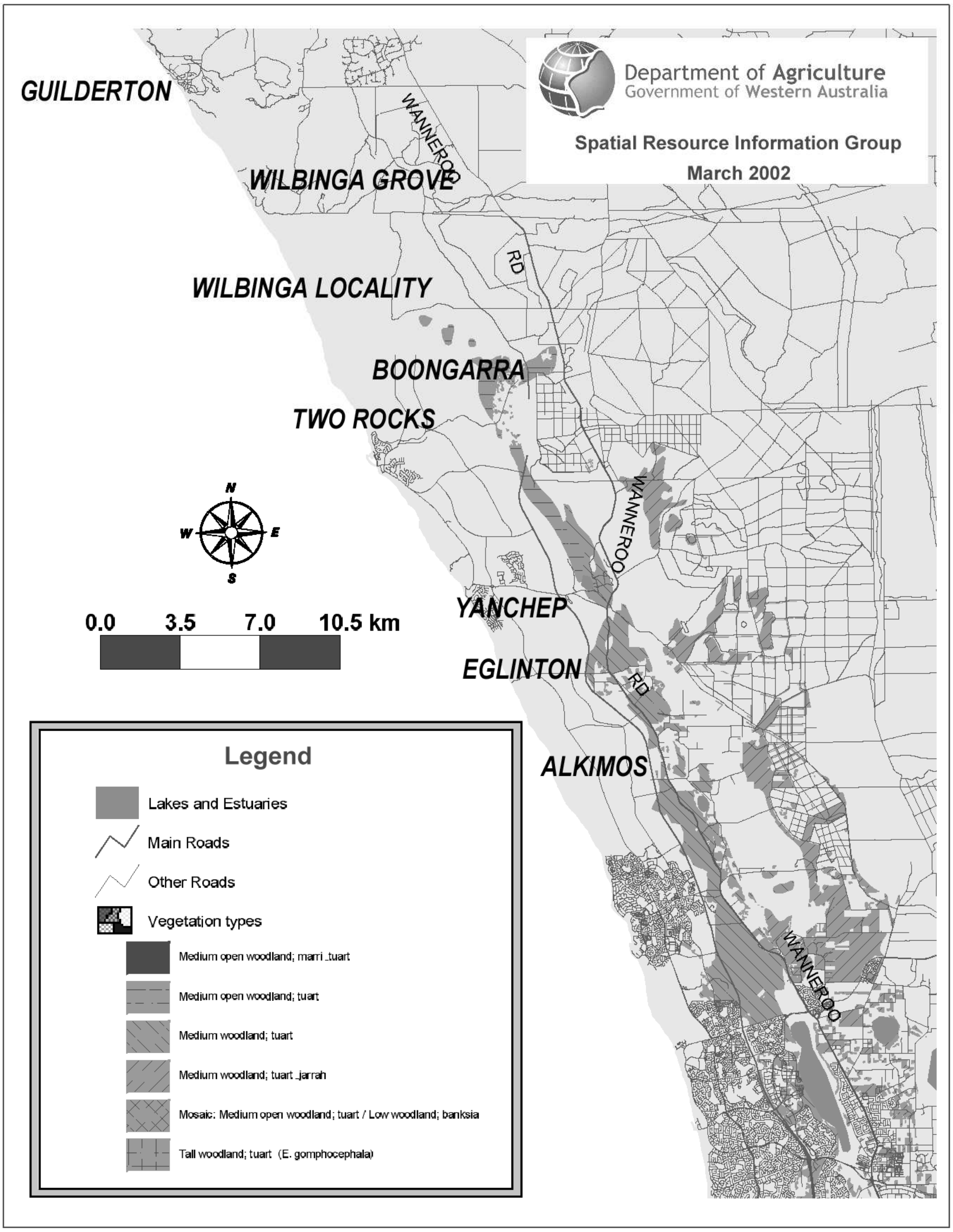
10.5 km
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002

Map 2a.


Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
GUILDERTON
WILBINGA GROVE
WILBINGA LOCALITY
BOONGARRA
TWO ROCKS
YANCHEP
EGLINTON
ALKIMOS
WANNEROO
RD
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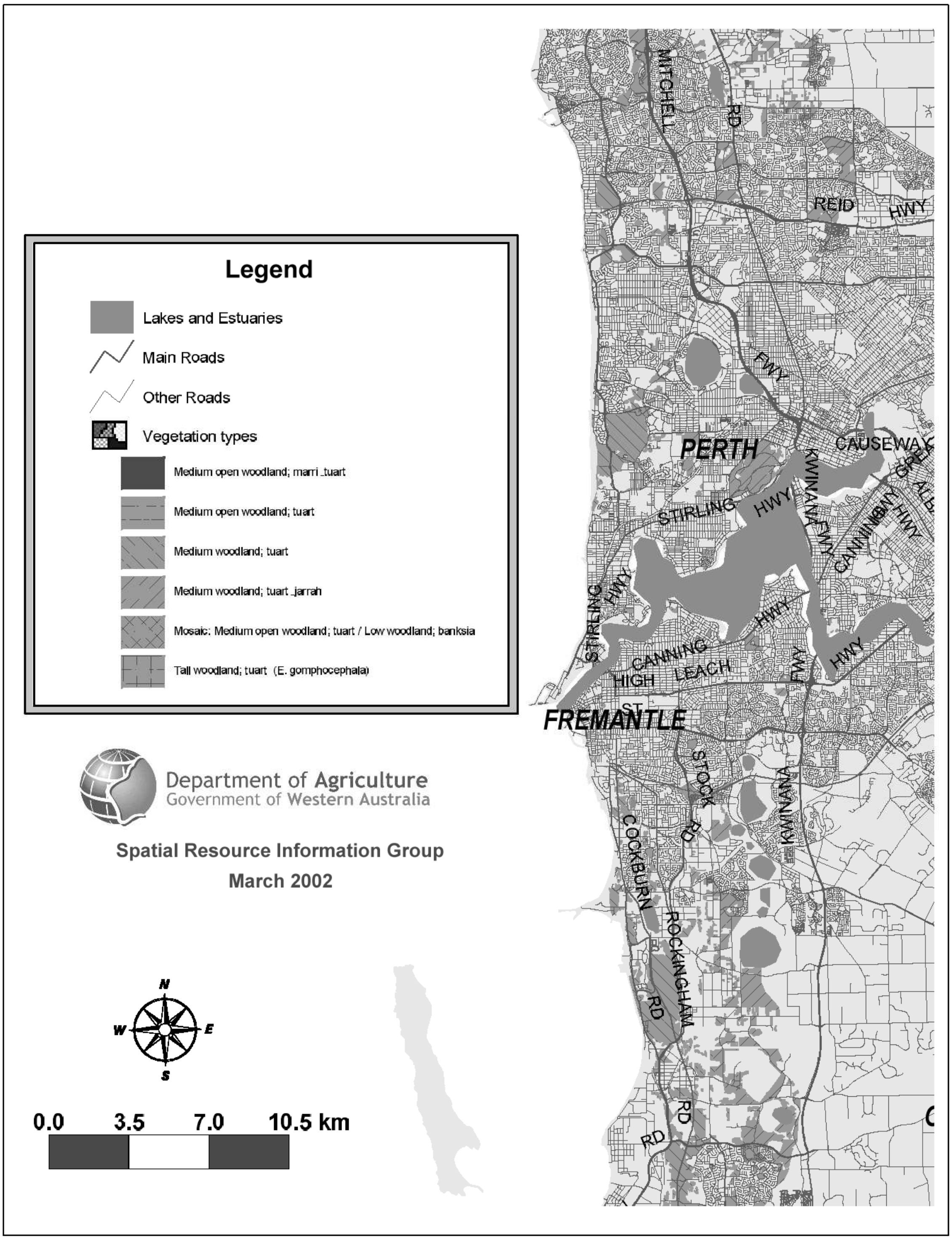
10.5 km
Legend
Lakes and Estuaries
Main Roads
Other Roads
Vegetation types
Medium open woodland; marri _tuart
Medium open woodland; tuart
Medium woodland; tuart
Medium woodland; tuart _jarrah
Mosaic: Medium open woodland; tuart / Low woodland; banksia
Tall woodland; tuart (E. gomphocephala)

Map 2b.


Legend
Lakes and Estuaries
Main Roads
Other Roads
Vegetation types
Medium open woodland; marri _tuart
Medium open woodland; tuart
Medium woodland; tuart
Medium woodland; tuart _jarrah
Mosaic: Medium open woodland; tuart / Low woodland; banksia
Tall woodland; tuart (E. gomphocephala)
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
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MITCHELL
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REID
HWY
FWY
PERTH
CAUSEWAY
KWINANA FWY
STIRLING
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CANNING
HWY
STIRLING
HWY
CANNING
HIGH
LEACH
FWY
HWY
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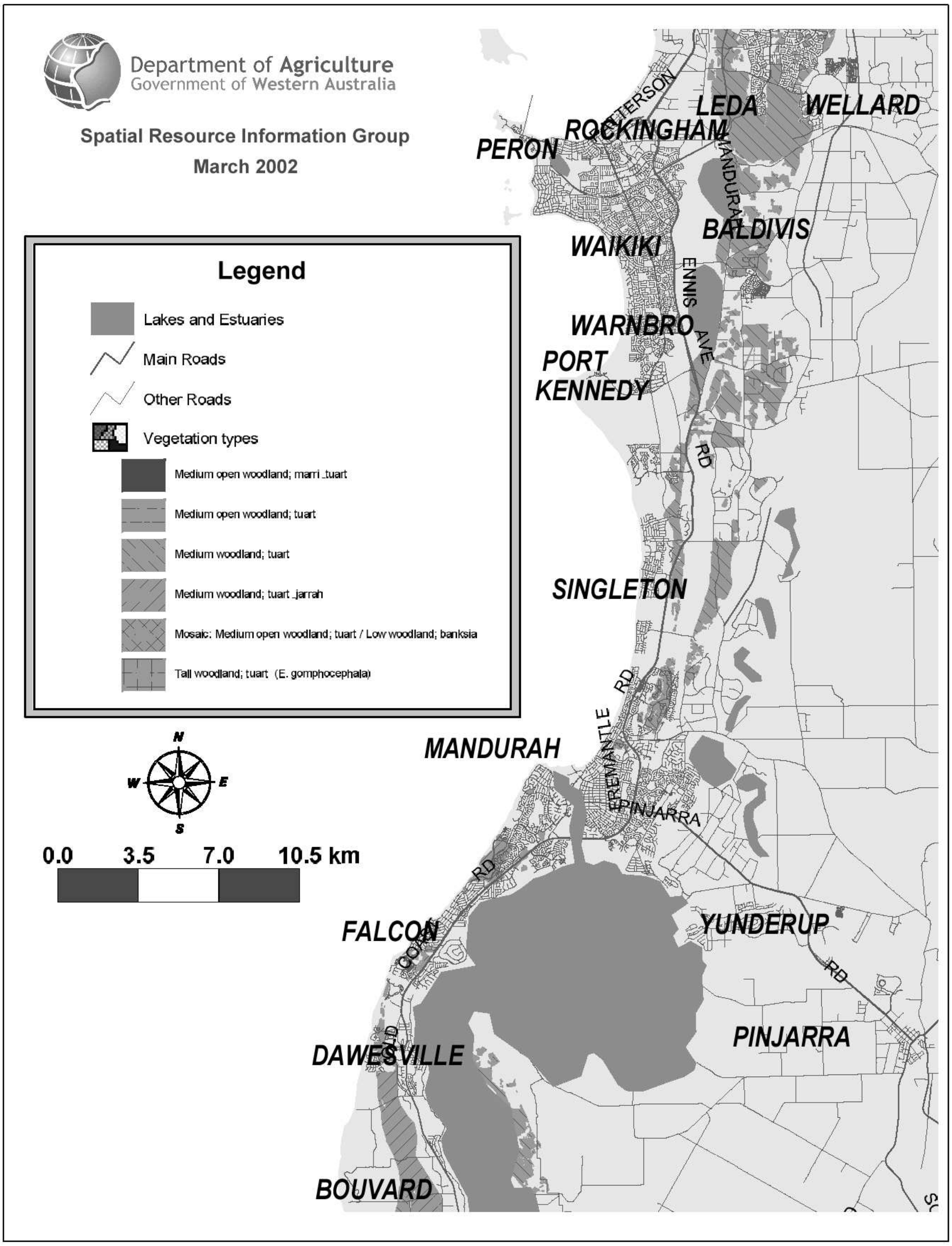
FREMANTLE
STOCK
RD
KWINANA
COCKBURN
ROCKINGHAM
RD
RD
RD

Map 2c.


Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
Legend
Lakes and Estuaries
Main Roads
Other Roads
Vegetation types
Medium open woodland; marri _tuart
Medium open woodland; tuart
Medium woodland; tuart
Medium woodland; tuart _jarrah
Mosaic: Medium open woodland; tuart / Low woodland; banksia
Tall woodland; tuart (E. gomphocephala)
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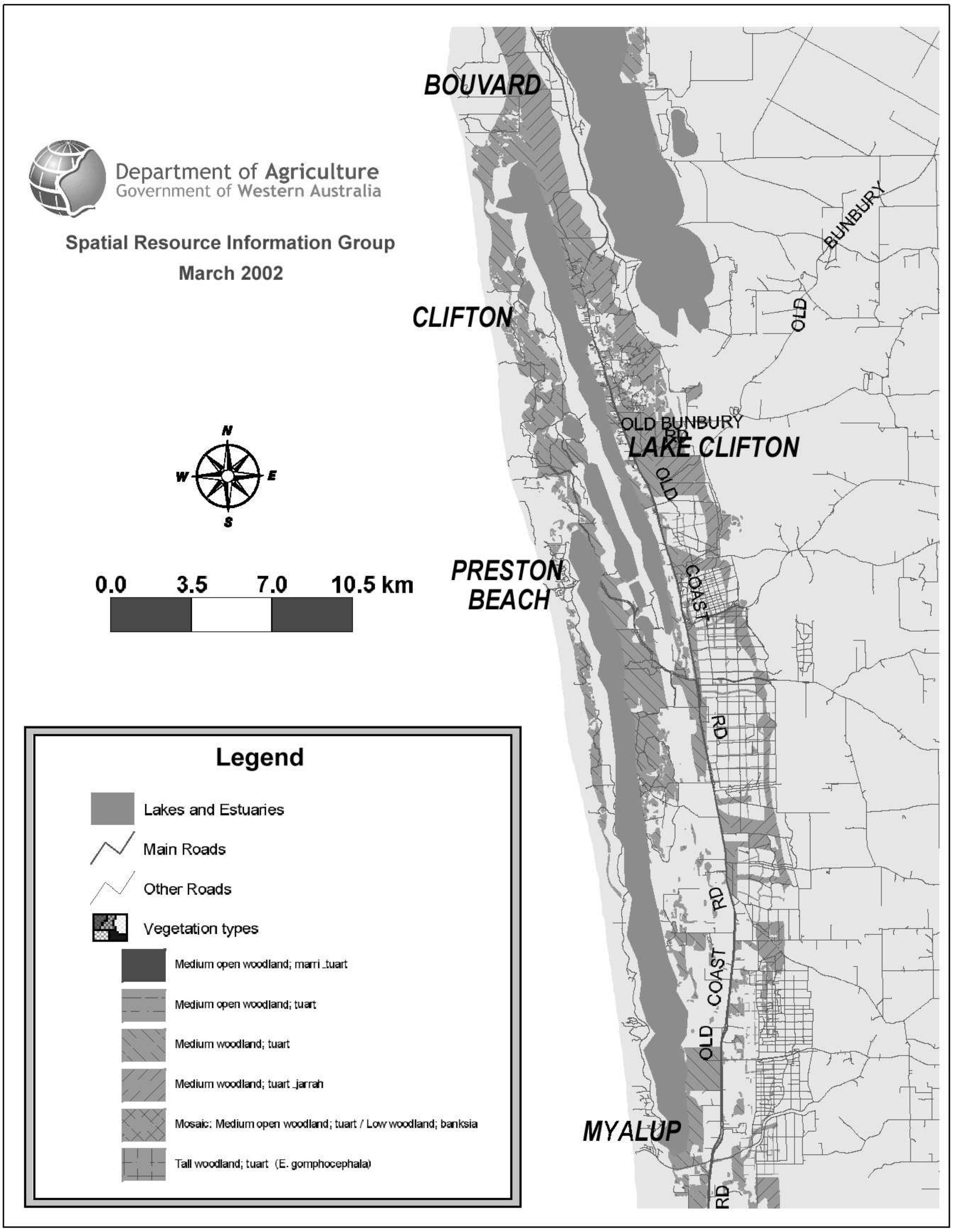
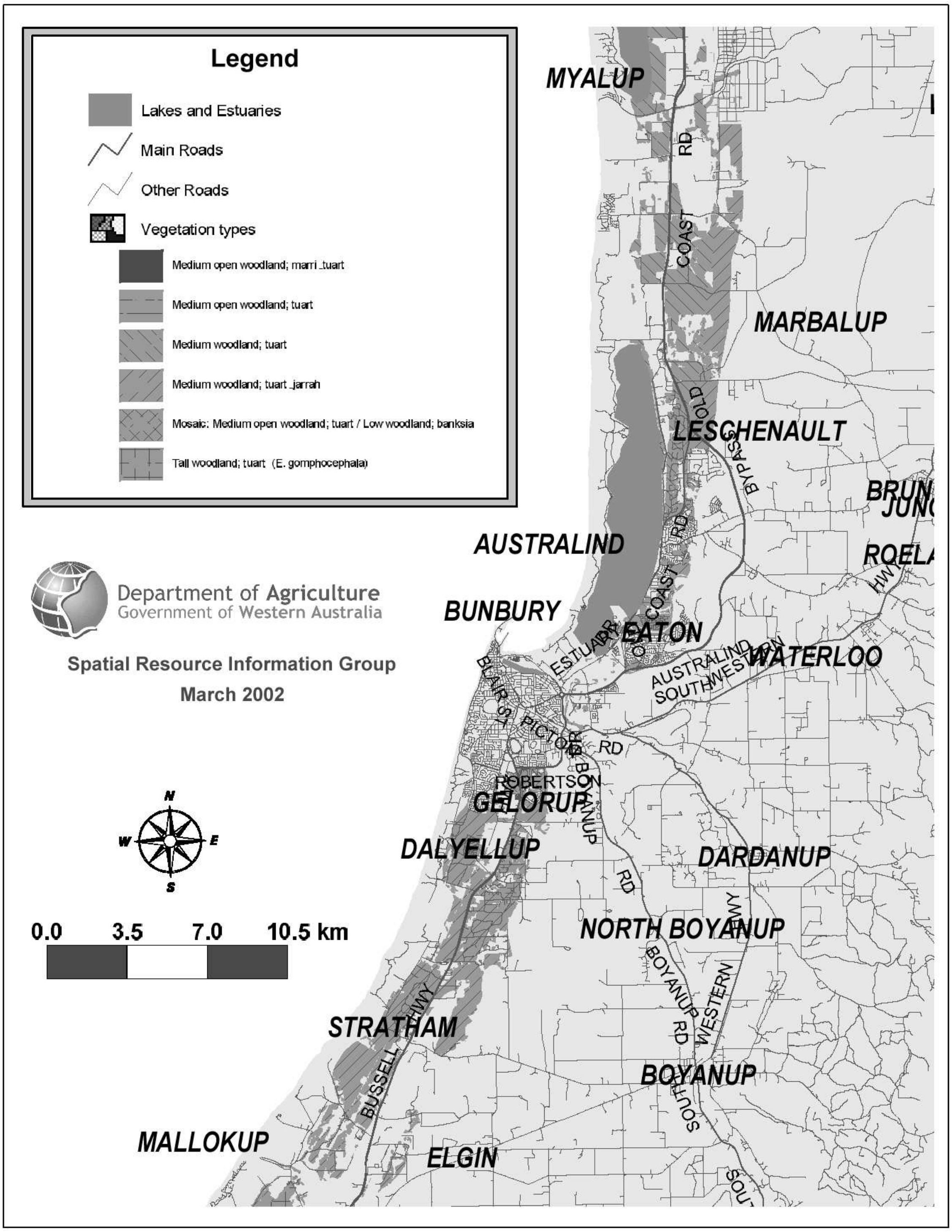
10.5 km
LEDA
WELLARD
ROCKINGHAM
PERON
BALDIVIS
WAIKIKI
ENNIS
AVE
RD
WARNBRO
PORT
KENNEDY
SINGLETON
RD
FREMANTLE
MANDURAH
PINJARRA
RD
FALCON
YUNDERUP
RD
PINJARRA
DAWESVILLE
BOUVARD

Map 2d.


BOUVARD
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
CLIFTON
OLD BUNBURY
RD
LAKE CLIFTON
OLD
COAST
RD
PRESTON BEACH
0.0 3.5 7.0 10.5 km
N
W
E
S
Legend
Lakes and Estuaries
Main Roads
Other Roads
Vegetation types
Medium open woodland; marri_tuart
Medium open woodland; tuart
Medium woodland; tuart
Medium woodland; tuart_jarrah
Mosaic: Medium open woodland; tuart / Low woodland; banksia
Tall woodland; tuart (E. gomphocephala)
MYALUP
OLD COAST RD
RD
OLD BUNBURY

Map 2e.


Legend
Lakes and Estuaries
Main Roads
Other Roads
Vegetation types
Medium open woodland; marri _tuart
Medium open woodland; tuart
Medium woodland; tuart
Medium woodland; tuart _jarrah
Mosaic: Medium open woodland; tuart / Low woodland; banksia
Tall woodland; tuart (E. gomphocephala)
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
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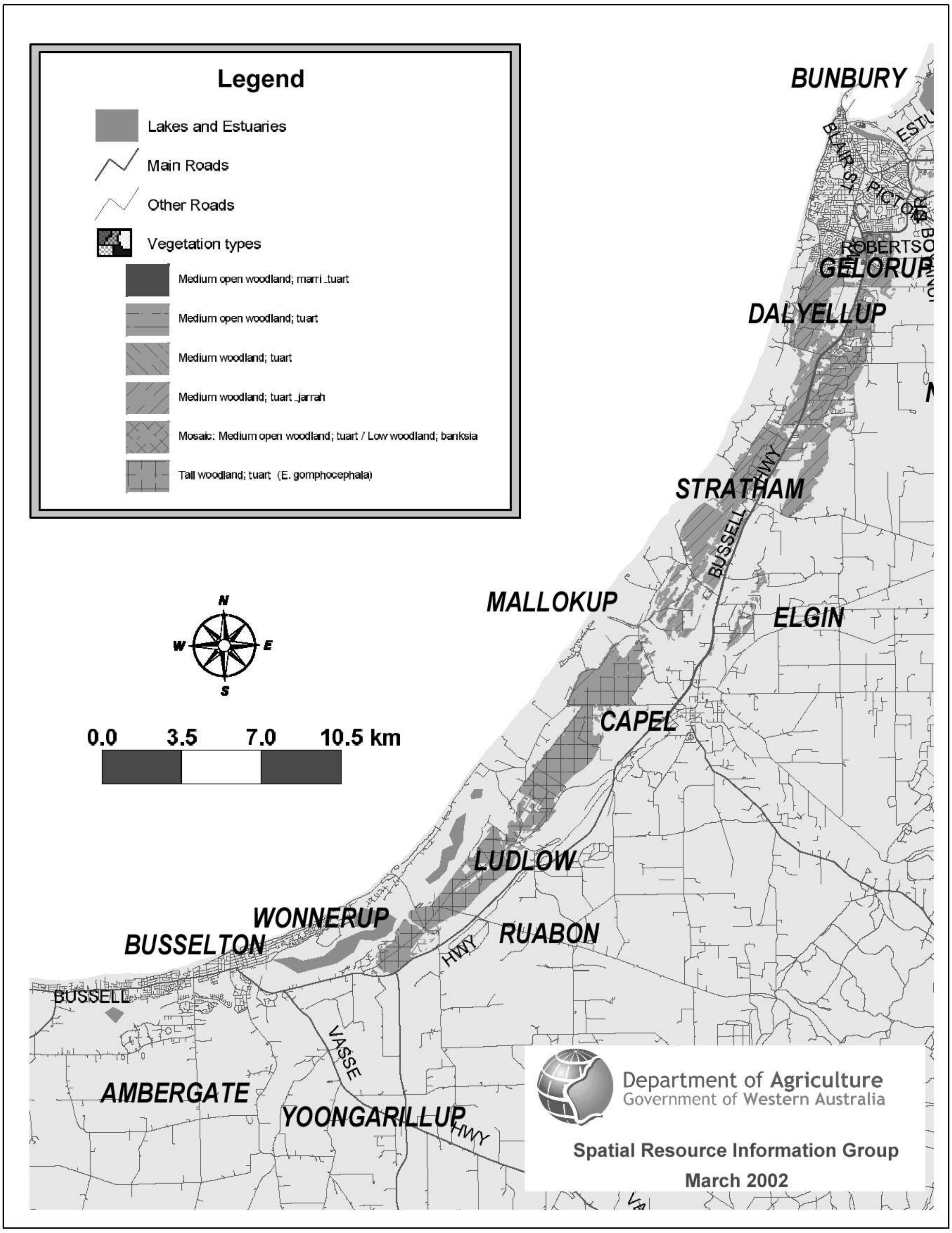
10.5 km
MYALUP
MARBALUP
LESCHENAULT
AUSTRALIND
BUNBURY
EATON
WATERLOO
GELORUP
DALYELLUP
DARDANUP
NORTH BOYANUP
STRATHAM
BOYANUP
MALLOKUP
ELGIN
COAST
RD
OLD
BYPASS
ESTUARY
AUSTRALIND
SOUTH WESTERN
PICTON
ROBERTSON
BOYANUP
WESTERN
BUSSELL
HWY
BLAIR ST

Map 2f.



Legend
Lakes and Estuaries
Main Roads
Other Roads
Vegetation types
Medium open woodland; marri _tuart
Medium open woodland; tuart
Medium woodland; tuart
Medium woodland; tuart _jarrah
Mosaic: Medium open woodland; tuart / Low woodland; banksia
Tall woodland; tuart (E. gomphocephala)
N
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S
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3.5
7.0
10.5 km
BUNBURY
GELORUP
DALYELLUP
STRATHAM
BUSSELL HWY
MALLOKUP
ELGIN
CAPEL
LUDLOW
WONNERUP
BUSSELTON
RUABON
HWY
BUSSELL
VASSE
AMBERGATE
YOONGARILLUP
HWY
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002

Map 2g.

MAPS 3a to g. Current extent of vegetation complexes containing Tuart structural formations.

Key

See Map Legend for symbols

Lakes and Estuaries
GIS database of Lakes and Estuaries supplied by DOLA.

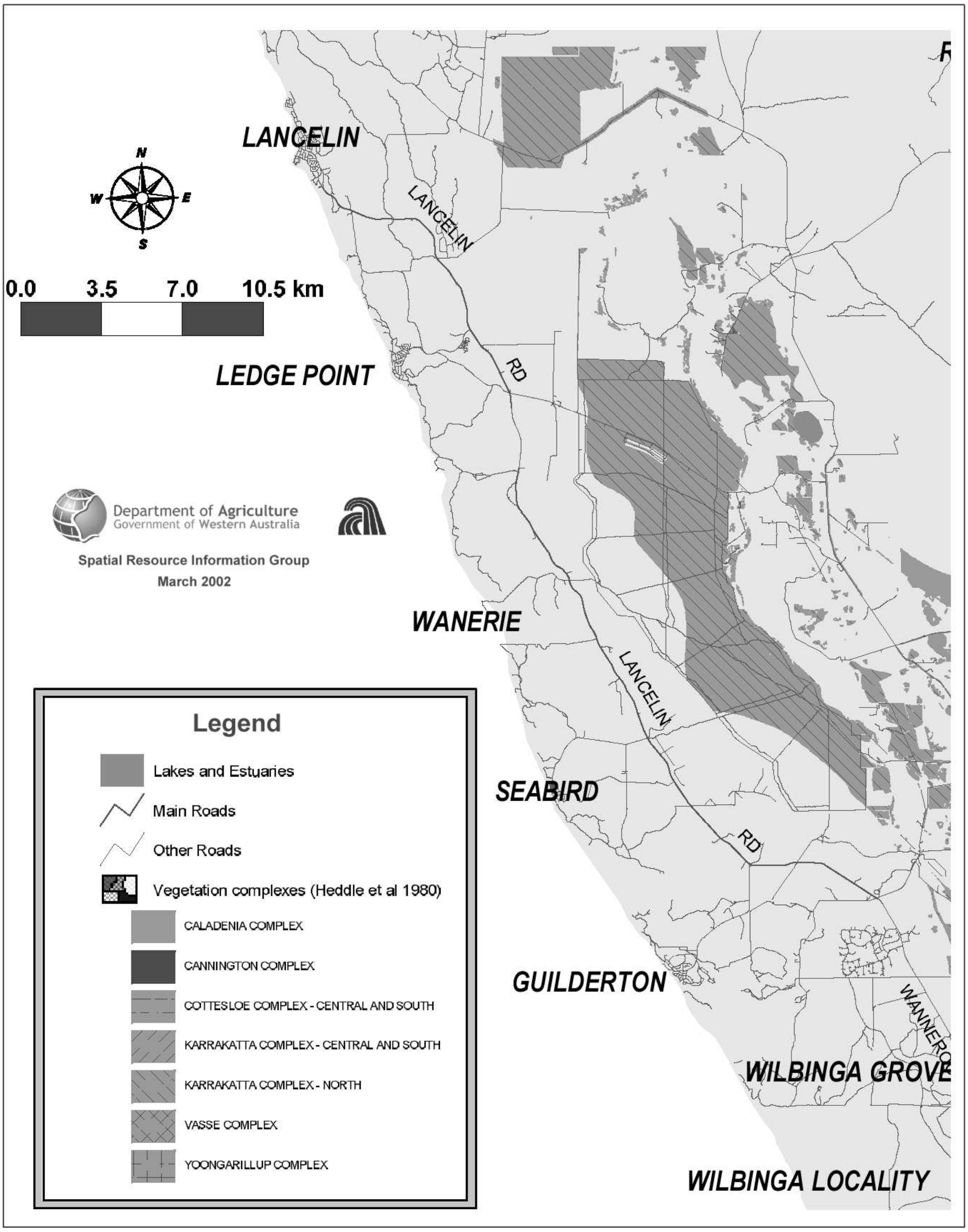
Main Roads/Other Roads
GIS database of Main Roads and Other Roads supplied by DOLA.

Vegetation complexes
The area of remaining native vegetation (after Beeston *et al*. 2001) in seven vegetation complexes (after Heddle *et al.* 1980) are mapped (see below). Plantations are generally not included.

Column 1 Tuart structural formations listed for the vegetation complexes (after Table 3.5, Heddle *et al.* 1980). Two 'levels', of occurrence are indicated, these are:
bold formations that should be present
non bold formation that should be present, but absence not critical.

Column 2 Units after Heddle *et al*. (1980), % Tuart dominated estimated by BJ and GJ Keighery

Structural Formations	Vegetation Complex % Tuart dominated vegetation
Combinations of Bassendean Dunes/Pinjarra Plain/Spearwood Dunes	
Open forest (with Jarrah and Marri)	CALADENIA COMPLEX: Mosaic of vegetation from adjacent vegetation complexes of Karrakatta, Yanga and Bassendean. **approx. 5%**
Open forest (with Jarrah and Marri)	CANNINGTON COMPLEX: Mosaic of vegetation from adjacent vegetation complexes of Bassendean, Karrakatta, Southern River and Vasse. **approx. 5%**
Spearwood Dunes	
Open forest (with Jarrah and Marri) **Woodland**	COTTESLOE COMPLEX - CENTRAL AND SOUTH: Mosaic of woodland of *Eucalyptus gomphocephala* and open forest of *E. gomphocephala - E. marginata - E. calophylla;* closed heath on the limestone outcrops. **approx. 20%**
Open forest (with Jarrah and Marri)	KARRAKATTA COMPLEX - CENTRAL AND SOUTH: Predominantly open forest of *Eucalyptus gomphocephala - E. marginata - E. calophylla* and woodland of *E. marginata - Banksia* species **approx. 50%**
Open forest	KARRAKATTA COMPLEX - NORTH: Predominantly low open forest and low woodland of *Banksia* species. *Eucalyptus todtiana,* less consistently open forest of *E. gomphocephala - E. todtiana - Banksia* species **approx. 30%**
Marine (lagoonal and estuarine) Deposits	
Open forest (with Jarrah and Marri) **Woodland**	VASSE COMPLEX : Mixture of the closed scrub of *Melaleuca* species fringing woodland of *E. rudis - Melaleuca* species and open forest of *E. gomphocephala - E. marginata - E. calophylla* **approx. 10%**
Tall woodland Open forest (with Jarrah and Marri)	YOONGARILLUP COMPLEX: Woodland to tall woodland of *Eucalyptus gomphocephala* with *Agonis flexuosa* in the second storey. Less consistently an open forest of *E. gomphocephala - E. marginata - E. calophylla.* **approx. 50%**



LANCELIN
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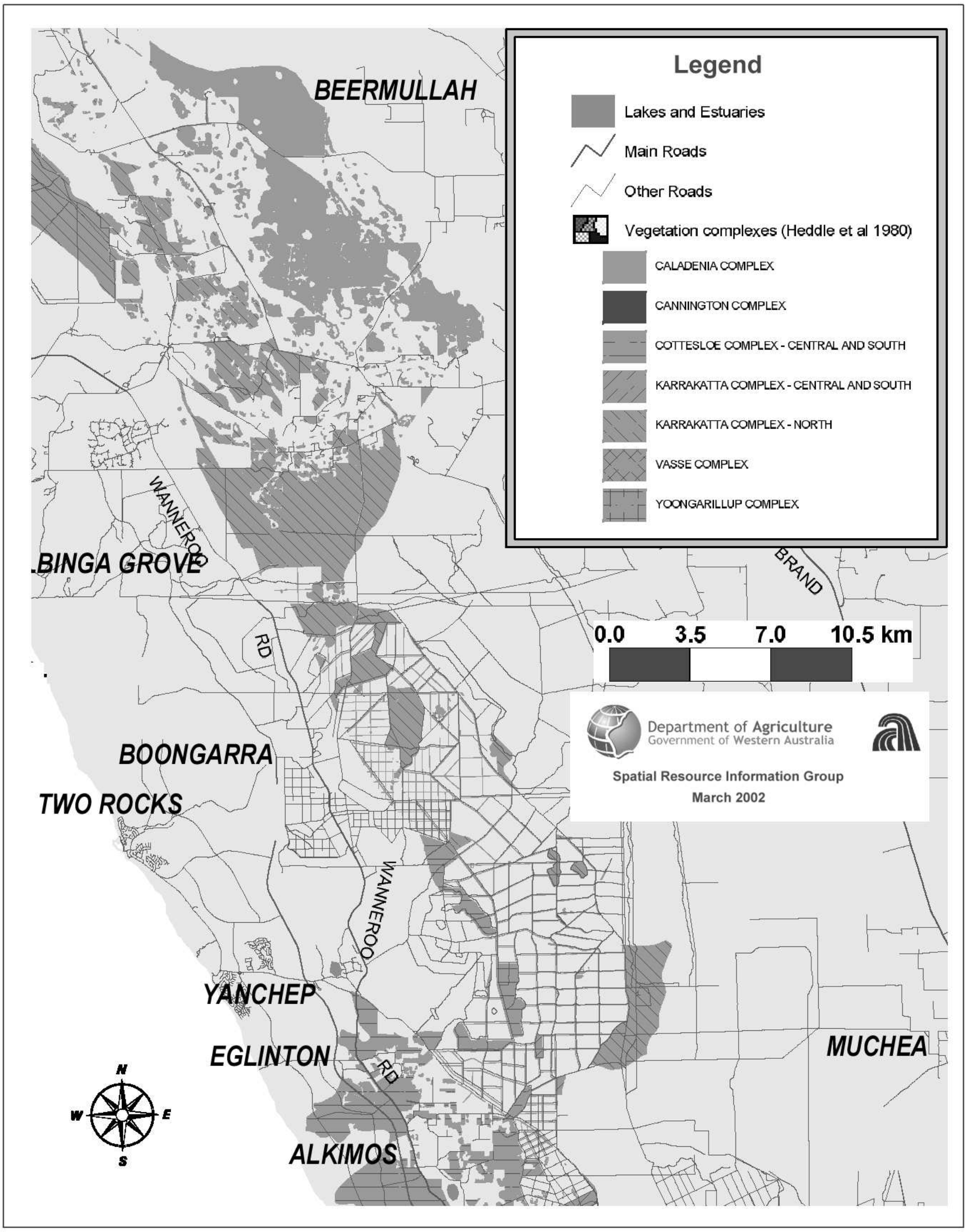
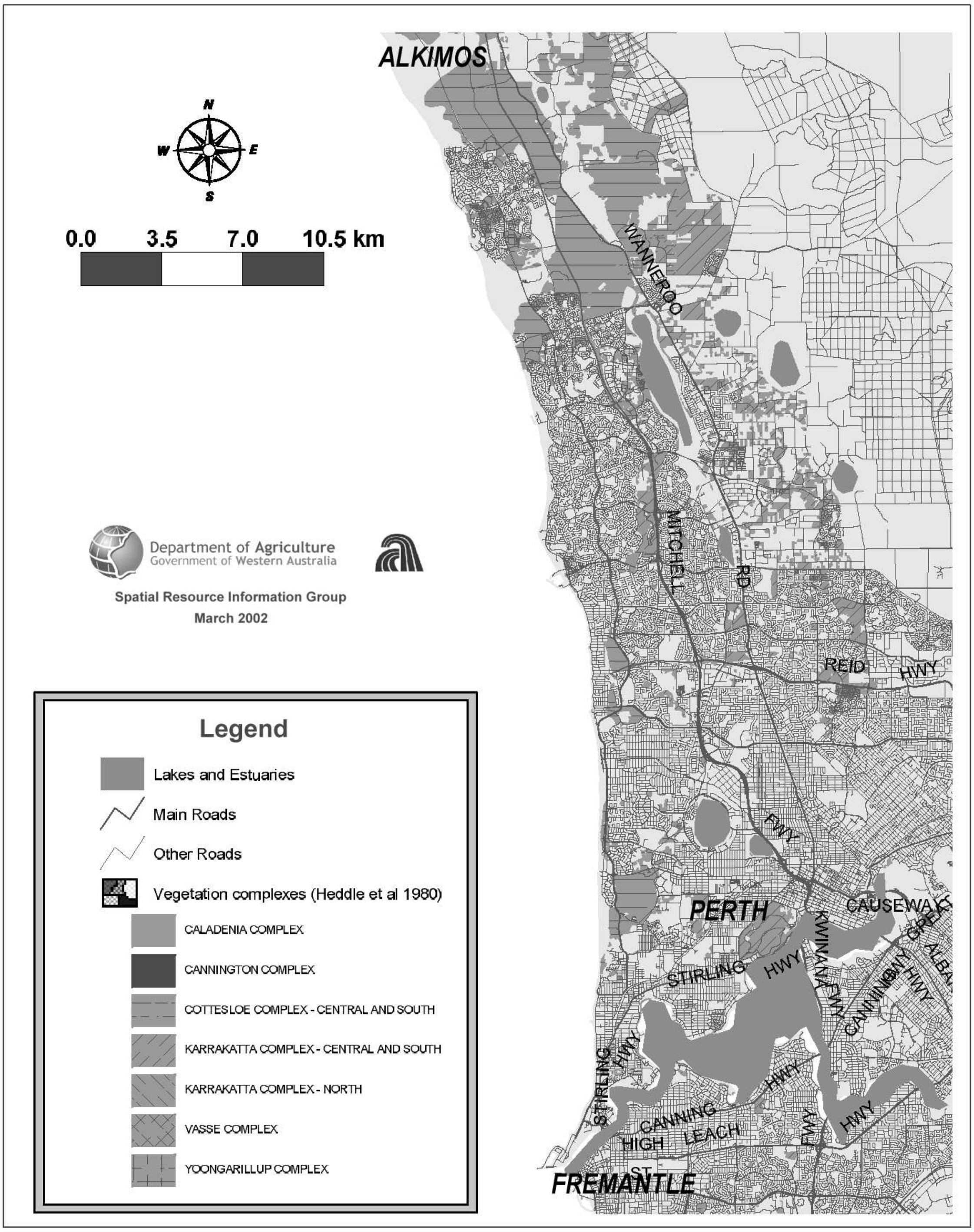
3.5
7.0
10.5 km
LANCELIN
RD
LEDGE POINT
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
WANERIE
LANCELIN
Legend
Lakes and Estuaries
Main Roads
Other Roads
Vegetation complexes (Heddle et al 1980)
CALADENIA COMPLEX
CANNINGTON COMPLEX
COTTESLOE COMPLEX - CENTRAL AND SOUTH
KARRAKATTA COMPLEX - CENTRAL AND SOUTH
KARRAKATTA COMPLEX - NORTH
VASSE COMPLEX
YOONGARILLUP COMPLEX
SEABIRD
RD
GUILDERTON
WILBINGA GROVE
WILBINGA LOCALITY

Map 3a.


Legend
Lakes and Estuaries
Main Roads
Other Roads
Vegetation complexes (Heddle et al 1980)
CALADENIA COMPLEX
CANNINGTON COMPLEX
COTTESLOE COMPLEX - CENTRAL AND SOUTH
KARRAKATTA COMPLEX - CENTRAL AND SOUTH
KARRAKATTA COMPLEX - NORTH
VASSE COMPLEX
YOONGARILLUP COMPLEX
BEERMULLAH
WANNEROO
BINGA GROVE
BRAND
RD
0.0 3.5 7.0 10.5 km
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
BOONGARRA
TWO ROCKS
WANNEROO
YANCHEP
EGLINTON
RD
MUCHEA
ALKIMOS
N
W
E
S

Map 3b.


ALKIMOS
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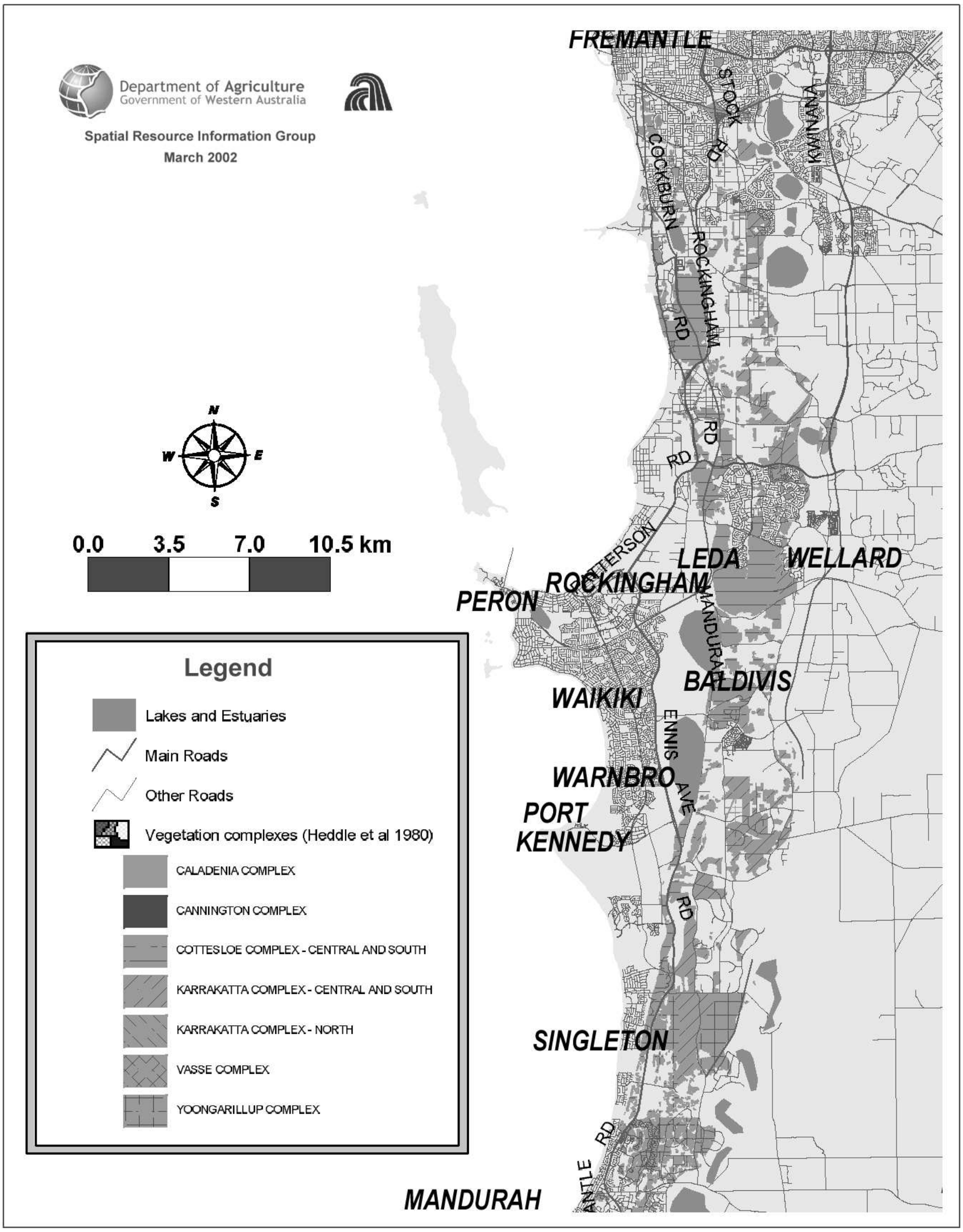
0.0 3.5 7.0 10.5 km
WANNEROO
MITCHELL
RD
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
REID HWY
Legend
Lakes and Estuaries
Main Roads
Other Roads
Vegetation complexes (Heddle et al 1980)
CALADENIA COMPLEX
CANNINGTON COMPLEX
COTTESLOE COMPLEX - CENTRAL AND SOUTH
KARRAKATTA COMPLEX - CENTRAL AND SOUTH
KARRAKATTA COMPLEX - NORTH
VASSE COMPLEX
YOONGARILLUP COMPLEX
FWY
PERTH
CAUSEWAY
KWINANA FWY
STIRLING HWY
CANNING HWY
STIRLING HWY
CANNING HWY
HIGH ST
LEACH HWY
FWY
HWY
FREMANTLE

Map 3c.


Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
N
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3.5
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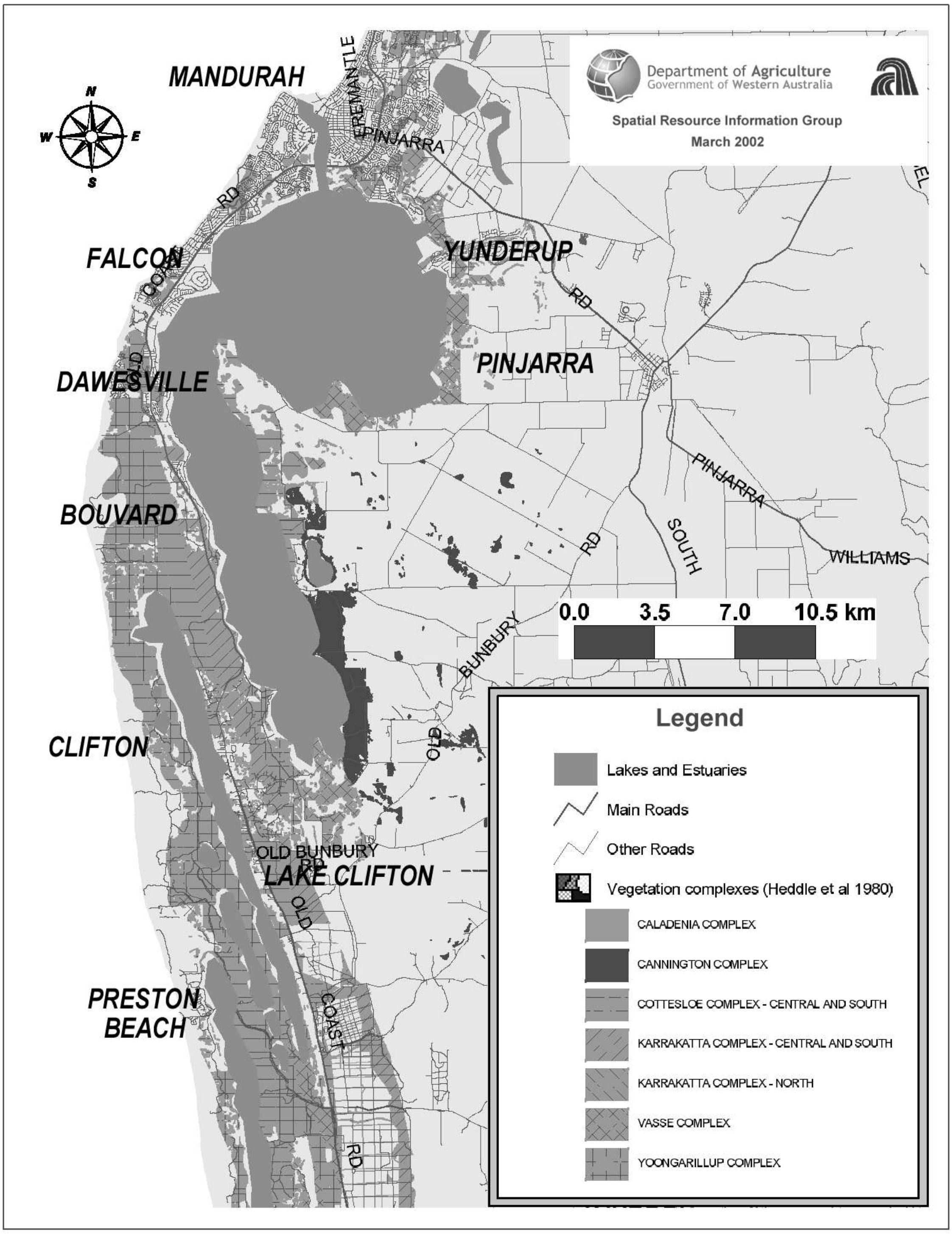
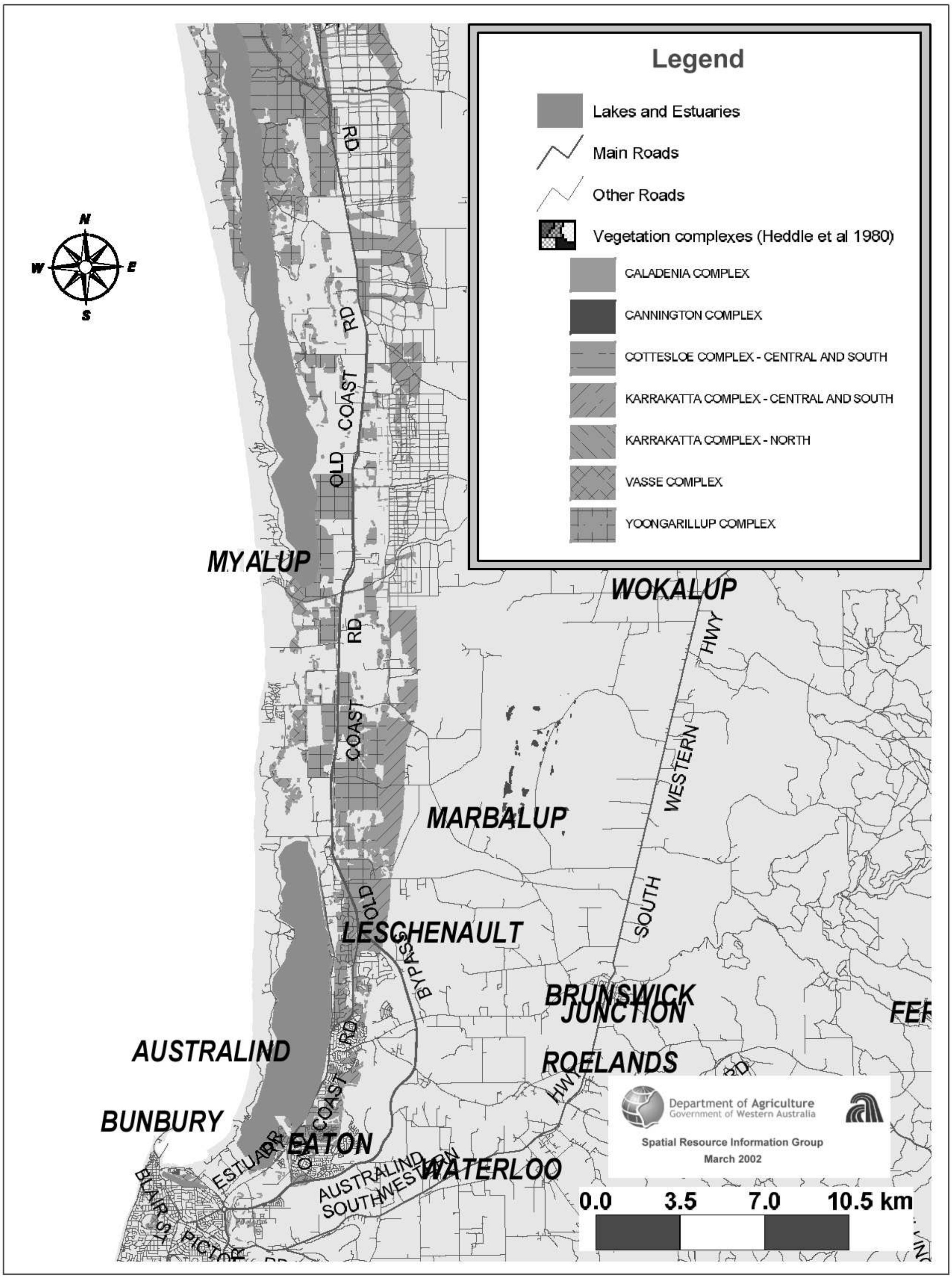
10.5 km
Legend
Lakes and Estuaries
Main Roads
Other Roads
Vegetation complexes (Heddle et al 1980)
CALADENIA COMPLEX
CANNINGTON COMPLEX
COTTESLOE COMPLEX - CENTRAL AND SOUTH
KARRAKATTA COMPLEX - CENTRAL AND SOUTH
KARRAKATTA COMPLEX - NORTH
VASSE COMPLEX
YOONGARILLUP COMPLEX
FREMANTLE
STOCK RD
KWINANA
COCKBURN
ROCKINGHAM RD
RD
RD
LEDA
WELLARD
ROCKINGHAM
PERON
MANDURAH
BALDIVIS
WAIKIKI
ENNIS AVE
WARNBRO
PORT KENNEDY
RD
SINGLETON
RD
MANDURAH

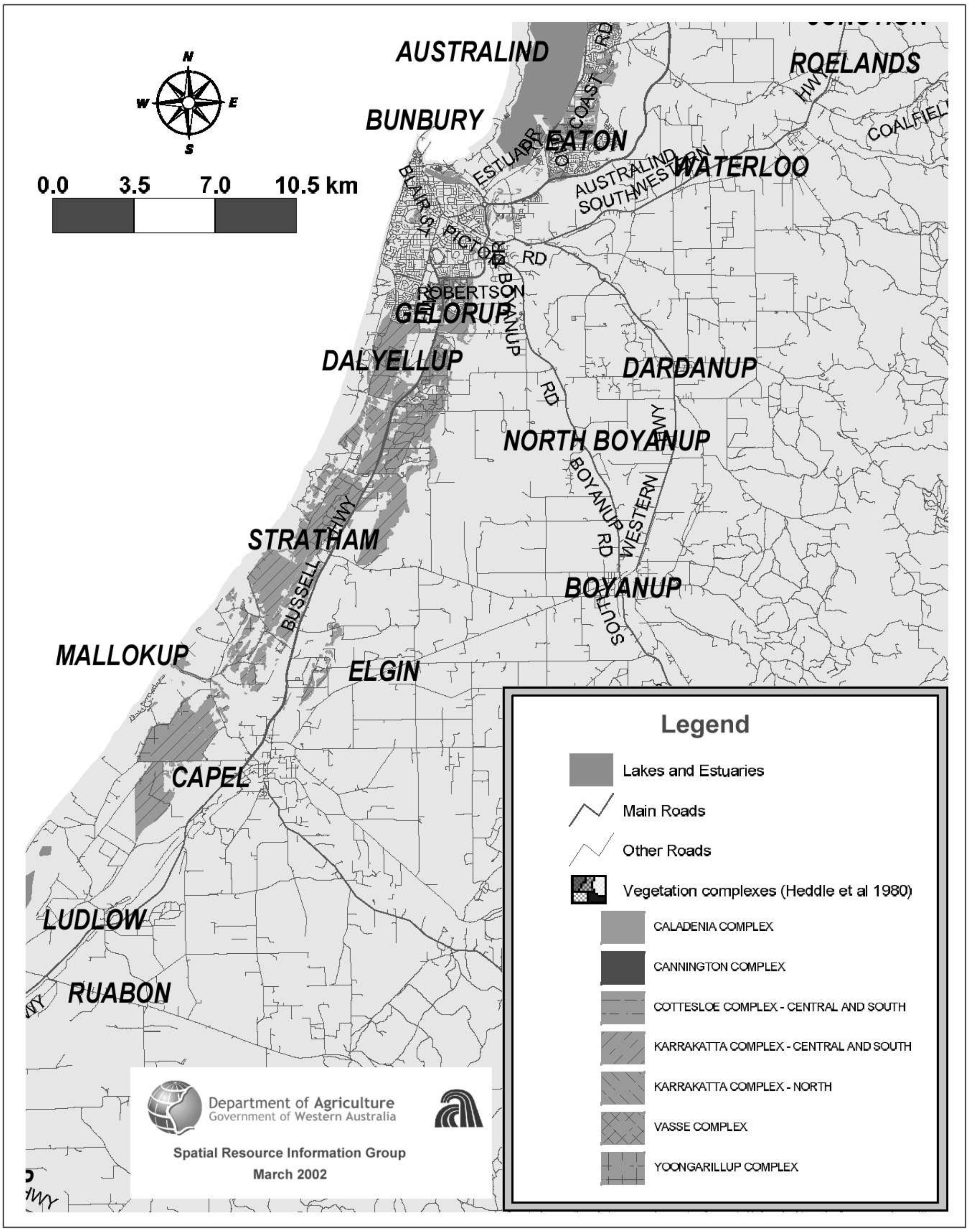
Map 3d.


MANDURAH
FALCON
DAWESVILLE
BOUVARD
CLIFTON
LAKE CLIFTON
PRESTON BEACH
YUNDERUP
PINJARRA
FREMANTLE
PINJARRA
OLD COAST RD
PINJARRA RD
SOUTH WESTERN
WILLIAMS
BUNBURY
OLD BUNBURY RD
OLD COAST RD
N
S
E
W
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
0.0 3.5 7.0 10.5 km
Legend
Lakes and Estuaries
Main Roads
Other Roads
Vegetation complexes (Heddle et al 1980)
CALADENIA COMPLEX
CANNINGTON COMPLEX
COTTESLOE COMPLEX - CENTRAL AND SOUTH
KARRAKATTA COMPLEX - CENTRAL AND SOUTH
KARRAKATTA COMPLEX - NORTH
VASSE COMPLEX
YOONGARILLUP COMPLEX

Map 3e.


Legend
Lakes and Estuaries
Main Roads
Other Roads
Vegetation complexes (Heddle et al 1980)
CALADENIA COMPLEX
CANNINGTON COMPLEX
COTTESLOE COMPLEX - CENTRAL AND SOUTH
KARRAKATTA COMPLEX - CENTRAL AND SOUTH
KARRAKATTA COMPLEX - NORTH
VASSE COMPLEX
YOONGARILLUP COMPLEX
N
S
E
W
MYALUP
WOKALUP
MARBALUP
LESCHENAULT
BRUNSWICK JUNCTION
AUSTRALIND
ROELANDS
BUNBURY
EATON
WATERLOO
OLD COAST RD
SOUTH WESTERN HWY
BYPASS
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
0.0
3.5
7.0
10.5 km

Map 3f.


N
W
E
S
0.0
3.5
7.0
10.5 km
AUSTRALIND
ROELANDS
BUNBURY
EATON
WATERLOO
COALFIEL
HWY
ESTUARY
COAST
RD
AUSTRALIND
SOUTH WESTERN
BLAIR ST
PICTON
RD
ROBERTSON
GELORUP
BOYANUP
DALYELLUP
DARDANUP
NORTH BOYANUP
BOYANUP
RD
WESTERN
HWY
STRATHAM
BUSSELL
HWY
BOYANUP
SOUTH
MALLOKUP
ELGIN
CAPEL
LUDLOW
RUABON
Legend
Lakes and Estuaries
Main Roads
Other Roads
Vegetation complexes (Heddle et al 1980)
CALADENIA COMPLEX
CANNINGTON COMPLEX
COTTESLOE COMPLEX - CENTRAL AND SOUTH
KARRAKATTA COMPLEX - CENTRAL AND SOUTH
KARRAKATTA COMPLEX - NORTH
VASSE COMPLEX
YOONGARILLUP COMPLEX
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002

Map 3g.

MAPS 4a to l. Bushland areas with natural populations of Tuart (see Table 4)

Key

See Map Legend for symbols

Lakes and Estuaries
GIS database of Lakes and Estuaries supplied by DOLA.

Main Roads/Other Roads
GIS database of Main Roads and Other Roads supplied by DOLA.

Bushland areas with natural populations of Tuart (after Table 4)
The boundaries of the Tuart Areas are approximate, they are not corrected to cadastre.

Column 1 Tuart Area Number
The areas are listed from north to south between Jurien and Busselton. Only those populations in areas with some level of protection or proposed protection are mapped and numbered.

Column 2 Map 4a to 4l

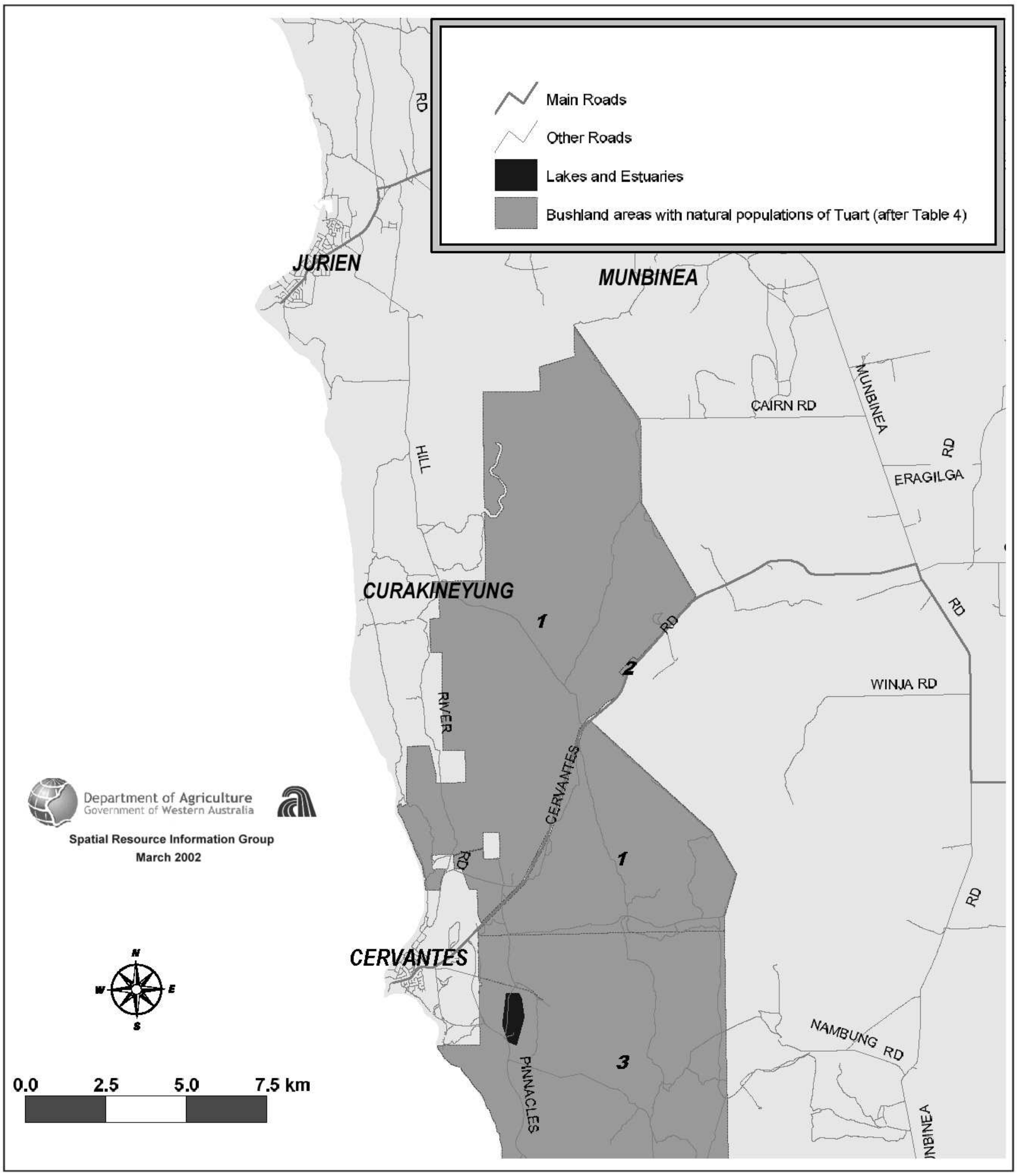
Column 3 Population/Bushland Area Name
Bush Forever Site numbers (Gov of WA 2000) and System Recommendation numbers (DCE 1976 and 1983) are given in brackets when applicable.

Mapped Tuart Area No	Map 4 No	Area Name (Bush Forever/System Area codes)
1	a	Southern Beekeepers Nature Reserve (3 large populations recorded)
2	a	'Cervantes Tuart Reserve' (Reserves 39400/41008, east of Cervantes)
3	a/b	Nambung National Park
4	b/c	Wangarren Nature Reserve
5	c	Bashford Nature Reserve
6	c	Nilgen Nature Reserve
7	d	Seabird UCL
8	d	Moore River Point Reserve (Reserves 21473 and 17949)
9	d	Wilbinga-Caraban Bushland (406)
10	d/e	Ningana Bushland, Yanchep/Eglington (289)
11	d/e	Yanchep National Park and Adjacent Bushland (288/M3)
12	f	Trigg Bushland and Adjacent Coastal Reserve, Trigg/Scarborough (308/M36)
13	f	Swanbourne Bushland, Swanbourne/City Beach (315/M46)
14	g	Woodman Point, Coogee/Munster (341/M90)
15	g/h	Lake Cooloongup, Lake Walyungup and Adjacent Bushland (356/M103)
16	h	Port Kennedy (377/M106)
17	d/e	South-West Link from Wilbinga to Yanchep National Park (284/M1)
18	d/e	East Link from Wilbinga to Yanchep National Park (396)
19	d/e	Ridges and Adjacent Bushland, Yanchep/Nowergup (381/M4)
20	d/e	State Forest 65 — Pinjar Plantation Central Bushland, Yanchep (1, 408 -11, 414 -15)
21	e	Bernard Road Bushland, Carabooda (129)
22	e	Link between Yanchep and Neerabup National Parks (130)
23	e	Hopkins Road Bushland, Nowergup (290)

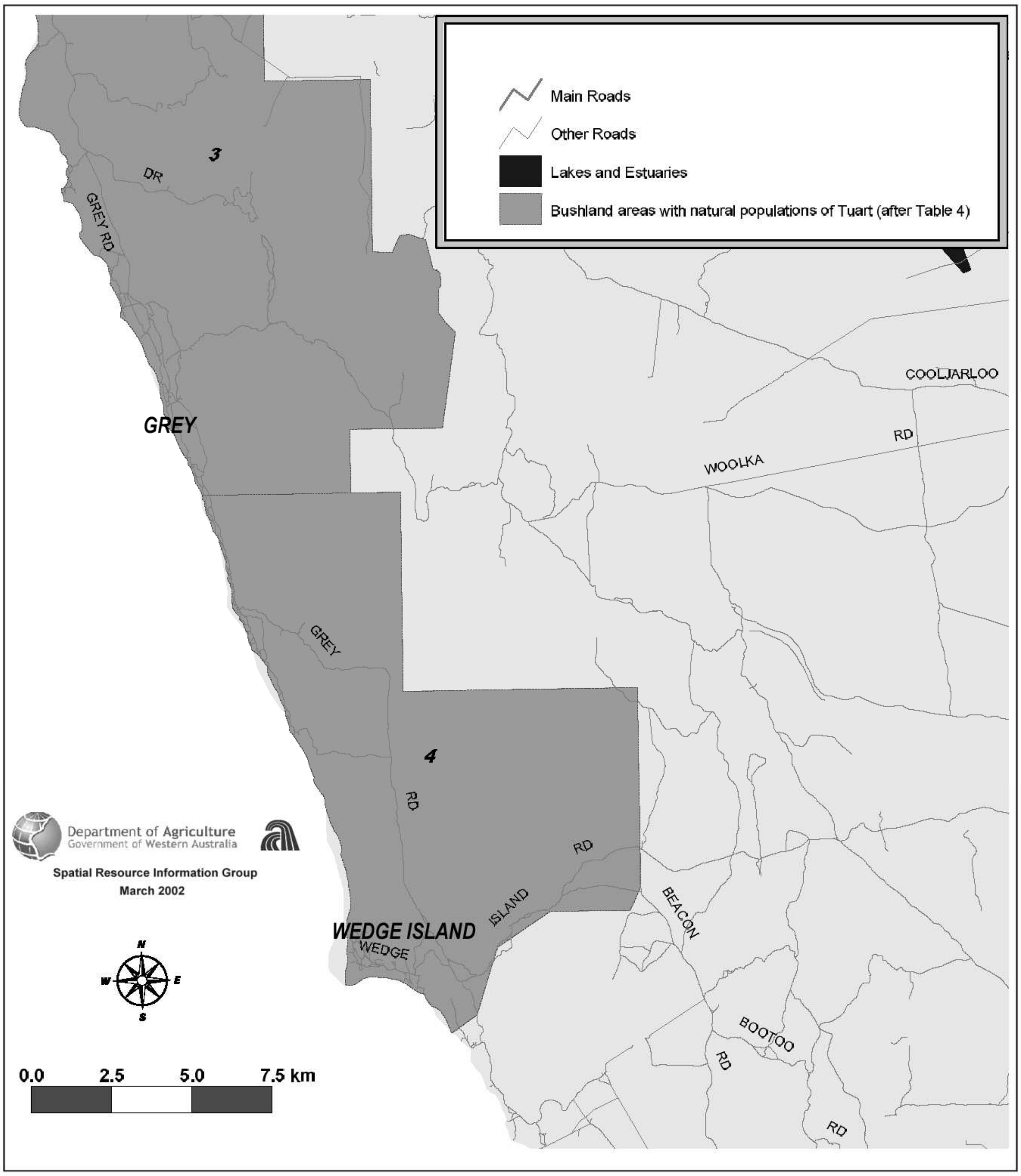
Mapped Tuart Area No	Map 4 No	Area Name (Bush Forever/System Area codes)
24	e	Neerabup National Park, Lake Gnowergup Nature Reserve and adj. Bushland (383/M6)
25	e	Burns Beach Bushland (322/M2)[1]
26	e	Neerabup Lake and Adjacent Bushland, Neerabup (384/M6)
27	e	Shire View Hill and Adjacent Bushland, Nowergup/Neerabup (293)
28	e	West Flynn Drive Bushland, Carramar (494)
29	e	Flynn Drive Bushland, Neerabup (295/M8)
30	e/f	Yellagonga Regional Park, Wanneroo/Woodvale/Kingsley (299/M7)
31	e	Conti Road Bushland, Wanneroo (164)
32	e	Caporn Street Bushland, Mariginiup (469)
33	e	Garden Park Bushland, Wanneroo (470)
34	e	High Road Bushland, Wanneroo (471)
35	e/f	Woodvale Nature Reserve, Woodvale (407)
36	e/f	Whitfords Avenue Bushland, Craigie/Padbury 303/M7)
37	f	Shepherds Bush Reserve, Kingsley (39)
38	f	Warwick Open Space Conservation Area (202/M11)
39	f	Star Swamp Reserve and Adjacent Bushland, North Beach/Waterman (204/M35)
40	f	Carine Swamps, Carine (M37)
41	f	Lake Gwelup Reserve, Gwelup (212/M39)
42	f	Bold Park and Adjacent Bushland, City Beach (312/M47)
43	f	Underwood Avenue Bushland, Shenton Park (119)
44	f	Shenton Bushland, Shenton Park (218)
45	f	Kings Park (317/M49)
46	f	Lake Claremont, Claremont/Swanbourne (220/M48)
47	f	Sir Frederick Samson Park, Samson (59/M72)
48	g	Manning Lake and Adjacent Bushland, Hamilton Hill/Spearwood (247/M92)
49	g	Market Garden Swamps, Spearwood/Munster (429, 435/M92)
50	g	Lake Coogee and Adjacent Bushland, Munster (261/M92)
51	g	Yangebup and Little Rush Lakes, Yangebup (M93)
52	g	Brownman Swamp, Mt Brown Lake and Adjacent Bushland (346/M91/92)
53	g	Wattleup Lake and Adjacent Bushland, Wattleup/Mandogalup (393/M93)
54	g	Mandogalup Road Bushland, Mandogalup (268)
55	g	The Spectacles (269)
56	g	Sandy Lake and Adjacent Bushland, Anketell (270)
57	g	Mandogalup Road Bushland, Hope Valley (267)
58	g/h	Parmelia Avenue Bushland, Parmelia (67)
59	g/h	Leda and Adjacent Bushland, Leda (349/M104)
60	h	Cassia Drive Bushland, Karnup (278)
61	g/h	Baldivis Swamp and Adjacent Bushland (495)
62	h	Stakehill Swamp, Baldivis (275)
63	h	Churcher Swamp, Baldivis (75)
64	h	Baldivis Road Bushland, Baldivis (376)
65	h	Anstey Swamp, Karnup (379)
66	h	Paganoni Swamp and Adjacent Bushland, Karnup (395)
67	f	Peppermint Grove Foreshore (403)
68	f	Mount Henry Bushland, Salter Point (227)
69	g/h	Doghill Road Bushland, Baldivis (369)
70	g/h	Lowlands Bushland - Eastern Block, Peel Estate (368/M105)
71	g/h	Lowlands Bushland - Western Block (Hymus Swamp), Peel Estate (372/M105)

[1] The adjacent Bush Forever Site 323 contains Tuart populations. These are not listed in Gov of WA (2000).

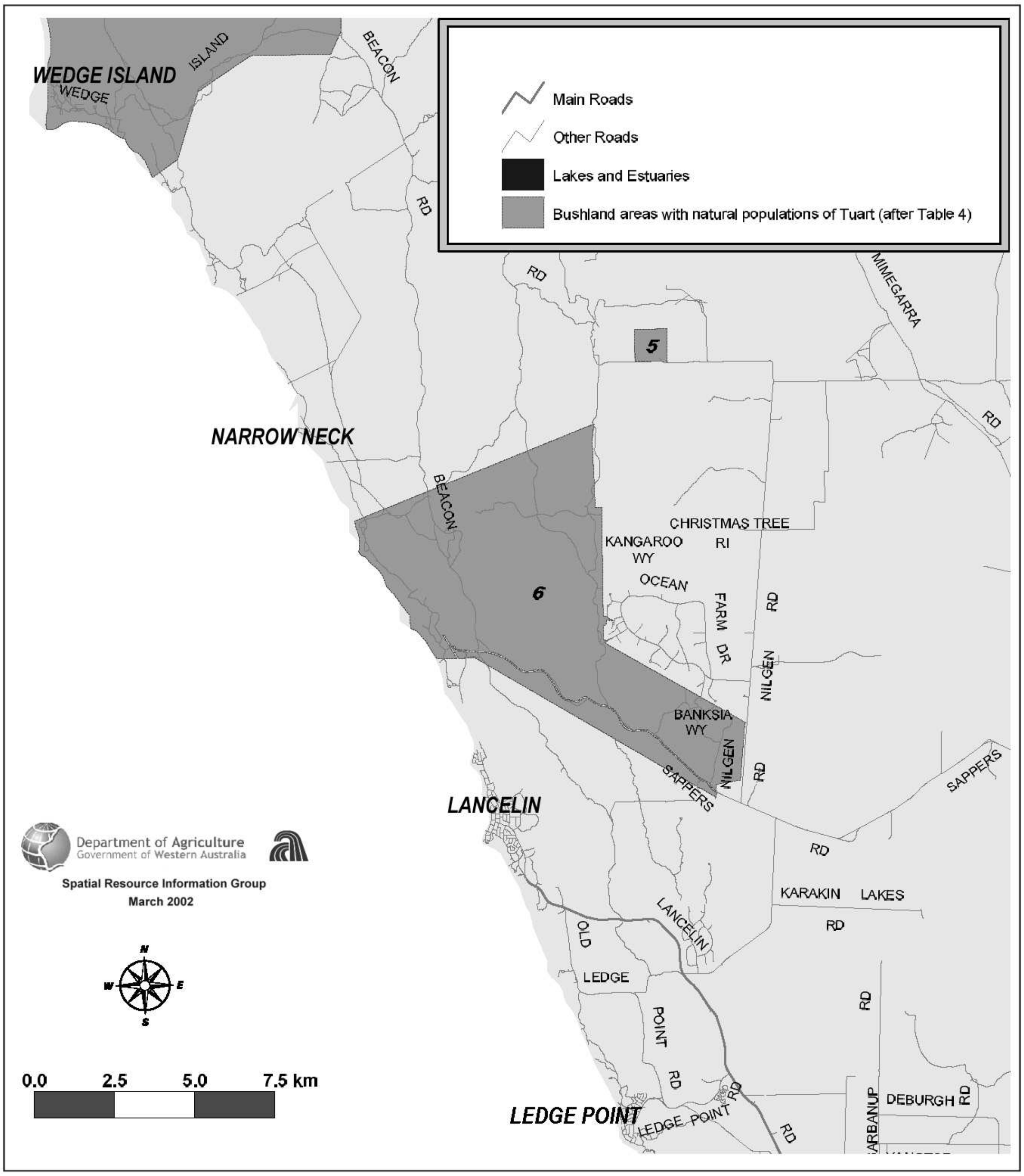
Mapped Tuart Area No	Map 4 No	Area Name (Bush Forever/System Area codes)
72	k	Leschenault Peninsular Conservation Park (C66)
73	k/l	The Maidens (South Bunbury Coastal Land C70)
74	k/l	Coastal Dalyellup Proposed Regional Open Space
75	i	Reserve 860 (part C51)
76	i	Carrabunyup Nature Reserve (part C50)
77	i	Stony Point Reserve 27528 (C51)
78	i	Mealup Point Nature Reserve
79	i/j	Yalgorup National Park (C54)
80	i/j	Clifton Management Priority Area (C55)
81	j	McLarty Management Priority Area (C56)
82	j	Myalup Management Priority Area/Lyons Forest Block (C57)
83	j	Crampton Nature Reserve (C61)
84	j/k	Myalup Swamp/Mialla Lagoon (C63)
85	k/l	'Shearwater Tuart Forest'
86	k/l	College Grove Bushland proposed ROS
87	k/l	Dalyellup Reserve (Reserves Near Dalyellup C71)
88	l	Tuart Forest Reserve (part System recommendation 1.1 (DCE 1978))
89	i	Harvey River Reserve (Res 13987)


Main Roads
Other Roads
Lakes and Estuaries
Bushland areas with natural populations of Tuart (after Table 4)
JURIEN
MUNBINEA
CAIRN RD
MUNBINEA
ERAGILGA
RD
HILL
CURAKINEYUNG
1
2
RD
WINJA RD
RIVER
CERVANTES
1
CERVANTES
3
NAMBUNG RD
PINNACLES
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
N
W
E
S
0.0
2.5
5.0
7.5 km

Map 4a.

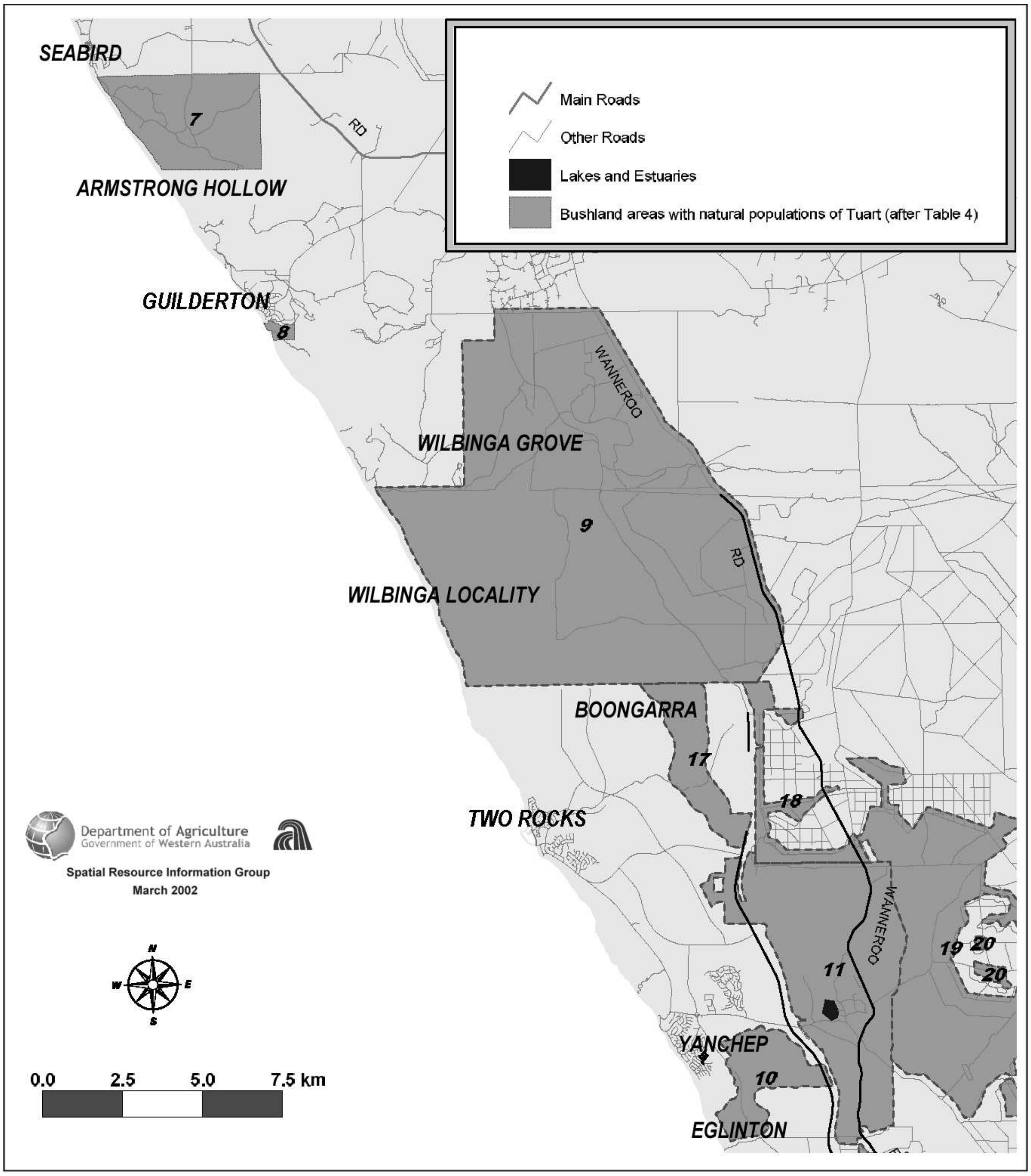

Main Roads
Other Roads
Lakes and Estuaries
Bushland areas with natural populations of Tuart (after Table 4)
3
DR
GREY RD
GREY
COOLJARLOO
RD
WOOLKA
GREY
4
RD
RD
ISLAND
BEACON
WEDGE ISLAND
WEDGE
BOOTOO
RD
RD
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
N
W
E
S
0.0
2.5
5.0
7.5 km

Map 4b.

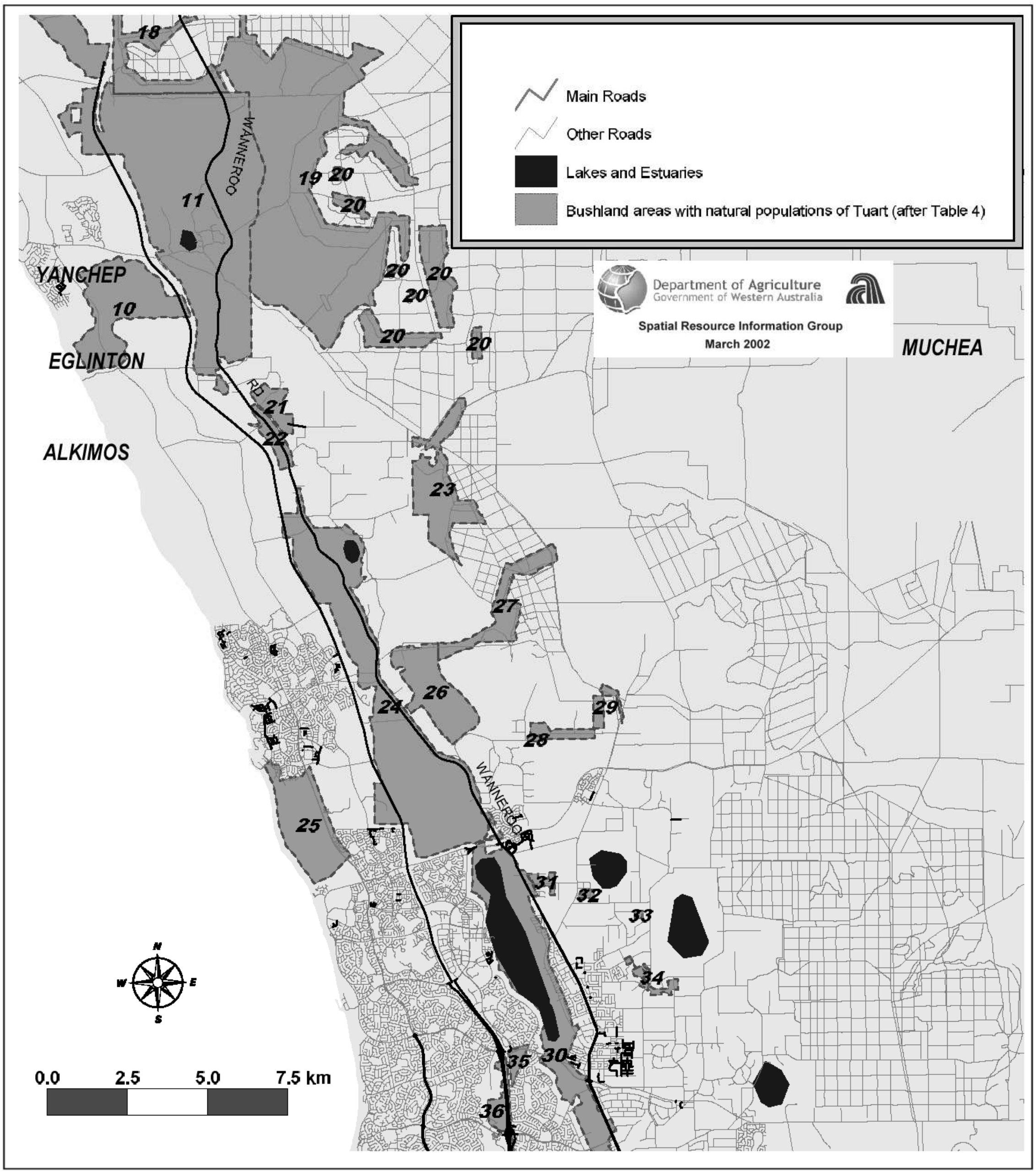


Main Roads
Other Roads
Lakes and Estuaries
Bushland areas with natural populations of Tuart (after Table 4)
WEDGE ISLAND
WEDGE
ISLAND
BEACON
RD
MIMEGARRA
5
NARROW NECK
6
CHRISTMAS TREE
KANGAROO
WY
RI
OCEAN
FARM
DR
NILGEN
BANKSIA
WY
SAPPERS
LANCELIN
KARAKIN
LAKES
OLD
LEDGE
POINT
LEDGE POINT
DEBURGH
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
N
E
S
W
0.0
2.5
5.0
7.5 km

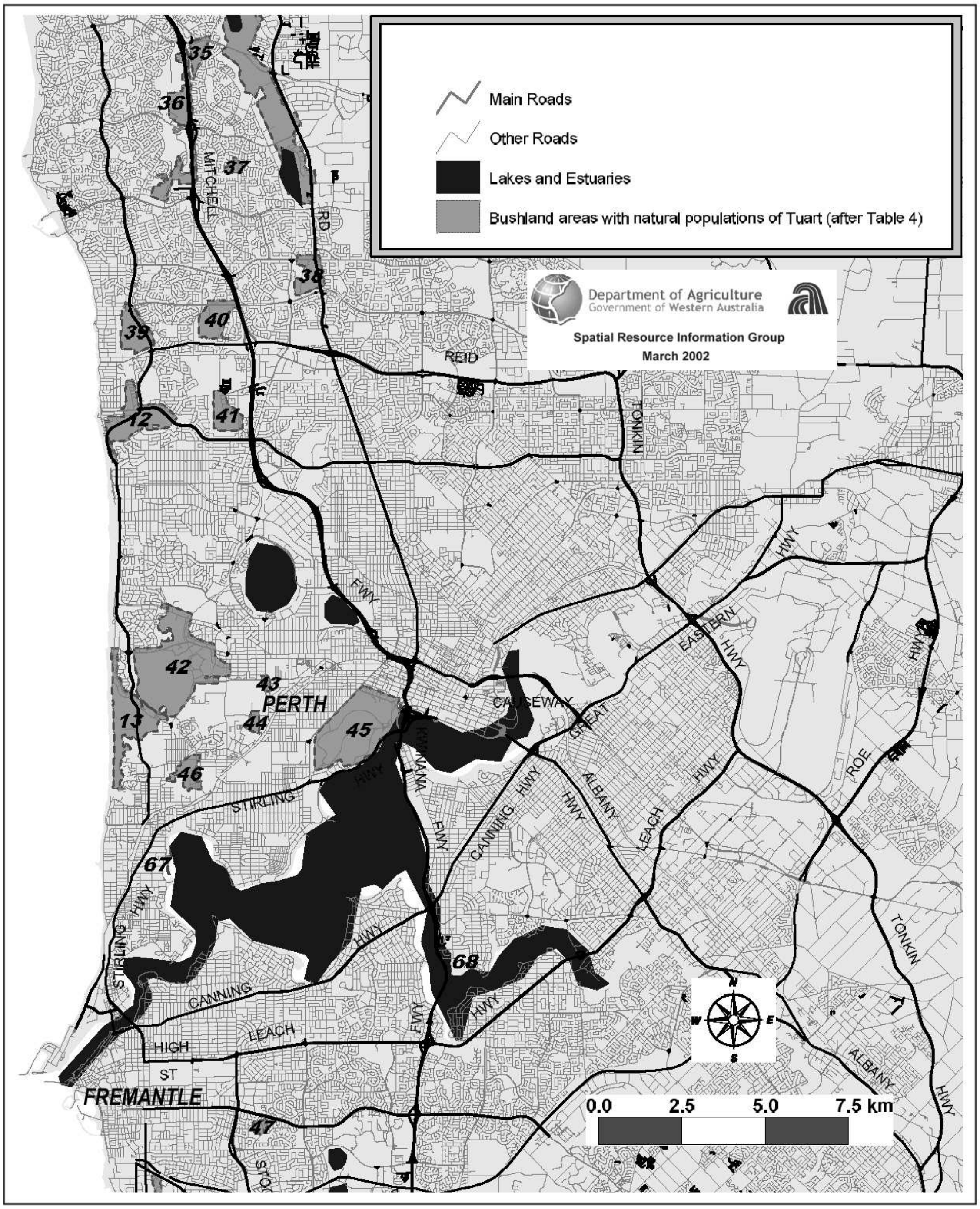
Map 4c.


Main Roads
Other Roads
Lakes and Estuaries
Bushland areas with natural populations of Tuart (after Table 4)
SEABIRD
7
ARMSTRONG HOLLOW
GUILDERTON
8
WILBINGA GROVE
9
WILBINGA LOCALITY
WANNEROO RD
BOONGARRA
17
18
TWO ROCKS
11
19
20
YANCHEP
10
EGLINTON
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
N
E
S
W
0.0
2.5
5.0
7.5 km

Map 4d.

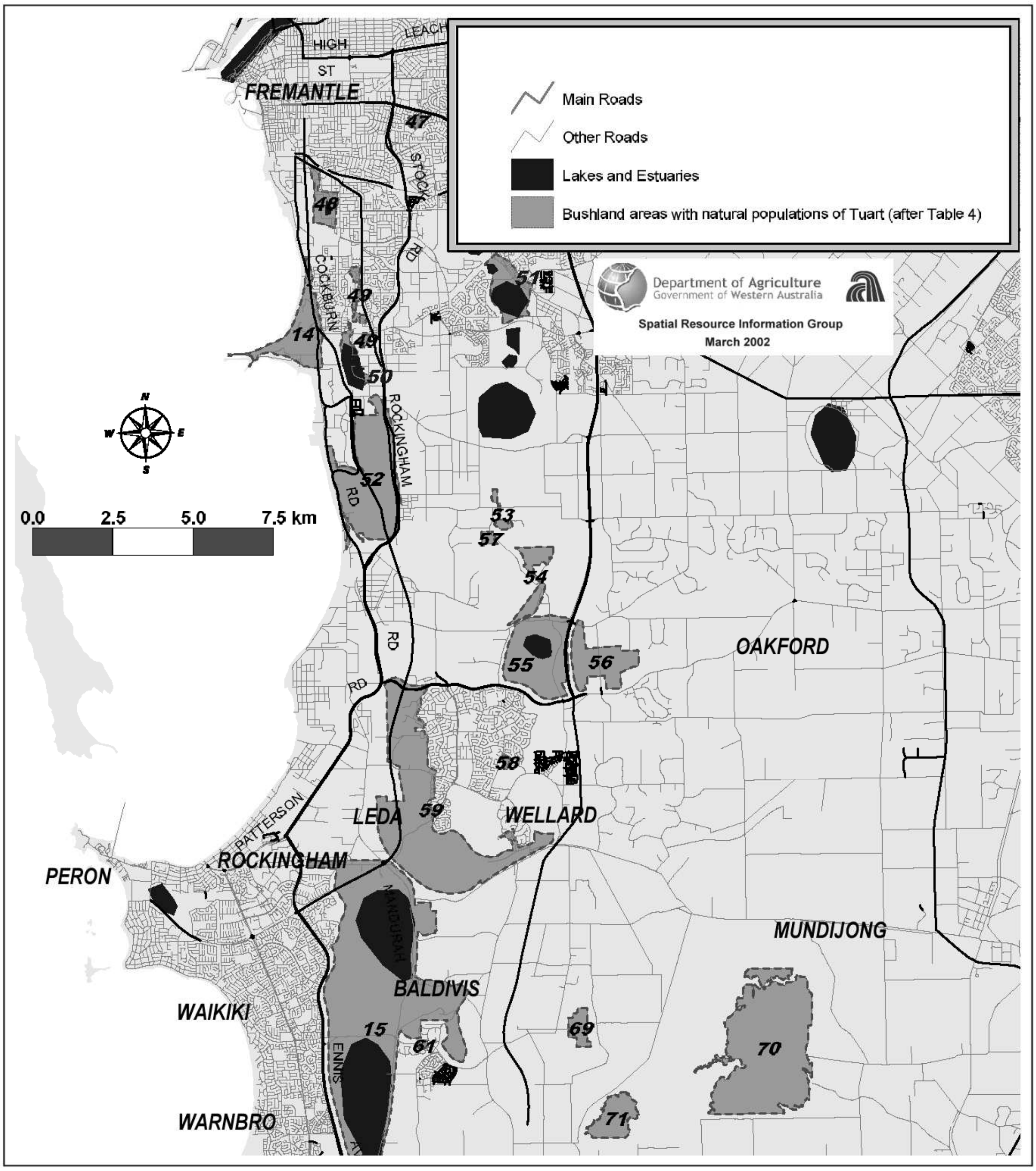

Main Roads
Other Roads
Lakes and Estuaries
Bushland areas with natural populations of Tuart (after Table 4)
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
YANCHEP
EGLINTON
ALKIMOS
MUCHEA
WANNEROO
RD
0.0
2.5
5.0
7.5 km
N
S
E
W
10
11
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36

Map 4e.

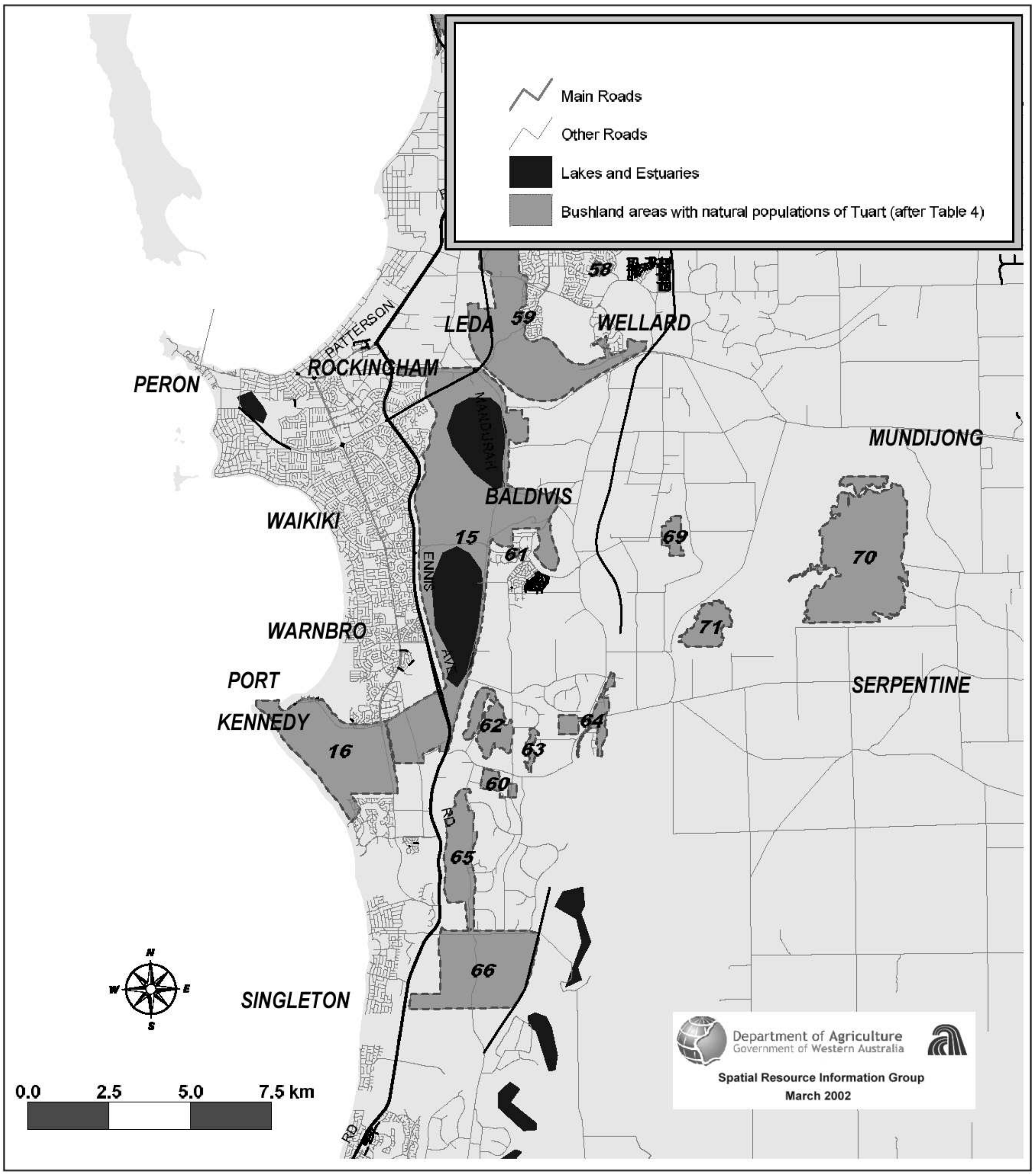


Main Roads
Other Roads
Lakes and Estuaries
Bushland areas with natural populations of Tuart (after Table 4)
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
PERTH
FREMANTLE
0.0 2.5 5.0 7.5 km

Map 4f.

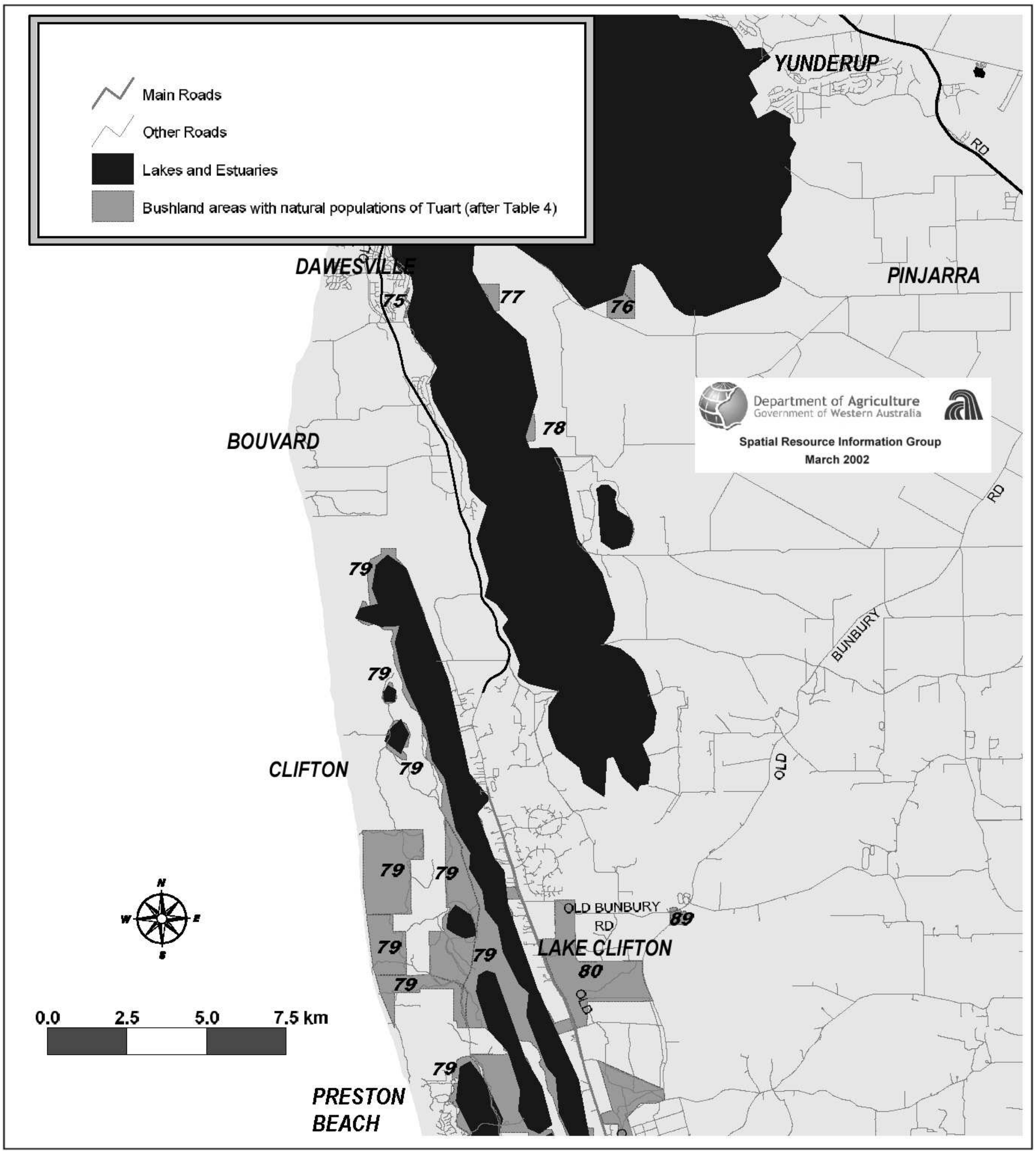

Main Roads
Other Roads
Lakes and Estuaries
Bushland areas with natural populations of Tuart (after Table 4)
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
0.0 2.5 5.0 7.5 km
FREMANTLE
OAKFORD
LEDA
WELLARD
ROCKINGHAM
PERON
MUNDIJONG
BALDIVIS
WAIKIKI
WARNBRO

Map 4g.

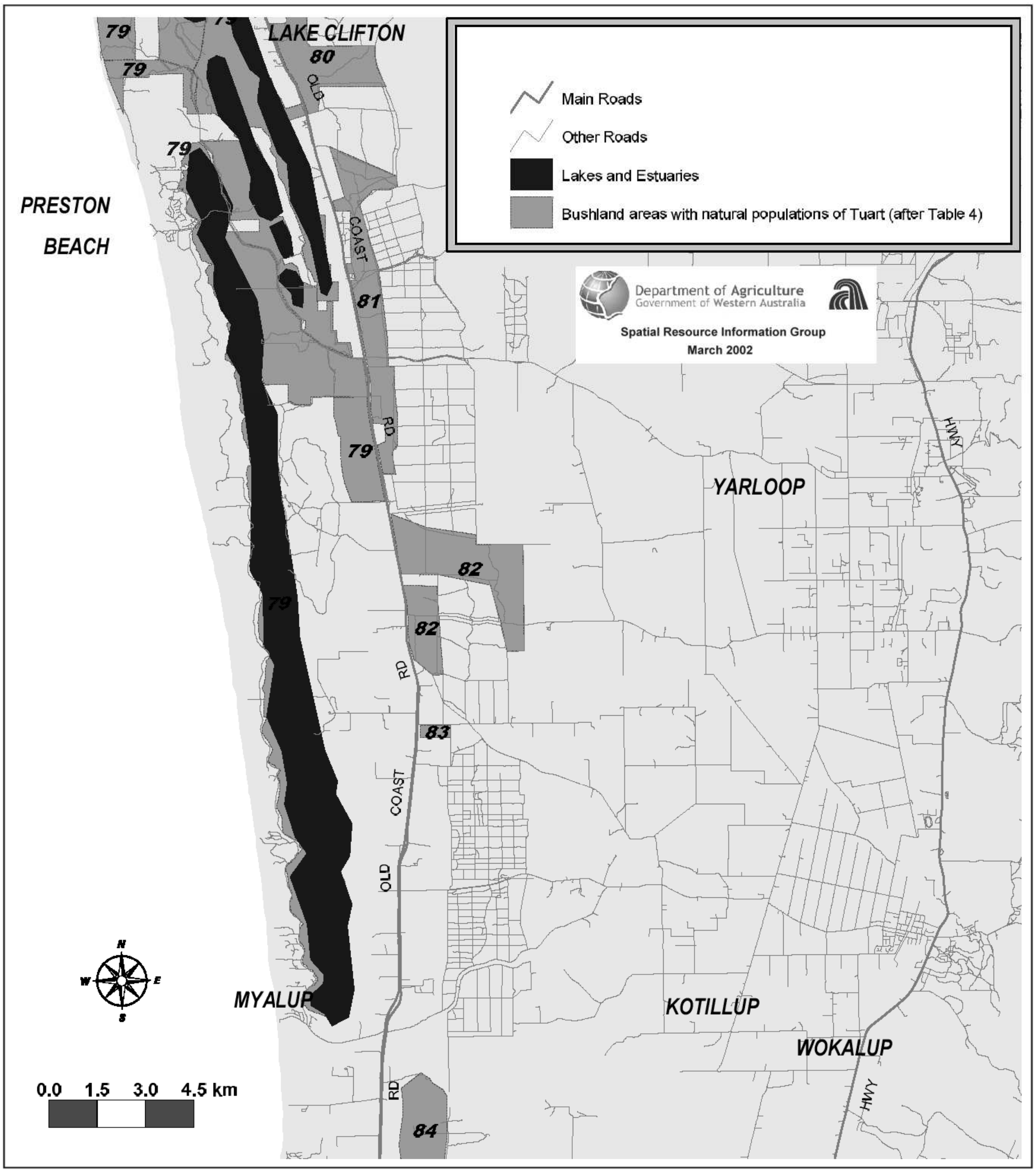


Main Roads
Other Roads
Lakes and Estuaries
Bushland areas with natural populations of Tuart (after Table 4)
PERON
ROCKINGHAM
PATTERSON
LEDA
WELLARD
MUNDIJONG
BALDIVIS
WAIKIKI
WARNBRO
PORT
KENNEDY
SERPENTINE
SINGLETON
ENNIS
AVE
RD
58
59
15
61
69
70
71
16
62
63
64
60
65
66
N
S
E
W
0.0
2.5
5.0
7.5 km
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002

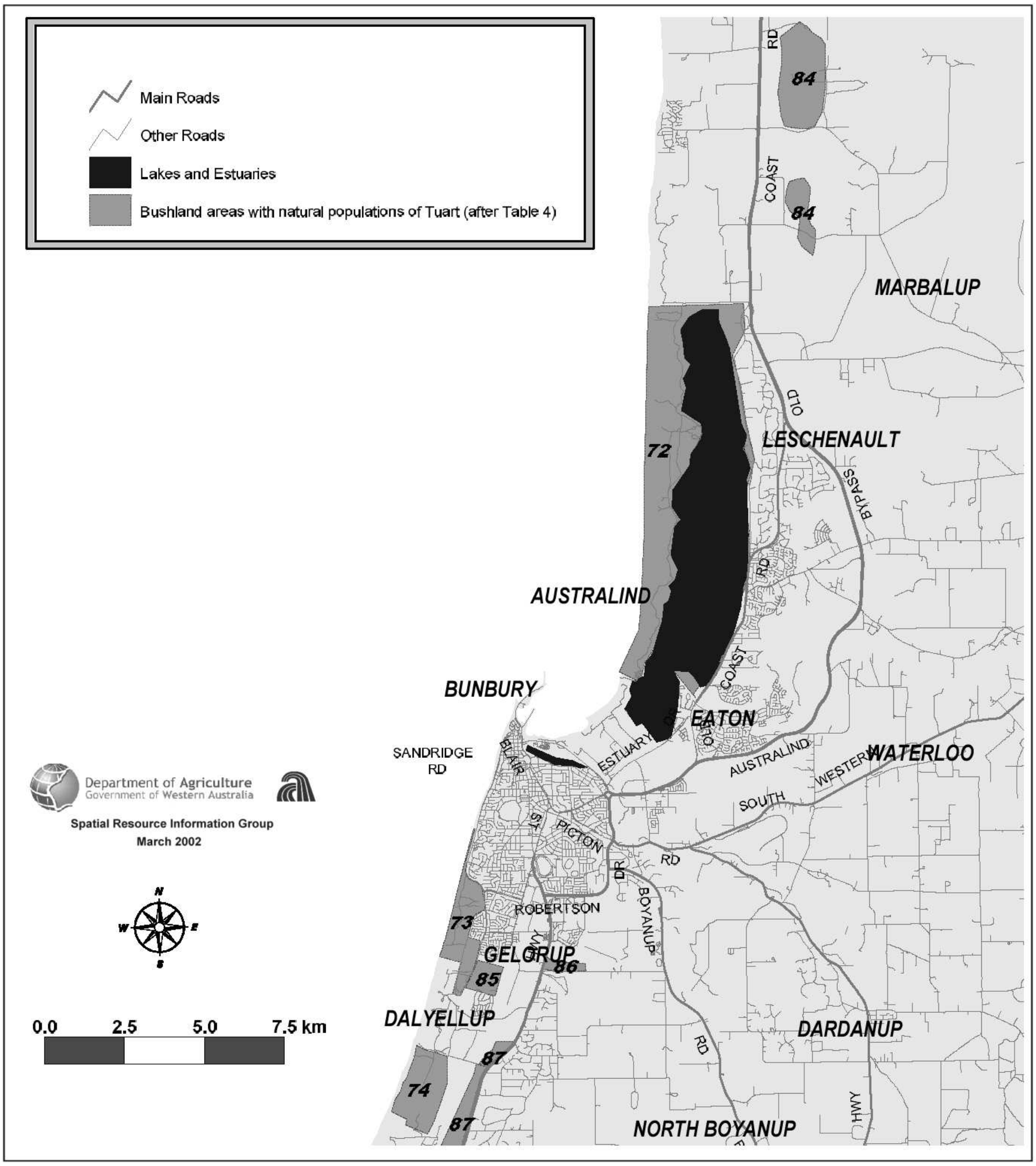
Map 4h.


Main Roads
Other Roads
Lakes and Estuaries
Bushland areas with natural populations of Tuart (after Table 4)
YUNDERUP
PINJARRA
DAWESVILLE
BOUVARD
CLIFTON
LAKE CLIFTON
PRESTON
BEACH
OLD BUNBURY
RD
BUNBURY
OLD
RD
75
76
77
78
79
80
89
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
0.0
2.5
5.0
7.5 km

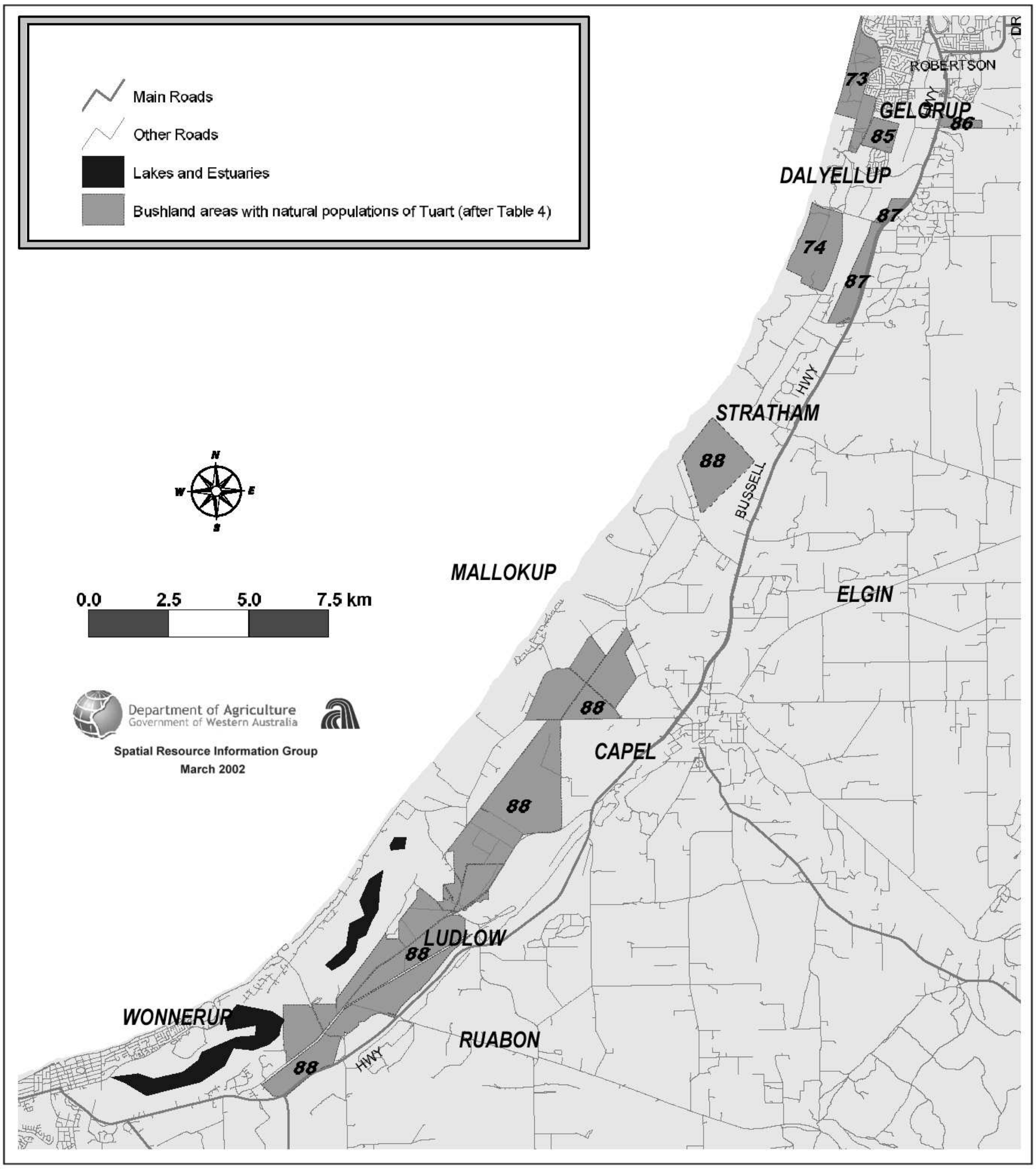
Map 4i.


Main Roads
Other Roads
Lakes and Estuaries
Bushland areas with natural populations of Tuart (after Table 4)
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
LAKE CLIFTON
PRESTON
BEACH
YARLOOP
MYALUP
KOTILLUP
WOKALUP
OLD COAST RD
HWY
79
80
81
82
83
84
N
S
E
W
0.0 1.5 3.0 4.5 km

Map 4j.


Main Roads
Other Roads
Lakes and Estuaries
Bushland areas with natural populations of Tuart (after Table 4)
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
0.0 2.5 5.0 7.5 km
MARBALUP
LESCHENAULT
AUSTRALIND
BUNBURY
EATON
WATERLOO
SANDRIDGE RD
GELORUP
DALYELLUP
DARDANUP
NORTH BOYANUP
ROBERTSON
72
73
74
84
85
86
87

Map 4k.


Main Roads
Other Roads
Lakes and Estuaries
Bushland areas with natural populations of Tuart (after Table 4)
0.0 2.5 5.0 7.5 km
Department of Agriculture
Government of Western Australia
Spatial Resource Information Group
March 2002
ROBERTSON
GELORUP
DALYELLUP
STRATHAM
MALLOKUP
ELGIN
CAPEL
LUDLOW
WONNERUP
RUABON
BUSSELL
HWY
73
85
86
87
74
88

Map 4l.

MAPS 5 – 16. Maps of the distribution of the floristic community types containing Tuart on the Southern Swan Coastal Plain (after Table 3)

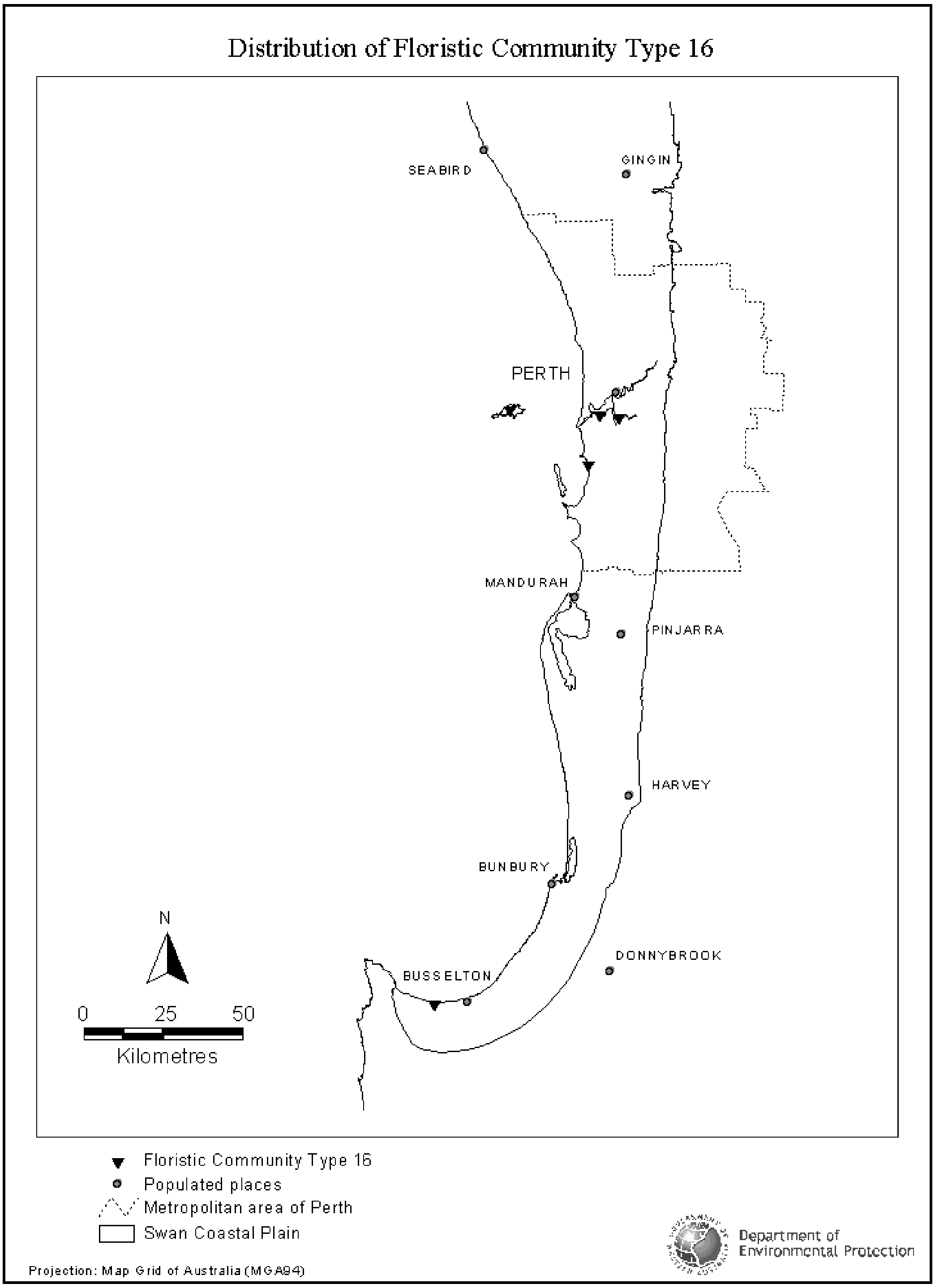
Key

See Map Legend for symbols

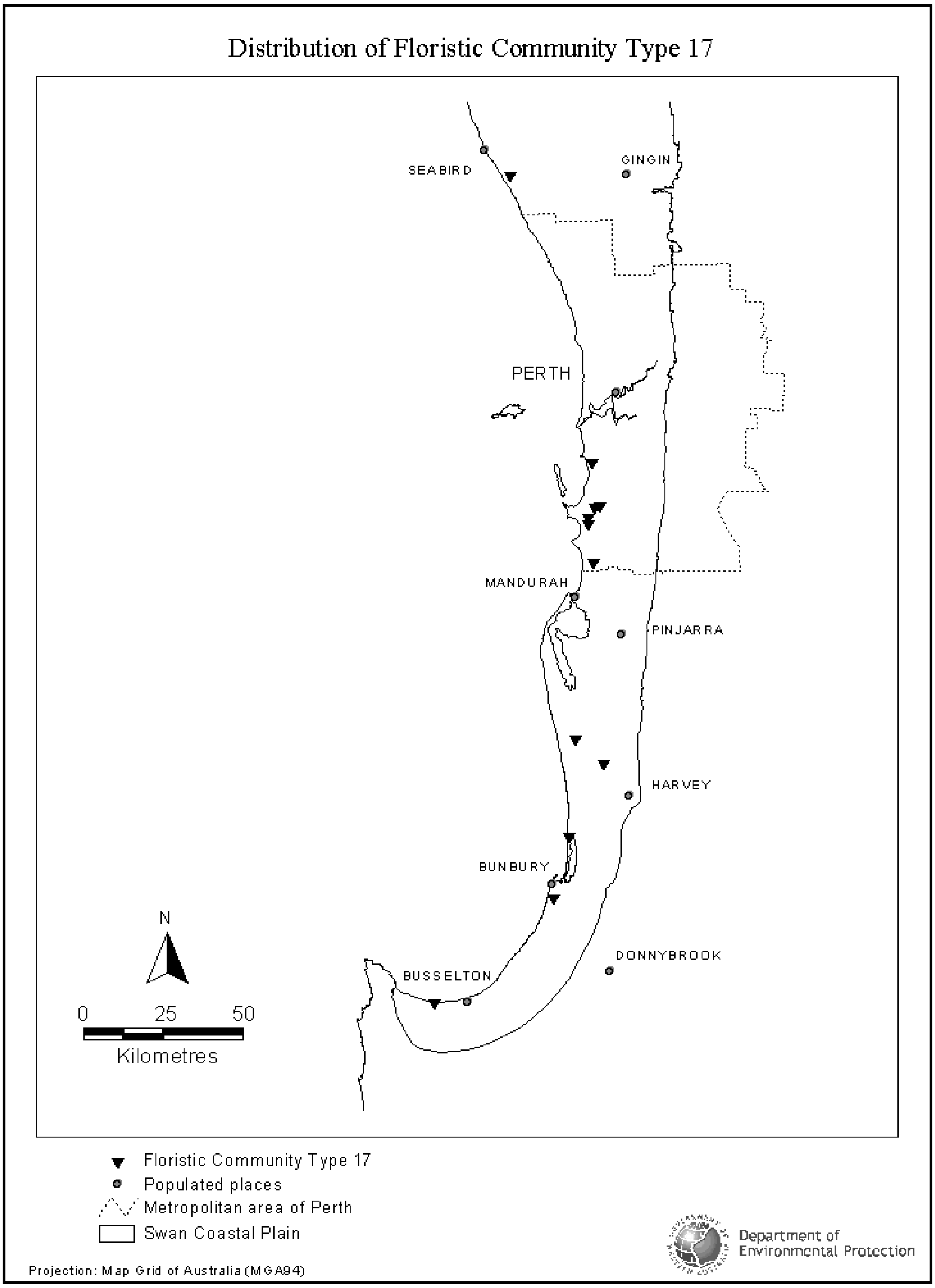
Plot Locations
Locations of all 10 m x 10 m plots identified in 12 of the floristic community types that contain Tuart. The map for floristic community type S15 is not included as this group is of uncertain affinities due to the presence of a significant number of weeds.

Floristic community types and map numbers
Column 1 Map number
Column 2 Floristic community type number code
Column 3 General description of the floristic community type

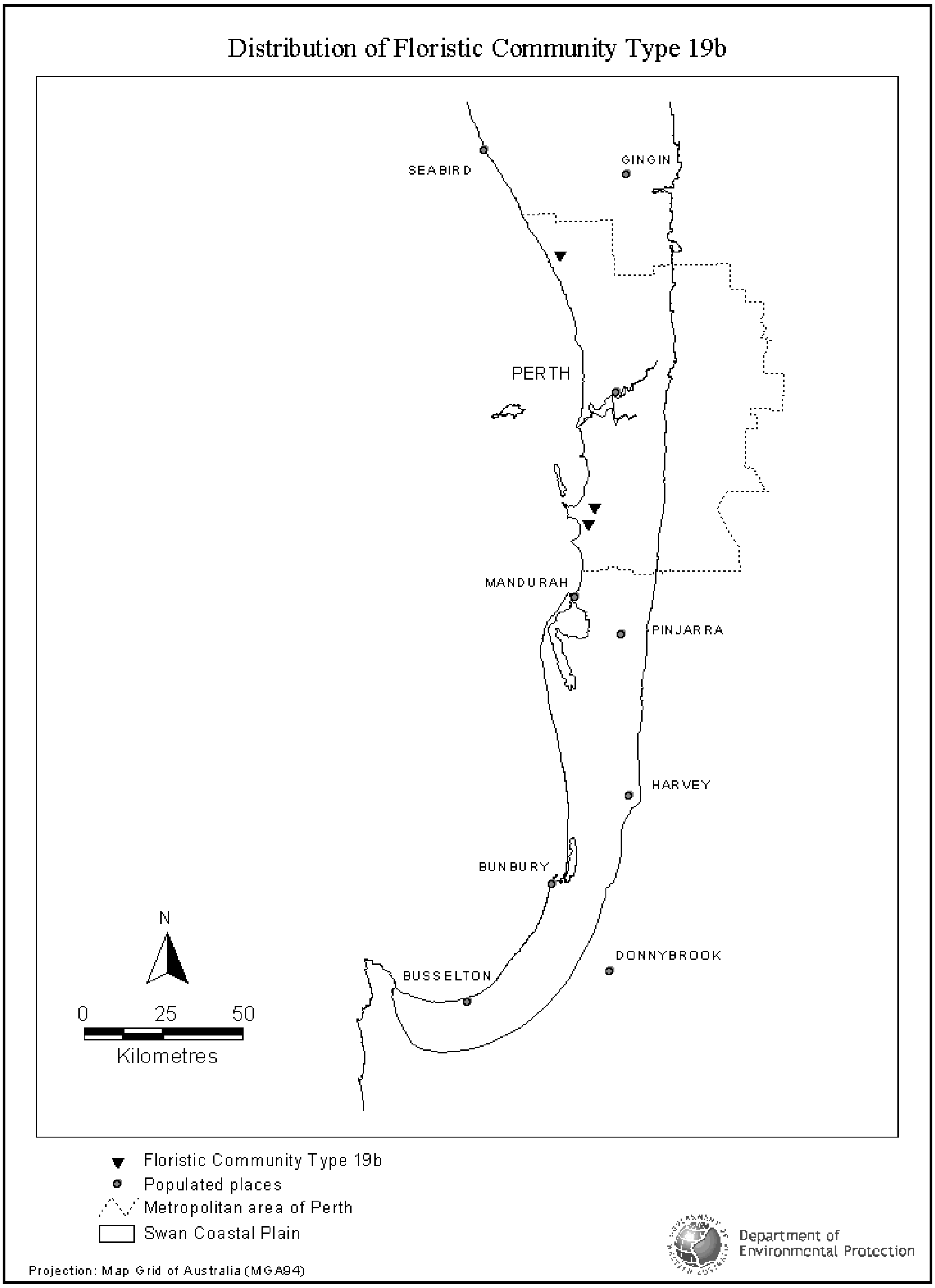
Map No.	FCT Code	Floristic Community Type Name (communities in which Tuart is a defining species are in bold)
Supergroup 2 - Seasonal Wetlands		
5	16	Highly saline seasonal wetlands
6	17	*Melaleuca rhaphiophylla* - *Gahnia trifida* seasonal wetlands
7	19b	Woodlands over sedgelands in Holocene dune swales
Supergroup 3 - Uplands centred on Bassendean Dunes		
8	21a	Central *Banksia attenuata* - *Eucalyptus marginata* woodlands
Supergroup 4 - Uplands centred on Spearwood and Quindalup Dunes		
Spearwood Dunes		
9	24	Northern Spearwood shrublands and woodlands
10	**25**	**Southern *Eucalyptus gomphocephala* – *Agonis flexuosa* woodlands**
11	26b	Woodlands and mallees on Limestone
12	28	Spearwood *Banksia attenuata* or *Banksia attenuata* - *Eucalyptus* woodlands
Quindalup Dunes		
13	29a	Coastal shrublands on shallow sands
14	**30b**	**Quindalup *Eucalyptus gomphocephala* and/or *Agonis flexuosa* woodlands**
15	30c2	Woodlands and shrublands on Holocene dunes (re-allocated from 30c and 30a Gibson *et al.* 1994)
16	S11	Northern *Acacia rostellifera* - *Melaleuca acerosa* shrublands



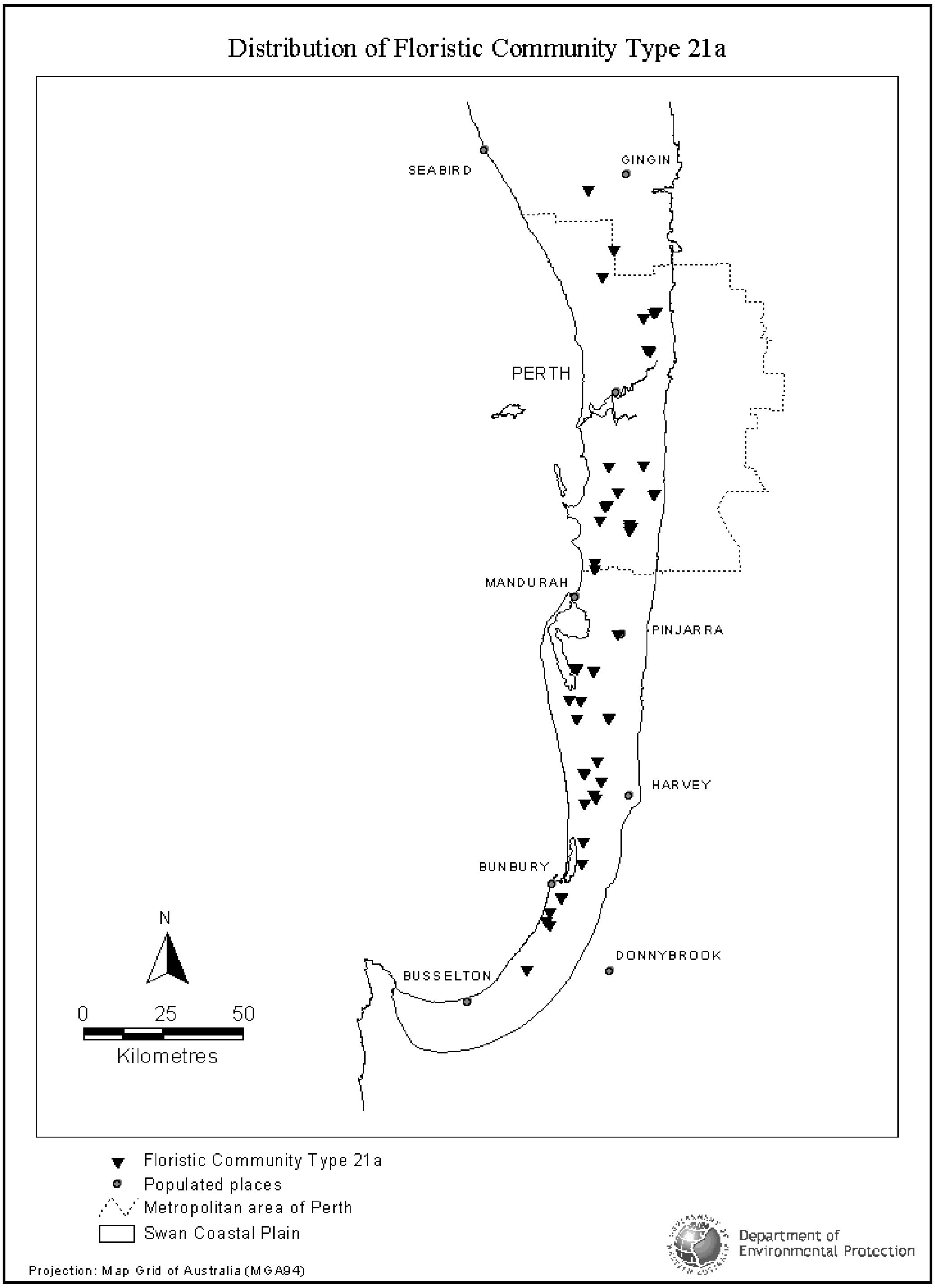
Map 5. Distribution of Floristic Community Type 16 on the Southern Swan Coastal Plain.



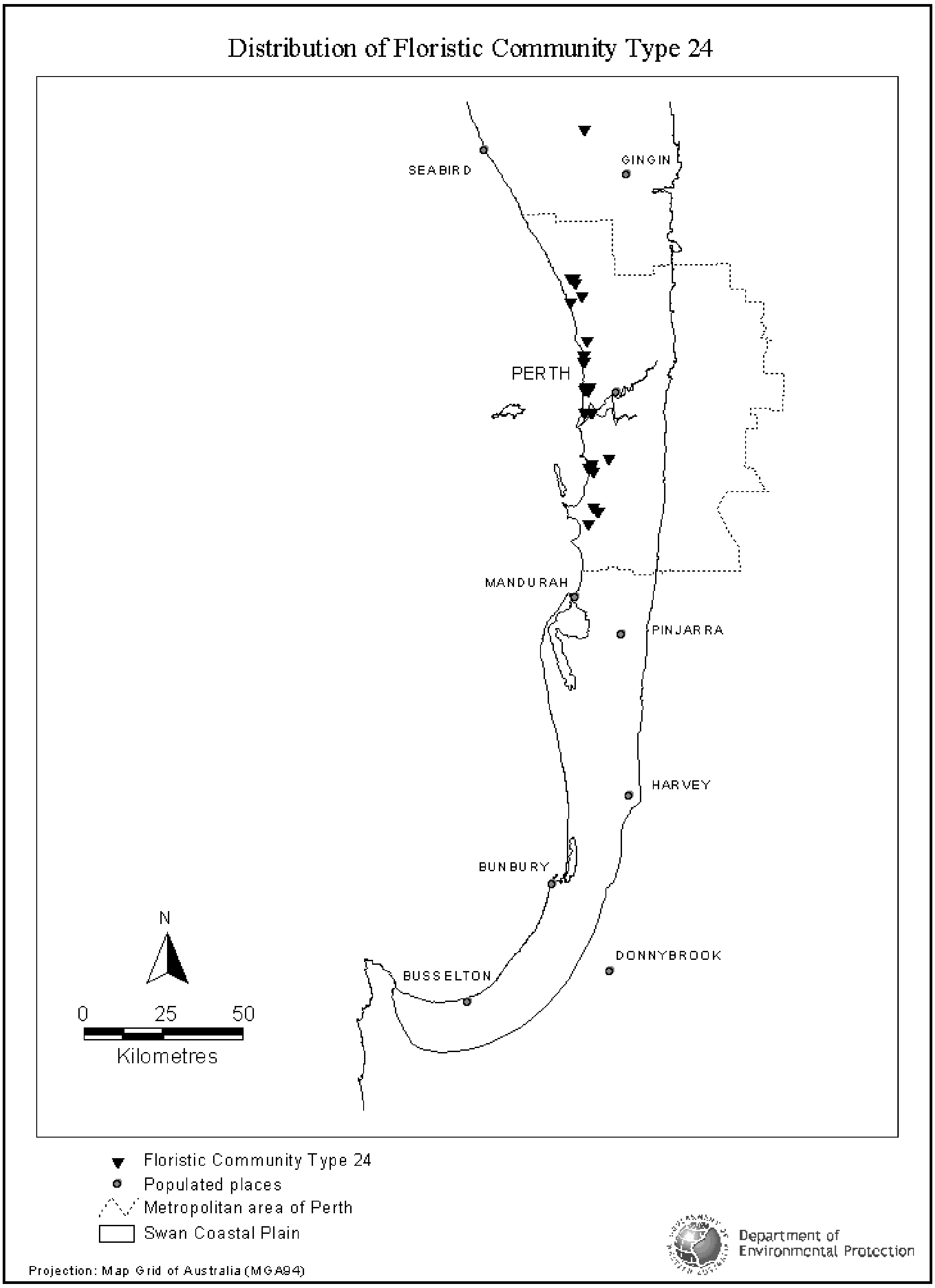
Map 6. Distribution of Floristic Community Type 17 on the Southern Swan Coastal Plain.



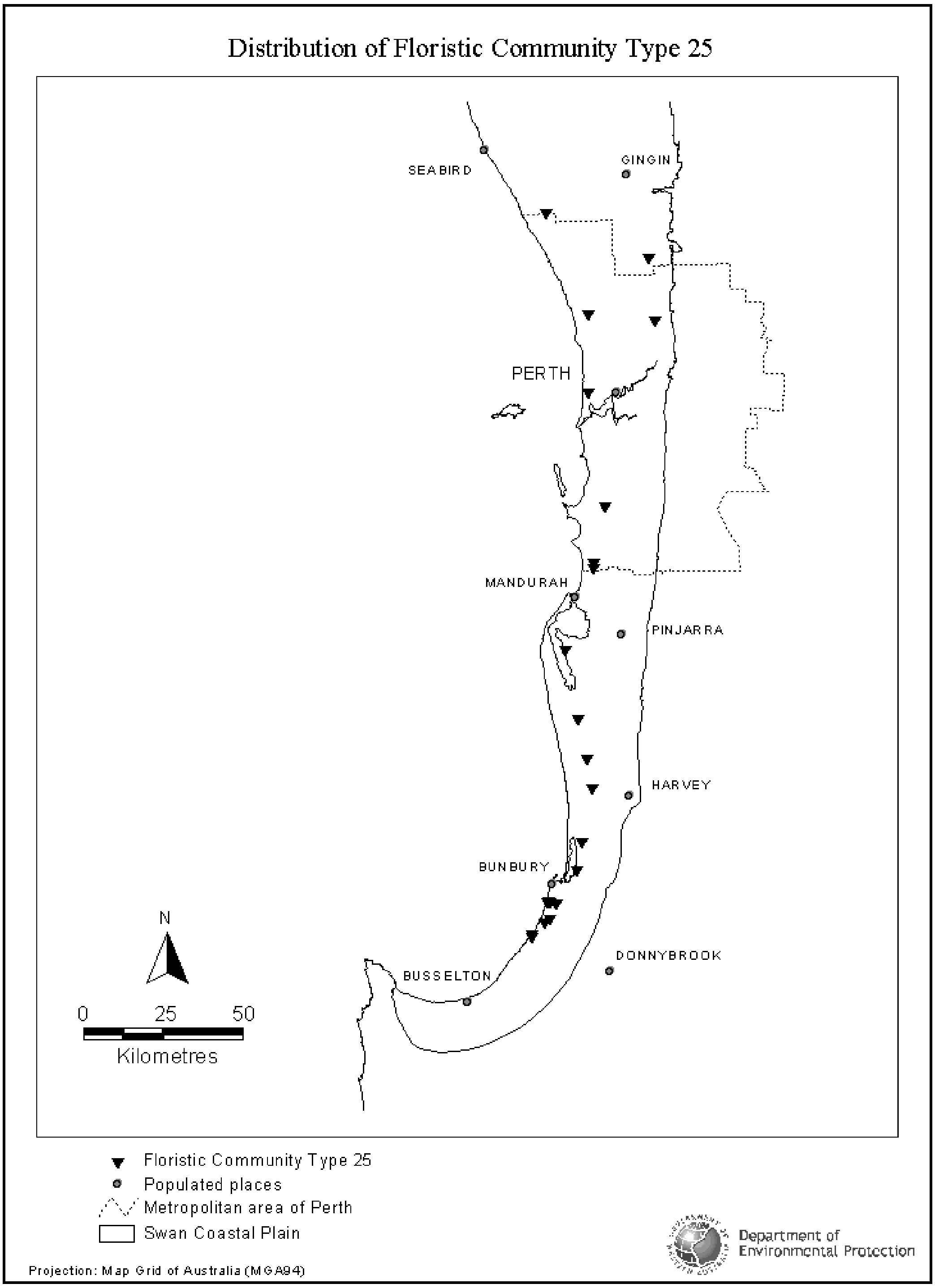
Map 7. Distribution of Floristic Community Type 19b on the Southern Swan Coastal Plain.



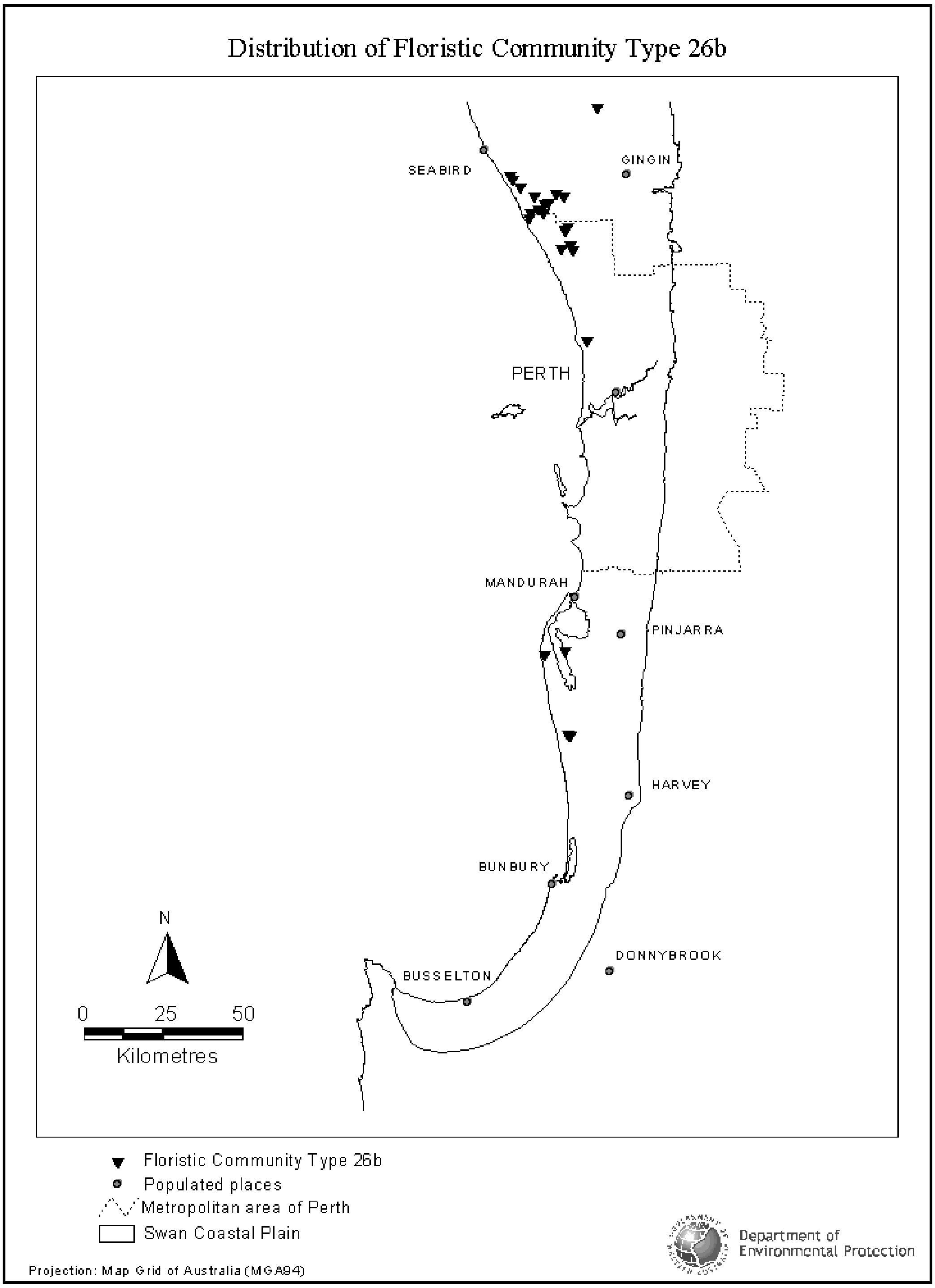
Map 8. Distribution of Floristic Community Type 21a on the Southern Swan Coastal Plain.



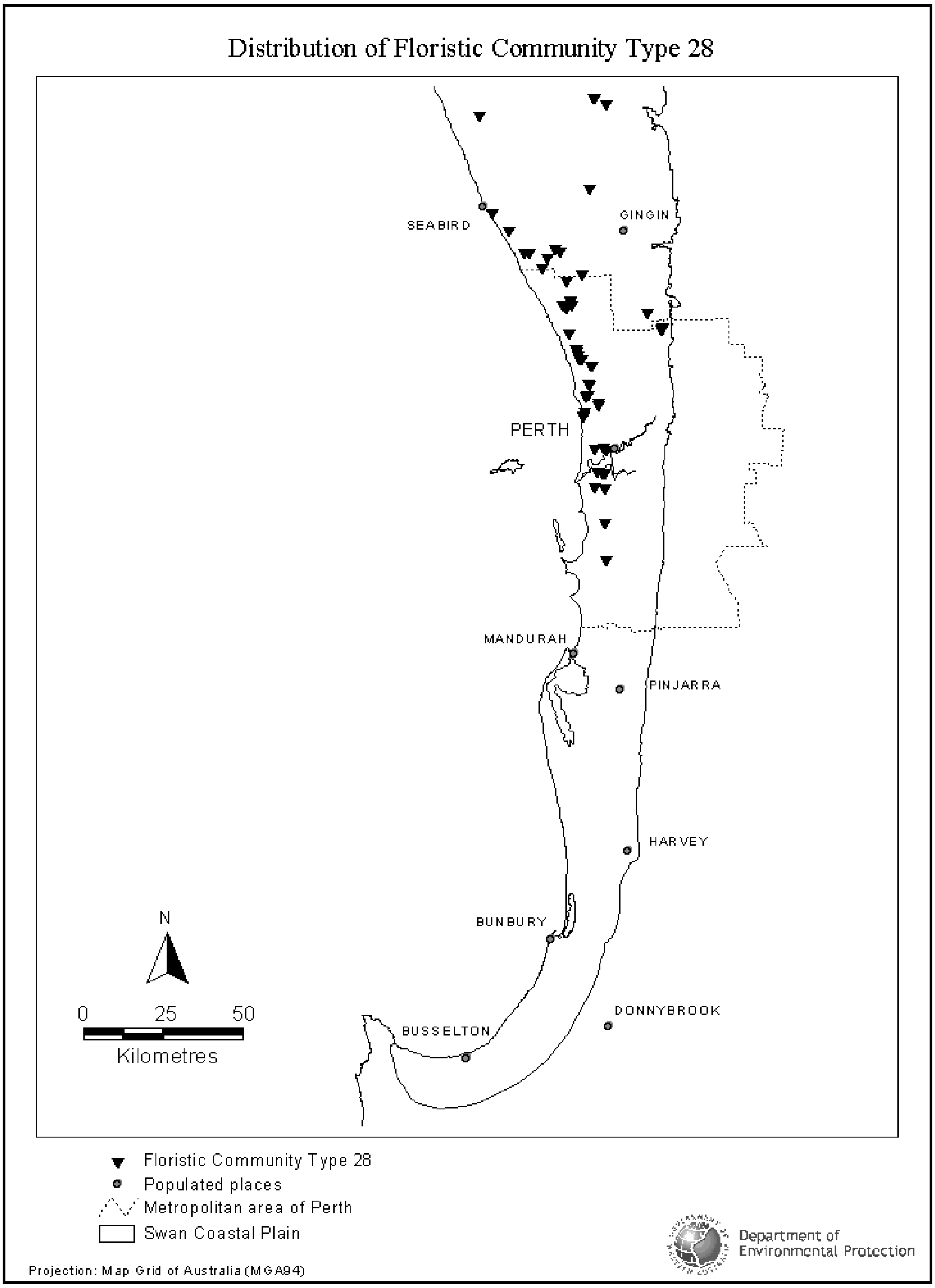
Map 9. Distribution of Floristic Community Type 24 on the Southern Swan Coastal Plain.



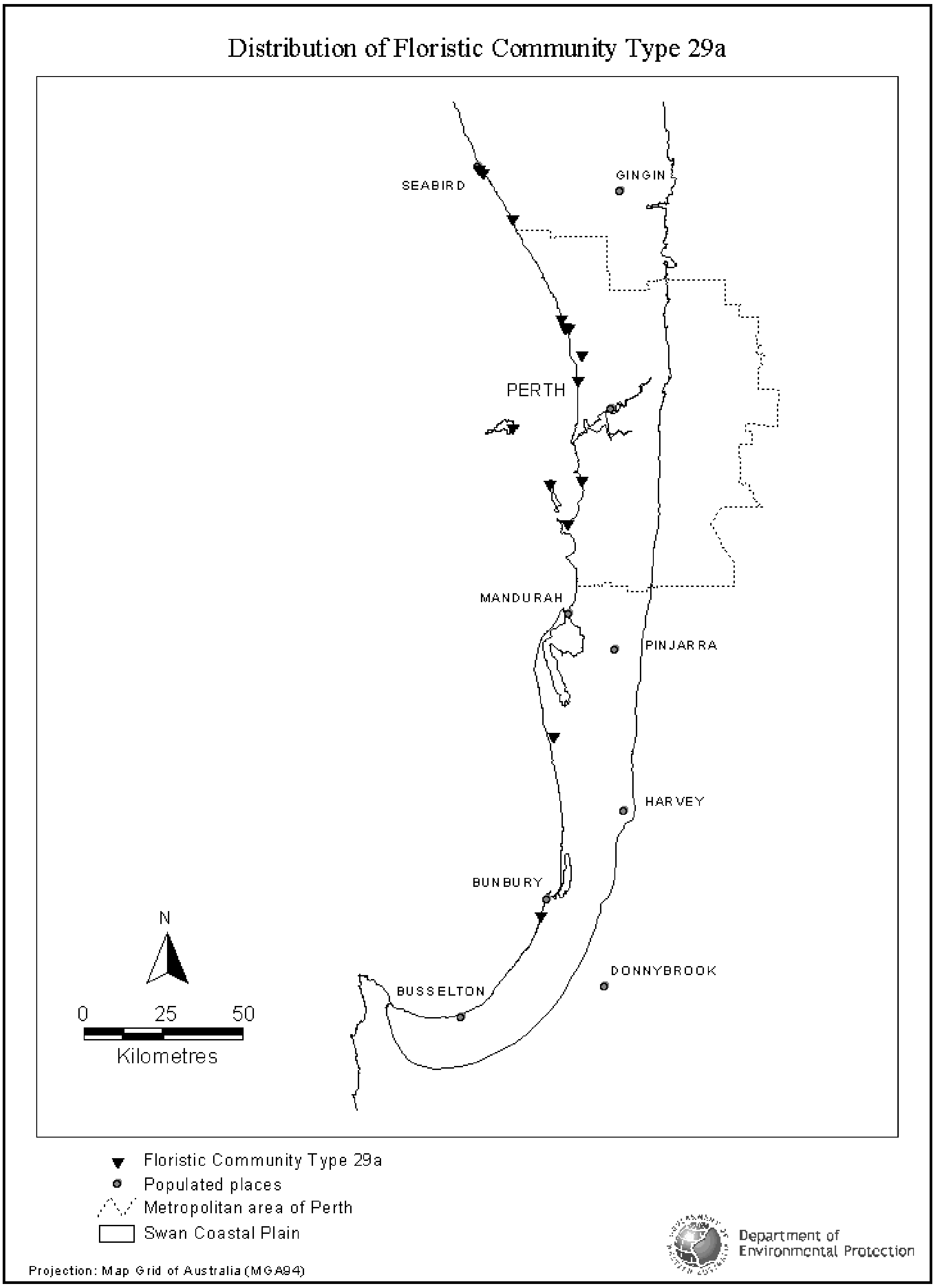
Map 10. Distribution of Floristic Community Type 25 on the Southern Swan Coastal Plain.



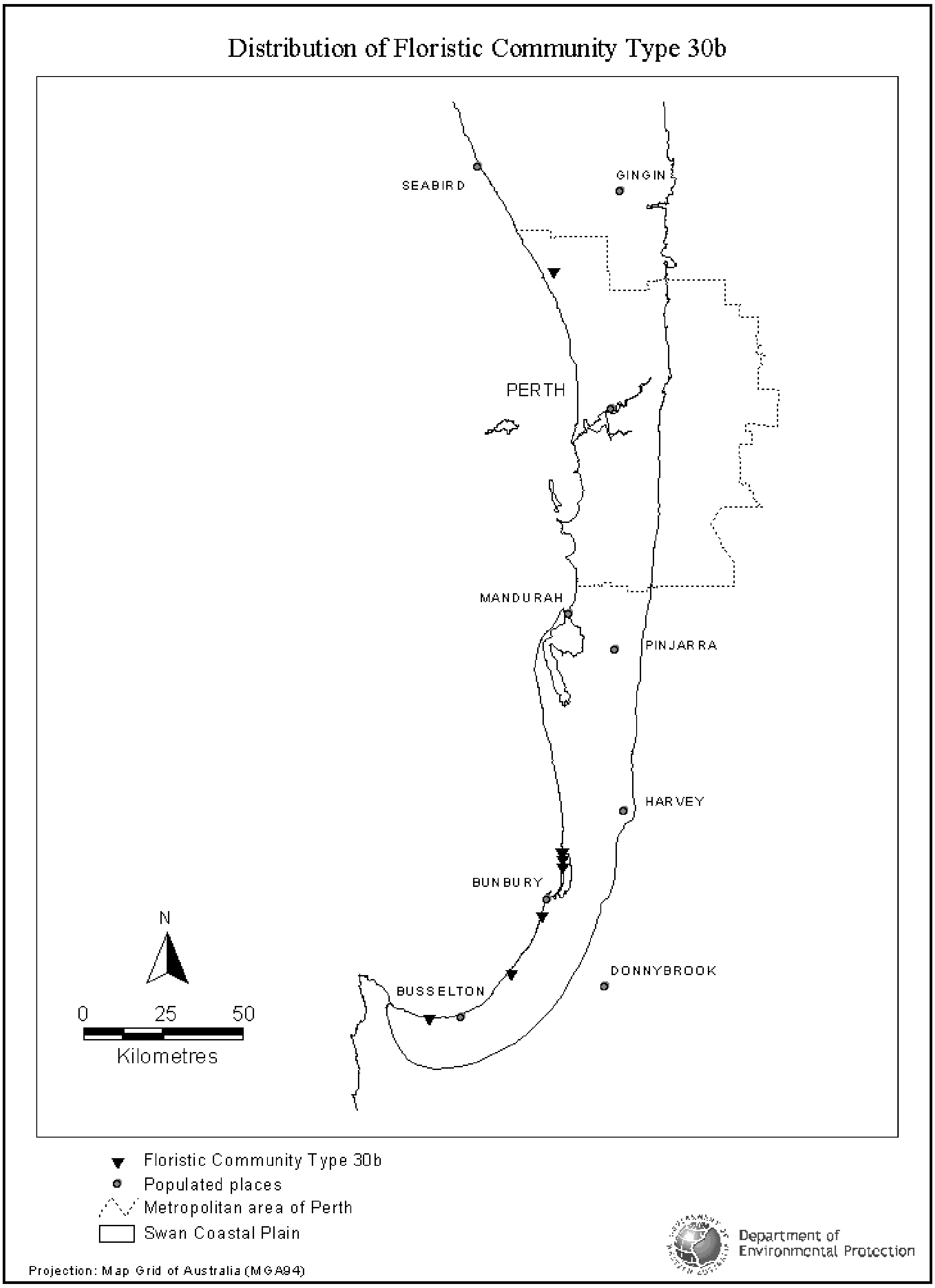
Map 11. Distribution of Floristic Community Type 26b on the Southern Swan Coastal Plain.



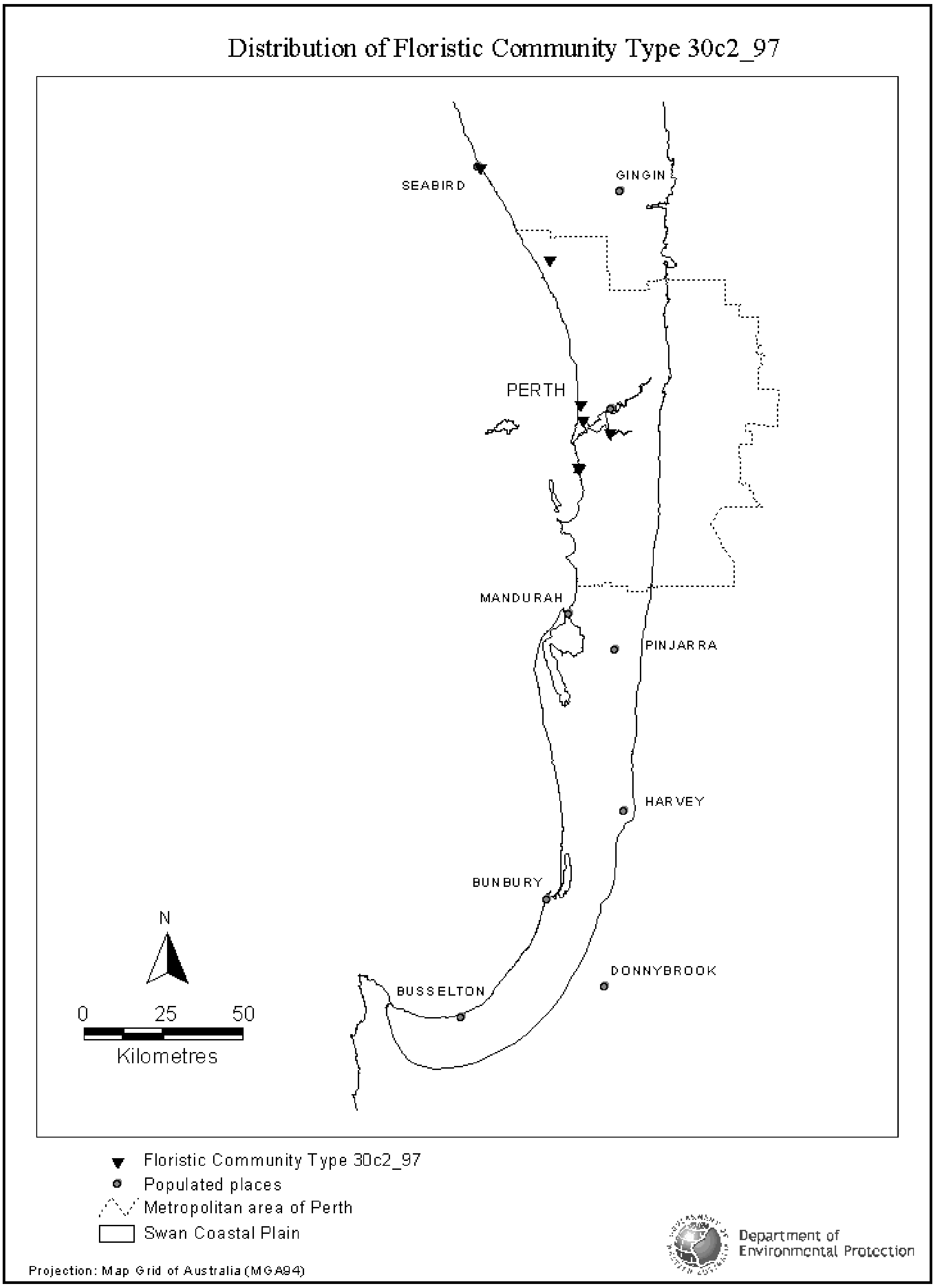
Map 12. **Distribution of Floristic Community Type 28 on the Southern Swan Coastal Plain.**



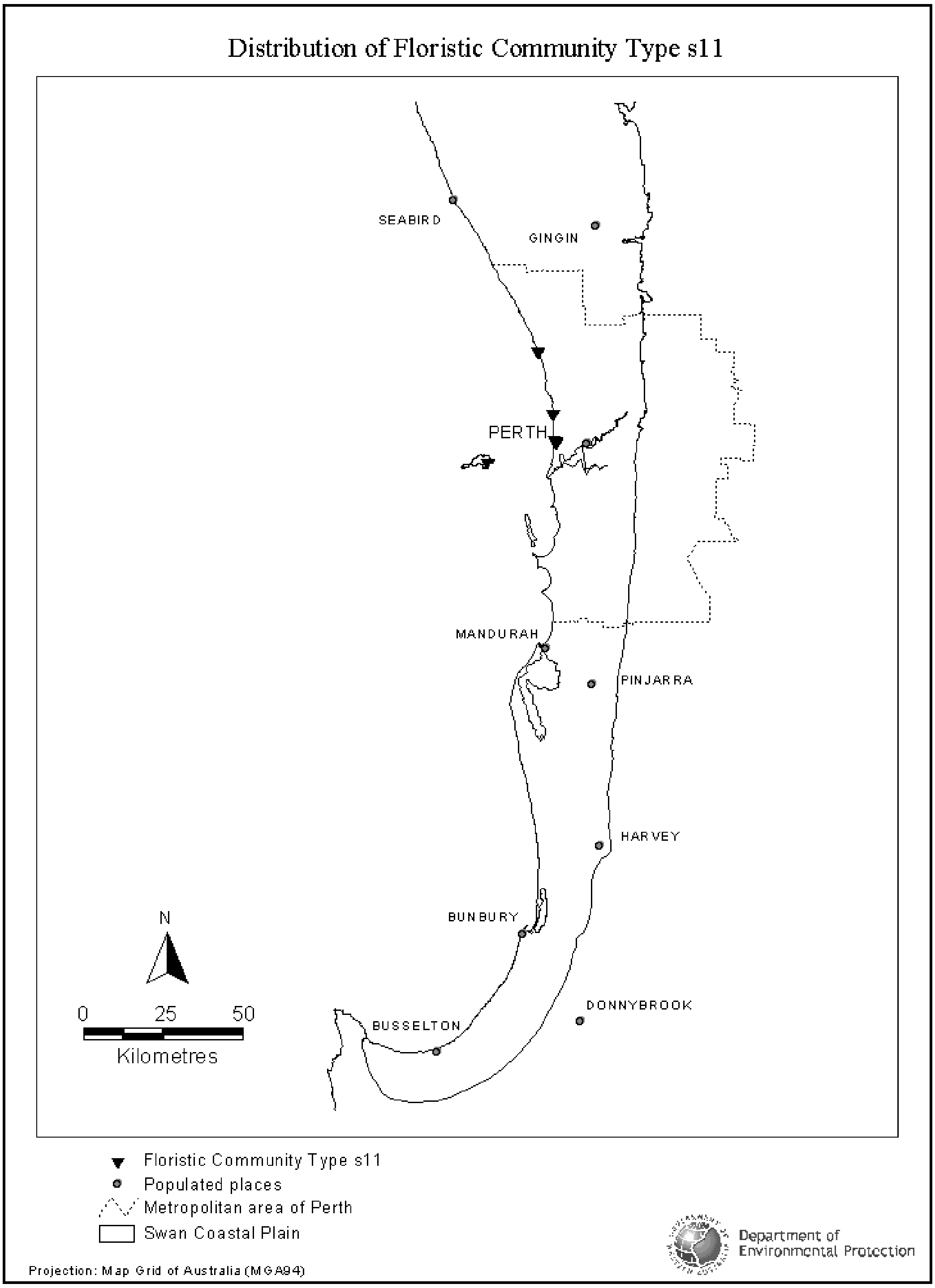
Map 13. Distribution of Floristic Community Type 29a on the Southern Swan Coastal Plain.



Map 14. Distribution of Floristic Community Type 30b on the Southern Swan Coastal Plain.



Map 15. Distribution of Floristic Community Type 30c2 on the Southern Swan Coastal Plain.



Map 16. Distribution of Floristic Community Type S11 on the Southern Swan Coastal Plain.

TUART - THE SPECIES

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GENETIC AND MORPHOLOGICAL VARIATION, AND THE MATING SYSTEM IN TUART

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ABSTRACT

Eucalyptus gomphocephala (Tuart) generally shows little morphological variation throughout its range. Noticeable exceptions are the Red Tuart found on the Swan River at Guildford and a mallee form on the Quindalup Dunes. Much of the genetic variation as determined from isozymes is found within populations with only 10.8% (G_{ST}) of the overall genetic diversity distributed between populations. Of the seven populations investigated genetic variation, as measured by allelic richness (*A*), proportion of polymorphic loci (*P*) and gene diversity (*H*e), was generally lower in the isolated northern populations at Cowalla Rd and Cervantes than in the five southern populations. Population phylogenetic analyses show that both northerly populations are moderately differentiated from the main Tuart distribution to the south. Seed collected from putative *E. gomphocephala* X *E. rudis* hybrids contained unique moderate frequency alleles at two loci not found in the Tuart populations and assumed to have come from *E. rudis*. There was also evidence that some seed material from Kings Park and the CALM Esperance plantation may be of hybrid origin. Mating system studies indicate that Tuart has a mixed mating system and that the isolated marginal Cervantes population has significantly lower levels of outcrossing than the Lake Preston population. Correlated paternity estimates suggest that even though outcrossing occurs at much lower levels in Cervantes it involves a larger number of paternal trees. This may be due to differences in pollinator type and behaviour, plant density and numbers of flowers per tree.

INTRODUCTION

Patterns of variation within plant species depends on a range of factors including geographic distribution, breeding system, and historical events. The latter may include range fragmentation associated with climatic and landscape instability, and population bottlenecks which are both strong determinants of population genetic structure. Eucalypts, like many other tree species, generally have high levels of genetic diversity compared to other plant species (Moran 1992). The partitioning of this genetic diversity, between and within populations, varies with population structure. In many widespread and regionally distributed species, with relatively continuous population systems, genetic variation is primarily distributed within populations rather than between (Moran and Hopper 1987, Byrne 1999). However, some species with regional distributions and disjunct population systems, such as *E. caesia* (Moran and Hopper 1983), *E. crucis* (Sampson *et al*. 1988), and *E. nitens* (Byrne *et al*. 1998) show significant genetic and morphological variation between populations. In these cases long term historical isolation and the lack of any significant gene flow between populations are major causal factors in the high levels of interpopulation differentiation.

Eucalyptus gomphocephala (Tuart) has a regional distribution generally confined to coastal sands and limestones from north of Jurien to north-west of Busselton, covering a distance of some 400 km. In coastal areas north of Perth Tuart occurs as a series of disjunct populations. It then extends southwards in more continuous series of coastal populations which more recently have become increasingly fragmented following land clearing. In a few areas Tuart extends in scattered populations along the Moore, Swan, Canning, Serpentine, Murray and Harvey Rivers inland beyond the coastal limestones to the Bassendean Dunes and rarely the Pinjarra Plain.

The aim of this study was to investigate morphological variation, patterns of population genetic variation and the mating system in relation to present geographical distribution and historical patterns of fragmentation.

MORPHOLOGICAL VARIATION

The Species and Varieties

The first known collection of Tuart comes from the Baudin expedition in 1801 and was collected at Geographe Bay in what is now the area of the Tuart Forest National Park (Peron 1807, Keighery and Keighery this publication). The Swiss botanist Augustin Pyramus de Candolle used this collection to describe *Eucalyptus gomphocephala*. The collection is held in the Paris Herbarium.

Although most texts, for example Brooker and Kleinig (1990) and Chippendale (1988), list no infraspecific variation in Tuart, there are several named taxa within the species, some unnamed hybrids and a mallee form.

Tuart generally shows little morphological variation[1] throughout its range including populations scattered inland along the Moore, Swan, Canning, Serpentine, Murray and Harvey Rivers which are indistinguishable from more coastal populations. However, at Guildford it was noted that the heartwood was red not uniformly yellow as in normal trees.

This form was named by Blakely and Steedman (1939) as variety *rhodoxylon* (Red Wood). In their description they noted

> ‘The tree is markedly distinct from the species in the colour of the timber, and therefore, cannot be classed with it and is deserving of a varietal name. It is difficult to account for the colour of the timber, as all other botanical characters, especially the seedlings, do not show any signs of hybridisation.’

The collection made by Steedman at Guildford in November 1937, from which the variety was described (type specimen), consists of stems bearing buds and fruits, bark and a cross section of the trunk showing the red heartwood. This collection is held in the NSW National Herbarium (NSW number 340934) at Sydney (Figure 1).

Steedman’s notes on the population at Guildford are quite detailed.

> ‘There are only five of these trees within 30 or 40 yards of each other; these are suckers from old stumps, growing in black sandy soil on a small rise just off a permanent creek, in association with Jarrah and Marri. They are 10 miles or more from Tuart country in the Guildford district, near Perth. The old settlers will not believe that they belong to the Tuart tribe. The old trees must have been of gigantic size as the old stumps at ground level are 6 feet or more across. It seems a mystery how they got there.’

In their description Blakely and Steedman (1939) commented that:

> ‘The tree is an interesting one and requires further research, and should be preserved for future study

[1] This comment refers to the absence of patterns to the variation. The stature and size of the buds, flowers and fruits are known to vary but this variation is recorded for populations of the species throughout its range and as such does not constitute variation that is useful in distinguishing varieties or subspecies.

by the Botanist and Forester.'

This proved a forlorn hope.

Little else has been heard of *Eucalyptus gomphocephala* var. *rhodoxylon*, except that it has slowly fallen from Botanical favour without any detailed future study. An Australia-wide review of the Eucalypts (Johnston and Marryatt 1965) listed the variety with a question mark followed by the statement 'Status doubtful'. Then another review (Pryor and Johnson 1971) described it as *Eucalyptus gomphocephala*, minor variant and not worthy of recognition.

Eucalyptus gomphocephala var. *rhodoxylon* is clearly distinct. There are a number of other Swan Coastal Plain taxa that have distinct variants on the eastern and western sides of the Plain, separated by the Bassendean Sands (Gibson *et al*. 1994). Some of these have been formally described in *Dryandra sessilis* (George 1996), and *Diplopeltis huegelii* (Keighery 1998).

The mallee form occurs as pure populations of Tuart on the Quindalup Dunes south-west of Yanchep (Figure 2 from Tuart Area 10, Map 4 in Keighery *et al.* this publication) and at Dalyellup (Tuart Area 74, Map 4 in Keighery *et al.* this publication).

The only other morphological variation within Tuart occurs in relation to the size of the trees. In the most northerly part of its range, particularly north of Jurien, trees are much smaller although they are not mallees.

Hybrids

Tuart overlaps with nine other species of naturally occurring Eucalypts within its range: *E. argutifolia*, *E. calophylla*, *E. cornuta*, *E. decipiens*, *E. foecunda*, *E. marginata, E. petrensis*, *E. rudis* and *E. todtiana.* Hybrids have been recorded between Tuart and three of these species. These hybrids are described below.

- *Eucalyptus gomphocephala* and *E. decipiens*: known from a single tree in the Guilderton area.

- *Eucalyptus gomphocephala* and possibly *E. rudis*: the named hybrid, *Eucalyptus x mundijongensis* Maiden (Mundijong Tuart)
  Since this taxon, now a presumed hybrid, was described as *Eucalyptus mundijongensis* by Maiden in 1913 (as quoted in Maiden 1921) it has had a somewhat confused history. The apparent sources of this confusion are two-fold, being related to the locality of the type specimen and the nature of the origins of the taxon.
  (i) Locality of the type specimen: The type specimen is reported to have been made by Cleland at Jarrahdale. However, Tuart does not occur naturally at Jarrahdale which is on the Darling Plateau. It is possible that the specimen is from a naturally occurring tree on the Serpentine River, where Tuart does occur naturally, in the Shire of Serpentine-Jarrahdale. In 1990 the Armadale-Kelmscott branch of the Wildflower Society and the Serpentine-Jarrahdale Land Conservation District Council circulated a poster offering a $100 reward for the re-discovery of *Eucalyptus mundijongensis.* No specimens were found in the Shire.
  (ii) Origins of the taxon: In 1971 Pryor and Johnson (1971) suggested that the type collection is a hybrid between *E. gomphocephala* and *E. wandoo*, hence the redetermination as *Eucalyptus x mundijongensis*. Collections from two other localities have also been determined as *E. x mundijongensis*. These are from the Crooked Brook area (first recorded by Robert Powell in 1971) and Yanchep. The affinities of the specimens from Crooked Brook are unclear. The specimen from Yanchep was collected by Bill Muir,

from the Department of Conservation and Land Management. This specimen won the reward for the re-discovery of *Eucalyptus mundijongensis* and is considered to be a hybrid between *E. gomphocephala* and *E. rudis* (Coy 1991). Both parent species occur at the Yanchep locality. While it does seem more likely that this is the combination producing *E. x mundijongensis*, as both species occur at Serpentine, this matter has not been resolved.

- *Eucalyptus gomphocephala* and *E. cornuta*: the named hybrid *E. x gomphocornuta* Trabut (Bastard Tuart).
  Eucalyptus x gomphocornuta was described by Trabut from cultivated material growing in Algeria. Similar trees were reported from Vasse (near Busselton) and natural hybrids are found in the Tuart forest at Wonnerup where the two species' distributions overlap.

Like many other eucalypts, Tuart will probably hybridize readily when planted with other species. One example was noted at Pyrton on the Swan River at Guildford where Tuart has been planted. At this site mature hybrids of the cross *E. gomphocephala* X *E. macrandra* (voucher G. Keighery 15676) were documented. This would explain the hybrid nature of some seed collections presented elsewhere in this paper.

GENETIC VARIATION AND MATING SYSTEMS

Materials and Methods

Seed Collections

Seed was collected from up to 10 trees per population from seven populations of Tuart (Figure 3) and from a single stand (possibly one tree) of a putative *E. gomphocephala* X *E. rudis* hybrid. Seed was also obtained from the Department of Conservation and Land Management Manjimup seed store from a collection taken from a Tuart plantation at Esperance.

Isozyme Electrophoresis

Up to 20 seeds per plant were germinated on moistened filter paper. The number of seeds used per population was dependent upon sample size requirements for mating system studies. Seedlings with recently emerged cotyledons provided the best material. Preparation of this material and the isozyme methods, using the Helena Laboratory cellulose acetate plate electrophoresis system, were described previously by Coates (1988).

Eleven enzyme systems were assayed: acid phosphatase (ACP, E.C. 3.1.3.2), aspartate aminotransferase (AAT, E.C. 2.6.1.1), esterase (EST, E.C. 3.1.1.-), glucose phosphate isomerase (GPI, E.C. 5.3.1.9), isocitrate dehydrogenase (IDH, E.C. 1.1.1.42), leucine aminopeptidase (LAP, 3.4.17.1), malate dehydrogenase (MDH, 1.1.1.37), malic enzyme (ME, E.C. 1.1.1.40), phosphoglucomutase (PGM, E.C. 2.7.5.1), phosphogluconate dehydrogenase (PGD, E.C. 1.1.1.44) and shikimate dehydrogenase (SDH, E.C. 1.1.1.25). Seventeen zones of activity were scored and each zone was assumed to represent a single locus. Fourteen polymorphic loci were detected. Their genetic interpretation was based on segregation patterns of progeny arrays from open pollinated families from the two populations used in mating system studies.

Genetic Variation Within and Among Populations

The average number of alleles per locus (A), percentage polymorphic loci (P), observed heterozygosity (H_o) and gene diversity (expected panmictic heterozygosity) (H_e) were estimated at the population level. Fixation indices (F_{IS}) (Wright 1978) were estimated to examine population deviation from random mating. Single locus diversity measures and F_{IS} were calculated using the computer program POPGENE (Yeh and Boyle 1997) .

The partitioning of genetic variation within and among populations, was analyzed by using measures proposed by Nei and Chesser (1983).

Roger's genetic distance was calculated between all populations and used to construct a Distance Wagner tree using BIOSYS. Phylogenetic relationships among populations were also investigated by restriction maximum likelihood method using gene frequency data. Multiple datasets (500) were generated by bootstrapping, a phylogeny determined for each dataset by the restriction maximum likelihood method and a consensus tree generated. The computer programs SEQBOOT, CONTML, and CONSENSE in PHYLIP 3.5 (Felsenstein 1995) were used for this analysis.

Mating System Analysis

Three loci were used to estimate mating system parameters in two populations: Cervantes and Lake Preston. Estimates were based on 10 and 11 families per population respectively with a mean of 14.4 progeny per family for both populations.

Mating system estimates based on different loci may be correlated if those loci show linkage disequilibrium. To test for associations between loci, Burrows composite measure of linkage disequilibria (Δ_{AB}) was calculated for all possible pairs of loci within populations with χ^2 tests for significance according to Weir (1990), using the computer package POPGENE (Yeh and Boyle 1997).

Maximum likelihood estimates of single locus (t_s) and multilocus (t_m) outcrossing rates (Ritland and Jain 1981) were based on the mixed-mating model of Brown and Allard (1970) with maternal genotypes inferred from progeny arrays. Correlation of outcrossed paternity (r_p) was estimated according to the sibling pair model (Ritland 1989). The inbreeding coefficient of maternal parents (F_m) was also calculated. All mating system parameters were estimated using the computer program MLTR version 0.9 (available from K Ritland). Standard errors for the population estimates of t_s, t_m, r_p, F_m, and t_m-t_s were based on 500 bootstraps with resampling among maternal plants (see Sun and Ritland 1998).

Results

Genetic Variation Within and Between Populations

Three loci (*Gpi*-1, *Pgd*-1 and *Sdh*-1) were monomorphic across all populations. The locus *Me*-1 was only polymorphic and heterozygous in seed material collected from the putative *E. gomphocephala* X *E. rudis* hybrid. Eleven loci were polymorphic across most populations. The *Mdh*-2 locus was only polymorphic in the Cervantes and Lancelin populations where a unique allele was observed at significant frequencies in the Cervantes populations. The remaining locus *Mdh*-3 was monomorphic in all populations except Lake Preston where a rare unique allele was detected.

The population means for allelic richness (*A*), percentage polymorphic loci (*P*), gene diversity (H_e) and heterozygosity (H_o) are presented in Table 1. Polymorphism, allelic richness, and gene diversity were generally lower in the Cervantes and Cowalla Rd populations than in the more southern populations, although the differences were not significant. In comparison with other eucalypt species, *E. gomphocephala* has slightly lower levels of genetic variability (*A*, *P* and *H*e) than widespread species and a number of regional and localized species. However, it does have similar levels of genetic diversity to regional species such as *E. diversicolor* (Karri) (Table 2).

Population fixation indices (F_{IS}) were positive in all populations and significantly greater than zero in all populations with the exception of Cervantes. These results indicate a general excess of homozygotes in the seed progeny.

Estimates of total genetic diversity (H_T), genetic diversity within populations (H_S) and the proportion of total genetic diversity among populations (G_{ST}) are shown in Table 3 for Tuart and other eucalypt species. Tuart has generally average levels of genetic diversity compared with most other eucalypts with only a relatively low proportion (10.8%) of the overall genetic diversity distributed between populations. This is comparable to G_{ST} values for widespread and regionally distributed eucalypts with relatively continuous population systems. The low level of divergence between Tuart populations is also reflected in the small average genetic distance among the seven populations (D = 0.023).

The analysis of phylogenetic relationships among all populations, based on Distance Wagner or Maximum Likelihood methods, gave similar tree topologies (Figure 4). The Maximum Likelihood analysis highlights the difference between the northern Cervantes and Cowalla Rd populations and the more southern populations in the main Tuart distribution.

Hybridization

The putative *E. gomphocephala* X *E. rudis* hybrid investigated contained two unique high frequency alleles at the *Pgi*-2 and *Mez*-1 loci not found in any individuals from the seven Tuart populations nor in seed collected from the Esperance CALM plantings of Tuart. These unique alleles are assumed to have come from the nearby *E. rudis* population. Phylogenetic analysis, particularly the Distance Wagner, clearly separated the putative hybrid material from the natural Tuart populations but did indicate reasonably strong affinity with the Esperance plantation seed. This was reflected by the sharing of high frequency alleles at the *Mdh*-1, and to some extent *Lap*-1, loci which generally only occur at very low frequencies in the seven Tuart populations.

The phylogenetic studies also indicated one other possible case of hybridization in the collections of seed analyzed in this investigation. The Kings Park population clustered between the other Tuart populations and the putative *E. gomphocephala* X *E. rudis* hybrid. There was some suggestion from the gene frequency data at the *Pgi*-2 and *Mdh*-1 loci that a component of seed from Kings Park may be of hybrid origin. However, these data were insufficient to resolve this issue further.

Mating System

Multilocus (t_m) and mean single locus (t_s) estimates of outcrossing rates for two populations (Cervantes and Lake Preston) are given in Table 4. Both populations had outcrossing rates significantly less than one. The outcrossing rate in the isolated Cervantes (t_m = 0.54, *t*s = 0.52) was significantly lower than the mean outcrossing rate for the Lake Preston population (t_m = 0.82, t_s = 0.75). Although there was no significant difference between the mean single locus and multilocus outcrossing estimates in either population the single locus estimates were notably lower in the Lake Preston population. Low levels of biparental inbreeding may be contributing to this trend.

The correlation of outcrossed paternity r_p (the probability that siblings shared the same father) was moderately high in the Lake Preston population and was significantly greater than zero (Table 4).

In contrast r_p was lower in the Cervantes population and not significantly different from zero. The "paternal mating pool", the estimated number of sires per plant, was correspondingly higher (5.4) in the Cervantes population and less than half that size (2.6) in the Lake Preston population. These data indicate that the size of the paternal mating pool is associated with population density.

The average fixation index for the maternal plants in the Cervantes and Lake Preston populations (F_m = -0.125, Table 4) is significantly lower than the average estimate for the two populations based on seed progeny (F_{IS} = 0.162, Table 1). This indicates selection favouring heterozygous individuals as plants mature from seedling to adult.

GENERAL DISCUSSION

Genetic Variation and Geographic Range

Geographic range is often used to predict patterns of genetic variation within plant species. For example Karron (1987) observed a significant correlation between geographic range and the level of genetic variability when comparing geographically restricted species with their more widespread congeners. Within *Eucalyptus* Moran and Hopper (1987) demonstrated that species with similar geographic distributions had comparable allelic distributions.

The levels of genetic variation found in Tuart (Tables 1 and 2) are comparable to those found in one other regionally distributed eucalypt, *E. diversicolor* (Karri) and to some extent *E. rhodantha* (Sampson *et al*. 1989), but not with four other regionally distributed eucalypts listed by Moran and Hopper (1987). Like Tuart, Karri has a reasonably continuous distribution over much of its range but also has notable outliers whereas other regionally distributed eucalypts shown in Table 2 have disjunct or dissected distributions. As suggested by Coates (1989) and Hamrick (1983) similarity between levels of genetic variation within populations are more likely in species with similar geographic range and population structure, such as Tuart and Karri, than in species based solely on geographic distribution.

The continuous distribution of Tuart throughout most of its range also explains why only 10.8% of the total genetic diversity within this species is found between populations. Apart from the northerly disjunct populations, gene flow, either by pollen movement or seed dispersal, appears to be sufficient to maintain a relatively homogeneous gene pool throughout the main range of the species. Similarly, other eucalypts with generally continuous population systems show similar levels of between population divergence whether they have widespread distributions or more regional distributions such as Karri (Table 3)

Despite the overall low levels of genetic differentiation there is some divergence between the two northern populations at Cervantes and Cowalla Rd and the main Tuart distribution. At the *Mdh*-3 locus there is an allele unique to both populations and the Restriction Maximum Likelihood tree based on gene frequencies (Figure 4a) separates out Cervantes and Cowalla Rd from the southern populations. This level of differentiation is comparable to that observed between Karri outliers at Rocky Gully and the Porongurups (Coates 1989) and the main Karri distribution to the south-west. In both Tuart and Karri the levels of differentiation are relatively low but sufficient to indicate separation and isolation predicted, in the case of Karri, to be due to increased aridity over the last 5000 years.

These data suggest that a minimal reserve design strategy for maximizing genetic resource conservation in Tuart would be a small number of large reserves within the main Tuart distribution. In addition reserves covering northerly disjunct populations which show some genetic divergence from the main distribution such as Cervantes and Cowalla Rd should be included. Although scattered inland populations along the Moore, Swan and Serpentine Rivers were not included in this study it would also be desirable to reserve at least one large inland population along each river system.

Hybridization

Of the nine eucalypt species known to overlap with Tuart, three occur in different subgenera (*E. calophylla*, subgenus Corymbia; *E. marginata*, *E. todtiana*, subgenus Monocalyptus) and are considered highly unlikely to hybridize with Tuart. Field observations support this view. The remaining six occur in the same subgenus (Symphyomyrtus) and although Tuart is not considered closely related to any other eucalypt species (Brooker and Kleinig 1990) field observations indicate it forms hybrids with *E. cornuta*, *E. decipiens,* and *E. rudis*. The putative *E. gomphocephala* X *E. rudis* hybrid investigated in this study contained two unique alleles not found in any of the Tuart populations studied and are assumed to have come from the nearby *E. rudis* population. Although allozyme studies were not carried out on this *E. rudis* population to confirm the origin of these alleles, these data, combined with observations on morphology, strongly support the view that this stand is of hybrid origin.

The notion that hybridization between Tuart and other eucalypt species may be a relatively frequent event is supported indirectly by allozyme data from the Esperance plantation and Kings Park. Both phylogenetic and gene frequency data suggest that at least some of the seed from the Esperance plantation is of hybrid origin. *E. camaldulensis* is planted nearby and, given its very close phylogenetic affinity with *E. rudis*, is an obvious candidate as the pollen parent.

Evidence for the hybrid origin of some seed material from the Kings Park Tuart, although less conclusive, is a possibility. Apart from species such as *E. calophylla* and *E. marginata* which normally co-occur with Tuart, a range of other eucalypt species have been planted in Kings Park within the vicinity of the Tuart stands. If Tuart seed is to be used to establish more Tuart in Kings Park a precautionary measure would be to use seed from the nearest large natural stand where no hybridization is likely, rather than from within the Park. This would avoid the possibility of establishing undesirable Tuart hybrids.

Genetic Variation Within Populations and Mating Systems

Population size, range fragmentation, geographic range and population location (central v peripheral) are all considered to be important determinants of levels of genetic diversity within populations. Small, isolated and peripheral populations are generally considered to have reduced genetic variation. Yet for any one of these population characteristics there is conflicting evidence regarding their importance in influencing genetic diversity within populations (Lesica and Allendorf 1995, Lammi *et al*. 1999, Ellestrand and Elam 1993). For example, there is also some evidence to suggest that heterozygous advantage could be increased in peripheral or marginal environments which could result in the maintenance of higher levels of genetic variation than expected (see Lesica and Allendorf 1995).

The fragmented northern populations of Tuart, particularly those at the end of the species range near Cervantes, might be expected to show lower levels of genetic diversity due to genetic bottleneck effects and reduced gene flow between populations. Both northern populations investigated in this study, at Cervantes and Cowalla Rd, have lower levels of genetic diversity than the southern populations (Table 1) although the differences are not significant. The relatively small reduction in genetic variability in these northern populations, and the only moderate levels of genetic divergence between these populations and those to the south, is most probably a consequence of only relatively recent fragmentation of the northern part of the species range in association with increased aridity over the last few thousand years.

Tuart, like other eucalypts, has a mixed mating system combining outcrossing with significant levels of selfing. Although only two populations were investigated, it is also evident that the proportion of outcrossing versus selfing within a population can vary dramatically between populations. The isolated marginal population at Cervantes has significantly lower levels of outcrossing than the central population at Lake Preston. This difference in the level of outcrossing between these two populations is not common in eucalypts (Table 5) although similar differences were found between marginal and more central populations of the mallee *E. rameliana* (Sampson *et al.* 1995).

Another mating system parameter of interest is the correlation of outcrossed paternity. The estimates indicate that the number of fathers crossing with maternal trees in the Cervantes population is 5.3, over twice the number for the Lake Preston population. This suggests that even though outcrossing occurs at much lower levels, in the Cervantes population it involves pollen from a lot more paternal trees. A number of factors could be contributing to this effect with pollinator type and behaviour, plant density and number of flowers per tree likely to be the most important.

Tuart is considered to be primarily pollinated by insects, although birds have been observed visiting flowers, and mammals might also be expected to be infrequent pollinators (Ruthrof *et al.* this publication). There is no data comparing pollinator type between the marginal and main distribution Tuart populations but there is the possibility that there may be a different suite of pollinators operating in the isolated marginal populations. Different insect pollinators or a change in the proportion of bird versus insect pollinators could lead to significant changes in the levels of outcrossing and the correlation of outcrossed paternity. For example Sampson *et al.* (1995) proposed that a shift in pollinator type from birds to insects could result in more self pollination in the case of *E. rameliana.*

Plant density is also likely to change mating system parameters by influencing both pollinator movements and the number of pollen parent plants during outcrossing (see Karron *et al.* 1995). In *Daviesia mimosoides* (Young and Brown 1998) density is negatively associated with correlated paternity and in *Lambertia orbifolia* (Coates and Hamley 1999) the lowest density population studied had the highest correlated paternity. In both cases reduced density was assumed to increase intraplant pollinator movement. Based on these findings the Lake Preston population with the higher correlated paternity would be expected to have a higher density. Field observations suggest that this is the case.

Another factor influencing outcrossing rates might be plant size and thus the number of flowers per plant. In the case of *E. rameliana* Sampson *et al.* (1995) suggested that the reduction in outcrossing in the marginal populations may be due to a reduction in the number of flowers and therefore effective population size in the ecologically marginal habitat. Significantly lower outcrossing rates are associated with smaller tree size in the Cervantes population although mating system studies on additional Tuart populations are needed to confirm this relationship.

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TABLES

TABLE 1. *E. gomphocephala* genetic diversity statistics.

Key

Column 1	**Tuart population**	
Column 2	***A***	**mean number of alleles per locus**
Column 3	***P***	**percentage of polymorphic loci**
Column 4	***H*o**	**observed heterozygosity**
Column 5	***H*e**	**gene diversity**
Column 6	F_{IS}	**fixation indices for all populations**

Population	*A* (SE)	*P* (SE)	H_o (SE)	H_e (SE)	F_{IS} (SE)
Cervantes (1)	1.6	47.1	0.115 (0.040)	0.135 (0.045)	0.161 (0.089)
Cowalla Rd (2)	1.6	47.1	0.059 (0.022)	0.129 (0.044)	0.448 (0.034)
Kings Park (3)	1.6	52.9	0.080 (0.028)	0.162 (0.053)	0.319 (0.118)
Lake Cooloongup (4)	1.7	52.9	0.092 (0.032)	0.192 (0.032)	0.281 (0.113)
Lake Preston (5)	1.8	64.7	0.131 (0.046)	0.171 (0.053)	0.162 (0.080)
Leschenault Peninsula (6)	1.8	47.1	0.147 (0.047)	0.181 (0.057)	0.186 (0.113)
Wonnerup (7)	1.7	52.9	0.084 (0.029)	0.151 (0.051)	0.265 (0.099)
Mean	**1.69 (0.03)**	**52.1 (2.4)**	**0.101 (0.011)**	**0.159 (0.008)**	**0.260 (0.040)**

TABLE 2. Estimates of allozyme variation at the population level in eucalypt species and *E. gomphocephala.*

Key

Column 1 **Species and the pattern of the species distribution over their range**
- Widespread: A range of 600 km in at least one direction (after Moran and Hopper 1987).
- Regional: A range between 150 km – 600 km (after Moran and Hopper 1987).
- Localized: Endemic to a narrow range of less than 100 km (after Moran and Hopper 1987).
- Continuous: Continuous system of populations over most of the range.
- Disjunct: Significant disjunction between populations over all or part of the range.

Column 2 ***n*** **number of populations**
Column 3 ***A*** **mean number of alleles per locus**
Column 4 ***P*** **percentage of polymorphic loci**
Column 5 **H_e** **gene diversity**
Column 6 **Source of information**

	n	*A*	*P*	H_e	Source
Widespread Continuous					
E. cloeziana	17	2.21	79.8	0.205	Moran and Hopper 1987
E. delegatensis	24	2.52	78.9	0.239	Moran and Hopper 1987
E. grandis	12	2.09	56.5	0.167	Moran and Hopper 1987
E. saligna	7	2.10	64.3	0.239	Moran and Hopper 1987
Mean	**15**	**2.23**	**69.9**	**0.213**	
Regional Continuous					
E. diversicolor	13	1.61	48.7	0.152	Coates 1989
E. gomphocephala	**7**	**1.69**	**52.1**	**0.159**	
Regional Disjunct					
E. caesia	13	1.31	29.0	0.068	Moran and Hopper 1987
E. crucis	10	1.90	60.9	0.187	Sampson *et al.* 1988
E. pulverulenta	4	1.41	27.0	0.068	Moran and Hopper 1987
E. lane-poolei	7	2.26	80.0	0.246	Moran and Hopper 1987
E. rhodantha	6	1.98	56.9	0.168	Sampson *et al.* 1989
Mean	**8**	**1.77**	**50.7**	**0.147**	
Localized					
E. johnsoniana	3	1.29	27.0	0.084	Moran and Hopper 1987
E. laterica	2	2.16	75.0	0.278	Moran and Hopper 1987
E. paliformis	6	1.44	36.7	0.137	Moran and Hopper 1987
E. parvifolia	8	2.29	70.6	0.213	Moran and Hopper 1987
E. pendens	7	1.80	60.0	0.170	Moran and Hopper 1987
E. suberea	3	1.85	60.0	0.174	Moran and Hopper 1987
Mean	**4.8**	**1.81**	**54.9**	**0.176**	
All plants					
Mixed mating animal pollinated	85	1.43	29.2	0.090	Hamrick and Godt 1989
Outcrossing animal pollinated	164	1.54	35.9	0.124	Hamrick and Godt 1989

TABLE 3. Estimates of total genetic diversity and distribution of genetic diversity in eucalypt species and *E. gomphocephala*.

Key

Column 1	**Species and the pattern of the species distribution over their range**
Widespread	A range of 600 km in at least one direction (after Moran and Hopper 1987).
Regional	A range between 150 km – 600 km (after Moran and Hopper 1987).
Localized	Endemic to a narrow range of less than 100 km (after Moran and Hopper 1987).
Continuous	Continuous system of populations over most of the range.
Disjunct	Significant disjunction between populations over all or part of the range.
Column 2	**H_T total genetic diversity**
Column 3	**H_S genetic diversity within populations**
Column 4	**G_{ST} proportion of total genetic diversity among populations**
Column 5	**Source of information**

	H_T	H_S	G_{ST}(%)	Source
Widespread Continuous				
E. cloeziana	0.230	0.205	11.0	Moran and Hopper 1987
E. delegatensis	0.272	0.238	12.5	Moran and Hopper 1987
E. grandis	0.190	0.167	12.0	Moran and Hopper 1987
E. saligna	0.260	0.198	8.0	Moran and Hopper 1987
Mean	**0.237**	**0.202**	**10.9**	
Widespread Disjunct				
E. nitens	0.202	0.140	30.2	Moran and Hopper 1987
Regional Continuous				
E. diversicolor	0.168	0.152	9.7	Coates 1989
E. gomphocephala	**0.217**	**0.194**	**10.8**	
Regional Disjunct				
E. caesia	0.176	0.068	61.4	Moran and Hopper 1987
E. crucis	0.291	0.202	24.4	Sampson *et al.* 1988
E. pulverulenta	0.100	0.070	30.0	Moran and Hopper 1987
E. lane-poolei	0.292	0.245	13.7	Moran and Hopper 1987
E. rhodantha	0.221	0.184	10.1	Sampson *et al.* 1989
Mean	**0.216**	**0.154**	**27.9**	
Localized				
E. johnsoniana	0.139	0.084	39.6	Moran and Hopper 1987
E. laterica	0.318	0.278	12.6	Moran and Hopper 1987
E. paliformis	0.141	0.136	3.9	Moran and Hopper 1987
E. parvifolia	0.228	0.212	7.0	Moran and Hopper 1987
E. pendens	0.170	0.156	8.2	Moran and Hopper 1987
E. suberea	0.197	0.170	13.7	Moran and Hopper 1987
Mean	**0.200**	**0.173**	**14.2**	
All plants				
Mixed mating animal pollinated	0.304	0.221	21.6	Hamrick and Godt 1989
Outcrossing animal pollinated	0.310	0.243	19.7	Hamrick and Godt 1989

TABLE 4. Mating system estimates for two populations of *E. gomphocephala*.

Key

Column 1	**Tuart population**
Column 2	**F_m inbreeding co-efficient for maternal parents**
Column 3	**t_m multilocus outcrossing rate**
Column 4	**t_s single locus outcrossing rate**
Column 5	**t_m - t_s**
Column 6	**r_p correlation of outcrossed paternity**
Column 7	**Paternal Neighbourhood size ($1/r_p$)**

Population	**F_m**	**t_m (SE)**	**t_s (SE)**	**t_m - t_s (SE)**	**r_p (SE)**	**Paternal Neighbour-hood size ($1/r_p$)**
Cervantes	0.02 (0.05)	0.54 (0.09)*	0.52 (0.10)*	0.03 (0.02)	0.19 (0.13)	5.3
Lake Preston	-0.27 (0.19)	0.82 (0.07)*	0.75 (0.06)*	0.07 (0.03)	0.38 (0.14)	2.6

* Significantly less than 1 for t_m and t_s, and significantly greater than zero for r_p ($P < 0.05$)

TABLE 5. Estimates of the multilocus outcrossing rate (t_m) in 12 eucalypt species and *E. gomphocephala*.

Species	**t_m**	Source
		Moran and Bell 1983
E. obliqua	0.76	Moran and Bell 1983
E. pauciflora	0.70	Moran and Bell 1983
E. delegatensis	0.79	Moran and Bell 1983
E. regnans	0.69	Moran and Bell 1983
E. stellulata	0.77	Moran and Bell 1983
E. stoatei	0.82	Moran and Bell 1983
E. kitsoniana	0.77	Moran and Bell 1983
E. citriodora	0.86	Moran and Bell 1983
E. grandis	0.84	Moran and Bell 1983
E. saligna	0.77	Moran and Bell 1983
Mean	**0.78**	
E. rhodantha (undisturbed stand)	0.59	Sampson *et al.* 1996
E. rhodantha (disturbed stand)	0.26	Sampson *et al.* 1996
E. rameliana (undisturbed)	0.92	Sampson *et al.* 1996
E. rameliana (marginal)	0.48	Sampson *et al.* 1996
***E. gomphocephala* (Lake Preston)**	**0.82 (0.07)**	
***E. gomphocephala* (Cervantes)**	**0.54 (0.09)**	

FIGURES

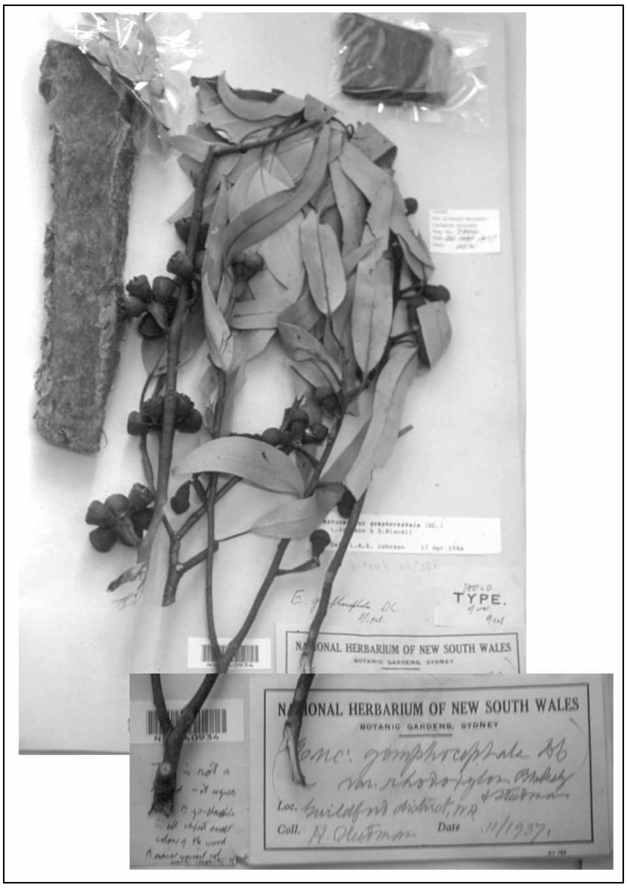

Figure 1. Type of *Eucalyptus gomphocephala* var. *rhodoxylon*. Photograph: Gregory Keighery.

Figure 2. Mallee form of Tuart. Photograph: Gregory Keighery.

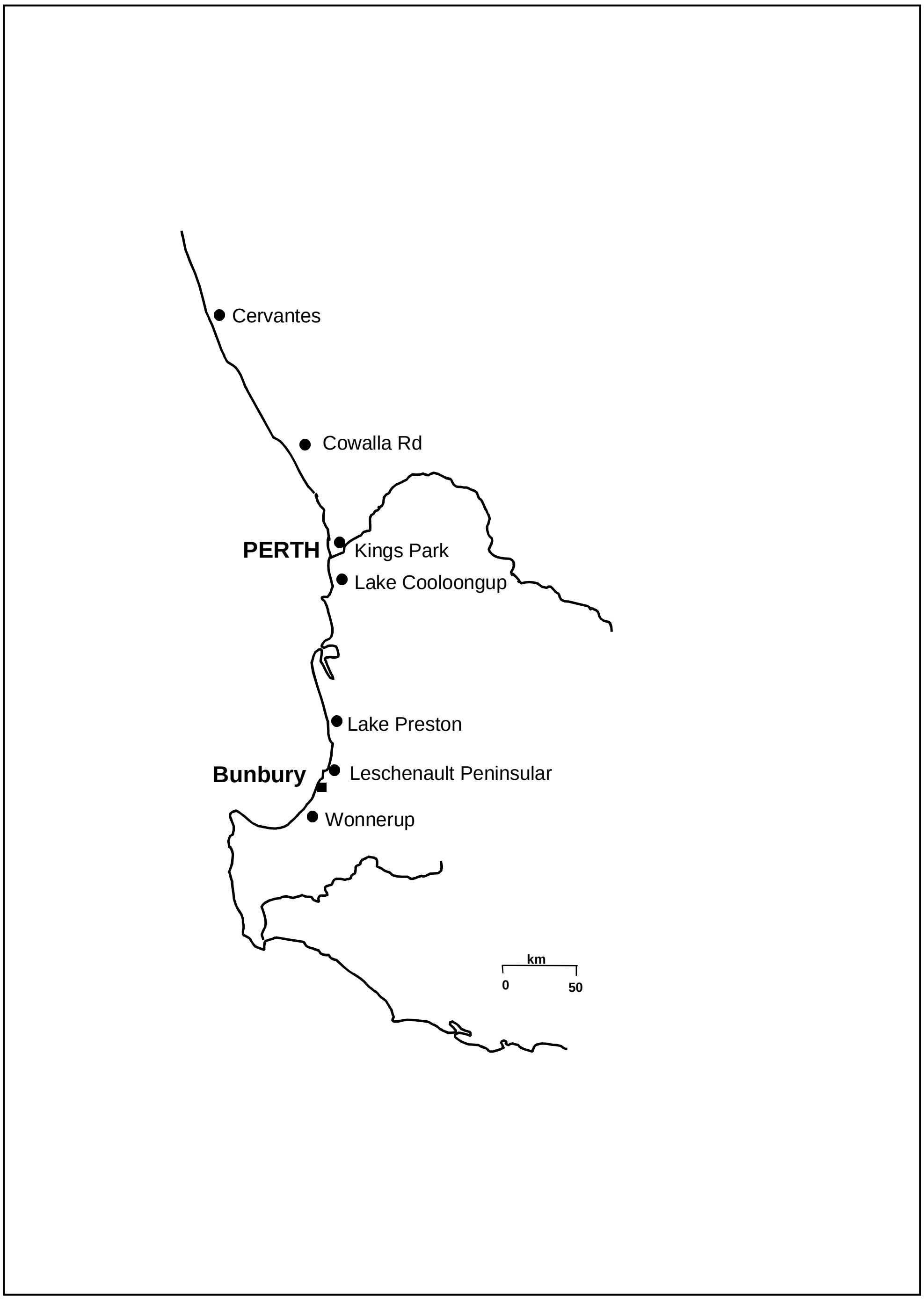

Figure 3. Populations sampled for isozyme analysis.

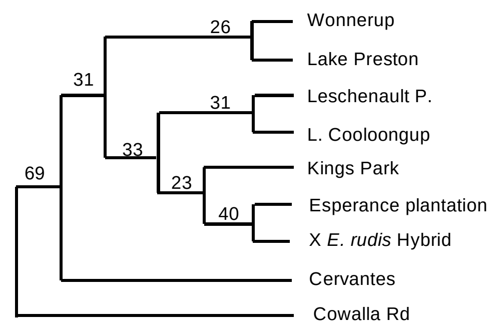

Figure 4a. Restriction Maximum Likelihood consensus tree based on gene frequency data.

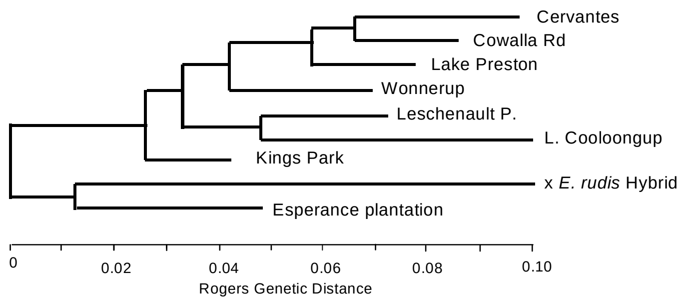

Figure 4b. Distance Wagner tree based on Roger's Genetic Distance.

THE BIOLOGY OF TUART

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ABSTRACT

The biology of Tuart has received little attention. Existing known studies, including work by the authors, are used to look at aspects of Tuart's reproductive biology, phenology, seed bank dynamics and seedling recruitment, as well as the effects of fragmentation and fire on Tuart populations.

The studies of Tuart's reproductive biology and phenology have found that flowering occurs from January to April with reports of mass flowering occurring every five to eight years and patchy flowering occurring intermittently. Seed production and supply in Tuart may show considerable temporal variation. A diverse array of insects and birds are most likely to be involved in pollination of Tuart.

Research currently on the seed bank dynamics of Tuart has observed that on average four seeds are stored in each woody fruit for up to two seasons. As a consequence, seed storage in the canopy may be high when heavy flowering seasons occur. Seeds are normally slowly released from the canopy, but can also be released *en masse* following disturbances such as fire. Tuart seed is susceptible to predation by ants that can remove a large proportion of seed in the soil quickly and hence, Tuart seeds do not form a long-lived soil seed reserve. Seeds have high viability (86%) and no innate dormancy. Mass recruitment of seedlings following fire occurs as the seeds swamp the predators.

Fragmentation and changed disturbance regimes are affecting many remnant Tuart woodlands, transforming community structure and species composition. There is evidence to suggest that Tuart is declining in urban remnants. Tuart flowering is patchy, in time and space, and therefore the size of the canopy seed store may vary considerably between years. Studies in remnants indicate that it takes some time for a Tuart population recovering from fire to become reproductive. If a fire occurs before this time, it is unlikely that adult trees will have a canopy seed store available for synchronous seed release following a fire to establish new trees. Mature Tuarts are regularly killed by fire when the fire breaches the bark and establishes in the wood. It is also been suggested that in urban remnants the abundance of naturally occurring wood boring insects may have increased as a consequence of their natural predators declining in numbers. This increased abundance of wood boring insects may be causing increased mortality in Tuart populations. Similar suggestions have been advanced for pathogenic fungi, such as *Armillaria.*

Some suggestions for future investigations to improve knowledge to aid in the management of Tuart in remnants are listed.

INTRODUCTION

Eucalyptus gomphocephala (Tuart) is most commonly a medium to tall tree endemic to the Swan Coastal Plain in south-western Australia. It occurs more or less continuously in a narrow coastal belt of sand dunes and sub-coastal plains between Jurien and the Sabina River (Keighery *et al.* Map 1 this publication).

Throughout this region Tuart communities have been extensively cleared for urban and agricultural development. Nowhere is this more evident than in the rapidly expanding northern and southern corridors of the Perth Metropolitan Region, and in the growing regional centres of Mandurah and Bunbury where Tuart communities are being increasingly fragmented into isolated remnants. Within this region there is a growing interest amongst individuals, community groups and government agencies, in the ecology, conservation and management of Tuart communities. Currently, information about the biology of Tuart is spread across disparate sources and, as a consequence, our knowledge is difficult to assess and our ability to answer questions regarding its conservation management is limited. This chapter aims to go some way towards overcoming this problem by providing an overview of what is currently known about the biology of Tuart. The chapter draws on the available literature and on studies by the authors, and highlights shortcomings in knowledge regarding Tuart populations.

ETYMOLOGY, TAXONOMIC STATUS AND LIFEFORM

The common name, Tuart, is derived from one of the many Nyoongar names for the species which include duart, moorun, mouarn and tooart (Bennett 1993). The species is less commonly known as White Gum in reference to its bleached grey-white typically box like bark and is the source for the Perth suburb name White Gum Valley. The first scientific description of Tuart was undertaken by the Swiss botanist Augustin Pyramus de Candolle in 1828 who classified and named the plant *Eucalyptus gomphocephala* from the Greek words *gomphos* (club) and *kephale* (head), in reference to the species' club headed flower bud (Figure 1). Tuart belongs to the largest *Eucalyptus* sub-genus Symphyomyrtus but is taxonomically very distinct, having no known close relatives and thus forming a monospecific section (Brooker and Kleinig 1990). Tuart most commonly occurs as a medium to tall tree and is a dominant in tall woodlands and woodlands but also occurs as a smaller tree, in heath, at the northern end of its distribution (Beard 1990) and as a mallee in several locations (Coates *et al.* and Keighery *et al.* this publication).

FACTORS AFFECTING THE DISTRIBUTION AND ABUNDANCE OF TUART

Climate and Geomorphology

The distribution and abundance of Tuart may be understood in terms of its interactions with the physical environment, other organisms and its resilience or ability to recover from disturbance. At the very broadest landscape scale, the distribution of Tuart is affected by climatic gradients and geomorphological soil patterns and its physiological limits. In this section we review existing information on the physical environment where the species has been recorded.

The climate throughout Tuart's distribution is Dry Warm Mediterranean to Warm Mediterranean with rain falling predominantly in the winter months between May and October (Beard 1990). The average annual rainfall increases and temperature and the number of dry summer months decreases along a north-south climatic gradient. Average annual rainfall, the maximum number of dry summer months, and the temperature range at the northern end of Tuart's distribution near Jurien Bay are: 567 mm; 5 months; and -1.0° to 45.2°C. At the southern end near Busselton the measurements are: 822 mm; 6 months; and 0.4° to 39.1°C (Bureau of Meteorology 1999). Not surprisingly, Tuart community physiognomy appears to be related to climate, with trees reaching their greatest height (and stature) forming Tall Woodlands at the southernmost end of the species' distribution where rainfall is highest (Beard 1990).

Geomorphology and soils also play an important determining role in Tuart's distribution. Tuart is most commonly found on the æolian derived Spearwood Dune System on the coastal limestone derived Cottesloe and Karrakatta soil units. Soils in these units are sandy, coarse and well drained with a high percentage of calcium carbonate (Semeniuk and Glassford 1989, McArthur 1991). Tuart is one of the few eucalypts adapted to these highly calcareous alkaline soils (Eldridge *et al.* 1994, Gibson *et al.* this publication). However, Tuart is also recorded on the younger Quindalup Dune System occasionally further inland on riverflats (Fox and Curry 1979, Beard 1989, Boland *et al.* 1984 and in this publication Coates *et al.*, Keighery *et al*. and Gibson *et al*.). These outlying populations may provide interesting insights into the evolutionary history and biogeography of Tuart.

Demographic Processes – Biological Interactions and the Effects of Fire

At the broadest regional scale, climate and geomorphological soil patterns interact with Tuart's physiological limits to determine the potential range of the species. At a more localized scale, within this range the distribution and abundance of individuals is affected by the demographic processes of dispersal, seedling recruitment (births) and plant mortality (deaths). This is best illustrated by considering Tuart's life cycle. For seedling recruitment to occur, trees have to flower, and flowers have to be pollinated and set and disperse viable seed; the seed then has to escape predation so that it can be incorporated into a soil seed bank where it must persist until the right conditions stimulate germination; the young plant then has to survive and grow to reproductive maturity (Harper 1977). The movement of individuals through this life-cycle is affected by biological interactions (e.g. pollination, seed predation and herbivory), stochastic processes (e.g. rainfall variability) and catastrophic events (e.g. fire). In this section we review the available information and studies currently being undertaken by the authors on the above processes within the context of Tuart's lifecycle.

Floral Biology and Pattern of Flowering

Beyond general descriptions of bud and flower morphology, only one comprehensive study of Tuart's reproductive biology and phenology has been undertaken. Inflorescences are produced from the current season's shoots in the outer canopy and develop laterally in leaf axils as unbranched clusters of up to seven buds which are mushroom shaped, sessile and of size 1.4-2.3 cm x 0.8-1.5 cm (Boland *et al.* 1984, Brooker and Kleinig 1990) (Figure 1). Flower buds are susceptible to predation by the Tuart Bud Weevil (*Haplonyx tibialis* Curculionidae) which lays an egg inside the flower bud before cutting the bud off partially or completely. The larvae then feed on the top part of the bud for four months before pupating and cutting their way out through the base (Fox and Curry 1979). The effects of the Tuart Bud Weevil have been reported since at least 1880 (Fox and Curry 1979).

Tuart has a typical eucalypt flower with creamy white filaments that are splayed upwards and outwards from the rim of the hypanthium, forming a flat topped array 1.3-2.7 cm in diameter and exposing a nectar producing disc. Across Tuart's range flowering has been recorded from January to April (Marchant *et al.* 1987, Brooker and Kleinig 1990, Ruthrof 2001), with reports of mass flowering occurring in populations every five to eight years and patchy flowering occurring intermittently (Keene and Cracknell 1972, Kay 1985). Similar patterns of mass flowering have been observed in other temperate eucalypts. For example, Ashton (1975) found in *Eucalyptus regnans* that during poor flowering years some trees flowered, but others did not and attributed this to individuals having their own cycle of bud production. Heavy flowering years occurred when there was a coincidence of phases between individuals. As a consequence, seed production and supply in Tuart may show considerable temporal variation.

Breeding System and Pollination Biology

Previous to this publication (Coates *et al.*), no studies of Tuart's breeding system are known. The majority of eucalypts studied are hermaphroditic and protandrous with anthers dehiscing before the stigma becomes receptive, and have asynchronous flower development within the canopy (House 1997, Potts and Wiltshire 1997). As a consequence, flowers within and between inflorescences can be in the male or female phase and pollinators only need to move the relatively short distance between flowers which are in the male phase to flowers which are in the female phase within the same inflorescence or plant to effect pollination (House 1997). There is therefore ample opportunity for self pollination and indeed, to date, all eucalypts studied have a mixed mating system combining outcrossing and inbreeding (for reviews see Moran and Hopper 1987, Sampson *et al.* 1990, House 1997, Potts and Wiltshire 1997). On the balance of evidence from other eucalypts, it is highly probable that Tuart similarly has a mixed mating system with preferential outcrossing. Coates *et al.* (this publication) establishes that this indeed is the case with Tuart.

Similarly, there are no known comprehensive studies of Tuart's pollination biology but again there is much that can be inferred from studies of other species in the genus. In summary, eucalypts share the same basic floral structure but there is considerable variation between species in traits such as bud size, the number of flowers produced, flower and inflorescence size, filament colour, production and presentation of nectar, and flowering time (Pryor 1976, Griffin 1982, House 1997). This variation and associations of traits such as flower size and filament colour has led Sargent (1928), Pryor (1976), Ford *et al.* (1979) and Hopper and Moran (1981) to propose that floral traits evolved in the genus in response to the selective behaviour of different pollen vectors.

Ford *et al.* (1979), Hopper and Moran (1981) and Griffin (1982) have hypothesised that eucalypts which produce small, white or cream flowers (e.g. *Eucalyptus muelleriana* (Ireland and Griffin 1984); *Eucalyptus foecunda* and *Eucalyptus cylindrifolia* (Hawkeswood 1982); *Eucalyptus stellulata* (House 1997); and *Eucalyptus marginata* (Yates *et al*. 2002 submitted)) with low volumes of concentrated nectar grouped into large conflorescences attract many insects, and less frequently birds and mammals, whereas eucalypts which produce large flowers with yellow or red filaments (e.g. *Eucalyptus stoatei* (Hopper and Moran 1981); *Eucalyptus incrassata* (Bond and Brown 1979); *Eucalyptus rhodantha* (McNee 1995); and *Eucalyptus ramelliana* (Sampson *et al*. 1995)) and large volumes of dilute nectar attract fewer insects but larger, more active birds and mammals. These studies generally confirm the above hypothesis. On the basis of these studies it would be expected that Tuart is pollinated by insects and birds.

There are two records of two animal species visiting Tuart flowers, the Singing Honeyeater (*Lichenostomus virescens*) and Brown Honeyeater (*Lichmera indistincta*) (Brown *et al.* 1997). Recent studies of the floral visitors to Jarrah (*Eucalyptus marginata*) in a mixed Jarrah/Tuart woodland suggest that a diverse array of insects are involved in pollination of mass flowering white-flowered eucalypts (Yates *et al*. 2002 submitted). The study observed 84 insect species from five orders including: Hymenoptera (ants, bees and wasps); Diptera (flies); Coleoptera (beetles); Lepidoptera (moths and butterflies); and Blattadea (cockroaches). Studies of Tuart are likely to yield similar results and this is an area for further research.

Seedbank Dynamics

There are no known published studies describing the seed bank dynamics of Tuart. Research currently being undertaken has observed that on average four seeds, though this is variable, are stored in woody fruit for up to two consecutive flowering seasons (Ruthrof 2001). As a consequence, seed storage in the canopy may be high when heavy flowering seasons occur. Seeds are black, flattish to saucer shaped, often flanged, with a distinct reticulum and are 2-3 mm long.

Seeds are gradually released from the canopy seed store as a light seed rain throughout the year but particularly in the summer months (Ruthrof 2001). Similar patterns of seed fall have been observed in other temperate eucalypts (Cremer 1965, Andersen 1989, Yates *et al*. 1994, House 1997). Seeds are released from the canopy seed reserve in four ways:

1. when fruit dry out over summer months;
2. when branches subtending fruit die and capsules dry out;
3. when unopened fruit are blown from the canopy and dry out on the ground; and
4. when cockatoos and parrots feed on seeds and some escape predation and fall to the ground freely or in dissected fruit (Cremer 1965, Yates *et al*. 1994, Ruthrof 2001).

In a number of temperate eucalypts seeds can also be released from the canopy reserve *en masse* following disturbances such as fire (O'Dowd and Gill 1984, Burrows *et al.* 1990). This is also likely to be the case in Tuart which displays mass recruitment of seedlings following fire (see below).

Following dispersal from the canopy, seed on the soil surface is susceptible to predation. In temperate eucalypts the most commonly observed predators are ants (Ashton 1979, Andersen 1982, O'Dowd and Gill 1984, Abbott and van Huerck 1985, Wellington and Noble 1985b, Yates *et al.* 1995, Majer *et al.* 1997). Generally these studies have observed that seed predation occurs throughout the year, but is highest in the summer months when ants are most active. Studies undertaken have similarly observed that Tuart seed is also susceptible to predation by ants (Ruthrof 2001). In mixed Jarrah/Tuart woodland, ants removed 47% of Tuart seeds from seed baits (cafeterias) within 4 days. One species of ant, *Meranoplus* sp., was seen removing seed from a cafeteria and in a concurrent pitfall trapping study 8 granivorous ant genera were recorded. The most frequently trapped ants belonged to two genera, *Solenopsis* and *Iridomyrmex* (Ruthrof 2001).

Post-dispersal predation by ants clearly affects the number of seeds that enter the soil where they must persist until suitable conditions occur for germination. Studies of Tuart's soil seed bank dynamics currently being undertaken in mixed Jarrah/Tuart woodland have observed that Tuart seeds do not form a long lived soil seed reserve (Ruthrof 2001). When an artificial seed reserve was established, the number of seeds recovered declined with increasing exposure and most seeds had germinated within 6 months of the onset of winter rains (Ruthrof 2001). Similar observations have been made for a number of other temperate eucalypts (Yates *et al.* 1995).

Germination, Establishment and Growth: the Regeneration Niche

Studies on the germination physiology of seeds collected from Tuart in an urban remnant, Kings Park Bushland, have observed high viability (86%) and no innate dormancy (Ruthrof 2001). The studies observed that under laboratory conditions seeds did not respond to commonly reported external dormancy breaking stimuli such as smoke. Seeds germinated readily at temperatures ranging from 13° to 23°C, with maximum germination at 13°C (Ruthrof 2001). Investigations of germination under field conditions observed that seeds sown into mixed Jarrah/Tuart woodland unburnt for 2 and 10 years germinated with the onset of the winter rains, but seedlings failed to survive the first summer.

The information presented thus far suggests that Tuart shares life history characteristics with eucalypts that recruit seedlings following large scale disturbances such as fire (O'Dowd and Gill 1984, Wellington and Noble 1985a). These characteristics include: canopy seed stores (Grose 1957 and 1960, Christensen 1971, Ashton 1975, Cremer *et al.* 1978, Wellington and Noble 1985a, Davies and Myerscough 1991); heavy seed predation by ants (Ashton 1979, O'Dowd and Gill 1984, Andersen and Ashton 1985, Wellington and Noble 1985b); the absence of a persistent soil seed bank (Carol and Ashton 1965, Barbour and Lange 1967, Wellington and Noble 1985a); and the failure of seedlings to establish during inter-fire periods (Wellington and Noble 1985a, Yates *et al*. 1996).

Indeed, recent studies both in an urban mixed Jarrah/Tuart woodland, Kings Park, and in relatively unfragmented woodland at the more southerly end of the Tuart's distribution, have observed mass recruitment of Tuart seedlings following fire (Ruthrof 2001). Widespread recruitment of Tuart seedlings in Kings Park was particularly evident following a fire in 1996. In the second winter after the fire there was an average of 52 seedlings in 5 m x 5 m quadrats with as many as 101 seedlings being recorded. The seedlings had relatively high growth rates and were, on average, 90 cm high with the tallest seedling being 215 cm.

Seedling recruitment following fire has been attributed to a number of interactions such as changes in seed dynamics and increased abundance of safe sites for germination and establishment (Wellington and Noble 1985a). It has been observed that fire induces a massive and synchronous release of all canopy stored seed (O'Dowd and Gill 1984, Andersen 1988, Burrows *et al.* 1990) which causes a temporary satiation of seed eating ants, resulting in lower rates of seed predation (O'Dowd and Gill 1984, Wellington and Noble 1985b, Andersen 1988) and the establishment of a temporary soil seed bank. However, fire also increases the abundance of safe sites for germination and establishment (O'Dowd and Gill 1984, Andersen 1987 and 1989) through its effects on soil physical, chemical and biological properties (Humphreys and Craig 1981, Walker *et al.* 1986). These changes influence seedling emergence, growth and survivorship (Pryor 1960 and 1963, Loneragan and Loneragan 1964) by increasing the availability of nutrients (Humphreys and Lambert 1965, Tomkins *et al.* 1991, Bauhus *et al.* 1993, Chambers and Attiwill 1994) and destroying the soil-litter complex of micro-organisms inhibitory to plant growth (Renbuss *et al.* 1973, Bell and Williams 1997); reducing competition, particularly in gaps created by the death of adult plants (Wellington and Noble 1985a) and removing the natural enemies of seedlings (Whelan and Main 1979, Whelan *et al.* 1980) .

Herbivory

Like most eucalypts, Tuart provides a resource for a range of leaf eating and wood boring insects and there are a number of herbivores and parasites that can affect the growth of seedlings and adults. There are no known detailed studies of herbivory in Tuart beyond describing the most common herbivores. Fox and Curry (1979) have listed a number of these. Insects feeding on foliage include leaf eaters such as the Tuart Miner (*Nepticula* sp. Nepticulidae Lepidoptera) and sawfly larvae (*Perga* sp. Pergidae Hymenoptera) and leaf suckers like leaf hoppers (Eurymeliadae Membracidae Hemiptera), shield bugs (Pentatomidae Hemiptera), and lerps (Psyllidae Hemiptera) (Fox and Curry 1979). Wood boring insects include: Tuart Borer (*Phorocantha impavida* Cerambycidae Coleoptera); *Culama* sp. (Cossidae, Lepidoptera); Stem Girdler (*Cryptophasa unipunctata* Lepidoptera); and Pinhole Borer (*Attractocerus kreuslerae* Lymexylidae Coleoptera) (Fox and Curry 1979).

CONSERVATION ISSUES

Large areas of Tuart woodland have been cleared for both urbanisation and agriculture throughout the species' range. Beard and Sprenger (1984) estimated that approximately 94% of Tuart woodlands and 90% of Tuart/Jarrah woodland have been cleared. More recently Hopkins *et al*. (1996) estimated that 90% of medium Tuart woodland, 96% of medium Tuart and Tuart/Jarrah woodland and 80% of medium open Tuart woodland have been cleared. Nowhere is this more evident than on the coastal strip which encompasses the rapidly growing areas of the greater Perth Metropolitan Region and Mandurah, which coincides with the central portion of Tuart's distribution. In this area Tuart woodlands are fragmented and subjected to disturbance regimes which differ in type, frequency, intensity and scale to that experienced by woodlands prior to European settlement.

The impacts of fragmentation and changed disturbance regimes are affecting many remnant Tuart woodlands, transforming community structure and species composition; the least resilient species are declining in abundance, some species are showing no change and others, predominantly exotic species though not always, are increasing in abundance (Recher and Serventy 1991, Dixon *et al*. 1995). There is considerable anecdotal evidence, and some scientific evidence, to suggest that Tuart is one species which is declining in a number of urban woodland remnants. This trend is well documented at Star Swamp in the northern suburbs of Perth where Piggot (1994) measured decline in Tuart canopy cover from 30% in 1953 to 7% in 1988. Piggot suggested this decline was associated with weed invasion and increased frequency of fire, weakening adult trees and impacting on recruitment.

Indeed, there is evidence in urban Jarrah/Tuart woodland remnants such as the Kings Park Bushland that invasion by the exotic grass *Ehrharta calycina* (Perennial Veldtgrass) has increased the frequency and intensity of fires and established a cycle that promotes fire and further invasion, and caused decline of native species and localized extinction of fire sensitive species (Wycherley 1984, Dixon *et al*. 1995).

It is seemingly a paradox that Tuart, which relies predominantly on fire for recruitment of seedlings and is relatively thick barked and able to resprout from epicormic buds, is declining in remnants which are frequently burnt. There are several explanations for this. Firstly, Tuart flowering is patchy in time and space and therefore the size of the canopy seed store may vary considerably between years. As a consequence, there may be considerable variation in the potential for seedling recruitment following a fire. Secondly, studies currently being undertaken in an urban Jarrah/Tuart woodland remnant indicate that it takes some time for a Tuart population recovering from fire to become reproductive. Ruthrof (unpublished data) observed that 3 years after fire 13% of resprouting adult Tuarts had buds but none held fruit within their canopy, and ten years after fire 60% of adults had buds and 73% had fruit. The exact time needed for Tuart to recover from fire and produce enough seed to recruit seedlings is unknown but these results suggest that the minimum time is between 4 and 9 years and that after a decade a considerable part of the population was not reproductive. Consequently, if a fire occurs before this time, it is unlikely that adult trees will have a canopy seed store available for synchronous seed release following a fire. Finally, Tuart generally does not form a lignotuber and seedlings and juveniles are therefore killed by fire until they reach a stem diameter where the bark is thick enough to protect sensitive cambial tissue. The time taken for juveniles to reach a size where they have some fire resistance is unknown but Fox (1981) has suggested that some resistance occurs after 3 to 4 years. In addition, mature Tuarts are regularly killed by fire when the fire breaches the bark and establishes in the wood. The fire continues internally after the causal fire, eventually killing the tree.

Clearly, increases in the frequency of fire have the potential to cause decline in Tuart populations and all efforts should be made to reduce the incidence of fire in urban remnants by reducing the abundance of weeds like Perennial Veldtgrass and quickly responding to and containing fires when they do occur.

Fragmentation and changes in the intensity and frequency of disturbance can have a direct impact on the abundance of Tuart. They can also affect the abundance of organisms that Tuart interacts with. It has been suggested that in urban remnants the abundance of naturally occurring wood boring insects including Tuart Borer *Phoracantha impavida*, Stem Girdler *Cryptophasa unipunctata* (Lepidoptera) and the moth larvae *Culama* sp. (Cossidae) may have increased as a consequence of their natural predators declining in numbers or becoming extinct (Fox 1981). For example, Carnaby's Cockatoo which feeds on the larvae of *P. impavida* and Grey Currawong which feeds on the adult borer have significantly declined or become locally extinct in many urban Tuart woodland remnants (John Dell pers. comm., Recher and Serventy 1991). Wood boring insects may cause considerable damage to Tuart, resulting in branch ring barking and even plant death. As a consequence, increased abundance of wood boring insects may be causing increased mortality in Tuart populations. Currently not enough is known about the factors which limit the distribution and abundance of wood boring insects and their relative abundances in disturbed urban woodland remnants and less disturbed relatively unfragmented Tuart woodlands. It is therefore difficult to assess whether the abundances of wood boring insects and rates of damage in disturbed urban remnants are within the range of what is observed in less disturbed relatively unfragmented Tuart woodlands. Clearly, determining the factors which limit the distribution and abundance of wood boring insects and documenting the spatial and temporal variation in their abundance would be fruitful areas for further research and provide important information for managing Tuart populations.

Fox (1981) has suggested that Tuart decline in some urban remnants may be due to increased rates of infection by fungi such as *Armillaria* and *Piptoporous*. Both fungi are regarded as secondary pathogens that invade weakened eucalypts (Palzer 1980). Evidence for fungal pathogens being a cause of decline is equivocal but it may be possible that increased frequency of fires in urban remnants has weakened trees and increased the amount of dead wood available for *Armillaria* and *Piptoporous* to invade. As with wood boring insects, there is little scientific data to determine whether rates of *Armillaria* have increased in urban remnants where Tuart is declining. Clearly this is an area worthy of further research.

It has been suggested that atmospheric pollution has had an adverse effect on Tuart populations (Seddon 1972, Chilcott 1992). Evidence for this is equivocal and must be viewed with caution as no long-term studies have been carried out on the direct impact of pollution on Tuart. Chilcott (1992) reported that the distribution of Tuart decline is generally restricted to urban areas and is worse in the Kwinana Industrial Area. General health increased with distance from the point of pollution. Chilcott (1992) concluded that the synergistic effect from the combination of SO_2 and NO_X pollution was acting to damage Tuart. However, revegetation trials with irrigated Tuart seedlings conducted by Meney and Fox (1986) showed that Tuart seedling survival was high (100% survival rate) at a site within the Kwinana industrial belt. Meney and Fox (1986) concluded that water availability was a more important factor than air pollution in determining early Tuart survival.

CONCLUSIONS

We have presented a brief review of what is currently known about the biology of Tuart. We have focused primarily on the ecological interactions which influence the distribution and abundance of the species; clearly there is still much to be learnt, in particular, how habitat fragmentation and disturbance influence the rates of these interactions. We suggest that the following avenues of research would be particularly useful:

- long term studies of reproductive phenology in both disturbed urban remnants and relatively undisturbed unfragmented woodlands;
- long term longitudinal monitoring of seedling cohorts and adult recovery following fire in both disturbed urban remnants and relatively undisturbed unfragmented woodlands;
- studies of the population dynamics and abundance of wood boring insects in both disturbed urban remnants and relatively undisturbed unfragmented woodlands;
- studies of Tuart pathology in both disturbed urban remnants and relatively undisturbed

unfragmented woodlands; and

- the development of management techniques for increasing Tuart abundance in remnants where it has declined.

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PERSONAL COMMUNICATIONS

Dell, John Department of Environmental Protection (previously Western Australian Museum)

FIGURES

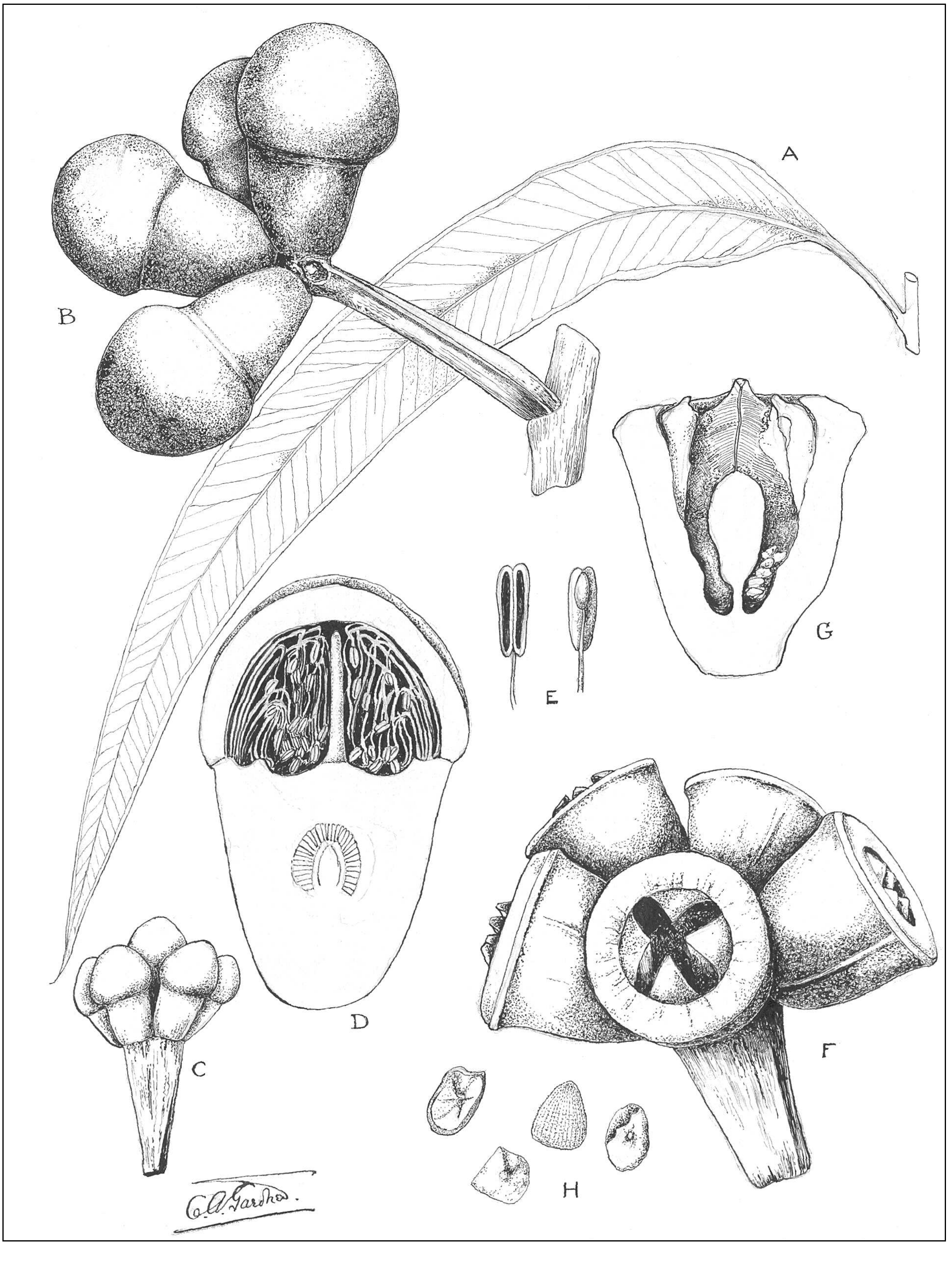

Figure 1. ***Eucalyptus gomphocephala* A. Leaf; B. Buds (x 1.5); C. Buds (x 0.5); D. Section of flower bud (x 2); E. anthers (much enlarged); F. Fruits (x1); G. Section of fruit (slightly enlarged); H. Seeds (much magnified) (Gardner 1987).** Reproduced from the original with the kind permission of the WA Herbarium.

FLORA OF TUART COMMUNITIES

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THE OCCURRENCE OF TUART IN PLANT COMMUNITIES ON THE SWAN COASTAL PLAIN

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ABSTRACT

An analysis was undertaken on the floristic variation of vegetation in which Tuart was known to occur. It was found that Tuart occurs in a wide range of community types, only some of which it dominates. The major environmental correlates with floristic composition were soil type and rainfall. Detailed soil chemical analysis of a subset of these sites showed Tuart to be tolerant of a suprisingly wide range of soil type. Generalized linear models suggested that soil pH and total phosphorous were the best predictors of Tuart occurrence and that Tuart and *Agonis flexuosa* had a higher probability of occurrence on soils with pH of over 7.3 than any of the other common canopy species. A model is proposed to describe Tuart occurrence on the Swan Coastal Plain.

INTRODUCTION

The natural distribution of Tuart extends for over 400 km from Jurien in the north to the Sabina River in the south, primarily along the coast but with outlying populations at Lowlands and Guildford on the eastern side of the Swan Coastal Plain. A detailed description of Tuart distribution is given in Keighery *et al.* (this publication). As a consequence of its broad distribution on the Coastal Plain, Tuart is not restricted to a single plant community but occurs in forests to very open mallee and from slopes of massive limestone ridges to seasonal wetlands.

In their regional overview of the vegetation complexes of the Darling System, Heddle *et al.* (1980) recorded Tuart forest and woodlands from seven of their landform units, with it being typical of four (Karrakatta - Central and South; Cottesloe - Central and South; Yoongarillup; and Vasse). Gibson *et al.* (1994) provided a regional classification of the vegetation of the southern Swan Coastal Plain based on species composition. In that classification Tuart was recorded from 10 of the 43 groups identified, with it being dominant in two of these (types 25 & 30b) (Table 1). Community type 25 typically occurs on Spearwood Dunes while community type 30b occurs on the younger Quindalup Dunes. Tuart has also been recorded from wetlands (type 17) and associated with river courses well east of the major distribution.

More recent complimentary floristic survey work on the Coastal Plain has resulted in further sampling of the Quindalup Dune system and seasonal wetlands, both habitats which were under sampled by Gibson *et al.* (1994). The results of this work have refined some of the earlier floristic group definitions and identified further floristic units in which Tuart occurs (Table 2).

The aim of the present paper is to examine the floristic variability of sites in which Tuart has been recorded and to examine similarities and differences of Tuart and other canopy species in relation to climate and soil parameters.

METHODS

Floristic Analysis

Species lists were available from a total of 64 sites which contained Tuart; the location of these sites is described in Keighery *et al.* (this publication). These sites came from the five studies outlined below.

- Gibson *et al.* (1994) – thirty-seven 10 m x 10 m quadrats from public lands which were scored on two occasions.
- DEP (1996) – fifteen 10 m x 10 m quadrats from public and private lands which were scored on one or two occasions.
- Keighery (1996) – six relevés, of approximately 100 m^2, from public lands which were scored once.
- Griffin (1993) – four relevés, of approximately 100 m^2, from public lands which were scored once. Two of these were from the Cervantes area and covered the under sampled northern part of Tuart's range (Figure 1).
- Griffin (1998) – two 10 m x 10 m quadrats from public and private lands which were scored once.

Within each site all vascular plants were recorded. Data on topographical position, slope, aspect, percentage litter, percentage bare ground, percentage exposed rock, and vegetation structure were collected from each site. Slope was scored on a one to three scale from flat to steep. Aspect was recorded as one of 16 cardinal directions. Vegetation structure was recorded using Muir's (1977) classification. Only taxa identified to at least species level were included in the analysis.

Sites were classified according to similarities in species composition. The site and species classifications undertaken used the Czekanowski coefficient and "unweighted pair-group mean average" fusion method (UPGMA, Sneath and Sokal 1973). Nomenclature generally follows Paczkowska and Chapman (2000).

Modelling Tree Species Distributions

Detailed soil chemistry and climatic data has recently become available for most of the 509 sites used in regional floristic classification (Gibson *et al.* 1994). Generalized linear models were produced for canopy species using binomial error structure and logit link function (Crawley 1993). Models were step-wise additive where terms were added if a 5% decrease in scaled deviance was achieved. At 505 sites, 24 soil samples were collected from the A horizon; these were bulked then analyzed for pH, electrical conductivity, total nitrogen, total phosphorous, percentage sand, percentage silt, percentage clay, exchangeable calcium, exchangeable magnesium, exchangeable potassium and exchangeable sodium using standard methods (McArthur 1991). Estimates of mean annual temperature and mean annual rainfall were derived from the BIOCLIM model of Busby (1986).

RESULTS

Floristic Analysis

A total flora of 414 taxa was recorded from the 64 sites; of these, 137 (33%) were only recorded once. After Tuart, the most widespread native taxa were *Hardenbergia comptoniana* (49 sites), *Daucus glochidiatus* (39 sites) and *Trachymene pilosa* (38 sites). Ninety weeds were recorded, of which 23 occurred in only one site while three (*Hypochaeris glabra*, *Sonchus oleraceus* and

Anagallis arvensis) occurred in more than half the sites.

Preliminary analysis showed that the singletons added little information and were excluded from the analysis. As a result the final data set consisted of 277 taxa in 64 sites. Species richness ranged from 6 to 69 taxa per site, with individual taxa occurring in between 2 and 64 sites.

The first division in the dendrogram gives a good separation of Spearwood sites (site groups 1 to 4) from Quindalup sites (site groups 5 to 12) (Figure 2). The Spearwood site groups (site groups 1 to 4) have much higher mean species richness than the Quindalup site groups with the exception of site group 2 which is a seasonal wetland (Table 3).

Site group 1 contains the typical Tuart dominated woodlands generally restricted to areas south of Pinjarra (Figure 1) grading into Tuart - *Banksia attenuata* woodlands. Most sites in this group were classified into community types 25 and 21a in the Gibson *et al.* (1994) regional classification. Outlying occurrences occur at Lowlands and Yellagonga, both these sites being adjacent to wetlands.

A single site in Tuart and *Banksia littoralis* over *Lepidosperma longitudinale* sedgeland forms site group 2. This site lies on a broad ecotone between Tuart woodland on the ridge above and a *Melaleuca* wetland; species richness is only half that of the other Spearwood site groups.

Site group 3 corresponds exactly to Gibson *et al*. (1994) community type 26b (woodlands and mallees on limestone) which generally occur around the base of the large limestone ridges in the Yanchep and Yalgorup areas. Species assemblage H differentiates this site group (Appendix 1). The final Spearwood site group (group 4) has a northern distribution replacing site group 1. Sites in this group include the Tuart over heaths grading into *Banksia attenuata* woodlands (Gibson *et al.* 1994). This group largely lacks species in species assemblages F, G, K and N that are typical of site group 1 (Appendix 1).

The Quindalup site groups tended to be somewhat more heterogenous than the Spearwood site groups and included three different wetland types. Site group 5 comprises the northern coastal Tuart sites extending from Cervantes to Woodman Point. These sites were Tuart over typical Quindalup shrublands. This grouping is consistent with Griffin's (1993) group 86 which included the two Cervantes sites groups with Tuart sites from Bold Park. The related site group 9 also occurs close to the coast but tends to have a more closed canopy and some of the shrub taxa are lacking, being replaced by herbs. The typical southern Quindalup Tuart - *Agonis* forests (type 30b - Gibson *et al.* 1994) occur in type 7 and are restricted to the coast in the Bunbury area (Figure 1). This site group has the highest mean species richness of the Quindalup groups (Table 3), and is differentiated by species assemblage G (Appendix 1).

Site group 6 is a heterogenous group made up of two sites on limestone along the Swan River and a dampland in a dune swale. The final upland group (site group 12) comprises disturbed Tuart woodlands over *Xanthorrhoea preissii* with a significant component of annual weed taxa (Figure 2, Appendix 1).

The three remaining Quindalup site groups are wetlands. Site group 8 comprises freshwater seasonal wetlands characterized by species assemblage P (Appendix 1); this site group was only recorded in the Yanchep area (Figure 1). *Melaleuca rhaphiophylla* was a co-dominant and *Carex appressa* was restricted to this site group.

Site group 10 consisted of a single site on a humus rich soil adjacent to the Moore River near Guilderton which was dominated by *Melaleuca rhaphiophylla* over *Baumea juncea*. This site was very species poor with only nine taxa being recorded.

The final site group (group 11) occurred in the Lake Cooloongup - Leda area and was dominated by Tuart and/or *Melaleuca rhaphiophylla* over *Gahnia trifida.* Soil chemical analysis (of one site in this group) showed the surface soils to be somewhat saline (Table 4).

Environmental Correlates

Given the direction of the major rainfall and temperature gradients along the Swan Coastal Plain, the geographic separation of sites groups strongly correlates with the regional climatic gradients. Within the Spearwood system, site groups 1 and 2 have largely southern distribution shown by higher mean annual rainfall and lower mean annual temperatures than site groups 3 and 4 (Table 5). Site group 7 is the cool temperature, high rainfall southern group of the Quindalup system, while groups 5, 8, 9 and 10 are drier and warmer than groups 11 and 12, reflecting their more northern distribution on the Plain (Table 5).

Soil chemical analysis is available for 37 of the 64 sites, covering 9 of the 12 groups. All Spearwood groups (groups 1 - 4) had lower mean pH than all Quindalup groups (Table 4). Site group 3, occurring on the massive limestone ridges, had a pH of 7.2, while the pH of the other Spearwood groups ranged from 6.4 to 6.5. The Quindalup site groups had pHs of between 7.6 and 8.7. Total phosphorous tended to be higher in the Quindalup groups while total nitrogen showed similar trends but the differences were not as marked. Electrical conductivity was generally low. Most site groups occurred on soils with percentage sand greater than 95%.

The exception to these general trends was a single site in group 11 (a saline wetland) for which data is available. This site had very high levels of phosphorous and all other nutrients. Electrical conductivity and exchangeable magnesium were an order of magnitude higher than in all other sites. These differences are likely to be directly related to the very high clay content (in excess of 20%) of the soils at this site. No soil data is available from the site in the humus rich wetland (site group 10).

Canopy Species Modelling

The floristic composition of sites in which Tuart occurs shows that it may be a characteristic component of a community (eg site groups 1, 4 and 7) or it may have a more opportunistic occurrence (eg the wetland groups). It could be useful to compare distributional and environmental data of Tuart with other major canopy species on the Coastal Plain to more precisely define its environmental tolerances. Inspection of the 64 Tuart sites indicates that it co-occurs with most tree species somewhere on the Plain (Table 6).

The most common canopy taxa with which Tuart co-occurs are *Banksia attenuata* (30% of sites) and *Agonis flexuosa* (25% of sites) while the least common co-occurrences were with *Banksia prionotes, Eucalyptus calophylla* and *Eucalyptus rudis* (each 2% of sites). The data did not include any co-occurrence with *Eucalyptus decipiens* (which has been observed) or with *Melaleuca lanceolata* (which has not).

Generalized linear models were produced of canopy species distribution based on species presence/absence in 505 data for which soil chemistry and climatic data were available. Models produced relate solely to the area of the Swan Coastal Plain south of the Moore River and extrapolation beyond this area may be misleading.

The percentage variance explained by the models ranged from 6.3% to 98.5%, with most taxa falling in the range of 15% to 30%. A series of taxa such as Jarrah and Marri have a continuous distribution in the southern part of the study area but show significant decrease in abundance in the northern area; others reach their northern distributional limits within the study area (eg *Agonis flexuosa*). Similarly, *Banksia menziesii* reaches it southern range limit within the study area. Models for these taxa include a broad scale climate parameter which is modified by soil parameters. Species that were more evenly distributed across the study area were generally found to be correlated to soil nutrient status or sand/silt percentages. For most taxa the variance explained by the models was less than 30%; however, for a few taxa of very limited distribution very precise models could be generated (Table 7).

The best single term model for Tuart's distribution was pH; this model could be further improved by the addition of a measure of total soil phosphorous. Phosphorous, by itself, gave no improvement in fit over the null model. A plot of total phosphorous against pH shows Tuart can occupy a wide range of soil pH from 5.5 to 8.7, generally at phosphorous levels of less than 200 ppm (Figure 3). However, the one saline wetland site for which we have data had total phosphorous levels of 774 ppm. Interestingly, electrical conductivity levels at this site were 244 mSm^{-1} or approximately 3.2% of the salinity of seawater.

The generalized linear models allow probabilities of occurrence to be calculated for each climate and soil attribute. A plot of the probabilities of occurrence of Jarrah, Marri, *Banksia menziesii, B. attenuata,* Tuart and *Agonis flexuosa* in relation to increasing pH shows the negative associations of the first four species and the positive associations of Tuart and *Agonis* (Figure 4). While Tuart had no significant relationship with total phosphorous, the *Banksia* species and Jarrah and Marri showed contrasting relationships (Figure 5). *Banksia attenuata* had very low probabilities of occurrence once total phosphorous rose above 100 ppm, while Jarrah and Marri showed a much more gradual decline in probability of occurrence with increasing phosphorous.

It should be emphasized that these models are only applicable on the Swan Coastal Plain south of the Moore River; *Agonis flexuosa*, for example, has much wider tolerance of soil types along the south coast where it occurs on coastal sands, clay and lateritic uplands.

DISCUSSION

It is clear from the analysis of the site data that Tuart can occur in many different community types (after Gibson *et al.* 1994), indicating wide environmental tolerances. The floristic analysis showed major differences in species composition between Tuart growing on the Spearwood and Quindalup land systems (Appendix 1). The major differences in species composition were correlated with major differences in soil nutrient status (Table 4). Within each of these major land systems Tuart occurred in a range of upland and wetland vegetation types, sometimes as the dominant of the community type but often only as an occasional element of those communities.

Tuart's wide environmental tolerance was confirmed by soil chemical analysis for 37 sites where Tuart occurs south of the Moore River. Tuart occurred on sites with pH ranging from 5.5 to 8.7 (Figure 3) and was the most likely canopy species to encountered on soils above pH 7.3 (Figure 4) which explains the early concept that this was a species of the highly calcareous coastal sands (Hutchins 1916, Kessell 1925). Tuart generally grows on sandy soils with low soil phosphorous but can occur on soil with clay contents of over 20% and phosphorous levels of over 750 ppm (Figure 3, Table 4). *Banksia* species are much more restricted in terms of soil phosphorous levels and soil type than Tuart (Figure 5).

Somewhat unusually for a eucalypt, Tuart grows in range of habitats from dry upland limestone ridges to fresh and saline wetlands. Soil chemical analysis confirms the observations of Kay (1985) that Tuart can tolerate a degree of salinity (Table 4). Tuart woodland becomes less common north of Perth and north of the Moore River is largely replaced by very open woodland, showing a strong correlation with rainfall gradients; it is nonetheless more common on the Coastal Plain north of Perth than either Jarrah or Marri.

A model is proposed for Tuart distribution on the Coastal Plain (Figure 6). This model recognizes the major environmental correlates in floristic composition (rainfall and soil type) and suggests factors (soil depth and depth to water table) that may be responsible for the differentiation of the floristic units within the different land systems.

The economic and aesthetic values of the southern Tuart forest have long been recognized (Hutchins 1916). What has not been appreciated until recently is just how large a range of soil types, climatic conditions and salinity levels can be tolerated by this species and, as a consequence, the wide range of community types with which it is associated.

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TABLES

TABLE 1. Community types (defined by Gibson *et al.* 1994) in which Tuart occurs and the dominant land system on which the Tuart sites occur. Communities where Tuart dominate are in bold.

Community type	Description	Land System
17	*M. rhaphiophylla* - *Gahnia trifida* seasonal wetlands	Spearwood
21a	Central *Banksia attenuata* - *E. marginata* woodlands	
24	Northern Spearwood shrublands and woodlands	
25	**Southern *E. gomphocephala* - *Agonis flexuosa* woodlands**	
26b	Woodlands and mallees on limestone	
28	Spearwood *B. attenuata* or *B. attenuata* - *Eucalyptus* woodlands	
29a	Coastal shrublands on shallow sands	Quindalup
30a	*Callitris preissii (*or *M. lanceolata)* forests and woodlands	
30b	**Quindalup *E. gomphocephala* and/or *A. flexuosa* woodlands**	
30c	Other mallees or scrubs	

TABLE 2. Additional community types (Gov of WA 2000) in which Tuart occurs and the dominant land system on which the Tuart sites occur.

Community type	Description	Land System
19b	Woodlands over sedgelands in Holocene dune swales	Quindalup
30c2	Woodlands and shrublands on Holocene dunes	
S11	Northern *Acacia rostellifera – Melaleuca acerosa* shrublands	
S15	Weedy group	

TABLE 3. Mean species richness by site groups also indicating number of sites and position in the landscape.

Site group	Mean species richness	Number of sites	Position in landscape
Spearwood 1	51.4	17	Upland
2	28.0	1	Wetland
3	48.9	8	Upland
4	46.8	13	Upland
Quindalup 5	23.1	7	Upland
6	28.0	3	Upland
7	38.0	3	Upland
8	29.5	2	Wetland
9	21.0	3	Upland
10	9.0	1	Wetland
11	21.0	4	Wetland
12	25.5	2	Upland

TABLE 4. Mean values of soil parameters for nine of the twelve major site groups for which soil data was available (37 sites). Values were derived from a bulked soil sample taken from 0-10 cm layer.

Soil parameters	1	2	3	4	5	6	7	11	12
Electrical conductivity (mSm^{-1})	5.69	4.00	4.67	6.00	9.00	10.0	10.0	244.0	17.5
pH	6.5	6.4	7.2	6.5	8.7	7.6	8.0	8.3	8.0
Sand (%)	96.8	97.0	95.8	96.3	97.5	94.3	96.5	51.5	94.0
Silt (%)	1.6	1.5	1.3	2.2	0.8	2.0	1.3	26.0	2.0
Clay (%)	1.6	1.5	2.8	1.5	1.8	3.8	2.3	22.5	4.0
Total N (%)	0.083	0.066	0.051	0.047	0.070	0.083	0.140	0.841	0.114
Total P (ppm)	74.8	40.0	80.3	52.6	115.0	110.5	134.0	774.0	157.5
Exchangeable Ca (me%)	5.28	4.00	3.33	4.57	4.35	5.17	12.71	15.67	8.98
Exchangeable Na (me%)	0.113	0.090	0.053	0.084	0.070	0.095	0.068	5.020	0.340
Exchangeable K (me%)	0.079	0.060	0.048	0.053	0.035	0.110	0.050	0.670	0.250
Exchangeable Mg (me%)	0.977	0.900	0.498	0.588	0.415	0.455	1.250	10.850	0.695

TABLE 5. Mean site group value for annual rainfall and annual temperature (standard deviation in brackets) estimated by BIOCLIM climate model based on 67 Tuart sites.

Site group	Mean annual rainfall mm (SE)	Mean annual temperature °C (SE)
1	914 (48.4)	17.0 (0.50)
2	905	17.6
3	831 (66.8)	18.1 (0.92)
4	812 (22.8)	18.2 (0.20)
5	753 (76.3)	18.5 (0.40)
6	849 (62.7)	17.6 (0.84)
7	908 (10.6)	16.7 (0.06)
8	798	18.4
9	778 (18.5)	18.1 (0.06)
10	789	18.6
11	845 (11.6)	17.8 (0.05)
12	835 (11.3)	17.9 (0.07)

TABLE 6. Percentage co-occurrence of canopy with Tuart in the 64 sites analysed.

Tree species co-occurring with Tuart	Number of sites	Percentage
Agonis flexuosa	16	25
Allocasuarina fraseriana	5	8
Banksia attenuata	19	30
Banksia grandis	8	13
Banksia littoralis	2	3
Banksia menziesii	2	3
Banksia prionotes	1	2
Callitris preissii	2	3
Eucalyptus calophylla	1	2
Eucalyptus marginata	8	13
Eucalyptus rudis	1	2
Melaleuca rhaphiophylla	5	8
Nuytsia floribunda	3	5

TABLE 7. Models of canopy species distribution based on 505 sites from Gibson *et al.* (1994) for which soil chemistry and climatic information is available. Terms were retained where stepwise addition resulted in decreased scaled deviance by at least 5%.

Tree species co-occurring with Tuart	Model terms	Fitted scaled deviance	Total scaled deviance	% explained by model	Number of occurrences
Agonis flexuosa	Temp + pH + Sand	134.5	210.6	36.1	16
Allocasuarina fraseriana	P	258.6	294.0	12.0	5
Banksia attenuata	P + Silt	306.5	646.5	47.4	171
Banksia grandis	Temp + EC	234.8	264.6	11.2	8
Banksia littoralis	N	76.9	82.1	6.3	8
Banksia menziesii	Temp + P + Sand	238.4	476.4	49.9	91
Callitris preissii	pH + Rain + Temp	25.1	65.1	61.4	6
Eucalyptus calophylla	Rain + EC + K	355.3	413.7	14.1	72
Eucalyptus decipiens	pH + EC + Ca	62.7	82.1	23.6	8
Eucalyptus gomphocephala	pH +P	223.1	264.6	15.7	37
Eucalyptus marginata	Temp + P + Sand	392.7	479.4	18.1	92
Eucalyptus rudis	pH +N	130.8	161.9	18.6	19
Melaleuca lanceolata	pH + P + Silt	0.7	46.6	98.5	4
Melaleuca rhaphiophylla	Na + Sand	169.2	233.0	27.3	31
Nuytsia floribunda	pH + Mg	283.1	303.5	6.7	45

FIGURES

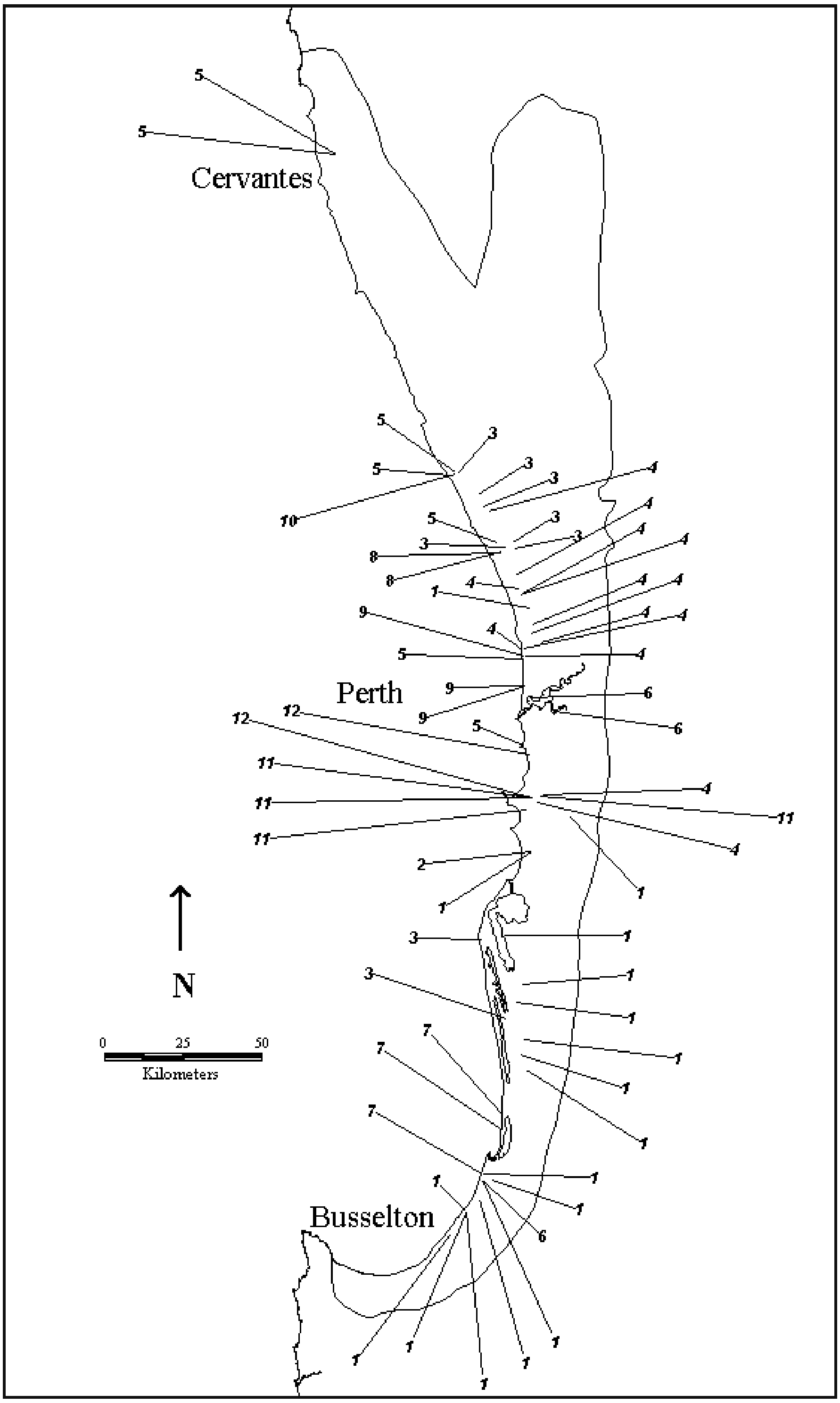

Figure 1. Map of the Swan Coastal Plain showing the locations and site groups of the 64 Tuart sites. Inland boundary of the Swan Coastal Plain Bioregion shown.

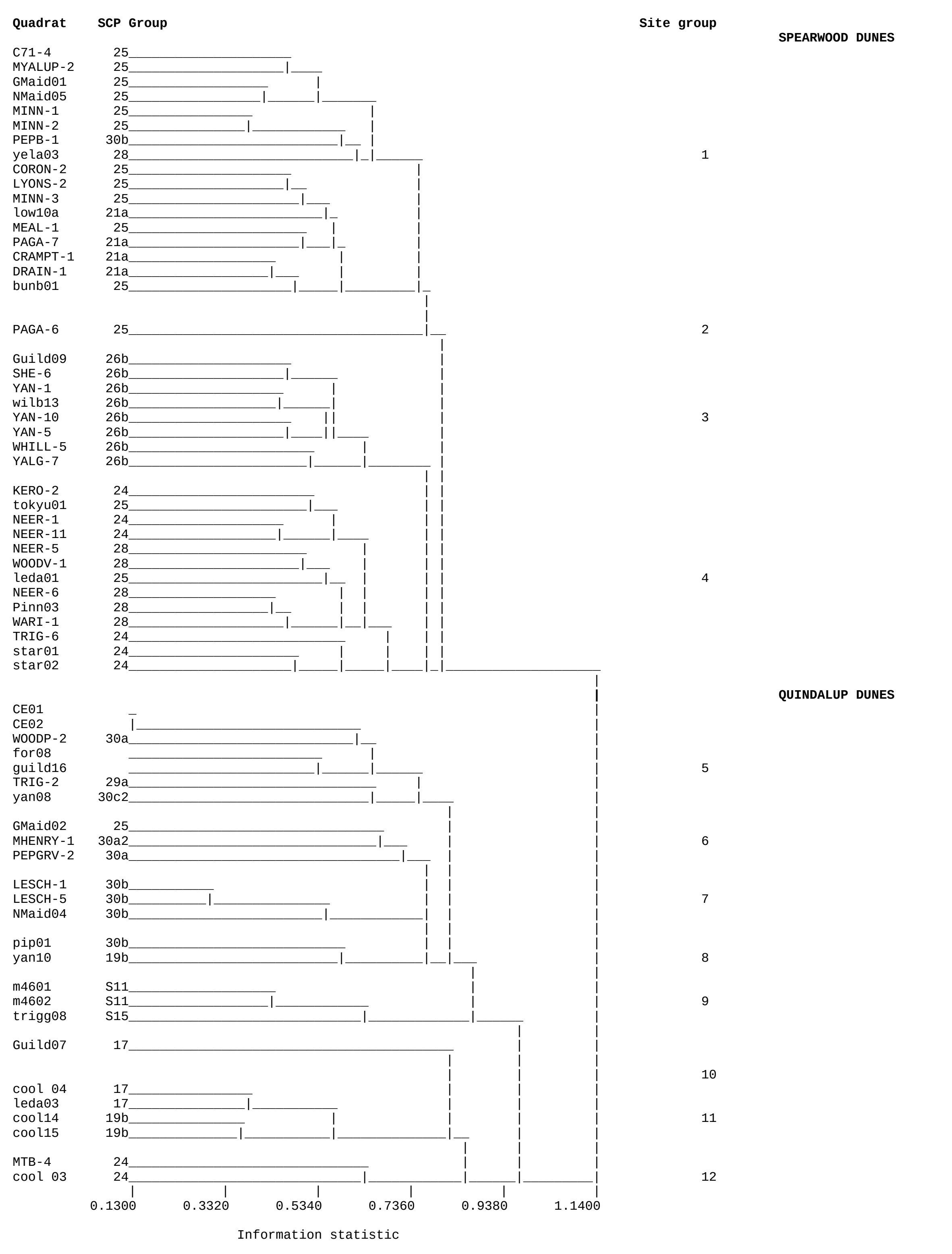

Figure 2. Dendrogram of the 64 Tuart sites showing major site types. The community types identified in Gibson *et al.* (1994) and Gov of WA (2000) are shown under 'SCP group'.

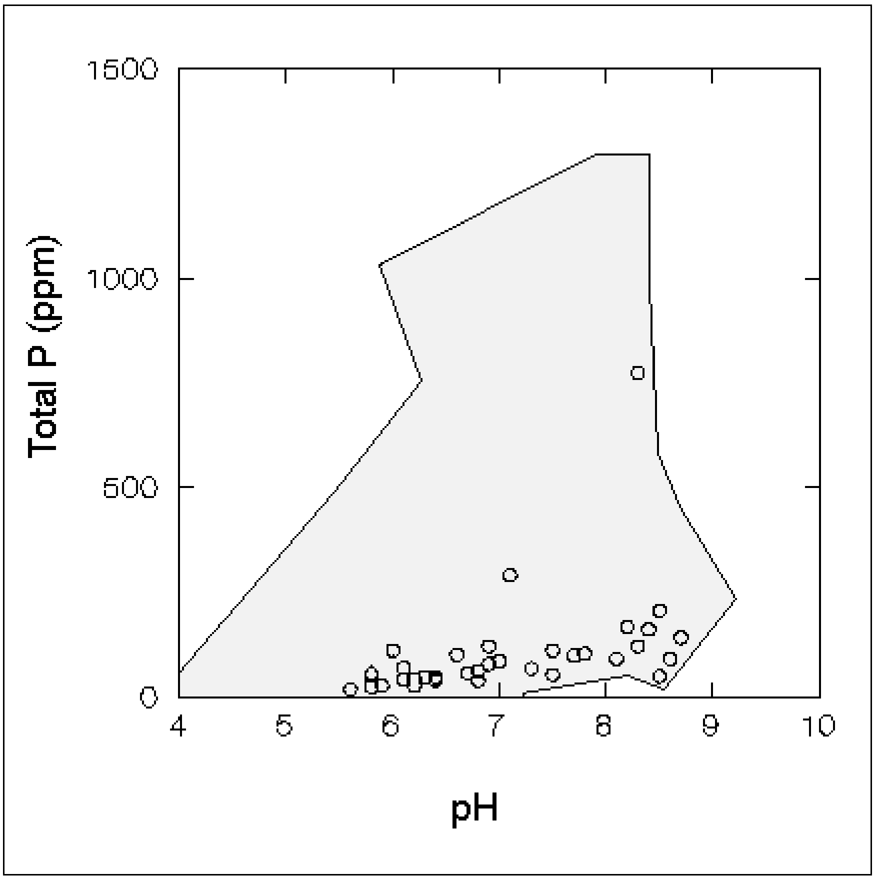

Figure 3. Plot of pH against total phosphorous. Shaded area shows the environmental domain of these factors on the Coastal Plain, circles represent locations of Tuart sites in this environmental space.

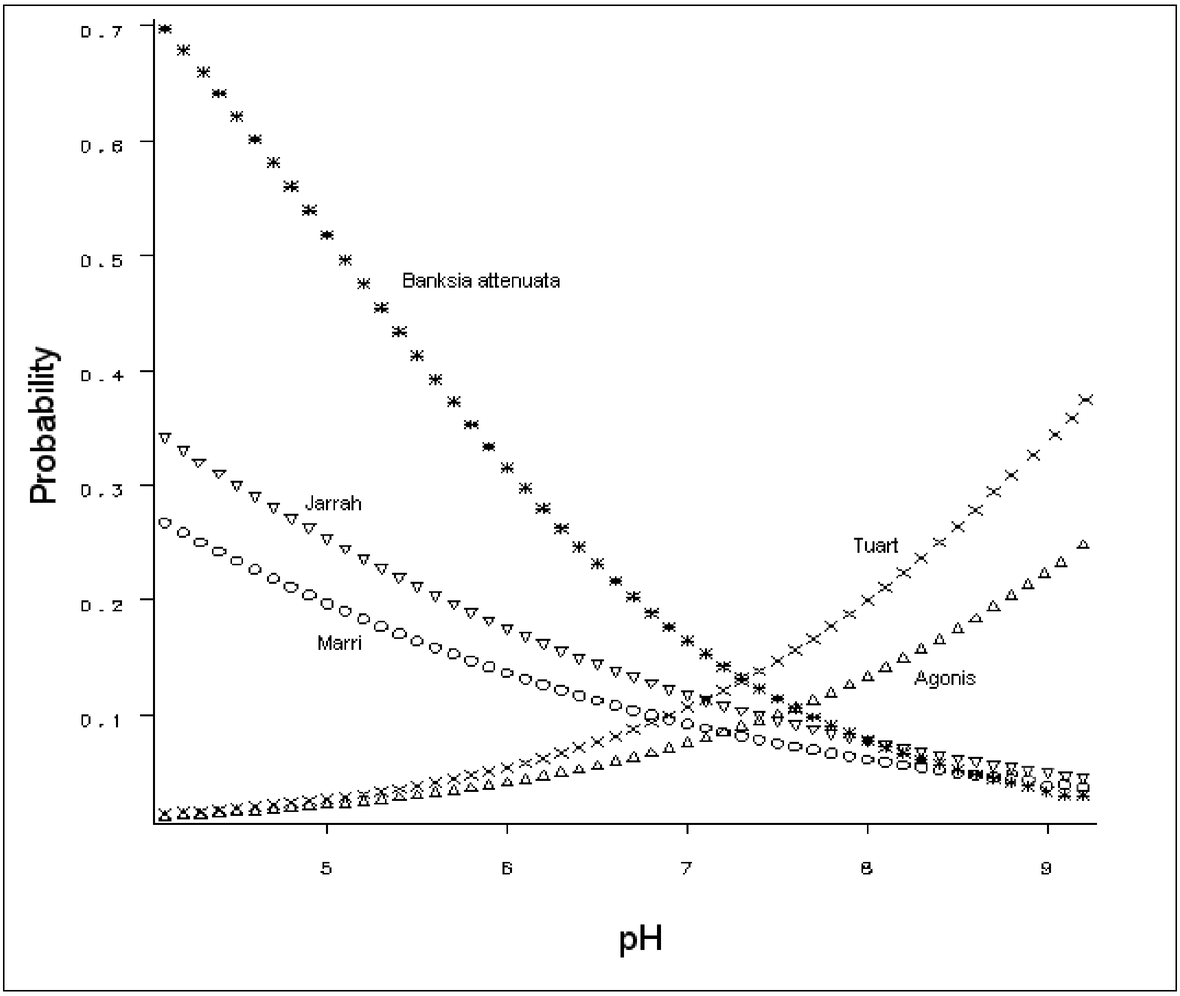

Figure 4. Probability of occurrence of major canopy species against pH as determined by generalized linear models.

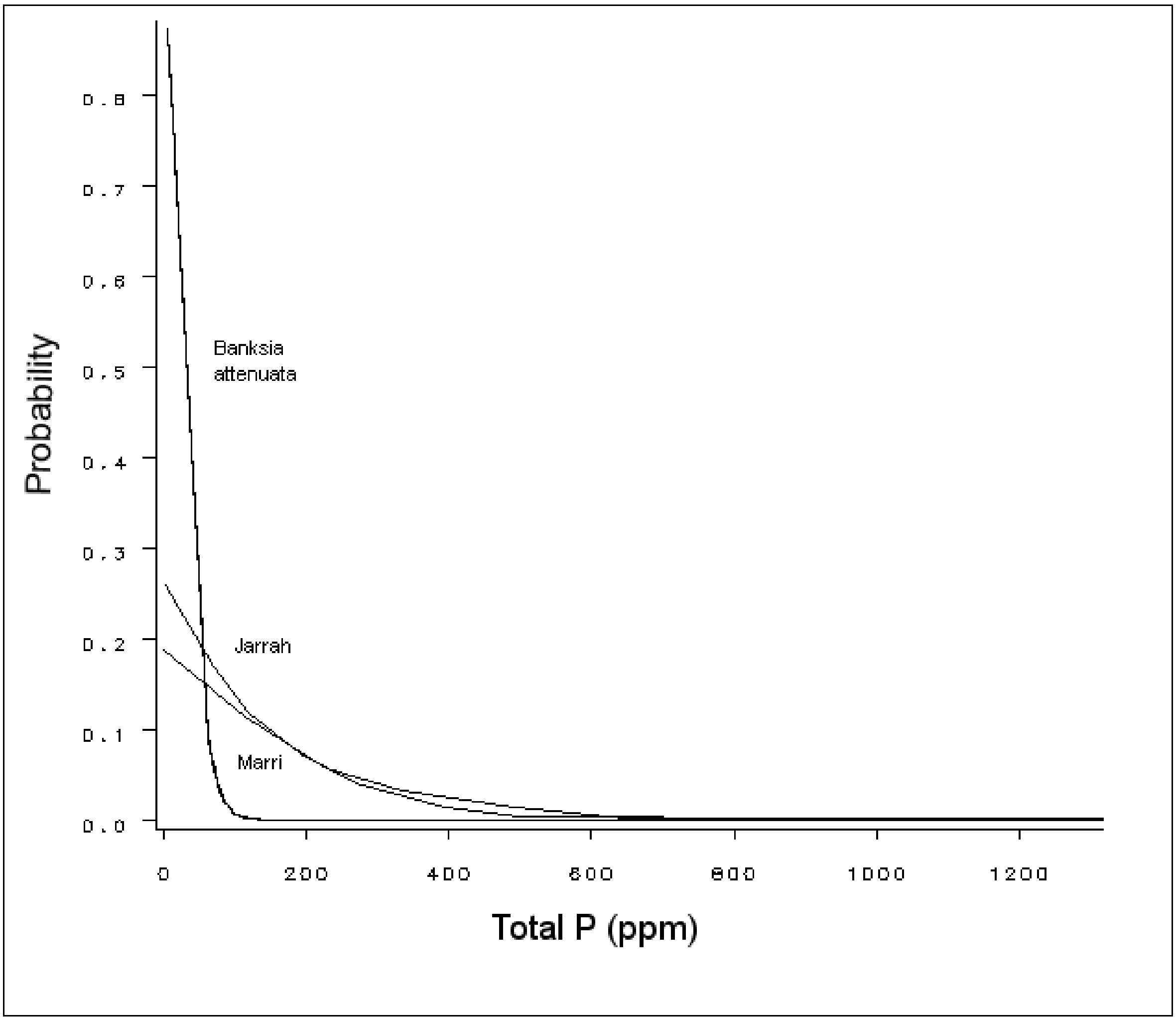

Figure 5. Probability of occurrence of selected canopy species against total phosphorous as determined by generalized linear models.

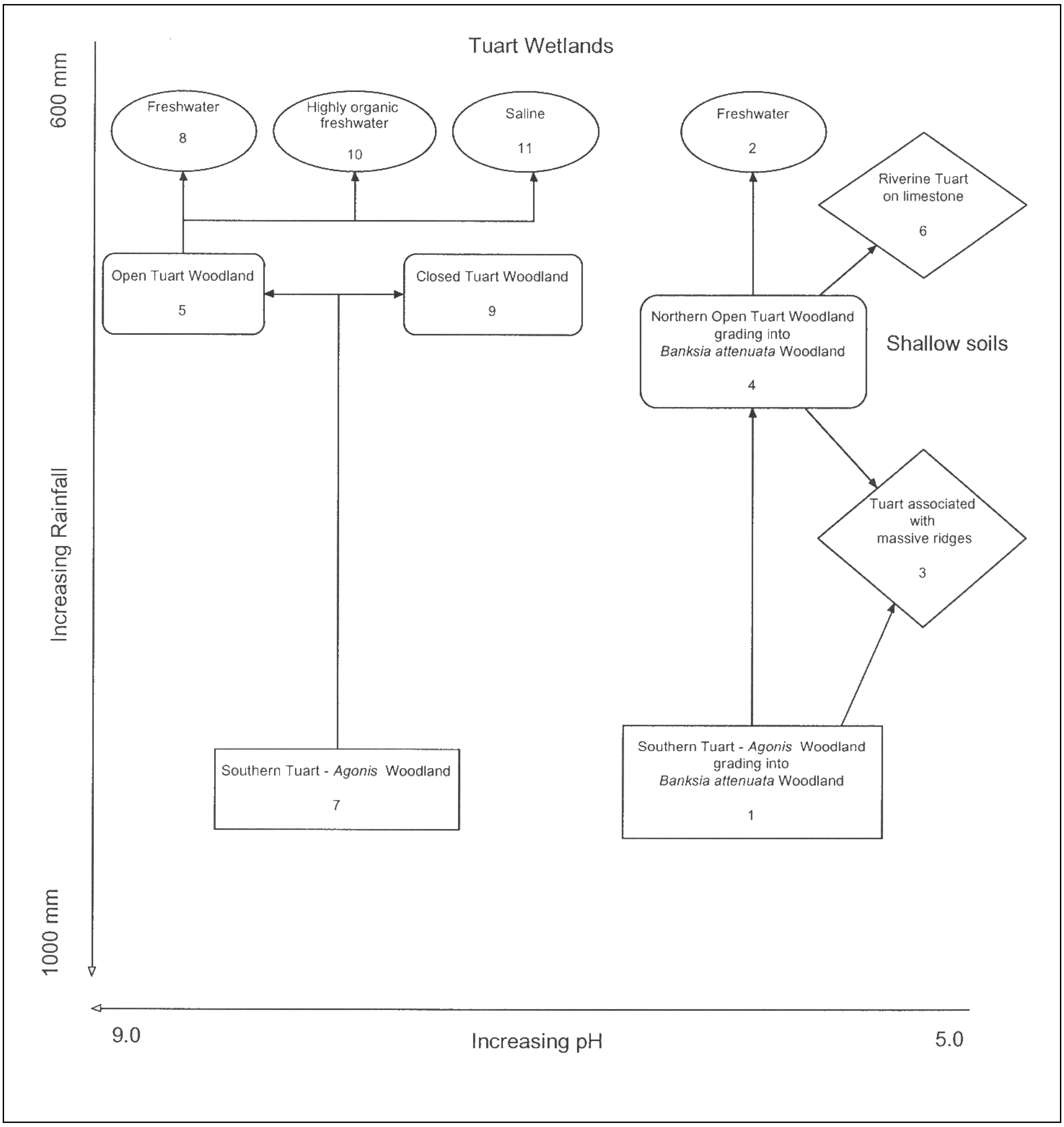

Figure 6. Proposed model of Tuart distribution on the Coastal Plain as a function of rainfall, pH, soil depth, depth to water table and salinity.

APPENDIX 1. Sorted Two Way Table Showing Species Occurrences by Sites and Site Groups.

Site names are in the columns.

```
                                                                       Site Groups                                    Spp.Groups
                                                  1        2     3        4            5     6   7   8  9 10  11  12

                                         CMGNMMPyCLMlMPCDb|P|GSYwYYWY|KtNNNWlNPWTss|CCWfgTy|GMP|LLN|py|mmt|G|clcc|Mc
                                         7YMMIIEeOYIoEARRu|A|uHAiAAHA|EoEEEOeEiARtt|EEOouRa|MHE|EEM|ia|44r|u|oeoo|To
                                         1AaaNNPlRONwAGAAn|G|iENlNNIL|RkEEEOdEnRIaa|00OriIn|aEP|SSa|pn|66i|i|odoo|Bo
                                         -LiiNNBaONN1LAMIb|A|l--b--LG|OyRRRDaRnIGrr|12D0lG0|iNG|CCi|01|00g|l|lall|-l
                                         4Udd---0NS-0--PN0|-|d61115L-|-u---V0-0--00|  P8d-8|dRR|HHd|10|12g|d| 011|4
                                          P001213--3a17T-1|6|0  30 -7|20115-1631612|  - 12 |0YV|--0|  |  0|0|0345| 0
                                          -15    22    -1 | |9     5 | 1 1 1       |  2 6  |2--|154|  |  8|7|4   | 3
                                          2            1  | |        |             |       | 12|   |  |   | |    |

                                                          | |        |             |       |   |   |  |   | |    |
Acacia cochlearis                          **         *   | |*       |             |       |   |  *|  |   | |  **|
Synaphea spinulosa                         **         *   | |        |             |       |   |   |  |   | |    |
Lepidosperma squamatum                     **            *| |        |             |       |*  |   |  |   | |    |
Leucopogon parviflorus                     ***  *         | |    *   |  *          |   * * |*  |  *|  |   | |    |*
Diplolaena angustifolia                                   | |        |             |   **  |   |   |  |   | |    |         A
Poa poiformis                              **             | |        |             |   **  |   |  *|  |   | |    |
Acacia pulchella                                    *     * | |   **   |      *  * **|       |*  |  *|**| **| |  * |
Lepidosperma gladiatum                                    | |        |             |       |** |* *|* |***| |    |
Euphorbia terracina                                       | | *      |             |       |   |   |  |* *| |    |
Calandrinia corrigioloides                                | |        |    *        |       |   |  *|  |   | |    |
Exocarpos sparteus                                        | |        |             |       |   |  *|  | * | |    |
Eremophila glabra                          *              | |        |             |       |  *|  *|  |   | |    |
Thysanotus patersonii                     **       **     | |   *    |       *     |       |***|  *|  |   | |    |
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+----+--
Pterostylis nana                                          | |        | *           |       |*  |   |  |   | |    |
Urospermum picroides                                      | |*       | *           |       |   |   |  |   | |    |         B
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+----+--
Acacia lasiocarpa                                         | |        |             |    *  | * |   |  |   | |    |
Eriochilus dilatatus                           *          | |        |             |       | * |   |  |   | |    |
Asparagus asparagoides                         *          | |        |  *          |  **   |  *|   |  |*  | |    |
Carduus pycnocephalus                          *          | |        |  *          |       |   |   |  |   | |    |
Adriana quadripartita                                     | |        |             |       |   |   |* |   | | *  |         C
Pittosporum phylliraeoides                                | |        |             |       |  *|   |* |   | |    |
Geranium solanderi                         *              | |        |      *      |       |   |   |* |   | |    |
Callitris preissii                                        | |        |             |     * |  *|   |  |   | |    |
Fumaria capreolata                                        | |        |             |       |  *|   |  |*  | |    |
Scaevola crassifolia                                      | | *      |             |       |  *|   | *|   | |    |
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+----+--
Acacia saligna                                            | |        |  *       *  |      *|   |   | *|  *| | ***|**
Euphorbia peplus                                          | |        |             |  *    |*  |   |  |  *| |  **|*
Hydrocotyle diantha                           *    *      | |      * |             |       |*  |   |  |   | |  **|
Opercularia hispidula                     *   *           |*|        |             |       |*  |   | *|   | | * *|
Centella cordifolia                                       | |        |             |       |   |   |  |   | |*** |
Gahnia trifida                                            | |        |             |       |*  |   |  |   |*|****|         D
Logania vaginalis                                         | |        |             |       |* *|   | *|   | | ** |
Templetonia retusa                          *             | |        |             |       |***| **|  |   | |* **|
Anthocercis littorea                                      | |        |             |       |   |   |  |   | |  **|
Trymalium albicans                                        | |        |             |       |  *|   |  |   | |  **|
Trachymene coerulea                              *        |*|        |             |       |   |** |  |   | |  **|
Muehlenbeckia adpressa                                    | |        |             | *     |   |   |  |   | |  * |
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+----+--
Acanthocarpus preissii                   * **             | |**   *  |  **    *   *|*******|  *|***|  |** | |*   | *
Rhagodia baccata                           * * *          | |** *  **|  **      *  |** ****|  *|***|**|***| |    | *
Spyridium globulosum                       * * *          | |*     * |             |*******|***|** |**|   | |    |
Acacia rostellifera                                       | |      * |           * |***    |   | * |  |** | |    |*
Clematis linearifolia                     *      *        | |        |          *  |***    |   | * | *|*  | |** *|*
Helichrysum cordatum                     **               | |        |          * *|**     |   |   |  |   | |    |         E
Olearia axillaris                        * *              | |       *|          *  |**     | * |   |  |***| |    |
Bromus arenarius                                          | |        |             |**  *  |   |   |  |   | |    |
Ehrharta brevifolia                                       | |        |             |**     |   |   |  |   | |    |
Comesperma integerrimum                                   | |        |             |*****  |   |   |  |   | |    |
Stipa elegantissima                                       | |        |             |***    |  *|   |  |   | |    |
Isolepis nodosa                              *            | |        |             |**     |*  |   | *|   | |    |
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+----+--
Astroloma ciliatum                        *        *      | |       *|             |       |   |   |  |   | |    |
Craspedia sp. (GJK 13121)                 *        *    **| |        |             |       |   |   |  |   | |    |
Pterostylis aff. nana                     *   *   **      | |      **|  *          |       | * |   |  |   | |    |
Lomandra suaveolens                      *    *    ** ** *| |  *     |     *       |       |   |   |  |   | |    |
Pterostylis vittata                           *    **  *  | |        |    *        |       |   |  *|  |   | |    |
Parentucellia latifolia                       *    *      | |        |             |       |   |   |  |   | |    |
Stipa semibarbata group                       *    *      | |        |             |       |   |   |  |   | |    |         F
Waitzia suaveolens                            *    *      | |     *  |             |       |   |   |  |   | |    |
Avena barbata                              * **          *| |        |  **         |       |   |   |  | **| |    |
Orthrosanthus laxus                      *   **    *     *| |        |   *   **    |       |   |   |  |   | |    |
Eucalyptus marginata                         **     *  *  | |       *|* *   *      |       |   |   |  |   | |    |
Geranium molle                               **           | |       *|  *    *     |       |   |   |  |*  | |    |
Trifolium cernuum                            ***          | |        |             |       |   |   |  |   | |    |
Veronica arvensis                            **           | |        |             |       |   |   |  |   | |    |*
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+----+--
Calandrinia brevipedata                                   | |      * |             |     * |   |** |  |   | |    |
Hydrocotyle alata                                         | |        |             |       |   |** |  |   | |    |
Senecio lautus                             *  *   *       | |      * |             | *   * |   |** |  |   | |    |
Carex preissii                                **          | |*       |  *          |       |   |***|  |  *| |    | *
Galium murale                            *   ***          | |*  *    |             |  *  * |   |** |  |   | |  * |*        G
Dichondra repens                             * *          | |        |             |       |*  |** |  |   | |    |
Hibbertia cuneiformis                       *****         | |        |             |       |   |** |  |   | |    |
Trachyandra divaricata                       *            | |        |             |  *    |   |** |  |   | |    |
Zantedeschia aethiopica                      * *    *     | |        |             |       |   |*  |  |   | |    |
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+----+--
Acacia cyclops                                            | | * **   |             |   * * |   |   |  |   | |    |
Persoonia comata                                          | | * ***  |             |       |   |   |  |   | |    |
Erodium botrys                                            | | *  *   |             |       |   | * |  |   | |    |
Nuytsia floribunda                                        | | *  *   | *           |       |   |   |  |   | |    |
Wahlenbergia preissii                                *     | |**  **  |      *      |       |   |   |  |   | |    |
```

```
                                                                    Site Groups                                    Spp.Groups
                                                  1        2     3        4             5      6   7    8  9 10  11  12
                                         CMGNMMPyCLMlMPCDb|P|GSYwYYWY|KtNNNWlNPWTss|CCWfgTy|GMP|LLN|py|mmt|G|clcc|Mc
                                         7YMMIIEeOYIoEARRu|A|uHAiAAHA|EoEEEOeEiARtt|EEOouRa|MHE|EEM|ia|44r|u|oeoo|To
                                         1AaaNNPlRONwAGAAn|G|iENlNNIL|RkEEEOdEnRIaa|00OriIn|aEP|SSa|pn|66i|i|odoo|Bo
                                         -LiiNNBaONN1LAMIb|A|l--b--LG|OyRRRDaRnIGrr|12D0lG0|iNG|CCi|01|00g|l|lall|-l
                                         4Udd---0NS-0--PN0|-|d61115L-|-u---V0-0--00|  P8d-8|dRR|HHd|10|12g|d| 011|4
                                          P001213--3a17T-1|6|0  30 -7|20115-1631612|  -  12|0YV|--0|  |  0|0|0345| 0
                                          -15    22     -1| |9     5 | 1 1 1       |  2 6  |2--|154|  |  8|7|4   | 3
                                          2            1  | |        |             |       | 12|   |  |   | |    |
                                                          | |        |             |       |   |   |  |   | |    |
Waitzia citrina                                   * *     | | * * * *|             |       |   | * |  |   | |    |
Conostylis candicans                              | |  * **  |   **  *     | ** ** |   |   | *|   | |    |
Conostylis setigera                                        | |    **  |             |       |   |   |  |   | |    |
Jacksonia stricta                                          | |  * **  |             |       |   |   |  |   | |    |
Sagina apetala                                             | |  * ****|             |       |   |   |  |   | |    |
Triglochin trichophorum                                    | |  *  ** |             |       |   | * |  |   | |    |
Carpobrotus virescens                                      | |   * *  |             |*      |   |   |  |   | |    |         H
Stipa compressa                                            | |   * *  |       * *   |       |   |   |  |   | |    |
Dryandra sessilis                                          | |* **    |           * |      *| **|   |  |   | |    |
Lomandra maritima                                          | |  **  **|   *      ** |  *   *|   |   |  |   | |    |
Haemodorum laxum                                           | |  **    |   *     *   |       |   |   |  |   | |    |
Petrophile macrostachya                                    | |  ***   |    *  * *   |       |   |   |  |   | |    |
Petrophile serruriae                                       | |  ***   |             |       |   |   |  |   | |    |
Hakea prostrata                             *              | |  **    |            *|       |   |   |  |   | |    |
Pelargonium littorale                       *              | |  **    |**           |       |*  |   |* |   | |   *|*
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+----+--
Allocasuarina humilis                                   * | |      * |          *  |       |   |   |  |   | |    |
Hakea lissocarpha                                          | |  *  ** |*    *    ** |       |   |   |  |   | |    |
Gnaphalium sphaericum                                      | |   *  * |      *      |       |   |   |  |   | |    |
Thomasia triphylla                        *                | |      * |             |       |   |   |  |   | |    |
Crassula glomerata                                         | |      * |*            |     * |   |   |  |   | |    | *
Dischisma arenarium                                        | |*     * |             | *  *  |   |   |  |   | |    | *
Bellardia trixago                        **      *         | |      **|             |       |   |   |  |   | |    |         I
Persoonia saccata                        **                | |       *|        *    |      *|   |   |  |   | |    |
Gompholobium polymorphum                         *         | |       *|             |       |   |   |  |   | |    |
Tetraria octandra                         *      *     *   | |    *  *|             |       |   |   |  |   | |    |
Hakea ruscifolia                                           | |       *|             |       |   |   |  |   |*|    |
Plantago major                                             | |      **|             |       |   |   |  |   | |    |
Melaleuca acerosa                                          | |       *|          *  |  *    |   |   |  |   | |    |
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+----+--
Calandrinia liniflora                                      | |     *  |      *      |       |   |   |  |   | |    |
Dischisma capitatum                                        | |        |      *     *|       |   |   |  |   | |    |
Glischrocaryon aureum                                      | |        |   *  *      |       |   |   |  |   | |    |
Conyza albida                            *          *      | |    *   |    **    *  |       | * |   |  |   | |   *|
Isolepis cernua                                     *      | |       *|    *        |       |*  |   |  |   | |   *|
Solanum nigrum                                             | | *      |     *    *  |     **|   |   |  |   | |*  *|
Crassula pedicellosa                                       | |        |    *       *|       |   |   |  |   | |    |         J
Pentaschistis airoides                                     | |        |    *  *    *|       |   |   |  |   | |    |
Drosera macrantha                                    *     | |        |   **        |       |   |   |  |   | |    |
Jacksonia sternbergiana                                *   | |        |  ***     * *|      *|   |   |  |  *| |    |
Schoenus clandestinus                                      | | *   *  |       **    |       |   |   |  |   | |    |
Trifolium dubium                                           | |       *|    * ***    |       |   |   |  |   | |    |
Sparaxis bulbifera                                         | |        |        * * *|       |   |   |  |   | |    |
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+----+--
Allocasuarina fraseriana                              *    | |        | * * **      |       |   |   |  |   | |    |
Banksia menziesii                                     *    | |        |     *       |       |   |   |  |   | |    |
Holcus setiger                                        *    |*|        |             |       |   |   |  |   | |    |
Stylidium piliferum                                 * *    | |        |             |       |   |   |  |   | |    |
Lepidosperma longitudinale                          *      |*|        |             |       |   |   |  |   |*|    |
Conostephium preissii                                **    | |        |             |       |   |   |  |   | |    |
Pimelea rosea                                        ***   | |        |             |       |   |   |  |   | |    |         K
Dichelachne crinita                         *      * **    | |        |             |       |   |   |  |   | |    |
Leucopogon racemulosus                               *     | |    *   |             |    *  |   |   |  |   | |    |
Podolepis lessonii                                   *     | |    *   |             |       |   |   |  |   | |    |
Podolepis gracilis                                   **    | |    *   |      **     |       |   |   |  |   | |    |
Poa drummondiana                         * *         **    | | * *   *|             |       |   |   |  |   | |    |
Ranunculus colonorum                         *       *     | |       *|             |       |   | * |  |   | |    |
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+----+--
Alexgeorgea nitens                                         | |        |     *  **   |       |   |   |  |   | |    |
Daviesia nudiflora                                         | |        |        **   |       |   |   |  |   | |    |
Wahlenbergia capensis                                      | |        |        **   |       |   |   |  |   | |    |
Conostephium pendulum                                      | |    *   |         *   |       |   |   |  |   | |    |
Podotheca angustifolia                                     | |        | *       *   |       |   |   |  |   | |    |
Triglochin sp. A  FPR (BJK&NG 095)                         | |        |         *   |       |   | * |  |   | |    |         M
Hypocalymma robustum                              *    *   | |        |     *   *   |       |   |   |  |   | |    |
Ptilotus drummondii                                        | |        |     **  *   |       |   |   |  |   | |    |
Trifolium arvense                           *           *  | |        |     *   *   |       |   |   |  |   | |    |
Daviesia triflora                                     *    | |        |*      ***   |       |   |   |  |   | |    |
Drosera menziesii                                  *  * *  | |        |       * *   |       |   |   |  |   | |    |
Opercularia vaginata                                  *    | |*       |         *   |       |   |   |  |   | |    |
Scaevola canescens                                    *    | |        |         *   |       |   |   |  |   | |    |
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+----+--
Avellinia michelii                                *        | |     *  |             |       |   |   |  |   | |    |*
Centaurium erythraea                                       | |        |             |       |   |   |  |   | |    |**
Comesperma confertum                      *                | |        |             |       |   |   |  |   | |    |*        N
Conyza bonariensis                                         | |        |         *   |       |   |   |  |   | |    |*
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+----+--
Anigozanthos manglesii                    *            *   | |        |             |       |   |   |  |   | |    |
Dampiera linearis                         *            *   | |        |             |       |   |   |  |   | |    |
Stylidium schoenoides                     *           **   | |        |             |       |   |   |  |   | |    |
Patersonia occidentalis                   *          * * * | |        |             |       |   |   |  |   | |    |
Bossiaea eriocarpa                        ** *       ***   | |  * *   |             |       |   |   |  |   | |    |
Drosera pallida                           *       *   * *  | |        |             |       |   |   |  |   | |    |
Xanthosia huegelii                        *           ***  | |        |     *       |       |   |   |  |   | |    |
Lomandra sericea                                 *    ***  | |        |             |       |   |   |  |   | |    |
Drosera stolonifera                       *      **  * **  | |        |             |       |*  |   |  |   | |    |
Conostylis juncea                                      **  |*|        |             |       |   |   |  |   | |    |         O
Dasypogon bromeliifolius                               **  | |        |             |       |   |   |  |   | |    |
Lomandra nigricans                                     **  | |      * |             |       |   |   |  |   | |    |
Lyginia barbata                                        **  | |        |*            |       |   |   |  |   | |    |
Astroloma pallidum                                    ** * | |        |        *    |       |   |   |  |   | |    |
Petrophile linearis                               *    * * | |        |*            |       |   |   |  |   | |    |
Xylomelum occidentale                             *      * | |        |             |       |   |   |  |   | |    |
Kunzea ericifolia                                   *   *  | |        |             |       |   |   |  |   | |    |
```

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                                                                       Site Groups                                    Spp.Groups
                                                  1        2     3        4            5     6   7   8  9 10  11  12

                                         CMGNMMPyCLMlMPCDb|P|GSYwYYWY|KtNNNWlNPWTss|CCWfgTy|GMP|LLN|py|mmt|G|clcc|Mc
                                         7YMMIIEeOYIoEARRu|A|uHAiAAHA|EoEEEOeEiARtt|EEOouRa|MHE|EEM|ia|44r|u|oeoo|To
                                         1AaaNNPlRONwAGAAn|G|iENlNNIL|RkEEEOdEnRIaa|00OriIn|aEP|SSa|pn|66i|i|odoo|Bo
                                         -LiiNNBaONN1LAMIb|A|l--b--LG|OyRRRDaRnIGrr|12D0lG0|iNG|CCi|01|00g|l|lall|-l
                                         4Udd---0NS-0--PN0|-|d61115L-|-u---V0-0--00|  P8d-8|dRR|HHd|10|12g|d| 011|4
                                          P001213--3a17T-1|6|0  30 -7|20115-1631612|  - 12 |0YV|--0|  |  0|0|0345| 0
                                          -15    22    -1 | |9     5 | 1 1 1       |  2 6  |2--|154|  |  8|7|4   | 3
                                          2            1 | |        |             |       | 12|   |  |   | |    |

                                                          | |        |             |       |   |   |  |   | |    |
Monadenia bracteata                             *       * | |        |             |       |   |   |  |   | |    |
Phlebocarya ciliata                                     **| |        |    *        |       |   |   |  |   | |    |
Lomandra preissii                                 *     * | |        |             |       |   |   |  |   | |    |
Melaleuca thymoides                               *     * | |        |             |       |   |   |  |   | |    |
Vulpia bromoides                                  *       | |   *    |             |       |   |   |  |   | |    |
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+-+----+--
Acacia willdenowiana                     ** ***           |*|        |          *  |       |   |   |  |   | |    |
Corynotheca micrantha                    ** *            *| |    * * |   *     **  |       |   |   |  |   | |    |
Daviesia divaricata                      ****            *| |        |         *   |       |   |   |  |   | |    |
Hovea trisperma var. trisperma            ***    * * **   | |       *|*       * *  |       |   |   |  |   | |    |
Kennedia prostrata                        ***  * *  *    *| |    **  | *      * ** |       |   |  *|  |   | |    |
Agonis flexuosa                          ******* **    * *| |      * |             |       |*  |***|  |   | |    |
Oxalis perennans                         ******* *   *    |*|      * |             |       |*  |***|**|   | |    |
Geranium retrorsum                       ** ** ***   *   *| |      * |             |       |   |***|  |*  | |    |
Caladenia latifolia                      ******* *        |*|      * |  **       * |  *  **|** |** |  |   | |****|
Parietaria debilis                          * *  * *      | |      * |             |       |   |***|**|   | |    |
Avena fatua                              **    **         | |        |*       ** * |       |   |   |  |   | |    |
Caesia micrantha                         **    *      *   | |       *|   * *     **|       |   |   |  |   | |    |
Dianella revoluta                        ****  * *        | |  *   * |***** *  ****|****   |***|  *|  | **| |    |
Ehrharta longiflora                       *  * **   *     | |        |**** *  *****|  * *  | * |   |* |* *| |    |
Stipa flavescens                         **  * **  *     *|*| ***    | * ** ** * **|    *  |  *| * |  |** | |   *|
Tricoryne elatior                         *    * *        | |   *    |         * **|       |  *| * |  |   | |   *|
Lagurus ovatus                               **           | |        |  *   *   ***|     * |   |   |  |** | |    | *
Vicia sativa                             *   * **         | |        |     *    ** |       |   |   |  |** | |    |
Pelargonium capitatum                     *               | |  * *   |     * ******|     **|   |   |  |** | |    |
Ehrharta calycina                        * *             *| |  *     |      * ** **|   *   |*  |   |  | * | |    |
Schoenus grandiflorus                    ***             *| |        |      *  *   |  * *  |   |   |  | * | |    |
Hybanthus calycinus                       **          *  *| |  **    |   *  **     |       |*  |   |  |   | |    |
Parentucellia viscosa                     **              | |      **|      *      |       |*  |   |  |   | |    |
Aira caryophyllea                             *  *** **  *| |**** ***|     **  *   |     * |   |   |  |   | |    |*
Lagenifera huegelii                       *   ** **** ****|*|********|  *  **  *   |       |   |   |  |   | |    |
Lomandra caespitosa                           *  *** *****| |  *    *|* * * * **   |       |   |   |  |   | |    |
Microlaena stipoides                      * * ** ***** ***|*|****   *|** *  *      |  *    |*  |** |* |   | |    |
Leucopogon propinquus                         *  ***** *  |*|  * * **|*          * |    *  |   |   |  |   | |    |
Centrolepis drummondiana                         **      *| |  * * **|*   * *      |       |   |   |  |   | |    |
Homalosciadium homalocarpum                      **  *  * | |   **** |    * ***    |       |   |   |  |   | |    |
Millotia tenuifolia                       *      **     * | |********| *  * *      |       |   | * |  |   | |    |
Dryandra nivea                            *      *    *   | | *** ***|*  *    * *  |      *|   |   |  |   | |    |
Loxocarya flexuosa                        *      *  * ****| |**** ***|***********  |       |   |   |  |* *| |    |
Xanthorrhoea preissii                            * *      | | *******|****** ***** |      *|   |   | *|  *| |   *|**
Lobelia tenuior                                   * * * * |*|****  * |      *      |       |   |***|  |   | |    |
Stellaria media                                  **   *   |*| **    *|     **     *|     * |   |***|  |   | |    |
Crassula colorata                                         | | ** * * |*   **** * **|       |   | * |  |   | |    | *
Isolepis marginata                         ** * *    **   | | ** ****|*     ** *  *|       |   |*  |  |   | |    | *
Heliophila pusilla                        *          **   | |* ***** |*      ***  *|       |   |   |  |   | |    |
Silene gallica                               **       *   | |* *   * |      *  *  *|       |   |   |  |   | |    | *
Hibbertia racemosa                        *       *   ** *| | *  *  *|*     * **   |**     |   |   |  |   | |    |*
Vulpia myuros                                    **   *   | |**   *  |        **   |**     |   |   |  |   | |    |*
Anagallis arvensis                          **   *  *** * | |  ******|* *****   ***|  *    |*  |***|* |   | |****|**
Cerastium glomeratum                     **  **     *     | |***** **|*******  * * |  *  * | * | * |  |   | |   *|**
Daucus glochidiatus                      ******  **** ****|*|********| ** ** ***   |**  ***|** |*  | *|   | |    |
Trachymene pilosa                         ***** ******* **|*|******* | *  ** ***   |*** * *| * |***|* |   | |    |
Eucalyptus gomphocephala                 *****************|*|********|*************|*******|***|***|**|***|*|****|**       O
Hardenbergia comptoniana                 ******* * *  ****| |   *****|****  ** *** |* *****|***|***|**| **| |****|**
Sonchus oleraceus                        * * ****** ***** | |******* |*** ***  **  |***  * | * |*  | *|   | |****|
Lepidosperma angustatum                  ***     * ****** |*|  *    *| ***  ** * * |  *    |   | **| *|  *| |  **| *
Phyllanthus calycinus                    **** *  *** * * *| |      **| ***  *  * * |  *   *|*  |***| *|   | |    | *
Briza maxima                             ********* *******| |        |* ***********|     * |   |   |  |** | |    |
Briza minor                              ** * *  ******   | |       *|* * *** *****|       |   |   |  |   | |    |
Hibbertia hypericoides                   ******  *** *****| |**   ***|* **** ***** |      *|   |   |  |  *| |    |
Macrozamia riedlei                       *** ** ******** *|*|** *****|****   *  * *|      *|   |   |  |   | |    |
Hypochaeris glabra                       ****** * ********|*|********|********** **|       | * |  *|  |   | |    |**
Sowerbaea laxiflora                      *****************|*|********|   ******* **|       |*  |   |  |   | |    |
Petrorhagia velutina                     ****** ********  | |*   **  | **  ***** **|       |   |   |  |   | |    |**
Dichopogon capillipes                    ********  *******| |      **|* **         |       |*  |   |  |   | |    |
Bromus diandrus                          * ******* * **   | |*     * |**** ** **** |**  *  |   | **|  |   | |    | *
Conostylis aculeata                      ** ***  *  * ****|*|  *   * |**    * *****|       |   |  *|  |   | |    | *
Trifolium campestre                      *   ** ** ***** *| |* *     | **    **  **|       |   |   |  |   | |   *|
Banksia attenuata                           * *   ********| | * * *  |**   *** *   |       |   |   |  |   | |    |
Burchardia congesta                       *       ***  ***| |     *  |** ******* * |       |   |   |  |   | |    |
Caladenia flava                           * ***   ***  ***| |   *   *|    *****    |       |   |   |  |   | |    |
Gompholobium tomentosum                   *         * * * | |        | *    ****   |       |   |   |  |   | |    |
Ursinia anthemoides                              ** * ****| |*   **  | *     ***   |       |   |   |  |   | |    |
Danthonia occidentalis                    *        *  * * | |   **   |** *     *   |       |   |   |  |   | |    |
Isotropis cuneifolia                      *           ****| |   *  * |        **   |       |   |   |  |   | |    |
Lomandra hermaphrodita                    *             **| |   *    |       * *   |       |   |   |  |   | |    |
Gladiolus caryophyllaceus                                 | |     *  |****** *** * |       |   |   |  |   | |    |
Poranthera microphylla                             * **   | |   *    |** ******  * |    *  |   |   |  |   | |    |
Mesomelaena pseudostygia                                  | |* ** *  |   *******   |       |   |   |  |  *| |    |
Romulea rosea                              ** *     *    *| |        |* ** ** **   |       |  *|   |  |   | |    |
Grevillea vestita                        *  *             | |  *     |   *   ***   |      *|   |   |  |   | |    |
Homeria flaccida                                *         | |        |  ** *  ** * |      *|   |   |  |   | |    |*
Asteridea pulverulenta                     *  *  ****   **| |        |      *  *   |       |   |   |  |   | |    |
Chamaescilla corymbosa                         * **** * **| |     *  |             |       |   |   |  |   | |*   |
Lomandra micrantha                           * * ****  *  | |       *|             |       |   |   |  |   | |    |
Quinetia urvillei                                ** * *   | |       *|       **    |       |   |   |  |   | |    |
Luzula meridionalis                          *  ****  *   | |        |*     *      |       |   |   |  |   | |    |
Orobanche minor                              ** ***  **   | |        |      *      |       |   | * |  |   | |    |
Drosera erythrorhiza                      *      * ** *   |*|  * ** *|    ****     |       |   |   |  |   | |    |
Eryngium pinnatifidum subsp. pinnatifidum        * *  *   |*|        |   *  ***    |       |   |   |  |   | |    |
Lyperanthus nigricans                             **      |*|        |       * *   |       |   |   |  |   | |    |
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+-+----+--
Alyogyne huegelii                                         | |        |             |      *|   |   |**|   | |    |
Leucopogon australis                                      | |        |             |      *|   |   | *|   | |    |
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                                                                       Site Groups                                   Spp.Groups
                                                  1        2     3        4            5     6   7   8  9 10  11  12

                                         CMGNMMPyCLMlMPCDb|P|GSYwYYWY|KtNNNWlNPWTss|CCWfgTy|GMP|LLN|py|mmt|G|clcc|Mc
                                         7YMMIIEeOYIoEARRu|A|uHAiAAHA|EoEEEOeEiARtt|EEOouRa|MHE|EEM|ia|44r|u|oeoo|To
                                         1AaaNNPlRONwAGAAn|G|iENlNNIL|RkEEEOdEnRIaa|00OriIn|aEP|SSa|pn|66i|i|odoo|Bo
                                         -LiiNNBaONN1LAMIb|A|l--b--LG|OyRRRDaRnIGrr|12D0lG0|iNG|CCi|01|00g|l|lall|-l
                                         4Udd---0NS-0--PN0|-|d61115L-|-u---V0-0--00|  P8d-8|dRR|HHd|10|12g|d| 011|4
                                          P001213--3a17T-1|6|0  30 -7|20115-1631612|  - 12 |0YV|--0|  |  0|0|0345| 0
                                          -15    22    -1 | |9     5 | 1 1 1       |  2 6  |2--|154|  |  8|7|4   | 3
                                          2            1  | |        |             |       | 12|   |  |   | |    |

                                                          | |        |             |       |   |   |  |   | |    |
Carpobrotus edulis                                        | |        |             |      *|   |   | *| * | |    |
Stypandra glauca                               *          | |        |             |      *|   |   | *|   | |    |
Amyema miquelii                                           | |        |             |       |   |   |**|   | |    |
Carex appressa                                            | |        |             |       |   |   |**|   | |    |
Cassytha racemosa                                         | |        |             |       |   |  *|**|   | |    |        P
Banksia littoralis                                        |*|        |             |       |   |   | *|   | |    |
Myoporum caprarioides                                     |*|        |             |       |   |   | *|   | |    |
Baumea juncea                                             | |        |             |       |   |   | *|   |*|* * |*
Melaleuca rhaphiophylla                                   | |        |             |       |   |   |**|   |*|**  |
Cynodon dactylon                                    *     | |        |             |       |   |   | *|   | |*   |
Cirsium vulgare                                           | |        |  *          |       |   |   | *|   | |    | *
Poa porphyroclados                                        | |        |   *      ** |       | * |   | *|   | |    | *
Banksia grandis                             *   **        | |    *   | *    *      |      *|   |   | *|   | |    |
Jacksonia furcellata                        *    *      * | |        |             |       |   |   | *|   | |    |
                                         -----------------+-+--------+-------------+-------+---+---+--+---+-+----+--
Lupinus cosentinii                              *         | |        |           * |       |   |   |  |   | |    |
Pimelea argentea                                *         | |        |             |       |   |   | *|   | |    |
Ptilotus stirlingii                         *   *         | |        |             |       |   |   |  |   | |    |        Q
Pteridium esculentum                           **   *     | |        |             |       |   |   |  |   | | *  |
Rumex acetosella                                *   *     | |        |             |       |   |   |  |   | |    |
Thysanotus arenarius                            *         |*|        |             |  *    |   |   |  |  *| |    |
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THE FLORA OF TUART WOODLANDS

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ABSTRACT

The vascular flora of Tuart woodlands in the 12 bushland areas from across Tuart's range are listed. Of the 575 vascular plants listed for the areas, 414 are native vascular plants and 161 are weeds. The flora of Tuart woodlands are predominantly widespread species on the Swan Coastal Plain that are characteristic of plant communities on the Spearwood and Quindalup Dune Systems. However, significant geographic, habitat and soil factors cause considerable variation in species recorded between areas. Although several species are largely confined to these communities Tuart is the only endemic recorded. Weeds are relatively common being most frequent in the Perth area and less frequent north and south of Perth. Bird-dispersed weeds may be an increasing problem in these woodlands.

INTRODUCTION

Woodlands dominated by Tuart are a unique feature of the Swan Coastal Plain and are a special feature of the Perth Metropolitan Region. However there have been no previous regional compilations of the native and naturalized flora of these woodlands even though the restoration of Tuart communities is of interest to a large number of people (see Longman and Keighery this publication).

METHODS

Published and unpublished flora lists for the Tuart woodlands in 12 bushland areas (Table 1 this paper, and Map 4 in Keighery *et al.* this publication) were compiled for this report (Appendix 1). These areas were selected to illustrate the variation in the flora of Tuart woodlands being distributed over Tuart's:

- geographic range, from the 'Cervantes Tuart Reserve' (east of Cervantes) to the Tuart Forest Reserve to the north-west of Busselton; and
- geomorphic range on the Quindalup and Spearwood Dunes.

Areas of bushland adjacent to the Spearwood/Bassendean interface, where the floras of the Tuart and *Banksia* woodlands merge, were avoided.

The majority of the records in these flora lists have been compiled through survey by the author. Survey work was structured to accommodate a variety of seasonal conditions and, when possible, fire. Multiple visits were made to each area, generally over at least two spring seasons and, to a lesser extent, over summer, autumn and winter.

For each bushland area both native and naturalized flora were listed under the principal vegetation associations observed in each area. When previous lists were known for an area these were incorporated (Table 1).

These lists, and others, culminated in a report on the conservation status of the vascular flora of the southern Swan Coastal Plain (Keighery 1999).

RESULTS AND DISCUSSION

Total Flora

A total of 575 vascular plant taxa are listed for the Tuart woodlands in the 12 bushland areas (Appendix 1). Of these 575 vascular plants:

- 414 are native vascular plants (72%);
- 161 are weeds (28%);
- 185 are Monocotyledons, including 132 native and 53 weeds;
- 382 are Dicotyledons, including 276 native and 106 weeds;
- four are gymnosperms, including two natives and two weeds; and
- four are native ferns.

Native Flora

Across their range Tuart woodlands vary greatly in the composition of the native and weedy vascular plants that characterize their understorey. A study of the floristics of 64 100m^2 sites in which Tuart is present (Gibson *et al.* this publication) classifies these sites into 12 groups with significant soil and geographic components. This is also reflected in the total flora lists, where many species are recorded only in northern or southern bushland areas, examples being:

- in northern areas - *Labichea cassioides*, *Chamelaucium uncinatum*, *Lechenaultia linarioides* and *Mesomelaena preissii*; and
- in southern areas - *Lindsaea linearis*, *Cheilanthes austrotenuifolia*, *Dichondra repens* and *Hibbertia cuneiformis*.

A series of other species show particular habitat preferences. Some examples include:

- species largely confined to Tuart on Quindalup sands - *Callitris preissii*, *Enchylaena tomentosa* and *Rulingia luteiflora*; and
- specific habitats under the canopy, such as wetlands - *Apium prostratum*, *Centella asiatica*, *Senecio ramosissimus* and *Lepidium pseudohyssopifolium*.

Another suite of species are those which are more characteristic of adjacent habitats and vegetation communities, but are sporadically recorded in Tuart woodlands.

This geographic, soil and habitat variation contributes greatly to the species composition and richness within and between Tuart woodlands. Such variation indicates that locally gathered data on species composition should be used to guide any restoration and revegetation plan for Tuart woodlands. Such variation in communities on the Plain is typical and collecting such information is fundamental in management of bushland areas (Keighery *et al.* 1999).

Family Representation

The flora of Tuart woodlands is, not suprisingly, dominated by species associated with the calcareous and sandy soils of the Quindalup and Spearwood sands. The largest families are the:

- Asteraceae (37 natives and 20 weeds):
- Orchidaceae (38 natives and 1 weed);
- Cyperaceae (26 natives and 2 weeds);
- Proteaceae (25 natives);
- Myrtaceae (20 natives and 1 weed);

- Papilionaceae (23 natives and 11 weeds);
- Anthericaceae (15 natives);
- Mimosaceae (13 natives and 2 weeds); and
- Poaceae (13 natives and 29 weeds).

Like the general flora of Quindalup and Spearwood Dunes, Tuart woodlands are relatively poor in the typical species-rich families of the heathlands of southern Western Australia, especially the Goodeniaceae, Stylidiaceae and Epacridaceae. The Proteaceae and Myrtaceae are also relatively poorly represented (when compared to *Banksia* woodlands on the Swan Coastal Plain). The relatively poor representations of the low trees and shrubs from the Epacridaceae, Proteaceae and Myrtaceae, together with the abundance of the non-woody species from the Asteraceae, Orchidaceae and Cyperaceae, contributes to the generally more open appearance of the woodlands, as these families contribute significantly to the lower tree and tall shrub layers.

Common Species and Life Forms

A group of 59 species are widespread in Tuart woodlands, being found in more than 70% of the Tuart woodlands in the different bushland areas. These species are generally widespread in sandy soils on the Swan Coastal Plain. These are grouped below in their different life form classes.

Ferns: *Pteridium esculentum* (perennial herb).

Gymnosperms: *Macrozamia reidlei* (shrub).

Flowering Plants

Shrubs (19 species): *Olearia axillaris*, *Rhagodia baccata*, *Hibbertia hypericoides*, *Adriana quadripartita*, *Phyllanthus calycinus*, *Logania vaginalis*, *Acacia cyclops*, *A. cochlearis*, *A. pulchella*, *A. rostellifera*, *A. saligna*, *Myoporum insulare*, *Melaleuca systena*, *Gompholobium tomentosum*, *Dryandra lindleyana*, *D. sessilis*, *Hakea prostrata*, *Thomasia cognata* and *Xanthorrhoea preissii*.

Climbers and Vines (7 species): *Cassytha racemosa*, *Hardenbergia comptoniana*, *Kennedia prostrata*, *Comesperma integerrimum*, *Muehlenbeckia adpressa*, *Clematis linearifolia* and *Opercularia hispidula*.

Grasses (3 species): *Austrostipa elegantissima*, *A. flavescens* and *Microlaena stipoides.*

Herbs (20 species)

Monocotyledons

Lilies and relatives

Perennials (5 species): *Dianella revoluta*, *Tricoryne elatior*, *Acanthocarpus preissii*, *Lomandra maritima* and *L. micrantha.*

Annually renewed (geophytes) (6 species): *Corynotheca micrantha*, *Dichopogon capillipes*, *Thysanotus arenarius*, *T. patersonii* and the orchids, *Acianthus reniformis* and *Caladenia latifolia.*

Dicotyledons

Annually renewed from seed (7 species): *Daucus glochidiatus*, *Trachymene coerulea*, *T. pilosa*, *Crassula colorata*, *Lobelia tenuior*, *Galium murale* and *Parietaria debilis*.

Annually renewed (geophytes) (2 species): *Pelargonium littorale* and *Oxalis perennans*.

Sedges (8 species)

Perennial (5 species): *Carex preissii*, *Isolepis nodosa*, *Lepidosperma gladiatum*, *L. squamatum* and *Schoenus grandiflora*.

Annually renewed from seed (3 species): *Isolepis marginata*, *Triglochin calcitrapa* and *T. centrocarpum*.

This distribution of life forms, 26 woody perennials (shrubs and climbers/vines) and 31 non-woody species (grasses, herbs and sedges) reinforces the previous comment on the generally open appearance of the woodlands. Also the non-woody layers have a predominance of lilies, sedges, and dicotyledonous herbs compared to the grasses.

While these species could be argued to 'characterize' Tuart Woodlands at the broad scale, they only represent about 14% of the native flora of these woodlands.

Significant Flora

Declared Rare and Priority Flora

Five rare taxa (priority taxa, that is taxa in consideration for declaration as Declared Rare Flora, see Table 3, Appendix 5 in Keighery and Keighery this publication) are listed in Appendix 1. These are: *Conostylis pauciflora* subsp. *pauciflora*, *Haloragis aculeolata*, *Jacksonia sparsa* ms, *Lasiopetalum membranaceum* and *Sarcozona bicarinata*. These and other species are discussed below.

Endemic Species

Previous work on the Spearwood Dune flora (Keighery 1991) identified that those species that are largely confined to areas dominated by Tuart woodlands are found throughout the Spearwood Dune system. As a consequence, only two taxa appear potentially confined to Tuart dominated communities. These are described below.

Lasiopetalum membranaceum (Sterculiaceae)
Lasiopetalum membranaceum appears to be largely confined to Tuart dominated communities. However, it does occur in other calcareous areas and there is an unconfirmed record from Dwellingup. This is a Priority 2 species (Atkins 2001; see also Table 3, Appendix 5 in Keighery and Keighery this publication).

Rorippa sp. Yalgorup (GJK 14455) (Brassicaceae)
Keighery (1999) listed *Rorippa* sp. Yalgorup (GJK 14455) as an endemic of Tuart woodlands. During the Swan Coastal Plain survey this species was only recorded twice, in Leschenault Peninsular Conservation Park and Yalgorup National Park. In each case the species was found in deep moss banks in unburnt forest, where it was locally common. It has probably been lost elsewhere by grazing followed by weed competition and fire. However, Ian Thompson (pers. comm.), who previously identified this as a *Rorippa*, currently considers that this taxon may be the introduced *Arabidopsis thaliana*. However generic determination in the Family Brassicaceae between *Cardamine*, *Rorippa* and *Arabidopsis* is very difficult and, as this taxon is found in the least disturbed areas of the Tuart woodlands, it is considered that this taxon deserves further study.

Geographically Significant Taxa

A total of 33 species are at their northern or southern extent on the Swan Coastal Plain on the Quindalup and Spearwood Dunes (Keighery 1991). Four of these species occur in Tuart woodlands. These are listed below.

Agonis flexuosa (Myrtaceae)
Agonis flexuosa (Peppermint) is at its northern range end in Bold Park (Tuart Area 42 on Table 4 and Map 4, Keighery *et al.* this publication) where it is locally common on the Quindalup Dune areas. Interestingly in this, and adjacent areas, it rarely occurs with Tuart as an overstorey. South of the City Beach/Swanbourne area there is an apparent disjunction in the distribution between here and Mandurah. In the Mandurah area and south of this area *Agonis flexuosa* is commonly found in

a variety of communities on both the Quindalup and Spearwood Dunes. In the Perth Metropolitan Region, outside of the Swanbourne/City Beach area, *Agonis flexuosa* is an invasive weed in Spearwood Dune communities, especially *Banksia* and eucalypt dominated woodlands. *Agonis flexuosa* should not be planted in these areas.

Stenopetalum robustum (Brassicaceae)
The only current record of *Stenopetalum robustum* from the Swan Coastal Plain is from the Tuart Forest Reserve. *Stenopetalum robustum* occurs between Ludlow and Albany and is replaced in the same habitat by *S. gracile* south of Bunbury (Keighery 2002).

Veronica stolonifera (Scrophulariaceae)
Veronica stolonifera was previously known as *Veronica* aff. *calycina* (BJK & NG 235) (Gibson *et al.* 1994). This taxon is related to *V. calycina* but is more robust and less densely pubescent and is currently known from only a few records on the Quindalup and Spearwood Dunes between the Tuart Forest Reserve and Yanchep. Most of the habitat type that it occurs in between Yalgorup and Yanchep has been cleared or degraded by grazing and it appears to be rare or at least very uncommon. *Veronica stolonifera* was described from Fremantle.

Other Species of Interest

Eleven species listed in Appendix 1 have been recognized as significant species on the Swan Coastal Plain (Gov of WA 2000) and/or are listed as priority taxa (Atkins 2001, see also Table 3, Appendix 5 in Keighery and Keighery this publication). Three of these species (*Agonis flexuosa*, *Lasiopetalum membranaceum* and *Veronica stolonifera*) have been discussed previously. The remaining species are not typical of Tuart woodlands but occur occasionally in the woodlands. Seven of these species are listed below together with some brief comments:
- *Lepidium pseudohyssopifolium* - a poorly collected species listed as Priority 1;
- *Cartonema philydroides* - a disturbance opportunist;
- *Callitris preissii* – a Swan Coastal Plain and Perth Metropolitan Region endemic;
- *Conostylis pauciflora* subsp. *pauciflora* - a Priority 4 species;
- *Haloragis aculeolata* - a poorly collected species listed as Priority 2;
- *Acacia alata* var. *tetrantha* – a poorly collected species; and
- *Jacksonia sparsa* ms - a poorly collected species listed as Priority 3.

The last of the 11 species, *Sarcozona bicarinata*, can be quite common in some Tuart woodlands and is in need of a more detailed treatment.

Sarcozona bicarinata (Aizoaceae)
Sarcozona bicarinata was previously known as *Carpobrotus* sp. Hepburn (GJK 11518) (Gibson *et al.* 1994). This is a Priority 3 species (Atkins 2001, and see Table 3, Appendix 5 in Keighery and Keighery this publication). This is an uncommon species until after fire when it is locally abundant. On the Swan Coastal Plain it is largely confined to Tuart woodlands and these populations are remarkably disjunct from their nearest neighbours in South Australia.

Weed Flora

A total of 161 species of naturalized vascular plants are recorded in Tuart woodlands of the 12 bushland areas. There are 23 commonly recorded weeds, being found in more than 70% of the Tuart woodlands in the different bushland areas. These are all non-woody species and are grouped below in their different life form classes.

Monocotyledons
Grasses: *Aira* species, *Avena* species, *Briza maxima*, *Briza minor*, *Cynodon dactylon*, *Ehrharta*

longiflora, *Lagurus ovatus* and *Vulpia myuros*.
Annually renewed (geophytes): *Romulea rosea.*

Dicotyledons

Annuals: *Hypochaeris* species, *Carduus pycnocephalus*, *Sonchus oleraceus*, *Brassica tournefortii*, *Petrorhagia prolifera*, *Euphorbia peplus*, *Orobanche minor*, *Lupinus cosentinii*, *Medicago polymorpha*, *Melilotus indica*, *Anagallis arvensis*, *Bellardia trixago, Dischisma arenaria* and *Solanum nigrum*.

However, numerous surveys of bushland areas containing Tuart woodland in the Perth Metropolitan Region have identified an additional suite of weeds that are aggressive invaders of these woodlands. Most of these have been previously listed for the Perth Metropolitan Region in Dixon and Keighery (1995). Many of these were infrequently recorded in the 12 bushland areas brought together for this study and probably have not reached their potential ranges. These species should be eradicated if found in areas of Tuart woodland.

Trees

Acacia pycnantha, *Agonis flexuosa* (outside of its natural range, see comment above), *Brachychiton populneus*, *Olea europea* and *Eucalyptus maculata*.

Shrubs

Leptospermum laevigatum, *Rhamnus alaternus* and *Solanum linnaeanum*.

Grasses

Annuals: *Bromus diandrus*, C*ynosurus echinatus*, *Lolium multiflora* and *Lolium rigidum*.
Perennials: *Ehrharta calycina*, *Eragrostis curvula*, *Hyparrhenia hirta* and *Pennisetum purpureum.*

Herbs

Monocotyledons

Annually renewed (geophytes): *Asparagus asparagoides*, *Asparagus crispus*, *Albuca canadensis*, *Chasmanthe aethiopica* (local serious weed on Mt Eliza and Woodmans Point), *Zantedeschia aethiopica*, *Freesia* hybrid, *Lachenalia reflexa*, *Ferraria crispa*, *Homeria flaccida*, *Gladiolus caryophyllaceus, Romulea rosea*, *R. flava* and *Watsonia meriana* var. *bulbillifera.*

Dicotyledons

Annually renewed from seed: *Sherardia arvensis*, *Centranthus macrosiphon*, *Arctotheca calendula*, *Carduus pycnocephalus*, *Cirsium vulgare*, *Centaurea melitensis*, *Urospermum picroides* and *Ursinia anthemoides*.
Perennials: *Euphorbia terracina* and *Pelargonium capitatum.*

These figures are comparable to some preliminary data presented by Keighery (1984) for Tuart dominated communities of the Perth Region (see Table 2). In the 1984 study Keighery found that Tuart woodlands contained 21% of the native flora recorded for the Perth Region, but 37% of the Tuart woodland flora was weeds. This was significantly higher than the percentage of the Perth Region flora that is weeds, 27%. However the 1984 study included many small highly disturbed remnants of the Perth Metropolitan Region. The results for this study, in less disturbed areas over Tuart's entire range, found that Tuart contains a similar proportion of weeds to the Perth Region, 28%, but a lesser percentage than that found in Tuart woodlands in the Perth Metropolitan Region.

Tuart woodlands are generally more impacted by the activities of Europeans than the surrounding communities (see also Keighery *et al.* this publication). The soils of Tuart woodlands on Spearwood sands are relatively nutrient rich and these areas have been preferentially grazed since cattle and sheep were introduced. To encourage annual regrowth and annual grasses and herbs they were also frequently burnt. As a consequence of these two disturbance regimes, the Tuart woodlands on these soils have a proportionally large number of weeds for the area occupied. While the Quindalup sands are less fertile, Tuart woodlands here are generally smaller in extent and they have also been impacted by frequent fires and grazing.

Areas of Tuart woodland in the Perth area, where the bushland areas are smaller and more fragmented, suffer from an additional suite of disturbances such as ‘enrichment’ plantings (plantings of non-local, often invasive species), dumping of garden refuse, nutrient enrichment, partial clearance and high human usage. In addition, as Tuart woodlands are typically on well drained soils near the coast, they are ideal areas for urbanisation.

Of particular interest in these remnants, and in the more isolated remnants in the rural areas, is the introduction to Tuart woodlands of a series of weeds distributed by seed-eating or omnivorous birds, such as Ravens. Tuart is generally significantly taller than other species in bushland areas and is preferentially used as a roosting site. As a consequence, a series of weed species are associated with the area around the base of Tuart trees; these include such species as *Asparagus asparagoides, A. crispus, Brachychiton populneus, Carpobrotus edulis, Lycium ferocissimum, Olea europea, Rhamnus alaternus, Solanum linnaeanum, S. nigrum*, and *Zantedeschia aethiopica*. These weeds are generally introduced from surrounding gardens and a wider range of introductions can be expected. A native species, *Acacia cyclops* which is typical of these communities, is also distributed in this way.

CONCLUSIONS

Tuart woodlands are characterized by species that are common and widespread on the calcareous soils of the western Swan Coastal Plain within the Quindalup and Spearwood Dunes. This is not suprising as the woodlands are largely confined to such soil types. There are no apparent endemics to these woodlands, apart from Tuart itself, although a number of restricted and geographically significant species are recorded from the woodlands.

Significant variation in species composition occurs across the range of Tuart woodlands due to geographic, soil and local habitat variation.

Weeds are relatively common in Tuart woodlands because of past and continuing disturbances. These weeds are most frequent in the areas with the highest disturbance levels associated with the Perth Metropolitan Region and are less frequent north and south of Perth. A group of bird-dispersed weeds, not normally a feature of Western Australian bushland, are becoming more common in Tuart remnants.

Restoration and revegetation plans for Tuart woodlands needs to be mindful of these patterns of variation in the understorey components.

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TABLES

TABLE 1. Bushland areas for which the Tuart woodland flora is listed in Appendix 1.

Key

Column 1 **Area Code**

Column 2 **Mapped Tuart Area Number**
After Map 4 in Keighery *et al.* (this publication) with Bush Forever Site number (Gov of WA 2000) in brackets, when appropriate.

Column 3 **Area Name**
After Keighery *et al.* (this publication). The System Area number (Department of Conservation and Environment 1983) is given in brackets when appropriate.

Column 4 **Landform Units**
QU Quindalup Dunes
SP Spearwood Dunes

Column 5 **Total number of vegetation associations and flora (in brackets) in the bushland area**

Column 6 **Information Source**
Information from this study is given as GJK; other studies are referenced.

Area Code	Tuart Area No. (Site No.)	Area Name (System Area or Bush Forever Site Number)	Land. Unit	Total No. Vege. Assocs (flora)	Information Source
CER	2	'Cervantes Tuart Reserve' (Reserves 39400/41008, east of Cervantes)	SP	1	GJK
SEA	7	Seabird UCL	QU	6 (383)	Keighery GJ *et al.* (1997)
YAN	part 11 (288)	Yanchep National Park (M3)	QU/ SP	8 (573)	GJK
TRI	part 12 (308)	Trigg Bushland, Trigg/Scarborough (M36)	QU/ SP	5 (251)	GJK
WO	14 (341)	Woodman Point, Coogee/Munster (M90)	QU	4 (169)	Powell and Emberson 1981, GJK
C/W	part 15 (356)	Lake Cooloongup, Lake Walyungup, Hillman to Port Kennedy (M103)	QU	10 (256)	Keighery BJ *et al.* (1997)
MEA	78	Mealup Point Nature Reserve	SP	4 (229)	GJK
YAL	79	Yalgorup National Park (C54)	SP	18 (563)	GJK
CRA	83	Crampton Nature Reserve (C61)	SP	6 (206)	GJK
LES	72	Leschenault Peninsular Conservation Park (C66)	QU	(263)	Trudgen (1984), GJK
MAI	73	The Maidens (South Bunbury Coastal Land C70)	QU/ SP	4 (164)	Hart Simpson and Associates (1994), GJK
FOR	88	Tuart Forest Reserve (System area 1.1.2 (DCE 1976))	SP	6 (705)	Keighery and Keighery (this publication)

TABLE 2. A comparison of the floristics of the Perth Region (after Marchant *et al.* 1987), Tuart woodlands in the Perth Metropolitan Region (Keighery 1984) and Tuart woodlands in this study.

Key

Perth Flora Perth Region after Marchant *et al.*(1987)

PMR Tuart Tuart woodlands in the Perth Metropolitan Region (PMR) after Keighery (1984)

SCP Tuart Tuart woodlands from 12 bushland areas, across Tuart's range on the Swan Coastal Plain (SCP), this study

TABLE 2a. A comparison of the native floras.

Group	Native species		
	Perth Flora	PMR Tuart	SCP Tuart
Ferns	23	0	4
Gymnosperms	5	2	2
Dicotyledons	1020	230	276
Monocotyledons	462	84	132
Total	1510	316	414

TABLE 2b. A comparison of the weed and total floras.

Group	Total (native & weed species)			Weed species		
	Perth Flora	PMR Tuart	SCP Tuart	Perth Flora	PMR Tuart	SCP Tuart
Ferns	25	0	4	2	0	0
Gymnosperms	7	3	4	2	1	2
Dicotyledons	1372	352	386	352	122	106
Monocotyledons	753	146	185	191	62	53
Total	2055	501	575	545	185	161
Proportion of the total flora				27%	37%	28%

APPENDIX 1. Flora of the Tuart woodlands in twelve bushland areas.

Key

Column 1 **Family group**
Families are listed alphabetically.

Column 2 **Plant Taxa**
Names include species, sub-species and varieties and are listed alphabetically.
* Weed species
ms Manuscript name (shown after the name)

Column 3 **Common Names**
Generally after listing in Bennett (1993).

Columns 4 - 15 **Bushland Areas**
See Table 1 for more detail on the areas.
W Weed species in this location

Area Code	Area Name (System Area No.)
CER	'Cervantes Tuart Reserve' (Reserves 39400/41008, east of Cervantes)
SEA	Seabird UCL
YAN	Yanchep National Park (M3)
TRI	Trigg Bushland, Trigg/Scarborough (M36)
WO	Woodman Point, Coogee/Munster (M90)
C/W	Lake Cooloongup, Lake Walyungup (M103)
MEA	Mealup Point Nature Reserve
YAL	Yalgorup National Park (C54)
CRA	Crampton Nature Reserve (C61)
LES	Leschenault Peninsular Conservation Park (C66)
MAI	The Maidens (South Bunbury Coastal Land C70)
FOR	Tuart Forest Reserve (System area 1.1.2 (DCE 1976))

Family		Plant taxa	Common names	FOR	MAI	LES	CRA	YAL	MEA	C/W	WO	TRI	YAN	SEA	CER
Adiantaceae		Adiantum aethiopicum	Common Maidenhair	•											
		Cheilanthes austrotenuifolia	Rock Fern	•									•		
Aizoaceae	*	Carpobrotus edulis	Hottentot Fig		•	•		•		•	•			•	
		Carpobrotus modestus	Inland Pigface					•					•		
		Carpobrotus virescens	Coastal Pigface		•	•					•				
	*	Tetragonia decumbens	Sea Spinach			•					•				
		Tetragonia tetragonoides	New Zealand Spinach						•						
Amaranthaceae		Ptilotus drummondii	Narrowleaf Mulla Mulla	•		•		•					•		
		Ptilotus manglesii	Pom Poms	•									•		
		Ptilotus polystachyus	Prince of Wales Feather										•		
		Ptilotus sericostachyus		•											
		Ptilotus stirlingii	Stirling's Mulla Mulla	•		•							•		
Amaryllidaceae	*	Amaryllis belladonna	Easter Lily	•											
	*	Narcissus tazetta	Jonquil			•					•				
Anacardiaceae	*	Schinus terebinthifolius	Brazilian Pepper			•									
Anthericaceae		Caesia micrantha	Pale Grass-Lily	•	•		•	•					•		
		Chamaescilla corymbosa var. corymbosa	Blue Squill					•		•					
		Corynotheca micrantha var. micrantha	Sand Lily	•	•		•	•		•		•	•		•
		Dichopogon capillipes		•	•		•	•	•	•		•	•	•	
		Sowerbaea laxiflora	Purple Tassels	•	•		•	•	•				•		
		Thysanotus arenarius		•	•	•		•			•				•
		Thysanotus dichotomus	Branched Fringe Lily					•							
		Thysanotus manglesianus	Fringe Lily	•										•	
		Thysanotus manglesianus/patersonii complex						•	•	•			•		
		Thysanotus multiflorus	Many-flowered Fringe Lily	•				•							
		Thysanotus patersonii	Twining Fringe Lily	•	•	•	•				•			•	
		Thysanotus sparteus								•					
		Thysanotus thyrsoideus					•								

Family	Plant taxa	Common names	FOR	MAI	LES	CRA	YAL	MEA	C/W	WO	TRI	YAN	SEA	CER
	Tricoryne elatior	Yellow Autumn Lily	•		•	•	•	•	•			•		
	Tricoryne tenella		•											
Apiaceae	Apium prostratum	Sea Celery							•					
	Centella asiatica								•					
	Daucus glochidiatus	Australian Carrot	•	•	•	•	•		•	•		•		•
	Eryngium pinnatifidum subsp. pinnatifidum	Blue Devils	•	•			•				•	•	•	•
	Homalosciadium homalocarpum		•				•					•		
	Hydrocotyle alata				•		•							
	Hydrocotyle callicarpa	Small Pennywort	•									•		
	Hydrocotyle capillaris	Thread Pennywort												•
	Hydrocotyle diantha		•		•		•		•			•		
	Hydrocotyle hispidula				•									
	Hydrocotyle pilifera var. glabrata				•									
	Hydrocotyle tetragonocarpa				•		•							
	Trachymene coerulea	Blue Lace Flower	•		•		•		•			•		•
	Trachymene pilosa	Native Parsnip	•	•	•	•	•			•		•		•
Apocynaceae	Alyxia buxifolia	Dysentery Bush	•	•	•		•					•		
Araceae	* Zantedeschia aethiopica	Arum Lily	•		•							•		
Asclepiadaceae	* Gomphocarpus fruticosus	Swan Plant						•						
Asparagaceae	* Asparagus asparagoides	Bridal Creeper	•						•	•		•		
Asphodelaceae	* Albuca canadensis		•											
	* Asphodelus fistulosus	Onion Weed	•	•						•		•		
	Bulbine semibarbata	Leek Lily	•		•							•		
	* Trachyandra divaricata	Strap Lily		•	•		•			•				
Asteraceae	* Arctotheca calendula	Cape Weed	•	•	•		•					•	•	
	* Aster subulatus	Bushy Starwort							•					
	Asteridea pulverulenta	Common Bristle Daisy	•	•	•	•	•					•		
	Bracteanthum macranthum						•					•		

Family	Plant taxa	Common names	FOR	MAI	LES	CRA	YAL	MEA	C/W	WO	TRI	YAN	SEA	CER
	Brachyscome iberidifolia	Swan River Daisy	•											
	* Carduus pycnocephalus	Slender Thistle	•	•	•		•		•	•		•	•	
	* Centaurea melitensis	Maltese Cockspur			•		•					•		
	* Cirsium vulgare	Spear Thistle		•	•				•	•		•		
	* Conyza albida	Tall Fleabane			•				•	•				
	* Conyza bonariensis	Flaxleaf Fleabane			•							•		
	Cotula australis	Common Cotula	•		•									
	* Cotula bipinnata	Ferny Cotula	•				•							
	* Cotula turbinata	Funnel Weed	•											
	Craspedia arenicola ms		•				•					•		
	* Dittrichia graveolens	Stinkwort	•		•				•	•				
	* Gamochaeta falcata		•											
	Euchiton gymnocephalus		•											
	Gnaphalium indutus		•										•	
	Euchiton sphaericus	Star Cudweed	•				•						•	
	* Hypochaeris glabra	Flat Weed	•	•	•	•	•		•			•	•	•
	Ixiolaena viscosa	Sticky Ixiolaena	•			•			•					
	* Lactuca serriola	Prickly Lettuce								•				
	Lagenophora huegelii	Coarse Lagenophora	•		•		•					•		
	Millotia myosotidifolia		•	•		•	•					•		•
	Millotia tenuifolia	Soft Millotia			•									
	Olearia axillaris	Coastal Daisybush	•	•	•	•	•			•		•		•
	Olearia rudis	Rough Daisybush					•					•		
	* Osteospermum ecklonis		•											
	* Osteospermum clandestinum	Stinking Roger			•							•		•
	Ozothamnus cordatus	Tangle Bush		•	•	•	•			•		•		
	Picris squarrosa		•				•					•		
	Pithocarpa pulchella	Beautiful Pithocarpa					•							
	Podolepis canescens											•		

Family	Plant taxa	Common names	FOR	MAI	LES	CRA	YAL	MEA	C/W	WO	TRI	YAN	SEA	CER
	Podolepis gracilis	Slender Podolepis				•	•					•	•	
	Podolepis lessonii						•							
	Podotheca angustifolia	Sticky Longheads	•				•					•		
	Podotheca chrysantha	Yellow Podotheca					•							
	Podotheca gnaphalioides	Golden Longheads	•										•	
	* Pseudognaphalium luteoalbum	Jersey Cudweed	•				•					•		
	Pterochaeta paniculata	Woolly Waitzia	•											
	Quinetia urvillei		•				•					•		
	Rhodanthe citrina						•							
	Rhodanthe corymbosa		•											
	* Senecio diaschides		•											
	Senecio hispidulus	Hispid Fireweed	•			•	•					•		
	Senecio lautus subsp. dissectifolius	Variable Groundsel	•											
	Senecio lautus subsp. maritimus	Variable Groundsel		•	•		•		•	•		•	•	
	Senecio quadridentatus	Cotton Fireweed	•											
	Senecio ramosissimus	Auricled Groundsel					•					•		
	Siloxerus humifusus	Procumbent Siloxerus	•									•		
	* Sonchus asper	Rough Sowthistle			•		•		•			•		
	Sonchus hydrophilus	Native Sowthistle							•					
	* Sonchus oleraceus	Common Sowthistle	•	•	•		•		•	•		•	•	•
	* Urospermum picroides	False Hawkbit			•		•					•	•	
	* Ursinia anthemoides	Ursinia	•	•	•		•							
	* Vellereophyton dealbatum	White Cudweed					•					•		
	Waitzia aurea	Golden Waitzia			•									
	Waitzia suaveolens var. suaveolens	Fragrant Waitzia	•				•					•		
Brassicaceae	* Brassica tournefortii	Mediterranean Turnip			•		•		•	•		•	•	•
	* Cakile maritima	Sea Rocket					•							
	* Cardamine hirsuta	Common Bittercress	•											
	* Cardamine paucijuga		•		•									

Family	Plant taxa	Common names	FOR	MAI	LES	CRA	YAL	MEA	C/W	WO	TRI	YAN	SEA	CER
	* Heliophila pusilla		•	•	•	•	•					•		
	Lepidium pseudohyssopifolium											•		
	Lepidium rotundum	Veined Peppercress					•					•		
	* Raphanus raphanistrum	Wild Radish			•									
	Rorippa sp (Yalgorup) GK 14455				•		•							
	Stenopetalum gracile			•	•	•	•					•		•
	Stenopetalum robustum		•											
Caesalpiniaceae	Labichea cassioides													•
Campanulaceae	* Wahlenbergia capensis	Cape Bluebell		•		•	•					•		
	Wahlenbergia multicaulis		•											
	Wahlenbergia preissii		•	•		•	•					•	•	
Caryophyllaceae	* Arenaria serpyllifolia				•					•		•		
	* Cerastium glomeratum	Mouse Ear Chickweed	•	•	•		•		•	•		•		
	* Corrigiola litoralis	Strapwort								•				
	* Minuartia hybrida		•		•		•		•			•		
	* Petrorhagia velutina	Velvet Pink	•	•	•	•	•		•			•	•	
	* Polycarpon tetraphyllum	Velvet Pink			•		•					•		
	* Sagina maritima				•				•					
	* Silene gallica	French Catchfly	•		•		•							
	* Silene nocturna	Mediterranean Catchfly					•					•	•	
	* Spergula arvensis	Corn Spurry	•											
	* Stellaria media	Chickweed			•		•		•			•	•	
Casuarinaceae	Allocasuarina humilis	Scrub She-oak										•		•
Centrolepidaceae	Centrolepis aristata	Pointed Centrolepis					•							
	Centrolepis drummondiana		•		•							•		
Chenopodiaceae	Enchylaena tomentosa var. tomentosa	Barrier Saltbush											•	
	Rhagodia baccata subsp. baccata	Berry Saltbush		•										
	Rhagodia baccata subsp. dioica	Berry Saltbush	•		•		•		•	•		•		•

Family	Plant taxa	Common names	FOR	MAI	LES	CRA	YAL	MEA	C/W	WO	TRI	YAN	SEA	CER
	Threlkeldia diffusa	Coast Bonefruit			•					•				
Colchicaceae	Burchardia congesta	Milkmaids	•				•					•		
	Wurmbea monantha						•		•					
	Wurmbea tenella		•											
Commelinaceae	Cartonema philydroides		•											
Convolvulaceae	Dichondra repens	Kidney Weed	•	•	•									
	* Convolvulus arvensis				•									
Crassulaceae	Crassula colorata var. colorata	Dense Stonecrop	•	•	•	•	•		•	•		•	•	•
	* Crassula decumbens	Rufous Stonecrop	•		•							•		
	Crassula exserta				•									
	* Crassula glomerata				•				•	•				
	* Crassula natans								•					
	Crassula peduncularis	Purple Stonecrop	•									•		
Cupressaceae	Callitris preissii	Rottnest Island Pine, Maro									•			
Cuscutaceae	* Cuscuta epithymum	Lesser Dodder			•		•			•		•		
Cyperaceae	Baumea articulata	Jointed Rush							•					
	Baumea juncea	Baumea Twigrush							•		•			
	Baumea vaginalis	Sheath Twigrush							•					
	Carex appressa	Tall Sedge										•		
	Carex preissii		•	•	•	•			•		•	•	•	
	Cyperus polystachyos	Bunchy Sedge							•					
	* Cyperus tenellus	Tiny Flat-sedge			•		•						•	
	Gahnia trifida	Coast Saw-sedge		•					•	•				
	Isolepis cernua	Nodding Club-rush							•			•		
	Isolepis cyperoides								•					
	* Isolepis marginata		•		•	•	•		•		•	•	•	•
	Isolepis nodosa	Knotted Club-rush	•	•	•				•	•	•	•		•
	Isolepis stellata	Star Club-rush							•					
	Lepidosperma gladiatum	Coast Sword-sedge, Kerbin	•	•	•				•	•	•	•		•

Family	Plant taxa	Common names	FOR	MAI	LES	CRA	YAL	MEA	C/W	WO	TRI	YAN	SEA	CER
	Lepidosperma leptostachyum		•									•		
	Lepidosperma longitudinale	Pithy Sword-sedge			•				•		•			
	Lepidosperma sp. (Coastal terete BJK & NG 231)						•			•				
	Lepidosperma squamatum		•	•	•	•	•	•	•	•	•	•	•	
	Mesomelaena preissii													•
	Mesomelaena stygia										•			
	Schoenoplectus validus								•					
	Schoenus clandestinus											•	•	
	Schoenus curvifolius		•											
	Schoenus grandiflorus	Large Flowered Bogrush	•	•	•	•	•		•	•		•	•	•
	Schoenus humilis		•											
	Schoenus nitens	Shiny Bog-rush							•					
	Schoenus subflavus	Yellow Bog-rush				•								
	Tetraria octandra								•					
Dasypogonaceae	Acanthocarpus preissii		•		•		•			•	•	•	•	•
	Dasypogon bromeliifolius	Pineapple Bush				•								
	Lomandra caespitosa	Tufted Mat Rush	•	•		•	•					•		•
	Lomandra hermaphrodita		•				•							
	Lomandra maritima	Coastal Mat-rush			•				•	•	•	•		•
	Lomandra micrantha subsp. micrantha	Small-flower Mat-rush	•			•						•		
	Lomandra preissii		•											
	Lomandra purpurea	Purple Mat Rush	•											
	Lomandra sericea	Silky Mat Rush				•								
	Lomandra suaveolens		•				•					•		
Dennstaedtiaceae	Pteridium esculentum	Bracken	•		•	•			•			•	•	
Dilleniaceae	Hibbertia cuneiformis	Cutleaf Hibbertia	•	•	•		•							
	Hibbertia hypericoides	Yellow Buttercups	•	•	•	•	•					•		•
	Hibbertia racemosa	Stalked Guinea Flower	•									•	•	

Family	Plant taxa	Common names	FOR	MAI	LES	CRA	YAL	MEA	C/W	WO	TRI	YAN	SEA	CER
	Hibbertia subvaginata					•						•		
Droseraceae	Drosera erythrorhiza	Red Ink Sundew	•				•					•		
	Drosera glanduligera	Pimpernel Sundew	•									•		
	Drosera menziesii subsp. penicillaris	Pink Rainbow	•											
	Drosera pallida	Pale Rainbow					•							
	Drosera stolonifera	Leafy Sundew	•				•							
Epacridaceae	Astroloma ciliatum	Candle Cranberry	•			•								
	Astroloma pallidum	Kick Bush	•	•		•	•					•		
	Conostephium pendulum	Pink-tipped Pearl	•				•							
	Conostephium preissii		•	•			•					•		
	Leucopogon capitellatus		•											
	Leucopogon oxycedrus									•				
	Leucopogon parviflorus	Coast Beard-heath	•	•	•					•		•		
	Leucopogon propinquus		•			•						•	•	•
	Leucopogon racemulosus						•							
Euphorbiaceae	Adriana quadripartita	Bitter Bush	•		•		•		•			•		•
	Beyeria cinerea				•							•		
	Euphorbia australis	Namana					•					•		
	* Euphorbia peplus	Petty Spurge	•	•	•		•		•	•		•	•	•
	* Euphorbia terracina	Geraldton Carnation Weed	•		•		•			•		•		•
	Monotaxis grandiflora	Diamond of the Desert			•									
	Phyllanthus calycinus	False Boronia	•	•	•	•	•		•	•		•	•	
	Poranthera microphylla	Small Poranthera		•	•	•						•		•
	Ricinocarpus glaucus	Wedding Bush			•							•		
Fumariaceae	* Fumaria capreolata	Whiteflower Fumitory	•		•				•	•		•		
	* Fumaria muralis	Wall Fumitory			•									
Gentianaceae	* Centaurium erythraea	Common Centaury			•		•		•			•		
Geraniaceae	* Erodium botrys	Long Storksbill			•									
	* Erodium cicutarium	Common Storksbill	•		•		•			•		•	•	

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	Erodium cygnorum	Blue Heronsbill					•					•		
	* Geranium molle	Dove's Foot Cranesbill	•		•									
	Geranium retrorsum						•							
	Geranium solanderi	Native Geranium	•	•	•							•	•	
	* Pelargonium capitatum	Rose Pelargonium	•	•	•		•			•		•		
	Pelargonium littorale		•	•	•	•	•		•			•		
Goodeniaceae	Dampiera linearis	Common Dampiera					•					•		
	Lechenaultia floribunda	Free-flowering Leschenaultia										•		
	Lechenaultia linarioides	Yellow Leschenaultia										•		
	Scaevola anchusifolia			•								•		
	Scaevola crassifolia	Thick-leaved Fanflower		•	•					•		•		
	Scaevola nitida	Shining Fanflower		•						•		•		
	Scaevola thesioides											•		
Gyrostemonaceae	Tersonia cyathiflora	Button Creeper					•					•		
Haemodoraceae	Anigozanthos humilis	Cat's Paw												•
	Anigozanthos manglesii	Mangles Kangaroo Paw				•	•					•		
	Conostylis aculeata	Prickly Conostylis	•	•		•	•	•	•	•		•		
	Conostylis candicans	Grey Cottonhead	•	•			•			•		•		•
	Conostylis pauciflora subsp. pauciflora	Dawesville Conostylis					•							
	Conostylis setigera	Bristly Cottonhead		•										
	Haemodorum spicatum	Mardja										•		
	Phlebocarya ciliata					•	•					•		
Haloragaceae	Haloragis aculeolata						•							
Hyacinthaceae	* Lachenalia reflexa										•			
Hypoxidaceae	Hypoxis glabella	Tiny Star	•									•		
Iridaceae	* Ferraria crispa	Black Flag	•		•							•		
	* Chasmanthe floribunda	African Corn Flag								•		•		
	* Freesia aff. leichtlinii	Freesia	•		•	•	•					•		
	* Gladiolus caryophyllaceus	Wild Gladiolus			•							•		

Family	Plant taxa	Common names	FOR	MAI	LES	CRA	YAL	MEA	C/W	WO	TRI	YAN	SEA	CER
	* Gladiolus undulatus	Wild Gladiolus	•											
	* Homeria flaccida	One-leaf Cape Tulip			•							•	•	
	Orthrosanthus laxus	Morning Iris	•		•	•	•					•		
	Patersonia occidentalis	Purple Flag, Koma	•				•					•		
	Patersonia juncea	Rush Leaved Patersonia	•											•
	* Romulea rosea	Guildford Grass	•	•	•		•		•	•		•	•	
	* Watsonia meriana var. bulbillifera	Bugle Lily			•									
Juncaceae	* Juncus bufonius	Toad Rush				•	•		•			•		
	* Juncus capitatus	Capitate rush				•	•					•		
	Luzula meridionalis	Field Woodrush	•		•	•	•					•		
Juncaginaceae	Triglochin calcitrapum subsp. incurvum		•	•	•									
	Triglochin calcitrapum subsp. recurvum ms					•	•					•	•	•
	Triglochin centrocarpum	Dwarf Arrowgrass	•	•	•		•	•				•	•	
	Triglochin trichophorum		•									•		
Lamiaceae	Hemiandra pungens	Snakebush		•	•		•			•		•		
	* Stachys arvensis	Stagger Weed	•									•		
Lauraceae	Cassytha flava	Dodder Laurel		•	•							•		
	Cassytha glabella	Tangled Dodder Laurel			•							•		
	Cassytha pubescens	Downy Dodder-laurel								•				
	Cassytha racemosa	Dodder Laurel	•	•	•		•		•	•		•	•	•
Linaceae	Linum marginale	Wild Flax							•	•				
Lindsaeaceae	Lindsaea linearis	Screw-fern			•									
Lobeliaceae	Isotoma hypocrateriformis	Woodbridge Poison			•		•					•		
	Lobelia alata	Angled Lobelia							•					
	Lobelia gibbosa	Tall Lobelia										•		•
	Lobelia heterophylla	Wing-seeded Lobelia			•									
	Lobelia tenuior	Slender Lobelia	•	•	•	•	•			•		•		
Loganiaceae	Logania serpyllifolia						•							

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	Logania vaginalis	White Spray	•	•	•		•		•	•		•	•	
	Mitrasacme paradoxa	Wiry Mitrewort					•					•		
Loranthaceae	Amyema miquelii	Stalked Mistletoe							•	•		•		
	Nuytsia floribunda	Christmas Tree, Mudja		•			•							
Malvaceae	Alyogyne huegelii var. glabrata ms						•					•		
	Alyogyne huegelii var. huegelii						•					•		
Mimosaceae	Acacia alata var. tetrantha											•		
	Acacia cochlearis	Rigid wattle	•	•	•		•		•	•		•		
	Acacia cyclops	Coastal Wattle	•	•	•		•		•	•		•	•	
	Acacia huegelii		•	•			•					•		
	Acacia lasiocarpha	Panjang		•	•					•		•		•
	* Acacia longifolia				•									
	* Acacia paradoxa	Kangaroo Thorn	•											
	Acacia pulchella var. glaberrima	Prickly Moses	•	•	•	•	•		•			•		•
	* Acacia pycnantha	Golden Wattle	•											
	Acacia rostellifera	Summer-scented Wattle			•		•		•	•		•		•
	Acacia saligna	Orange Wattle	•	•	•	•	•		•	•		•	•	•
	Acacia stenoptera	Narrow Winged Wattle					•							
	Acacia truncata								•					
	Acacia willdenowiana	Grass Wattle	•				•		•			•		
	Paraserianthes lophantha	Albizia	•											
Moraceae	* Ficus carica	Fig			•							•		
Myoporaceae	Eremophila glabra	Tar Bush	•	•	•		•			•		•		
	Myoporum caprarioides	Slender Myoporum	•	•	•		•	•	•			•		
	Myoporum insulare	Native Juniper					•			•		•		•
Myrtaceae	Agonis flexuosa	Peppermint, Wonil	•	•	•	•	•					W		
	Calothamnus quadrifidus	One-sided Bottlebrush			•									•
	Calytrix angulata	Yellow Starflower					•							
	Chamelaucium uncinatum	Geraldton Wax												•

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	Eremaea pauciflora													•
	Eucalyptus calophylla	Marri, Mari	•											
	Eucalyptus cornuta	Yate	•											
	Eucalyptus decipiens	Redheart											•	
	Eucalyptus gomphocephala	Tuart, Duart	•	•	•	•	•	•	•	•	•	•	•	•
	Eucalyptus marginata subsp. marginata	Jarrah, Djara	•	•		•	•					•		
	Eucalyptus mundijongensis											•		
	Eucalyptus rudis subsp. rudis	Flooded Gum, Kulurda										•		
	Hypocalymma robustum	Swan River Myrtle					•							
	* Leptospermum laevigatum	Victorian Teatree			•					•				
	Leptospermum spinescens						•					•		
	Melaleuca huegelii	Chenille Honey-myrtle			•					•				
	Melaleuca preissiana	Moonah							•					
	Melaleuca rhaphiophylla	Swamp Paperbark							•					
	Melaleuca systena	Coastal Honeymyrtle	•		•	•	•			•		•		•
	Melaleuca thymoides						•							
	Melaleuca teretifolia	Banbar							•					
Olacaceae	Olax benthamiana				•							•		
Oleaceae	* Olea europaea	Olive	•		•									
Orchidaceae	Acianthus reniformis	Mosquito Orchids	•	•	•		•		•	•		•	•	
	Caladenia arenicola	Carousel Spider Orchid					•							
	Caladenia chapmanii		•											
	Caladenia crebra	Arrowsmith Spider Orchid												•
	Caladenia flava subsp. flava	Cowslip Orchid	•	•			•					•		•
	Caladenia georgei	Tuart Spider Orchid	•	•			•					•		
	Caladenia hirta	Sugar Candy Orchid	•											
	Caladenia latifolia	Pink Fairy Orchid	•	•	•		•		•	•		•	•	
	Caladenia longicauda	Common White Spider Orchid			•	•						•		
	Caladenia marginata	White Fairy Orchid	•											

Family	Plant taxa	Common names	FOR	MAI	LES	CRA	YAL	MEA	C/W	WO	TRI	YAN	SEA	CER
	Caladenia speciosa	Sandplain White Spider Orchid	•											
	Caladenia vulgata	Spider Orchid					•							
	Corybas recurvus	Helmet Orchid	•											
	Cyanicula gemmata	Blue China Orchid	•									•		
	Cyanicula sericea	Silky Blue Orchid					•					•		
	Cryptostylis ovata	Slipper Orchid	•											
	Cyrtostylis huegelii	Mosquito Orchid		•										
	Diuris amplissima		•											
	Diuris corymbosa	Common Donkey Orchid	•									•		
	Elythranthera brunonis	Purple Enamel Orchid	•				•					•		
	Elythranthera emarginata	Pink Enamel Orchid												
	Eriochilus dilatatus	White Bunny Orchid	•		•		•					•		
	Leporella fimbriata	Hare Orchid	•											
	Leptoceras menziesii	Rabbit Orchid	•				•			•		•		
	Lyperanthus nigricans	Red Beak Orchid	•				•					•	•	
	Microtis media	Tall Mignonette Orchid	•										•	
	* Monadenia bracteata	South African Orchid	•				•					•		
	Prasophyllum calcicola								•					
	Prasophyllum elatum	Tall Leek Orchid							•					
	Pterostylis aff. nana	Dwarf Snail Orchid	•			•							•	•
	Pterostylis aff. vittata	Grey Banded Greenhood				•								
	Pterostylis aspera	Brown-veined Shell Orchid	•											
	Pterostylis brevisepala ms		•		•							•	•	
	Pterostylis recurva	Jug Orchid				•	•					•		
	Pterostylis rogersii		•											
	Pterostylis sanguinea	Dark Banded Greenhood	•	•										
	Pterostylis vittata	Banded Greenhood	•				•					•		
	Thelymitra benthamiana	Cinnamon Sun Orchid	•											

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	Thelymitra crinita	Blue Lady Orchid	•											
Orobanchaceae	* Orobanche minor	Lesser Broomrape	•	•	•		•		•			•	•	
Oxalidaceae	* Oxalis glabra		•											
	Oxalis perennans		•	•	•	•	•		•			•	•	•
	* Oxalis pes-caprae	Soursob	•	•	•					•		•		
Papilionaceae	Bossiaea eriocarpa	Common Brown Pea	•	•		•	•					•		
	Brachysema praemorsum		•											
	Chorizema diversifolium	Yellow-eyed Flame Pea	•	•										
	Daviesia divaricata	Marno		•		•	•					•		•
	Daviesia preissii		•											
	Gompholobium confertum						•							
	Gompholobium tomentosum	Hairy Yellow Pea	•	•	•		•		•	•		•		•
	Hardenbergia comptoniana	Native Wisteria	•	•	•		•		•	•		•	•	•
	Hovea chorizemifolia	Prickly Hovea	•											
	Hovea stricta	Hovea										•		
	Hovea trisperma var. trisperma	Common Hovea	•			•	•					•		
	Isotropis cuneifolia subsp. cuneifolia	Granny Bonnets	•				•					•		
	Jacksonia calcicola											•		•
	Jacksonia furcellata	Grey Stinkwood	•	•	•		•							
	Jacksonia sparsa ms			•										
	Jacksonia sternbergiana	Stinkwood, Kapur		•	•		•					•		
	Kennedia coccinea	Coral Vine	•	•			•		•					
	Kennedia prostrata	Scarlet Runner	•	•		•	•			•		•		
	* Lotus angustissimus	Narrowleaf Trefoil					•							
	* Lupinus angustifolius	Narrowleaf Lupin	•		•									
	* Lupinus cosentinii		•	•	•		•					•	•	
	* Medicago polymorpha	Burr Medic		•	•		•			•		•	•	
	* Melilotus indicus	King Island Melilot		•	•					•		•	•	
	Nemcia reticulata						•					•		

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	Sphaerolobium medium		•											
	Templetonia retusa	Cockies Tongues		•	•				•	•		•		
	* Trifolium angustifolium	Narrowleaf Clover		•	•									
	* Trifolium arvense	Hare's Foot Clover		•										
	* Trifolium campestre	Hop Clover	•		•	•	•		•			•		
	* Trifolium cernuum	Drooping Flower Clover			•									
	* Trifolium dubium	Suckling Clover	•	•										
	* Trifolium glomeratum	Cluster Clover	•									•		
	* Trifolium repens	White Clover	•											
	* Vicia sativa subsp. sativa	Common Vetch	•	•	•		•					•		
Phormiaceae	Dianella brevicaulis		•				•							
	Dianella revoluta	Blueberry Lily	•	•	•	•	•		•	•	•	•	•	•
	Stypandra glauca	Blind Grass	•				•					•		
Phytolaccaceae	* Phytolacca octandra	Red Ink plant					•					•		
Pinaceae	* Pinus pinaster	Maritime Pine	•											
	* Pinus radiata	Radiata Pine	•			•								
Pittosporaceae	Billardiera variifolia						•							
	Pittosporum phylliraeoides	Weeping Pittosporum	•		•							•		
	Sollya heterophylla	Australian Bluebell	•				•					•		
Plantaginaceae	Plantago debilis				•		•					•		
	* Plantago lanceolata	Ribwort Plantain	•		•		•							
Poaceae	* Aira caryophyllea	Silvery Hairgrass	•	•	•	•	•			•	•	•	•	
	Amphipogon turbinatus		•											
	Austrodanthonia occidentalis		•	•		•	•							
	Austrodanthonia pilosa	Smoothflower Wallaby Grass												
	Austrostipa compressa													•
	Austrostipa elegantissima	Feather Speargrass		•	•		•			•		•		•
	Austrostipa flavescens		•	•	•		•		•	•	•	•	•	

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	Austrostipa pycnostachya		•			•								
	Austrostipa semibarbata	Bearded Speargrass	•						•					
	* Avena barbata	Bearded Oat	•	•	•		•		•	•	•	•	•	
	* Avena fatua	Wild Oat	•										•	
	* Briza maxima	Blowfly Grass	•	•	•	•	•		•	•		•	•	
	* Briza minor	Shivery Grass	•		•	•			•			•	•	
	Bromus arenarius	Sand Brome		•	•									
	* Bromus diandrus	Great Brome	•	•	•	•	•		•	•		•	•	•
	* Bromus hordeaceus	Soft Brome	•				•							
	* Cynodon dactylon	Couch	•	•	•				•			•	•	
	* Cynosurus echinatus	Rough Dog's Tail	•						•					
	* Desmarzeria rigida				•					•		•		
	Dichelachne crinita	Long Hair Plume Grass	•	•										
	* Ehrharta calycina	Perennial Veldtgrass		•										
	* Ehrharta longiflora	Annual Veldtgrass	•	•	•	•					•	•	•	
	* Eragrostis curvula	African Lovegrass	•											
	Hemarthria uncinata	Matgrass							•					
	* Holcus lanatus	Yorkshire Fog	•											
	* Hordeum leporinum	Barley Grass	•	•										
	* Lagurus ovatus	Hare's Tail Grass	•	•	•		•		•	•		•	•	•
	* Lolium multiflorum	Italian Ryegrass		•	•		•					•	•	
	* Lolium perenne	Perennial Ryegrass							•					
	* Lolium rigidum	Wimmera Ryegrass	•	•			•		•					
	Microlaena stipoides	Weeping Grass	•	•	•		•		•			•	•	
	* Paspalum dilatatum	Paspalum	•											
	* Pentaschistis airoides	False Hairgrass					•					•		
	* Poa annua	Winter Grass	•		•							•		
	Poa drummondiana	Knotted Poa		•	•		•			•		•		
	Poa poiformis	Coastal Poa	•	•	•								•	

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	Poa porphyroclados						•		•	•				
	* Polypogon monspeliensis	Annual Beardgrass							•					
	Polypogon tenellus								•					
	* Stenotaphrum secundatum	Buffalo Grass			•				•	•				
	* Vulpia bromoides	Squirrel Tail Fescue		•	•									
	* Vulpia myuros	Rat's Tail Fescue	•		•	•	•		•	•		•	•	
Polygalaceae	Comesperma confertum	Milkwort		•			•		•	•		•		
	Comesperma integerrimum	Milkwort			•		•			•		•		•
Polygonaceae	* Emex australis	Double Gee	•		•							•		
	Muehlenbeckia adpressa	Climbing Lignum	•				•		•			•		•
	Muehlenbeckia polybotrya											•		
	* Rumex acetosella	Sorrel	•											
Portulacaceae	Calandrinia brevipedata	Short-stalked Purslane			•		•							
	Calandrinia calyptrata	Pink Purslane	•		•					•				
	Calandrinia corrigioloides	Strap Purslane		•	•		•					•	•	
	Calandrinia granulifera	Pygmy Purslane			•	•								
	Calandrinia liniflora	Parakeelia		•										
Primulaceae	* Anagallis arvensis var. arvensis	Pimpernel	•	•	•	•	•		•	•		•	•	
	* Anagallis arvensis var. foemina	Pimpernel					•							
	Samolus repens	Creeping Brookweed							•					
Proteaceae	Banksia attenuata	Slender Banksia, Piara	•	•	•	•	•					•		•
	Banksia grandis	Bull Banksia, Pulgarla	•			•								
	Banksia leptophylla var. leptophylla													•
	Banksia littoralis	Swamp Banksia, Pungura							•					
	Banksia menziesii	Firewood Banksia										•		•
	Banksia prionotes	Acorn Banksia												•
	Conospermum stoechadis x triplinervium	Common Smokebush												•
	Conospermum triplinervium	Tree Smokebush										•		
	Dryandra lindleyana	Couch Honeypot	•				•			•		•	•	•

Family	Plant taxa	Common names	FOR	MAI	LES	CRA	YAL	MEA	C/W	WO	TRI	YAN	SEA	CER
	Dryandra sessilis	Parrot Bush, Pudjak			•		•		•	•		•		•
	Grevillea crithmifolia						•					•		
	Grevillea preissii	Spider Net Grevillea								•				
	Grevillea vestita		•									•		
	Hakea lissocarpha	Honey Bush				•	•					•		•
	Hakea prostrata	Harsh Hakea			•		•		•	•		•		•
	Hakea trifurcata													•
	Persoonia longifolia	Snottygobble				•								
	Persoonia saccata	Snottygobble	•			•								
	Petrophile linearis	Pixie Mops	•									•		
	Petrophile serruriae													•
	Petrophile striata													
	Stirlingia latifolia	Blueboy					•					•		
	Synaphea floribunda		•											
	Synaphea polymorpha	Albany Synaphea, Pinda												
	Xylomelum occidentale	Woody Pear, Djandjin				•								
Ranunculaceae	Clematis linearifolia	Slender Clematis	•	•	•		•		•	•		•	•	•
	Clematis pubescens	Common Clematis			•	•	•					•		
	Ranunculus colonorum	Common Buttercup	•		•		•					•		
	* Ranunculus muricatus	Sharp Buttercup			•									
	Ranunculus pumilio	Smallflower Buttercup	•		•		•						•	
Restionaceae	Hypolaena exsulca													
	Desmocladus aspera			•	•		•			•	•	•		•
	Loxocarya pubescens										•			
Rhamnaceae	Cryptandra arbutiflora	Waxy Cryptandra	•				•							
	Cryptandra mutila						•							•
	Spyridium globulosum	Basket Bush	•	•	•					•		•		
	Spyridium tridentatum											•		
	Trymalium ledifolium subsp. ledifolium						•		•	•				

Family	Plant taxa	Common names	FOR	MAI	LES	CRA	YAL	MEA	C/W	WO	TRI	YAN	SEA	CER
Rosaceae	* Acaena echinata	Sheep's Burr	•											
Rubiaceae	* Galium aparine	Goosegrass	•							•				
	* Galium murale	Small Goosegrass		•	•		•		•	•		•	•	
	Opercularia hispidula	Hispid Stinkweed	•	•			•		•	•		•		
	Opercularia vaginata	Dog Weed	•	•	•	•	•	•				•	•	
	* Sherardia arvensis	Field Madder	•		•		•							
Rutaceae	Boronia alata	Winged Boronia			•									
	Diplolaena dampieri	Southern Diplolaena	•	•	•		•			•				
Santalaceae	Exocarpos sparteus	Broom Ballart, Djuk	•	•	•		•			•		•		
	Leptomeria cunninghamii						•					•		
	Leptomeria preissiana									•				
	Santalum acuminatum	Kwandong, Warnga		•	•		•			•		•		
Sapindaceae	Diplopeltis huegelii subsp. subintegra													•
	Dodonaea aptera	Coast Hop-bush		•			•					•		
Scrophulariaceae	* Bartsia trixago	Bellardia		•	•		•		•			•	•	
	* Dischisma arenarium		•	•	•		•		•	•		•		
	* Dischisma capitatum	Woolly-headed Dischisma	•											
	* Kickxia spuria				•									
	* Parentucellia latifolia	Common Bartsia	•				•		•			•	•	
	* Parentucellia viscosa	Sticky Bartsia					•		•					
	* Verbascum virgatum		•						•	•				
	Veronica stolonifera		•		•		•					•		
	* Veronica arvensis	Wall Speedwell	•				•							
	* Verbascum thapsus		•											
Solanaceae	Anthocercis ilicifolia						•					•		•
	Anthocercis littorea	Yellow Tailflower		•	•				•	•		•		
	* Physalis peruviana	Cape gooseberry	•							•		•		
	* Solanum americanum	Glossy Nightshade										•		
	* Solanum linnaeanum	Apple of Sodom	•				•					•	•	

Family	Plant taxa	Common names	FOR	MAI	LES	CRA	YAL	MEA	C/W	WO	TRI	YAN	SEA	CER
	* Solanum nigrum	Black Berry Nightshade	•	•	•	•	•		•	•		•	•	•
	Solanum symonii		•		•		•		•	•			•	
Stackhousiaceae	Stackhousia monogyna				•		•		•			•		
	Tripterococcus brunonis	Winged Stackhousia					•							
Sterculiaceae	Guichenotia ledifolia				•									
	Lasiopetalum membranaceum		•	•			•					•		
	Rulingia luteiflora												•	
	Thomasia cognata			•	•		•		•			•	•	
	Thomasia purpurea				•									
	Thomasia triphylla		•				•					•	•	
Stylidiaceae	Stylidium bulbiferum		•											
	Stylidium calcaratum	Book Triggerplant		•			•							
	Stylidium glaucum	Dotted Triggerplant					•							
	Stylidium junceum	Reed Triggerplant		•								•		
	Stylidium repens	Matted Triggerplant					•					•		
Thymelaeaceae	Pimelea argentea	Silvery Leaved Pimelea	•		•		•					•		
	Pimelea calcicola						•							
	Pimelea rosea	Rose Banjine	•		•		•					•		
Tremandraceae	Tetratheca hirsuta (glabrous)	Black Eyed Susan					•					•		
Tropaeoleaceae	* Tropaeolum majus	Garden Nasturtium			•									
Typhaceae	Typha domingensis	Bulrush, Djandjid							•					
	* Typha orientalis	Bulrush							•					
Urticaceae	Parietaria debilis	Pellitory	•	•	•		•	•	•			•		•
	* Urtica urens	Stinging Nettle	•											
Valerianaceae	* Centranthus macrosiphon						•							
Verbenaceae	Phyla nodiflora	Fogfruit							•					
Violaceae	Hybanthus calycinus	Wild Violet	•	•			•		•			•		•
Xanthorrhoeaceae	Xanthorrhoea brunonis			•										
	Xanthorrhoea preissii	Palga	•	•			•		•		•	•	•	•

Family	Plant taxa	Common names	FOR	MAI	LES	CRA	YAL	MEA	C/W	WO	TRI	YAN	SEA	CER
Zamiaceae	Macrozamia riedlei	Zamia, Djiridji	•	•	•	•	•	•	•		•	•	•	•
Zygophyllaceae	Zygophyllum apiculatum			•										
	Zygophyllum fruticulosum	Shrubby Twinleaf			•									

FLORISTICS OF THE TUART FOREST RESERVE[1]

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ABSTRACT

The Tuart Forest Reserve contains a series of upland and wetland plant communities that once characterized the coastal area between Busselton and Bunbury. It contains the largest remnant of Tuart Tall Woodland to Woodland, which is the only remaining contiguous example of the uplands, wetlands and rivers of the Ludlow Plain Land System of the Spearwood Dune System. A total vascular flora of 705 species is described for the Forest, comprising 543 natives and 162 weeds. There are ten priority taxa and one species of Declared Rare Flora in the Forest. The Forest has a long history of multiple disturbances. The major weeds are Arum Lilies (*Zantedeschia aethiopica)*, Bridal Creeper (*Asparagus asparagoides*) and a range of annual grasses. Historical accounts of the flora and vegetation of the Forest are detailed and compared with the current Tuart Forest Reserve and some perceptions of the Tuart Forest Reserve.

INTRODUCTION

The 'Tuart Forest Reserve' encompass 2,880 hectares (ha) of public (crown) reserves in the Shires of Busselton and Capel (Maps 1 and 2). The central and southern sections, between the Capel and Sabina Rivers, are essentially State Forests 1 and 2 (Map 2), an area of 1,385 ha, which were gazetted in 1919 (Forests Department 1919). Portions of this area were purchased as early as 1903 and 1904. The remaining areas were private lands but, since 1919, have been progressively repurchased by the Crown. This area is now the Tuart Forest National Park and adjacent State Forest[2] (Maps 1 and 2). For the purposes of this study this area is referred to as the Tuart Forest Reserve. This same area was identified in System 1 (Section 1.1.2) of the 1976 report 'Conservation Reserves for Western Australia' (DCE 1976). The general area of the Tuart Forest Reserve is called the Tuart forest[3] as it is often unclear as to which specific area early studies and/or comment have been applied. The Tuart Forest Reserve contains the remaining remnants of the Tuart dominated communities and associated wetlands that once characterized much of this area.

The Tuart forest has long been of interest to the Western Australian community as it:
- contains one of the first forests to be protected as State Forest;
- contains areas that have been the subject of numerous management documents (for example Forests Department of Western Australia 1921, Forests Department of Western Australia 1956, Forests Department of Western Australia 1979); and

[1] This report is Part V in the series 'Floristics of Reserves and Bushland Areas in the Busselton Region (System 1)'. A 1996 Wildflower Society of Western Australia (Inc.) publication contains Parts I to IV (Keighery *et al.* 1996).
[2] The State Forest areas included the Tuart Forest Reserve are contiguous with the National Park areas (Maps 1 and 2). State Forest 12 is not included in the Tuart Forest Reserve.
[3] The term 'forest' as used in these names is used in a general rather than technical sense as the height and cover of Tuart trees in the area do not necessarily constitute a forest.

- is the site of the original forestry school in 1921.

Despite this long association with the Forests Department the vegetation and flora of this large and significant area has not previously been systematically surveyed. This lack of base information on both the flora and plant communities of the Tuart forest has lead to a great deal of speculation as to their nature (for example see Broadbent this publication). As a consequence this paper both describes the present vegetation and flora of the Tuart Forest Reserve (after the boundaries in Map 1) and compares this with the known historical records that describe aspects of the vegetation and flora of the Tuart Forest Reserve.

LOCATION AND GEOGRAPHIC DETAILS

The Tuart Forest Reserve is located between Busselton and Capel on the Swan Coastal Plain (Map 1). The old forestry settlement of Ludlow (Map 1) is central to the Reserve and the area is often referred to as the Ludlow Tuart Forest. A series of other names are used to describe sections of the Reserve as the Reserve has been divided into a series of named 'paddocks' (Map 2 after Forests Department 1975). This report uses these names to designate the various areas of the Tuart Forest Reserve, referring to them as 'Blocks'.

State Forest 12 lies to the south-east of the Tuart Forest Reserve (Maps 1 and 2).

Four rivers flow through the area of the Tuart Forest Reserve. From the north-east to the south-west these are the Capel, Ludlow, Abba and Sabina Rivers (Map 1). Only two of these, the Ludlow and Abba Rivers, flow through the Reserve. The Sabina River marks the south-east boundary of the distribution of Tuart, and the Reserve (see Keighery *et al.* this publication). The Capel River flows through private land between the main area of the Reserve and Minninup Block (Map 1). Early descriptions of the area indicate these rivers, then unnamed, were all referred to as the 'Vasse River'.

SURVEY METHOD

Survey work in the Tuart Forest Reserve was performed at various times of the year over six years of survey from April 1992 to 1997 and in December 2001.

Twenty-nine sites were located and described in the Tuart Forest Reserve (Appendix 1) to sample the range of vegetation associations identified using aerial photographs and field interpretation. The sites are located in those areas observed to be in the best condition in the particular unit being sampled. These sites can be divided into the two groups described below.

- Four 100 m^2 study sites were permanently located using four steel pegs (Appendix 1). Several botanists recorded information in a set format on physical location and attributes, vegetation structure, density and condition and the total flora of these permanent study sites (Keighery 1994). The permanent sites were sampled on at least two occasions and are included in a detailed regional floristic survey of the Swan Coastal Plain (Gibson *et al.* 1994).
- Twenty-five 100 m^2 relevés were located. The physical location and attributes, vegetation structure density and condition and partial flora lists were recorded for each site.

Opportunistic plant collections and records, that is from outside the sites, were made during foot and vehicle transects of the area at various times of the year over the six years of survey. Information on the vegetation associated with each collection or record was recorded. Identification of plant collections were verified at the Western Australian Herbarium.

Over 200 specimens of unusual, rare and interesting species located in the Tuart Forest Reserve during these surveys have been lodged in the Western Australian Herbarium.

Herbarium collections and known published and unpublished surveys were checked for additional records for the Tuart Forest Reserve.

A composite list of the flora of the Tuart Forest Reserve listed against the associated vegetation was compiled from all of the records describe above (Appendix 2 and 3). It is considered that over 90% of the flora has been documented.

GEOMORPHOLOGY AND SOILS

The Tuart Forest Reserve is located on the Swan Coastal Plain and is aligned north-east to south-west (Map 1), forming a band approximately 18 km long (25 km when Minninup Block is included) by 3 km wide lying parallel to the coast. It lies principally within the Spearwood Dune System, bounded to the coast by the Quindalup Dunes System and the Wonnerup Inlet and inland by the Pinjarra Plain. At places on the inland side, areas of Pinjarra Plain are included in the boundary of the Tuart Forest Reserve. While typically on the Swan Coastal Plain the Spearwood Dunes are separated by the Bassendean Dunes, this is not the case in the east-south-east area of the Reserve, where the Bassendean Dunes are present as low dunes over the alluvium of the Pinjarra Plain.

There have been a series of studies mapping the geology and soils of the study area and these are outlined below.

The Urban Geology (Bunbury to Burekup, Anon. 1981) and Environmental Geology (Capel, Belford 1987a and b) series map similar units at a 1 : 50 000 scale. A series of units are mapped in the Tuart Forest Reserve for the different landforms, and these are described below.

- Low sandy rises: 'Sands associated with Tamala Limestone' (Qts) are mapped in the Minninup Block and, the equivalent unit, 'Sands derived from Tamala Limestones' (S7, calcareous sands) are mapped in the Ludlow area (North, Lime Kiln, James and Buffer Blocks). Towards the west there are only thin sheets of sand over limestone where 'Tamala Limestone' (Ls7) is mapped.
- Wetlands: A variety of units are mapped in these. On the edge of the Wonnerup Inlet are Estuarine deposits of 'Calcareous sand overlying estuarine silt' (S27). In other wetland areas are Swamp deposits of clayey silty sands (Cps1) and two types of Alluvium: sandy silts (Ms2) and clayey sandy silts (Msc1) of the Guildford Formation.
- Rivers: Two types of 'Alluvium' are mapped: silty sands (Sm1) on the Ludlow River and clayey sandy silt (Msc1) along the Abba and Sabina Rivers.

Tille and Lantzke (1990) map a series of land units in the land and capability study of the Busselton-Augusta area. This study identifies a series of land systems on the Swan Coastal Plain in the Busselton area associated with the major soil landform units of the Plain. These are outlined in Table 1.

The Tuart Forest Reserve is generally confined to the Ludlow Plain Land System. However, to the east-south-east the Ludlow Plain Land System meets the Abba Plain Land System and the boundary between these units is difficult to determine. The units mapped by Tille and Lantzke (1990) can be considered according to the same landform units as described previously.

- Low sandy rises: Low rises to 15m above sea level of well drained deep brownish yellow sand (L, Spearwood sands).
- Wetlands: Several units are mapped in these. To the north-west on the edges of the Wonnerup

Inlet are poorly drained shallow brownish yellow sands overlying limestone (Lwr). To the south-east are low lying depressions with clayey (Cokelup) soils (Lwg). These depressions are poorly drained in winter and some areas are saline. While not mapped as such, it appears that in the area of the Simpson Wetland (see below) the Ludlow Plain meets the Abba Plain and there are areas of winter wet flats with sandy grey brown soils (Aw).

- Rivers: Narrow floodplains of sandy alluvial soils (Lv).

Both studies give comparable descriptions of the landforms and soils of the area of the Tuart Forest Reserve.

VEGETATION

The Vegetation Map

The vegetation map (Map 3) shows the distribution of the principal plant communities in the Tuart Forest Reserve. The distribution of the communities is based on the structural units described in the Forest (Appendix 1). Five plant communities are mapped. Four of these units are associated with upland areas and the other with seasonally inundated or waterlogged areas. Of the upland units, two are highly modified, being: Tuart over pasture and Pine Plantations. The remaining three are less modified, being: two units of Tuart Woodland and the wetland areas which are a mosaic of units. Included in the wetland mosaic are: woodlands dominated Flooded Gum (*Eucalyptus rudis*), Marri (*Eucalyptus calophylla*), *Melaleuca rhaphiophylla* and *Melaleuca cuticularis* and shrublands dominated by *Melaleuca* species and *Halosarcia.* Two other units can be distinguished: an area of Yate (*Eucalyptus cornuta*) Woodland and the communities associated with the river edges and channels. These are both relatively small in area and highly disturbed and are not mapped. All of these units are described in more detail below.

Uplands

<u>Pine Plantations</u> (Mapping unit: pP)
The cover of native species in the this area is very low however there are Tuart, *Agonis flexuosa* (Peppermint), native shrubs, grasses, sedges and herbs in the area. The density of these native species varies.

<u>Tuart Tall Woodland over pasture</u> (Mapping unit: tW)
These areas have a groundcover of introduced grasses and herbs. The cover of native species, other than Tuart and *Agonis flexuosa,* is low but there are native shrubs, grasses, sedges and herbs in the area. The density of these native species varies.

<u>Tuart Tall Woodland over Candlestick Banksia (*Banksia attenuata*) Woodland</u>
(Mapping unit: tbW; Quadrats Minn 01, Minn 02 and Minn 03 after Gibson *et al.* 1994)
In this area Tuart is scattered or forms an Open Tall Woodland to Woodland over a Woodland dominated by Candlestick Banksia (*Banksia attenuata*). Peppermint (*Agonis flexuosa*) may be co-dominant in this Woodland. Low Jarrah trees are scattered in this community. Other typical understorey species are characteristic of the Spearwood Dune System and include the following:

- shrubs *Leucopogon parviflorus*, *Rhagodia baccata* and *Hibbertia hypericoides*;
- herbs *Arthropodium capillipes*, *Orthrosanthos laxus*, *Sowerbaea laxiflora*, *Daucus glochidiatus*, *Hardenbergia comptoniana*, **Trifolium campestre*;
- grasses *Austrostipa flavescens*, **Briza maxima*; and
- sedges *Isolepis nodosa*.

Native species diversity in quadrats ranges from 49 to 28, and weeds from 8 to 22.

Tuart Tall Woodland over Peppermint (*Agonis flexuosa*) Open Forest
(Mapping unit: taW; Quadrats: PEPB 01 after Gibson *et al.* 1994)
In this area Tuart forms an Open Tall Woodland to Woodland over an Open Forest to Woodland dominated by Peppermint (*Agonis flexuosa*). Other typical understorey species are characteristic of the Quindalup and Spearwood Dune Systems and include the following:

- shrubs - *Spyridium globulosum, Rhagodia baccata* and *Hibbertia cuneiformis*;
- herbs - *Arthropodium capillipes, Stypandra grandiflora, Sowerbaea laxiflora, *Trifolium campestre;*
- climbers - *Hardenbergia comptoniana, Kennedia prostrata;*
- grasses - *Microlaena stipoides, *Briza maxima;* and
- sedges - *Carex preissii.*

Native species diversity in one quadrat was 27 with 12 weeds. As outlined previously this site is in the area of this unit observed to be in the best condition. South of North Block the diversity and density of native taxa in the understorey decreases and the density of weeds increases.

Yate Woodland
Yate (*Eucalyptus cornuta*) reaches its northern limit on the eastern banks of the Sabina River and appears to replace Tuart from here south. This community dominated by Yates once occurred on the western margins of the Reserve however today only remnant trees occur in the area and isolated trees can be found on road verges, in adjacent paddocks and in the Sabina Nature Reserve (Keighery 1999). The community appears to be totally destroyed and is not able to be mapped. The occurrence of Tuart mapped by Smith (1973) in this area is apparently Yate Woodland.

Wetlands
(Mapping unit: WM)

Four areas of flat and basin wetland (Semeniuk 1987) are distinguished within the Tuart Forest Reserve. These wetland areas can be divided into two groups, being:

- Two are on the coastal side of the Forest on the north-western margin of Lime Kiln Block and Webster Block; and
- two are to the inland side (south-eastern side) on the south-eastern margin of Buffer Block and Simpson Block.

The coastal wetland areas are part of the extensive Wonnerup Wetland system. The vegetation is influenced by the saline conditions and the estuarine deposits of ‘calcareous sand overlying estuarine silt’ in these wetlands.

The inland wetlands are on Swamp deposits of clayey silty sands and two types of alluvium; sandy silts (Ms2) and clayey sandy silts (Msc1) of the Guildford Formation, part of the Pinjarra Plain. The predominantly freshwater conditions in these wetlands is reflected in the vegetation.

A series of communities can be distinguished on the seasonally inundated and waterlogged areas. The mosaic nature of these plant communities is a feature of the heavy soil wetlands on the Swan Coastal Plain (Keighery and Trudgen 1992; Gibson *et al*. 1994; Keighery, Keighery and Gibson 1996). The presence of the different communities is related to the surface and subsurface soils and the degree and duration of winter inundation and/or waterlogging.

Coastal Saline Wetland: Lime Kiln Wetland
(Quadrat Lime Kiln Wetland 01)
This small area is part of a larger wetland on the coastal side of the Tuart Forest, which has been predominantly cleared for pasture. The area in the Tuart Forest is dominated by Flooded Gum

(*Eucalyptus rudis*). The understorey is significantly altered and few natives remain in this community.

Coastal Saline Wetland: Webster Wetland
(Quadrats Webster Wetland 01 – 06)
As with the Lime Kiln wetland this area is part of a larger wetland that extends to the north and west and has been significantly disturbed. This area supports communities dominated by wetland species typically associated with saline water including the sedges **Carex divisa and Juncus kraussii* and the samphires *Sarcocornia quinqueflora* and *Halosarcia indica*. However the tree species in the area, Flooded Gum and *Melaleuca rhaphiophylla* reflect that fresher water is available. Typical herbs of these communities are *Cotula coronopifolia, Centella asiatica, Apium prostratum* and *Lobelia alata*.

Inland Fresh Wetland: Buffer Wetland
(Quadrats Buffer Wetland 01 - 05)
A series of communities dominated by various *Melaleuca* species occur in this seasonally inundated wetland. The principal *Melaleuca* species are *M. rhaphiophylla*, *M. viminea* and *M. lateritia*. Interestingly, while the latter two species are always shrubs, *M. rhaphiophylla* can be either a low tree or tall shrub. At times *Eucalyptus rudis* is also present. Typically these woodlands and shrublands are over sedgelands dominated by species such as *Lepyrodia muirii*, *Chorizandra enodes, Schoenus maschalinus* and *Baumea articulata*. As the soils in the wetlands dry, an herbaceous layer becomes evident dominated by such species as *Senecio glomerata*, *S. quadridentatus*, *Ixiolaena viscosa*, *Alternanthera nodiflora*, *Goodenia micrantha* and *Angianthus drummondii* and patches of the grass *Agrostis avenacea.* When the lowest area of the wetland is inundated (Quadrat 03) it is dominated by the aquatic phase of *Cotula coronopifolia* and the aquatic *Montia australasica.*

Inland Fresh Wetland: Simpson Wetland
(Quadrats Simpson Wetland 01 - 09)
The largest area of wetland is found in Simpson Block. A series of communities can be described in a transect across the wetland from better drained margins on sandy clays to the wetter core of the wetland on clays. Tall Woodlands on the margins and sandy rises within the wetlands can be dominated by a series of eucalypts including Tuart, Marri (*Eucalyptus calophylla*) and Flooded Gum. While Tuart and Marri are not considered typical wetland species they are here associated with other species typically associated with wetlands such as the following:

- trees - *Melaleuca preissiana* and *Banksia littoralis;*
- shrubs - *Viminaria juncea*, *Melaleuca viminea*, *M. incana*, *M. rhaphiophylla*, *Kunzea glabrescens*, *Hakea prostrata*, *H. varia, Regelia ciliata* and *Pericalymma ellipticum*; and
- sedges - *Gahnia trifida*, *Lepidosperma longitudinale* and *Baumea rubiginosa*.

The seasonally inundated area of this wetland is dominated by the same suite of shrubs as the Buffer Wetland as well as several other species. These are *Melaleuca viminea*, *M. incana, M. lateriflora* and *M. uncinata.* In this wetland *Melaleuca rhaphiophylla* is generally a low tree. Typically these woodlands and shrublands are over sedgelands dominated by species such as *Lepidosperma longitudinale*, *Gahnia trifida* and *Chorizandra enodes*. As the soils in the wetlands dry, a mixed herbaceous layer becomes evident. When the lowest area of the wetland is inundated (Quadrat 07) it is dominated by the aquatics *Schoenus natans*, *Aponogeton hexatepalus* and *Villarsia submersa.*

Rivers
(Quadrats Ludlow River Bank 01 - 02, Ludlow River Channel 01 and Abba River 01)

Flooded Gum and Marri Woodland are associated with the edges of the Ludlow and Abba Rivers, while the channel is dominated by *Eucalyptus rudis* Woodland over *Melaleuca rhaphiophylla* Low Woodland. All areas have been subject to extensive unnatural disturbance by grazing. The weed **Watsonia meriana* var. *bulbillifera* and introduced grasses predominate along the rivers.

Floristic Community Types

The regional study of the floristic variation of the Swan Coastal Plain by Gibson *et al.* (1994) identified two floristic community types in the Forest (Table 2):

- floristic community type 25: Southern *Eucalyptus gomphocephala* - *Agonis flexuosa* woodlands; and
- floristic community type, 30b: Quindalup *Eucalyptus gomphocephala* and/or *Agonis flexuosa* woodlands.

The wetlands were not sampled in this or subsequent studies however four additional groups are considered to be present as indicated by the floristics of the areas (i.e. inferred groups in Table 1, Appendices 1, 2 and 3). These are:

- floristic community type 1b: Southern *Eucalyptus calophylla* woodlands on heavy soils;
- floristic community type 4: *Melaleuca preissiana* damplands;
- floristic community type 9: Dense shrublands on clay flats; and
- floristic community type 13: Deeper wetlands on heavy soils.

FLORA

Historical Records of the Flora

The earliest known collections from the Tuart forest are from three sources. The exact provenance of these collections is unknown. The three sources are listed below.

- The Baudin expedition - including the type specimen of Tuart.
- Georgiana Molloy - over 150 collections were made and many of these or material grown from her seed collections were used as type material by Professor John Lindley in ‘A Sketch of the Vegetation of the Swan River Colony’ (Hasluck 1990).
- Ludwig Preiss - who stayed with Georgiana Molloy (Hasluck 1990).

The earliest accurately located collections from the area were made by Alexander Morrison in 1898 (most are in Edinburgh Herbarium) and WV Fitzgerald in 1903 (collections are in Sydney).

When the Forestry School was established at Ludlow, the Botanist for the Forests Department, CA Gardner, made the first of his 25 collections of 16 taxa from the area, spread over the years 1920, 1923, 1925, 1927, 1936 and 1940. The majority of these species have been recently re-collected except for: *Calandrinia liniflora*, *Conospermum acerosum* subsp. *acerosum* (originally collected in 1920), C*onospermum caeruleum* subsp. *marginatum* and the doubtful record of *Pultenaea drummondii* (labelled as collected near Ludlow). The lecturer at the Forestry School, TN Stoate also collected near Ludlow and eight of these collections remain. Stoate also collected *Conospermum acerosum* in 1922. Other collections made that have not been re-collected are *Hibbertia rhadinopoda* and *Olearia strigosa*. Dr. Nancy Burbidge made four collections from Ludlow in 1942; all of these are wetland taxa and all have been recollected.

Further historical information on the flora comes from a recently located account of the understorey vegetation of parts of the Tuart forest in d’Espeissis (1938a, b, c and d)[4]. These reports, and especially the associated notebooks, document soil and vegetation surveys carried out

[4] These and other reports cited are in the archives of the Department of Conservation and Land Management.

as pine plantations were established in the late 1930s. Soil and vegetation attributes are described for over 300 sites of which 265 are dominated by Tuart. While the vegetation information for each of the sites is incomplete, this source gives more information on the flora of the area than any other[5]. A total of 149 species were recorded by d'Espeissis from these sites (Appendix 4). Taking account of name changes since these records were made, these can be compared with current day records (Appendices 2 and 3). While the majority of the species recorded have been recorded in this study, the following groups are of interest:

- species not located today – *Allocasuarina fraseriana, Allocasuarina humilis, Anigozanthos viridis, Carpobrotus ?aequilaterale, Hibbertia amplexicaulis/perfoliata, Isopogon formosus, Lobelia gibbosa, ?Olearia pubescens/strigosa* and *Patersonia xanthina;*
- commonly recorded species confined to Minninup Block today - *Calandrinia linifolia, Conostephium pendulum* and *Melaleuca thymoides;* and
- commonly recorded species uncommon in the same blocks today - *Anigozanthos manglesii, Banksia attenuata, Conostylis aculeata, Dampiera linearis, Daviesia divaricata, Daviesia podophylla, Gompholobium tomentosum, Hovea trisperma, Isotropis cuneiformis, Lobelia tenuior, Macrozamia riedlei* and *Scaevola phlebopetala.*

These records do not appear to have been seen by later authors even though d'Espeissis stated he placed collections in the Ludlow Herbarium. No collections under his name could be located in the WA Herbarium today. It is possible that the collections by Stoate and Gardner are the remnants of this herbarium.

The Curator of the Western Australian Herbarium, RD Royce, collected approximately 30 species around Ludlow in 1951, 1954 and 1957. Of these, seven species have not been re-collected for this study; these are: *Calycopeplus oligandrus*, **Setaria palmifolia*, **Watsonia marginata*, *Isopogon formosus* subsp. *dasylepis*, **Ixia maculata*, *Kennedia carinata* and *Petrophile squamata* subsp. *pluridissecta* ms. However, all of the natives are heavy soil wetland or riverine taxa, rather than species of the Tuart dominated communities and it is possible that some are from State Forest 12.

McCutcheon (1974) undertook an inspection of the Tuart Forest in 1974 as part of plans to set up walking trails in the area. This report lists 53 species, all of which we have re-recorded. As part of this study he made a series of collections, which were initially held in Bunbury, but now largely in the WA Herbarium.

Bartholemew (1986) and Piggot (1984) added another 65 species to the flora list as the result of their (and co-workers Fox and White) studies, making a total of 141 species recorded for the Tuart forest. Weston (1989) recorded a further eight species bringing the total to 149. All of these records have been re-recorded by the authors.

Searches of the Department of Conservation and Land Management's Western Australian Herbarium using Flora Base (CALM 2001) for specimens associated with a series of key words such as Ludlow, Tuart forest, Collectors Names, 'Paddock' names and Rivers resulted in a listing of over 450 specimens. A large proportion of these collections were the results of this and other surveys made to compile the data for Gibson *et al.* (1994) and Keighery (1999). Those remaining were individually checked and collections obviously made beyond the boundaries of the Tuart Forest Reserve and those of doubtful origin were eliminated, although the latter were retained for future field searches. The collections of most interest remaining are:

- **Agrostis stolonifera*, Ludlow River, Ludlow, K. Forrest s.n. Probably a weed of the settlement.
- *Caladenia lobata*, Ludlow, Forestry Department, 10–10–1961. Not re-collected, a very unusual record.

[5] A more complete appraisal of this information will be made in a future publication.

- *Hibbertia ferruginea*, Ludlow, AT Hotchkiss s.n., 04-Sept.-1953. A dampland species, rarely recorded on the Swan Coastal Plain.

None of these taxa are 'typical' of Tuart dominated communities and they have not been re-collected in the area.

Prior to this study there had been approximately 240 species recorded from within the boundaries of the Tuart Forest Reserve. The historical records, though incomplete, suggest that major changes have occurred in the floristics of the Tuart Forest Reserve.

Current Flora

The Tuart Forest Reserve contains a vascular flora of at least 705 taxa (Appendices 2 and 3). Of these, 233 taxa were recorded in Minninup Block and 671 taxa in the contiguous blocks. Twenty-eight natives and four weeds were only recorded in Minninup Block and are indicated by an 'M' in Appendix 2.

The 705 recorded taxa can be divided into the following groups
- 543 are natives,
- 162 are weeds,
- 12 are non-flowering vascular plants, nine being ferns and fern allies and three Gymnosperms,
- 267 are monocotyledons (214 natives and 53 weeds), and
- 426 are dicotyledons (317 native and 109 weeds).

The Orchidaceae (54 taxa, including 1 weed), Myrtaceae (40 taxa, including 5 weeds), Cyperaceae (44 taxa including 5 weeds), Asteraceae (62 taxa including 16 weeds), Poaceae (52 native taxa including 32 weeds), Anthericaceae (20 taxa), Papilionaceae (40 taxa including 16 weeds), Proteaceae (19 taxa), Stylidiaceae (19 taxa), Apiaceae (17 taxa) and the Mimosaceae (13 taxa) are the most species diverse families.

Many taxa present in the Tuart Forest Reserve (Appendices 2 and 3) are characteristic of the wet heavier soils of the southern side (or eastern side of the Plain north of Capel) of the Swan Coastal Plain.

Significant Flora – Species of Special Interest

Declared Rare and Priority Flora

One species of Declared Rare Flora and ten rare taxa (priority taxa, that is taxa under consideration for declaration as Declared Rare Flora, see Appendix 5, Table 3) were located in the Tuart Forest Reserve. Of these eleven taxa:

- six are endemic to the Swan Coastal Plain, these being - *Aponogeton hexatepalus, Jacksonia sparsa* ms, *Myriophyllum echinatum, Rhodanthe pyrethrum, Schoenus capillifolius and Verticordia plumosa* var. *vassensis;*
- nine are restricted to the southern side of the Plain (or eastern side of the Plain north of Capel), these being - *Aponogeton hexatepalus, Blennospora doliiformis* ms, *Chamaescilla gibsonii*, *Eryngium ferox* ms, *Myriophyllum echinatum*, *Rhodanthe pyrethrum*, *Schoenus capillifolius*, *Trichoclin*e sp. Treeton (BJ Keighery & N Gibson 564) and *Verticordia plumosa* var. *vassensis*;
- nine are species of clay based wetlands, these being - *Aponogeton hexatepalus, Blennospora doliiformis* ms, *Chamaescilla gibsonii, Eryngium ferox* ms, *Myriophyllum echinatum, Rhodanthe pyrethrum, Schoenus capillifolius, Schoenus natans, Trichocline* sp. Treeton (BJ Keighery & N Gibson 564) and *Verticordia plumosa* var. *vassensis*;
- three are true aquatic species, growing, flowering and seeding in inundated wetlands

(sumplands), these being - *Aponogeton hexatepalus, Schoenus capillifolius* and *Schoenus natans*.

These taxa are described below.

Declared Rare Flora
One vascular plant from the Tuart Forest Reserve is currently listed as Declared Rare Flora (DRF, Atkins 2001), *Verticordia plumosa* var. *vassensis* (Myrtaceae). This is one of the three varieties (*Verticordia plumosa* var. *vassensis*, var. *ananeotes* and var. *pleiobotrya*) of the Plumed Feather Flower listed as DRF. All three varieties are confined to the sandy clays of the southern side, or eastern side of the Plain north of Capel, of the Swan Coastal Plain. *V. plumosa* var. *pleiobotrya* is known from the Mundijong area in the Shire of Serpentine–Jarrahdale and *V. plumosa* var. *vassensis*, from the Ambergate area south of Busselton.

Two other species recorded for the Tuart Forest Reserve, *Aponogeton hexatepalus* and *Schoenus natans*, were until recently listed as DRF. However, the location of large populations of both species has led to the reappraisal of the threat to both species and they are not currently listed.

Priority Flora (listed in Priority groups and then alphabetical order after family)
Ten Priority Flora are currently recorded in the Tuart Forest Reserve; these are described below.

Trichocline sp. Treeton (BJ Keighery & N Gibson 564) (Asteraceae) - Priority 2
This as yet undescribed species is confined to clay based wetlands, principally on the Plain. The rosetted, annually renewed herb produces attractive Gerbera-like flowers in late spring to early summer, when the soils are dry.

Schoenus capillifolius (Cyperaceae) - Priority 2
This aquatic *Schoenus* was found in the Simpson Wetlands. The aquatic form of this species is confined to clay based wetlands of the Swan Coastal Plain.

Blennospora doliiformis ms (Asteraceae) - Priority 3
This taxon was first recognized in the Gibson *et al*. (1994) study as *Blennospora* aff. *drummondii* (BJK & NG 20) from eight populations from floristic community types 7, 10a and 18. While this taxon is related to *Blennospora drummondii*, it can be distinguished from it by the golden corolla lobes that do not age brown and several other features. Typical *Blennospora drummondii* was only found north of Perth. This species is listed on the priority list as *Blennospora* sp. Ruabon (BJ Keighery & N Gibson 20).

Chamaescilla gibsonii (Anthericaceae) - Priority 3
This newly described species was previously known as *Chamaescilla* aff. *spiralis* (GJK 12501). It is confined to clay based wetlands and on the Plain is found between Gingin and the Tuart Forest Reserve. This taxon was first recognized at the Brixton Street Wetlands (Keighery and Keighery 1991). This taxon differs from *C. spiralis* in having straight, not spirally twisted leaves, pale blue flowers and it grows and flowers in inundated claypans (clay based sumplands).

Eryngium ferox ms (Apiaceae) - Priority 3
A newly recognized species of claypans, known from Waroona to the Lake Muir area. The type collection is from the Tuart Forest Reserve.

Rhodanthe pyrethrum (Asteraceae) - Priority 3
This attractive annual daisy flowers in the nearly dry clay based wetlands. It is known from seven sites from Midland to near Albany.

Myriophyllum echinatum (Haloragaceae) - Priority 3
This is a small inconspicuous species growing in inundated areas but flowering in waterlogged soils. This poorly collected species is only found on the seasonally inundated heavy soils of the Pinjarra Plain.

Schoenus natans (Cyperaceae) - Priority 4
Schoenus natans is an annual aquatic that rises from a single basal stem that branches towards the surface. The stems reach the surface of the water, but do not emerge and lie just below the water surface. Inflorescences are produced at the ends of the stems during spring. The inflorescences float on the surface and produce stigmas then stamens above the water to enable wind pollination to occur. The resulting fruits are held on the plant until mature when the pedicel decays. They then presumably sink into the drying mud as summer approaches. This aquatic is confined to claypans, and is known from Perth to the Lake Muir area.

Aponogeton hexatepalus (Aponogetonaceae) - Priority 4
Aponogeton hexatepalus, Stalked Water Ribbons, is an aquatic herb found in clay based seasonally inundated wetlands (sumplands) on the southern/eastern side of the Swan Coastal Plain.

Jacksonia sparsa ms (Papillionaceae) - Priority 4
This open shrub *Jacksonia* is a dominant understorey plant in the *Banksia* Woodlands of the Busselton Region both on the Plain and on the Blackwood Plateau. While locally common in these areas, its reservation status would need to be considered carefully before its status as a rare species was changed.

Geographically Significant Taxa
Stenopetalum robustum (Brassicaceae)
The only current record of *Stenopetalum robustum* from the Swan Coastal Plain is from the Tuart Forest Reserve. *Stenopetalum robustum* occurs between Ludlow and Albany and is replaced in the same habitat by *S. gracile* south of Bunbury (Keighery 2002).

Wurmbea tenella (Colchicaceae)
The only current record of this species on the Swan Coastal Plain is from the Tuart Forest Reserve.

Tuart (*Eucalyptus gomphocephala*, Myrtaceae)
Tuart is at its southern range end on the eastern side of the Sabina River at the south-western end of the Tuart Forest Reserve (see Keighery *et al*. this publication).

Yate (*Eucalyptus cornuta*, Myrtaceae)
This tree, previously thought to only occur as far north as Cape Naturaliste (Brooker and Kleinig 1990), is in fact the dominant tree on the Wonnerup flats west of the Tuart Forest Reserve. Trees extend into the south-western end of the Tuart Forest Reserve, where rare hybrids between Yate and Tuart are found.

Montia australasica (Portulacaceae)
The only known record of this species on the Swan Coastal Plain is from the Buffer Wetland. Previously it had been collected from the Swan River at Maylands.

Significant Species Co-occurrences
Hyalosperma pusillum/H. cotula/H. simplex (Asteraceae)
This complex of wetland species co-occur in the Simpson Wetlands. There is only one other site (at Waterloo) where *Hyalosperma pusillum* and *H. simplex* co-occur, but there are no other sites

known where all three species occur together.

Isolepis fluitans and *I. producta* (Cyperaceae)
These two floating aquatics occur between Perth and the Stirling Ranges. Interestingly the only other recorded co-occurrence is in the Stirling Ranges.

Species Restricted to Clay Based Wetlands
Also of interest are the large group of species recorded from the Tuart Forest Reserve that are restricted to clay based wetlands. Sixteen of these have been described in the sections above: *Aponogeton hexatepalus*, *Blennospora doliiformis* ms, *Chamaescilla gibsonii*, *Eryngium ferox* ms, *Hyalosperma pusillum*/*H. cotula/H. simplex*, *Isolepis fluitans*, *I. producta*, *Montia australasica, Myriophyllum echinatum*, *Rhodanthe pyrethrum*, *Schoenus capillifolius*, *Schoenus natans*, *Trichocline* sp. Treeton (BJ Keighery & N Gibson 564) and *Verticordia plumosa* var. *vassensis*. A further five are worthy of comment.

Eryngium pinnatifidum subsp. *palustre* ms (Apiaceae)
This taxon is a subspecies confined to clay based wetlands between Gingin and Lake Muir.

Podolepis gracilis (Swamp form GJK 13 255) (Asteraceae)
A robust glabrous form of this species with large pink or white flowers from the seasonally inundated heavy soils of the Pinjarra Plain from Gingin to Busselton. Further studies on this form are required to establish if it can be distinguished taxonomically.

Dysphania glomulifera subsp. *glomulifera* (Chenopodiaceae)
This is another annual herb that flowers once the ponded water has dried but the soils are still waterlogged and occurs between Bayswater and Bridgetown.

Goodenia claytoniacea (Goodeniaceae)
This perennial herb flowers after the wetlands have dried. It is also recorded between Perth and Albany.

Haloragis tenuifolia (Haloragaceae)
This annual herb is a rarely collected semi-aquatic species growing in seasonally inundated areas. This species flowers once the ponded water has dried but the soils are still waterlogged.

A further two species are of interest.

Acacia paradoxa (Mimosaceae)
An uncommon taxon on the Swan Coastal Plain generally found associated with riverine banks of several geomorphological systems. This species is often listed as introduced to southern Western Australia, although it does not behave or occur like a weed. Gibson *et al.* (1994) found that the vegetation of the riverine areas was so degraded that it is not possible to sample the natural community in which this taxon occurred.

Conospermum flexuosum subsp. *laevigatum* (Proteaceae)
This distinctive pale blue flowered *Conospermum* is a recently recognized subspecies (Bennett 1995). It is found from Capel to Busselton on the Plain and east to Nannup with isolated occurrences to the north along the Scarp and Plateau (Waroona and Jarrahdale area).

Weeds

There are a large number of weeds (162 species) recorded for the Tuart Forest Reserve

(Appendices 2 and 3).

The majority of the weed species are:

- annual or annually renewed species; and
- confined to and/or occur in significant densities on the edges of the tracks and drains or are found in areas which have been partially cleared and/or grossly disturbed by grazing in the past ('Disturbed' areas in Appendices 2 and 3).

However, there are a significant number that may impact on the more intact areas of natural vegetation in the Tuart Forest Reserve. These more significant weeds can be ranked in regard to the habitats they most affect (Dixon and Keighery 1995). The most significant weed species and species groups which pose the most significant threat to natural values in the Forest are described below, as well as a group of interesting and potentially serious weeds.

Generalist Weeds (uplands and wetlands)

Arum Lilies (*Zantedeschia aethiopica*) (Araceae)

This is a widespread weed of both the wetlands and uplands being listed for all vegetation units in Appendices 2 and 3. Arum Lilies are toxic and unpalatable to stock. As a consequence the persistence and spread of this species has been aided by grazing through:

- the reduction/loss of competing palatable native species;
- increased light when trees are pruned in the lower levels; and
- the increased fertility of the soil.

Both Arum Lilies and Bridal Creeper (see below) have succulent berries that are eaten and distributed by birds.

Bridal Creeper (*Asparagus asparagoides*) (Asparagaceae)

Weed of *Eucalyptus rudis* Woodlands and Riverine areas especially but spreading throughout the whole forest.

Upland Weeds

There are many species in this group but of most concern are a group of annual grasses being: *Bromus diandrus*, *Cynosurus echinatus*, *Ehrharta longiflora*, *Lagurus ovatus*, *Lolium* species and *Vulpia myuros*. Again these are species favoured by cattle grazing and probably encouraged by managers. Annual grasses create fire hazard and restrict regeneration of Tuart and understorey species.

Wetland Weeds

Widespread wetland weeds include Arum Lily, *Sparaxis bulbifera* and the thistles (*Carduus pycnocephalus* and *Cirsium vulgare*).

Riverine Weeds

Riverine weeds are: the perennial grasses, Couch (*Cynodon dactylon*), Kikuyu (*Pennisetum clandestinum*) and Buffalo (*Stenotaphrum secundatum*); **Watsonia meriana* var. *bulbillifera* and *Fumaria capreolata*. Weeds of the river pools and estuarine areas are: *Carex divisa* (especially on the edges of the Wonnerup Inlet*),* *Isolepis prolifera*, Freshwater Couch (*Paspalum distichum*) and *Typha orientalis*.

Other Weeds of Interest

Locally abundant weeds include *Albuca canadensis* (abundant around the Abba River), *Acacia pycnantha* (especially in Lime Kiln Block), *Gladiolus undulatus* and *Oxalis pes-caprae* (especially along the rivers).

Potentially serious weeds are: Black Flag (*Ferraria undulata*), Freesia (*Freesia* hybrid) , Olives (*Olea europea*), Victorian Ti Tree (*Leptospermum laevigatum*), Geraldton Carnation Weed (*Euphorbia terracina*), feral pines and eucalypts from plantations and plantings.

A comprehensive weed management plan needs to be developed and all grazing of wetland areas should cease as a matter of urgency.

VEGETATION CONDITION

Vegetation Condition was recorded for most of the plots described in the Tuart Forest Reserve (Appendix 1). However in considering the overall condition of the Reserve it should be noted that the plots are located in the most intact areas of vegetation observed. That is, the condition recorded for the plots is that of the vegetation observed to be in the best condition. As a consequence the general condition of areas can be different than that described for the plots.

The condition of the vegetation of the Reserve needs to be considered in terms of the upland, wetland and riverine areas.

Uplands

The vegetation in the upland units in the Tuart Forest Reserve ranges from Very Good to Completely Degraded (Appendix 1 and Map 3). Of the various blocks Minninup Block is in the best condition, generally being in Good to Very Good condition. The contiguous southern blocks are generally in a Good to Degraded condition with Completely Degraded and Very Good areas. In general, condition declines from the north of these blocks to the south. That is the vegetation structure has been significantly altered and there are very obvious signs of multiple disturbance. Interestingly those areas in which pines have been planted retain significant numbers of the original native species and when the pines are removed have a comparable structure and floristics to that of the more disturbed areas.

Wetlands

The wetlands are generally in better condition than the uplands, ranging from Excellent to Degraded condition but generally being in Excellent to Very Good condition.

River

The vegetation of the rivers is generally in a Degraded to Completely Degraded condition.

DISCUSSION

Vegetation

This paper describes the present day vegetation of the Tuart Forest Reserve (Vegetation section, Appendix 1 and Map 3). A series of features of the vegetation identify the Reserve as being of regional conservation value. These features are listed and discussed below.

The largest most southern remnant of Tuart Tall Woodland to Woodland on the Swan Coastal Plain

A series of studies have identified the Tuart dominated vegetation of the Tuart Forest Reserve area as being of particular value as it is the largest area of Tuart Tall Woodland/Woodland remaining on the Plain (Smith 1973, Beard 1981). Here the focus is on the values of the trees of the Tall Woodlands/Woodlands, that is the density and maturity of the Tuart trees. This large area of mature Tuart trees maintains high fauna conservation values and has considerable scenic beauty (see also Dell *et al*. this publication). While these are very significant values, consideration should also be given to the relationship between Tuart dominated communities in the Reserve and other communities containing Tuart across the range of Tuart. This regional context is demonstrated by reference to the floristic community types. Two floristic community types, floristic community type 25 (Southern *Eucalyptus gomphocephala* - *Agonis flexuosa* woodlands) and floristic community type 30b (Quindalup *Eucalyptus gomphocephala* and/or *Agonis flexuosa* woodlands) are identified in the Forest; both have Tuart as a dominant species (see Gibson *et al*. this publication). In addition, these two floristic community types have a predominantly southern distribution (Maps 4 and 5). Interestingly, floristic community type 25 is generally associated with the Spearwood Dunes and floristic community type 30b is more commonly associated with the Quindalup Dunes. The only other bushland area with this same combination of floristic community types dominated by Tuart is the Maidens/Shearwater Forest (see Keighery *et al*. this publication) area south of Bunbury, emphasising the southern nature of these two groups.

Complex and diverse area of wetlands

Previous to this study, the wetlands of the Tuart Forest Reserve have generally been overlooked. The floristics of the wetlands indicates that they contain a mosaic of three floristic community types: type 4 (*Melaleuca preissiana* damplands), type 9 (Dense shrublands on clay flats) and type 13 (Deeper wetlands on heavy soils). An additional floristic community type, type 1b (Southern *Eucalyptus calophylla* woodlands on heavy soils) is considered to be associated with the rises in these wetlands. These floristic community types are typically associated with wetlands of the eastern side (and southern side, south of Busselton) of the Swan Coastal Plain. All remaining naturally-vegetated wetlands on the eastern side of the Plain have significant conservation value (Keighery and Trudgen 1992, Gibson *et al.* 1994, Keighery *et al.* 1996). The regional floristic survey of the Plain (Gibson *et al.* 1994) recommended that

> 'As a consequence of the small amount of remnant vegetation on the eastern side* of the plain, all such remnants in the study area with the basic vegetation intact or able to be regenerated are of high conservation value.'
>
> *includes the southern side, south of Busselton.

As a consequence of the loss of this vegetation across the Plain, several of these floristic community types (types 1b and 9), have been determined to be threatened ecological communities (English and Blyth 1997). Ecological communities are defined as

> 'naturally occurring biological assemblages that occur in a particular type of habitat'.

Information on the geographic extent of each ecological community and the threatening processes that may be operating on the community is used to determine if an ecological community is 'threatened'. Threatened ecological communities are those that have been assessed and assigned to one of four categories related to the status of the threat to the community. The categories are 'Presumed Totally Destroyed', 'Critically Endangered', 'Endangered' or 'Vulnerable' (Appendix 5, Table 4). Floristic community types 1b and 9 are in the Vulnerable category.

These wetlands acquire additional significance in that while they are on clayey soils they are mapped within the Spearwood Dune System, not on the Pinjarra Plain (eastern side of the Plain). However, as mentioned earlier, these wetlands are at or near the interface of the Pinjarra Plain and the Spearwood Dune System on the Ludlow Plain Land System and this may account for the floristic similarities. Elsewhere on the Plain such a complex suite of wetland communities has not been found in association with the Spearwood Dune System.

Only remaining example of contiguous areas of upland, wetland and rivers of the Ludlow Plain Land System of the Spearwood Dune System

The Ludlow Plain Land System as mapped by Tille and Lantzke (1990) occurs throughout the Busselton area but is best developed in this area and the Reserve forms the largest remnant containing upland, wetland and riverine areas. The upland and wetland areas have been discussed previously but the riverine vegetation, although significantly altered, is of particular regional significance as there is very little riverine vegetation remaining on the Plain.

Flora

The flora of the Tuart Forest Reserve shows a relatively high level of species diversity (Appendices 2 and 3). The diversity of wetland plant communities and their associated flora, together with extensive upland areas, accounts for this diversity.

Interestingly, the flora of the upland areas (Tuart Woodland) is typical of the southern Spearwood Dune System and shows strong similarities with other such bushland areas (see Keighery this publication). There is no indication from the currently and previously recorded flora that the Tuart Forest Reserve had a significantly different understorey than that of today. This issue is discussed after the following section.

Vegetation Condition

Before embarking on a comparison between present day vegetation and historical accounts of the Tuart Forest Reserve there is a need to consider information on the condition of the vegetation in the Reserve. There is substantial indication that much of the Reserve has been subject to gross levels of disturbance over a long period. Four different practices/activities that have contributed to this are described below.

- Grazing - Grazing by domestic animals has been practised in the Tuart forest since settlement of the area in the mid-1830s (Hasluck 1990), beginning in 1834 and increasing after 1837. Grazing leases within the boundaries of the Tuart Forest Reserve have been recorded since 1885 (Forests Department 1921). This practise became ‘institutionalized’ by the Forests Department in 1919, when the Department fenced the area into paddocks and provided water points. In archival materials it is apparent that some plant introductions (clovers and medics) to promote grazing were also made at this time. Toxic native species, such as *Macrozamia* were also actively removed to aid grazing.

- Fire - Uncontrolled fires also occurred frequently last century until the fencing and grazing increased in the early part of last century.

- Forestry - Management practices were largely focused on promoting the crop of standing timber. Richardson (1912) in the Annual Report of the Woods and Forests Department, 1912 p. 10 states that

  > ‘A reserve of 1200 acres near the Capel River is being fenced, and it is intended to take steps to assist nature in re-afforesting this area. All that is necessary is to assist nature by destroying the over matured useless trees, removing the inferior ones, such as the peppermints, *Banksia* etc. and cleaning up and burning off all debris. At the present time two traction engines are busily engaged in pulling down all the old worthless tuarts, peppermints etc’.

- Softwood Plantations - In addition, a considerable area of the original forest (over 600 hectares) was almost totally alienated, being converted to Pines. In 1907 the Western Australian Government approved the formation of softwood plantations at Ludlow and it was planned to clear 5,000 acres. In 1910 (Richardson 1910) 30 men, 40 bullocks and 2 traction engines were working at Ludlow and by 1915 some 575 acres were cleared and planted with *Pinus radiata*, *P. pinaster* and *P. nigra* (*P. laricio*) (Richardson 1913 and 1916). The preferred species, *P. radiata* was not very successful and its failures lead to the soil surveys of d’Espeissis in the 1930s.

These management practices have greatly increased disturbance and promoted weeds. To a lesser but significant extent the Reserve has been disturbed by tracks associated with logging and the plantations, farm drainage schemes and dieback disease.

Given the pressures on the forest by fire, alienation, narrow focused management practices and grazing it is somewhat staggering to read in the Tuart Working Plan 1975-1980 (Forests Department 1975, page 8) that

> 'There is little evidence as to whether any species have been eliminated by grazing, although it certainly does limit most plant growth. Past experience has shown that regular cattle grazing has kept down competition from certain species that throve when the overhead canopy is opened up, for example *Jacksonia*, and the creepers.'

It is clear from such statements that grazing was only considered in respect to its impact on the forest (Tuart) trees not in respect to its impact on other species in the community. If this statement is considered in respect to the lack of systematic flora survey before grazing, or since (prior to this paper), and the limited historical collections suggesting loss of species, this statement cannot be seriously considered. It would be more correct to state that grazing has caused the demise of much of the original understorey and has seriously compromised many of the floristic values, hence nature conservation values, of the Reserve.

The condition of the vegetation of the Tuart Forest Reserve needs to be considered in terms of the upland, wetland and riverine areas.

Uplands
The vegetation in the upland units in the Tuart Forest Reserve ranges from Very Good to Completely Degraded. Of the various blocks Minninup Block is in the best condition, generally being in Good to Very Good condition. The contiguous southern blocks are generally in a Good to Degraded condition with Completely Degraded areas, such as the Pine Plantations. That is, the vegetation structure has been significantly altered and there are very obvious signs of multiple disturbance.

Wetlands
The wetlands are generally in better condition than the uplands, ranging from Excellent to Degraded condition but generally being in Excellent to Very Good condition. The wetlands on the northern side of the Wonnerup Inlet have been severely impacted by grazing and fire.

River
The vegetation of the rivers is generally in a Degraded to Completely Degraded condition.

However, the areas that have been cleared and/or grazed are regenerating and it would be expected that if weeds are controlled in these areas regeneration will occur naturally from the adjacent intact vegetation. The Tuart Forest Reserve needs careful management to slow, halt and reverse the decline in vegetation condition.

Vegetation Past and Present

This section systematically considers the known historical records of the Tuart forest (and the Tuart Forest Reserve) vegetation and flora. These records are critically interpreted on the basis of:

- the timing and context of the records;
- current knowledge of the vegetation and flora of the Swan Coastal Plain; and
- current knowledge of the vegetation and flora of the Tuart Forest Reserve and Tuart dominated communities.

The first known observations on the Tuart forest were made by François Peron and Leschenault de la Tour who visited the area with the Baudin expedition in 1801. They both commented on the country as being flat, covered with a magnificent forest with black soil formed of vegetable mould, however, they provided no other details (Peron 1807). The term 'mould' is used frequently in the early descriptions and, is considered, to best equate with humus.

The earliest detailed account of the forest is found in the notes prepared by John Bussell of a trip to the area in 1831 (Bussell 1833, page 191). In this he states

> 'The country, as we advanced on the other side of the rivulet, improved rapidly; the ground on which we trod was a vivid green, unsullied with burnt sticks or blackened grass trees; not that it was covered with a decided turf, but the vegetation seemed more succulent than woody, and the plants growing to about the same height, presented to the eye a smooth surface.'

Bussell then lapses into prose but later further describes the understorey as:

> 'varied in form, or brilliant in colour; the grass was plentiful, and the clover I have noted above with it's bright scarlet and yellow flower, the daisy, Buttercup and a purple marigold'.

From current knowledge of plant distribution and these descriptions we can make the following inferences about the plants described:

- 'grasses' were most probably a mixture of sedges, grasses and herbs as all were grouped as 'grass', that is edible plants;
- 'bright scarlet and yellow flower' either *Kennedia coccinea* or *K. prostrata;*
- 'Buttercup' either *Hibbertia* species or *Ranunculus colonorum* and;
- 'a purple marigold' that is a daisy and most likely *Olearia rudis*

This interpretation, in relation to the nature of grasses, is further supported by Bussell's description of the edge of Wonnerup Inlet (page 194):

> 'After dinner we walked two miles on the banks of the lake, N.E.; fields of grass, in some places to the water side, were waving like corn.'

The 'grasses' in this case were Sedges (Cyperaceae) from genera such as *Schoenoplectus*, *Isolepis* and *Bolboschoenus*.

Bradshaw (2000) infers that Bussell's description is more likely to apply to areas of Marri/Flooded Gum plains in the area and that Bussell's description of 'white gum' fits *Eucalyptus rudis* by its soil requirements and locality. Bussell's description can be interpreted to apply to Tuart as Bussell knew Marri previously from Augusta and visited the area in spring when the area dominated by *E. rudis* would have been flooded. When Bussell's notes are read sequentially he describes the swamp area (page 190) before his description of the Tuart forest, that is

> 'We now entered an extensive plain, the soil of which was damp and in some places was standing water. The surface of this plain, composed of clay and sand'

and further (page 192)

> 'About a hundred or two hundred yards on the other side, we obtained a sight of the sea bearing NW. The country here was so clear that a farmer could hardly grudge the fine spreading trees of the red and white gum and peppermint the small portion of the ground they occupied….'.

Bussell describes two 'white gums', one he knew from Augusta (Karri, *Eucalyptus diversicolor*) and the tree he encountered in the area of the Vasse River (page 196).

> 'I now term the white gum, that which is seen on the moist stiff Flats; of small stature; sending out it's branches from below; changing it's bark so frequently, so as soon to lose the marks of fire, but imperceptibly, and not in large sheets; its wood is white, its bark is light grey.'

This description fits Tuart well, especially when Bussell compares the bark and size of Tuart and Karri.

Of all the historical records considered here, Bussell's is accepted as the most accurate as:

- it provides the ONLY approximate description of the Tuart forest before grazing by stock had

impacted the condition of the Tuart forest; and
- it is sufficiently descriptive to allow some informed inferences to be made about the species being described.

By comparison, later descriptions of Tuart forest are very limited, and in effect, less informative. Examples include the following.
- Bessie Bussell wrote to Capel Carter in April 1834 (Bussell undated), describing the Vasse country as

    'a beautiful undulating grassy lawn, between the huge tooart trees'.
- Lieutenant Bunbury in 1836 (Bunbury and Morrell 1930, page 90) described the area between the Preston and Capel Rivers

    'an undulating Tooart country of considerable extent, with plenty of grass'.

    and on page 71

    'We came now into more open country with a good deal of grass growing on a light soil under very large white gums, called by the natives 'Tooarts' - the soil evidently fertile, though sandy, and free from the sharp scrub that had annoyed us during the forenoon, tearing our trousers and legs. It was quite refreshing to get into this fine country through which travelling was quite easy'.

This persistent reference to 'grassy' plains and woodlands, when interpreted in light of the Bussell's use of 'grass' to describe sedges (and other grass-like plants) provides a different picture of these communities. If other early descriptions of the vegetation across the Plain are considered in this light these 'grassy' understoreys can be related to present day communities on the Plain. A series of authors have commented on this misinterpretation of 'grass' in a Western Australian context and Appendix 6 looks at these issues broadly on the Plain and elsewhere.

By the late 19th and early 20th century there are a series of general statements about the open, sparse or grassy nature of the forest understorey (Ednie-Brown 1896; Wilson 1911 as quoted in Gabbedy 1988, page 20; Lane-Poole 1920; Gardener 1925 and 1944). For example Wilson (in Gabbedy 1988), the minister for land, described Tuart as suitable for agriculture

' ….with Tuarts dotted in parklike fashion, and an occasional brake of Peppermints and a rich carpet of annual grasses'.

By this stage the annual grasses are obviously WEEDS, since most native grasses are perennials, and the area had been grazed for over 70 years.

This is also reflected in the published and unpublished photographs of the area (many are reproduced in Weston 1989) and especially the photo in Ednie-Brown (1896) which he described in very general terms as

'of a more than typical portion of the Tuart Forests'.

This photo is unfortunately without other details including provenance. Despite this, some subsequent authors have stated that the photo was taken at Ludlow. It was probably taken in autumn, and shows an understorey of short or grazed grasses and scattered herbs or possibly low shrubs. The photo has the appearance of a highly altered plant community, the result of many years of fire and grazing. Although it is very similar to the area of Central and Malling Blocks near Ludlow (Minninup Block has a completely different appearance), it cannot be proven that the photograph is from the Tuart Forest Reserve.

Gardner (1944, page xlviii), commenting on the Tuart forest, wrote

'Here it is a true savannah formation, with an understory of Agonis and Banksia, Melaleuca and Hakea, with a herbaceous ground covering in which the shrubs are comparatively few. To the north the understorey becomes shrubby, but retains something of the nature of savannah.'

Like Bussell he notes a predominance of low trees and tall shrubs over low herbs NOT grasses.

In the descriptions for vegetation maps of the area Smith (1973) and Beard (1981) focus more on the nature of the tree formation than the floristic components of the vegetation. Smith (1973) notes that

> ' formerly massive Tuarts, up to 8m girth, formed high open forest [40m tall or more] in their most favourable areas, with crowns intermingled and only a low scrub understory. Today there is only a small area, just east of Sabina River and south of the rifle range (State Forest 12) that resembles high open forest'

Beard (1981, page 97), described the Ludlow Tuart as the only example of Tall Woodland in the State but noted in his discussion of the Tuart forest that

> ' there is no information on the ground vegetation'..

That is, in all the records considered above there is no detail of the floristics of the vegetation. As a consequence these descriptions are open to different interpretations. Often these interpretations are made on the basis of a very limited knowledge of the vegetation and flora of the Swan Coastal Plain and current knowledge of the vegetation and flora of the Tuart Forest Reserve and Tuart dominated communities. The interpretations presented in this paper are based on this background information.

Further support for the interpretation presented here comes from a recently located account of the understorey vegetation of parts of the Tuart forest in d'Espeissis (1938a, b, c and d)[6]. These reports, and especially the associated notebooks, document soil and vegetation survey carried out before the pine plantations were completed in the late 1930s. Soil and vegetation attributes are described for over 300 sites, of which 265 are dominated by Tuart. While the vegetation information for each of the sites is incomplete, this source gives more information on the floristics of the area than any other. A more complete appraisal of this information will be made in a future publication but the report on Malling Block (d'Espeissis 1938b) can be used as an example of the information contained in the reports and notebooks. Ten sites are described, of which 6 are dominated by pure Tuart, 2 have Tuart and Marri and 2 have Tuart, Marri and Flooded Gum. Thirty-one species are listed for the block, of which 3 are trees, 15 are shrubs, 2 vines, 8 perennial herbs or sedges, 5 ?annual herbs and 2 are annual grass weeds. These records are consistent with present day vegetation and hardly suggest an abundance of grasses! However, d'Espeissis commonly records Banksia in his sites suggesting that parts of the two areas may have been more similar in the past.

In conclusion the original Tuart forest was most likely a Tall Open Forest to Tall Open Woodland. In the southern area of the Tuart forest it appears that Tuart grew over scattered trees of *Agonis flexuosa* and *Banksia grandis* over low mixed shrubland over sedges, grasses and herbs. Towards the north, shrubs and *Banksia attenuata* become more common on the northern sandy rises. This is especially true in Minninup Block. Substantial alteration of the understorey had occurred at least in part of the area before 1900, especially in the main blocks of the forest.

CONCLUSION

The Tuart Forest Reserve is the largest vegetated remnant on the Swan Coastal Plain in the Busselton to Bunbury area and is one of the largest of such areas on the Plain.

The Tuart Forest Reserve is significant on the Swan Coastal Plain as it:

- contains the largest, most southern, remnant of Tuart Tall Woodland to Woodland on the Plain;
- contains a series of wetland plant communities, and their associated flora, that are now rare on the Plain;
- is part of the only remaining contiguous examples of the uplands, wetlands and rivers of the

[6] These and other reports cited are in the archives of the Department of Conservation and Land Management.

Ludlow Plain Land System (after Tille and Lantzke 1990) of the Spearwood Dune System;
- has a total vascular flora of over 705 species, comprising 543 natives and 162 weeds. There are nine priority taxa and one species of Declared Rare Flora in the Forest; and
- has a diverse upland flora typical of the southern Spearwood Dunes.

The Reserve has a long history of multiple disturbances which has impacted significantly on large areas of the Reserve. The major weeds are Arum Lilies (*Zantedeschia aethiopica),* Bridal Creeper (*Asparagus asparagoides*) and a range of annual grasses.

The comparison of the limited historical accounts of the flora and vegetation of the Tuart forest and the present vegetation and flora of the Tuart Forest Reserve clearly indicates that the Reserve's past flora and vegetation was similar to the relatively intact areas of the Reserve remaining today. However, before 1900, substantial alteration of the understorey had occurred in the main blocks of the forest. It is considered that these early changes in the vegetation, and the generally vague descriptions of the Tuart forest vegetation before this time, have led some previous authors to different conclusions as to the nature of the Tuart forest vegetation.

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TABLES

TABLE 1. Relationship between land systems (Tille and Lantzke 1990) and major landform units of the Swan Coastal Plain (after McArthur and Bettenay 1960 and Gov of WA 2000).

Land system	Major landform element
Quindalup Coast	Quindalup Dunes
Ludlow Plain	Spearwood Dunes
Abba Plain*	Pinjarra Plain*

*The Bassendean Dunes System is poorly developed in the Busselton area. The Bassendean Sands occur in low rises over the alluvium of the Pinjarra Plain. These low rises are most common to the north-east of Busselton but are found in patches over the Abba Plain.

TABLE 2. Floristic Community Types (floristic community types after Gibson *et al*. 1994).

Key

Column 1 **Floristic Community Type Codes**
After Gibson *et al.* (1994). An * preceding the number indicates that the type has been inferred from the floristic data (see Appendix 1, 2 and 3).

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

Column 3 **Mapping Unit and Plots in which the Floristic Community Type was identified**

Column 4 **Average Species Richness per Floristic Community Type**
Modified from Table 6 in Gov of WA (2000). Average species richness per 10m x 10m plot, less those species only occurring in a single plot (single records). Some community types can have a high proportion of single records and these estimates of average species richness are underestimates in some cases.

Supergroup 1 - Foothills/Pinjarra Plain

*1b	Southern *Eucalyptus calophylla* woodlands on heavy soils	WM	65.0

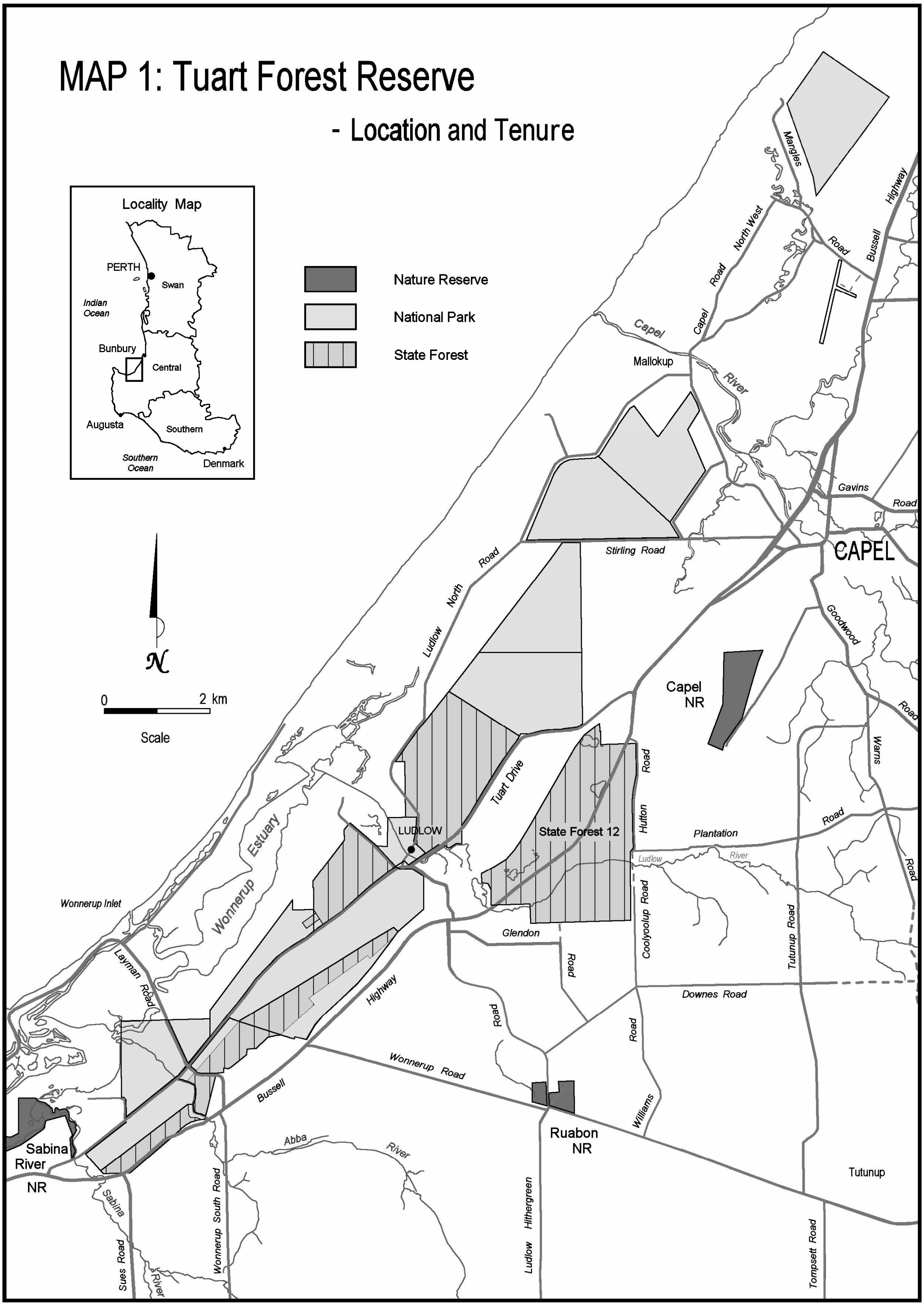
Supergroup 2 - Seasonal Wetlands

*4	*Melaleuca preissiana* damplands	WM	33.2
*9	Dense shrublands on clay flats	WM	34.8
*13	Deeper wetlands on heavy soils	WM	16.9

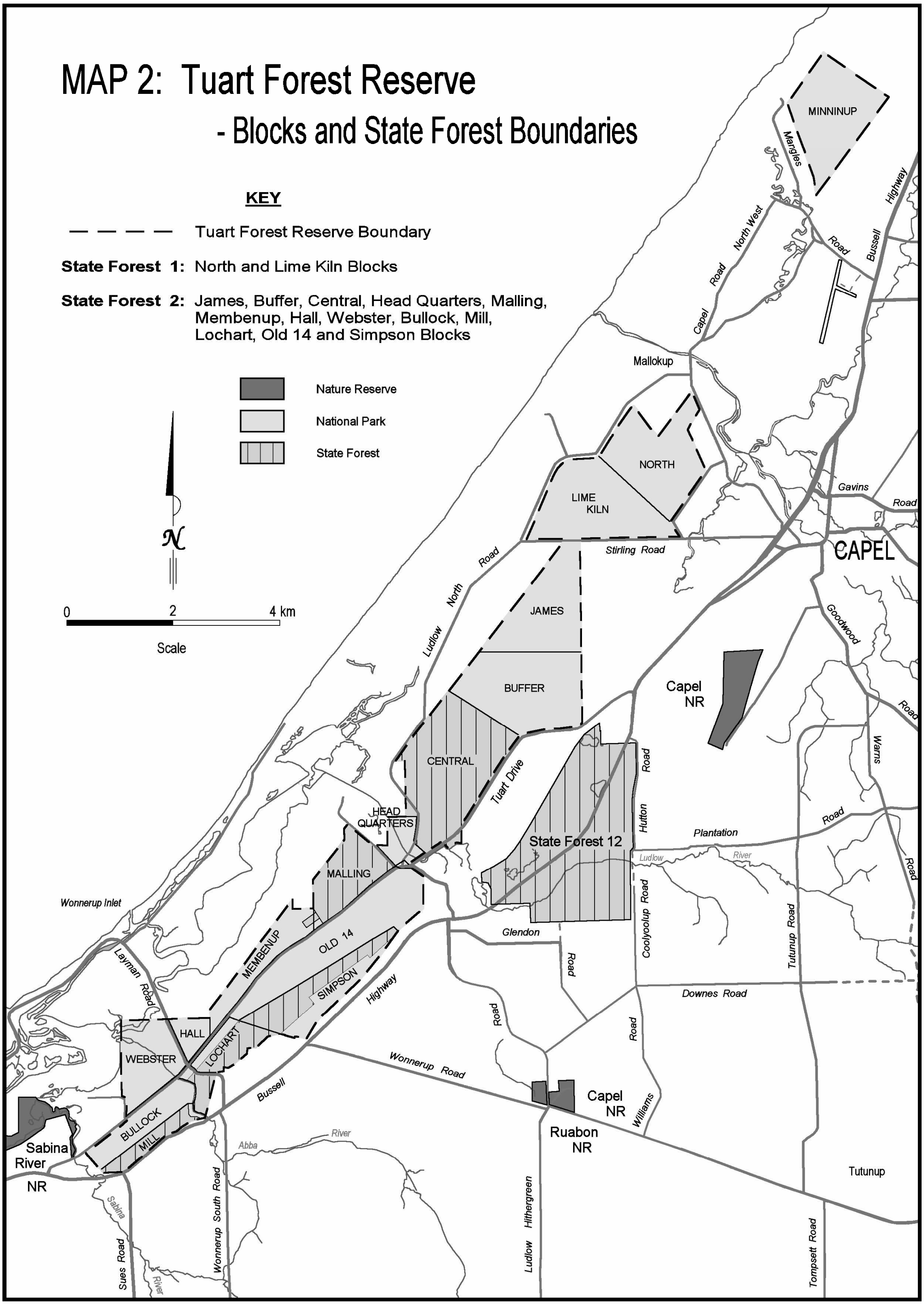
Supergroup 4 - Uplands centred on Spearwood and Quindalup Dunes

Spearwood Dunes			
25	Southern *Eucalyptus gomphocephala* - *Agonis flexuosa* woodlands	tbW (MINN 01,02)	48.1
Quindalup Dunes			
30b	Quindalup *Eucalyptus gomphocephala* and/or *Agonis flexuosa* woodlands	tW (PEPB01)	35.0

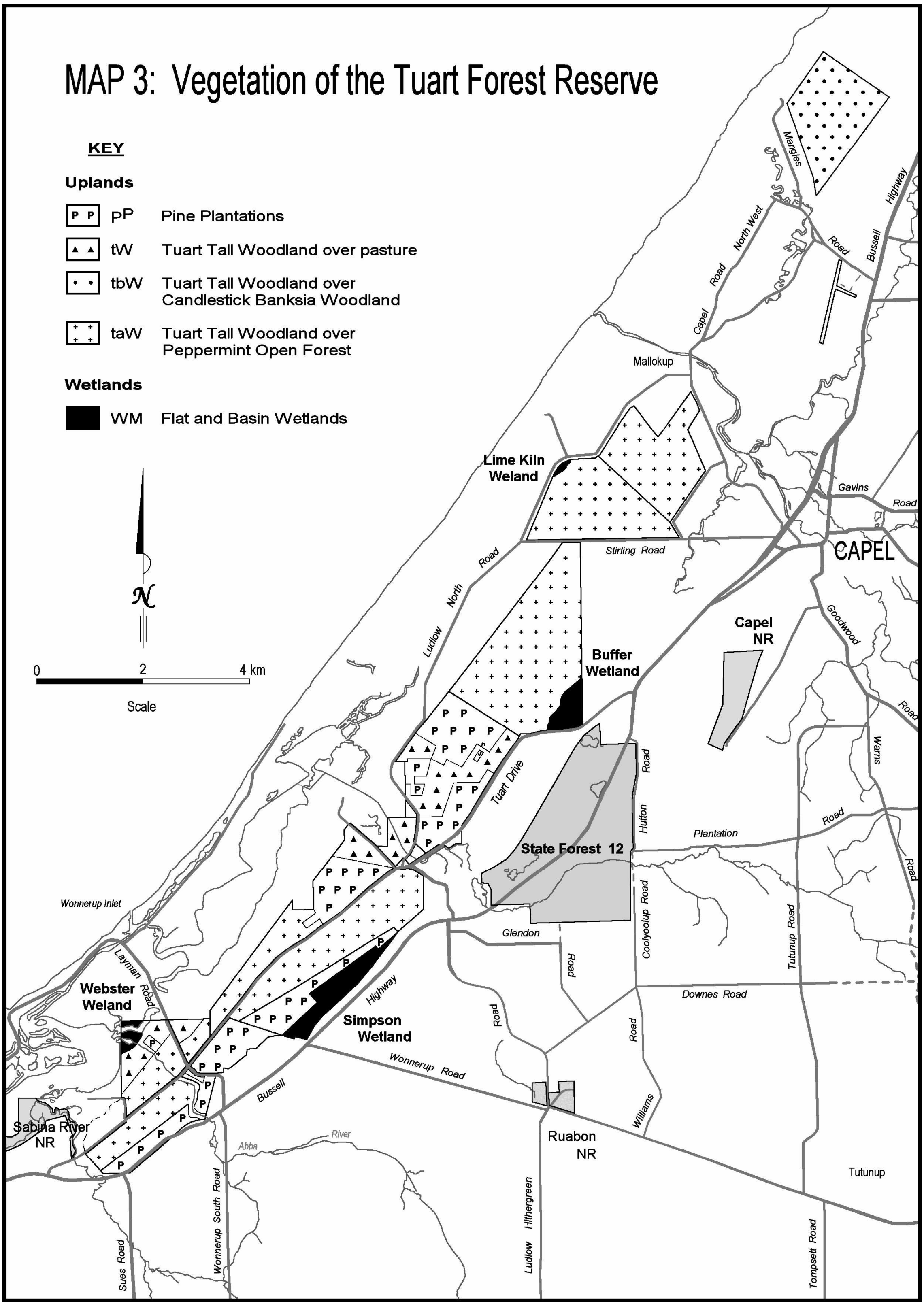
MAPS



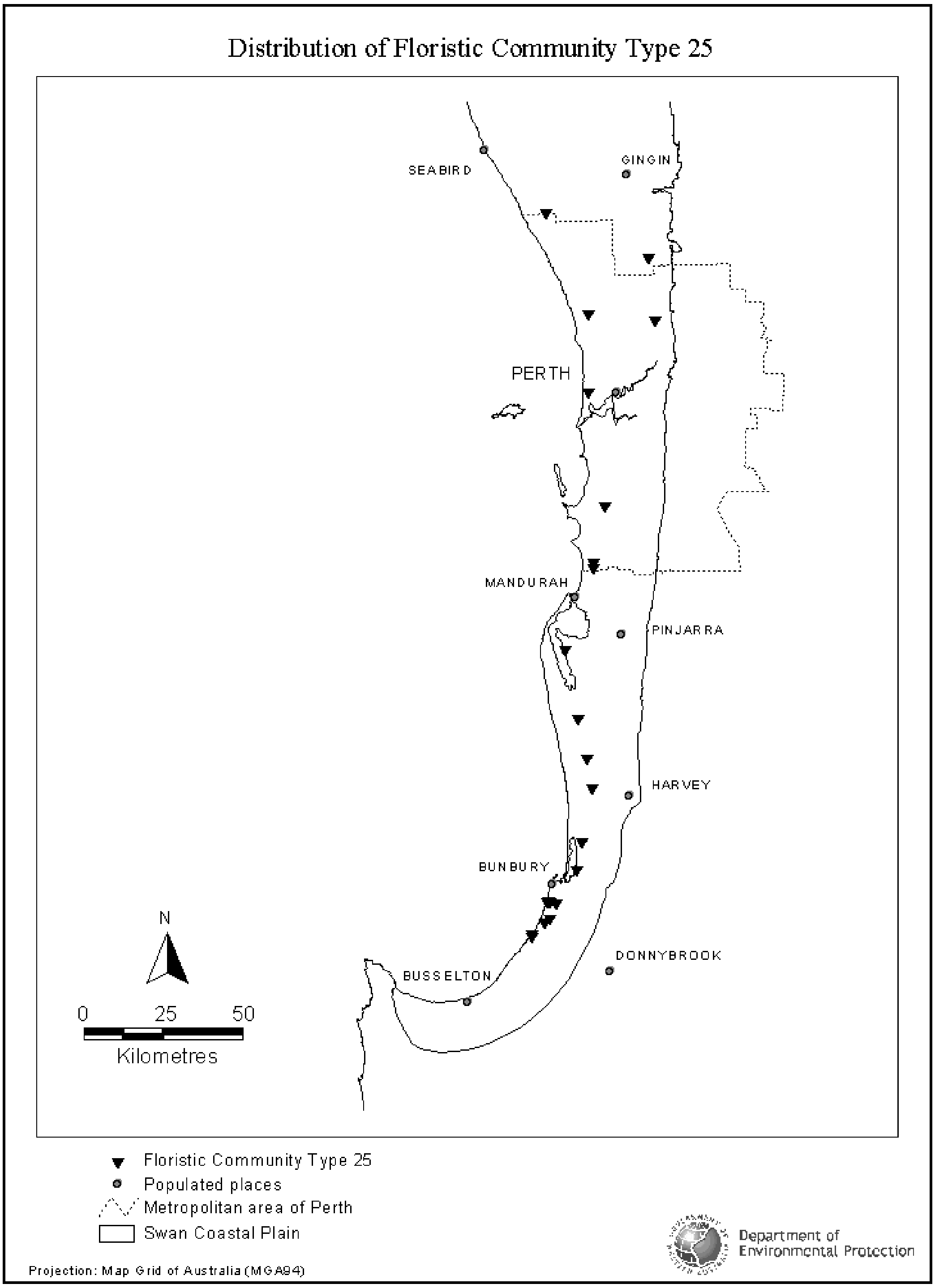
Map 1. **Location of the Tuart Forest Reserve.**



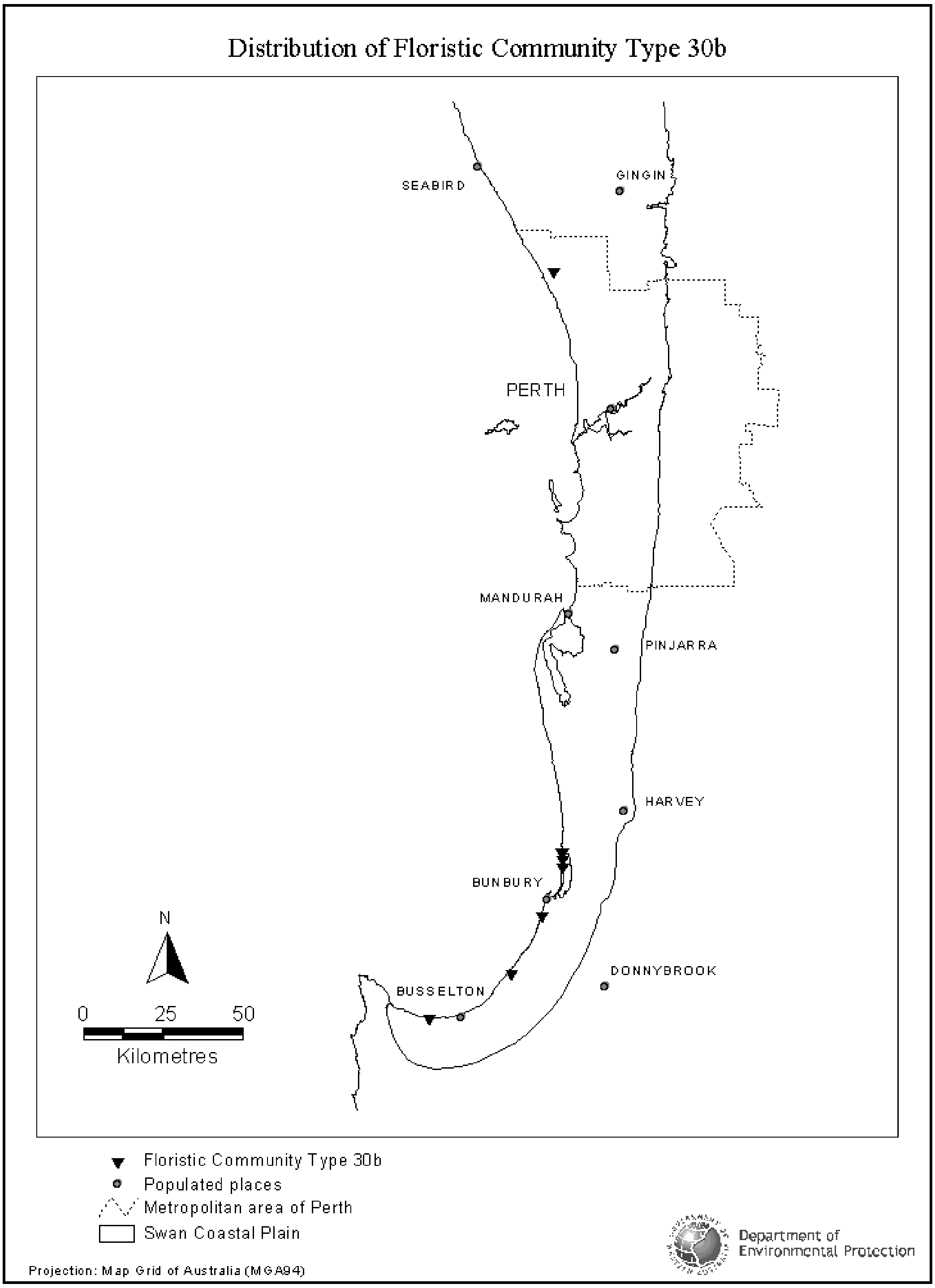
Map 2. Tuart Forest Reserve - Blocks and State Forest Boundaries.



Map 3. **Vegetation of the Tuart Forest Reserve.**



Map 4. Distribution of the Floristic Community Type 25 (Gibson *et al.* 1994 and DEP 1996).



Map 5. Distribution of the Floristic Community Type 30b (Gibson *et al.* 1994 and DEP 1996).

APPENDIX 1. Vegetation Descriptions and Conditions.

General Information

Broad mapping units are used for the vegetation mapping (Map 3). The determination of these units is based on vegetation descriptions from the sites. The general boundaries between the mapping units were determined from 1992 Department of Land Administration black and white 1 : 50 000 orthophotograph sheets. The vegetation descriptions for each of the mapped units are from the areas considered to best illustrate these units, being 'typical' and in the best condition.

Sites are grouped on the basis of the mapping units.

Keys to the terminology used for the vegetation descriptions and specific condition ratings are given in Appendix 5, Tables 1 and 2.

UPLANDS

Mapping Unit – tbW: Tuart Tall Woodland over *Banksia attenuata* Woodland

Floristic Community Type 25

MINN O1

Tuart Tall Woodland over *Agonis flexuosa* Open Woodland to Open Low Woodland over *Leucopogon parviflorus* and *Rhagodia baccata* Low Open Shrubland over **Briza maxima* Grassland, **Trifolium campestr*e Herbland and *Isolepis nodosa* Open Sedgeland.

Total Species:	50, 28 natives and 22 weeds		
Condition Rating:	Good to Degraded		
Comments:	Annual weeds formed a layer of >70% cover. Seedling **Zantedeschia aethiopica* were recorded. Tuart of different ages.		
Soil:	brown sand over pale orange sand	Litter:	90%
Drainage:	well	Aspect:	flat
Location:	33^{o} 28' 24.0"S 115^{o} 28' 42.2"E		

MINN O2

Scattered Tuart over *Agonis flexuosa* and *Banksia attenuata* Open Forest to Low Open Forest over *Hibbertia hypericoides* Low Shrubland over **Briza maxima* Grassland and **Trifolium campestre* and *Arthropodium capillipes* Herbland.

Total Species:	64, 42 natives and 22 weeds		
Condition Rating:	?Good		
Soil:	brown sand over pale orange sand		
Drainage:	well	Aspect:	flat
Location:	33^{o} 28' 24.0"S 115^{o} 33' 42.2"E		

MINN O3

Tuart Tall Open Woodland over *Banksia attenuata* Open Forest to Low Open Forest over *Hibbertia hypericoides* Low Shrubland over **Briza maxima* Grassland and **Trifolium campestre* and *Arthropodium capillipes* Herbland.

Total Species:	57, 49 natives and 8 weeds
Condition Rating:	Very Good to Good
Comments:	The density of Tuart was atypical for the general area of the plot. In general the Tuart were scattered Tuart or formed a Tall Open Woodland. **Briza maxima* and **Trifolium campestre* have a combined cover of 20 –30% and are small

	non-vigorous plants. Evidence of frequent fire. Mixed age Tuart.		
Soil:	brown sand over yellow/brown sand	Litter:	90%
Drainage:	well	Aspect:	gentle, S
Location:	33^{o} 28' 44.1"S 115^{o} 33' 44.4"E		

Mapping Unit – tW: Tuart Tall Woodland over *Agonis flexuosa* Open Forest

Floristic Community Type 30b

PEPB O1
Tuart Tall Woodland over *Agonis flexuosa* Open Forest over *Spyridium globulosum* Tall Open Shrubland over *Hibbertia cuneiformis* and *Rhagodia baccata* Open Shrubland over **Briza maxima* Closed Grassland to Grassland, *Pteridium esculentum* Fernland, and **Asparagus asparagoides*, mixed annual weeds and *Arthropodium capillipes* Herbland to Closed Herbland.

Total Species:	39, 27 natives and 12 weeds		
Condition Rating:	Good		
Comments:	Annual weeds formed a layer of >70% cover in mid-October. Arum Lilies were recorded.		
Soil:	brown sand over red/brown sand and limestone	Litter:	100%
Drainage:	well	Aspect:	gentle, W
Location:	33^{o} 32' 24.9"S 115^{o} 30' 45.1"E		

WETLANDS

Mapping Unit – WM: Wetland Mosaic

Floristic Community Types 1b, 4, 9 and 13
(These types have been inferred and are considered to occur in a mosaic)

Lime Kiln Wetland 01
Eucalyptus rudis Open Woodland over **Acacia pycnantha* Woodland with scattered *Agonis flexuosa* over *Exocarpos sparteus*, *Acacia cyclops*, *Spyridium globulosum*, *Rhagodia baccata* Tall Shrubland with vines of **Asparagus asparagoides* over *Pteridium esculentum* Closed Fernland over **Bromus diandrus*, **Avena fatua* and **Briza maxima* Grassland.

Condition Rating:	Degraded to Good		
Soil:	brown/grey loamy sand over marl		
Drainage:	moderate to poor	Aspect:	gentle to the south west

Buffer Wetland (an area of seasonally inundated sumpland and dampland; the plots are in a transect from east to west)
Buffer Wetland 01
Melaleuca viminea Tall Shrubland over *Melaleuca lateritia* Shrubland over *Lepyrodia muirii* and *Chorizandra enodes* Open Sedgeland, *Agrostis avenacea* Open Grassland and mixed Closed Herbland.
Other species noted – Herbs: *Goodenia micrantha* and *Angianthus drummondii*.

Condition Rating:	Excellent to Very Good		
Soil:	grey clayey sand		
Drainage:	poor	Aspect:	flat

Buffer Wetland 02
Melaleuca viminea Open Scrub over *Schoenus maschalinus* Closed Sedgeland.
Condition Rating: Excellent
Soil: grey clayey sand
Drainage: poor Aspect: flat

Buffer Wetland 03
Melaleuca rhaphiophylla Low Woodland over *Melaleuca viminea* Tall Shrubland over
- when the wetland is inundated - *Cotula coronopifolia* and *Montia australasica* Closed Herbland: and
- when the wetland soils are waterlogged and drying - Mixed Open Herbland including *Senecio glomerata*, *S. quadridentatus*, *Ixiolaena viscosa*, *Alternanthera nodiflora*, **Dittrichia graveolens*, **Conyza albida* and **Zantedeschia aethiopica.*

Condition Rating: Excellent to Very Good
Soil: grey clayey sand
Drainage: poor Aspect: flat

Buffer Wetland 04
Eucalyptus rudis Woodland to Very Open Woodland over *Melaleuca rhaphiophylla* Low Woodland over *Melaleuca viminea* Tall Shrubland over *Lepidosperma longitudinale* Sedgeland and **Zantedeschia aethiopica* Herbland.
Other species noted – Herbs: **Conyza albida*, **Mentha pulegium*, *Alternanthera nodiflora*, *Senecio glomeratus*
Condition Rating: Very Good to Good
Soil: grey clayey sand
Drainage: poor Aspect: flat

Buffer Wetland 05 (power line)
Melaleuca rhaphiophylla Low Forest over patches of *Baumea articulata* Sedgeland
Condition Rating: Good to Degraded
Comments: This vegetation unit is associated with the power line and appears to have formed in response to the disturbance of the vegetation associated with the power line installation.
Soil: grey clayey sand
Drainage: poor Aspect: flat

Simpson Wetland
Seasonally waterlogged areas (intermittently inundated)
Simpson Wetland 01 (edge)
Tuart Tall Woodland over *Melaleuca viminea*, *M. incana* and *M. rhaphiophylla* Tall Shrubland over *Gahnia trifida* Sedgeland.
Condition Rating: ?Excellent to Very Good
Soil: ?grey clayey sand
Drainage: poor Aspect: flat

Simpson Wetland 02 (rise)
Eucalyptus calophylla Woodland over *Agonis flexuosa* Low Woodland over *Kunzea glabrescens* and *Hakea prostrata* Open Scrub over Mixed Sedgeland.
Condition Rating: Very Good
Soil: ?grey clayey sand
Drainage: poor Aspect: flat

Simpson Wetland 03
Eucalyptus rudis Woodland over scattered *Viminaria juncea* over *Regelia inops* Closed Heathland over *Lepidosperma longitudinale* Sedgeland.
Condition Rating: ?Good to Disturbed
Soil: ?grey clayey sand
Drainage: poor Aspect: flat

Simpson Wetland 04
Eucalyptus calophylla Woodland over scattered *Eucalyptus rudis* and *Agonis flexuosa* over *Melaleuca preissiana* Open Low Woodland over *Kunzea glabrescens* Open Scrub over *Dasypogon bromeliifolius* and *Xanthorrhoea brunonis* Low Shrubland over Mixed Sedgeland.
Other species noted – Trees: *Nuytsia floribunda, Persoonia longifolia*; Grasses: **Ehrharta longifolia, *Briza maxima, *Aira caryophyllea, Microlaena stipoides*; Herbs: *Craspedia variabilis, Opercularia hispidula*
Condition Rating: Excellent to Very Good
Comment: In open patches there are areas of Open Grassland and Open Herbland dominated by combinations of the other species noted.
Soil: grey sand over clay
Drainage: poor Aspect: flat

Simpson Wetland 05
Scattered *Eucalyptus calophylla* over *Eucalyptus rudis* Open Woodland over *Melaleuca preissiana* Low Open Woodland over *Kunzea glabrescens* and *Hakea varia* Tall Shrubland over *Regelia ciliata* Shrubland over *Phlebocarya ciliata* Herbland.
Other species noted – Shrubs: *Jacksonia furcellata*, *Xanthorrhoea brunonis*, *Acacia saligna*, *A. stenoptera*, *A. extensa*; Sedges: *Schoenus rigens*, *Cyathochaeta avenacea*, *Lepidosperma squamatum*, *Mesomelaena tetragona*, *Tetraria octandra*; Grasses: **Ehrharta longifolia*, **Briza maxima*, **Vulpia myuros*; Herbs: *Conostylis aculeata*, *Haemodorum spicatum*, *Patersonia occidentalis*, **Hypochaeris glabra*
Condition Rating: Very Good to Good
Comment: In open patches there are areas of Open Grassland and Open Herbland dominated by combinations of the other species noted.
Soil: grey sand over clay
Drainage: poor Aspect: flat

Simpson Wetland 06
Eucalyptus calophylla Woodland over *Melaleuca preissiana* and *Banksia littoralis* Low Woodland over *Kunzea glabrescens*, *Acacia saligna* and *Agonis flexuosa* Tall Open Shrubland over

- *Pericalymma ellipticum* Closed Heath; or
- *Baumea rubiginosa* Sedgeland; or
- Mixed Sedgeland

Other species noted – Shrubs: *Xanthorrhoea brunonis*, *Adenanthos meisneri*, *Synaphea petiolaris*, *Dryandra lindleyana*, *Acacia extensa*; Sedges: *Hypolaena pubescens*, *Desmocladus fascicularis*, *Lepidosperma squamatum*, *Mesomelaena tetragona*, *Tetraria octandra*; Herbs: *Phlebocarya ciliata*
Condition Rating: Excellent
Comment: In open patches there are areas of Open Grassland and Open Herbland dominated by combinations of the other species noted.
Soil: grey sand over clay
Drainage: poor Aspect: flat

Seasonally inundated areas
Simpson Wetland 07
Melaleuca rhaphiophylla Low Open Forest over *Lepidosperma longitudinale* Sedgeland and, when inundated: *Schoenus natans* Sedgeland and *Aponogeton hexatepalus* and *Villarsia submersa* Herbland.

Condition Rating: Excellent to Very Good
Comments: At times *Melaleuca rhaphiophylla* forms a Low Closed Forest without any understorey.
Soil: grey clay
Drainage: poor Aspect: flat

Simpson Wetland 08
Scattered emergent *Melaleuca preissiana* over *Melaleuca viminea*, *M. incana, M. lateriflora* and *M. uncinata* Tall Shrubland over scattered *Gahnia trifida* over *Chorizandra enodes* Sedgeland and Mixed Closed Herbland.

Condition Rating: ?Excellent to Very Good
Comments: Patches with *Melaleuca viminea*, *M. incana and M. rhaphiophylla* as dominants
Soil: grey clayey sand
Drainage: poor Aspect: flat

Simpson Wetland 09
Melaleuca viminea Open Scrub over scattered clumps of *Kunzea micrantha* over Mixed Herbland.

Condition Rating: ?Excellent to Very Good
Soil: ?grey clay
Drainage: poor Aspect: flat

Webster Wetland
Webster Wetland 01
Scattered *Eucalyptus rudis* to *Eucalyptus rudis* Open Woodland over **Ehrharta longifolia*, **Vulpia myuros* and **Bromus diandrus* Grassland over *Juncus kraussii* Very Open Sedgeland

Condition Rating: Degraded
Soil: grey clay
Drainage: poor Aspect: flat

Webster Wetland Site
Juncus pallidus Open Sedgeland

Condition Rating: Degraded
Soil: grey sand over clay
Drainage: poor Aspect: flat

Webster Wetland Site
Carex divisa Closed Sedgeland over *Centella asiatica* Herbland

Condition Rating: Degraded
Soil: saline clay
Drainage: poor Aspect: flat

Webster Wetland Site
Sarcocornia quinqueflora Closed Low Heath

Condition Rating: Good
Soil: saline clay
Drainage: poor Aspect: flat

Webster Wetland Site
Halosarcia indica Closed Low Heath over *Cotula coronopifolia* Open Herbland
Other species noted – Sedges: *Triglochin striata*; Herbs: *Atriplex hypoleuca*, **A. prostrata*
Condition Rating: Good
Comments: Clumps of **Cynodon dactylon* are found in the area of the plot.
Soil: clay
Drainage: poor Aspect: flat

Webster Wetland 02
Melaleuca rhaphiophylla Low Open Forest over *Carex divisa* Closed Sedgeland, **Paspalum distichum* Grassland and scattered emergent *Apium prostratum* and *Lobelia alata* over *Centella asiatica* Closed Herbland.
Condition Rating: Good to Degraded
Comments: Clumps of *Juncus kraussii* and **Zantedeschia aethiopica* occur in the area of the plot, the former towards the Inlet and the latter inland.
Soil: ?grey clay
Drainage: poor Aspect: flat

RIVERINE

Ludlow River
Ludlow River Bank 01
Eucalyptus calophylla Open Forest with scattered *Eucalyptus rudis* over *Persoonia longifolia* and *Acacia saligna* Low Open Woodland over *Lepidosperma squamatum* Open Sedgeland *Pteridium esculentum* Fernland and Mixed Weedy Grassland.
Other species noted – Shrubs: scattered *Acacia pulchella*, *Adenanthos meisneri*; Grasses: *Microlaena stipoides*; Herbs: **Hypochaeris glabra, Daucus glochidiatus, Tricoryne elatior*, **Monadenia bracteata*
Condition Rating: Degraded
Soil: sandy yellow brown clay
Drainage: moderate to poor Aspect: flat

Ludlow River Bank 02 (occurs as scattered patches)
Eucalyptus marginata Open Tree Mallee over *Hibbertia cuneiformis*, *H. hypericoides*, *Grevillea manglesioides* and *Adenanthos meisneri* Shrubland over *Phyllanthus calycinus*, *Gompholobium tomentosum* and *Xanthorrhoea brunonis* Low Shrubland over *Lepidosperma squamatum* Open Sedgeland and *Phlebocarya ciliata* and *Conostylis aculeata* Herbland.
Other species noted – Shrubs: *Macrozamia fraseri*; Climbers: *Hardenbergia comptoniana*; Grasses: **Briza maxima*; Herbs: *Arthropodium capillipes, Patersonia occidentalis, Tricoryne elatior;* Sedges: *Tetraria octandra*
Condition Rating: Degraded
Soil: sandy yellow brown clay over clay
Drainage: moderate Aspect: flat

Ludlow River Channel 01
Eucalyptus rudis Woodland over scattered *Melaleuca rhaphiophylla* over *Hemarthria uncinata* and **Paspalum dilatatum* Grassland.
Other species noted – Herbs: **Asparagus asparagoides*, **Gladiolus undulatus*, **Zantedeschia aethiopica*.
Condition Rating: Degraded
Soil: grey clayey sand with ironstone inclusions
Drainage: poor Aspect: flat

Abba River 01
Eucalyptus rudis Woodland over *Melaleuca rhaphiophylla* Low woodland over **Paspalum distichum* Closed Grassland and **Zantedeschia aethiopica* and *Centella asiatica* Herbland.
Other species noted – Herbs: **Asparagus asparagoides*, **Gladiolus undulatus*, **Rumex* species.
Condition Rating: Degraded
Soil: ?grey clayey sand with ironstone inclusions
Drainage: poor Aspect: flat

APPENDIX 2: Flora of Minninup Block, Tuart Forest Reserve.

Key

Column 1 **Family group**
Families are listed alphabetically.
M Only recorded for Minninup Block

Column 2 **Plant Taxa**
Names include species, sub-species and varieties and are listed alphabetically.
* Weed species
ms Manuscript name (shown after the name)

Column 3 & 4 **Vegetation Unit**
T Bushland areas dominated by Tuart
D Disturbed areas

Family group	**Plant Taxa**	**Veg. Unit**	
		T	D
Amaranthaceae			
M	Ptilotus drummondii	•	
	Ptilotus manglesii	•	
M	Ptilotus sericostachyus subsp. sericostachyus	•	
	Ptilotus stirlingii	•	
Anthericaceae			
	Arthropodium capillipes	•	
	Caesia micrantha	•	
	Chamaescilla corymbosa	•	
	Corynotheca micrantha	•	
	Sowerbaea laxiflora	•	
	Thysanotus arenarius	•	
	Thysanotus patersonii	•	
	Tricoryne elatior	•	
	Tricoryne tenella	•	
Apiaceae			
	Daucus glochidiatus	•	
	Eryngium pinnatifidum subsp. pinnatifidum	•	
	Homalosciadium homalocarpum	•	
	Hydrocotyle callicarpa	•	
	Hydrocotyle diantha	•	
	Trachymene pilosa	•	
Araceae			
*	Zantedeschia aethiopica	•	•
Asclepiadaceae			
*	Gomphocarpus fruticosus		•

Family group		Plant Taxa	Veg. Unit	
			T	D
Asphodelaceae				
	*	Asphodelus fistulosus	•	
	*	Trachyandra divaricata		•
Asteraceae				
	*	Arctotheca calendula	•	•
		Asteridea pulverulenta	•	
M		Brachyscome iberidifolia	•	
	*	Carduus pycnocephalus	•	•
	*	Cirsium vulgare		•
	*	Conyza albida		•
		Cotula australis	•	
	*	Cotula bipinnata		•
	*	Cotula turbinata	•	•
		Craspedia variabilis	•	
M		Gnaphalium sphaericum	•	
	*	Hypochaeris glabra	•	•
		Lagenophora huegelii	•	
		Millotia myosotidifolia	•	
M		Olearia axillaris	•	
	*	Osteospermum ecklonis	•	•
		Picris squarrosa	•	
		Podotheca angustifolia	•	
M		Podotheca gnaphaloides	•	
	*	Pseudognaphalium luteo-album		•
M		Pterochaeta paniculata	•	
		Quinetia urvillei	•	
		Senecio hispidulus	•	
M		Senecio lautus subsp. dissectifolius	•	
M		Senecio minimus	•	
		Siloxerus humifusus	•	
	*	Sonchus oleraceus	•	•
	*	Ursinia anthemoides	•	•
		Waitzia suaveolens	•	
Brassicaceae				
	*	Brassica tournefortii		•
	*	Heliophila pusilla	•	•
	*	Raphanus raphanistrum		•
		Stenopetalum robustum	•	
Campanulaceae				
M	*	Wahlenbergia capensis		•
		Wahlenbergia preissii	•	•
Caryophyllaceae				
	*	Cerastium glomeratum	•	•

Family group		**Plant Taxa**	**Veg. Unit** T	D
	*	Petrorhagia velutina	•	•
M	*	Silene gallica var. gallica	•	
	*	Spergula arvensis	•	•
	*	Stellaria media		•
Centrolepidaceae				
		Centrolepis drummondiana	•	
Chenopodiaceae				
		Rhagodia baccata	•	
Colchicaceae				
		Burchardia congesta (Burchardia umbellata in Gibson *et al.* 1994)	•	
Convolvulaceae				
		Dichondra repens	•	
Crassulaceae				
	*	Crassula alata		•
		Crassula colorata	•	
		Crassula peduncularis	•	
Cyperaceae				
		Carex preissii	•	
		Isolepis marginata	•	•
M		Isolepis nodosa	•	
		Lepidosperma angustatum	•	
		Schoenus curvifolius	•	
		Schoenus grandiflorus	•	
Dasypogonaceae				
		Acanthocarpus preissii	•	
		Lomandra caespitosa	•	
		Lomandra hermaphrodita	•	
		Lomandra micrantha	•	
M		Lomandra preissii	•	
		Lomandra purpurea	•	
		Lomandra suaveolens	•	
Dilleniaceae				
		Hibbertia cuneiformis	•	
		Hibbertia hypericoides	•	
		Hibbertia racemosa	•	•
Droseraceae				
		Drosera erythrorhiza	•	
		Drosera menziesii subsp. penicillaris	•	

Family group	**Plant Taxa**	**Veg. Unit**	
		T	D
	Drosera pallida	•	
M	Drosera stolonifera	•	
Epacridaceae			
M	Astroloma ciliatum	•	
	Astroloma pallidum	•	
M	Conostephium pendulum	•	
	Conostephium preissii	•	
M	Leucopogon capitellatus	•	
	Leucopogon parviflorus	•	
M	Leucopogon propinquus	•	
Euphorbiaceae			
	Adriana quadripartita	•	
*	Euphorbia peplus	•	•
	Phyllanthus calycinus	•	
M	Poranthera microphylla	•	
Fumariaceae			
*	Fumaria capreolata		•
*	Fumaria muralis		•
Geraniaceae			
*	Erodium cicutarium	•	•
*	Geranium molle	•	
	Geranium solanderi	•	
*	Pelargonium capitatum	•	•
Haemodoraceae			
	Conostylis aculeata	•	
	Conostylis candicans	•	
Hypoxidaceae			
M	Hypoxis glabella	•	
Iridaceae			
*	Freesia hybrid	•	•
	Orthrosanthus laxus	•	
	Patersonia occidentalis	•	
*	Romulea rosea	•	•
Juncaceae			
	Luzula meridionalis	•	
Juncaginaceae			
	Triglochin centrocarpum	•	
	Triglochin trichophorum	•	

Family group	**Plant Taxa**	**Veg. Unit** T	D
Lauraceae			
	Cassytha racemosa	•	
Lobeliaceae			
	Lobelia tenuior	•	
Mimosaceae			
	Acacia cochlearis	•	
	Acacia cyclops	•	•
	Acacia huegelii	•	
	Acacia pulchella	•	
	Acacia saligna	•	
	Acacia willdenowiana	•	
	Paraserianthes lophantha	•	
Myoporaceae			
	Eremophila glabra	•	
	Myoporum caprarioides	•	
Myrtaceae			
	Agonis flexuosa	•	•
	Eucalyptus gomphocephala	•	
	Eucalyptus marginata	•	
Orchidaceae			
	Caladenia flava	•	
	Caladenia latifolia	•	
M	Caladenia georgei	•	
M	Caladenia longicauda	•	
	Caladenia speciosa	•	
	Cyrtostylis huegelii	•	
	Cryptostylis ovata	•	
	Elythranthera brunonis	•	
	Eriochilus dilatatus	•	
	Leporella fimbriata	•	
	Leptoceras menziesii	•	
*	Monadenia bracteata	•	•
	Pterostylis aff. nana	•	
M	Pterostylis aspera	•	
	Pterostylis brevisepala	•	
	Pterostylis vittata	•	
	Pyrorchis nigricans	•	
	Thelymitra benthamiana	•	
	Thelymitra crinita	•	
Orobanchaceae			
	Orobanche australiana	•	

Family group		**Plant Taxa**	**Veg. Unit** T	D
Oxalidaceae				
		Oxalis perennans	•	
Papilionaceae				
		Bossiaea eriocarpa	•	
		Gompholobium tomentosum	•	
		Hardenbergia comptoniana	•	
M		Hovea chorizemifolia	•	
		Hovea trisperma	•	
		Isotropis cuneifolia	•	
		Jacksonia furcellata	•	
		Kennedia prostrata	•	
	*	Lotus angustifolius		•
	*	Lupinus angustissimus	•	•
	*	Lupinus cosentinii	•	•
	*	Medicago polymorpha		•
	*	Ornithopus compressus		•
	*	Trifolium campestre	•	•
M	*	Trifolium cernuum		•
	*	Trifolium dubium		•
M	*	Trifolium glomeratum	•	
	*	Vicia sativa subsp. nigra	•	•
Phormiaceae				
		Dianella revoluta	•	
Poaceae				
	*	Aira cupaniana	•	•
		Amphipogon turbinatus	•	
		Austrodanthonia occidentalis	•	
		Austrostipa flavescens	•	
M		Austrostipa semibarbata	•	
	*	Avena barbata	•	•
	*	Briza maxima	•	•
	*	Briza minor	•	•
	*	Bromus diandrus	•	•
	*	Bromus hordeaceus	•	
	*	Cynodon dactylon		•
		Dichelachne crinita	•	
	*	Ehrharta longiflora	•	•
	*	Eragrostis curvula		•
	*	Hordeum leporinum	•	•
	*	Lagurus ovatus	•	•
	*	Lolium rigidum	•	•
		Microlaena stipoides	•	
	*	Pennisetum clandestinum		•
	*	Poa annua	•	•

Family group		**Plant Taxa**	**Veg. Unit**	
			T	D
		Poa poiformis	•	
	*	Sporobolus indicus		•
	*	Stenotaphrum secundatum		•
	*	Vulpia bromoides		•
	*	Vulpia myuros	•	•
Pinaceae				
	*	Pinus pinaster	•	•
Polygonaceae				
	*	Acetosella vulgaris	•	
	*	Emex australis	•	
Portulacaceae				
		Calandrinia calyptrata	•	
M		Calandrinia linifolia	•	
Primulaceae				
	*	Anagallis arvensis	•	•
Proteaceae				
		Banksia attenuata	•	
		Banksia grandis	•	
M		Grevillea vestita	•	
M		Persoonia saccata	•	
		Petrophile linearis	•	
Ranunculaceae				
		Clematis linearifolia	•	
		Ranunculus colonorum	•	
		Ranunculus pumilio		
Rhamnaceae				
		Cryptandra arbutiflora	•	
		Spyridium globulosum	•	
Roasaceae				
	*	Acaena echinata	•	
Rubiaceae				
	*	Galium aparine	•	
		Opercularia hispidula	•	
		Opercularia vaginata	•	
	*	Sherardia arvensis	•	•

Family group		**Plant Taxa**	**Veg. Unit** T	**Veg. Unit** D
Rutaceae				
		Diplolaena dampieri	•	
Santalaceae				
M		Exocarpos sparteus	•	
Scrophulariaceae				
	*	Dischisma arenarium	•	
	*	Parentucellia latifolia	•	
	*	Parentucellia viscosa		•
	*	Veronica arvensis	•	
		Veronica calycina	•	
Solanaceae				
	*	Physalis peruviana	•	
	*	Solanum linnaeanum	•	
	*	Solanum nigrum	•	
Thymeleaceae				
		Pimelea argentea	•	
		Pimelea rosea	•	
Urticaceae				
		Parietaria debilis	•	
Violaceae				
		Hybanthus calycinus	•	
Xanthorrhoeaceae				
		Xanthorrhoea preissii	•	
Zamiaceae				
		Macrozamia riedlei	•	

APPENDIX 3. Flora of the Contiguous Blocks (North to Bullock/Mill), Tuart Forest Reserve.

Key

Column 1 — **Family group**.
Families are listed alphabetically.

Column 2 — **Plant Taxa**.
Names include species, sub-species and varieties and are listed alphabetically.

*	Weed species
ms	Manuscript name (shown after the name)

Columns 3-8 — **Vegetation Unit**.

T	Upland areas dominated by Tuart
WM Rise	Rises in the Wetland Mosaic generally dominated by Jarrah and Marri
WM Mel	Bushland wetland areas dominated by *Melaleuca* species
WM Er	Bushland areas dominated by *Eucalyptus rudis*
R	Native vegetation along and in rivers
D	Disturbed areas

Family group		Plant Taxon	Vegetation Unit					
			T	WM Rise	WM Mel	WM Er	R	D
Adiantaceae								
		Adiantum aethiopicum					•	
		Cheilanthes austrotenuifolia	•					
Amaryllidaceae								
	*	Amaryllis belladonna	•					•
Amaranthaceae								
		Alternanthera nodiflora				•		
	*	Amaranthus lividus				•		
		Ptilotus manglesii	•					
		Ptilotus stirlingii	•					
Anthericaceae								
		Agrostocrinum scabrum		•		•		
		Arthropodium capillipes	•	•			•	
		Arthropodium preissii			•			
		Borya scirpoidea		•			•	
		Caesia micrantha					•	
		Caesia occidentalis		•				
		Chamaescilla corymbosa					•	
		Chamaescilla gibsonii (= aff. spiralis)			•			
		Corynotheca micrantha	•					
		Laxmannia ramosa					•	
		Sowerbaea laxiflora	•	•			•	
		Thysanotus manglesii	•				•	
		Thysanotus multiflorus	•	•				

Family group		**Plant Taxon**	**Vegetation Unit**					
			T	WM Rise	WM Mel	WM Er	R	D
		Thysanotus patersonii					•	
		Thysanotus sparteus					•	
		Thysanotus thyrsoideus				•	•	
		Thysanotus triandrus					•	
		Tricoryne elatior	•				•	
		Tricoryne tenella					•	
Apiaceae								
		Apium prostratum				•		
		Centella cordifolia				•		
		Daucus glochidiatus	•	•	•			
		Eryngium ferox ms			•			
		Eryngium pinnatifidum subsp. palustre ms			•			
		Eryngium pinnatifidum subsp. pinnatifidum	•					
		Homalosciadium homalocarpum		•				
		Hydrocotyle alata			•			
		Hydrocotyle callicarpa	•					
		Hydrocotyle diantha		•				
		Hydrocotyle hirta	old record, no known current location					
		Platysace compressa		•				
		Schoenolaena juncea			•			
		Trachymene coerulea	•	•				
		Trachymene pilosa	•	•				
		Xanthosia ciliata		•				
		Xanthosia huegelii					•	
Apocynaceae								
		Alyxia buxifolia	•			•	•	
	*	Vinca major				•		•
Aponogetonaceae								
		Aponogeton hexatepalus			•			
Araceae								
	*	Zantedeschia aethiopica	•	•	•	•	•	•
Asclepiadaceae								
	*	Gomphocarpus fruticosus				•		•
Asparagaceae								
	*	Asparagus asparagoides	•			•	•	•
Asphodelaceae								
	*	Albuca canadensis	•			•		•
	*	Asphodelus fistulosus	•			•		
		Bulbine semibarbata	•					

Family group	Plant Taxon	Vegetation Unit					
		T	WM Rise	WM Mel	WM Er	R	D
Asteraceae							
	Angianthus aff. drummondii (BJ Keighery & N Gibson 013)			•			
	Angianthus aff. preissianus (GJ Keighery 13527)			•			
*	Arctotheca calendula				•		
*	Artemisia absinthium						•
*	Aster subulatus						•
	Asteridea pulverulenta		•				
	Blennospora sp. Ruabon (BJ Keighery & N Gibson 20) (= B. aff. drummondii (golden bracts) BJK&NG 20)			•			
	Brachyscome bellidioides			•			
*	Carduus pycnocephalus	•			•		•
	Centipeda cunninghamii	•			•		•
*	Cirsium vulgare		•			•	•
*	Conyza albida				•		
	Cotula australis	•	•				
*	Cotula bipinnata				•		
	Cotula coronopifolia			•		•	
	Cotula cotuloides			•			
*	Cotula turbinata	•					•
	Craspedia variabilis		•				
*	Dittrichia graveolens	•					•
	Gnaphalium gymnocephalum	•					
	Gnephosis tenuissima			•			
	Hyalosperma cotula		•	•			
	Hyalosperma pusillum			•			
	Hyalosperma simplex			•			
*	Hypochaeris glabra	•	•	•		•	•
	Ixiolaena viscosa	•	•				
	Lagenophora huegelii	•	•				
	Millotia myosotidifolia		•				
	Myriocephalus helichrysoides			•			
*	Osteospermum ecklonis	•			•		
	Picris squarrosa	•					
	Podolepis gracilis (Swamp form) (GJ Keighery 13126) (= 'Swamp' GJK 13126)			•		•	
	Podotheca angustifolia		•				
	Pogonolepis stricta			•			
	Pogonolepis sp. Mundijong (GJ Keighery 13226) (="star")			•			
*	Pseudognaphalium luteoalbum			•			
	Quinetia urvillei		•				
	Rhodanthe corymbosa	•	•				

Family group	Plant Taxon	Vegetation Unit					
		T	WM Rise	WM Mel	WM Er	R	D
	Rhodanthe pyrethrum			•			
	Siloxerus multiflorus		•	•			
*	Senecio diaschides	•					
	Senecio glomeratus		•	•	•		
	Senecio hispidulus	•				•	
	Senecio quadridentatus	•		•	•	•	
	Senecio ramosissimus					•	
	Siloxerus filifolius			•			
	Siloxerus humifusus		•				
*	Sonchus asper			•		•	
	Sonchus hydrophilus				•		
*	Sonchus oleraceus	•	•			•	•
	Trichocline spathulata		•				
	Trichocline sp. Treeton (BJ Keighery and N Gibson 564)			•			
*	Ursinia anthemoides		•				•
	Waitzia suaveolens		•				
*	Vellereophyton dealbatum				•	•	•
Brassicaceae							
*	Brassica tournefortii						•
*	Cardamine hirsuta	•					
	Cardamine paucijuga		•		•	•	
*	Heliophila pusilla	•	•				•
*	Raphanus raphanistrum						•
*	Sisymbrium erysimoides						•
	Stenopetalum robustum	•					
Campanulaceae							
	Wahlenbergia multicaulis	•	•				
	Wahlenbergia preissii	•	•				
Callitrichaceae							
*	Callitriche hamulata			•			
*	Callitriche stagnalis					•	
Caryophyllaceae							
*	Cerastium glomeratum	•	•		•		•
*	Corrigiola littoralis			•	•		•
*	Petrorhagia velutina	•	•				•
*	Silene gallica var. quinquevulnera						•
*	Spergula arvensis						•
*	Stellaria media						•
Centrolepidaceae							
	Aphelia cyperoides			•			
	Brizula drummondii			•			
	Brizula muelleri			•			

Family group	**Plant Taxon**	**Vegetation Unit** T	WM Rise	WM Mel	WM Er	R	D
	Centrolepis alepyroides			•			
	Centrolepis aristata		•	•		•	
	Centrolepis cephaloformis			•			
	Centrolepis drummondiana	•	•				
	Centrolepis glabra			•			
	Centrolepis polygyna			•			
Chenopodiaceae							
	Atriplex hypoleuca				•		
*	Atriplex prostrata				•	•	
*	Chenopodium multifidum				•		•
*	Chenopodium murale				•	•	
	Dysphania glomulifera			•	•		
	Halosarcia indica				•		
	Halosarcia pergranulata				•		
	Rhagodia baccata	•			•	•	
	Sarcocornia quinqueflora				•		
	Suaeda australis				•		
	Threlkeldia diffusa				•		
Colchicaceae							
	Burchardia congesta (= Burchardia umbellata)		•				
	Burchardia multiflora			•			
	Wurmbea dioica			•			
	Wurmbea pygmaea			•			
	Wurmbea tenella	•					
Commelinaceae							
	Cartonema philydroides	•	•				
Convolvulaceae							
	Dichondra repens	•					
Crassulaceae							
*	Crassula alata				•		
	Crassula colorata	•	•				
*	Crassula decumbens	•					•
*	Crassula natans			•		•	
	Crassula peduncularis	•	•				
	Crassula thunbergiana				•		•
Cyperaceae							
	Baumea articulata			•			
	Baumea juncea			•	•	•	
	Baumea preissii					•	
	Baumea vaginalis					•	
	Bolboschoenus caldwellii					•	

Family group	Plant Taxon	Vegetation Unit					
		T	WM Rise	WM Mel	WM Er	R	D
*	Carex divisa				•	•	
	Carex preissii	•				•	
	Chorizandra enodis			•			
	Cyathochaeta avenacea		•				
	Cyathochaeta equitans		•				
*	Cyperus congestus					•	
*	Cyperus eragrostis					•	
*	Cyperus tenellus			•		•	•
	Gahnia trifida			•	•		
	Isolepis cernua			•			
	Isolepis fluitans			•			
	Isolepis marginata	•	•	•			
	Isolepis oldfieldiana			•			
	Isolepis producta			•			
*	Isolepis prolifera					•	
	Isolepis stellata		•	•			
	Isolepis sp. (GJ Keighery 14895)					•	
	Lepidosperma angustatum	•	•			•	
	Lepidosperma gladiatum	•			•	•	
	Lepidosperma leptostachyum	•	•				
	Lepidosperma longitudinale			•		•	
	Lepidosperma squamatum		•				
	Mesomelaena tetragona		•			•	
	Schoenus bifidus	old record, no known current location					
	Schoenus capillifolius			•			
	Schoenus curvifolius		•				
	Schoenus efoliatus		•	•			
	Schoenus elegans			•			
	Schoenus grandiflorus	•					
	Schoenus humilis	•		•			
	Schoenus odontocarpus			•			
	Schoenus rigens		•				
	Schoenus subbulbosus		•				
	Schoenus sublaxus		•				
	Schoenus tenellus			•			
	Schoenoplectus validus					•	
	Tetraria octandra		•				
Dasypogonaceae							
	Acanthocarpus preissii	•					
	Dasypogon bromeliifolius		•				
	Lomandra caespitosa	•	•				
	Lomandra hermaphrodita		•				
	Lomandra micrantha	•	•				
	Lomandra nigricans		•				
	Lomandra purpurea		•				
	Lomandra sericea		•				
	Lomandra suaveolens		•				

Family group	Plant Taxon	Vegetation Unit T	WM Rise	WM Mel	WM Er	R	D
Dennstaedtiaceae							
	Pteridium esculentum	•			•	•	
Dilleniaceae							
	Hibbertia cuneiformis	•	•				
	Hibbertia cunninghamii		•				
	Hibbertia hypericoides		•				
	Hibbertia racemosa	•	•				
	Hibbertia rhadinopoda	old record, no known current location					
	Hibbertia stellaris			•			
	Hibbertia vaginata		•				
Droseraceae							
	Drosera erythrorhiza	•	•				
	Drosera gigantea			•			
	Drosera glanduligera	•	•	•			
	Drosera macrantha subsp. macrantha		•	•			
	Drosera menziesii subsp. penicillaris			•			
	Drosera neesii			•			
	Drosera pallida		•				
	Drosera rosulata			•			
	Drosera tubaestylis			•			
Elatinaceae							
	Elatine gratioloides			•			
Epacridaceae							
	Astroloma pallidum		•				
	Conostephium preissii	•	•				
	Leucopogon parviflorus	•	•				
Euphorbiaceae							
	Adriana quadripartita				•	•	
*	Euphorbia peplus	•	•				•
*	Euphorbia terracina						•
	Phyllanthus calycinus	•	•				
Fumariaceae							
*	Fumaria capreolata	•				•	•
*	Fumaria muralis						•
Gentianaceae							
*	Cicendia filiformis			•			
*	Centaurium erythraea		•	•		•	
Geraniaceae							
*	Erodium cicutarium	•					•

Family group		Plant Taxon	Vegetation Unit					
			T	WM Rise	WM Mel	WM Er	R	D
		Erodium cygnorum	old record, no known current location					
	*	Geranium molle	•					
		Geranium solanderi	•					
	*	Pelargonium capitatum				•		•
		Pelargonium littorale	•					
Goodeniaceae								
		Anthotium junciforme			•			
		Dampiera linearis		•				
		Dampiera trigona			•			
		Goodenia claytoniacea			•			
		Goodenia eatoniae			•			
		Goodenia micrantha			•			
		Goodenia pulchella		•	•			
		Lechenaultia expansa		•	•			
		Scaevola phlebopetala		•				
		Velleia trinervis		•				
Haemodoraceae								
		Anigozanthos flavidus					•	
		Anigozanthos manglesii		•				
		Conostylis aculeata		•		•		
		Conostylis candicans	•					
		Haemodorum simplex			•			
		Haemodorum sparsiflorum		•	•			
		Haemodorum spicatum		•				
		Phlebocarya ciliata		•				
		Tribonanthes australis			•			
		Tribonanthes ?uniflora			•	•		
		Tribonanthes violacea			•			
Haloragaceae								
		Haloragis brownii					•	
		Haloragis tenuifolia			•			
		Myriophyllum echinatum			•			
Hydatellaceae								
		Trithuria bibracteata			•			
		Trithuria submersa			•			
Hypoxidaceae								
		Hypoxis occidentalis			•			
Iridaceae								
	*	Chasmanthe floribunda						•
	*	Ferraria crispa	•					•
	*	Freesia X refracta	•					•
	*	Gladiolus undulatus	•			•		•

Family group		Plant Taxon	Vegetation Unit					
			T	WM Rise	WM Mel	WM Er	R	D
		Orthrosanthus laxus	•	•			•	
		Patersonia juncea	•	•				
		Patersonia occidentalis	•					
		Patersonia occidentalis (Swamp Form)		•	•			
	*	Romulea rosea		•	•		•	
	*	Sparaxis bulbifera			•		•	
	*	Watsonia meriana var. bulbillifera					•	•
Isoetaceae								
		Isoetes drummondii			•			
Juncaceae								
	*	Juncus articulatus			•		•	•
	*	Juncus bufonius			•		•	•
		Juncus caespiticius			•			
	*	Juncus capitatus		•	•			
		Juncus kraussii			•		•	
	*	Juncus microcephalus					•	
		Juncus pallidus			•		•	
		Juncus pauciflorus			•			
		Juncus planifolius			•			
		Luzula meridionalis	•					
Juncaginaceae								
		Triglochin calcitrapum subsp. recurvum ms			•			
		Triglochin centrocarpa		•				
		Triglochin huegelii					•	
		Triglochin lineare			•			
		Triglochin mucronatum			•			
		Triglochin muelleri			•			
		Triglochin striata					•	
		Triglochin trichophora	•					
Lamiaceae								
		Hemiandra pungens		•				
	*	Lavandula stoechas				•		
	*	Mentha X piperita			•		•	•
	*	Mentha pulegium			•		•	•
	*	Stachys arvensis	•					•
Lauraceae								
		Cassytha racemosa	•			•		
Lemnaceae								
		Lemna disperma			•		•	
Lentibulariaceae								
		Polypompholyx multifida			•			

Family group		Plant Taxon	T	WM Rise	WM Mel	WM Er	R	D
			Vegetation Unit					
		Polypompholyx tenella			•			
		Utricularia inaequalis			•			
Linaceae								
		Linum marginale		•				
Lindsaeaceae								
		Lindsaea linearis		•			•	
Lobeliaceae								
		Grammatotheca bergiana			•			
		Isotoma scapigera			•			
		Lobelia alata				•	•	
		Lobelia rhombifolia		•				
		Lobelia tenuior		•				
	*	Monopsis debilis			•			
Loganiaceae								
		Logania serpyllifolia		•				
		Logania vaginalis	•			•		
		Phyllangium paradoxum		•	•			
Loranthaceae								
		Nuytsia floribunda		•				
Lycopodiaceae								
		Phylloglossum drummondii			•			
Lythraceae								
		Lythrum hyssopifolia			•		•	
Marsileaceae								
		Marsilea angustifolia			•			
		Pilularia novae-hollandiae			•			
Melianthaceae								
	*	Melianthus major						•
Menyanthaceae								
		Villarsia albiflora			•			
		Villarsia capitata			•			
		Villarsia parnassifolia			•			
		Villarsia submersa			•			
		Villarsia violifolia			•			
Mimosaceae								
		Acacia alata	•					
		Acacia cochlearis	•					

Family group	Plant Taxon	Vegetation Unit					
		T	WM Rise	WM Mel	WM Er	R	D
	Acacia cyclops	•			•		
	Acacia extensa		•				
	Acacia huegelii	•	•				
	Acacia incurva			•			
	Acacia paradoxa	•					
	Acacia pulchella	•	•				
*	Acacia pycnantha	•			•		
	Acacia saligna	•	•			•	
	Acacia stenoptera		•				
	Acacia willdenowiana	•	•				
	Paraserianthes lophantha				•	•	
Myoporaceae							
	Eremophila glabra	•					
	Myoporum caprarioides				•	•	
	Myoporum insulare				•		
Myrtaceae							
	Agonis flexuosa	•	•			•	•
	Agonis linearifolia					•	
	Astartea aff. fascicularis (GJ Keighery 14066)			•		•	
	Astartea sp. I (GJ Keighery 14061)			•			
	Astartea sp. Gingalup (N Gibson & M Lyons 119) (GJ Keighery 14074)			•			
	Baeckea camphorosmae		•				
	Calothamnus lateralis			•			
	Calothamnus quadrifidus		•				
	Calytrix flavescens		•				
	Darwinia oederoides		•				
	Eucalyptus calophylla		•				
	Eucalyptus cornuta	•					
	Eucalyptus cornuta X gomphocephala	•					
	Eucalyptus decipiens		•			•	
*	Eucalyptus diversicolor						•
*	Eucalyptus globulus		•				
	Eucalyptus gomphocephala	•	•			•	•
*	Eucalyptus maculata		•				•
	Eucalyptus marginata		•				
	Eucalyptus rudis subsp. cratyantha				•	•	
	Hypocalymma angustifolium		•	•			
	Kunzea ericifolia		•				
	Kunzea recurva		•	•			
	Kunzea rostrata			•			
*	Leptospermum laevigatum						•
	Melaleuca cuticularis				•	•	
	Melaleuca incana	•	•	•			
	Melaleuca lateriflora			•			

Family group	Plant Taxon	Vegetation Unit T	WM Rise	WM Mel	WM Er	R	D
	Melaleuca lateritia			•			
	Melaleuca leptoclada			•			
	Melaleuca preissiana		•		•		
	Melaleuca rhaphiophylla			•	•	•	
	Melaleuca systena	•					
	Melaleuca uncinata			•			
	Melaleuca viminea			•			
	Pericalymma spongiocaule			•			
	Regelia ciliata			•	•		
	Verticordia attenuata		•				
	Verticordia densiflora var. caespitosa		•	•			
	Verticordia plumosa var. vassensis		•				
Olacaceae							
	Olax benthamiana		•				
Oleaceae							
*	Olea europea	•			•	•	•
Onagaraceae							
	Epilobium billardierianum			•	•		
	Epilobium hirtigerum				•		
Orchidaceae							
	Caladenia brownii		•				
	Caladenia chapmanii	•	•				
	Caladenia flava	•	•	•			
	Caladenia georgei		•				
	Caladenia hirta	•					
	Caladenia latifolia	•	•				
	Caladenia lobata		•				
	Caladenia lorea	•					
	Caladenia macrostylis		•				
	Caladenia marginata	•	•				
	Caladenia nana		•	•			
	Caladenia paludosa			•			
	Caladenia radiata			•			
	Caladenia reptans		•				
	Caladenia serotina		•				
	Caladenia speciosa	•	•				
	Caladenia variegata	old record, no known current location					
	Corybas despectans	old record, no known current location					
	Corybas dilatatus					•	
	Cyrtostylis huegelii	•	•		•		
	Cryptostylis ovata		•	•		•	
	Cyanicula deformis		•				
	Cyanicula gemmata	•	•				
	Diuris aff. amplissima (GJ Keighery 13788)	•					

Family group	Plant Taxon	Vegetation Unit					
		T	WM Rise	WM Mel	WM Er	R	D
	Diuris amplissima	•					
	Diuris filifolia			•			
	Diuris laxiflora			•			
	Elythranthera brunonis	•	•				
	Elythranthera emarginata		•				
	Eriochilus dilatatus	•					
	Eriochilus helonomos			•			
	Leporella fimbriata		•				
	Leptoceras menziesii	•					
	Lyperanthus nigricans		•				
	Microtis atrata			•			
	Microtis media subsp. media	•		•			
	Microtis orbicularis			•			
*	Monadenia bracteata	•	•	•			
	Prasophyllum drummondii		•	•			
	Prasophyllum macrostachyum			•			
	Pterostylis aff. nana (GJ Keighery 13648)	•					
	Pterostylis brevisepala	•					
	Pterostylis pyramidalis			•			
	Pterostylis rogersii	•					
	Pterostylis sp. Cauline Leaves (N Gibson and MN Lyons 1490)	•					
	Pterostylis sp. Slender Snail (GJ Keighery 14516)	•					
	Pterostylis vittata	•	•				
	Thelymitra antennifera			•			
	Thelymitra crinita		•				
	Thelymitra flexuosa			•		•	
	Thelymitra pauciflora		•				
Orobanchaceae							
	Orobanche australiana	•	•				
Oxalidaceae							
	Oxalis perennans	•	•			•	
*	Oxalis pes-caprae	•					•
*	Oxalis polyphylla	•				•	•
*	Oxalis purpurea					•	
Papilionaceae							
	Bossiaea eriocarpa		•				
	Brachysema praemorsa	•	•			•	
	Callistachys lanceolata					•	
	Chorizema diversifolium	•	•				
	Chorizema nanum		•				
	Daviesia decurrens		•				
	Daviesia podophylla		•	•			
	Daviesia preissii	•	•				

Family group		**Plant Taxon**	**Vegetation Unit** T	WM Rise	WM Mel	WM Er	R	D
		Eutaxia virgata			•	•		
		Gompholobium aristatum		•				
		Gompholobium marginatum		•				
		Gompholobium tomentosum		•				
		Hardenbergia comptoniana	•	•		•		
		Hovea stricta		•				
		Hovea trisperma		•				
		Isotropis cuneifolia		•				
		Jacksonia furcellata	•	•				
		Jacksonia sparsa ms		•	•			
		Kennedia coccinea	•			•		
		Kennedia prostrata	•	•				
	*	Lotus angustifolius		•	•	•	•	•
	*	Lotus uliginosus					•	
	*	Lupinus angustissimus					•	•
	*	Lupinus cosentinii	•				•	
	*	Lupinus luteus						•
	*	Medicago polymorpha					•	•
	*	Melilotus indica				•	•	
		Mirbelia dilatata					•	
		Sphaerolobium medium	•					
	*	Sutherlandia frutescens						•
	*	Trifolium campestre	•	•			•	•
	*	Trifolium dubium	•	•				
	*	Trifolium fragiferum	old record, no known current location					
	*	Trifolium repens	•				•	•
	*	Vicia sativa subsp. nigra	•					•
	*	Vicia sativa subsp. sativa				•	•	•
		Viminaria juncea			•	•		•
Philydraceae								
		Philydrella drummondii			•			
		Philydrella pygmaea			•			
Phormiaceae								
		Dianella brevicaulis	•			•		
		Dianella revoluta	•	•				
		Stypandra grandiflora	•	•			•	
Phytolaccaceae								
	*	Phytolacca octandra					•	•
Pinaceae								
	*	Pinus pinaster	•	•				•
	*	Pinus radiata	•					•
Pittosporaceae								
		Pittosporum angustifolium	•					

Family group	Plant Taxon	Vegetation Unit					
		T	WM Rise	WM Mel	WM Er	R	D
	Sollya heterophylla	•					
Plantaginaceae							
*	Plantago lanceolata	•				•	
Poaceae							
	Agrostis avenacea		•	•			
	Agrostis plebeia			•			
*	Aira cupaniana	•	•	•			
	Amphibromus nervosus			•			
	Amphipogon turbinatus		•				
*	Anthoxanthum odoratum		•	•		•	
	Aristida ramosa		•				
	Austrodanthonia occidentalis	•					
	Austrodanthonia setacea		•	•			
	Austrostipa compressa		•	•			
	Austrostipa flavescens	•					
	Austrostipa pycnostachya	•	•				
*	Avena barbata						•
*	Avena fatua	•	•			•	•
*	Briza maxima		•	•		•	•
*	Briza minor		•	•	•	•	•
*	Bromus catharticus						•
*	Bromus diandrus	•					•
*	Bromus hordeaceus	•				•	
*	Cynodon dactylon	•		•		•	•
*	Cynosurus echinatus	•					
*	Dactylis glomerata					•	
	Deyeuxia quadriseta			•		•	
*	Digitaria sanguinalis				•	•	
*	Ehrharta longiflora	•	•		•	•	•
*	Eragrostis curvula	•			•		
	Glyceria declinata (cosmopolitan freshwater native species)			•			
*	Glyceria maxima			•			•
*	Hainardia cylindrica	•		•			
	Hemarthria uncinata				•	•	
*	Holcus lanatus	•				•	
*	Hordeum leporinum	•				•	
*	Hordeum marinum				•	•	•
*	Lagurus ovatus	•	•		•	•	•
*	Lolium rigidum			•	•	•	
	Microlaena stipoides	•	•			•	
	Neurachne alopecuroidea		•				
*	Parapholis incurva			•	•	•	
*	Paspalum dilatatum	•			•	•	
*	Paspalum distichum					•	
	Paspalum vaginatum				•	•	

Family group		**Plant Taxon**	**Vegetation Unit**					
			T	WM Rise	WM Mel	WM Er	R	D
		(cosmopolitan freshwater native species)						
	*	Pennisetum clandestinum				•	•	•
	*	Phalaris paradoxa				•		•
	*	Poa annua		•		•		
		Poa poiformis		•				
	*	Polypogon monspeliensis			•	•	•	
		Polypogon tenellus			•			
	*	Sporobolus indicus				•	•	
	*	Stenotaphrum secundatum				•	•	•
	*	Vulpia bromoides	•	•				
	*	Vulpia myuros		•	•			
Polygalaceae								
		Comesperma calymega		•				
		Comesperma polygaloides			•			
		Comesperma virgatum		•				
Polygonaceae								
	*	Acetosella vulgaris	•				•	•
	*	Emex australis	•					•
		Muehlenbeckia adpressa	•				•	
		Persicaria prostratum			•		•	
		Persicaria salicifolium					•	
	*	Rumex crispus					•	
	*	Rumex pulcher					•	
Portulacaceae								
		Calandrinia calyptrata	•					
		Calandrinia composita		•				
		Montia australasica			•			
Primulaceae								
	*	Anagallis arvensis	•	•	•		•	•
		Samolus junceus			•			
Proteaceae								
		Adenanthos meisneri		•				
		Banksia attenuata		•				
		Banksia grandis		•				
		Banksia littoralis		•	•		•	
		Conospermum flexuosum subsp. laevigatum		•				
		Dryandra lindleyana subsp. lindleyana (D. nivea GJK 6622 in Gibson *et al.* 1994)	•	•				
		Grevillea manglesioides		•			•	
		Hakea lissocarpha	old record, no known current location					
		Hakea prostrata		•				
		Hakea sulcata			•			
		Hakea varia			•	•		

Family group		Plant Taxon	Vegetation Unit					
			T	WM Rise	WM Mel	WM Er	R	D
		Persoonia elliptica		•				
		Persoonia longifolia		•				
		Petrophile linearis	•	•				
		Stirlingia latifolia		•				
		Synaphea floribunda	•					
		Synaphea petiolaris		•				
Ranunculaceae								
		Clematis linearifolia	•			•		
		Ranunculus colonorum	•	•				
	*	Ranunculus muricatus					•	•
		Ranunculus pumilio	•					
Restionaceae								
		Anarthria prolifera		•				
		Anarthria scabra			•			
		Desmocladus fasciculatus		•				
		Desmocladus flexuosus		•				
		Hypolaena exsulca		•				
		Hypolaena pubescens		•				
		Lepyrodia muirii			•		•	
		Lyginia barbata		•				
		Meeboldina coangustata			•			
		Meeboldina scariosa			•			
		Stenotalis ramosissima			•			
Rhamnaceae								
		Cryptandra arbutiflora	•					
		Spyridium globulosum	•	•			•	
		Trymalium ledifolium				•	•	
Rosaceae								
	*	Acaena echinata	•					
Rubiaceae								
	*	Galium aparine	•					
		Opercularia hispidula	•	•		•		
		Opercularia vaginata		•				
	*	Sherardia arvensis	•					•
Rutaceae								
		Boronia dichotoma			•			
		Boronia fastigiata		•				
		Diplolaena dampieri	•	•				
		Philotheca spicata		•				
Santalaceae								
		Exocarpos odoratus			•			

Family group		Plant Taxon	Vegetation Unit					
			T	WM Rise	WM Mel	WM Er	R	D
Scrophulariaceae								
	*	Bartsia trixago			•	•		
	*	Dischisma arenarium	•			•		
	*	Dischisma capitatum	•					
		Gratiola pubescens			•	•	•	
		Glossostigma diandrum			•			
	*	Linaria maroccana						•
	*	Parentucellia latifolia			•	•	•	
	*	Parentucellia viscosa			•			
	*	Verbascum thapsus	•					•
	*	Verbascum virgatum	•					•
	*	Veronica arvensis	•			•		
		Veronica calycina	•					
Selaginellaceae								
		Selaginella gracillima			•			
Solanaceae								
	*	Physalis peruviana	•			•	•	
	*	Solanum americanum				•	•	
	*	Solanum hoplopetalum				•	•	
	*	Solanum linnaeanum				•	•	
	*	Solanum nigrum	•			•	•	
		Solanum symonii	•		•	•		
Sterculiaceae								
		Lasiopetalum membranaceum	•					
		Thomasia triphylla	•					
Stylidiaceae								
		Levenhookia pusilla		•				
		Levenhookia stipitata		•				
		Stylidium amoenum		•				
		Stylidium megacarpum (GJ Keighery 14850)	•		•			
		Stylidium calcaratum		•				
		Stylidium crassifolium		•	•			
		Stylidium dichotomum			•	•		
		Stylidium divaricatum			•			
		Stylidium ecorne			•			
		Stylidium emarginatum			•			
		Stylidium guttatum			•			
		Stylidium inundatum			•			
		Stylidium longitubum			•			
		Stylidium mimeticum			•			
		Stylidium petiolare			•			
		Stylidium piliferum		•	•			

Family group		**Plant Taxon**	**Vegetation Unit**					
			T	WM Rise	WM Mel	WM Er	R	D
		Stylidium repens		•				
		Stylidium striatum		•				
		Stylidium utricularioides			•			
Thymeleaceae								
		Pimelea angustifolia		•				
		Pimelea argentea	•					
		Pimelea hispida			•			
		Pimelea rosea	•	•				
Typhaceae								
		Typha domingensis					•	
	*	Typha orientalis					•	
Urticaceae								
		Parietaria debilis	•			•		
	*	Urtica urens	•					•
Verbenaceae								
	*	Verbena officianalis					•	
Violaceae								
		Hybanthus calycinus	•	•				
Xanthorrhoeaceae								
		Xanthorrhoea brunonis		•				
		Xanthorrhoea gracilis	old record, no known current location					
		Xanthorrhoea preissii		•				
Zamiaceae								
		Macrozamia riedlei	•	•				

APPENDIX 4. Composite Flora Lists from the work of d'Espeissis.

TABLE 1. Listing of species recorded from Tuart dominated sites (Pure Tuart, Tuart and Marri, Tuart and Jarrah and Tuart and Flooded Gum) in Malling Block from d'Espeissis (1938b) and soil site notebooks 122 and 123, held in the archives of the Department of Conservation and Land Management at Woodvale.

*Acaena species
Acacia alata
Acacia cyclops
Acacia extensa
Acacia heteroclita
Acacia huegelii
Acacia littorea
Acacia pulchella
Acacia saligna
Acacia willdenowiana
Adenanthos meisneri
Agonis flexuosa
*Aira species
Allocasuarina fraseriana
Allocasuarina humilis
*Anagallis arvensis
Anigozanthos manglesii
Anigozanthos viridis
*Arctotheca calendula
Arthropodium capillipes
Astroloma drummondii
Astroloma pallidum
Austrostipa semibarbata
*Avena species
Banksia attenuata
Banksia grandis
Banksia littoralis
Boronia spathulata
Bossiaea eriocarpa
Bossiaea linophylla (T/M)
*Briza maxima
*Briza minor
Burchardia multiflora
Burchardia umbellata
Caladenia flava
Calandrinia liniflora
Callistachys lanceolata
Carpobrotus ?aequilaterale
Comesperma virgatum
Conostylis aculeata
Craspedia variabilis
Cryptandra arbutiflora var. tubulosa
Dampiera linearis
Dampiera ?triloba
Daviesia divaricata
Daviesia incrassata
Daviesia podophylla
Desmocladus fasciculatus
Dianella revoluta
Drosera macrantha
Dryandra lindleyana
*Erodium ?moschatum
Eryngium pinnatifidum
Eucalyptus calophylla
Eucalyptus gomphocephala
Eucalyptus rudis
Geranium solanderi
*Geranium molle
Gompholobium tomentosum
Grevillea vestita
Hakea prostrata
Hardenbergia comptoniana
Hemiandra pungens
Hibbertia amplexicaulis/perfoliata
Hibbertia cuneiformis
Hibbertia cunninghamii
Hibbertia hypericoides
Hibbertia racemosa
Hovea trisperma
Hybanthus calycinus
*Hypochaeris glabra
Isopogon formosus subsp. dasylepis
Isotropis cuneifolia
Jacksonia furcellata
Jacksonia ?sternbergiana
Kennedia coccinea
Kennedia prostrata
Lagenophora huegelii
Lasiopetalum membranaceum
*Lavatera species
Leucopogon propinquus
Lepidosperma gladiatum
Lepidosperma species
Lobelia tenuior
Logania serpyllifolia
Logania species (?vaginalis)
Lomandra preissii (?micrantha)
Lyginia barbata
Macrozamia riedlei
Melaleuca preissiana

Melaleuca rhaphiophylla
Melaleuca thymoides
Microlaena stipoides
Muehlenbeckia adpressa
Nuytsia floribunda
Olearia ?pubescens
Opercularia hispidissima
Opercularia vaginata
Orthrosanthus laxus
Patersonia occidentalis
Patersonia xanthina
Pelargonium littorale
Persoonia longifolia
Persoonia saccata
*Petrorhagia prolifera
Petrophile linearis
Petrophile striata
Philotheca spicata
Phyllanthus calycinus
Pimelea argentea
Pimelea rosea
Pyrorchis nigricans
Ranunculus colonorum
Senecio species (?lautus)
Sowerbaea laxiflora
Stackhousia monogyna
*Stellaria media
Synaphea ?favosa
Synaphea petiolaris
Tetraria octandra
Thelymitra crinita
Thysanotus ?arenarius
Thysanotus manglesii/patersonii
Thysanotus sparteus
Trachymene species
Tricoryne elatior
*Trifolium species
Tripterococcus brunonis
Viminaria juncea
Waitzia aurea
Xylomelum occidentale

TABLE 2. Listing of species recorded from River Paddock (Central Block) from d'Espeissis (1938c) and soil site notebook 123. Sites described as Tuart, Flooded Gum and Jarrah/Marri/Tuart.

Acacia pulchella
Acacia saligna
Acacia stenoptera
Agonis flexuosa
*Aira caryophyllea
Allocasuarina humilis
Anigozanthos manglesii
Anigozanthos viridis
Astroloma ?drummondii
Astroloma pallidum
Arthropodium capillipes
Austrostipa semibarbata
Banksia attenuata
Banksia grandis
Banksia littoralis
Borya scirpoidea
Bossiaea eriocarpa
Brachyscome iberidifolia
*Briza maxima
Conostephium pendulum
Conostylis aculeata
Dampiera linearis
Dasypogon bromeliifolius
Daviesia divaricata
Desmocladus fasciculata
Dianella revoluta
Dryandra lindleyana
Erodium cygnorum
Eryngium pinnatifidum
Eucalyptus calophylla
Eucalyptus cornuta
Eucalyptus gomphocephala
Eucalyptus marginata
Eucalyptus rudis
Geranium pilosum/solanderi
Gompholobium tomentosum
Hakea prostrata
Hardenbergia comptoniana
Hemiandra pungens
Hibbertia cunninghamii
Hibbertia hypericoides
Hibbertia racemosa
Hybanthus calycinus
*Hypochaeris glabra
Jacksonia furcellata
Kennedia prostrata
Lagenophora huegelii
Leucopogon propinquus
Lobelia gibbosa
Lobelia tenuior
Lomandra (?micrantha)
Lepidosperma species
Lyginia barbata
Macrozamia reidlei
Melaleuca species
Melaleuca thymoides
Meeboldina sp. (Restio confertospicatus)
Mesomelaena tetragona
Muehlenbeckia adpressa
Nuytsia floribunda
Opercularia vaginata
Patersonia occidentalis
Patersonia xanthina
Pericalymma ellipticum
Persoonia longifolia
Petrophile linearis
*Petrorhagia velutina
Philotheca spicata
Phlebocarya ciliata
Phyllanthus calycinus
Pteridium esculentum
Ptilotus species
Ranunculus colonorum
Scaevola striata
Senecio species
Sowerbaea laxiflora
Stypandra glauca
Synaphea ?spinulosa
Tetraria octandra
Thysanotus sparteus
Tricoryne elatior
*Trifolium species
Tripterococcus brunonis
Viminaria juncea
Xanthorrhoea preissii
Xylomelum occidentale

APPENDIX 5. Reference tables used for describing vegetation, vegetation condition, DRF and Priority categories and threatened ecological communities.

TABLE 1. Vegetation Structural Classes (Keighery 1994 (adapted from Muir 1977, and Aplin 1979)).

Life Form/ Height Class	Canopy Cover (percentage)			
	100 - 70%	**70 - 30%**	**30 - 10%**	**10 - 2%**
Trees >30m	Tall Closed Forest	Tall Open Forest	Tall Woodland	Tall Open Woodland
Trees 10-30m	Closed Forest	Open Forest	Woodland	Open Woodland
Trees < 10m	Low Closed Forest	Low Open Forest	Low Woodland	Low Open Woodland
Tree Mallee	Closed Tree Mallee	Tree Mallee	Open Tree Mallee	Very Open Tree Mallee
Shrub Mallee	Closed Shrub Mallee	Shrub Mallee	Open Shrub Mallee	Very Open Shrub Mallee
Shrubs > 2m	Closed Tall Scrub	Tall Open Scrub	Tall Shrubland	Tall Open Shrubland
Shrubs 1-2m	Closed Heath	Open Heath	Shrubland	Open Shrubland
Shrubs < 1m	Closed Low Heath	Open Low Heath	Low Shrubland	Low Open Shrubland
Grasses	Closed Grassland	Grassland	Open Grassland	Very Open Grassland
Herbs	Closed Herbland	Herbland	Open Herbland	Very Open Herbland
Sedges	Closed Sedgeland	Sedgeland	Open Sedgeland	Very Open Sedgeland

TABLE 2. Vegetation Condition Scale (Keighery 1994).

Pristine (1) Pristine or nearly so, no obvious signs of disturbance.
Excellent (2) Vegetation structure intact, disturbance affecting individual species and weeds are non-aggressive species.
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 (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
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.
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.

TABLE 3. Definitions of Declared Rare Flora and Priority Flora (after Atkins 2001).

'**Declared Rare Flora — Extant Taxa** (R): Taxa which have been adequately searched for and are deemed to be in the wild either rare, in danger of extinction, or otherwise in need of special protection, and have been declared under section 23F of the *Wildlife Conservation Act 1950* to be "rare flora".'

'**Declared Rare Flora — Presumed Extinct Taxa** (X): Taxa which have not been collected, or otherwise verified, over the past 50 years despite thorough searching, or of which all known wild populations have been destroyed more recently, and have been declared under section 23F of the *Wildlife Conservation Act 1950* to be "rare flora".'

A 'Declared Rare Flora and Priority Flora List' is published each year by CALM (Atkins 2001). Priority Flora are taxa that are under consideration for declaration as 'rare flora' but are in need of further survey or continued monitoring. The list recognizes four categories of Priority Flora:

'**Priority One — Poorly Known Taxa** (1): 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** (2): 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** (3): Taxa which are known from several populations, and the taxa 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 Four — Rare Taxa** (4): 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.'

TABLE 4. Definitions of the status of the threat to ecological communities (English and Blyth 1997).

Category 1
Presumed Totally Destroyed
An ecological community which 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.

Category 2
Critically Endangered
An ecological community which has been adequately surveyed and found to have been subject to a major contraction in area and/or which 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.

Category 3
Endangered
An ecological community which 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.

Category 4
Vulnerable
An ecological community which has been adequately surveyed and found to be declining and/or has declined in distribution and/or condition and whose ultimate security has not been assured and/or a community which 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.

Category 5
Data Deficient
An ecological community for which there is inadequate data to assign it to one of the above categories and/or which is not yet evaluated with respect to status of threat.
(Usually an ecological community with poorly known distribution or biology that is suspected to belong to any of the above categories. These ecological communities have a high priority for survey and/or research.)

Category 6
Lower Risk
A community which has been adequately surveyed and evaluated and available information suggests that it does not qualify for one of the above categories of threat.

APPENDIX 6. Grassy Woodlands in Western Australia

There are a series of references to 'grassy woodlands' in early accounts of the vegetation of Western Australia. For example, Fraser (1830) in his account of the vegetation of the margins of the Swan River, wrote

> 'Proceeding up the river from the above mentioned creek [Claise Brook] the country assumes a distinct appearance from that seen below. On the left is an expansive marsh [Walters Brook, on the boundary of Perth and Maylands], bordered by thickets of *Casuarina*, surrounded by a flat of the richest description, rivalling in point of soil that of the Hawkesbury. Here I first observed the Brome or Kangaroo Grass of New South Wales in great luxuriance (with the exception of some seen on the banks at Point Frazer [near Herrison Island])'.

Fraser, a botanist form the east of Australia was unfamiliar with the diversity of sedges on the Swan Coastal Plain. *Themeda triandra* (Kangaroo Grass) does not penetrate the Swan Coastal Plain beyond the Pinjarra Plain (Guildford Clays), a great distance upstream from the area described by Fraser. What he had to be observing was a sedge, perhaps *Mesomelaena tetragona*, but more likely *Bolboschoenus*, *Schoenoplectus* or *Isolepis nodosa* at the edge of the semi-saline Swan Estuary, not a rich fresh alluvial flat. This is further supported by Bussell's reference to Cyperaceae as 'grasses' along the edge of the Wonnerup Inlet. Fraser is here acting as a salesman for the Colony as Kangaroo Grass was a desirable pasture grass.

This apparent broad classification of grass continues. Dakin (1919), in describing the habitat of the Albany Pitcher Plant (*Cephalotus follicularis*) shows a photo (Figure 2) labelled

> 'Pitcher Plants on ground amongst grasses etc'.

The picture clearly shows the Pitcher Plants amongst sedges and rushes (Cyperaceae and Restionaceae species) NOT grasses. Even as late as 1991, Pickering *et al.* (1991) in their study of herbicide control of grasses in the Tuart forest list sedges, *Conostylis aculeata*, Lomandras, *Patersonia occidentalis* and Lilies as 'Native Grasses'.

Unfortunately many authors (for example Ward 2000, Bradshaw 2000) have accepted these comments at face value and continue to refer to 'grassy' communities on the Plain even though such communities cannot be located today.

A series of other authors have commented on the status of grasses in the south-west and the apparent inaccuracies of these assumptions. Some examples of such comments from studies by botanists who have documented aspects of the south-west's vegetation and flora are given below.

- **Diels (1906) in *Die Pflanzenwelt von West-Australien südlich des Wendekreises.***

In a specific section on 'Families under represented in the Southwest province', Diels makes the following statements

> 'If one examines the general floristic character of the south-west, a striking feature will be apparent: namely, the relatively few members of the families Graminaceae and Compositae which are present.'…..
>
> 'The same holds good for the Graminaceae. The occurrence of grasses on sandy soils is extremely poor. Griseback's statement in "Vegetation der Erde" (11, 216) quoting Drummond that the sandy areas of the Swan River Colony are "preferably used as grassland" is absolutely incorrect.' (Diels has a footnote here to say that 'I have found no such remark in Drummond's writings. A misunderstanding must have occurred.')….
>
> 'The rarity of the occurrence of Graminaceae and Compositae in south-west Australia is very difficult to understand. Climatically similar areas, e.g. the Mediterranean and the Cape region of South Africa, are rich in members of both of these families. Moreover, introduced species, particularly annuals, do remarkably well in south-west Australia. *Briza maxima*, for example, is at present more common than any of the indigenous grasses.'

- **Beard (1981) in *Vegetation Survey of Western Australia, Swan, 1:1,000,000 series, explanatory notes to Sheet 7.***

Beard comments specifically on the mystery of the Kangaroo Grass of Fraser (1830)

> 'as there seems to be no indigenous grass in Western Australia fitting the description'.

He was quite right since it was a sedge. Beard continued

> 'It is an equal botanical mystery to try and identify the plants growing in the beautiful open grassy country so often alluded to by pioneers. There are few native grasses in the southwest and it seems unlikely they actually formed grasslands. It is more probable that the settlers used the term 'grassy' in a loose sense to mean young green herbage which could consist of annuals of all kinds, new shoots of perennials, sedges and Restionaceae as well as grasses'.

In addition, but not mentioned by Beard, Fraser was familiar with temperate Eastern Australia where grasslands of *Austrodanthonia*, *Poa* and *Themeda* are developed.

- **Keighery and Trudgen (1992) in *Remnant Vegetation on the Alluvial Soils of the Eastern Side of the Swan Coastal Plain.***

Keighery and Trudgen discussed historical accounts of the vegetation of the Pinjarra Plain, in particular that by Fraser (March, 1827 in Seddon 1972) which described the

> '...magnificent Angophoras (*Eucalyptus calophylla*)' and 'The Brome, or Kangaroo-grass of New South Wales in great luxuriance'

and observations of other early settlers that resulted in the development of a concept that the area had an

> 'open, park-like appearance...with scattered trees and the grassy ground layer.'

Here it was also considered very probable that the grasses Fraser describes, that is the 'Brome or Kangaroo-grass', are in fact *Mesomelaena tetragona* and *Cyathochaeta avenacea*. These two species, members of the Cyperaceae, are very common and conspicuous in the understorey of the remnants of this vegetation and have inflorescences that would give the semblance of the Bromes (members of the genus *Bromus*) and Kangaroo Grass (members of the genus *Themeda*). The grasses described by Fraser are common components of the *Eucalyptus* woodlands of the eastern states and Fraser would have expected to see these understorey species. *Mesomelaena tetragona* would have been completely new to Fraser, being from a genus endemic to WA.

Fraser's description of 'Brome or Kangaroo-grass' as a conspicuous component of the understorey should apparently be modified as was the reference to magnificent 'Angophoras', which were actually the endemic *Eucalyptus calophylla*. Keighery and Trudgen supported Beard's (1979) conclusion that the areas referred to by Fraser were not grassy woodlands. They concluded that the mystery of the grasses mentioned by Beard should now be considered resolved and supported Beard's description of the vegetation of the area as being:

> '....open woodland of *E. calophylla* ......little but herbaceous under growth',

with the following addition in relation to the understorey being

> '…….a mixture of herbs and sedges.'

- **Mattiske Consulting (1995) in *A Review of Grassy Woodlands in the Western Australian Wheatbelt.***

Mattiske Consulting listed Tuart, York Gum, Salmon Gum, Wandoo, Morrell, Merrit and Yate woodlands as possible grassy woodlands. However, they found that, (page 21)

> 'In all examples studied grasses formed a minor component of the understory. The ground layer was dominated by herbs and sedges and by monocots, daisies and other herbs with grass like form. This, not the dominance of grasses accounts for the park like and grassy appearance of these sites'.

These studies and other biological surveys of the Swan Coastal Plain and Wheatbelt undertaken over the past decade support the above statements that grassy woodlands are NOT a feature of the south-west Australian landscape.

FAUNA OF TUART COMMUNITIES

CONTENTS

VERTEBRATE FAUNA OF TUART WOODLANDS

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ABSTRACT

Vertebrate data from 12 Tuart woodland locations on the Swan Coastal Plain are presented with an appraisal of changes since European settlement.

The avifaunal communities in Tuart woodlands are diverse with 92 species definitely recorded. There have been sharp declines in some wide-ranging species that previously seemed to favour Tuart woodlands. Other specialist woodland species have declined in both Tuart as well as other woodlands on the Swan Coastal Plain. Despite the diversity of birds, there have been no detailed studies on the role of avifauna in Tuart woodlands or the significance of resources such as tree hollows to breeding birds.

Only 16 of the 35 mammal species that either currently or previously occurred on the Swan Coastal Plain have been definitely recorded in Tuart woodlands. Despite the probable loss of mammal species from the woodlands, several species with distributions centred in the southern Tuart woodlands still persist in this area. The Western Ringtail Possum and the Common Brushtail Possum have very dense populations associated with the Tuart/Peppermint forest of the Ludlow area. Mammal species surviving best are those that utilize tree hollows for daytime refuges.

The herpetofaunal community of Tuart woodlands is relatively diverse with 43 species of reptiles and 7 frog species. This comprises slightly more than half of the 71 reptile species and less than half of the 15 frog species that either currently or previously occurred on the Swan Coastal Plain. Most reptile species are widespread in other vegetation associations of the coastal plain but some reach their maximum abundance in the Tuart woodlands.

INTRODUCTION

Tuart woodlands[1] are confined to the near-coastal sands of the Swan Coastal Plain extending from Jurien in the north, southward to the Sabina River (see Maps 1 and 4 in Keighery *et al*. this publication). Communities dominated by this eucalypt are under threat from the many anthropogenic changes associated with near-coastal localities, such as agriculture, grazing and urbanisation. In areas of urban development the clearing and fragmentation of Tuart woodlands has had a marked impact on their extent and fires have become more frequent, while their faunal assemblages have been adversely affected by predation from introduced foxes and cats.

The vertebrate fauna of Tuart woodlands is very poorly documented and no previous regional assessment of faunal assemblages has been made. This contrasts with the information available on the vertebrate fauna of the *Banksia* woodlands of the Swan Coastal Plain, the focus of numerous surveys and ecological studies (see How and Dell 1989), and vegetation mosaics of the Darling Scarp (see Dell 1983, Dell and How 1988, Wellington and Dell 1989).

[1] Editors' Note: The terms forest and woodland are used in a non-technical manner in this paper.

METHODS

Published and unpublished data sources were examined for information on specific areas of Tuart woodland. These are listed below for each of the major vertebrate groups and presented in Table 1 and also shown on Map 4 in Keighery *et al*. (this publication). How *et al.* (1996) sampled several additional sites with Tuart emergents but these were not included in the compilation because Tuart comprised less than two percent of the canopy cover of the upper stratum. These sites, at Tuart Hill, Shenton Park, Mount Claremont and Kings Park in the Perth area, had no species additional to those already included from the Tuart woodland sites in the metropolitan area.

Birds

Data were compiled from a series of sources which are detailed in Table 1. These data appear in Table 2. Nomenclature and family sequence of bird names follows Johnstone (2000).

Mammals

Data were compiled from a series of sources which are detailed in Table 1. Fenced pitfall traps were used in all surveys and Elliott aluminium box traps in the majority, while mist-netting for bats was undertaken in the studies by Burbidge and Rolfe, and Napier (1982). These data appear in Table 3.

Reptiles and Amphibians

Data for these groups were collated from the same sources as for the mammals but with the addition of several unpublished surveys. The sources are detailed in Table 1. Data for reptiles appear in Table 4 and for amphibians in Table 5.

RESULTS AND DISCUSSION

Birds

A total of 92 bird species (Table 2) have definitely been recorded in the 12 Tuart woodlands from the data sources listed in Table 1. This number is low compared to the total of over 200 species listed for the Swan Coastal Plain (Storr and Johnstone 1988). However many of these additional species are associated with heathlands, swamps or lakes and would not be expected to occur in woodlands. Despite this, a number of other species could occur as many of the Tuart woodlands, especially those on the southern portions of the Swan Coastal Plain, have not had systematic surveys.

The avifauna of the Swan Coastal Plain has been well documented with major regional publications by Alexander (1921), Serventy (1948) and Storr and Johnstone (1988). These references are particularly useful as each documents temporal changes and highlights species reductions due to the effects of habitat destruction and other perturbations.

Storr and Johnstone (1988) summarized sharp declines in wide-ranging species that previously seemed to favour Tuart woodlands on the Swan Coastal Plain. These included the Yellow Robin, Crested Shrike-tit, Rufous Treecreeper, Yellow-plumed Honeyeater and Grey Currawong, all having declined even in large reserves where habitat changes have been minimal. Of these, the

Rufous Treecreeper and Crested Shrike-tit no longer occur on the Swan Coastal Plain, the Yellow-plumed Honeyeater is only known from Flooded Gums (*Eucalyptus rudis)* at Lowlands on the Serpentine River, and the Yellow Robin and Grey Currawong only occur in the more extensive woodlands in the northern or southern parts of the Swan Coastal Plain. All of them, however, still occur in Wandoo (*Eucalyptus wandoo)* and other woodlands of the Darling Scarp.

Other specialist woodland species have declined in both Tuart as well as other woodlands on the Swan Coastal Plain. These include the Red-capped Parrot, Weebill, Western White-naped Honeyeater (regarded by Alexander (1921) as fairly common, especially in the Tuart forest), Purple-crowned Lorikeet and Varied Sittella. Alexander (1921) commented that in the valleys on the eastern slopes of the coastal hills Tuart “grows into a fine forest tree”. Presumably many of these trees were harvested for timber with consequent inimical effects on the bird assemblage.

The Regent Parrot is an exception to those species that have declined as it has definitely increased in recent times on the Swan Coastal Plain, particularly in the partly cleared Tuart woodlands south of Mandurah where it breeds.

Unlike the detailed study of the impact of fire on *Banksia* woodland birds (Bamford 1986) and its significance to honeyeaters as a food resource (Tullis *et al.* 1982, Collins 1985), there have been no detailed studies on the role of avifauna in Tuart woodlands. The loss of, or decline in, the insectivorous bird species from the Swan Coastal Plain has not been examined in detail, neither has the role of birds in controlling damaging insects. This loss of bird species may explain the increase in Tuart Longicorns (*Phoracantha impavida*) and leaf eating insects that sometimes severely damage Tuart trees.

The structural significance of Tuart woodlands to bird species is illustrated by the data from Southern Beekeepers Reserve. This small isolate of Tuart has a diverse bird assemblage (Burbidge and Boscacci 1989) and forms an important roosting and nesting location for numerous bird species that utilize the surrounding extensive low *Banksia* woodlands and heaths; it also provides possibly the only source of suitable tree hollows in which Carnaby’s Cockatoo can nest. This provision of breeding or shelter resources probably applies to many bird species throughout the range of Tuart woodlands.

Sixteen of the 92 bird species included in Table 2 are obligate breeders in tree hollows and Tuart woodlands are important to their breeding success in coastal locations. Other species such as some of the birds of prey in coastal locations mainly breed in Tuart trees, further adding to the significance of these woodlands.

Mammals

Native mammal species are becoming increasingly uncommon on the highly modified landforms of the near coastal regions of Western Australia. This is particularly the case on the Swan Coastal Plain in the vicinity of Perth where urbanisation and agriculture have accelerated the local extinction of numerous native mammal species (How and Dell 1993). Many species which included woodlands in their preferred habitats have either disappeared or become much reduced in number and range.

Only 15 of the 35 mammal species that either currently or previously (How and Dell 1993) occurred on the Swan Coastal Plain have been definitely recorded in Tuart woodlands (Table 3). However, many of the species recorded on the Swan Coastal Plain have become locally extinct since settlement and, consequently, there are fewer extant species available to persist in Tuart woodlands.

Early reports of the mammalian fauna from the Busselton region (Shortridge 1909 and 1936) suggest that numerous species occurred in the savanna woodlands (Tuart woodlands) of the region at the time of first settlement. However, recent surveys have indicated that most species have probably become very rare or locally extinct. The Western Brush Wallaby (*Macropus irma*) was never common in southern coastal districts between Cape Naturaliste and Cape Leeuwin, although the Woylie (*Bettongia penicillata*), Tammar (*Macropus eugenii*), Quokka (*Setonix brachyurus*) and Numbat (*Myrmecobius fasciatus*) may have occurred in or adjacent to the coastal woodlands in the south-west (Shortridge 1909). Recent pitfall trapping surveys have indicated that small mammals are now rarely, if ever, found in this woodland type (Napier 1982, McDonald and O'Reilly pers. comm., How *et al.* 1987). The marsupials, the Honey Possum (*Tarsipes rostratus*), Dunnart (*Sminthopsis* spp.), Mardo (*Antechinus flavipes*) and Pygmy Possum (*Cercartetus concinnus*), and the rodents, the Western Bush Rat (*Rattus fuscipes*) and Ash-grey Mouse (*Pseudomys albocinereus*), may all have occurred in or adjacent to the Tuart woodlands.

Despite the spatially and temporally extensive sampling in Tuart woodlands undertaken in the last 20 years (see References), only the Western Bush Rat and Honey Possum, among the small ground mammals, are known to persist in these woodlands (according to one of the authors, J Dell and Burbidge and Boscacci 1989). The bat fauna of Tuart woodlands has only been surveyed at Southern Beekeepers Nature Reserve (Burbidge and Boscacci 1989), Yanchep National Park (Burbidge and Rolfe pers. comm.) and Ludlow (Napier 1982). These studies highlight the importance of this forest type to aerial species as it provides both food resources and essential roosting sites.

In the Ludlow area, grazing has been permitted for up to nine months each year for over a century, resulting in a marked alteration to the shrub and ground cover of the area and probably decline and disappearance of small mammal species dependent on the food or shelter resource provided by the understorey. Fuel reduction burning was a constantly used management tool in the Ludlow area (McDonald and O'Reilly pers. comm., Broadbent this publication) and, although ceased in the 1920s, was probably a contributing factor in the decrease of small mammal species in this vegetation type.

Despite the probable loss of species from south-western forests, several mammals with distributions centred in the southern Tuart woodlands still persist in this part of the Swan Coastal Plain. The Western Ringtail Possum (*Pseudocheirus occidentalis*) and the Common Brushtail Possum (*Trichosurus vulpecula*) have very dense populations associated with the Tuart/Peppermint (*Agonis flexuosa*) woodland of the Ludlow area, while the latter species and the Southern Brush-tailed Phascogale (*Phascogale tapoatafa*) have viable populations in Tuart woodland further north. The Southern Brush-tailed Phascogale is still reported on the Swan Coastal Plain as far north as Yalgorup National Park, while the Common Brushtail Possum has a range that extends further again with outlying populations as far north as Geraldton. These three species are all nocturnal and arboreal and generally depend on tree hollows for daytime refuges.

There has been considerable recent research on these three arboreal marsupials (Rhind 1996 and pers. comm., Jones *et al.* 1994a and b, How and Hillcox 2000) that has highlighted their dependence on forest resources for population persistence. The insectivorous Southern Brush-tailed Phascogale is not as abundant in Tuart forest as it is in the Jarrah (*Eucalyptus marginata*)/Marri (*E. calophylla*) forests of the south-west, but nonetheless it is reported frequently by surveys and visitors to the Ludlow Tuart Forest. The most abundant naturally-occurring populations of the Common Brushtail Possum recorded so far in Western Australia are located in the Ludlow Tuart Forest (How and Hillcox 2000). This species is an obligate tree-hollow user for its daytime refuges, and in the Tuart forest around the Abba River reaches densities of 2-3 individuals per hectare. The most abundant populations of the Western Ringtail Possum are to be found in the Peppermint forests of the near-coastal sands of the south-western corner of Western Australia. However, there are also dense populations in the Tuart/Peppermint forests of the Ludlow area, particularly along the Abba River (Jones *et al.* 1994b), where the species both builds nests and uses hollow branches and tree stumps. In the Ludlow Tuart forests the Western Ringtail Possum is sympatric with the Common Brushtail Possum, also an arboreal foliovore, and it feeds extensively on the Peppermint trees that make up the dense understorey below Tuarts.

Reptiles and Amphibians

There has been little historical interest in the reptiles and frogs of the Tuart forest with most early chronicles either ignoring the herpetofauna of this vegetation type or mentioning only the larger and more visible snakes and lizards.

The surveys of Tuart woodlands over the last 20 years have revealed a relatively diverse herpetofaunal community in these woodlands consisting of 7 species of frogs and 43 species of reptiles. More than half of the 71 reptile species that either currently or previously occurred on the Swan Coastal Plain (How and Dell 1993 and 1994) have been recorded recently in Tuart woodlands (Table 4). This situation is similar for amphibians where 7 species out of a total of 15 species on the Swan Coastal Plain (How and Dell 1993) have been recorded in Tuart woodlands (Table 5).

The woodlands with the richest frog assemblages are those that occur adjacent to free-standing water, for instance at Ludlow and Yanchep. The only species that can live permanently in Tuart woodlands is the Turtle Frog (*Myobatrachus gouldii),* a species with direct development and the young hatching out in the breeding burrow. Although Bamford (1992) was studying fire in *Banksia* woodlands, he concluded that the Moaning Frog (*Heleioporus eyrei)* was probably little affected by fire but that the Banjo Frog (*Limnodynastes dorsalis)* and Turtle Frog were both more frequent in areas that had not been burnt recently. These three species are the most frequently recorded frogs in Tuart woodlands.

Many reptile species that are widespread in other vegetation associations of the Swan Coastal Plain reach their maximum abundance in the Tuart woodlands (How *et al.* 1996). Included in these species are the arboreal skink *Cryptoblepharus plagiocephalus* and gecko, *Christinus marmoratus*, and the litter specialists *Aprasia repens*, a legless lizard, and *Menetia greyi*, a skink. It is apparent, however, from both published and unpublished surveys of Tuart woodlands that there are no species unique to this vegetation type. The most diverse reptile assemblages reported are those in Tuart woodlands that have been the focus of repeated surveys (e.g. Ludlow) or subjected to numerous years of sampling (e.g. Trigg Bushland and Bold Park).

In a long-term examination of four vegetation types in Bold Park, How (1998) showed that the Tuart woodland associations had the least rich herpetofaunal assemblage but that several species attained their greatest abundance in this vegetation type. This long-term survey of Tuart woodland associations in Bold Park also provides an interesting example of the impact of extended temporal sampling on the determination of herpetofaunal assemblages. How (1998) documented a herpetofauna of 2 frogs and 15 reptiles in Tuart woodland after the first seven years trapping involving 399 days (2,394 pitdays). At the end of 12 years of sampling the recorded assemblage has grown to 3 frogs and 23 reptiles after 889 days of trapping involving 6,804 pitdays (How *et al*. 1996, Harvey *et al.* 1997). It is possible that over an even more extended timeframe all 29 reptile species occurring in Bold Park will be recorded in the Tuart forest sampling site.

CONCLUSIONS

Tuart woodlands have a diverse vertebrate assemblage with at least 158 species recorded. Although none of these species are restricted to them, Tuart woodlands have considerable conservation significance. Specialist woodland insectivorous bird species have declined in both Tuart as well as other woodlands on the Swan Coastal Plain and some species such as the Weebill and the Western White-naped Honeyeater are now infrequently recorded in other vegetation associations on the Swan Coastal Plain. Tuart trees also provide essential hollows for obligate tree hollow breeders as well as tall trees for other species such as diurnal birds of prey.

Among the mammal species the Western Ringtail Possum, Common Brushtail Possum and Southern Brush-tailed Phascogale have declining populations that on the Swan Coastal Plain are mainly centred in Tuart woodlands. These arboreal mammals are largely dependent on woodlands for their survival. Many of the bat species on the Swan Coastal Plain are dependent on tree hollows as daytime roosts and Tuart woodlands are an important roosting and breeding resource.

Although no reptile species is unique to Tuart woodlands, some species reach their maximum population level in them. Included here are arboreal as well as litter inhabiting species.

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TABLES

TABLE 1. Vertebrate fauna sampling locations of Tuart woodlands showing sources of data.

Key
Column 1 **Mapped Tuart Area Number.** From Map 4 in Keighery *et al.* (this publication).
Column 2 **Sampling Locations.**
Column 3-6 **Information Sources.** Two categories are listed:
Published/Unpublished reports referenced to author/s (see original publications for the date and time of study).
Unpublished records records published for the first time in this study, referenced to group/individuals together with time of the study.

Mapped Tuart Area No.	Sampling Locations	Information Sources			
		Birds	**Mammals**	**Reptiles**	**Amphibians**
1	Southern Beekeepers Nature Reserve	Burbidge and Boscacci (1989)	Burbidge and Boscacci (1989)	Burbidge and Boscacci (1989)	Burbidge and Boscacci (1989)
5	Bashford Nature Reserve	Burbidge and Birds Australia			
general area of 8	Moore River Area	Dell - spring 1997	Dell - spring 1997	Dell - spring 1997	Dell - spring 1997
part 11	Yanchep National Park	Burbidge and Rolfe - October 1987, April 1988	Burbidge and Rolfe - October 1987, April 1988	Burbidge and Rolfe - October 1987, April 1988	Burbidge and Rolfe - October 1987, April 1988
part 24	Neerabup National Park	Burbidge *et al*. (1993) and Dell, Burbidge and Birds Australia - several seasons		Dell, Maryan and Robinson - several seasons	Dell, Maryan and Robinson - several seasons
part 38	Hepburn Heights	How *et al*. (1996)	How *et al*. (1996)	How *et al*. (1996)	How *et al*. (1996)
part 12	Trigg Bushland		Cowan - spring, autumn 1993-1997	Cowan - spring, autumn 1993-1997	Cowan - spring, autumn 1993-1997
part 42	Bold Park Bushland	How and Dell (1990) and Dell - several seasons	How and Dell (1990) and How – all seasons 1986 - 1998	How and Dell (1990) and How – all seasons 1986 - 1998	How and Dell (1990) and How – all seasons 1986 - 1998
14	Woodman Point	How *et al*. (1996)	How *et al*. (1996)	How *et al*. (1996)	How *et al*. (1996)
79	Yalgorup National Park	Dell - June 1998			
73	The Maidens	Dell - March 1998	Dell - March 1998	Dell - March 1998 and Bow (1999)	Dell - March 1998 and Bow (1999)
part 88	Ludlow Tuart Forest (part Tuart Forest Reserve)	McDonald and O'Reilly - all seasons 1985, Dell - autumn 1985, summer 1986 and Harold - spring 1985	Napier (1982), McDonald and O'Reilly - all seasons 1985, Jones *et al*. (1994a) and Harold - spring 1985	Napier (1982), McDonald and O'Reilly - all seasons 1985, Jones *et al*. (1994a) and Harold - spring 1985	Napier (1982), McDonald and O'Reilly - all seasons 1985, Jones *et al*. (1994a) and Harold - spring 1985

TABLE 2. **Birds recorded from Tuart woodlands on the Swan Coastal Plain.**

Key

Column 1 **Bird Family, Common and Species Names**

- * Introduced species
- \+ Colonised naturally
- \# Still occurs on the Swan Coastal Plain but not recorded on sites reported herein.

Columns 2-12 **Recordings of birds at sampling locations** are indicated by an 'x'. Origins of the data are listed in Methods and Table 1.

FAMILY **Common Name** ***Species***	**Sampling Locations**										
	Southern Beekeepers N.R.	**Bashford N.R.**	**Moore River**	**Yanchep N.P.**	**Neerabup N.P.**	**Hepburn Heights**	**Bold Park**	**Woodman Point**	**Yalgorup N.P.**	**The Maidens**	**Ludlow Tuart Forest**
CASUARIIDAE											
Emu *Dromaius novaehollandiae*	**X**	**X**							**X**		
ANATIDAE											
Australian Shelduck *Tadorna tadornoides*	**X**				**X**		**X**		**X**		**X**
Grey Teal *Anas gracilis*			**X**								
Pacific Black Duck *Anas superciliosa*							**X**		**X**		**X**
Australian Wood Duck *Chenonetta jubata*							**X**				
ACCIPITRIDAE											
Osprey *Pandion haliaetus*											**X**
Black-shouldered Kite *Elanus caeruleus*		**X**				**X**	**X**			**X**	
Whistling Kite *Haliastur sphenurus*							**X**			**X**	**X**
Collared Sparrowhawk *Accipiter cirrocephalus*	**X**						**X**		**X**	**X**	
Brown Goshawk *Accipiter fasciatus*		**X**		**X**	**X**		**X**	**X**			**X**

FAMILY **Common Name** ***Species***	**Sampling Locations**										
	Southern Beekeepers N.R.	**Bashford N.R.**	**Moore River**	**Yanchep N.P.**	**Neerabup N.P.**	**Hepburn Heights**	**Bold Park**	**Woodman Point**	**Yalgorup N.P.**	**The Maidens**	**Ludlow Tuart Forest**
Wedge-tailed Eagle *Aquila audax*					X				X	X	
Little Eagle *Aquila morphnoides*		X			X		X	X	X	X	X
Spotted Harrier *Circus assimilis*		X									
FALCONIDAE											
Peregrine Falcon *Falco peregrinus*											X
Australian Kestrel *Falco cenchroides*	X	X	X				X				X
Brown Falcon *Falco berigora*		X			X						
Australian Hobby *Falco longipennis*			X			X	X		X	X	
TURNICIDAE											
Painted Button-quail *Turnix varia*							X			X	
CHARADRIIDAE											
Banded Lapwing *Vanellus tricolor*	X										
COLUMBIDAE											
***Domestic Pigeon** *Columba livia*		X			X	X	X				
Common Bronzewing *Phaps chalcoptera*		X			X			X	X	X	X
Crested Pigeon *Ocyphaps lophotes*		X									
***Spotted Turtle Dove** *Streptopelia chinensis*							X				

FAMILY **Common Name** ***Species***	**Sampling Locations**										
	Southern Beekeepers N.R.	**Bashford N.R.**	**Moore River**	**Yanchep N.P.**	**Neerabup N.P.**	**Hepburn Heights**	**Bold Park**	**Woodman Point**	**Yalgorup N.P.**	**The Maidens**	**Ludlow Tuart Forest**
***Laughing Turtle Dove** *Streptopelia senegalensis*					X	X	X	X			
PSITTACIDAE											
Baudin's Cockatoo *Calyptorhynchus baudinii*									X	X	X
Carnaby's Cockatoo *Calyptorhynchus latirostris*	X		X	X	X		X		X		
+**Galah** *Cacatua roseicapilla*	X	X	X	X	X	X	X	X	X	X	
Butler's Corella *Cacatua pastinator butleri*		X	X								
***Corella** *Cacatua* spp				X	X	X	X				
Purple-crowned Lorikeet *Glossopsitta porphyrocephala*							X				X
***Rainbow Lorikeet** *Trichoglossus haematodus*						X	X				
Red-capped Parrot *Platycercus spurius*				X	X		X	X	X	X	X
Western Rosella *Platycercus icterotis*										X	
Ring-necked Parrot *Platycercus zonarius*	X	X	X	X	X	X	X	X	X	X	X
+Regent Parrot *Polytelis anthopeplus*										X	X
Elegant Parrot *Neophema elegans*					X	X	X				X
CUCULIDAE											
Pallid Cuckoo *Cuculus pallidus*		X			X		X				X

FAMILY Common Name *Species*	Sampling Locations										
	Southern Beekeepers N.R.	Bashford N.R.	Moore River	Yanchep N.P.	Neerabup N.P.	Hepburn Heights	Bold Park	Woodman Point	Yalgorup N.P.	The Maidens	Ludlow Tuart Forest
Fan-tailed Cuckoo *Cuculus flabelliformis*	X			X	X		X	X	X		X
Horsfield's Bronze Cuckoo *Chrysococcyx basalis*	X				X			X			
Shining Bronze Cuckoo *Chrysococcyx lucidus*	X	X		X	X	X	X	X			
STRIGIDAE											
Boobook Owl *Ninox novaeseelandiae*	X						X			X	X
TYTONIDAE											
Barn Owl *Tyto alba*		X					X				X
PODARGIDAE											
Tawny Frogmouth *Podargus strigoides*	X			X			X		X	X	X
AEGOTHELIDAE											
Australian Owlet-nightjar *Aegotheles cristatus*	X						X				
APODIDAE											
Fork-tailed Swift *Apus pacificus*											X
HALCYONIDAE											
***Laughing Kookaburra** *Dacelo novaeguinea*	X	X	X	X	X	X	X	X	X	X	X
Sacred Kingfisher *Todiramphus sanctus*		X	X	X	X	X	X	X			X
MEROPIDAE											
Rainbow Bee-eater *Merops ornatus*		X	X	X	X	X	X	X			X

FAMILY **Common Name** ***Species***	**Sampling Locations**										
	Southern Beekeepers N.R.	**Bashford N.R.**	**Moore River**	**Yanchep N.P.**	**Neerabup N.P.**	**Hepburn Heights**	**Bold Park**	**Woodman Point**	**Yalgorup N.P.**	**The Maidens**	**Ludlow Tuart Forest**
MALURIDAE											
Variegated Fairy-wren *Malurus lamberti*		X	X								
Blue-breasted Fairy-wren *Malurus pulcherrimus*		X									
Splendid Fairy-wren *Malurus splendens*	X		X	X	X		X	X	X	X	X
PARDALOTIDAE											
Spotted Pardalote *Pardalotus punctatus*					X		X		X	X	X
Striated Pardalote *Pardalotus striatus*		X	X	X	X	X	X	X	X	X	X
ACANTHIZIDAE											
Western Gerygone *Gerygone fusca*	X	X	X	X	X	X	X	X		X	X
Weebill *Smicrornis brevirostris*		X	X	X	X	X	X	X	X	X	X
Broad-tailed Thornbill *Acanthiza apicalis*	X	X	X	X	X		X	X	X	X	X
Yellow-rumped Thornbill *Acanthiza chrysorrhoa*	X	X	X	X	X	X	X	X	X	X	X
Western Thornbill *Acanthiza inornata*		X			X						X
White-browed Scrubwren *Sericornis frontalis*		X	X	X	X			X	X	X	X
MELIPHAGIDAE											
Brown Honeyeater *Lichmera indistincta*	X	X	X	X	X	X	X	X	X	X	X
#Yellow-plumed Honeyeater *Lichenostomus ornatus*											

FAMILY **Common Name** ***Species***	**Sampling Locations**										
	Southern Beekeepers N.R.	**Bashford N.R.**	**Moore River**	**Yanchep N.P.**	**Neerabup N.P.**	**Hepburn Heights**	**Bold Park**	**Woodman Point**	**Yalgorup N.P.**	**The Maidens**	**Ludlow Tuart Forest**
Singing Honeyeater *Lichenostomus virescens*		X		X	X	X	X	X			
Western White-naped Honeyeater *Melithreptus chloropsis*							X				
White-cheeked Honeyeater *Phylidonyris nigra*					X	X	X				
New Holland Honeyeater *Phylidonyris novaehollandiae*		X		X	X		X		X	X	
Western Spinebill *Acanthorhynchus superciliosus*		X	X	X	X	X	X		X	X	
Red Wattlebird *Anthochaera carunculata*	X	X	X	X	X	X	X	X	X	X	X
Western Little Wattlebird *Anthochaera lunulata*				X	X		X				X
PETROICIDAE											
Scarlet Robin *Petroica multicolor*		X		X	X				X	X	X
White-breasted Robin *Eopsaltria georgiana*		X	X							X	
Yellow Robin *Eopsaltria australis*											X
NEOSITTIDAE											
Varied Sittella *Daphoenositta chrysoptera*				X	X	X	X		X	X	
PACHYCEPHALIDAE											
Golden Whistler *Pachycephala pectoralis*	X				X			X		X	X

FAMILY **Common Name** ***Species***	**Sampling Locations**										
	Southern Beekeepers N.R.	**Bashford N.R.**	**Moore River**	**Yanchep N.P.**	**Neerabup N.P.**	**Hepburn Heights**	**Bold Park**	**Woodman Point**	**Yalgorup N.P.**	**The Maidens**	**Ludlow Tuart Forest**
Rufous Whistler *Pachycephala rufiventris*	X	X	X	X	X	X	X	X	X	X	X
Grey Shrike-thrush *Colluricincla harmonica*	X	X		X	X	X	X	X	X	X	X
DICRURIDAE											
Restless Flycatcher *Myiagra inquieta*									X		
Grey Fantail *Rhipidura fuliginosa*	X	X	X	X	X		X	X	X	X	X
Willie Wagtail *Rhipidura leucophrys*		X	X		X		X	X	X		X
Magpie Lark *Grallina cyanoleuca*	X	X			X		X	X	X		X
CAMPEPHAGIDAE											
Black-faced Cuckoo-shrike *Coracina novaehollandiae*	X	X		X	X	X	X	X	X	X	X
ARTAMIDAE											
Dusky Woodswallow *Artamus cyanopterus*					X						X
Black-faced Woodswallow *Artamus cinereus*					X						
CRACTICIDAE											
Australian Magpie *Cracticus tibicen*	X	X			X	X	X	X	X	X	X
Pied Butcherbird *Cracticus nigrogularis*	X										
Grey Butcherbird *Cracticus torquatus*	X	X	X	X	X	X	X	X	X	X	X
#Grey Currawong *Strepera versicolor*											

FAMILY **Common Name** ***Species***	**Sampling Locations**										
	Southern Beekeepers N.R.	**Bashford N.R.**	**Moore River**	**Yanchep N.P.**	**Neerabup N.P.**	**Hepburn Heights**	**Bold Park**	**Woodman Point**	**Yalgorup N.P.**	**The Maidens**	**Ludlow Tuart Forest**
CORVIDAE											
Australian Raven *Corvus coronoides*	X	X	X	X	X	X	X	X	X	X	X
HIRUNDINIDAE											
Welcome Swallow *Hirundo neoxena*		X		X	X		X	X			
Tree Martin *Hirundo nigricans*			X	X	X		X	X	X	X	X
ZOSTEROPIDAE											
Grey-breasted White-eye *Zosterops lateralis*	X	X	X	X	X	X	X	X	X	X	X
DICAEIDAE											
Mistletoebird *Dicaeum hirundinaceum*	X			X			X		X		
MOTACILLIDAE											
Australian Pipit *Anthus australis*		X									
TOTAL BIRD SPECIES	**33**	**47**	**29**	**37**	**54**	**30**	**61**	**36**	**42**	**42**	**50**

TABLE 3. **Mammals recorded from Tuart woodlands on the Swan Coastal Plain.**

Key

Column 1 **Mammal Family, Common and Species Names**

* Introduced species

Columns 2-10 **Recordings of mammals at sampling locations** are indicated by an 'x'. Origins of the data are listed in Methods and Table 1.

FAMILY **Common Name** ***Species***	**Sampling Locations**								
	Southern Beekeepers N.R.	**Moore River**	**Yanchep N.P.**	**Hepburn Heights**	**Trigg Bushland**	**Bold Park**	**Woodman Point**	**The Maidens**	**Ludlow Tuart Forest**
TACHYGLOSSIDAE									
Echidna *Tachyglossus aculeatus*			x						
DASYURIDAE									
Southern Brush-tailed Phascogale *Phascogale tapoatafa*									x
PERAMELIDAE									
Southern Brown Bandicoot *Isoodon obesulus*							x	x	
TARSIPEDIDAE									
Honey Possum *Tarsipes rostratus*	x								
PHALANGERIDAE									
Common Brushtail Possum *Trichosurus vulpecula*			x			x		x	x
PSEUDOCHEIRIDAE									
Western Ringtail Possum *Pseudocheirus occidentalis*								x	x
MACROPODIDAE									
Western Grey Kangaroo *Macropus fuliginosus*	x	x	x	x				x	x

FAMILY **Common Name** ***Species***	**Sampling Locations**								
	Southern Beekeepers N.R.	**Moore River**	**Yanchep N.P.**	**Hepburn Heights**	**Trigg Bushland**	**Bold Park**	**Woodman Point**	**The Maidens**	**Ludlow Tuart Forest**
MURIDAE									
House Mouse **Mus musculus*	x	x	x	x	x	x	x	x	
Western Bush Rat *Rattus fuscipes*		x							
Black Rat **Rattus rattus*			x		x	x	x	x	x
VESPERTILIONIDAE									
Gould's Wattled Bat *Chalinolobus gouldii*			x						x
Western False Pipistrelle *Falsistrellus mackenziei*									x
Lesser Long-eared Bat *Nyctophilus geoffroyi*			x					x	
Greater Long-eared Bat *Nyctophilus timoriensis*			x						x
Gould's Long-eared Bat *Nyctophilus gouldi*									x
Southern Forest Bat *Vespadelus regulus*	x								x
MOLOSSIDAE									
Southern Freetail-bat *Mormopterus planiceps*									x
White-striped Freetail-bat *Tadarida australis*	x		x					x	
LEPORIDAE									
Rabbit **Oryctolagus cuniculus*	x	x	x	x	x	x	x	x	x
BOVIDAE									
European Cattle **Bos taurus*									x

FAMILY **Common Name** ***Species***	**Sampling Locations**								
	Southern Beekeepers N.R.	**Moore River**	**Yanchep N.P.**	**Hepburn Heights**	**Trigg Bushland**	**Bold Park**	**Woodman Point**	**The Maidens**	**Ludlow Tuart Forest**
FELIDAE									
Cat **Felis catus*		x	x	x	x	x	x	x	x
CANIDAE									
Dog **Canis familiaris*	x								x
Red Fox **Vulpes vulpes*	x	x		x	x	x	x		x
TOTAL MAMMAL SPECIES	**8**	**6**	**11**	**5**	**5**	**6**	**6**	**10**	**16**

TABLE 4. Reptiles recorded from Tuart woodlands on the Swan Coastal Plain.

Key
Column 1 **Reptile Family and Species Names**
Columns 2-11 **Recordings of reptiles at sampling locations** are indicated by an 'x'. Origins of the data are listed in Methods and Table 1.

FAMILY ***Species***	**Sampling Locations**									
	Southern Beekeepers N.R.	**Moore River**	**Yanchep N.P.**	**Neerabup N.P.**	**Hepburn Heights**	**Trigg Bushland**	**Bold Park**	**Woodman Point**	**The Maidens**	**Ludlow Tuart Forest**
GEKKONIDAE										
Christinus marmoratus		x	x	x	x	x	x		x	x
Crenadactylus ocellatus			x	x						
Diplodactylus spinigerus		x	x			x	x			
Underwoodisaurus milii				x						
PYGOPODIDAE										
Aclys concinna		x								
Aprasia repens				x	x	x	x	x		x

FAMILY *Species*	**Sampling Locations**									
	Southern Beekeepers N.R.	**Moore River**	**Yanchep N.P.**	**Neerabup N.P.**	**Hepburn Heights**	**Trigg Bushland**	**Bold Park**	**Woodman Point**	**The Maidens**	**Ludlow Tuart Forest**
Delma grayii				x						
Lialis burtonis				x	x	x	x	x	x	
Pygopus lepidopodus		x				x				
AGAMIDAE										
Pogona minor				x	x		x		x	x
SCINCIDAE										
Acritoscincus trilineatum			x						x	x
Cryptoblepharus plagiocephalus			x	x	x	x	x	x	x	x
Ctenotus fallens		x		x	x	x	x	x		
Ctenotus australis						x	x		x	
Ctenotus impar										x
Ctenotus labillardieri									x	
Cyclodomorphus celatus		x	x	x	x	x				
Egernia kingii										x
Egernia napoleonis									x	x
Hemiergis peronii										x
Hemiergis quadrilineata		x	x	x	x	x	x	x	x	x
Lerista distinguenda										
Lerista elegans		x	x	x	x	x	x		x	x
Lerista lineata								x		
Lerista lineopunctulata			x				x			
Lerista praepedita	x	x		x	x	x	x			
Menetia greyii		x		x	x	x	x	x	x	x
Morethia lineoocellata									x	x
Morethia obscura			x		x	x	x			x

FAMILY *Species*	**Sampling Locations**									
	Southern Beekeepers N.R.	**Moore River**	**Yanchep N.P.**	**Neerabup N.P.**	**Hepburn Heights**	**Trigg Bushland**	**Bold Park**	**Woodman Point**	**The Maidens**	**Ludlow Tuart Forest**
Tiliqua occipitalis				x						
Tiliqua rugosa	x	x	x	x	x	x	x	x	x	x
VARANIDAE										
Varanus rosenbergi										x
Varanus gouldii							x			
Varanus tristis								x		
BOIDAE										
Morelia spilota				x						
TYPHLOPIDAE										
Ramphotyphlops australis			x		x	x	x		x	x
ELAPIDAE										
Brachyurophis fasciolatus							x			
Brachyurophis semifasciatus				x	x	x	x			
Neelaps bimaculatus				x			x		x	
Neelaps calonotos							x			
Parasuta nigriceps										x
Pseudonaja affinis				x	x	x	x		x	x
Simoselaps bertholdi		x			x	x	x			
TOTAL REPTILE SPECIES	**2**	**12**	**12**	**20**	**17**	**19**	**23**	**9**	**16**	**19**

TABLE 5. Amphibians recorded from Tuart woodlands on the Swan Coastal Plain.

Key

Column 1 **Amphibian Family and Species Names**

Columns 2-11 **Recordings of reptiles at sampling locations** are indicated by an ‘x’. Origins of the data are listed in Methods and Table 1.

FAMILY *Species*	**Sampling Locations**									
	Southern Beekeepers N.R.	**Moore River**	**Yanchep N.P.**	**Neerabup N.P.**	**Hepburn Heights**	**Trigg Bushland**	**Bold Park**	**Woodman Point**	**The Maidens**	**Ludlow Tuart Forest**
MYOBATRACHIDAE										
Crinia insignifera			x						x	x
Limnodynastes dorsalis			x		x		x	x	x	x
Heleioporus eyrei			x				x		x	x
Myobatrachus gouldii					x	x	x			
Pseudophryne guentheri										x
HYLIDAE										
Litoria adelaidensis			x							x
Litoria moorei			x						x	x
TOTAL AMPHIBIAN SPECIES			**5**		**2**	**1**	**3**	**1**	**4**	**6**

TUART AND MANAGEMENT

CONTENTS

CONTENTS (continued)

TUART ISSUES
Responses to the Questions and Issues Raised at the Workshop
VM Longman and BJ Keighery

TUART IN THE LANDSCAPE

R Powell[1] and BJ Keighery[2]

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INTRODUCTION

Previous papers have discussed Tuart[1] plant communities and their value. This paper discusses the Tuarts that remain in our urban and rural landscapes, and how to maintain or restore Tuart as a feature of these landscapes.

TUART LANDSCAPES

Tuart occurs from near Jurien to the Sabina River, near Busselton, and dominates the landscape in many places between Moore River and the Sabina River. These include the otherwise cleared sandy (sometimes alluvial) flats from Ludlow to Mandurah and the dune country from Bunbury to the Moore River.

Although mostly confined to a coastal strip 5-10 km wide, Tuart does extend further inland along the margins of our rivers and estuaries. The western block of the Lowlands property, on the Serpentine, and remnant trees on the flats at Ravenswood, on the Murray River, and in the Perth suburb of Ferndale, near Bannister Creek, illustrate these landscapes. A distinctive variety was known to occur at Guildford (see Coates *et al*. this publication). Some of the interdunal wetlands are typified by Tuart groves; significant locations are Manning Lake, where they grow into the lake, and the Perry Lakes, where they grow on the sandy flats round the lakes.

REMAINING OCCURRENCES

Most of the area where Tuart occurs has been cleared, or largely cleared, for agriculture or housing. A number of places, however, are preserved for conservation (see Table 4 in Keighery *et al*. this publication). The most famous of these is Tuart Forest National Park, at Ludlow, near Busselton. Well known conservation reserves south of Perth containing Tuart include Yalgorup National Park and Leschenault Peninsula Conservation Park. Northwards of Perth are Southern Beekeepers Reserve, Nambung National Park, and Bashford Nature Reserve. Within the Perth Metropolitan Region are Yanchep and Neerabup National Parks, Woodman Point and Thomsons Lake Nature Reserves, Kings Park, Bold Park, Star Swamp and Trigg Bushlands and Blackwall Reach Reserve.

In suburban Perth Tuart has largely been destroyed. Isolated old specimens, however, still occur in such Perth suburbs as Nedlands, Floreat Park, Scarborough, Applecross and suburbs east and south of Fremantle. Further out, parks in Wanneroo and Joondalup, sadly cleared of most of their natural vegetation, remain dominated by Tuart.

[1] Since 'tuart' and other common names of plants and animals are common nouns (like 'street'), and not proper nouns (like 'Hay Street'), Robert Powell prefers to write them with their initials in lower case. The policy of the Wildflower Society of Western Australia (Inc.), however, is to write the common names of plants and animals with upper-case initials.

VALUES OF TUART

Tuart is useful for shade and shelter, for binding the soil and for lowering the watertable — but so are many other species of tree. What counts most is Tuart's additional values as a local species, when growing in its area of natural occurrence.

Local species of tree have important special values. Powell & Emberson (1997) give the following:

- scenic value, in preserving something of the natural variety of the area's landscape;
- a link with history: old specimens that predate European settlement are a reminder of the landscape as seen by the first European settlers;
- value for wildlife, as the tree species with which our local animals evolved;
- special beauty, as a result of the influence of the insects supported by the local tree: a more complex growth; softened colours; and individuality of character; and
- low environmental costs, in needing no water or fertilizer once established.

Tuart is a particularly good example of the first of those: the scenic value of local tree species. It is the largest naturally occurring tree on the Swan Coastal Plain, growing in places to over 35 m, with trunks 2 m thick near the base. Combined with this majesty is its grace, as a result of its flowing and well spaced branches.

Other local eucalypts, such as Jarrah (*Eucalyptus marginata*) and Marri (*E. calophylla*), grow tall in the Darling Range, but smaller on the Swan Coastal Plain. Jarrah in particular is a much lower (and often spreading and weeping) tree on the Plain.

Moreover, Tuart's colour-scheme (grey-green foliage and white-grey trunks) is not matched by any other eucalypt natural to the Plain. The near-white colour of the trunks, particularly in mature specimens, gives rise to an alternative common name for Tuart, 'White Gum'. One of the earliest land grants in the Perth area records the name 'White Gum Block' for a part of the farm dominated by Tuart. Although preserved in the name of the suburb White Gum Valley, 'White Gum' is nowadays used for the tree only by oldtimers; its Aboriginal name 'Tuart' has prevailed.

Another aspect of Tuart that sets it apart from most other eucalypts on the Swan Coastal Plain is its speed of growth. Only Flooded Gum (*Eucalyptus rudis*) and Limestone Marlock (*E. decipiens*) (in its early years) may be comparable. In its natural belt of occurrence, Tuart's growth is often slowed down greatly by its many associated insects: much of the tree's enormous energy is put to the worthwhile use of supporting these assorted creatures. It is when Tuart is grown away from its natural belt that it best shows itself to be definitely among the faster-growing eucalypts. For example, in Fred Jacoby Park, Mundaring, it appears to have outgrown all the species of fast-growing eastern-states eucalypts planted on the site.

Tuart typically adopts what Powell (1990) calls a 'splitting' habit of growth. Rather than having a dominant central trunk, with side-branches coming off it (the 'shaft' habit), as many forest trees do, Tuart tends to split into several nearly equal spreading branches.

That habit is well suited to Tuart's occurrence near the coast. Salt carried by the frequent onshore winds is very damaging to foliage. The broad, rounded canopy that results from Tuart's habit, together with a greater mass of foliage than is found in most eucalypts, tends to deflect these salt winds, reducing their effect.

Tuart is not the only eucalypt on the plain to adopt a splitting habit. Flooded Gum does so very typically. Jarrah, which has more of a shaft habit in the Darling Range, has a splitting habit on the plain. But Tuart's form is nonetheless distinctive. Its branches are more flowing and upwards-tending than those of Jarrah, and sturdier and more widely spaced apart than those of most specimens of Flooded Gum. Its foliage is thicker and more clumped than Flooded Gum's.

Thus Tuart, through its size, colouring and form, gives an identity to the landscapes of the Swan Coastal Plain.

Tuart varies greatly in size and shape over its range. Although it is often a tall tree, it is of low to medium height in the northern parts of its range, or on very shallow soils, or close to the ocean. Near the ocean, where most affected by salt winds, it is asymmetrical in shape, much broader than tall, and with a more closed canopy than elsewhere. In several near-coastal locations, north of Pipidinny Road in the Perth Metropolitan Region and on the coast at Dalyellup, south of Bunbury, it forms a mallee (see Keighery *et al*. this publication).

The type of vegetation formation it creates varies greatly too. In some places it forms a forest, in others a woodland or open woodland. Or the trees may be spread still further apart, as isolated specimens, or clumped together in small groves. Thus Tuart contributes much towards the variety of landscapes on the Plain. The remaining Tuart groves and individual trees in otherwise mostly cleared areas of the Plain are thus important landscape features and a significant part of our natural heritage. The conservation of these Tuarts is vital in maintaining the distinctive landscape of the near-coastal lands on the plain.

In Perth Tuart provides a link with history through the occurrence of specimens that were part of the vegetation before it was cleared for urban development. Even in Subiaco, one of Perth's oldest and most highly cleared suburbs, three specimens are still surviving in the Subiaco School and Theatre Centre Gardens. They have been pruned in past years, but two of them have regained something of their previous majesty.

Tuart is one of the most biologically valuable trees of Perth (Powell 1990). The older trees provide hollows for possums, bats and many species of bird. Of especial importance, however, is Tuart's value to insects.

Recent studies (e.g. Recher & Majer 1996) are beginning to show what a high number of insects and other invertebrate animals are associated with naturally occurring eucalypts. For example, probably more than 750 invertebrate species are associated with Jarrah or Marri, of which well over 400 occur in just the foliage alone. These studies also show that eucalypts of the more fertile soils tend to support more insects than those of less fertile soils. Since Tuart occurs on more fertile soils than either Jarrah or Marri, it is likely to support even more insect species. Insects and other invertebrates comprise most of the diversity of terrestrial ecosystems, and are also extremely important in the ecology. They pollinate plants, recycle plant materials, regulate each other's numbers, and provide food for birds, lizards and other vertebrate animals.

That Tuart supports many insect species can readily be seen by examining the foliage of specimens growing in the Tuart belt. All sorts of different marks can be seen, evidence of the ways of life of many different insects. One can thus appreciate that such trees are part of a living ecosystem. The Sydney naturalist Densey Clyne (1984) writes:

> 'Much of the fascination of a tree lies in its relationship with insects, birds and mammals. Their comings and goings leave signs behind on stems and leaves and bark, so a tree without such blemishes is like a friendless stranger in a foreign land'.

A Tuart growing in its natural belt is a fascinating tree. By contrast, the Spotted Gums (*Eucalyptus maculata*) and Lemon-scented Gums (*E. citriodora*), and particularly the poplars and Norfolk

Island Pines — and most of the other non-local trees planted in Perth — tend to be largely free of blemishes; these are Clyne's 'friendless strangers'.

As for the last of the values of local trees listed above, Tuart can be established with no or minimal watering, and needs no watering or fertilizing once established. Moreover, it is more resistant than almost all other eucalypts to the salt winds and limy soils of sites close to the ocean.

TUART OUTSIDE ITS NATURAL RANGE

Ironically, the towns in Western Australia where Tuart features most strongly are outside Tuart's natural range: Geraldton and Esperance. Here it has been planted extensively, as also on Rottnest Island, another place where it does not occur naturally. Outside Western Australia Tuart has been planted in other states, particularly South Australia, and in other countries overseas, particularly round the Mediterranean.

Tuart does well in many of these other areas, tolerating coastal conditions better than many other tree species. But of course it is just as much an intrusion into the natural landscapes there as non-local tree species are here. On Rottnest, for example, it would have been much better to plant the local Rottnest Cypress (*Callitris preissii)*, Moonah (*Melaleuca lanceolata*) and Cheesewood (*Pittosporum phylliraeoides*). Planting Tuart outside its natural range is no substitute for valuing and preserving it as a local tree on the Swan Coastal Plain.

DECLINE OF TUART IN THE LANDSCAPE

Like most plants and animals today, Tuart is suffering from the direct and indirect effects of the activities of human beings. An obvious direct effect is clearing. Indirect effects include changes to fire patterns and the introduction of weeds and canker fungi. The recent severe decline of many Tuarts over a wide area south of Mandurah, although caused directly by the larvae of a native beetle, has no doubt been triggered by stresses or ecological imbalances brought about by human activities.

The natural distribution of Tuart, the coastal strip from near Busselton to north of Guilderton, corresponds closely with the places where today's West Australians most like to live. Consequently the effect of humans on Tuart has been severe, with much of the land formerly occupied by Tuart cleared for houses or other human uses, and many of the bushland reserves containing Tuart greatly affected by weeds and frequent or severe fires.

The human population of this coastal strip continues to increase. Currently the urban areas are expanding, alongside an increase in the density of buildings within established suburbs, both in housing lands and grassed parklands. This change in density is mirrored in rural areas in the expansion of horticulture into grazing lands and the subdivision of large blocks into smaller lots in special rural subdivisions. These changes in density bode ill for the remnant Tuarts of the Plain. Tuart is a large tree and is not perceived by many as being compatible with housing, even though trees have persisted and graced urban yards since housing was established.

Many local municipalities have policies on retaining trees and in some cases replacing them. Unfortunately these often focus on planted non-local trees rather than the local species, and there is a need to catalogue these significant local remnant trees and act to preserve and replace them. Much of this replacement could be achieved by using Tuart in coastal suburbs when landscape plans allow tall trees.

However, the currently favoured landscape trees in Perth and other urban areas include plane trees — a hybrid variety from the Northern hemisphere — Spotted Gums and Norfolk Island Pines. These are grown to around two metres and planted to create an instant treed suburb. In some places the use of plane trees may have some merit, where a deciduous tree is preferred and is in keeping with early European town plantings. It is hard to see the rationale, however, for the selection of spotted gums, a native of the eastern states of Australia. This species is of similar size to Tuart, but with far less wildlife value; and has a shaft form, which does not reflect the local environment. Norfolk Island pine is a tree that should be planted with caution. Being very tall, it is visually very dominant. It also physically dominates other trees by overshadowing them.

The Spotted Gums are just one of many different eucalypts from the eastern states that have been planted, and the plane trees and Norfolk Island Pines just two of many exotic species. Thousands of these non-local tree species have been, and continue to be, planted in urban areas within the Tuart belt, competing visually with those Tuart trees that do remain in parks and gardens. Many parks in the newer suburbs begin with a very visible group of Tuart trees, but the Tuarts soon become less visible as planted non-local trees distract attention away from them, or ultimately hide them from view. The Challenge Stadium alongside Bold Park, and the roundabout on Safety Bay Road to the east of Lake Cooloongup, are two of many examples of such insensitive planting. It is now non-local trees that are visually dominant in our urban areas, not only because of their numbers, but also because many are large vigorous species. They are all the more large and vigorous, and all the more brightly coloured too, because they support fewer insects than the local species, and fewer than they themselves would in their natural environment. Tuart today is prominent in very few places in Perth apart from some bushlands, where there is less visual interference from non-local trees.

For the same reason, Tuarts are losing their visibility in many rural areas. In many districts where Tuarts created much of the visual character, they no longer do. Numerous nationally significant natural landscapes dominated by Tuart are slowly being eroded in this way.

PUBLIC APPRECIATION OF TUART

Cunningham (1998) in her book on significant trees of Western Australia details the history of the use of Tuart's timber, and comments on the tree's conservation status. This reputation is not merely confined to Western Australia, but is national and international: Tuart is included in numerous publications on significant trees of Australia or the world. Everett (1969) in *Living Trees of the World* describes the qualities of Tuart's timber and refers to the tree's restricted distribution.

But is Tuart known and appreciated by ordinary Western Australians? The use of its name for sixteen streets in Perth, one more than the number of streets named after the much more widespread Jarrah, suggests that it might be.

That Tuart has value to Western Australians was demonstrated in the widespread outrage expressed in 1995 when a highly visible paddock of Tuarts along the coast road north of Bunbury was cleared for a horticultural project. (Some shelter-belts of Tuart are being established in the development, but it will take many years for them to reach the dimensions of the trees that were cleared.)

On the other hand, it is no doubt true that, whereas many West Australians would have heard of Tuart, the vast majority would have little familiarity with this tree. Those people most likely to know Tuart are those who live, camp or holiday in the less developed coastal areas between Jurien and Busselton, where Tuart occurs in groves or forests. Many of these people would value these trees, but most would appreciate them simply as 'trees' or 'gum trees', and not know that they were Tuarts.

In Perth, older residents will still talk about the 'White Gums' they knew as a child in eastern Fremantle, or Coogee or other places. A generation or two ago many people did recognize Tuart, but very few would now. The reason, no doubt, is that Tuart is no longer a prominent feature of this city.

THE FUTURE

What can be done if we wish Tuart to remain, or be restored as, a feature of our landscape? In summary, we need to do this directly — by preserving those Tuarts that remain, and, where necessary, increasing their numbers or visibility — and also indirectly — by encouraging the human community to be aware of and value Tuart.

To preserve those Tuart trees that remain, there is a need to catalogue these significant local remnant trees and act for their preservation or replacement. Much of the replacement of trees that cannot be preserved could be achieved by using Tuart in coastal suburbs when landscape plans allow for tall trees.

Increasing the number of Tuarts where few remain is quite possible in many areas, and in some places is already being done. Tuarts have been and continue to be planted in many public parks; the recent plantings at the southern entrance to the Floreat Forum is just one example. As a result, the number of Tuarts in some urban areas has been increasing in recent years.

In many cases, unfortunately, too little care is given to where the trees are sited. Many of the spots chosen for them do not allow for their full height or spread when mature. On sites close to the ocean, they are often placed without regard to the asymmetrical shape they will develop as a result of salt winds, and therefore often too close to obstacles to their east. To get the best out of Tuarts as a landscape feature, the establishment of the trees should where possible aim at a result that looks natural. Copying the natural groupings of trees, and including some of the natural understorey will help, as will making use of natural regeneration wherever possible. Powell and Emberson (1996, page 69) have set out guidelines on this subject, under the heading 'Planting trees to copy nature'.

Restoring the visibility of Tuart trees will also be helped by removing the non-local trees growing amongst or near them. Most local governments would consider the removal of healthy, growing trees to be too drastic an action. However, all trees eventually die, or become dangerous, and at that stage are removed. With the right long-term planning, it would be possible for the non-local trees gradually to be replaced with Tuarts, or other local plant species that naturally associate with Tuart.

Just as management plans are being written for more and more bushlands, the time will surely come when other public lands are better planned. Too many parks and gardens are a mish-mash of trees and shrubs that do not relate well to each other, or create any particular visual effect. Proper planning for these areas could ensure that they better serve their varied purposes. Some of them could be designated as places where local species of tree or plant communities should prevail.

As for encouraging the community to be aware of and value Tuart, improving Tuart's visibility should help. As further means of achieving this, we should turn our attention to the media and the education curriculum.

As noted above, the print medium contains some information about Tuart. In addition to those books already mentioned, there are Seddon's *Swan River Landscapes* and *Sense of Place*, Powell's *Leaf and Branch* and Rippey and Rowland's *Plants of the Perth Coast and Islands* (Seddon 1970 and 1972, Powell 1990, Rippey and Rowland 1995).

However, in each of those the text on Tuart is only a few pages at most. As a tree that so typifies the environment where many Western Australians live, Tuart warrants a book to itself. With its character and beauty, its varied occurrence, and all its associated wildlife, Tuart would make a superb subject for a book, if written by persons who know and love this tree. That would be a wonderful way of helping others to get to know the tree better.

A popular and powerful medium is television. An enormous difference could be made by having a good nature program about the plants and animals of this region, their ways of life, and how we can grow some of the plants or encourage some of the animals in our gardens. We need a program of this sort to learn about Tuart and all the other plants and animals of our region.

Many Western Australians go through school learning little or nothing about their local trees. Schools should be encouraged to grow some of the local species in their grounds, and the curriculum should provide for students to see these trees and learn how to recognize them and appreciate their role in the ecology of the area.

CONCLUSION

Tuart, once the dominant tree of much of the Swan Coastal Plain, still gives a distinctive character to our natural landscapes, with its colour and habit, its variety, its vigour, its majesty and grace. Despite land-clearing and ecological pressures it is possible to retain and restore something of this distinctive landscape, if people can be brought to understand and value Tuart's natural qualities.

ACKNOWLEDGEMENT

Jane Emberson made useful comments on a draft of this text.

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TUART AT BUNBURY

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This Workshop presentation was a beautiful photographic essay on the Tuart dominated communities of the southern Bunbury vegetation transect (see Tuart Areas 73, 85 and 86 from Table 4 and Map 4 in Keighery *et al*. this publication). A photograph from this presentation is used on the cover of this publication. The following contribution gives an insight into the vegetation and landforms of the central section of the southern Bunbury vegetation transect. The transect is also referred to as the 'Ocean to Preston Corridor', 'South Bunbury Bushland Corridor', 'Bunbury Ocean-Preston River Regional Park' or the 'South Bunbury Open Space Link'.

Editors' Note

What is the explanation for *Banksia attenuata* woodland occurring in Tuart country and does this represent an occurrence of Bassendean in an area of Spearwood? It is suggested here that in the southern Bunbury transect the occurrences of *Banksia* woodland in an area where Spearwood formation was mapped previously do indeed represent Bassendean Formation.

For stratigraphic research a transect perpendicular to the prevailing geomorphological trends with good interfaces between different landform and vegetation units is essential.

In southern Bunbury a continuous transect of remnant vegetation stretches over a distance of 7 km from the Ocean in the west to the Preston River in the east. The importance of this east-west transect through the western Swan Coastal Plain formations has been given special recognition in Keighery and Keighery (1999).

> 'The sequence of vegetated landform elements (Quindalup/Spearwood/Bassendean Dunes - Pinjarra Plain) encompassed in the corridor is unusual in the Plain and does not appear to occur elsewhere.'

In addition to the æolian dune systems and the alluvial plain, there is the broad flat valley of the Five Mile Brook/Hay Park wetlands (?'Yoongarillup' Plain) which divides the Spearwood Dune System into a western and eastern tongue.

With the support of a Natural Heritage Trust grant, a programme of mapping was carried out based, in the traditional way, on landform, soil and vegetation. Decisive for the drawing of boundaries of Quindalup was the landform; for Spearwood the distribution of Tuart trees; for Bassendean the lack of Tuart trees and occurrence of *Banksia attenuata* woodland; and for Pinjarra Plain, landform and the rich brown soil, with occasional ironstone near the surface. When my mapping confirmed the existence of *Banksia* woodland (Koch 1989) where Spearwood had been mapped previously (Anon. 1981), I needed to find an explanation for the origin of these isolated occurrences, before I could be confident that the *Banksia* woodland indeed represented an occurrence of Bassendean.

Coming from a geological-geomorphological rather than a botanical background, I accepted what the vegetation clearly indicated and looked for clues in the landforms and contours for an explanation. The one-dimensional static map became alive and evolved into a three-dimensional and dynamic dune sequence, that was shifted to and fro, reworked, redeposited, that was removed from one area and piled up again further inland, that was covered with vegetation and denuded again, that was eroded by wind or water, that was subject to changing climatic conditions and sealevels, and that was chemically depleted or enriched with calcium carbonate by vadose water or the water table. There were tens of thousands, if not hundreds of thousands of years available for all this to happen.

The larger story of which the above is only a small part goes something like this: strong winds blew first siliceous (Bassendean) sand and then calcareous (Spearwood) sand ashore during times of lower sea levels, piling them up into huge sand dunes that moved inland until they petered out on the extensive alluvial Pinjarra Plains. More recently, the sea level rose above today's level (at least 4 m), causing the sea to intrude into a swale between the most advanced Spearwood Dunes and to create the marine estuarine plain (?'Yoongarillup') which now is drained by the Five Mile Brook.

Back to the *Banksia* woodland with Tuart surrounds. It occurs as a narrow band on the eastern side of the Five Mile Brook / Hay Park Plain (?'Yoongarillup' Plain), and as an irregular patch on the western side. East of Bussell Highway, it occupies the lower slope, while Tuart occupies the upper slope and the crest. The steepness of the slope, which is much greater than a normal wind-blown westerly slope, suggests an erosional origin. Aerial photos also strongly suggest the presence of eroded limestone cores within the Five Mile Brook Plain.

All these and other parameters led me to the conclusion that the Spearwood sands were eroded and washed away, leaving the underlying Bassendean sands exposed on the surface, ready to be recolonized by whichever plants found the conditions suitable; this was obviously not always the species or the species community that was growing nearby.

The importance of Tuart as a stratigraphic indicator derives from its specific pH requirements (see Gibson these proceedings). It therefore is a valuable indicator for the calcareous Quindalup and Spearwood Dunes. But, because calcium carbonate can be transported by chemical means and under certain conditions by mechanical means, the pH and therefore Tuart can exist where it is not expected. In such cases, its distribution needs to be considered in the context of other parameters as well.

Gibson *et al*. (1994) confirm that 'floristic types are broadly correlated with geomorphological/ geological units', although they found that statistic evaluation of the 509 quadrats indicates 'there is generally not a direct one-to-one correspondence'.

This tells us that geological-geomorphological mapping is not reliable when based purely on plant species surveys and that it needs to be tested against other parameters as well. Basically its stratigraphic reliability needs to be judged on a case by case basis.

In the Bunbury transect, the at-first unexpected distribution of Tuart trees and *Banksia attenuata* woodland led to a new understanding of the stratigraphy and history of a section of the Bunbury landscape.

Considering the Swan Coastal Plain as a whole, it seems quite possible or even likely that similar occurrences of Bassendean within Spearwood, or for that matter Spearwood within Bassendean, would exist elsewhere in the Plain and would have a similar erosional origin. This therefore emphasizes the usefulness of Tuart and *Banksia* woodland for stratigraphic analyses in the Swan Coastal Plain.

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TUART MANAGEMENT ISSUES IN THE LUDLOW TUART FOREST

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This Workshop presentation considered both present management issues and some historical notes in relation to the Ludlow Tuart Forest (part of the Tuart Area 88 from Table 4 and Map 4 in Keighery *et al.* this publication). The historical section should be read in conjunction with the paper in this publication on the *Floristics of the Tuart Forest Reserve* (Keighery and Keighery) which includes a discussion of historical descriptions of the Tuart forest. Also of interest is a paper by Johnston (1993) on *The History of the Tuart Forest* (Chapter 5, In: Portraits of the South West. Edited by BK de Garis, University of Western Australia Press, Nedlands, WA).

The text below was prepared for the Workshop presentation (21st March 1998).

Editors' Note

CURRENT MANAGEMENT ISSUES

The current management issues in the Ludlow Tuart Forest (part of Tuart Area 88, Map 4 in Keighery *et al.* this publication) are listed (not in priority order).

1. Protecting old growth forest from fire.
2. Fire hazard reduction methods – grazing vs. prescribed burning vs. chemical application.
3. Fence maintenance (keep cattle in and people out).
4. Fire break maintenance – grading vs. chemical.
5. Regeneration – gaps and ashbed establishment.
6. Protection of Western Ringtail Possum and its habitat.
7. Declared noxious weeds (Arum Lilies/Apple of Sodom).
8. Eradication of feral animals (foxes/rabbits).
9. Mineral sand mining (mining exploration).
10. Horse riding – commercial and individual.
11. Interrelationships with the Vasse Wonnerup wetland.
12. Recreation and tourism development – picnic sites, walk trails.
13. Heritage values and their protection (lime kilns).
14. Mosquitoes and Ross River Virus (kangaroo [host] population).
15. Archaeological sites.
16. Public access.
17. Urban development
18. Pine plantation – removal and regeneration to Tuart.

HISTORY OF THE LUDLOW TUART FOREST AREA

In the 1830s Mr JC Bussell made several trips to the area from the Augusta settlement.

He described the area as:

> 'Open grazing country not with decided turf but with vegetation that seemed more succulent than woody. Its growth gave the impression of a smooth surface.'

Busselton was surveyed in 1837 and settlement commenced.

The grazing possibilities of this fine open grassed country were an inducement to settlement, but the comparatively few head of stock during the first decade probably did little harm.

However, heavy stocking and repeated fires soon had an adverse effect on the country. Tuart re-growth was prevented or destroyed and Peppermints multiplied rapidly, defying all efforts of extermination.

The first sawmill commenced in 1870, mainly for Jarrah timber but some Tuarts were utilized. The mill closed in 1883.

The government repurchased 9,900 acres (Location 41) for $10,000 which included the whole of the Tuart forest.

Over-grazing continued.

The first State forest was declared in 1919 under the Forest Act of 1918.

The value of Tuart timber for railway coaches and carriage building was soon realized and to ensure timber supplies were available the following regulation came into force in 1906.

> 'No Tuart or Wandoo shall be felled, cut or sawn except for the supply to government departments of Western Australia – for use and not for sale.'

The Forest Department working plan No. 2 July 1921 Tuart Working Circle described the Tuart forest as a:

> 'Pure forest that has all the characteristics of the sclerophyllous type Eucalypt forest contains large portions of large over mature trees with occasional groups of young trees.
>
> 60 years ago this forest was open forest with few large peppermints forming a sparse understorey but excessive grazing and constant fires have had an effect of causing Peppermint to become more dominant.
>
> Re-growth of Tuart practically ceased 50 years ago.'

Regeneration commenced in 1918 using clear felling with seed trees – artificial regeneration using nursery stock and seed broad casting.

The situation has not changed much since 1921, although there are additional modern day issues.

TUART ISSUES

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INTRODUCTION

The last session for the day's programme was a workshop session, open to all participants. The workshop participants were invited to comment on issues raised by the speakers, present their own issues and raise questions related to these issues. The speakers formed a panel to respond to these issues/questions and responses, and further comment was invited from all participants.

Most of the issues/questions raised in this session were related to Tuart health, management and conservation. This section addresses those questions related to Tuart health and management. Tuart conservation is considered in the first paper in this publication.

It was evident in the discussions in this session that there was insufficient information available to the group on the day to respond adequately to some of the issues/questions. It was proposed that the workshop organizers would investigate these issues further and respond in the proceedings. As a consequence, this section of the proceedings has been structured to reflect the issues/questions raised as a series of questions, followed by a response taken from the responses on the day and further research. Much of this information, particularly on Tuart decline, is a result of investigations carried out from 1998 through to March 2002.

At times it has not been possible to obtain a definitive answer to a question. In such cases the need for further research is highlighted with some indication of the nature of the research considered to be required. The questions are grouped by subject.

DECLINE AND DEATH OF TUART IN THE YALGORUP AREA

Charlie Evans from Lake Clifton raised this issue; he was concerned about the health of Tuart trees in the Lake Clifton area and the broader area from Mandurah to Bunbury. Charlie first observed these problems in August/September 1996. He tabled a letter written by the Minister for the Environment, Cheryl Edwardes, to Judy Edwards, Member for Maylands; this letter outlined the then current understanding of the problem. Responses at the workshop to this issue and the continued health problems of Tuart in this area led to a detailed investigation of current knowledge of the problem.

What has been happening to the Tuart trees between Mandurah and Bunbury, especially in and around Yalgorup National Park?

CALM started receiving enquiries from the public concerned about the health of Tuart trees in Yalgorup about 1994 (Wills pers. comm.). In 1997 CALM officers and members of the public noticed a marked decline in the health of the crowns of Tuarts in the Martin Tank Lake campground within Yalgorup National Park (CALM 2000) and along the Old Coast Road. Concerned members of the public wrote letters to the relevant minister, and questions to Parliament resulted. Over the last few years the decline of the Tuart trees in the area has generated much comment and speculation about possible causes.

Throughout 1997, 1998 and 1999 the decline spread further afield and continued to get worse, with many trees having all branches and leaf area affected (CALM 2000).

The typical progression of decline observed in the Tuart trees at Yalgorup was described at the workshop by Charlie Evans and subsequently by CALM's David Mitchell (CALM 2000). There was discolouration, desiccation then death of foliage on individual, usually small outer branches; this resulted in dead 'cauliflower patches' on the trees. In some cases, up to three-quarters of the tree died off. The death of the branches occurred from about August through to May (Stookley pers. comm.). Dark gum stains were prominent on the trunks of both declining and healthy Tuarts. Eventually the dead leaves began to drop from the trees, causing obvious thinning of the canopy. Some trees developed stags, that is dead branches protruding above the top of the canopy, like the antlers of a stag.

In the following spring and summer (the time of normal leaf growth for Tuart), the trees resprouted epicormic growth. Epicormic growth is a natural response Tuarts have to regrow after fire, insect attack and loss of branches from events such as strong winds. Trees in different areas of Yalgorup showed varying amounts of epicormic sprouting. This epicormic growth (particularly along the highway) gave the impression that the Tuart trees were recovering, and that the problem wasn't so bad. However, by April in each of 1998, 1999 and 2000 this epicormic growth had died. That is, there has been a repeated cycle of epicormic growth and death, characterized by a weaker and weaker recovery in successive cycles as the tree's reserves became depleted.

Eventually many of the Tuart trees died. There has been total death of 80 percent of the mature Tuart trees in the area most affected within Yalgorup National Park (Yalgorup NP). Some very badly affected areas of the National Park have virtually no living Tuart trees; in others up to one third of the trees are dead (CALM 2000). Most of the trees affected were the older, more mature ones.

CALM closed the camping and picnic sites in the National Park due to the potential danger to the public of limbs falling from dead trees (CALM 2000); these sites have subsequently been reopened after the removal of the dead trees and limbs by CALM. The local shire removed dead trees and limbs from roadsides within the park. CALM released a pamphlet to inform the public briefly on what was thought to be happening to the Tuart trees at Yalgorup.

It is observed that the decline was 'patchy'; that is, not all trees in an area were affected and dead trees could be in close proximity to healthy ones. Further, it is important to note that, for some trees (the proportion is uncertain), the leaves died over almost the whole tree, all at once, whereas for others (mentioned above) the foliage died only in clumps or over one limb at a time.

An interesting observation is the purpling or reddening of mature leaves on certain Tuart trees (CALM 2000). The leaves are purple sometimes on just one surface, sometimes throughout. It is not known if this purpling is related to the decline of the tree. It may perhaps be an indicator of, or precursor to, the tree's decline. If indeed it is, the decline could well be extending in range, as Mitchell (pers. comm.) noted more recordings of trees with this 'leaf purpling', as well as poor leaf development, in September to November 2001 in areas significant distances to the north and south of the originally affected area (even as far north as Woodvale and as far south as Bunbury). So by early 2002 Tuarts in these new areas were showing symptoms that were similar to the early symptoms observed at Lake Clifton in 1997 and in the White Hill Road area in 2000; time will tell if trees in this new area will continue to decline, or recover. Note that leaf purpling has been known to be an indicator of nutrient deficiency (see later section entitled 'Changes to nutrient supply').

It is, however, encouraging to note that the epicormic growth of summer 2000/2001 has survived and continued to grow during 2001. In many areas, this one-year-old epicormic growth put on additional growth in summer of 2001/2002 and has continued to survive through to March 2002 (Mitchell pers. comm.) The critical question is whether this will lead to permanent recovery, or whether there will be another cycle of defoliation and still further epicormic growth. To answer this question needs time, and an understanding of the causes.

Overall, the observed decline of Tuart fits the description of 'dieback' (Podger 1981), characterized by progressive decline in the health of trees, including cycles of defoliation and regrowth, which may end in death of the tree. The term 'dieback' is commonly used in this way in the eastern states, but in Western Australia its use is confusing as it has become almost synonymous with what is often called 'Jarrah dieback'. 'Jarrah dieback' refers to the effect on susceptible plant species of the root-rot fungus *Phytophthora cinnamomi*. The progressive deterioration of Tuart is therefore not called 'dieback' in this report, but instead is referred to as a 'decline'.

What areas in particular were affected?

The worst-affected Tuart trees occurred in Yalgorup NP. Within the 12,888 ha of Yalgorup NP (which contains large areas of lake) there are 3,184 hectares of Tuart (Mitchell 1999). Of this, in February 1999 about 1,800 hectares round the southern part of Lake Clifton were affected, based on an assessment from the air (see Figure 1). A repeat of this survey in November 1999 showed the decline had spread (Figure 2); note that this change from the February to November surveys indicates the single episode of canopy (including epicormic foliage) death that occurred in late summer, that is shortly after February. It does not necessarily indicate a continual rate of decline between February and November.

These aerial surveys also showed there were areas of private land, farmland, roadsides, roadhouses, caravan parks and National Park affected to varying degrees, from White Hill Road to south of Preston Beach Road, a distance along the Old Coast Road of about 30 kilometres (Mitchell 1999).

Note that as at early 2001, Tuarts north and south of this area were relatively healthy, and were not obviously showing signs of the widespread decline and death seen in Yalgorup. However since then, trees in these new areas have been noted to exhibit leaf purpling, which may indicate spread of the decline.

What factors may have caused or contributed towards the decline and death of the Tuart trees?

A large number of environmental causes, both biological and physical, have been proposed for decline and death of trees elsewhere in Australia, and throughout the world. Heatwole and Lowman (1986) studied the phenomenon and reviewed the possible roles of drought, flood, changes in watertables, salinity, insect attacks, fungal diseases, land clearing, fertilizer application, soil erosion and overstocking with domestic animals. Chilcott, in his study of decline of Tuarts in remnant bushland of the Kwinana area (Chilcott 1992), listed 53 hypotheses of possible causes for Tuart decline.

In Perth in 1999, Clay and Majer (2001) studied the decline of flooded gum (*Eucalyptus rudis*). The resulting report suggested an association between leaf-eating psyllids and decline of trees, and between absence of native groundcovers and decline. However it was recognized that these were unlikely to be the primary causes of the decline, and that probably no single factor may be involved but rather interactions between two or more factors may be responsible.

The observation that in most cases decline cannot be attributed to a single cause is, in fact, a widely held opinion. It is also thought that possibly different causes are operational in different locations and/or on different tree species, although White (1986) has proposed that changes in weather patterns could initiate the decline in several cases studied.

Mitchell (1999) has described the decline of Tuart as a syndrome to which several factors probably contribute, leading to a reduction in the vigour of the trees.

Factors that may stress Tuart trees are detailed below, and are grouped according to whether they are physical or biological environmental factors. Each factor may operate independently or in association with other factors.

Physical Environmental Factors

Drought

Average annual rainfall in the south-west of Western Australia is currently following a declining trend; in particular, there has been a decline in the usually reliable cool season (May-October) rainfall over south-western Australia since about the middle of the 20th century and an increase in the number of dry days in the region (Bates *et al*.). The consequences for Western Australia's water resources management, agriculture and forestry are sufficiently serious that in 1997 the Government initiated the Indian Ocean Climate Initiative, a partnership between Federal and State Government agencies, including the CSIRO and the Bureau of Meteorology, to research climate variability and more effective seasonal forecasting, particularly for south-western Australia (IOCI 1999).

Figure 3 graphically illustrates Bureau of Meteorology rainfall data for Lake Preston Lodge (latitude 32^{o}59'43"S longitude 115^{o}43'34"E), slightly inland of Lake Preston. Rainfall information for Lake Preston Lodge is incomplete for the years 1983 and 1999-2001, so annual rainfall data for these years cannot be graphed on Figure 3. The trend line drawn on Figure 3 shows that annual rainfall is decreasing by about 8 mm a year over the 38 years of recordings. More detailed statistics should of course be performed on the data to determine if the decrease in rainfall observed is statistically significant.

The average annual rainfall for the area, over the 38 years of recording, is 869.3 mm. At Lake Preston Lodge over the 38 years from 1961 to 1998 there have been twenty years (53%) of below-average rainfall (and one year with no annual rainfall data); over the 19 years from 1961 to 1979 there have been eight years (42%) of below-average rainfall; over the 19 years from 1980 to 1998 there have been twelve years (63%) of below-average rainfall (and one year with no annual rainfall data).

Rainfall data for another site south of Lake Preston (Parkfield, latitude 33^{o}11'38"S longitude 115^{o}42'23"E) indicates rainfall was above average in 1999 but was again well below average in 2000. During winter 2001 rainfall totalling 257 mm fell at Parkfield, compared with a winter average of 451.2 mm; the total rainfall for the year was again well below average.

Wills (pers. comm.) has indicated a problem with using average rainfall figures, for average rainfall relates only to the period for which records have been taken. It is unknown how the rainfall fluctuates in the long term, or what part of a long-term fluctuation may have been recorded. Perhaps therefore the recent rainfall decline could be, at least partially, the result of natural variability of the climate. Of course the apparent decrease in rainfall over several decades may cause Tuart decline (by affecting groundwater conditions for example – see 'Changes to hydrogeology' section), but Wills suggests it might be extreme variations such as severe droughts in consecutive years which might be responsible.

Historic observations of Tuart decline sometimes coincide with periods of unusually low rainfall. In 1939 there were reported high losses of planted Tuart (Fox and Curry 1980); Wills in Mitchell (1999) has correlated this phenomenon with dry years in 1936 and 1938, and extreme drought in 1940. The rainfall record shows a peak in rainfall in 1933, followed by a 3 or 4 year decline to a trough in 1936. The same pattern was observed in 1974-77, 1984-1987 and 1991-94. Each of these periods terminated in notable El Niño droughts which resulted in deaths of plantation trees (Bluegums or pines) on susceptible sites. However the results of a comparison are occasionally contraindicative; Ludlow experienced decline in 1967 and the rainfall record shows 1959 and 1960 were dry years but 1963 to 1965 were boon years.

White (1986) reports that altered rainfall patterns have been implicated in decline of eucalypts. If these are a part of the cause, cycles of decline may re-occur in association with the predicted effect of global warming on rainfall (Clay and Majer 2001).

There is some evidence, from observations in the decline of another species (*Leptomeria ellytes*) in the Yalgorup area, that drought in the area since 1996 is having a significant impact. *Leptomeria ellytes* (previously known as *L. lehmanii*) is only known on the Swan Coastal Plain from the vegetated wetland in Yalgorup NP transected by Ellis Road. In 1996 the *Leptomeria ellytes* population was devastated by fire. Being a reseeder (killed by fire, but regrowing after fire from seed) it was expected that the population would be replaced by seedlings. However several searches since 1996 have failed to locate any seedlings and the wetland is noticeably drier.

Wills (pers. comm.) studied variation in rainfall for the much of the Swan Coastal Plain from Gingin in the north to Busselton in the south and concluded variation in rainfall is more or less the same across the whole Swan Coastal Plain regardless of local variation in actual amount of rainfall. Apparently, therefore, other local factors must be important for the decline to be geographically restricted to the Yalgorup area, and for the variation in expression of decline.

<u>Changes to hydrogeology</u>
Yalgorup lies at the western edge of the Swan Coastal Plain on the Spearwood Dune System; this is characterized by Cottesloe and Karrakatta soils, with leached sands at the surface and yellow to reddish-brown subsoils, and sometimes with outcropping limestone. The Quindalup Dune System extends for about 1 kilometre inland from the coast and comprises unconsolidated sands.

The lakes of Yalgorup are situated within 5 kilometres of the coast and are arranged in three parallel systems. Lake Preston is just inland of the Quindalup Dune System and is separated from the Martins Tank chain of lakes by a limestone ridge, and Lake Clifton and the Martins Tank chain of lakes are divided by a low sand ridge (Commander 1988). Lakes Preston and Clifton are extremely elongated.

The Yalgorup lakes vary from about 1 to 4 metres in depth. They are supplied by direct rainfall and inflow of fresh groundwater. The lakes are underlain by hypersaline groundwater and, since this is denser than seawater, the levels of some lakes periodically fall below sea level (Commander 1988). The hypersaline bodies of water are groundwater sinks, with salinity gradually increasing through evaporation from the lakes. The lakes themselves are saline, the actual salinity levels depending on their interaction with the underlying hypersaline groundwater.

Lake Clifton, Lake Preston and some of the other shallow lakes can dry out to varying degrees in summer and autumn; Martins Tank and Yalgorup Lakes are joined by a narrow channel and are perennial.

To the east of the lakes and between Harvey Estuary and Leschenault Inlet is an unconfined freshwater aquifer, up to 30 metres thick (Commander 1988). West of the lakes, and along the peninsula between Harvey Estuary and the ocean, hypersaline or saline groundwater at the bottom of the aquifer is overlain by lens-shaped bodies of fresh or brackish water; these lenses are recharged directly by rainfall. The mixed zones at the interface between these layers of very different salinity are narrow close to the lakes (Commander, 1988, reports the salinity rising from 10,000 to 50,000 mgL^{-1} TDS within a vertical distance of only one metre just inland of the shore of Lake Preston), but more diffuse near the coast and Harvey Estuary where they are affected by tidal oscillations. For some distance around the lakes the depth of fresh water overlying the hypersaline water is very shallow, but it increases with distance from the lake; by about 0.5 kilometres east of Lake Preston the groundwater is fresh right to the base of the unconfined aquifer.

Watertable and lake levels respond to changes in annual rainfall, and Yesertener (pers. comm.) has found a good correlation between cumulative departures from monthly mean rainfall and water levels in Lake Clifton. Further, it has been found that water levels in Lake Preston (and therefore probably Lake Clifton) reflect groundwater levels; this indicates that annual rainfall controls recharge, which in turn controls groundwater levels. Between 1990 and 1993 there was an approximate 0.7 metre drop in Lake Clifton (and consequently probably groundwater levels); although water levels have increased from 1993, they still continued to be below average till at least December 2000 when the last reading was graphed (Commander pers. comm.). The lenses of fresh water are probably more susceptible to change from local rainfall variations than the large freshwater aquifer east of the lakes.

Judging by the monitored water levels in Lake Clifton, the watertable in the vicinity of the lake may have dropped by about 0.8 metres between winter 1991 and summer 1994. It has not been ascertained whether this drop is of a sufficient magnitude to influence the health of Tuart trees. It is further not known if much change in watertable levels is required to have an effect, or how much tree roots are buffered to handle change.

It is, however, known that eucalypts generally survive drought by growing roots deep enough to reach water unavailable to other plants (Eldridge *et al.* 1993), rather than by producing leaves capable of withstanding tissue desiccation (Bell and Williams 1997). Tuarts growing in an area experiencing drought, as well as a falling watertable, may have an inadequate root system to take up sufficient moisture in periods of high temperatures or low rainfall in order to survive desiccation. There is only one known case of the excavation of Tuart roots (Oracle 2001) where roots of several 30 metre tall trees were excavated to 13 metres, but it is expected that Tuart roots go much deeper (Froend pers. comm.) as 13 metres is still a relatively shallow depth and it is known that Tuart roots form the root mats in limestone caves at Yanchep (Jasinska 1997). Colin Yates (workshop comment) commented that at Kings Park he understood groundwater was 70 metres below the Tuart trees in some places.

It is expected that Tuart, like many other south-western tree species, will obtain water from three zones, being: the soil, the saturated zone above the groundwater and the groundwater itself (Froend pers. comm.). The relative significance of each of these ‘zones’ will depend on the conditions under which the tree was established. Excavation of Tuart to determine the depth to which Tuart roots go in search of water is needed to be done with some precision as the roots can be quite small in diameter (Froend pers. comm.).

Interestingly, the areas where Tuart first declined in Yalgorup and those areas most severely affected appear to have shallow depth to groundwater, to be low-lying, to be where there is only a thin layer of fresh water overlying the more saline groundwater, or where there are lens-shaped bodies of fresh water overlying and surrounded by saline groundwater (Mitchell 1999). Perhaps low rainfall has dropped the watertable until there is no fresh water overlying the hypersaline water close to the lakes, or possibly the fresh-saline water interface has become more diffuse; as a consequence, this area may be more susceptible to the effect of drought than some other areas (Mitchell 2001). The shallow depth to groundwater in this area also means that the root system of trees here is smaller than trees higher in the landscape that have more space to explore. It is important to emphasize that much of this is conjecture as there have been no recent studies of water levels and salinity in the Yalgorup area.

Horticulture could also affect the watertable of the Yalgorup area, east of the lakes but the effect of groundwater abstraction has not been formally researched. Commander (1988) established a network of bores to enable monitoring of changes of water levels due to variations in rainfall and the extraction of groundwater, as well as assessing the groundwater resources and establishing approximate water balances for the coastal lakes but these bores are no longer accessible.

Another possible cause for tree decline is a raised watertable. Permanently raised watertables deprive roots of essential oxygen, leading to rotting of the roots and death of trees. River red gum has been killed in this way in eastern Australia. Although this has again not been studied at Yalgorup, it is doubtful that this is a problem here. Variation of the watertable in the limestone is low owing to its high transmissivity (Commander 1988). It is this same reasoning that also precludes any effect from the Dawesville Cut, a channel constructed in the early 1990s to improve the flushing of the estuary by seawater. Since the channel has been opened the tidal level in the estuary now rises and falls about three or four times as much as before, and it now takes only about half the time for the estuary to flush (Coastal Action Geography Action Week 1998).

In summary, changes in hydrogeological conditions may indeed be a predisposing factor in the decline of Tuart, but more research is needed. Subtle differences in the underlying hydrogeology may account for the decline being localized in just part of the greater area of below average rainfall. Availability of water is influenced by localized soil conditions, such as presence of dense limestone, which can reduce the soil's ability to hold water. Variations in transpiration due to the amount of understorey and overstorey, and fluctuations in the watertable, creating alternatively dry and waterlogged conditions, could also contribute to the patchiness of the decline.

<u>Changes to nutrient supply</u>
The soil is a reservoir of mineral nutrients required for plant growth. To harvest nutrients, plant roots have the capacity to penetrate soil, they have evolved root hairs to provide a large surface to contact the soil, and they have evolved symbiotic associations with mycorrhizal soil fungi.

Tall eucalypt forests in seasonally harsh Mediterranean regions of Australia often grow in areas with highly leached and impoverished soil. Yalgorup is no exception, having poor alkaline calcareous soil with only a limited supply of nutrients such as potassium and phosphorous (Mitchell 1999). Gibson *et al.* (this publication) report that Tuart can tolerate a large range of soil types, climatic conditions and salinity levels. They found Tuart occurred on sites with pH ranging from 5.5 to 8.7 and was the most likely canopy species to be encountered on soils above pH 7.3 which explains the early descriptions of Tuart being a species of the highly calcareous coastal sands (Hutchins 1916, Kessell 1925). In addition, Tuart generally grows on sandy soils with low soil phosphorous but can occur on soil with phosphorous levels of over 750 ppm.

The success of such eucalypts has been attributed to the conservation and recycling of nutrients (O'Connell and Grove 1996) and the use of mycorrhiza to capture these scarce nutrients (Bougher and Tommerup 2000).

Essential to the continued growth and development of green plants are, amongst others, carbon, hydrogen, oxygen, phosphorous, potassium, nitrogen, sulfur, calcium, iron and magnesium. Of these 10 elements, the salts of the last seven are dissolved in the soil water. This makes possible their passage through the cell wall and cytoplasmic membranes of root hairs. Lack of available soil water, such as may occur during a drought, affects the mobilization and uptake of several nutrients by slowing growth of root hairs, concentrating salts, and slowing the mobility of nutrients in plants. This causes a break in the nutrient loop and affects overall tree health, including the production of leaves.

Further, in alkaline calcareous soils, the pH affects the availability of ions and cations, such as phosphate. Phosphorous is extremely important as a structural part of many compounds and is vital for photosynthesis. As might be expected, phosphorous deficiency affects all aspects of plant metabolism and growth. Eucalypts growing on alkaline calcareous soils have evolved tolerances to severe alkalinity (as shown by Gibson *et al.* this publication), but Bell and Williams (1997) report Tuart can still be relatively sensitive to such conditions.

Phosphorous deficiency is rare, yet has been observed in Tuart planted on nutrient-poor mine waste spoils at Collie (Fox pers. comm.). Deficiencies show in the older leaves, which take on a purple colour, often with dry tips and margins (Phillips 1996). More research would be needed to determine whether the observed reddening/purpling of leaves of some Tuart trees at Yalgorup indicates a nutrient deficiency on particularly calcium-rich soils, as any nutrient deficiency, especially combined with drought, would decrease the vigour of the trees. Note that purple tints are also related to low temperatures in winter and these should not be confused with phosphorous deficiency.

Runoff from agricultural land, stormwater runoff, industrial discharge and seepage from domestic sewerage systems contribute to nutrient enrichment (particularly of nitrogen and phosphorous) in wetlands, waterways and groundwater. Nutrient enrichment is common in Australia, and can cause higher concentrations of nutrients, particularly nitrogen, to accumulate in a tree's foliage. These elevated concentrations may, in turn, encourage the outbreak of foliage-feeding insects. Although studies on nutrient levels have not been conducted at Yalgorup, it is unlikely the area has a problem with nutrient enrichment as there are few wide-spread sources of nutrient enrichment. It is worth noting that there are no obvious foliage-feeding insects associated with the Tuart decline.

Roadworks

In the late 1990s, Main Roads South West region constructed a second carriageway to duplicate the existing road on two sections of the Old Coast Road, just east of Lake Clifton and Lake Preston. Main Roads Western Australia reported that construction and operation of the roadworks was unlikely to affect the nearby wetlands due their distance from the road and the localized effect of roadside drainage on hydrology (Main Roads Western Australia South West Region 1999); the road drainage had been designed to retain off-road runoff within the roadside table drain prior to seeping into the soil.

The Environmental Management Plans for the projects also advise that, although areas of Tuart-Peppermint woodland were to be cleared for the roadworks, the utmost care was to be taken to protect priority flora found nearby. It was noted that the clearing of vegetation (7.1 ha for the Clifton section) would have negligible overall effect on the vegetation due to the extent of the Tuart-Peppermint woodland vegetation in the nearby Yalgorup NP and areas of State Forest. The Environmental Management Plan instructed that mature trees especially be conserved as far as practicable and not be disturbed for temporary works such as access tracks, spoil areas or site offices. Vehicles and equipment were not be parked or driven over tree roots.

It is therefore unlikely that roadworks would have caused undue stress to the Tuart trees of Yalgorup.

Frost

Griselda stated (workshop comment) that a ranger had informed her that frost was partly responsible for the decline in the Yalgorup area and frost was indeed one of the original factors implicated in the Tuart decline.

Mitchell reports (CALM 2000) that a severe frost was recorded in the area in 1997. This frost was reported to be severe enough to burn the foliage of mature Tuarts, and caused burning of shrubland in the foredunes of the coast (Murray Love pers. comm.). Frosts normally do not have a severe effect, especially with the proximity of Yalgorup to the ocean, and there have been severe frosts in the past with no ill effects. There are a few records of severe frosts at Wokalup that ought to have been remarkable for Tuart if it were sensitive to frost, but there has been no previous decline such as this. However, possibly some defoliation associated with frost, on top of other general climate and groundwater stresses could have compounded the reduction in vigour of the trees.

Fire

Fire is often considered to be a major cause of degradation of Tuart woodlands. Healthy Tuart is considered moderately resistant to fire but, unlike most Perth eucalypts, it does not generally develop a lignotuber[1], and relies mostly on its bark to protect it from fire (Powell 1990, Ruthrof *et al.* this publication). After fire, surviving Tuart trees resprout from epicormic buds. However, despite these adaptations to fire, Tuart is declining in some remnants that are frequently burnt (for example Ruthrof *et al.* this publication and Fox and Curry 1980). It appears that this decline relates to:

- an immediate loss of mature Tuarts if fire continues internally in the tree until the tree collapses (for example, loss of over 50 percent of the Tuart trees was observed by one of the authors, BJ Keighery, in a paddock east of Rockingham in the 1990s in the weeks after a grass fire); and
- the reduced survival of seedlings and juveniles.

Fox and Curry (1980) suggest the latter may be due to several factors: seedlings and juveniles may be burnt before they have a bark thick enough to protect them from the fire; introduced annuals are favoured, providing competition (for moisture in particular) for Tuart seedlings, and hence increasing the risk of annual burning by producing yet more inflammable material; insufficient fuel remains to provide adequate ashbeds for new seed to germinate into; senescence of trees of seed-bearing size is hastened as crown regrowth may be burnt back. Coupled with bud weevil attack (on fewer available food sources), seed production is reduced. If all foliage is lost in a fire, then with good leaf recovery from epicormic growth new seed will not be produced for a minimum of 4 to 9 years after the fire (Ruthrof *et al.* this publication). Fires which occur when there is no seed in the crowns or when the seedlings are small are clearly of no benefit to regeneration. Further, it may be possible that more frequent fires in urban remnants has weakened trees and increased the amount of dead wood available for the fungi *Armillaria* and *Piptoporous* to invade, and may predispose trees to insect attack (Fox and Curry 1980).

The recent fire history within Yalgorup NP includes fairly frequent fires until the declaration of the National Park in 1968, after which a policy of fire exclusion was implemented, and consequently burning became less frequent. The latest wildfire was in March 1996 in the area immediately south of Preston Beach Road and west of the Old Coast Road. Frequent fire is not likely to be a stress

[1] Mallee forms of Tuart have only recently been recorded. Two localities of mallee Tuart are now known (Keighery *et al.* this publication).

factor contributing to Tuart decline in Yalgorup. Similarly, frequent fires are not a feature of the parkland cleared areas also affected by the Tuart decline.

A hypothesis has been presented by Bradshaw (2000) and Ward (2000) that argues that a change in fire regimes, notably a reduction in the frequency of burning, has resulted in increases in density of the Peppermint (*Agonis flexuosa*) midstorey of the Tuart woodland. This hypothesis is based on the suggestion that the Yalgorup NP Tuart woodlands were significantly different to those currently observed in the National Park; it is suggested that the understorey was predominantly grassy, as was also suggested for the Tuart Forest around Ludlow. Keighery and Keighery (this publication) discuss the situation at Ludlow and find no evidence to support the presence of a grassy understorey in the past. The presence of such an understorey at Yalgorup NP, either now or in the past, is considered even less likely. The issue of the density of Peppermint is discussed later in the section on 'Interactions between different species in the Tuart dominated plant communities in the Yalgorup area'.

<u>Clearing or Disturbance</u>
Fox and Curry (1980) consider that it is not only development as such that leads to the loss of trees in the urban landscape. They point out that any road or other opening alters the environment and exposes trees to more sun, more wind and a greater edge effect than in the natural condition in which the trees have developed. Their paper suggested that insect infestation appeared to increase with degree of disturbance.

It is thought that during and immediately after an area is disturbed, the trees suffer. Following this, the ecosystem undergoes readjustment, and may settle into a new state, when the trees can recover (Powell pers. comm.). Accounts of Tuart's recovery in various places are given under the heading 'Has the death or decline of Tuart *en masse* been seen before?'.

Although clearing has not occurred in the middle of Yalgorup NP, there has been disturbance in the surrounding districts. East of the Old Coast Road is State Forest in which the native vegetation has been cleared and replanted with pines. Nearby there is land of private ownership, consisting of areas of native vegetation, pasture, and small areas of irrigated arable land on which lucerne and vegetables are grown. An area on the north-eastern shore of Lake Clifton has recently been sub-divided for housing. Roadworks have in some places exposed trees that previously were surrounded by vegetation.

Biological Environmental Factors

<u>Interactions between different species in the Tuart dominated plant communities in the Yalgorup area</u>
Prior to the current decline and deaths of Tuart in Yalgorup NP, it contained the largest area of intact Tuart dominated communities south of Perth (Keighery *et al.* this publication, Yates workshop comment). A series of studies have considered aspects of the vegetation and flora of the Park. These studies include both flora and vegetation information:

- flora - Fox *et al.* (1980) and Keighery (1996); and
- vegetation – Beard (1979) and Smith (1973) broadly mapped vegetation in the Park (1 : 250 000 scale, see Keighery *et al.* this publication); Trudgen (1991) maps vegetation units in some detail in that part of the Park in the City of Mandurah; and Gibson *et al.* (1994) document the regional floristic groups identified in the Park.

While these studies are useful, the flora and plant communities of the Park are yet to be adequately documented. This can be illustrated by a comparison between the Fox *et al.* study which recorded approximately 250 taxa for Yalgorup NP while the more recent survey by Keighery recorded in excess of 560 taxa.

When considered over its range from Jurien to the Sabina River, Tuart occurs in a variety of vegetation units and floristic community types (see Gibson *et al.*, Keighery, Keighery *et al.* and Keighery and Keighery this publication). The density of Tuart in these communities is variable; Tuart may only occur as scattered trees or, when a dominant, form an open woodland through to forest. However, Tuart is typically associated with a suite of other species; only in the highly altered communities are there few other native species present in the community. Several authors (Beard 1967, Piggot 1994, Fox and Curry 1980) have described the decline of Tuart in some remnants in the Perth Metropolitan Region and have found that this decline is generally associated with factors related to disturbance and weed invasion. While these authors describe a changed vegetation structure in these communities with the decline in Tuart densities, they do not describe a change in the floristic composition of the communities or attribute the changes to competition with native species.

However, Bradshaw (2000) and Ward (2000) have suggested that the death and decline of Tuarts in the Yalgorup area could relate to competition with other native taxa typical of the area, principally Peppermint (*Agonis flexuosa*). The basis for this hypothesis is the reported increase in Peppermint in the Yalgorup plant communities since fire frequency declined post-declaration of the National Park. Such competition is considered not likely to be a stress factor contributing to Tuart decline in the Yalgorup area for the following reasons.

- The decline has equally affected parkland cleared areas, where competition from peppermints does not exist.
- Floristic studies show that Peppermint is a typical species of Tuart dominated communities and other woodland communities south of Perth (recorded from 11 of the 43 floristic community types listed in Gibson *et al.* 1994).
- Smith (1973) mapped Peppermint as the dominant tree in the Yalgorup area, not long after the National Park was declared.
- Peppermint is generally favoured by frequent burning, regenerating from a lignotuber, epicormic growth and seedlings after fire.
- Peppermint and Tuart have not been shown to be competing for resources.

<u>Borers</u>

It was suggested by Greg Keighery (workshop comment) that insect attack is a significant factor in the decline of Tuarts at Yalgorup.

Like all native trees, Tuart has a suite of native insect herbivores that have evolved with it (Fox and Curry 1980, Fox 1981, Ruthrof *et al.* this publication). Wood boring insects that damage Tuart shoots and lead to the development of stags include the following:

- Longicorn Beetles and their boring larvae (borers), including the Tuart Longicorn Beetle (*Phoracantha impavida* Coleoptera: Cerambycidae), *Phoracantha semipunctata* and the Bullseye Borer (*P. acanthocera*);
- Stem Girdlers (*Cryptophasa unipunctata* Xyloryctidae); and
- moth larvae *Culama* sp. (Cossidae).

Of these, the Tuart Longicorn Beetle (*P. impavida*) appears to be the most significant (Fox 1981) in the death of branches and formation of stags.

Longicorn Beetles and their boring larvae, that is Tuart Borers, are common and natural components of Australian forests (Elliott *et al.* 1998) and they normally have a limited effect on the tree. However, it is thought that, for some reason, borers of the Tuart Longicorn Beetles have had a much more severe effect than usual in Yalgorup. Many trees had all branches and leaf area affected by the borer (CALM 2000).

Limited work at Yalgorup (Wills pers. comm.) found abundant evidence of borer activity on the declining Tuarts. This included:

- the galleries, larvae and pupal chambers of the Tuart Longicorn Beetle (*Phoracantha impavida)*;
- pupal chambers of the Bullseye Borer (*P. acanthocera*); and
- the galleries and larvae similar to those of *Bimia bicolor*, an obscure and rarely collected branch borer last collected from Tuart in about 1920.

Phoracantha semipunctata has also been found at Yalgorup NP, in particular on trees at the Martins Tank campsite that had been dead for two or three years (Mitchell pers. comm.).

Observation suggested higher densities of borers on declining trees than on healthy ones. However, Wills *(*pers. comm.) considers that none of the borers present was capable, either in combined attack or singly, of causing the magnitude of foliage loss that resulted. This conclusion was drawn as a result of observation of abundant Tuart Longicorn Beetle and Bullseye Borer activity in healthy trees in other parts of the range of Tuart. In general, borers don't kill trees. They can girdle large branches, and they can girdle and cause smaller branches (up to 13 mm diameter) to break off, as their galleries can be large in comparison to the diameter of these small branches. Borers contribute to loss of foliage, and they can cause the stag-headed look of many trees. But it is thought that they cannot kill a tree, unless there is already a severe restriction to the growth of the tree and epicormics. Elliott *et al.* (1998) consider borers as secondary pests, attacking stressed, dying or damaged standing trees and freshly cut logs.

Other researchers (for example, Morgan 1984) however do suggest a primary role for some insects in the decline of trees; some species of Longicorn Beetle, such as *Phoracantha semipunctata,* have been recorded as primary factors that have caused trees to die or decline (Pook and Moore 1966, Pook 1967).

Prolonged drought stress over large areas of forest and woodland elsewhere in Australia has resulted in some notable population increases of longicorn beetles (Pook 1967, Pook and Forrester 1984). It has been observed that Tuarts in irrigated parks or suburban gardens, where there is no water stress, are more healthy and more able to repair themselves from damage by borers than trees in bushland (Hopper workshop comment, Powell pers. comm.).

Healthy eucalypts are able to withstand a certain amount of insect attack due to their natural defence mechanisms. They secrete gum which engulfs the invading insect and kills it (Phillips 1996). The presence of the gum does not necessarily mean the tree is unhealthy; rather it may mean that the tree is successfully resisting an attack. Trees that are drought-stricken or stressed in any way may have a lower moisture content and produce less gum, thus enabling borers to bore successfully into the wood.

Further factors that reduce the vigour of trees, making them more susceptible to attack by insects, include insufficient natural control of insects (predators and parasites), damage to the trees, or plantings of the trees on unsuitable sites.

Tuart trees affected by borers do not necessarily die quickly and the onset of the visible symptoms of decline may be months after the stress events. The trees may partially or completely recover, depending on the severity of the attack. However, complete stem girdling is irreversible and the girdled stems eventually die (Mitchell 1999). Sometimes epicormic shoots give the appearance of a recovering tree, but repeated attack by borers can lead to cycles of epicormic recovery and death;

this further weakens the tree and has a feedback effect, limiting the tree's abilities to rebuild reserves for future growth and to resist further insect attack (Mitchell 2001).

Sometimes birds, such as the Carnaby's Black Cockatoo, complete the partial girdling by the Tuart Borer as they excavate the bark searching for larvae. They locate the larvae by listening to their tunnelling, then chew into the branchlets with their strong beaks and eat the larvae (Powell 1990). The resulting damage to the trees is minor, and the birds are undoubtedly beneficial in helping to keep the Tuart Borer in check. However this control is most likely to be effective when the borers are in low numbers; it is unlikely that cockatoos would have a significant impact on large outbreaks of borer as occurred at Yalgorup (Mitchell pers. comm.). Other birds of Tuart communities, some of which have declined, are also important predators of insects associated with Tuart (see 'Lack of natural control of borers' and Dell *et al*. this publication).

Decline of Tuart is reported to have spread to the north and east of the initial area in Yalgorup; perhaps this is due to the spread of the effect of the primary cause of stress. Alternatively, it has been suggested the numbers of borers may have increased to a level where they can create damage without the trees even being stressed. Biology has been described as a numbers game: with some species, 90 percent of insects do not normally make it to adulthood, so if 10 percent more survive (that is, more successful breeding due to tree stress or fewer predators), this leads to many more adults being available for the next generation. When small numbers of insects attack a tree, the holes become filled with resin and the insects die. But if thousands of insects are making their holes simultaneously, the tree may not have enough resin to defend itself.

The wounds from the borer attack can allow further invasion, this time by bacteria, fungi and other insects (CALM 2000).

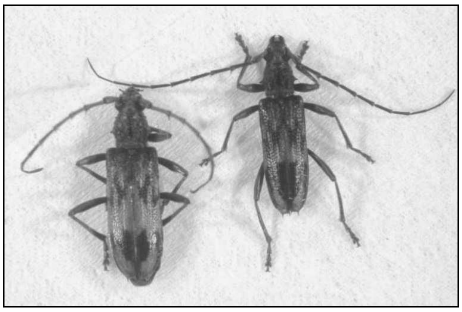
The patchiness of Tuart decline could be due to Longicorn Beetles being quite particular about the types of trees, even within a tree species, that they lay their eggs on; this has been found to be the case with psyllids (Morgan 1984, White 1993). Psyllids, in their search for suitable feeding sites, can also be influenced by the reproductive state of the tree (flowering or fruiting). Lawrence *et al.* (1999) suggest the variation of resistance of eucalypts to attack by *P. semipunctata* is associated with the moisture content of the bark; that is, in trees with moist bark, larvae fail to reach the cambium, feeding instead on tissues beneath the bark surface. Trees that are resistant to attack by wood borers are those that are most tolerant of drought.

An insect outbreak normally ends when there is destruction of the insects' resources, when natural enemies bring the insects under control, when the weather or other conditions become unfavourable to the insects, or when the weather or other conditions improve so that the trees are no longer under stress.

In summary, while the effects of the Tuart Borer is the most obvious sign of the Tuart decline, it is not considered by most scientists to be the primary cause of the decline. Rather, the Borer infestation indicates that the trees are already under some stress from other causes. Stress can reduce the leaf area and vigour of trees, decreasing their ability to resist attack by insects. The borer has been able to increase in numbers and affect the trees to the extent where an obvious physical decline and death of Tuarts has occurred. More research is obviously needed to study attack by borers on the Tuart trees of Yalgorup.

The Tuart Longicorn Beetle and its larva, the Tuart Borer
(Phoracantha impavida)

The Tuart Longicorn Beetle, Phoracantha impavida, *is a native longicorn (or longhorn) beetle, in the family Cerambycidae. It is an elongate beetle up to 3 cm long with straight sides and long swept-back antennae (hence the name 'longicorn'). The adult beetle is illustrated below.*



The adult beetles emerge and fly from about October to December. They fly actively at night and are often attracted to lights (Phillips 1996). They fly about for a week or two and mate. The females then lay eggs in cracks and wounds in the bark of small outer branches of trees, usually but not always Tuart trees. They seem to prefer the thinner bark of branches rather than the thick bark of trunks (Wills pers. comm.), although they attack the trunks of juvenile Tuarts (Powell pers. comm.). Shortly after, they die.

The eggs hatch within a few weeks. The larva of the Longicorn Beetle is a borer, the Tuart Borer, illustrated below.

Tuart Borers are creamy-white, wrinkled, with a roughly cylindrical shape, a widened thorax and brown-black head and mouthparts, and no obvious legs. They burrow their way around the limb in the cambium beneath the bark in a process known as 'girdling'. In sufficient numbers they can ringbark and cause the death of the limb. Tunnels formed by Tuart Borers are oval in shape and tightly packed with frass, a mixture of sawdust and faeces (Phillips 1996). Extensive tunnelling can cause structural weakness of the stem.

Tuart Borers burrow for about 12 months but premature death of the branch may force them to shorten their larval feeding period to less than 12 months (Wills in Mitchell 1999). They pupate in the sapwood then the adults emerge from the tree, chewing their way out and leaving oval exit holes up to 20 mm in diameter.

Powell (pers. comm.) reports that the signs of borer attack are always more visible in winter and spring; although by spring the larvae are pupating, it is then that the effects of the increased appetite of the larvae due to their increased size just before pupation become apparent. The trees have purplish leaves; some branches have died; the bark can lift slightly; and there are dark streaks of gum running down the branches. Normally after a couple of months there are epicormic shoots present and the trees start recovering.

Text: Vanda Longman *Photographs: David Mitchell.*

Lack of natural control of borers

Charlie Evans spoke of the clearing of bushland leading to a loss of insectivorous birds in the Yalgorup region.

There are several parasitoids and predators of longicorn beetles and their larvae. Parasitoids include small wasps and flies (Phillips 1996); predators include birds and mammals. A natural understorey provides habitat for the feeding, nesting and breeding of the parasitoids and predators of insects, thereby assisting in natural control. Normally, in a system in balance, the natural control (parasitoids, predators and disease) of the Tuart Borer would build up and reduce the numbers of Borers.

John Dell (workshop comment) and Fox (1981) report that the natural predators of adult Tuart Longicorn Beetles are now absent in many areas within the distribution of Tuart and in reduced numbers in other areas. The main bird predator of the adult beetle, the Grey Currawong (*Strepera versicolor*), has become locally extinct in much of Tuart's range and is in low numbers in other parts. Carnaby's Black Cockatoo (*Calyptorhynchus latirostris*), which predates the larvae, has also declined severely on the coastal plain. The status of the Ringnecked or Twenty-eight Parrot (*Platycercus zonarius*) and the Red Wattlebird (*Anthochaera carunculata*), observed by Fox and Curry (1980) feeding on insects on twigs and in bark of Tuart trees, is not known in Yalgorup.

Nocturnal mammal predators such as the Brush-tailed Phascogale are now absent from much of the Tuart forest, and nocturnal birds preying on large insects are probably similarly less abundant than before.

Reduction in the predation levels of adult longicorns naturally results in higher numbers of eggs being produced and a subsequent higher number of damaging larvae. The greatest mortality, and therefore the greatest control of borers would normally be at the egg stage (due to poor site selection for egg laying, and fungal attack) and at the larval stage (from parasitoids and fungi). With increased clearing, fragmentation of bushland (Ford 2001) and less natural understorey on the Swan Coastal Plain, any natural control is likely to be impaired, helping to contribute to the population explosion and spread of the borer.

Possibly, natural control mechanisms may eventually develop and reduce the numbers of borers, or possibly the original factor causing tree stress may be alleviated before this happens.

Fungi

At the workshop, *Armillaria* was suggested as a possible contributing factor in the decline and death of Tuart.

Fungi, as with Tuart Borers, have evolved as a natural part of the forest with each type of fungus playing a crucial role in the ecosystem (Bougher and Tommerup 2000). There have not been any comprehensive surveys of fungi in Tuart communities other than recent industry reports on fungi at Bold Park by Bougher (1999) and at Ludlow by Bougher and Tommerup (2001) and Bougher (pers. comm.) reports that many fungi are still unreported.

Nevertheless, well in excess of 100 species of saprotrophic, biotrophic, and necrotrophic fungi are known to be associated with Tuart. These fungi are members of the following nine main ecological groups.

- Canker Fungi, including *Botryosphaeria ribis*, *Endothia gyrosa*, and *Cytospora sp.* Cankers are infections of the bark or bark and cambium that can occur on all parts of a tree (Old and Davison 2000). In severe cases, infection can lead to twig and branch death, coppice death and

stem distortion. Cankers are extremely common and are usually of limited extent because fungal invasion triggers cellular and tissue responses in the phloem, cambium and wood that restrict fungal invasion. The rate at which the tree responds to invasion by Canker Fungus can be modified by environmental conditions so that stress, such as that caused by defoliation, can result in increased canker size.
- Leaf Spot Disease Fungi.
- Pocket Rot Fungi.
- White Rot Fungi, including *Piptoporus portentosus* or Punk Fungus (a white rot that can attack lignin and cellulose, leading to slow tree death), *Omphalotus nidiformis, Polyporus sp.* and *Fomes sp.*
- Brown Rot Fungi.
- Root Disease Fungi, including *Armillaria luteobubalina.*
- Endophyte Fungi.
- Mycorrhizal Fungi, including many dozens of mainly ectomycorrhizal species.
- Decomposer Fungi, again including many dozens of species.

Some of these fungi are beneficial to plants, some are pathogenic and some can be opportunistically pathogenic. Most of the fungi associated with Tuart are native species, but they are not necessarily specific to Tuart. Fortunately, Tuart is resistant to *Phytophthora*.

Wood-attacking fungi may be present, but repressed, in a tree (Bougher pers. comm.), they may be attempting to invade the tree, or they may be present on the tree as spores waiting for suitable conditions. When trees are under stress, pathogens can become active, inducing symptoms. Stress factors include drought, defoliation, frost damage, insect attack and moist humid weather in summer.

A tree has defence mechanisms to ward off attack by pathogenic fungi. These include gum veins and certain other metabolic processes; stress may reduce the flow of gum, hence making the tree more susceptible to attack. If a tree limb is broken or there is a crack in the bark, perhaps due to insect attack, the tree will seal off the break; this happens less quickly if the tree is not healthy, hence allowing more time for fungi to become established.

It has been observed that in the 1960s there was much of clearing of land in the western suburbs of Perth and many woody stumps were left lying around, resulting in a fungal epidemic and the death of many Tuarts (Bougher pers. comm.).

Fox and Curry (1980) have suggested that Tuart decline in some urban remnants may be due to infection by fungi such as *Armillaria* and *Piptoporous*, and may have been encouraged by more frequent fires weakening trees and increasing the amount of dead wood available. Tuart has indeed been reported as a host to *Armillaria luteobubalina* (Kile *et al.* 1983). However, Shearer *et al.* (1998) believe *Armillaria* is really a problem only in amenity plantings such as gardens and playing-fields where there are associated changes in moisture regime and fertility. Fox (pers. comm.) reports death of Tuart in Kings Park due to watering and subsequent infection of *Armillaria*. Also Broadbent (workshop comment) has observed the death of numerous large Tuarts at Capel Golf Course, presumably due to prolonged summer watering encouraging *Armillaria* infection. Excessive water often means higher humidity and favours the germination of fungal spores, and mycelial growth. Possibly above-average summer rainfall in recent years could have increased infection by fungi, but again this has not been investigated at Yalgorup. It is generally considered that *Armillaria* infections are more patchy, and not causing as rapid or extensive a decline as actually seen at Yalgorup (Mitchell 1999).

Shearer *et al*. (1998) also obtained estimates of the susceptibility of plant species of south-western

Australian coastal dune vegetation to being killed by *Armillaria luteobubalina*. It was found that Tuart fell into the group of species least susceptible, and therefore it could be considered comparatively resistant in undisturbed communities as it consistently survived *A. luteobubalina* in disease centres.

In conclusion, as with borers, many fungi are common, predominantly naturally occurring and not normally primary pathogens that by themselves cause trees to die. Also as with borers, there are few scientific data to determine whether rates of fungal attack have increased in Yalgorup, or indeed anywhere in the south-west (Bougher pers. comm.).

A major group of fungi, mycorrhizal fungi, are beneficial to plants in that they assist in the uptake of nutrients. Other decomposing fungi may not directly affect plants, but they are vital in the cycling of nutrients in the system. A Tuart tree's vigour can be reduced by conditions that cause decomposer fungi or mycorrhizal fungi to disappear. Both are important in keeping the soil healthy and in assisting plants to take up nutrients. Well over 1,000 species of mycorrhizal fungi may be associated with eucalypts. There is no information on historical or current levels of mycorrhizal fungi in Yalgorup and scientists are ambivalent about their suggested health status. Disturbance, removal of leaf litter, loss of vegetation, decreasing size of patches of vegetation, shifts in the balance of plant species leading to a reduction of diversity and altered fire regimes are all thought to disturb mycorrhizal fungi. Tommerup and Bougher (1999) report that there are far more decomposer fungi, and probably mycorrhizal fungi, found in older undisturbed forests than in remnant urban bushland. If for some reason the conditions at Yalgorup are becoming less suitable for mycorrhizal and decomposer fungi, the health of the trees could suffer.

Other Possible Environmental Factors

There are many other factors that may, possibly in combination with other factors, be causing Tuart decline at Yalgorup.

Chilcott (1992) concluded in his study that the main factor affecting health in the Kwinana region was industrial air pollution, a factor that would probably not be implicated at Yalgorup. Another possible, though unlikely, reason for a reduction in vigour of Tuart is decline or changes to water quality. Further, there may be an unidentified pathogen of Tuart which has not yet been isolated.

Models for the Collapse of the Tuart Population at Yalgorup

Due to the complex nature of the problem, studies of modern tree decline need to be sophisticated enough to consider interactions between multiple factors. Several models of tree decline involving multiple stresses have been proposed, including Schafer *et al.* (1988) and Wylie and Landsberg (1990).

In 1967 a model was suggested to account for the deterioration and crown loss of the large old eucalypts in Kings Park (Beard 1967); it involves factors of clearing, fire and competition for soil moisture.

Wills in Mitchell (1999) proposed the following model outlining how Tuart stress, due to rainfall drought and lowered watertable, may result in tree decline and death.

1. The leaf area thins throughout the crown of the tree. This occurs due to the following reasons.
    - Drought conditions bring forward the onset of leaf senescence, and the annual flush of new growth is reduced. Recurrent below-average rainfall leads to a reduction of leaf area in crowns.
    - Drought affects the mobility of nutrients since the availability and uptake of nutrients is

related to the moistness of soils. The alkaline soils of Yalgorup have limited nutrients such as potassium and phosphorous so leaf flush during periods of adequate soil water is constrained.

2. The stem, branch or whole tree dies.
   - In some instances, trees may directly die from water stress. A few scattered trees within stands sometimes die of this cause, usually after hot and drying conditions. Their death is rapid.
   - Stress due to drought may reduce a tree's resistance to common fungal pathogens causing stem or root cankers, which eventually girdle the stems, causing decline and death of the affected stems. Further, benign organisms (viruses, phytoplasmas, etc.) may switch to pathogenicity, triggered by the declining health of the trees.
   - Severe stress due to drought or girdling by cankers may make the trees extremely attractive to the Tuart Longicorn Beetle and the Tuart Borer, *Phoracantha impavida*. These borers are capable of girdling large stems, leading to large losses of canopy. *P. semipunctata* would be expected only in the terminal stages of decline.
   - Stress due to drought may exacerbate the effects of partial or complete girdling of branches by the Tuart Borer. The amount of sapwood may be reduced by galleries in the branches, or rot in wounded areas, thereby possibly decreasing the stream of transpiration carried to the leaves.

Several other models and theories have been proposed for population explosions of insect pests throughout the world. One, the catastrophe theory, is concerned with studying phenomena characterized by a surprising production of large changes in behaviour from small changes in circumstances. Often the models are simplified significantly so they can be represented mathematically, hence rendering them not totally realistic.

What is the current situation (March 2002) at Yalgorup?

Repeated cycles of epicormic growth followed by death of the new growth continued until early 2000. At that time the area clearly affected was from the White Hill Road in the north to just south of Preston Beach Road. Within this area there were very severely affected areas with death of 80 percent of the mature Tuart trees.

Encouragingly, the epicormic growth from the summer of 2000/01 was not attacked later that summer and continued to grow through 2001. In many areas, this one-year-old epicormic growth put on additional growth in the summer of 2001/2002 and has continued to survive through to March 2002 (Mitchell pers. comm.).

This continued survival of new growth could indicate a recovery of the affected trees, and interestingly coincides with early predictions of recovery by Department of Conservation and Land Management entomologists, based on simple models of the likely cycle of borer attack and tree recovery. However it is yet to be seen if there will be another episode of foliage death.

As previously mentioned, there have also been signs of a possible spread in the Tuart decline; purple foliage and poor new leaf development has spread significantly to the north and south of the previously affected area. It is possible the spread of the Tuart decline is a result of poor rainfall during the winters of 2000 and 2001. It is not known if the trees that have been recently affected will progressively decline to the same extent as those at Lake Clifton (which are a result of repeated decline over four or more years).

Even if the decline ceased, there are large areas in the National Park and nearby private property where the Tuart overstorey has been lost. In some areas there are a number of seedlings and young trees, but it is not known if these would be sufficient in number, or will survive long enough, to replace the lost Tuart overstorey. There are some areas of the National Park that have no regenerating Tuart, and with the death of most mature trees, no source of seed for regeneration.

Fire should be kept out of the area, as a fire now would kill these young regenerating Tuarts (their bark is too thin to protect them); any old 'sick' trees would burn very well with all the dead wood, stressing them even more.

What is CALM doing about the decline and death of Tuart?

Charlie Evans (workshop comment) was very concerned that something be done about the decline of Tuarts.

All nature reserves in the wetlands area and Yalgorup National Park are vested in (i.e. under the care, control and management of) the Conservation Commission of Western Australia (formerly the National Parks and Nature Conservation Authority). The reserves and Yalgorup National Park are managed by the Department of Conservation and Land Management (CALM) on behalf of the Conservation Commission of Western Australia. Consequently, there is an expectation for CALM to do something about the decline of the stands of Tuart trees.

CALM has been measuring the extent of the damage to the Tuart trees; monitoring the spread of the area affected; and, with assistance and advice from specialists from other agencies and organizations including the Water and Rivers Commission, Universities and the Department of Agriculture, examining the causes of the problem. This information can then help form the basis of information and advice to the Conservation Commission, Main Roads, local authorities and the public; in fact, much of the information in this report has resulted from CALM's preliminary research. In 2000, CALM commissioned a report to look at the regeneration and maintenance of Tuart in Yalgorup NP (Bradshaw 2000; see also in this paper the sections on 'Fire' and 'Interactions between different species in the Tuart dominated plant communities in the Yalgorup area'). In October 2001, CALM produced a draft brochure for landowners, outlining various options for responding to the Tuart decline and the likely success of those options (Mitchell 2001).

There are areas of Yalgorup NP, road reserves and private property that have required actions to make them safe. This includes assessing the risk and removing limbs and trees where needed. CALM has removed dead trees and limbs where they pose a threat to public safety, and the Shire of Murray, Main Roads WA and some private property owners have done similar works on the lands under their responsibility. There is a need to continue to monitor for safety for some time yet. It is also possible that some areas will need significant works to regenerate and maintain the Tuart forest, including the planting of seedlings or spreading of seed.

What should the government do, or why should we do anything?

In Western Australia's early history, the timber of Tuart was valued for its toughness and was used in applications where great strength, solidity and durability were needed. However, the Tuart mill at Ludlow closed in 1975 and Tuart is no longer used as a timber tree.

Now, although there is little commercial value in the timber, there is economic value attached to the Tuart forest through tourism. Yalgorup National Park is one of the closest national parks to Perth and its visitation is rapidly increasing. Yalgorup NP was established in the early 1970s to protect the Tuart woodland, the coastal lakes and the swamps. Tuart is the dominant tree species in Yalgorup NP and its adds greatly to the aesthetic appeal of the park. The magnificent stands of Tuart (currently much devastated) are a well-recognized feature of the much-travelled Old Coast

Road.

As well as indirect economic value, there is also high conservation, scientific, educational and social value attached to the Tuart woodland. The Yalgorup Lakes area is recognized under the Ramsar convention as a wetland of international importance. The lakes contain living stromatolites and thrombolites. Mature living and dead Tuart trees provide nest-hollows for fauna species.

The current decline of Tuart has resulted in the loss of an almost an entire layer in the Yalgorup NP communities; even if it recovers, the forest will not look the same again for a long time. It would be desirable to have an understanding of the factors that contribute to the decline so that further destruction can be avoided; otherwise the same decline may occur elsewhere, perhaps at Ludlow.

It is imperative that the government should both collate existing information on Tuart, its communities and associated fauna and fund further research into these and their relationship with the decline if we are to retain large Tuart trees as a distinctive feature of our south-west . Further urban development in the area should be approached cautiously and landowners should be encouraged to establish Tuart communities on private property.

In response to public concern at the decline and death in the Yalgorup area and loss of Tuart communities in the south-west, the formation of a 'Tuart Response Group' was announced by the Minister for Environment and Heritage, Hon. Judy Edwards MLA, on 16th November 2001. The brief media release announced that the group would have representatives from the Tuart Forest Coalition, Department of Environment, Water and Catchment Protection (formerly the Department of Environmental Protection, and the Water and Rivers Commission), Department of Conservation and Land Management, Department for Planning and Infrastructure, South-West Development Commission and the Lake Clifton Landcare Group. The group is to develop a conservation strategy for Tuart trees, woodlands and associated communities.

The Tuart Response Group shall consider:

- the extent to which the natural variation of Tuart trees, Tuart ecosystems and associated communities is (i) identified, and (ii) adequately represented and managed for conservation within protected areas and outside reserves;
- the integration of Tuart conservation management regimes across all land categories to meet environmental, economic and social objectives;
- the supporting measures necessary to minimize the impact of threatening processes on the conservation of Tuart;
- existing and future knowledge requirements for full and effective implementation of Tuart conservation management regimes;
- measures that increase the awareness and involvement of all communities in Tuart conservation;
- national protocols and cooperative mechanisms that might contribute to the achievement of Tuart conservation; and
- priorities, timeframes, legislation, other regulatory mechanisms, complementary strategies and funding requirements for the implementation of Tuart conservation programs.

In performing its function, the Tuart Response Group shall:

- develop goals for the protection and conservation of Tuart trees, Tuart ecosystems and associated communities;
- use the principles of the *precautionary approach*, *adaptive management* and the *conservation of biological diversity* to guide the development of objectives and strategies for Tuart conservation;
- establish a performance indicator framework as the starting point for assessing effectiveness in

meeting Tuart conservation objectives and the implementation of management regimes;

- consult widely with relevant local government authorities, land and resource managers, special interest groups and the community, and if appropriate with the Commonwealth Government, on Tuart conservation;
- facilitate the initiation of relevant research and data collection projects; and
- facilitate the prompt implementation of key actions identified within the Tuart Conservation Strategy.

We look forward to the outcomes and actions developed by this group.

What further research should be done?

There is already a body of published literature on various aspects of Tuart; much of this information is included and/or referenced in this publication. Ruthrof has just completed a thesis (Ruthrof 2001) in which she monitored attack by borers on Tuarts in Kings Park, Yanchep and Yalgorup. Martin Landolt, a student with Murdoch University's School of Biological Sciences and Biotechnology has also recently commenced PhD studies involving assessment of the role pests and diseases play in the decline of Tuart.

It is essential that investigations into the health and conservation of Tuart make reference to the existing information on Tuart and the communities in which it grows.

Further, geographical information is available on groundwater, salinity, rainfall, fire, and visual symptoms of the decline. Though limited, this is good primary information for developing a model or hypothesis for testing.

Nevertheless, David Coates (workshop comment), the workshop participants and others consulted for the preparation of this report generally agree that there is an obvious need for further investigations to map the extent and pattern of tree decline, to identify the primary cause(s) and mechanisms of decline and to provide recommendations for future actions. Ideally, comprehensive research would be carried out over a long time period (more than 5 years) by a multidisciplinary team, including ecologists, pathologists, entomologists, plant physiologists, hydrologists, and more. Consultation with and involvement of the public would also prove useful.

Any further research will most likely need to be conducted in disturbed communities such as urban fragments in the Perth Metropolitan Region, as well as in large unfragmented pieces of bush; Yalgorup used to be an example of a community at the healthy end of the spectrum but it may well now be regarded as quite disturbed.

A technique must be developed which shows whether Tuart is recovering. This should not necessarily be how healthy the trees look as there could be some time lag (or no trees left!), and it would be preferable to have a measure that reflects the primary agent of stress.

CALM, other agencies (including the Department of Agriculture, the Department of Environment, Water and Catchment Protection, etc.) and local government will continue to have an important role in informing and interacting with the public during the research and after it is completed. They will be instrumental in providing advice to the public about the state of the National Park, and to the owners of private land on how to manage the affected Tuart trees.

Suggestions for further research include the following, listed under headings used previously.

Physical Environmental Factors

Geology

- Determine if there is an association between Tuart decline and varying geological conditions.

Land use

- Determine if there is an association between the decline and land use.

Geography

- Determine if there is an association between the decline and geographical location.

Groundwater

- Determine if there is an association between the decline and watertable contours.
- Map the aquifers over a topographic map and watch the level of water within a year and between years; this really need decades of study.
- Monitor the effect of the removal of groundwater for horticulture.

Rainfall

- Examine historical rainfall records and determine if there is an association between the decline and rainfall.

Salinity

- Determine if salinity is increasing in the groundwater underlying the area of Tuart decline.

Nutrients

- Study the uptake of nutrients by roots in the local soils, with current conditions of drought.
- Determine if there is increasing nutrient concentrations in groundwater underlying the area of Tuart decline.
- Study the nutrient status of healthy and unhealthy trees.

Fire

- Determine the effect of fire on the nutrient cycle.
- Study the effect of fire on competition between the overstorey and understorey.
- Determine the direct effect of fire on *Phoracantha impavida* larvae.
- Determine whether fire increases or decreases Tuart's vigour, or causes stress in Tuart.
- Determine whether fire damage to Tuart tree branches encourages borers to deposit more eggs.
- Study the role of fire in regeneration of the affected areas.

Biological Environmental Factors

Tuart, the tree, and its decline

- Study the biology of Tuart.
  Investigate the growth cycle of Tuart, factors that contribute to the health or vigour of individual trees and the survival or death of epicormic growth.
- Determine the distribution and nature of Tuart decline.
  Perform detailed and systematic on-ground mapping, recording health and age of individual trees; this will enable changes in the distribution of decline, and recovery, of Tuart trees to be monitored over time.
- Determine the pattern of spread of the decline and death.
  Monitor the spread of Tuart decline, to determine if there is an advancing front of the area affected.
- Determine the stages of decline.
  Record the progression and stages of the decline on selected trees at various locations.
- Make comparisons of healthy and declining trees.

There are rating methods that are refined enough to monitor changes in the condition of crowns of individual trees without resorting to more precise measures of leaf area. There are also some sophisticated experimental methods for measuring the competence of the photosynthetic apparatus of foliage *in situ* and they might possibly be used to indicate canopy health in the absence of readily visible symptoms. The Scholander Bomb technique is a simple and direct method of measurement of water stress in leaves. Samples of leaves are collected before dawn, either being shot down or clipped with pole clippers.

- Study resistance to the decline.
  Look for resistance to borers or drought in individual trees and find the means by which these trees resist attack or cope with lower water levels.
- Identify treatment.
  Identify the best methods of treating individual trees that are in decline. Identify any possible remedial action, regeneration or ongoing maintenance to alleviate the decline in the National Park.

<u>Tuart dominated plant communities</u>

- Determine the distribution and abundance of Tuart in the different community types (both structural and floristic) in which it occurs.
- Study ranges in composition and species diversity of the different community types.
- Determine fauna of the various community types, historical and present.
- Recognize and understand a complete healthy Tuart community from an incomplete, poor one.
- Determine if an association exists between the decline and the community type and community condition .
- Study the role Peppermints play as an understorey species.

<u>Borers</u>

- Perform a literature review of *Phoracantha impavida*.
- Examine the research on *P. semipunctata* (see Ruthrof 2001 for a list of papers on this borer) as it may be useful as a model for the biology of Tuart Borer; it is important to note that *P. semipunctata* is an extreme stress opportunist while *P. impavida* can appear on unstressed trees.
- Measure borer populations.
- Determine factors that limit the distribution, abundance and feeding characteristics of wood borers.
- Determine details of the life cycle of the borers.
- Further study to determine if the rate of borer attack on saplings following fires is higher in disturbed communities than in larger areas of natural bush.

<u>Other insects</u>

- Sample extensively wood and canopy invertebrates over time, to identify which, if any, other invertebrates contribute to the decline.
- Look for invertebrate groups that are in significantly higher numbers on declining trees than healthy ones.
- Regularly monitor invertebrates; this helps to detect population growth before the pest species devastate host plants over large areas.

<u>Natural control of insects</u>

- Identify the natural predators and parasites of the Tuart Borer.
- Study the role of insect parasitoids and fungal pathogens of the Tuart Borer, determine if these parasitoids and pathogens have declined, and describe the consequences of these declines.
- Determine the role birds and other predators play in controlling insects that may be affecting the health of Tuarts.
- Study the decline or loss of insectivorous bird species from the Yalgorup area in particular.

- Identify the best methods of encouraging larger populations of these predators and parasites.

Fungi
- Determine the fungi associated with Tuart.
- Determine the methods of entry into the tree by the fungi.
- Study the effects of fungi on Tuart.
- Determine if the fungi can decompose cellulose or lignin, or both.
- Determine how the fungi interact with other organisms.
- Monitor fungi, such as *Armillaria* and *Piptoporus*, to observe any changes in abundance.
- Study the role of mycorrhizal fungi.

Other possible causes
Identify any other possible causes of Tuart decline.

Has the decline or death of Tuart *en masse* been seen before?

It is almost certain that borer explosions have happened naturally in the past. However, Wills (pers. comm.) agrees that the current outbreak at Yalgorup is the worst seen since European settlement.

There are several accounts of the decline of Tuarts over the last eighty years, as well as accounts of its recovery. As early as 1921 comment was passed on the deterioration in condition of the Tuart forest (Forests Department 1979). Widespread defoliation caused by insect damage occurred in the Ludlow Tuart forest in the late 1960s. In April 1967 Steve Curry (Mitchell 1999) reported that Tuarts aged five to forty years old were attacked by Tuart Borers, resulting in stagheads and the apparent death of trees. Another stand of planted 13-year-old trees was also severely attacked by Borers, but by 1978 observations appear to indicate that most of the attacked trees had recovered.

In parts of the Perth metropolitan region, decline of eucalypts was reported from the 1920s onwards (Beard 1967). In 1939 high losses of planted Tuart were attributed to borer attack (Fox and Curry 1980).

Keighery (workshop comment) and Powell (pers. comm.) both report that the Tuarts in Bold Park about 25 years ago declined in health. Fox (pers. comm.) recalls the decline of Tuart in Bold Park coincided with the clearing and opening up of surrounding areas for residential purposes. Bougher (pers. comm.) reports a similar increase in Tuart deaths due to fungi around this time in the western suburbs, and attributed it to the clearing of vegetation and the increasing number of woody stumps being left behind. Fires also started becoming more frequent at that time. It was feared that the Tuart trees in Bold Park were going to die out completely but many have recovered, some quite dramatically (Powell pers. comm.). However, the population size of Tuarts in the park is smaller than originally (Fox pers. comm.). As well as the Bold Park recovery, there has been a general recovery in many of Perth's older suburbs, such as Bicton, Nedlands, Floreat Park and Wembley Downs, where many of the Tuarts are much healthier now than they were in the 1960s (Powell pers. comm.).

Why does Tuart in other areas, such as at Woodman Point, not have the problem of decline or death?

Carr (Workshop comment) said he had observed only a very small amount of insect attack, in isolated spots, at Woodman Point. Although he had seen part of one branch or possibly one branch of a couple of Tuart trees dying off, he was confident there were no stag formations. He suggested that this could possibly be explained by Woodman Point having a large number of Tuart trees in a relatively small area and a fairly original, intact understorey. Perhaps some of the other stresses affecting Tuart elsewhere are not present at Woodman Point.

A similar view was earlier expressed by Powell and Emberson (1981) who remarked at the time of writing their book on Woodman Point that in the Perth metropolitan area many natural Tuarts of Perth's Quindalup belt, near the coast, were dead, and most of the remainder were dying. They wrote that the Tuart trees at Woodman Point, in contrast, were remarkably healthy with no outstanding signs of borer attack. Powell and Emberson suggested that the health of trees at Woodman Point could be attributed to the comparatively pre-European condition of the vegetation there. Whereas Tuart in the rest of its range had had to cope with fire, disturbance and other effects of European settlement, Tuart at Woodman Point had been left alone to cope only with the difficult, marginal natural environment. Without any outside stresses, Tuart had coped remarkably well and continues to do so.

However since the 1980s, many of the Tuarts in Perth's Quindalup belt have recovered well, and so the contrast between the Tuart trees at Woodman Point and in the rest of the Quindalup belt in Perth is now less marked (Powell pers. comm.).

Such comparisons as this are not particularly useful in gaining an understanding of the death and decline at Yalgorup. Woodman Point and Yalgorup are separated by almost 100 kilometres, the Tuarts are on different landform systems (Woodman Point on the Quindalup Dunes and Yalgorup on the Spearwood Dunes), and the communities in which the Tuart grows are quite different. In addition, the vegetation at Yalgorup, before the Tuart decline, was even less disturbed than the vegetation at Woodman Point (see Keighery *et al.* this publication).

What will happen in the long-term?

At best, the decline of Tuarts at Yalgorup may be found to be a natural (if extreme) and to some extent cyclical phenomenon with a high visual impact (Mitchell pers. comm.). At worst, the decline could be the precursor to (or indicator of) a more widespread and serious decline not only in Tuart, but also in other tree species and vegetation.

If the primary stress ceases, the decline and insect outbreak should be expected to subside when the balance of nature is re-established. If the cause of the stress is removed, the recovery of the surviving trees will not be immediate, because the trees have lost vigour and will need to recover their leaf area. Conditions would need to remain favourable to sustain recovery. In many cases the architecture of the crown is affected and badly affected trees may have stag tops for years. Trees with stag tops can nonetheless be vigorous and healthy if they redevelop a good mass of foliage. The stags often provide good perches and nest-hollows for birds.

If the decline ceases, the greatest effects in the long term will be to Tuart parklands on pastures (that is, privately owned property) where recruitment of seedlings may be minimal due to grazing and competition with weeds, or due to loss of the overstorey and hence the seed source. Most of these remaining, often lone trees in rural parklands are very mature and are doomed in the long term in any case, for trees have a finite life span. One interpretation of the observed decline on pastures is acceleration of the natural senescence of these trees.

Provision for recruitment of seedlings should be made by landholders and communities if they wish to retain large Tuart as a distinctive feature of the coast road rural landscape. Similarly some areas of bushland in Yalgorup National Park and on private property that have lost their Tuart overstorey (and therefore their seed source) have also lost the ability to naturally regenerate Tuart trees. These areas may also require active regeneration to return the Tuart overstorey (see section 'How do you maintain Tuart trees and maintain and restore the Tuart community on small properties?').

Time will tell whether the epicormic growth of 2000 and 2001 will continue to survive, or whether there will be another cycle of defoliation and epicormic growth. Further, other stands of Tuart will need to be monitored to determine if the decline spreads.

WHAT CAN LANDOWNERS DO ABOUT THE DEATH OR DECLINE OF TUART ON THEIR OWN PROPERTIES?

Private landowners experiencing death or decline of Tuarts on their properties are eager to learn what they can do to improve the health of their remaining trees. In October 2001, the Department of Conservation and Land Management produced a draft brochure for landowners, outlining various options for responding to the Tuart decline and the likely success of those options (Mitchell 2001). Obviously, it would be beneficial to have a more thorough understanding of the causes of the decline than we currently have, and that should be of the highest priority.

Landowners of course can do little to change the hydrogeology underlying their property, or to relieve drought or protect against frost. Depending on the type and size of the property, it may be possible, however, to make changes such as altering the input of nutrients and water or improving hygiene practices to prevent the spread of pathogens.

A review of some of the methods of responding to Tuart decline follow.

Chemical Control

Judy (workshop comment) asked about injection of chemicals to kill wood-boring insects; subsequently many workshop participants related anecdotes about their successes, and failures, with the use of insecticides.

One conference participant reported success in Attadale where he treated individual trees affected by borers. He drilled a series of holes in the trunk 2 metres above the ground and injected an undisclosed insecticide into the holes. The holes were then plugged with corks. He reported that the treatment was effective and the trees recovered. Another participant suggested soaking dowels in systemic insecticides and then hammering them into holes in the tree.

There are however many reasons scientists advise against attempting to control borers by using chemicals. Especially in national parks and on large private properties, the size and number of unhealthy trees would make chemical control too costly. In addition, it is obvious from the preceding discussion that using chemicals to control borers may only be treating a symptom and not the primary cause of decline. Further, chemicals are environmentally unfriendly and many other invertebrate and vertebrate species living on Tuart could be affected by any chemical treatment. Finally, the Department of Agriculture, in its pamphlet on control of insect pests of trees (Western Australian Department of Agriculture Farmnote No. 116/84), doubts whether systemic insecticides even work with Tuart Borer.

Phillips (1996) reports there are no satisfactory chemical means of controlling Tuart Borer. The main problem seems to be that injected insecticides cannot make their way to where the borers feed. Ralph (pers. comm.) said the only insecticide registered in Western Australia for trunk injection (Rogor) would not work as the insecticide goes to the leaves rather than lingering in the wood; also Rogor would not be potent enough to kill the borers. Malathion, which would be strong enough to kill the larvae, is not systemic: that is, it stays where it is injected. Further, Malathion is not registered for injection. Methylated spirits is similarly not registered for injection. It has been suggested methylated spirits could be poured into the borer hole (workshop comment), but, with all the wiggles of the tunnels, it is unlikely to actually get to any borers, if any were actually present at the time.

Overseas trials of methods to control *Phoracantha semipunctata* show treatment with systemic insecticidal treatment to be ineffective and impractical. The work of Curry (Mitchell 1999) would seem to indicate this for *P. impavida* as well; in the late 1960s Curry experimented with injecting systemic insecticides and applying sprays (including DDT, Dieldrin, Chlordane and Dimethoate), but without marked success and with the resultant death of some of the trees.

Nevertheless, perhaps further experimentation with chemicals will result in a new successful treatment for attack by borers; private landowners have expressed a willingness to help out in trials. Note that it may be necessary to apply insecticide repeatedly, because a tree that is ‘healthy’ is likely to become a target for egg-laying as suitable wood becomes depleted on other, untreated, trees in the area. Monitoring of the trees for the establishment of borers would be essential. Since the borers are adult beetles or in pupae or eggs for part of the year (spring and summer), and so certainly not likely to be affected by a systemic insecticide during this time, the chemical would have to be applied when the young larvae hatch and are active (autumn to winter).

Phillips (1996) reports the possibility of reducing longicorn beetle populations by using trap trees, a technique used elsewhere in the world with other species of beetle. Trap trees are healthy, uninfested trees felled prior to the beetle’s flight period and left to absorb attacking insects; the trap trees are then removed and burnt before the adult beetles emerge. Alternatively, sometimes trap trees are treated with a systemic insecticide prior to felling, and arriving beetles are killed as they construct egg galleries. Wills (pers. comm.) suggests the use of trap trees works with *Phoracantha semipunctata* but does not work so well with *P. impavida*.

Removal of branches

The Department of Agriculture raises the option of removing affected branches and trees and burning them, then increasing the vigour of the remaining trees by watering and fertilizing (Western Australian Department of Agriculture Farmnote No. 116/84). Certainly, removing the affected branches of a couple of special trees attacked by borer in Kings Park, including the Friends’ tree that was planted by the Premier in 1993, appeared to work according to Steve Hopper (workshop comment).

Removing branches does remove some of the breeding animals; however, there is a concern that the borers will also be elsewhere in the trees, not just in those branches obviously affected. Also, surely removing branches is simply doing what the borers do, that is further removing leaf area. As Charlie Broadbent and Martin mentioned (workshop comments), any limbs growing back after pruning will have arisen from epicormic shoots, and are not normally as strong as natural limbs and could well break during a winter storm. It is generally thought that pruning of branches should be only for reducing the risk of branches falling (Mitchell 1999).

Application of fertilizer and extra water

Applying fertilizer to affected trees after the removal of the stress factors may stimulate a recovery but other factors, such as lack of soil moisture, may reduce the effectiveness of this approach (Mitchell 1999). Nevertheless, there is anecdotal evidence that fertilizing and watering of affected Tuart trees has improved their health. Perhaps only experimentation can determine if these strategies will work in a given situation. Care must be taken with fertilizers since too much fertilizer can affect the quality of groundwater and wetlands. Also fertilizing has been known to increase the nutrient levels of the trees, making them more attractive to insect pests.

Use of fire

When investigating the effect of fire at Yanchep in 1971, Curry reported that surface charring or blackening of bark killed borers under the bark of Tuart trees, and complete charring of bark killed larvae in pupal chambers in the sapwood (Mitchell 1999). Fire is, however, an impractical method of controlling borers as the borer, under the bark of the tree and normally high in the branches, is unlikely to be affected by any but the most intense fire, which would severely affect the health of the tree itself (Mitchell 2001).

Implementation of good hygiene practices

There are not really any practical techniques for curing fungal diseases, but the spread of fungi can be prevented by implementing good hygiene practices (David Coates workshop comment). These include minimizing movement or disturbance of the soil; making as few tracks in the bush as possible; only bringing in material such as woodchips, gravel, limestone or foreign plant stock from reputable sources; removing woody stumps and roots of lopped and fallen trees for these encourage pathogenic fungi such as *Armillaria*; washing down vehicles if there is evidence of fungal disease in the area; carefully isolating infected soil or branches; and not overwatering during the summer months as warm wet conditions are optimal for the growth of fungi (Charlie Broadbent workshop comment).

HOW DO YOU MAINTAIN TUART TREES AND MAINTAIN AND RESTORE THE TUART COMMUNITY ON SMALL PROPERTIES (5-10 ACRES)?

Participants at the workshop requested information on maintaining Tuart and the associated plant communities on the Swan Coastal Plain on their own properties. As a consequence, this response has been broadened to respond to restoration and revegetation issues across the range of Tuart, in respect to both the trees and the community with which they are associated.

There is a considerable amount of information now available on restoration and revegetation. This section will address Tuart issues directly and also list some suitable literature, training opportunities and contacts that should be useful for restoration and revegetation of Tuart and its communities.

Individual Tuart Trees

If large Tuarts are to be retained as a distinctive feature of the Swan Coastal Plain landscape, landholders and land managers within the natural distribution of Tuart (see Keighery *et al.* Map 1 this publication) need to make provision for the recruitment of seedlings.

In rural areas where there are individual mature trees, natural regeneration of Tuart can be encouraged by creating a seed bed around the trees; this can be achieved by controlling weeds and limiting cultivation. It may be necessary to fence these areas to prevent grazing and/or general access. When seed trees are not available, direct seeding and planting of seedlings are alternatives. The selection of seed should be guided by Coates *et al.* (this publication).

Tuart Communities

Restoring entire Tuart communities rather than just a few trees is more complex. The Wildflower

Society of Western Australia (Inc.) generally favours bushland management that focuses on augmenting natural regeneration through limiting disturbance, that is, restoration. This approach is favoured as it is appreciated that the complexity of most plant communities on the Swan Coastal Plain is great and there is no possibility that they can be re-created once destroyed. At best, revegetation work can only establish elements of these communities. However it is appreciated that revegetation by planting of seeds or seedlings may be required in some areas. Various approaches and techniques were presented at the workshop (Colin Yates, Greg Keighery and others), all of these related to the 'intactness' (generally expressed by the abundance of weeds) of the Tuart community. Central to each of these was the control of weeds. As a consequence, bushland management in Tuart communities is addressed under the following three sections.

Weed Control

Tuart communities are typically weed invaded (see Keighery *et al.* this publication). Controlling weeds can be done by removing them physically, by applying herbicides or by using controlled grazing and fire. If the block is not badly infested with weeds, removing weeds by hand, before they set seed, works quite well. Applying herbicides over an extensive area can be prohibitively expensive. If fire is used to remove weeds, this must be followed up by the intensive removal of regenerating weeds. If this method is used, it is important to become familiar with, and to adhere to, local fire regulations.

Restoration Activities - Intact Tuart Communities

The first goals would be to remove weeds and rely on natural regeneration to restore the native understorey. The success of this method depends on the amount of native seed in the soil's seed bank. If the area is intact, there will be sufficient individual plants and soil-stored seed to allow for natural regeneration. If there is little seed, all that will happen is that one weed will be replaced by another, rather than a native species.

Revegetation Activities - Non-intact Tuart Communities

After removing the weeds, the seed bank is supplemented by direct seeding or planting seedlings. As the revegetation work is aimed at restabilizing elements of the local Tuart dominated plant community, all revegetation should be done using local plant material (that is, seed and other propagating material). The use of the term 'local' is dependant on the local conditions, the nature of the local plant communities and the patterns of variation in the particular plant (species, subspecies, variety or form) being considered for use.

<u>Local Conditions</u>
Each locality has specific attributes related to position in the landscape, soils and water availability (rainfall, groundwater, etc.). These need to be addressed when selecting species complements for revegetation.

<u>Local Plant Communities</u>
Tuart occurs in a variety of plant communities across its range from Jurien to the Sabina River. These proceedings can be used to gain specific information on the plants in the communities in which Tuart occurs across this range. Several types of information are available, these being:

- Specific 10 m^2 plot lists – Figure 2 in Gibson *et al*. lists the majority of the species in the 64 plots sampled for this study; species found in a single plot are not listed.
- Flora Lists – Appendix 1 in Keighery lists plants associated with Tuart in a series of bushland areas, these being (from north to south): 'Tuart Reserve' (Reserves 39400/41008, east of Cervantes), Yanchep National Park, Trigg Bushland and Adjacent Coastal Reserve, Woodman

Point, Lake Cooloongup and Lake Walyungup Bushland, Mealup Point Nature Reserve, Yalgorup National Park, Crampton Nature Reserve, Leschenault Peninsular Conservation Park, The Maidens and the Tuart Forest (boundaries after Keighery and Keighery this publication). Flora lists are available for other bushland blocks containing Tuart (for example, see references in Bush Forever Site descriptions in Gov of WA 2000).

Keighery *et al*. (this publication) also list and map the bushland areas from which Tuart is known. Using these sources, information can be gained on the specific plants in local communities.

Local Plant Material

Some guiding principles in determining what can be considered 'local plant material' for revegetation work, for the conservation of biodiversity, follow.

- In all cases, the precautionary principle should be followed. That is:
  - when the source of propagating material is not known, it should NOT be used;
  - if local material is not available and there is insufficient information available to determine if the material from more widespread sources is of the same form, it should NOT be used; and
  - if there is insufficient information on the patterns of variation in a species then material should only be used from the study area.
- ONLY plant species recorded for the study area should be considered for use in revegetation unless revegetation is focusing on a community that has been totally destroyed in the study area. In the later case a 'reference' community (determined as described below) in the local area should be used as the guide for selection of appropriate species.
- NO plant material from outside WA should ever be used.
- Focus revegetation on that complement of species which best 'mimics' the natural community and will grow from locally collected material.
- If the pattern of genetic variation is known for a species then material can be collected for use from within the range of the genetic variant identified in the local area. Coates *et al.* (this publication) illustrate and discuss variation within Tuart on the Swan Coastal Plain.
- When there is known to be a high percentage of local forms of a species, or the pattern of variation in the species is not well known, collection should be confined to within 15 kilometres of the revegetation area and from the same position in the landscape (that is, the same ecological niche). To do this, plant material for revegetation should also be selected on a site by site basis. That is, material should be selected to match the topographic position, soils, drainage and natural plant communities of the area where they are to be planted. The plots described in Gibson *et al.* (this publication) and Keighery (this publication) are useful guides to suitable material.

Other Sources of Information

There is a large amount of literature and a series of training programs that are useful for learning about weeding, bushland restoration, revegetation, local plants, etc. CALM has a document on options for responding to Tuart decline on private property (Mitchell 2001); it includes sections on regeneration and is specific to Tuart. Further useful resources are outlined below.

Support/Training Groups

Ecoplan - Department of Conservation and Land Management

Telephone	08 9474 7040
Fax	08 9368 4299
Email	margoo@calm.wa.gov.au
Postal Address	PO Box 1167, Bentley Delivery Centre WA 6983

Apace Aid Incorporated

Telephone	08 9336 1262
Fax	08 9430 5729
Email	apace@argo.net.au
Address	Winter House, 1 Johannah Street North Fremantle WA 6159

Wildflower Society of Western Australia (Inc.)

Telephone	08 9383 7979
Fax	08 9383 9929
Email	wildflowers@ozemail.com.au
Postal Address	PO Box 64 Nedlands WA 6909
Address	Perry House, corner Perry Lakes Drive and Oceanic Drive Floreat WA 6014

Other contacts include: Local Government Environment Officers, Bushland Friends groups, Greening Australia (Inc.), Australian Association of Bush Regenerators (Inc.), Swan Catchment Centre and Bushcare and Landcare Officers.

Books/Packages

All but the first of the publications listed below are available from the Wildflower Society of Western Australia (Inc.). *Managing Perth's Bushlands* is currently out of print but is available from most libraries.

Managing Perth's Bushlands edited by Scheltema and Harris (1995)
A series of authors describe the soils and plant communities of the Perth region and the various aspects of bushland regeneration. The section on the weeds of the region, weed control techniques and weed characteristics and control is particularly useful.

Bush Regeneration - Recovering Australian Landscapes by Buchanan (1989)
A comprehensive text prepared for the Bush Regeneration course run at TAFE in NSW. This course was the model for other such courses around Australia.

Bringing Back The Bush by Bradley (1988)
The Bradley sisters pioneered bush regeneration through minimum disturbance in Australia through their work in bushland in Sydney. An interesting and practical guide to their work.

Growing Locals by Powell and Emberson (1996)
The techniques of establishing local plants are well explained in Powell and Emberson (1996). This book, along with other interesting information:

- lists local species suitable for planting, based on soil types on the Swan Coastal Plain;
- explains how some seeds can be treated with smoke or hot water to break their dormancy; and
- gives techniques for revegetation on a small scale (urban gardens and parks).

Gum Tree Pack by Keighery and Pieroni (1989)
Activities for knowing and growing eucalypts from seed with children.

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FIGURES

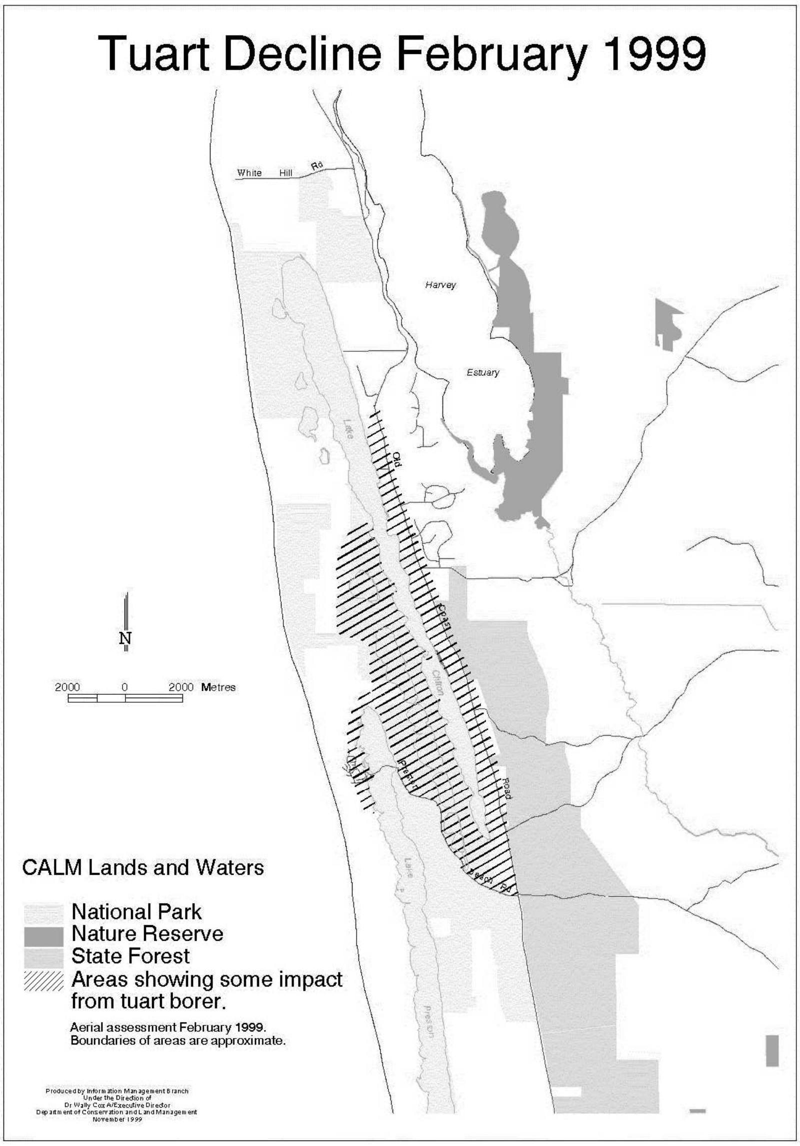

Figure 1. Map showing the extent of the area affected by Tuart decline as at February 1999. Map: David Mitchell.

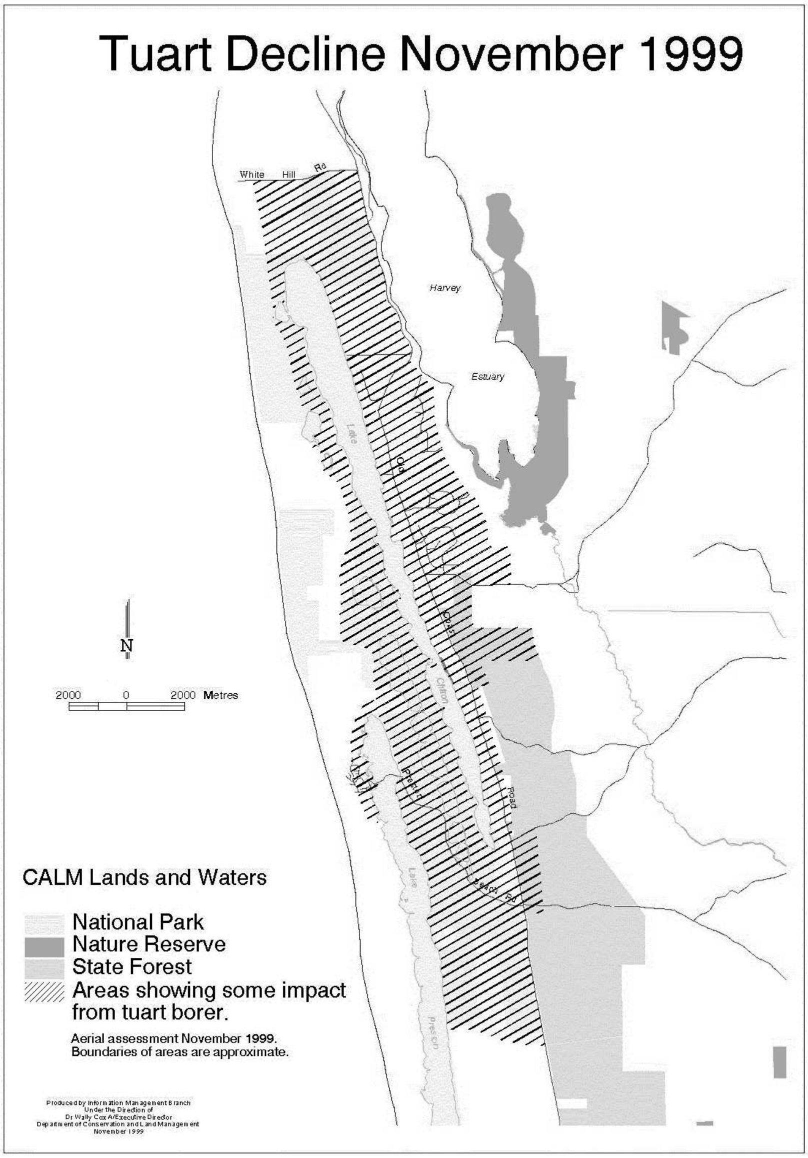

Figure 2. Map showing the extent of the area affected by Tuart decline as at November 1999. Map: David Mitchell.

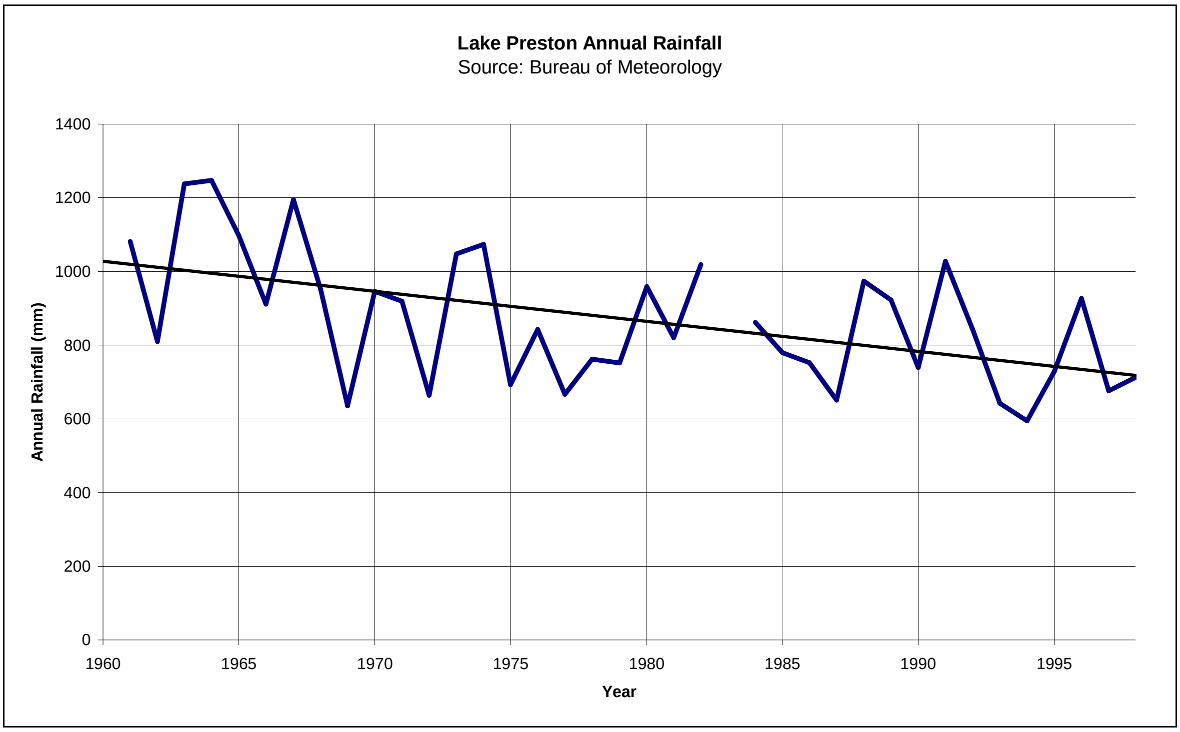

Figure 3. Rainfall data for Lake Preston Lodge (latitude 32°59'43"S longitude 115°43'34"E) from Bureau of Meteorology, Perth (pers. comm.).