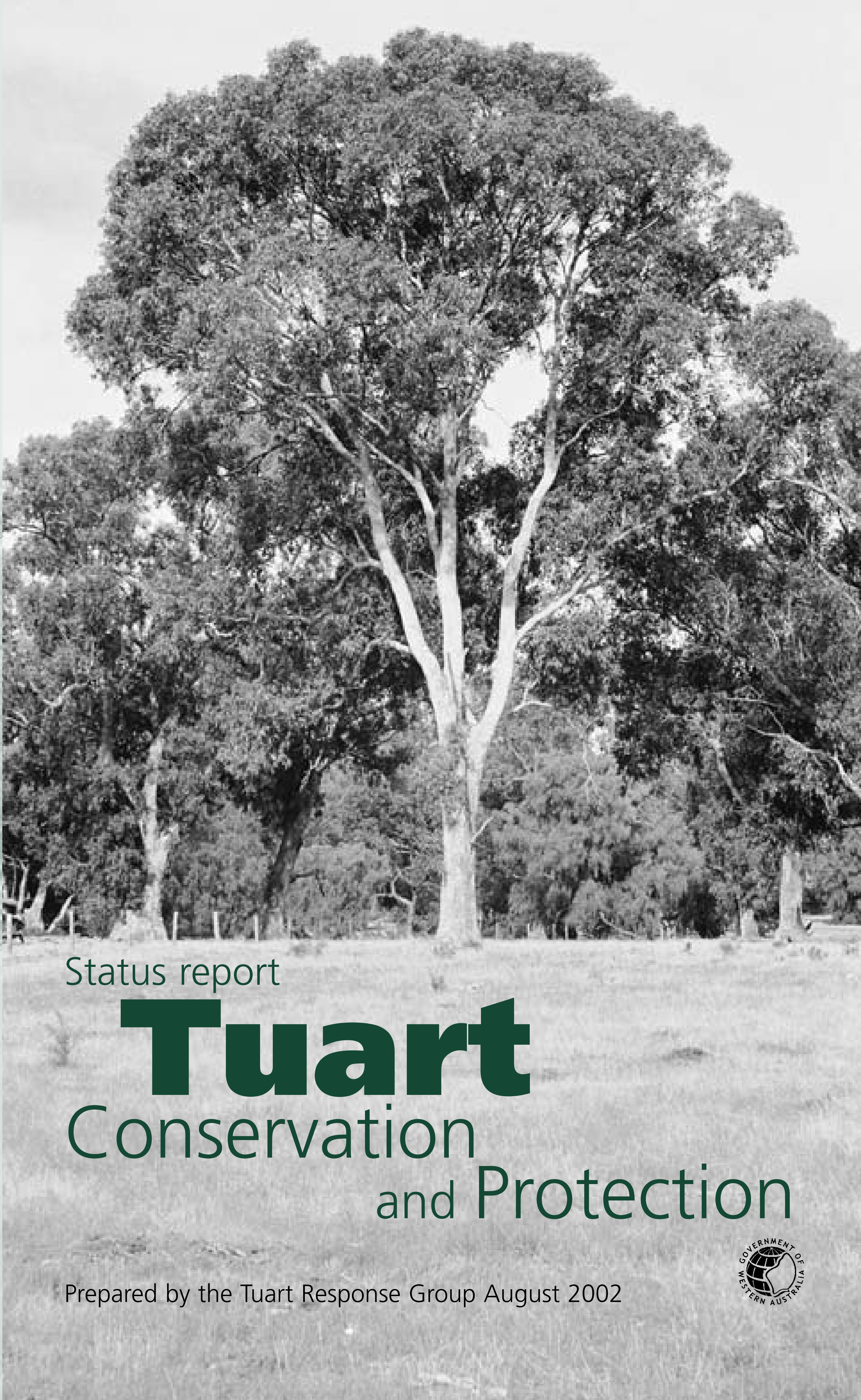

Status report

Tuart Conservation and Protection

Prepared by the Tuart Response Group August 2002

GOVERNMENT OF WESTERN AUSTRALIA

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ACKNOWLEDGEMENTS

The Status Report on the Conservation and Protection of Tuart recognises the assistance of the Department of Conservation and Land Management's:

- Science Division for contributions on vegetation health modelling and tuart decline research directions;
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Information on the hydrogeology of the Swan Coastal Plain was provided by the Department of Environmental Protection; Water and Rivers Commission.

The cover photograph was taken by and is provided courtesy, of Robert Powell.

SUMMARY

Tuart is endemic to the Swan Coastal Plain, growing near the coast in a 400-kilometre band from Jurien Bay on the Plain's north to the Sabina River, east of Busselton.

Tuart is mostly confined to two coastal aeolian dune belts, the Quindalup Dunes and the Spearwood Dunes, although there is a series of outlying populations near the Murray, Serpentine, Swan and Canning Rivers.

Tuart woodlands and their communities are managed on public lands by the Department of Conservation and Land Management using area management plans in national parks, conservation parks, regional parks and nature reserves. They are also managed by prescription in State forest and timber reserves according to the Forest Management Plan.

The most prominent tall woodland tuarts grow in the Tuart Forest National Park at Ludlow, while medium woodland tuarts grow at Yalgorup National Park. Other significant reserves are at Bold Park and Kings Park. Half the existing tuart estate is on freehold lands, some of them being included in *LandCare* and *Land for Wildlife* programs.

As a species, tuart appears to be well represented in parks and reserves but its conservation adequacy is less clear when considered relative to (i) its presently described six structual ecosystems and (ii) the composition of the flora associated with tuart. These are only partly understood and require further data collection, classification and mapping.

In recent years reductions in the health and vitality of some tuart woodlands has highlighted the need for a comprehensive conservation strategy for all tuart ecosystems. Climate variability and change, hydrology, altered fire regimes and repeated attack by insect wood borers are important threatening processes.

In November 2001 the Minister for the Environment and Heritage announced the formation of a Tuart Response Group. It has representatives from community groups (the Tuart Coalition and the Lake Clifton Landcare Group), the Departments of Conservation and Land Management, Environmental Protection; Water and Rivers Commission, Planning and Infrastructure and Agriculture, and the South West and Peel Development Commissions.

The main work of the Response Group is to use its resources and knowledge to:

- investigate the hierarchy of causes of the observed decline in tuart health;
- devise a Tuart Conservation and Protection Strategy; and
- compile educational material for landowners and the community to combat the decline of tuart trees.

EARLY DESCRIPTIONS OF TUART ECOSYSTEMS

Botanical surveys of tuart woodlands were undertaken soon after European settlement of Western Australia's south west. Bradshaw (2000) summarised the general descriptions of some early explorers as follows.

- 1831 "*The country passed over this morning was beautiful, reassembling a fine Park in England, with excellent timber, five or six to the acre.*" Lieutenant William Preston in the Vasse estuary area.
- In 1831 John Bussell wrote: "*A farmer could hardly grudge the fine spreading trees of red and white gum and peppermint the small portion of the ground they occupied, with an understory typically of bright scarlet and yellow flower, daisy, buttercup and a purple marigold.*"
- 1836 "*Open country with a good deal of grass*[1] *growing on a light soil under very large white gums called…'tooarts.'*" Lieutenant H.W. Bunbury in the Lake Preston Capel River area.
- 1896 Limestone country with "*tuarts dotted in a parklike fashion, and occasional brakes of peppermint (Agonis flexuosa)…..and a rich carpet of annual grasses.*" Pioneer xxx Ednie-Brown in the Ludlow area.

Keighery and Keighery (2002) consider that Bussell's records of tuarts are more historically accurate because they provide the only approximate description of tuart woodlands before grazing by stock. This enables more informed inferences about the species and tuart communities being described.

Historical and anecdotal evidence suggests that Aboriginal burning maintained the tuart woodlands in open savannah conditions (Bradshaw 2000). Burning was probably undertaken at any time of the year when it was possible, and this is likely to have occurred mainly in summer. An assessment of fire scars on balgas (grass trees) in the Yalgorup National Park show that before 1900 fire intervals of between two and four years were common.

[1] Includes sedges, grasses and herbs.

TUART AND THE PLANT COMMUNITIES IN WHICH IT GROWS

Flora

Tuart is endemic to the Swan Coastal Plain, growing near the coast in a 400-kilometre band from Jurien Bay on the northern margin of the Plain to the Sabina River, east of Busselton. Tuart is generally confined to the two coastal aeolian dune belts, the Quindalup Dunes and the Spearwood Dunes[2] with a series of outlying populations from the Murray, Serpentine, Swan and Canning Rivers. The outlying population on the Swan was named as a separate variety but now appears to be extinct. Tuart is relatively uncommon on the Quindalup Dunes but common on the deeper soils of the Spearwood Dunes.

The distribution of tuart and the vegetation in which it grows have been considered in a series of studies. They have been described structurally, as vegetation complexes, and as floristic community types. The first of these (maps 1 and 2) are the broad tuart-dominated structural units mapped by Speck (1952, 1958), Beard (1979a, b, c, 1981) and Smith (1973, 1974).

The second study of tuart distribution by Heddle *et al* (1980) formed part of the review of conservation reserves within the Darling System, known to as the System 6 Area (Department of Conservation and Environment 1983). Plots were established to define the underlying values of geology, landform, soils, vegetation and land use. The project involved defining and mapping a series of vegetation complexes, based on other mapping and ecological data for the region. As part of this project, the extent of tuart woodlands on the Swan Coastal Plain (Appendix 1) was defined.

The work by Heddle *et al* (1980) was published as a series of maps and associated text by the Department of Conservation and Environment in 1980. The mapping included defining the original extent (pre-1750) of the vegetation on the Swan Coastal Plain from Busselton to Moore River, through extrapolation to values that still persist in remnant vegetation. The mapping also accounted for the underlying determinants of the vegetation such as landform, soils and climate.

The third study of tuart distribution is based on information derived from plots on tuart's regional floristic groupings. Floristic community types in which tuart is found (Appendix 2), were described by Gibson *et al* (1994) and the Department of Environmental Protection (1996). The plots in these studies have also been used to assess the location of the natural populations of tuart communities (Keighery *et al* 2002). Floristic studies of upland and wetland communities of the Ludlow Tuart Forest National Park and adjacent State forests in the Shires of Busselton and Capel are reported by Keighery and Keighery (2002). As expected, tuart occurs in a variety of floristic community types across its range including both fresh and saline wetlands and upland limestone ridge types. Its wide environmental tolerance is confirmed by soil chemical analysis with pHs ranging from 5.5 to 8.7 (Gibson *et al* 2002). Only in the southern tuart and peppermint woodlands of the Spearwood dunes, and the tuart and/or peppermint woodlands of the Quindalup dunes is tuart a defining species. Modelling of the occurrence of tuart in plant communities on the Swan Coastal Plain demonstrates high reliance on soil type and rainfall (Gibson *et al* 2002).

Fauna

Vertebrate fauna

The vertebrate fauna of tuart woodlands is poorly understood. Dell *et al* (2002) reported on the data from 12 tuart woodlands sites and assessed the impacts on the species and populations since European settlement. Key findings include:

- 158 species of vertebrates;
- 92 bird species. The role of avifauna in regulating the natural ecological balance of tuart woodlands has not been studied;
- 16 of the 35 Swan Coastal Plain's mammal species live in tuart woodlands, with the western ringtail possum and the common brushtail possum well represented in the tall tuart-peppermint woodlands of the Ludlow area;

[2] All references to the Spearwood Dunes include the Yoongarillup System and other associated soil taxonomy (eg. Wonnerup, Karrakatta and Cottesloe associations).

- a need for more understanding on the distribution and significance of tree hollows as daytime refuges and breeding sites for mammals and birds; and
- 43 species of reptiles and seven species of frogs. This equates to more than 50 per cent of occurrences previously recorded on the Swan Coastal Plain for reptiles and less than 50 per cent for frogs.

Invertebrate fauna

Invertebrates are the most diverse component of terrestrial ecosystems. They are also vital to the ecology, being the chief food of many birds, reptiles, amphibians and mammals. They also perform other essential functions such as recycling nutrients, pollinating plants, and keeping nature in balance by supporting many important predators and their parasites. The invertebrate animals, although studied for eucalypts such as jarrah (*E. marginata*), marri (*E. calophylla*), wandoo (*E. wandoo*) and powder bark wandoo (*E. accedens*), are poorly known for tuart (Powell *pers comm* 2002).

Tuart in the landscape

Powell and Emberson (1997) described the landscape importance of local tree species to include scenic beauty, linkages with history, value for wildflife, individuality of character and low management costs. Tuart has special significance as a local species when growing in its area of natural occurrence (Powell and Keighery 2002). For example, it is the largest naturally occurring mature tree on the Swan Coastal Plain, has rapid growth and a distinctive grey-green foliage and white trunk. Its splitting growth habit (rather than a central dominant stem) and rounded dense crown is well suited to tuart's occurrences near the coast and exposure to strong salt laden winds.

Tuart varies in size and shape across its natural range. It occurs as a tall tree in southern parts, and as a low to medium tree in northern occurrences. Its vegetation formation is also variable occurring as tall woodlands with grassy savannah understorey, medium open woodlands with dense shrubby understorey, and as mosaics with other species. Tuart plays an important landscape role as remnant vegetation on the Swan Coastal Plain following extensive clearing for urban development, horticulture and industry. It is also an important tree in Perth's regional open space, parks and golf courses.

CONSERVATION AND PROTECTION OF TUART ECOSYSTEMS

Most tuart woodlands have been cleared for agriculture and urban development. The remaining extensive stands are found at Ludlow, Yanchep and Yalgorup National Parks (Department of Conservation and Land Management 1987, 1989, 1995). Significant tuart woodlands are also conserved in Bold Park and Kings Park, and where tuart occurs fringing *Pinus radiata* and *P. pinaster* plantations in State forest at Myalup and McLarty, and in unallocated Crown land and *Bush Forever* sites at Yanchep, Woodman Point, Port Kennedy, and the Harvey Estuary. Smaller remnants of tuart are scattered across its natural range from Jurien to south of Busselton.

The conservation and protection of natural ecosystems is provided at three levels. The first and primary means involves establishing a secured system of comprehensive, adequate and representative (CAR[3]) formal reserves. Tuart's CAR status was last assessed in the early 1980s (Department of Conservation and Environment 1983). It was not re-evaluated as part of the Western Australian Regional Forest Agreement (Commonwealth of Australia and the State of Western Australia 1999) because the majority of the Swan Coastal Plain, in which tuart is naturally confined, was excluded.

A second level for conserving and protecting tuart is required to ensure activities that may disturb residual tuart ecosystems outside the reserve system are carefully considered and, where possible, complementary to the objectives for tuart conservation within secured reserves. This level is important because more that 50 per cent of the existing tuart occurs on lands where conservation is not a priority land use. Proposals for ongoing development on the Swan Coastal Plain.

Because tuart woodlands are now remnants of the original pre-1750 extent, a third level of conservation and protection is necessary to protect taxa and ecological communities that have potentially gone beyond the reach of the above two levels of protection, and where their survival is likely to be threatened. Criteria for determining threatened ecological communities are provided by (English and Blyth 1999).

Bush Forever[4], *Regional Parks*[5], *Land for Wildlife*[6] and *LandCare* provide further opportunities for the protection and conservation of tuart woodlands, their associated communities and tuart trees, both in reserves and on private lands.

Conservation in reserves

Nationally agreed criteria for the establishment of a National Reserve System for forests in Australia require 15 per cent of tuart ecosystems to be protected in a CAR reserve system.

However flexibility in determining the level of formal reservation is necessary to allow both regional circumstances to be taken into consideration and to maximize the extent of CAR reserves.

For example, a reduction in CAR reserves may occur where the objectives for maintaining biodiversity are demonstrated to be met with a lesser area, or where it is impractical to purchase land because ecosystems occur largely on private property.

Alternatively, the 15 per cent formal reservation level of the pre-1750 distribution may be exceeded for rare and endangered forest ecosystems, where all remaining occurrences require reservation or protection. A rare ecosystem[8] (eg. tall tuart woodlands) is one where its geographic distribution involves a total range of generally less than 10,000 hectares.

Hopkins et. al. (1996) investigated the conservation status of vegetation types throughout Western Australia using a refinement of Beard's (1979) mapping of structural vegetation types. Six of these contain tuart and are estimated to have an original pre-1750 extent of 111,609 hectares (Table 1, Map 1). The current extent of the six structural vegetation types are summarised at Table 1, Appendix 3 and Map 2. The data was derived by intersecting the refined Beard data (Hopkins *et al* 1996), with Western Australian land categories as determined by the Department of Land Administration, and remnant vegetation [9] (Department of Agriculture, unpublished).

The Department of Conservation and Land Management's Forest Information System (FMIS) also maps tuart occurrence on lands vested in the Conservation Commission of Western Australia and estimates a total area of 23,230 hectares. This compares to 13,993 using Hopkins *et al* (1996) (Table 1), but includes areas not originally classified by Beard and Sprenger (1984) in the coastal zone between Two Rocks and Lancelin, east of Yalgorup National Park and at Bunbury.

There have also been several fine scale studies of tuart distribution over the past decade including more detailed floristic investigations (Trudgen 1991,

[3] CAR reserves are described at http://www.ea.gov.au/parks/nrs/sciguide/nrsgui_prt1b.html#principles

[4] *Bush Forever* is concerned with the protection of regionally significant bushland and associated wetlands on the Swan Coastal Plain portion of the Perth Metropolitan Region.

[5] Regional Parks provide for the coordinated conservation and recreation management of significant public and private lands.

[6] *Land for Wildlife* is a voluntary scheme that aims to encourage and assist private landholders in Western Australia to provide habitats for wildlife on their property, even though the property may be managed primarily for other purposes.

[7] Rarity is a naturally occurring phenomenon that does not necessarily imply that the ecosystem is under immediate threat.

[8] The conservation status of tuart's remnant vegetation depends on the quality and condition of both overstorey and understorey components.

Gibson 1994, Gibson *et al* 2002). At the floristic community level, tuart's conservation status is complex and requires further analysis. For example, existing plot data requires interpretation and conversion to maps showing tuart floristic communities and their relationships with vegetation complexes both within and outside reserves.

Trudgen (1991) surveyed tuart woodlands in a 45 kilometre coastal strip from Singleton to Martins Tank Lake within the Shire of Mandurah. The study aimed to list flora and vegetation units at a fine scale (1:25,000) relative to landform, document populations of threatened species and assess significance based on conservation and socio-economic values.

Gibson *et. al* (1994) conducted floristic surveys of the southern Swan Coastal Plain at 509 sites collecting data on major regional plant community types. Tuart was characteristic in seasonal wetlands, uplands centred on Bassendean dunes, and uplands centred on Spearwood and Quindalup dunes. Floristic communities were considered well reserved if plots containing tuart communities occurred in two widely separated national parks and/or nature reserves. Communities known from one national park or nature reserve were considered poorly reserved. Communities not known in any national park or nature reserve were considered unreserved.

Using this approach, Gibson *et al* (1994) assessed the threats to tuart's conservation in the following key communities:

- community type 19b, woodlands over sedgelands in Holocene dune swales was classified as endangered[10] and unreserved;
- community type 30a2, *Callitris preissii* and/or *Melaleuca lanceolata* forests and woodlands was classified as vulnerable[11] and poorly reserved;
- community type 25, southern *Eucalyptus gomphocephala—Agonis flexuosa* woodlands, and type 29, coastal shrublands on shallow sands were classified as susceptible[12] and poorly reserved; and
- community type 30c2, woodlands and shrublands on Holocene dunes was classified as poorly known and unreserved.

Allowing for the expected variations between studies, tuart the species does not rank as a threatened taxon. However, some of the floristic associations that occur with tuart appear under-represented in conservation reserves and are subject to threatening processes. Tuart also comprises a range of woodland structures, vegetation types and floristic compositions. This natural variation requires representation in reserves.

Table 1: Land categories and extent of tuart ecosystems described by Beard (1979a;b;c) and amended by Hopkins *et al* (1996).

Tuart ecosystems	Orig. Pre-1750 extent	Current extent (I) to (IV)		IUCN Reserve Categories Conservation		Other lands vested in the Commission		Other lands[9]	
	(ha)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Tall woodland: tuart	3,155	2,088	66.2	1,451	46.0	386	12.2	251	8.0
Medium woodland: tuart	51,575	19,742	38.3	5,140	10.0	1,391	2.7	13,212	25.6
Medium woodland: tuart-jarrah	54,077	15,998	29.6	1,501	2.8	3,757	6.9	10,739	19.9
Medium open woodland: tuart	1,080	778	72.0	256	23.7	111	10.3	411	38.0
Medium open woodland: marri-tuart	1,213	78	6.4	0	0	0	0	78	6.4
Mosaic: medium woodlands, tuart with low woodland, banksia	509	145	28.5	0	0	0	0	145	28.5
Total	111,609	38,829	34.8	8,348	7.5	5,645	5.1	24,836	22.2

9 Appendix 3 provided further analysis of the composition of Other lands.

10 Endangered: A community in danger of severe modification or destruction throughout its range, if causal factors keep operating.

11 Vulnerable: A community likely to move into the endangered category in the near future, if the causal factors keep operating.

12 Susceptible: A community of concern because there is evidence that it can be modified or destroyed by human activities, or would be vulnerable to new threatening processes.

Protection outside reserves

While the security of conservation purpose is highest for tuart woodlands within IUCN reserves, other land categories outside reserves are managed as complementary components of the formal reserve system. These include lands vested in the Conservation Commission of Western Australia (eg. State forests and timber reserves), and lands vested in the Botanic Parks and Gardens Authority (eg. Kings Park and Bold Park), as well as some local government authority reserves managed for conservation and recreation.

The security of conservation purpose for tuart woodlands is least in remaining reserves, unallocated Crown lands and public and private freehold lands. Although some programs exist to encourage better management of tuart's biological diversity on these lands (eg. *LandCare, Land for Wildlife*), more effort is required to raise both the standard of protection and conservation management, and the levels of technical expertise and financial assistance.

The conservation of tuart woodlands and associated communities outside protected areas therefore needs to be strengthened. This is best achieved and integrated *in situ*, with consistent approaches across all Crown and freehold lands where tuart occurs (Commonwealth of Australia 1996). Particular emphasis is necessary for the rural and urban conservation of tuart trees, ecosystems and communities such as (i) integrating tuart conservation into structure planning policies and development programs, (ii) encouraging action by local governments to retain and improve natural tuart ecosystems, and to use tuart for plantings in urban areas, and by (iii) promoting community tuart conservation programs.

Species and ecosystem management

Species and ecosystem management strategies aim to (i) protect threatened taxa and ecological communities, and (ii) control the impact of processes that threaten the functioning of natural ecosystems. The most effective way to manage threatened species and ecosystems, and threatening processes is to appropriately manage their natural habitats.

Threatened species and ecosystems

Although tuart is not classified as a threatened species, *Jacksonia sericea* (Priority 3), *Lasiopetalum membranaceum* (Priority 3), *Dodonaea hackettiana* (Priority 4), *Haloragis aculeolata* (Priority 2), and *Acacia benthamii* (Priority 2) appear with tuart as associated threatened species. Of these, *L. membranaceum* is a typical tuart woodland understorey species occurring near the coast and occurs on sand over limestone soils. The other species are not typical of tuart ecosystems, preferring either winter wet areas, clay/calcareous soils or limestone outcropping (Atkins *pers comm* 2002).

Many of the remaining tuart have been disturbed over long periods because of grazing, altered fire regimes, management based on forest silviculture, past timber harvesting and alienation for other land uses. In recent years alternative land uses such as urban development, mining and horticulture, road construction, inappropriate burning regimes, recreation and other public access have created a new range of disturbances.

Other processes, such as wildfires, predation by feral animals, weed invasion, and flora death from plant diseases, also endanger the survival and expansion of threatened flora and fauna and ecological communities.

Threatening processes

The primary reason(s) for the recent increased decline and chronic insect infestation in tuart is not clear, as there are a number of contributing and inter-related factors. Potential influences include the ongoing reduction in winter rainfall, hydrological and salinity factors near wetlands, soil type and nutrient supply, altered fire regimes, changes in the ecological balance between insect wood borers and their predators, competition with understorey species, land clearing and roadworks. Both visual assessment (Appendix 4) and satellite remote sensing (Appendix 5) tools are being developed to monitor changes in the extent and the health of tuart trees and associated understorey vegetation.

Climate

Climate variability and change has recently emerged as having a potentially significant effect on the health and vitality of natural ecosystems, as south western Australia experiences a sustained and substantial shift to drier conditions (CSIRO 2001, Indian Ocean Climate Initiative 2001). The change has been marked by below average winter rainfall, less rain days, less rain on extreme days, and higher temperatures. There is now evidence that this climate shift may not simply be a random occurrence, but driven by changes in atmospheric circulation and ocean currents, and compounded by increased temperatures associated with the accumulation of *greenhouse* gases (Sadler *pers comm* 2002). Reduced rainfall and increased temperatures have an impact on plant health systems by affecting internal water relations and nutrient status of trees and shrubs.

Soil and hydrology

The Swan Coastal Plain's geology is shown at Appendix 6. Changes in hydrological conditions (Appendix 7) resulting from climate variability and change or horticultural activities[13], may be a predisposing factor in the decline of tuart health in the vicinity of wetlands (eg. Lakes Clifton and Preston). Subtle differences in the underlying hydrology may also account for localised declines. Further, water availability may be influenced by soil conditions, such as presence of dense limestone which can reduce the water-holding capacity of the soil. Variations in overstorey and understorey transpiration capacity and fluctuations in water tables (creating alternating dry and waterlogged conditions), could also contribute to the pattern of tuart decline. Salinity and associated reductions in nutrient and water availability may also cause physiological stress in tuarts. Outcomes from the workshop held on hydrological factors involved with tuart decline are described at Appendix 8.

Insects

Like all native trees, tuart has a suite of native insect predators that have evolved with it and which normally have an ephemeral and minor impact. One of these is the longicorn beetle (*Phoracantha impavida*), a common and natural component of Australian forests (Elliott *et al* 1998). It is known that the activities of the larvae of the longicorn beetles, (or borers) have caused the branch death of tuart trees. Healthy trees are able to withstand a certain amount of insect attack due to their natural defense mechanisms. They secrete a gum called kino which engulfs and kills invading insect. Trees that are exposed to environmental stresses have lower internal moisture contents and produce less *kino*, thus enabling borers to mount more successful attacks. Tuart trees normally develop epicormic branches following damage to tree foliage lost through insect girdling. However since 1997 epicormic regrowth has been again attacked by the tuart borer resulting in death of the new growth (Appendix 5). This repeated attack has in turn weakened the trees and limited their ability to maintain appropriate levels of health and vitality to resist further environmental stress including insect attack.

Understorey competition

Bradshaw (2000) suggests that the increasing peppermint (*Agonis flexuosa*) understorey, and changes in management practices have been significant in reducing the regeneration capacity of tuart. Changes in Aboriginal fire regimes (after the 1850s) and the introduction of grazing (1840s–1860s) are implicated at the primary *drivers* for the observed changes in below canopy vegetation structure since the 1860s. The cause of increased peppermint density is unclear. Kessel in 1923 reported excessive resprouting of peppermint rootstocks under non-Aboriginal fire regimes characterised by reduced fire frequencies and increased severe fires (cited by Bradshaw 2000). Reduced tuart regeneration is also associated with grazing, based on the observation that stock graze tuart at all times in preference to peppermint in open conditions (Anon 1921, Brockman 1921 cited by Bradshaw 2000).

[13] In the last decade agricultural landuse has changes particularly south of Mandurah from parkland grazing to intensive horticulture under sprinkler irrigation (Department of Agriculture 1990).

Clearing disturbance

Fox and Curry (1979) suggest that clearing alters the environment and exposes trees to more sun, more wind and a greater edge effect than in the natural condition in which trees have developed. Insect infestation has been observed to increase following clearing disturbance (Anon 2001). Disturbance has also been implicated in the decline seen in health of tuarts in Bold Park (Powell *pers comm* 2002). Clearing for pine plantations, agriculture, housing development, and roadworks in the vicinity of Yalgorup National Park, may be implicated with tuart decline seen in the area.

Management practices

Changes in the understorey structure of tuart woodland communities have been associated with major changes in management practices. The decline in the influence of regular Aboriginal burning began about the 1850s. Grazing in the Ludlow forest began about the 1840s with more extensive grazing from 1918. Grazing in the Yalgorup area began in the 1860s and continued for 100 years. While these woodlands were afforded fire protection, the reduced frequency in planned fires increased the number of severe fires in ungrazed areas. There are no records of when peppermint became dominant as an understorey, but it is possible it became more prominent in the Yalgorup area with less frequent and more severe fires of the 1950s and 1960s (Bradshaw 2000).

Other threatening processes

There are other possible threatening processes that may in combination with other factors, result in tuart decline. These could include industrial air pollution (Chilcott 1992), declining water quality, fungi as pathogenic or beneficial (mycorrhizal, litter decomposing) agents, loss of natural biological control mechanisms (Anon 2001), and frost (Mitchell *pers comm* 2001).

MINING

Map 3 shows the extent of mineral and petroleum exploration licenses on the Swan Coastal Plain. While there are no approved mining tenements in areas of tuart occurrence on Crown lands, there has been on-going interest in the Ludlow area. This relates to the declaration of the Ludlow Tuart Forest National Parkin 1987, when an area of 1,160 hectares was excluded because of Mining Act (1904) exploration claims, and because of the need to harvest State forest *Pinus radiata* (pine) plantations.

Exploration License M70/86 for mineral sand mining at Ludlow (215 hectares), occurs within pine plantations on former tuart woodland sites and it is located immediately adjacent to the Tuart Forest National Park. When the pine plantation was established, 10 per cent of the tuart trees were retained to enable subsequent restoration back to tuart woodlands. This strategy is consistent with:

- the Greenbook Report, *Conservation reserves in Western Australia*, prepared for the Environmental Protection Authority (Conservation through Reserves Committee 1974);
- The Report *Conservation Reserves in Western Australia for Systems 1,2,3 and 5*, (Environmental Protection Authority 1976);
- The report on the *Implementation of Conservation Reserves for Western Australia 1976–1984* (Environmental Protection Authority 1984);
- the *Ludlow Working Plan 1978–1985* (Department of Conservation and Land Management 1978); and
- the *Red Book Status Report on the implementation of conservation reserves for Western Australia* (Environmental Protection Authority 1993).

An application by the tenement holders for mining to proceed is currently the subject of an Environmental Protection Authority Environmental Review and Management Program.

WATER EXTRACTION

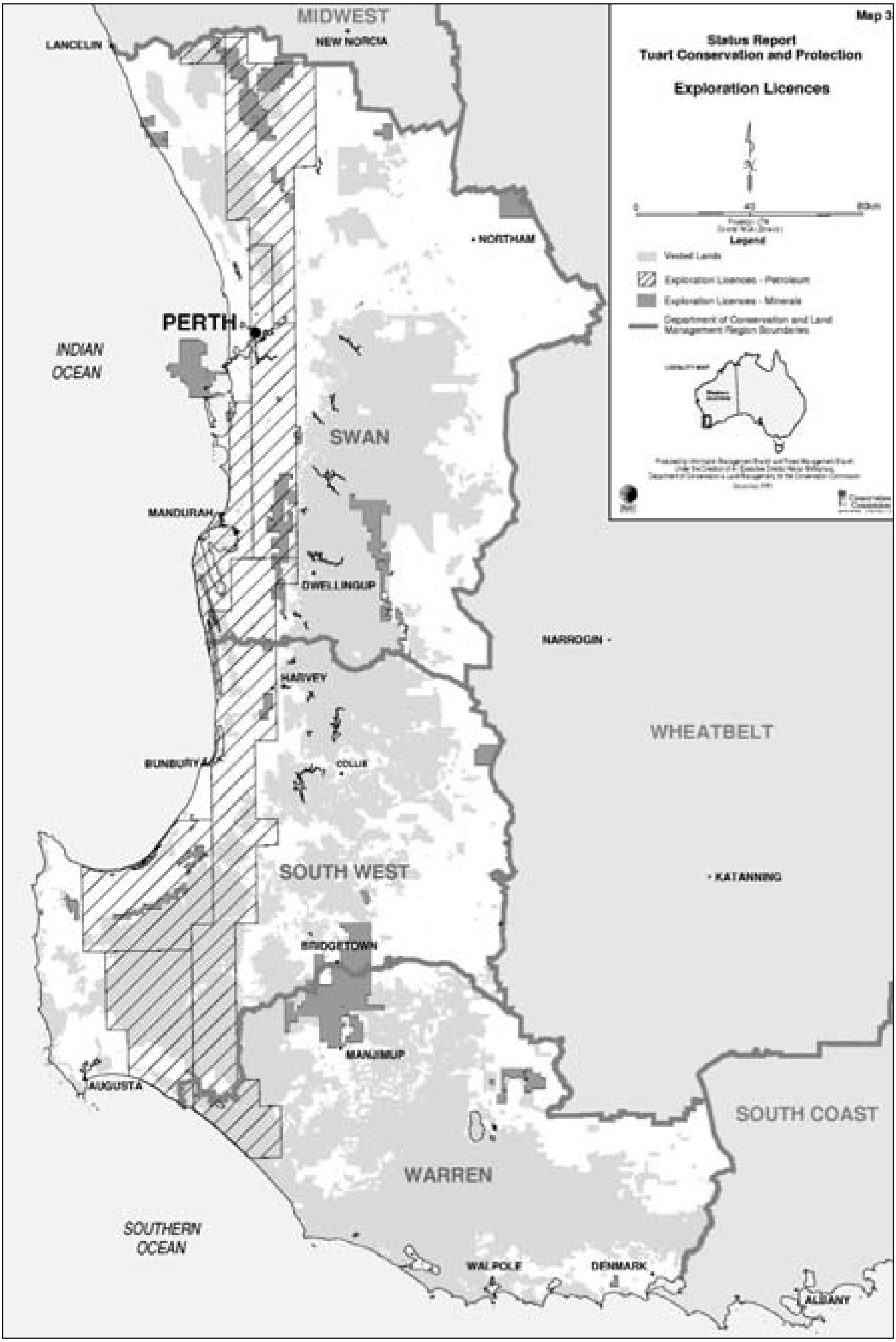
Water extraction for horticulture has the potential to impact the water tables supporting tuart ecosystems. Typical areas are at Yalgorup, on the sandy soils of the Spearwood and Bassendean dune systems of Perth's rural/urban interface, near Myalup south of Lake Preston, and at Guilderton.

Although the area of irrigated land near Yalgorup is comparatively small, substantial quantities of groundwater are used. However it appears that water table levels alone cannot explain tuart decline at Yalgorup because (i) tuart decline is occurring west of Lake Clifton and remote from groundwater abstraction, (ii) water tables at Yalgorup (unlike Gnangara) are regulated by high transmissivity in the underlying limestone aquifer and the proximity of lake and sea levels, and because (iii) tuart has the capacity to grow and function in ecosystems on upland sites where there is considerable depth the groundwater.

While the environmental impact of groundwater abstraction has not been formally researched, the Department of Environmental Protection; Water and Rivers Commission has established a network of bores at Yalgorup to monitor changes in water level due to variations in rainfall and groundwater extraction. This work seeks to assess fluxes in groundwater resources to manage appropriate water balances for these coastal lakes. (Commander *pers comm* 2002). Further research is required:

- to determine the extent to which recent drier years are changing the hydrology of the Swan Coastal Plain at Yalgorup by reducing the thickness of the fresh water lens under tuart woodlands. In 1979 and 1980 the fresh water lens was measured between 14 and 18 metres at the Lake Clifton Series Monitoring Bores (Department of Environmental Protection; Water and Rivers Commission 2002); and
- to determine the extent to which water abstraction from individual bores and bore fields is resulting in the development of shallow localised saline water cones. Groundwater abstraction takes place east of Lakes Clifton and Preston, and the area with underlying saline groundwater extends about a kilomete east of the lakes. Private bores or wells used for irrigation in this area have previously shown to raise salinity levels at the end of summer pumping. Higher measured water salinity is localised and attributed to upconing of the salt water interface directly beneath the bore (Department of Environmental Protection; Water and Rivers Commission 2002).

Map 3: Exploration Licenses on the Swan Coastal Plain



Communications and public involvement

Since the mid-1990s there has been growing community concern about the noticeable decline in the health of tuart trees south of Mandurah. The Tuart Response Group (Appendix 9) seeks to establish a partnership with local communities to plan and manage the conservation of tuart trees and ecosystems, and investigate the causes of tuart's decline. The Tuart Response Group's *Communications and Public Involvement Plan* (2002) details the consultation strategies necessary to involve the community in the development of the *Tuart Conservation and Implementation Strategy*. Mechanisms for stakeholder involvement and consultation include:

- joint planning with stakeholders during the development of the *Tuart Conservation and Protection Strategy*;
- establishing strategic alliances to generate support and ideas for tuart conservation and protection on public and freehold lands;
- holding consultative workshops with key stakeholder groups to investigate ways of achieving the State's goals for the conservation and protection tuarts on freehold lands; and
- community education to boost levels of knowledge and awareness about tuart conservation and protection. The brochure *Saving our tuarts* was distributed widely in the community during June 2002.

Tuart research

Australian Research Council Linkage Project

In June 2002, Murdoch University (Principal Investigator), the Department of Conservation and Land Management (Partner Investigator) and Alcoa Australia (Partner Investigator) submitted a collaborative research application, seeking funds through the Australian Research Council's[14] 2003 National Competitive Linkage Grants Program. The research sought to investigate The possible cause(s) of the *Eucalyptus gomphecephala* decline epidemic in Western Australia, with the following aims:

- to develop an understanding of the physiology of tuart in relation to water and nutrient use under different environmental parameters, including reduced understorey competition;
- to develop a model to describe and compare the morphological and physiological condition of healthy and declining tuart in relation to edaphic (soil type, salinity, water tables) factors across its natural range;
- to determine whether pathogens are associated with tuart tree decline and if these are related to predisposing environmental factors;
- to describe the insect fauna of healthy and diseased tuart and determine whether systematic insecticides can be used to halt or reverse the decline; and
- to develop strategies and provide land managers and community groups with appropriate tools to reduce and manage the impact of tuart decline.

Tuart Science Workshop

In July 2002 the Tuart Response Group convened a Tuart Science Workshop. Its purpose was to involve Government agencies, industry and the scientific community in research programs leading to the development of sustainable management practices for tuart ecosystems. It aimed:

- to involve Government agencies, industry and research institutions in the development of priority research proposals for investigating (i) the decline in the health of tuart trees and ecosystems according to the Tuart Vegetation System Heath Model (Appendix 10) and (ii) management options for regenerating tuart ecosystems and sustaining tuart dominant woodlands;
- to ensure that a range of Government agency, industry and scientific viewpoints are represented in developing future research directions for the sustainable management of tuart ecosystems; and
- to provide opportunities for Government agencies, industry and research institutions to participate in and contribute to future research programs for the sustainable management of tuart ecosystems.

Outcomes from the Tuart Science Workshop are summarised at Appendix 11.

[14] The main role of the Australian Research Council is to, (i) advise the Commonwealth Government on research funding and policy, (ii) promote research and research training that is of the highest quality for the benefit of the Australian community. The Linkage element encourages and extends collaborative research ventures, at national and international levels, between agencies, industry and research institutions. Linkage projects provide national benefits and advance Australia's economic and industrial performance.

Tuart Atlas

The Tuart Atlas project began in June 2002 to assess tuart's extent, the density of its overstorey and the quality its understorey (Appendix 12). The project will integrate and build on physical, biological and environmental information to produce a comprehensive set of maps and explanatory text.

It will deliver the following outcomes:

- the occurrence, and overstorey and understorey condition of tuart, inside and outside the secured reserve system, throughout its natural range;
- mapping that builds on (i) the earlier broad tuart overstorey structural units mapped by Speck (1952), that were further developed by Beard (1979a,b,c, 1981) and consolidated by Hopkins *et al* (1996), and Smith (1973, 1974), (ii) the review of the conservation estate within the System 6 area by the Department of Conservation and Environment (Heddle *et al* 1980) and (iii) information derived from plots on the regional floristic groupings of tuart (Gibson *et al* 1994, Department of Environmental Protection 1996); and
- a preliminary basis for refining the present CAR reserve system for tuart conservation and protection.

Conservation and protection strategy

There is no specific document identified as the State's tuart conservation and protection strategy. Tuart woodlands and associated vegetative communities are managed on public lands under the provisions of the Conservation and Land Management Act (1984) according to:

- area management plans in national parks (Department of Conservation and Land Management 1989, 1995. 1998a);
- conservation parks (Department of Conservation and Land Management 1998b);
- regional parks (Department of Conservation and Land Management 2000; 2001);
- nature reserves(Department of Conservation and Land Management (1998a); and
- by prescriptions in State forest under the authority of the Forest Management Plan (Department of Conservation and Land Management 1994).

Tuart is also managed in other significant reserves such as Bold Park and Kings Park (Botanic Parks and Gardens Authority, 1995, 2000). Almost half of the existing tuart estate occurs on freehold lands. Some stands of tuart on private land are included in *LandCare* and *Land for Wildlife* programs.

The call for a comprehensive conservation strategy for tuart trees, ecosystems and associated communities requires the development of an integrated land use approach that complements existing formal conservation mechanisms. A suggested structure for the *Tuart Conservation and Protection Strategy* is shown at Appendix 13. Important principles used to develop the strategy include;

- meeting IUCN reserve targets for nominated under-represented tuart ecosystems;
- integrating protection and conservation objectives and strategies across all tenures;
- managing threatening processes;
- improving knowledge and understanding;
- involving the community; and
- implementing programs based on the precautionary approach[15] and adaptive management[16].

The Tuart Conservation and Protection Strategy will also:

- encourage the community to be more aware of tuart and more involved in its conservation and protection;
- ensure tuart trees and ecosystems are identified and adequately represented and managed for conservation within and outside reserves;
- ensure that significant stands and specimens of tuart trees outside conservation reserves are retained and appropriately managed;
- promote partnerships with community groups with differing interests in tuart trees and ecosystems;
- introduce research based remedial support to minimise the impact of processes that threaten the health of tuart trees; and
- ensure that accumulated knowledge leads to improved tuart management.

[15] The precautionary principle is concerned with decision-making where action should be taken to prevent damage even where there is no absolute certainty that damage will occur. It applies where there is a threat of serious or irreversible damage.

[16] Adaptive management requires protection and conservation programs to be updated over time in based on new information from research, monitoring and auditing

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APPENDIX 1

VEGETATION COMPLEXES CONTAINING TUART ON THE SWAN COASTAL PLAIN (after Heddle et al 1980)

Vegetation Complex[17] **% Tuart dominated**	**Native Vegetation**[18] **%SCP**[19]**/%PMR**[20]
Spearwood Dunes	
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%	31/ 20 (20)
Karrakatta Complex—North: Transition Vegetation Complex: A transition complex of low open forest and low woodland of Banksia species —*Eucalyptus todtiana* on the transition zone of a series of high sand dunes between Bassendean-North and Karrakatta-North. Approx 5%	81/81 (79)
Karrakatta Complex—Central And South: Predominantly open forest of *Eucalyptus gomphocephala —E. marginata—E. calophylla* and woodland of *E. marginata*—Banksia species. Approx 50%	24/21 (18)
Cottesloe Complex—North: Predominantly low open forest and low woodland of *Banksia attenuata —B menziesii—Eucalyptus todtiana*; closed heath on the limestone outcrops. Approx 10%	41/71 (70)
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%	41/39 (36)
Quindalup Dunes	
Quindalup Complex : Coastal dune complex consisting mainly of two alliances—the strand and fore-dune alliance and the mobile and stable dune alliance. Local variations include the low closed forest of *M. lanceolata—Callitris preissii* and the closed scrub of Acacia rostellifera. Approx 5%	29/48 (48)
Marine (Lagoonal and Estuarine) Deposits	
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%	25/72 (72)
Vasse Complex: Mixture of the closed scrub of Melaleuca species fringing woodland of *E. rudis*— 24/1 (1) Melaleuca species and open forest of *E. gomphocephala—E. marginata—E. calophylla.* Approx 10%	

[17] Units after Heddle *et al.* 1980. Per cent tuart dominated estimated by B. J and G. J Keighery

[18] Remnant Native Vegetation from Department of Agriculture (1998) and Bush Forever

[19] SCP: Swan Coastal Plain

[20] PMR: Perth Metropolitan Region

APPENDIX 2

REGIONAL FLORISTIC GROUPS CONTAINING TUART, AND THEIR RESERVATION AND CONSERVATION ON THE SOUTHERN SWAN COASTAL PLAIN (after Gibson et al 1994 and Department of Environmental Protection 1996).

Comm Type	General Description of Floristic Community Types[21]	Reservation Status	Conservation Status
Supergroup 2—Seasonal Wetlands			
16	Highly saline seasonal wetlands	Poor	Vulnerable
17	Melaleuca rhaphiophylla—Gahnia trifida seasonal wetlands	Good	Low risk
19b	Woodlands over sedgelands in Holocene dune swales	Unreserved	Endangered
Supergroup 3—Uplands Centred on Bassendean Dunes			
21a	Central Banksia attenuata—Eucalyptus marginata woodlands	Good	Low risk
Supergroup 4—Uplands Centred on Spearwood and Quindalup Dunes			
Spearwood dunes			
24	Northern Spearwood shrublands and woodlands	Good	Susceptible
25	Southern *Eucalyptus gomphocephala—Agonis flexuosa* woodlands	Poor	Susceptible
26b	Woodlands and mallees on Limestone	Good	Low risk
28	Spearwood *Banksia attenuata* or *Banksia attenuata*—Eucalyptus woodlands	Good	Low risk
Quindalup dunes			
29a	Coastal shrublands on shallow sands	Poor	Susceptible
30a2	Callitris preissii and/or Melaleuca lanceolata forests and woodlands	Poor	Vulnerable
30b	Quindalup *Eucalyptus gomphocephala* and/or *Agonis flexuosa* woodlands	Good	Susceptible
30c2	Woodlands and shrublands on Holocene dunes (re-allocated from 30c)	Unreserved	Poorly known
S11	Northern *Acacia rostellifera—Melaleuca acerosa* shrublands		
S15	Weed group Not allied with any supergroup		

[21] After Gibson et al (1994) and Department of Environmental Protection (1996). Communities in which tuart is a defining species are in bold

LAND CATEGORIES[22] AND EXTENT[22] OF TUART ECOSYSTEMS (after Beard 1979 and Hopkins et al 1996).

Tuart ecosystems	Orig. Pre-1750 extent	Current extent		IUCN Reserve Categories (I) to (IV)		Other lands vested in the Conservation Commission		Other lands managed for conservation		Other reserves		Unallocated Crown land		Freehold lands		Lands not classified	
		(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Tall woodland: tuart	3,155	2,088	66.2	1,451	46.0	386	12.2	2	0.1	6	0.2	3	0.1	151	4.8	89	2.8
Medium woodland: tuart	51,575	19,742	38.3	5,140	10.0	1,391	2.7	1,721	3.3	480	0.9	926	1.8	9,208	17.9	877	1.7
Medium woodland: tuart-jarrah	54,077	15,998	29.6	1,501	2.8	3,757	6.9	1,069	2.0	365	0.7	165	0.3	8,603	15.9	537	1.0
Medium open woodland: tuart	1,080	778	72/0	256	23.7	111	10.3	0	0	0	0	0	0	409	37.9	2	0.2
Medium open woodland: marri- tuart	1,213	78	6.4	0	0	0	0	0	0	0	0	0	0	60	4.9	18	1.5
Mosaic: medium woodlands, tuart with low woodland, banksia	509	145	28.5	0	0	0	0	0	0	0	0	0	0	135	26.5	10	2.0
TOTAL	111,609	38,829	34.8	8,348	7.5	5,645	5.1	2,792	2.5	851	0.8	1,094	1.0	18,566	16.6	1,533	1.4

[22] Freehold lands includes land held freehold by Government agencies. Lands not classified are those where there is missing values in the Department of Land Administration's tenure data

[23] Current data accuracy is qualified due to:
- reliance on early System 6 mapping of the Swan Coastal Plain;
- new plot information that has not been interpreted and mapped; and
- absence of data in some areas.

APPENDIX 4

VISUAL INTERPRETATION OF TUART DECLINE AT YALGORUP

Box 1: This data shows the extent of tuart decline and the severity of its impact. The area surveyed was from White Hills Road in the north, down to mid-Lake Preston.

The data was obtained from visual assessments of tuart canopies taken from a light plane flying over the area. Results were recorded at the time of survey by hand onto maps. The three impact classes were interpreted as follows:

High: 80% of canopy lost;

Medium: 50% of canopy lost; and

Low: some crown decline and stags visible.

Figure 1 shows the extent of tuart decline in November 1999, but does not differentiate between the severity of its impact.

Figure 2 show the extent of tuart decline and the severity of its impact in June 2000.

Figure 3 shows the changes in the extent and impact of tuart decline in October 2001.

Figure 1: Extent of tuart decline November 1999.
Source: D. Mitchell. DCLM

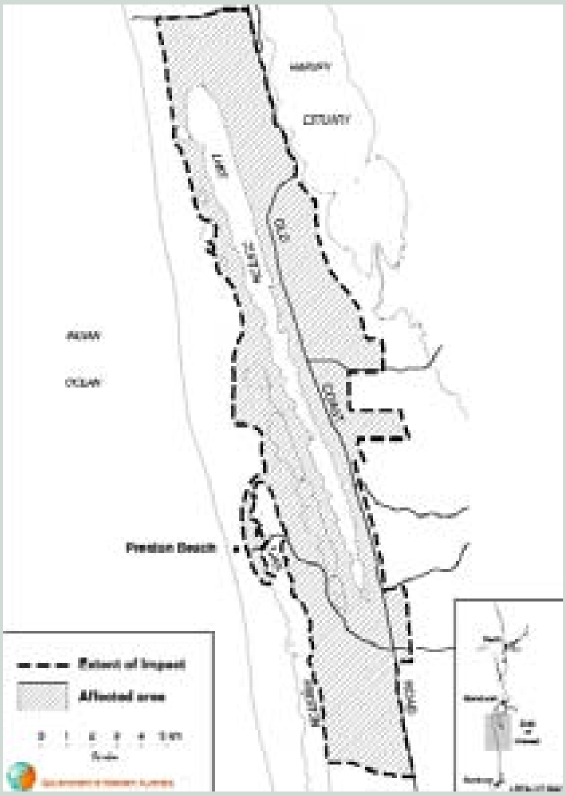


Figure 2: Extent and impact of tuart decline, June 2000.
Source: D. Mitchell. DCLM

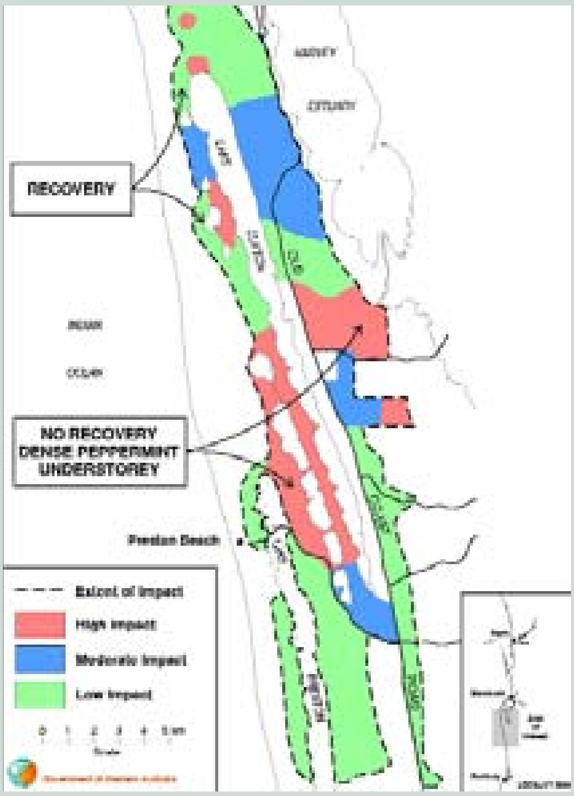
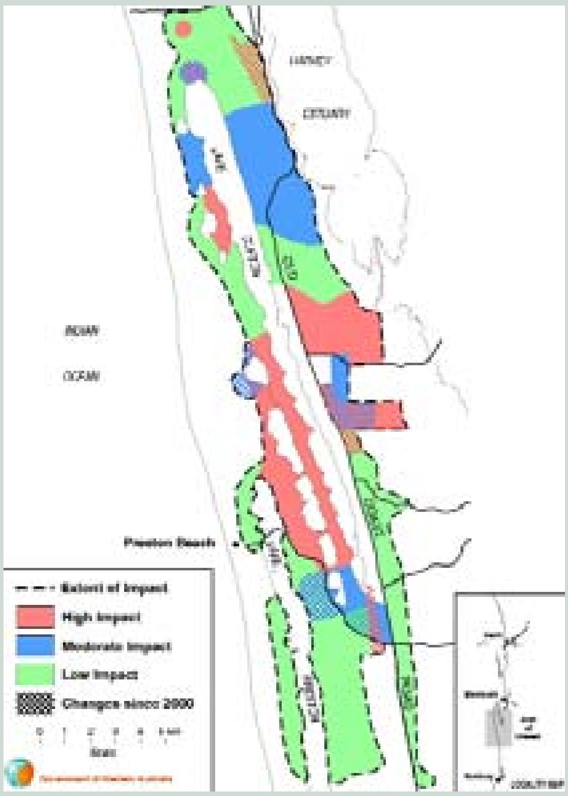


Figure 3: Changes in extent and impact of tuart decline, October 2001. *Source: D. Mitchell. DCLM*



INTERPRETING TUART DECLINE AT YALGORUP USING LANDSAT TM TO TEST FOR VEGETATION CHANGES.

Photo 1: Severe tuart decline showing evidence of repeated deaths on resprouted crowns.
Photo: D. Mitchell. DCLM

Box 2: Figure 4 and 5 are LandSat TM images showing vegetation changes between August 1999 and December 2001. These data have undergone preliminary analysis (Figures 6,7,8 and 9) to contrast categories of tuart crown decline as follows:

Red: speckled areas are dead tuart crowns. Note that full colour equates to open water;

Yellow: bare branches and sparse crowns;
Blue: receding crowns;
Green: full crowns; and
P*urple:* no interpretation available.

Data in Figures 6,7,8 and 9 now requires calibration with ground conditions so as to further contrast healthy and declining tuarts. This includes:

selecting 30-40 training sites reflecting different canopy densities;

collecting ground crown health and crown openness data at each site; and

developing relationships between foliar *percentage* cover and the crown health for each site.

Tuart Health Indices may be developed using LandSat TM by selecting the most appropriate combination of spectral bands for each specified crown density.

Figure 4: LandSat TM images of tuart decline, Lake Clifton (Aug. 1999).
Source: Li Shu. DCLM

Figure 5: LandSat TM images of tuart decline at Lake Clifton (Dec. 2001).
Source: Li Shu. DCLM

INTERPRETING LANDSAT TM IMAGES (BOX 2) TO TEST FOR CANOPY CHANGES IN TUART VEGETATION.

Figure 6: Preliminary categories of tuart decline. (September 1999).
Source: Li Shu. DCLM

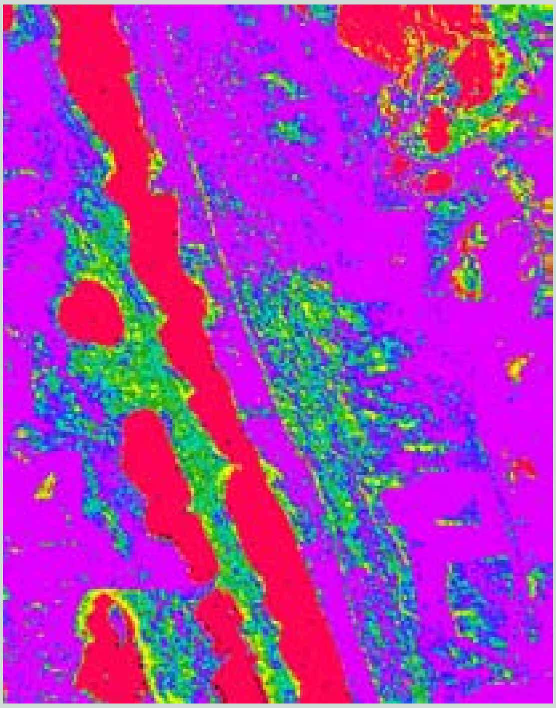


Figure 7: Preliminary categories of tuart decline. (February 2000).
Source: Li Shu. DCLM

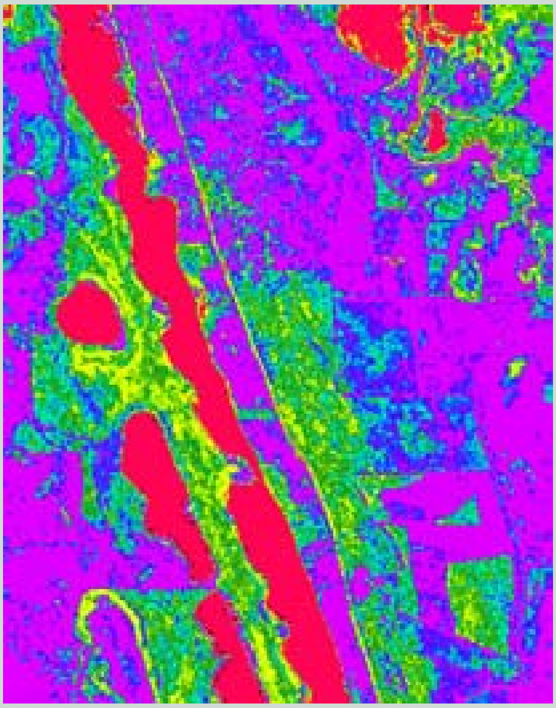


Figure 8: Preliminary categories of tuart decline. (November 2000).
Source: Li Shu. DCLM

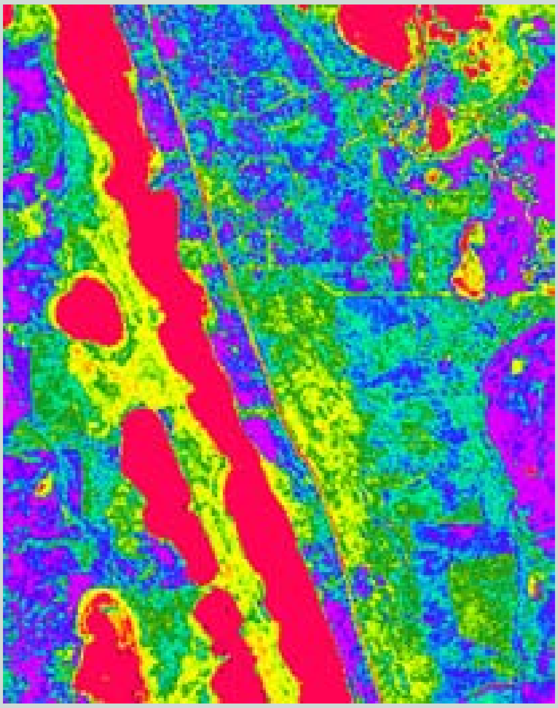
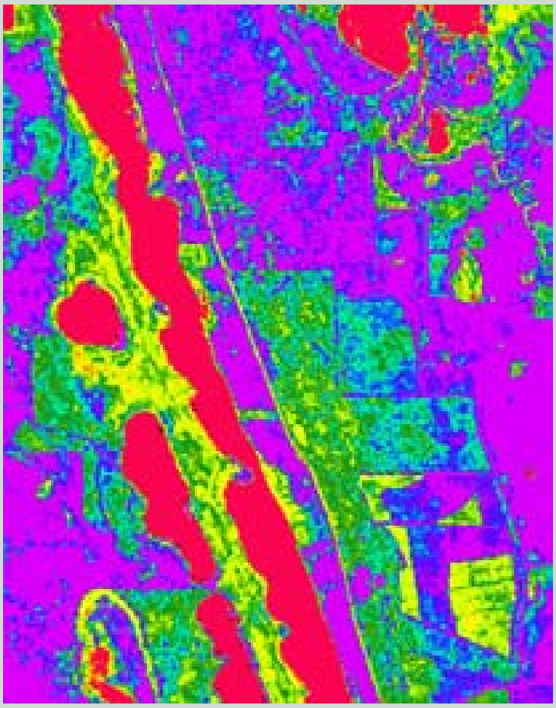


Figure 9 Preliminary categories of tuart decline. (December 2001).
Source: Li Shu. DCLM



SWAN COASTAL PLAIN GEOLOGY

Box 3: Geology of the Swan Coastal Plain.

Figure 10: The Swan Coastal Plain occupies the coastal strip between Busselton and Geraldton and is bounded in the east by the Darling and Dandaragan Plateaux

Figure 11: The geological units on the Swan Coastal Plain correspond to physiographic features related to parallel dune systems. They consist of the Pinjarra Plain (brown) in the east, followed by the Bassendean and Spearwood dunes (yellow) in the centre, and the Quindalup dune (yellow) in the west. The water table is depicted by the pink line.

Figure 12: The Quaternary sediments of the Swan Coastal Plain typically consist of the Guildford Formation in the east (yellow), Bassendean Sand in the center (yellow), and Tamala Limestone (yellow peaks) in the west with Safety Bay Sand along the coast (yellow peak). The saturated thickness is generally around 30metres but reaches a maximum of around 70metres in the Gnangara Mound

Figure 10: Map of the Swan Coastal Plain.
Source: P. Commander. DEWCP.

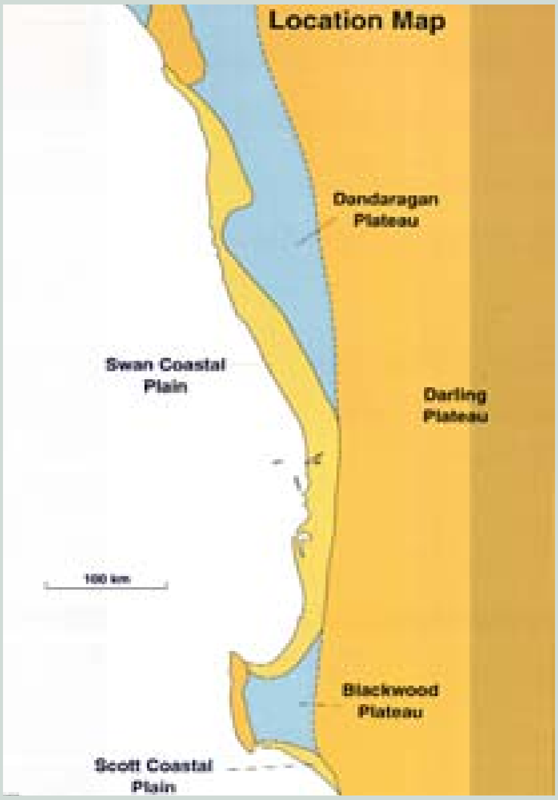


Figure 11: Geological units of the Swan Coastal Plain.
Source: P: Commander. DEWCP.

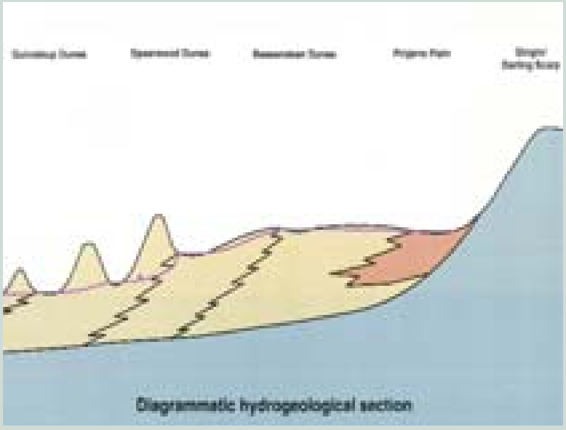
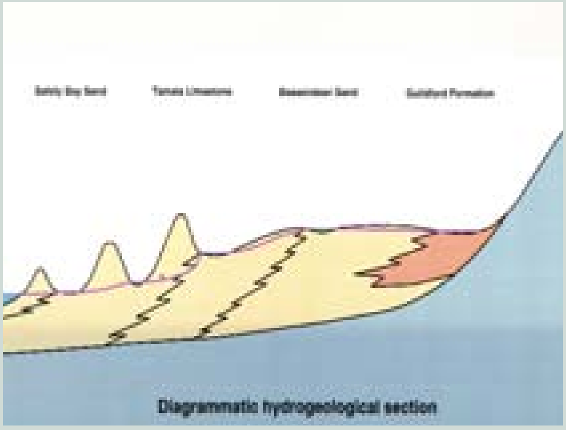


Figure 12: Quaternary sediments of the Swan Coastal Plain.
Source: P. Commander: DEWCP.



APPENDIX 7

SWAN COASTAL PLAIN HYDROLOGY

Box 4: Hydrology of the Swan Coastal Plain

Figure 13 The Swan Coastal Plain contains a number of groundwater mounds in which the water table is highest in the centre of the plain, with groundwater flowing radially outward

Figure 14: The groundwater catchmenrt area to the Yalgorup Lakes extends about 10 kilometres inland. All infiltrating rainfall in the groundwater catchment areas flows into the lakes, and the contained salts are progressively concentrated in the lakes and the underlying groundwater. Groundwater flow is radially outwards from groundwater mounds, to discharge to estuaries and at the coast.

Figure 15: The water table is close to the surface over much of the coastal plain, maintaining numerous wetlands. These are mainly within the Bassendean Dunes, and in interdunal areas within the Spearwood and Quindalup Dune Systems.

Figure 13: Groundwater mounds at Gnangara and Jandakot.
Source: P: Commander. DEWCP.

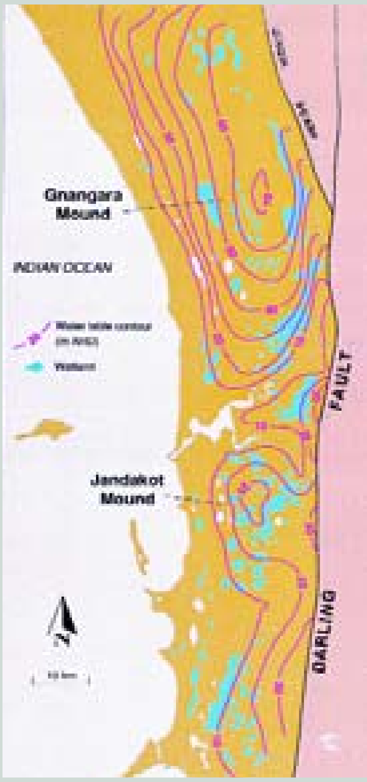


Figure 14: Groundwater flow to the Yalogorup Lakes.
Source: P. Commander. DEWCP.

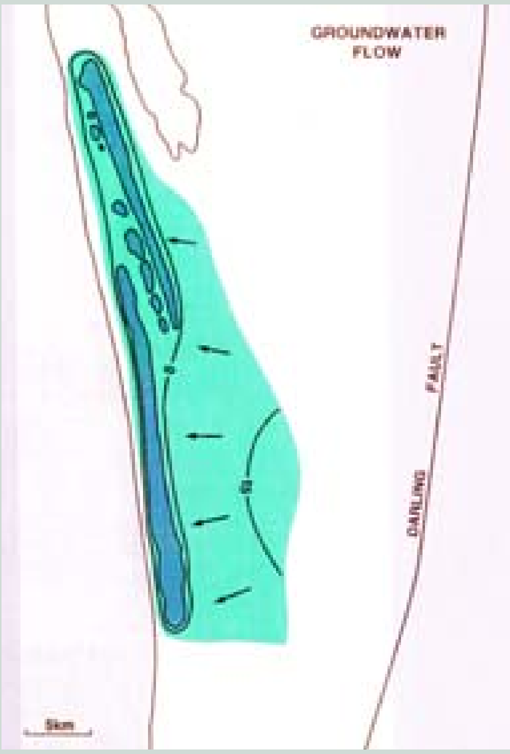
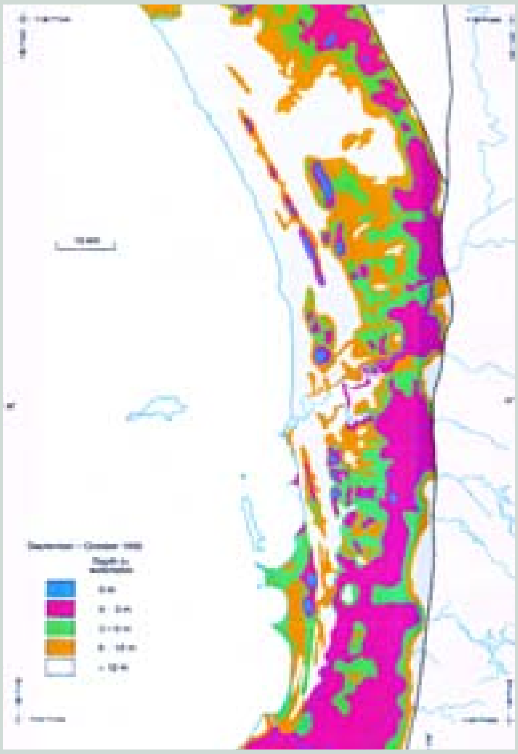


Figure 15. Depth to watertable of the Swan Coastal Plain.
Source: P. Commander. DEWCP.



HYDROLOGICAL FACTORS INVOLVED IN TUART DECLINE

Tuart water use

Soil moisture factors

Anecdotal evidence that tuarts survive well in the natural environment despite a range of surface treatments such as watering and water harvesting.

Facultatative phreatophytes (ability for opportunistic use of groundwater)

Tuarts grow both close to the water table, where they are likely to be able to access groundwater, but also high above the water table, where they almost certainly have the capacity to live without groundwater

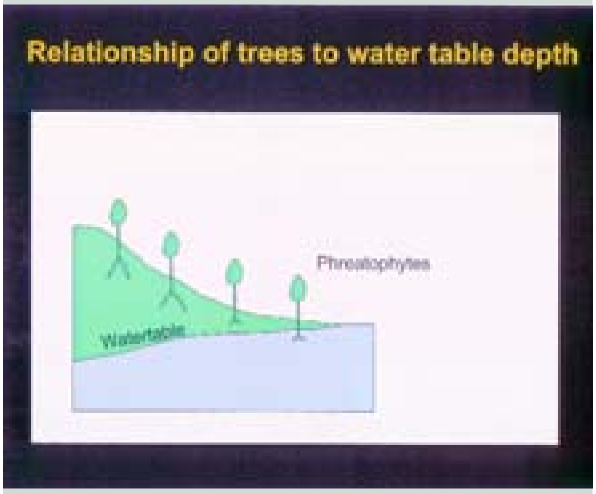
Groundwater quality

It is not known whether tuarts respond to different groundwater salinities.

Pattern of decline related to groundwater regime

The core area of tuart decline (west of Lake Clifton, adjacent to Lake Pollard and Duck Pond) is in an area of relatively shallow water table, where the trees could access groundwater. The decline has spread to areas high above the water table. The core area of decline has an underlying, relatively thin layer of brackish groundwater sitting on type of hypersaline groundwater. These conditions between Lakes Clifton and Preston are unique on the coastal plain.

Figure 16: Model of tuart's access to water.
Source: P. Commander. DEWCP.



Box 5: Relationship of tree distribution to water table depth is shown in Figure 16.

Tuarts appear to grow in all landscape positions in the Spearwood Dunes.

Those growing in low lying areas are likely to be able to access groundwater, and may achieve a certain amount of dependency.

Those trees growing on the ridge tops almost certainly do not access groundwater, and depend solely on soil moisture.

HYDROLOGICAL FACTORS INVOLVED IN TUART DECLINE

Box 6: Pattern of decline related to groundwater regime

Figure 17: Lakes Clifton and Preston are groundwater sinks. They receive groundwater flow from the east, which discharges along the eastern shore of the lakes. The lakes have underlying hypersaline groundwater with a salinity ranging from 44,000 to 64,000 mg/l (compared with seawater of 35,000 mg/l). The higher density of the hypersaline groundwater allows the lake levels to fall below sea level.

Figure 18: Rainfall within the groundwater catchment of the lakes contributes to groundwater flow into the lakes.

Figure 19: Groundwater salinity in the catchments of the lakes increases from less than 250 mg/l on the crest of the groundwater mounds to about 1,000 mg/l near the lakes. The area with underlying saline or hypersaline groundwater extends from Harvey Estuary to the southern end of Lake Preston.

Figure 17: Lake Clifton and Lake Preston groundwater sinks.
Source: P. Commander. DEWCP.

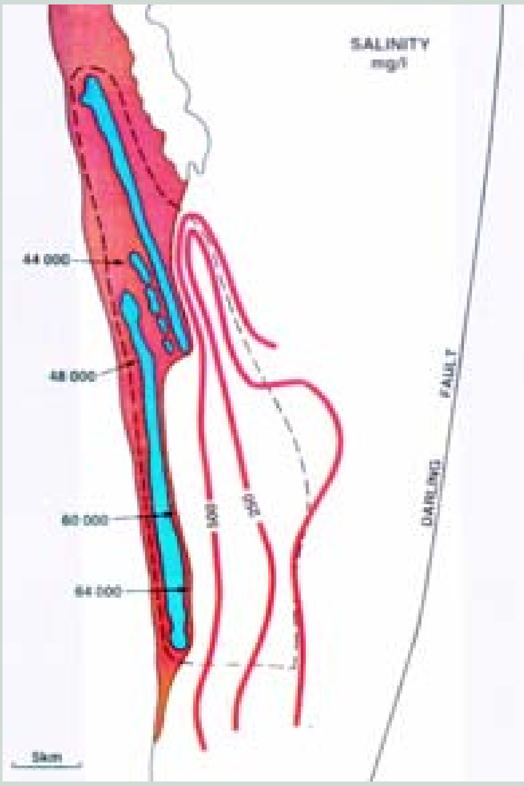


Figure 18: Rainfall, groundwater flow and wetland hydrology.
Source: P. Commander. DEWCP.

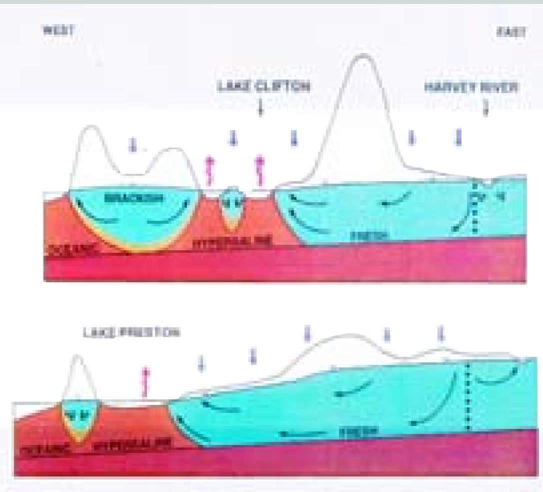
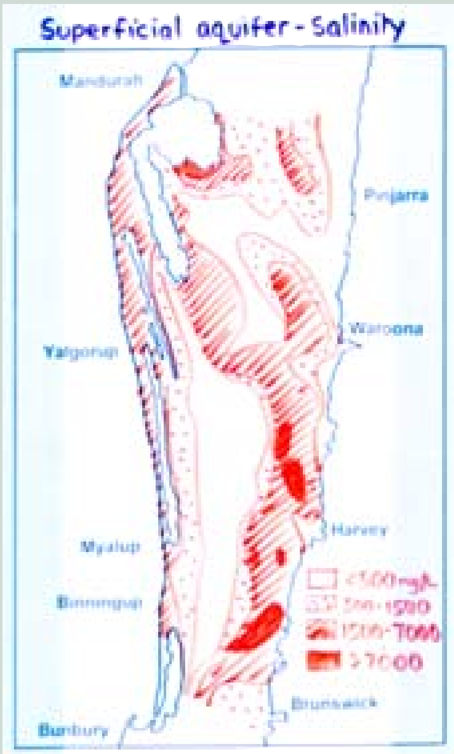


Figure 19: Groundwater salinity in lake catchments.
Source: P. Commander. DEWCP.



HYDROLOGICAL FACTORS INVOLVED IN TUART DECLINE

Climatic factors

Long term change in rainfall

Rainfall in the last 25 years has been significantly below the long term average (CSIRO 2001, Indian Ocean Climate Initiative 2001). This lowered rainfall might affect the margins of a species distribution, but how long would it take? The core area of tuart decline is in the centre of their range

Dry years

Two particularly dry years in 1993 and 1994 may have been a trigger for water stress, either from soil moisture or lowered water table.

Effect on groundwater levels and salinity

It has been recently shown that shallow groundwater levels on the Gnangara and Jandakot Mounds respond to the Cumulative Departure From the Mean rainfall (CDFM) (ie. they gently fall in periods of consistently low rainfall and rise in periods of consistently higher than average rainfall). In the past 30 years, shallow groundwater levels have been falling in areas of native vegetation, where there are no other factors involved.

In the core area of decline, the water table fluctuates through a comparatively narrow range, being regulated by high transmissivity in the underlying limestone aquifer, and the proximity of lake and sea levels. It is unlikely that the water table could drop significantly to affect a whole population.

Lake Clifton's water level was low in early 1994, which appeared to have triggered an increase in overall salinity from around 15,000 mg/l to 25,000 mg/l. It is difficult to envisage a sudden change to groundwater salinity, but reduced recharge would lead to an eventual thinning of the brackish lens and an increase in salinity at the water table

Impacts of human activities

Changed water balance of cleared, irrigated, subdivided land

Fire has the potential to raise groundwater levels. The core area of tuart decline has not been affected by wildfires. Parkland clearing can be expected to increase recharge and hence water levels. Private land adjacent to the core area of decline has not changed land use recently.

Impact of groundwater abstraction on groundwater levels and quality

Groundwater abstraction from the shallow aquifer, and irrigation, can be expected to result in lowered water table levels, and increased salinity where abstraction takes place above a salt water interface. The core area of decline is remote from groundwater abstraction and hydraulically isolated by Lake Clifton.

Impact of irrigation on groundwater levels and quality

Recirculation of irrigation water can be expected to raise the salinity of the underlying shallow groundwater, and add nutrients from fertilizer application.

Groundwater level and quality monitoring

Responsibility

The Water and Rivers Commission is responsible for monitoring groundwater levels, where it is a necessary part of managing groundwater abstraction.

Interagency cooperation

Other agencies also collect water data, including the Departments of Conservation and Land Management, and Agriculture.

Irrigation bores, abstraction, water levels and water quality

The Water and Rivers Commission is responsible for managing groundwater abstraction through the Groundwater Management Plan for the South West Coastal Groundwater Area. Collection and submission of data on abstraction, water levels and water quality is a condition of some licences.

APPENDIX 9

TUART RESPONSE GROUP TERMS OF REFERENCE

In accordance with a decision by the Minister for the Environment and Heritage, the State Government is establishing a Tuart Response Group 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 tenures to meet environmental, economic and social objectives;
- the supporting measures necessary to minimise 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.

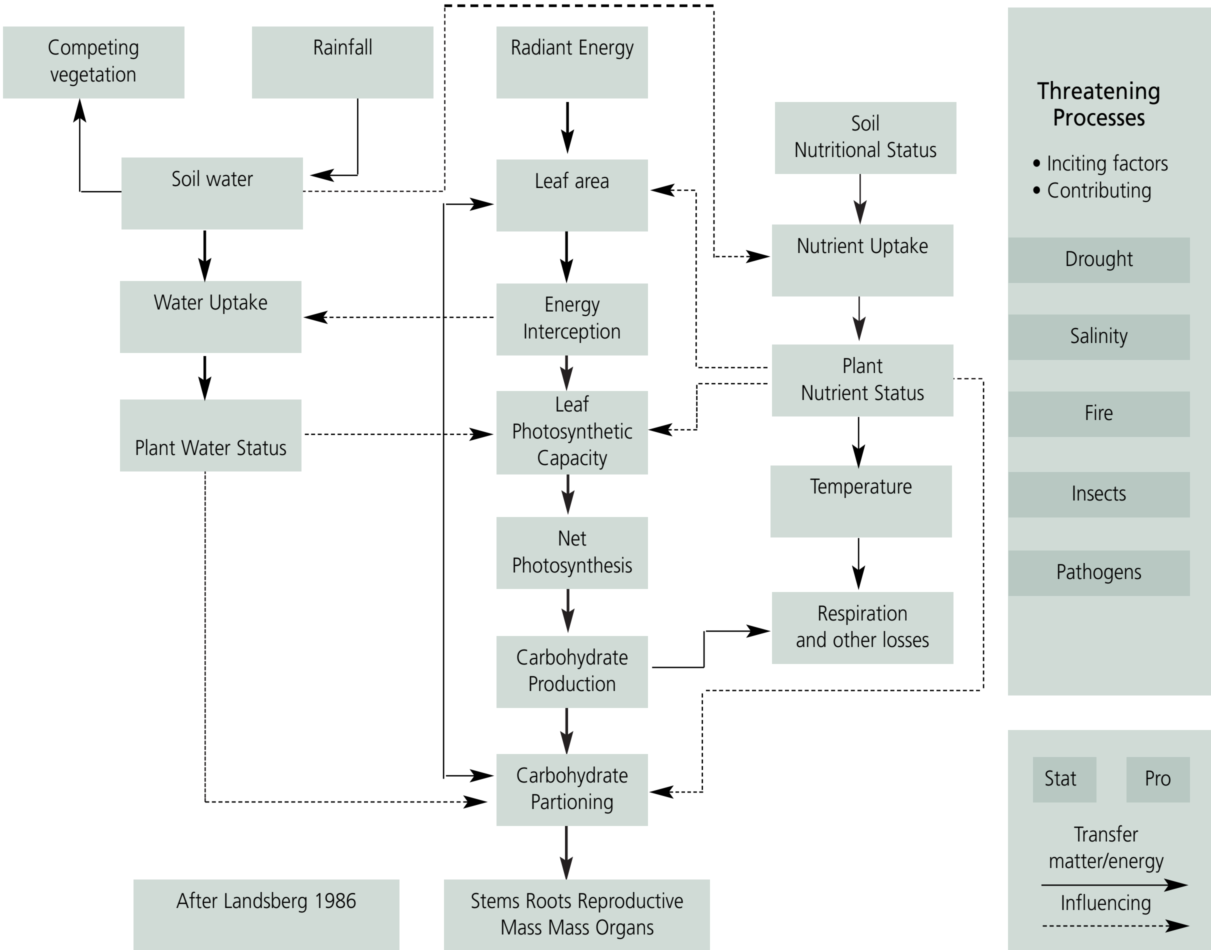
In performing its function the Tuart Response Group shall:

- 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; and
- 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.

Deliverables required from the Tuart Response Group:

- a Tuart Conservation Strategy and Implementation Plan; and
- a Communication Strategy covering the various types of information required by the public.

TUART VEGETATION SYSTEM HEALTH MODEL



APPENDIX 11

OUTCOMES FROM THE TUART SCIENCE WORKSHOP

Existing background knowledge

- Tuart range is relatively limited compared to its pre-European extent, with a number of current threats.
- Detailed knowledge of changes in rainfall and other climatic factors during the last 100 years is available.
- Variability is normal, implying some resilience of vegetation.
- There is a possibility of a general decline in the health and vitality of woodland communities.
- Knowledge has been gained of the biota of the tuart vegetation communities.
- There are links between the *performance* of vegetation and rainfall and evaporation at a broad scale.
- There is a framework for understanding the interaction between predisposing, inciting and contributing factors.

Existing specific knowledge

- There is good knowledge of the groundwater systems of the Swan Coastal Plain.
- There is an understanding of the interactive nature of the factors that control tree health and vitality.
- Tuart is more susceptible to threatening processes than other species (eg. peppermints).
- The effect of tree decline is most severe on the dominant overstorey component in both tuart and wandoo.
- There is evidence of changes in fire frequency and intensity.
- There is knowledge that the insect fauna is likely to cause decline.
- There is some understanding of the fungal pathogens that may have a role.
- There is extensive knowledge of relatively simple soil profiles.
- Relatively simple soil profiles, extensive knowledge.

Rehabilitation and management

- What are we trying to achieve?
- There has been some success, for example in Ludlow.
- The task is not complete. Management systems need to be developed so that tuart regeneration survives and that the tuart species establishes its natural dominance.
- The physical, chemical and biological integrity of soil is essential.
- For regeneration to succeed the trees must produce adequate seed which must continue to survive and produce seedlings. .
- The control of pests and weeds is essential.
- There is an important role for fire and nutrition.
- There is a need for a greater focus on the rehabilitation aspects of the problem.

Knowledge gaps

- What are we trying to achieve?
- What are the scientific and social benchmarks?
- What is the actual diagnosis of the cause? Could it be water?
- There is a lack of climatic knowledge before the 1880s.
- Short and/or continuing drought may play a role.
- Could changes to groundwater be related to reduced winter rainfall (general effect) and groundwater extraction (spatial variability).
- Does tuart use groundwater sources?
- How does vegetation structure change from place to place (spatially)?
- Is there a changed role in the competition for nutrients and water after fires?
- What is the role of nutrient supply in the health of tuart trees? Nutrients alone are unlikely to be a major factor.
- Knowledge of pathogens is limited.
- Has the most active stage of the decline occurred? Are we now looking at primary or secondary effects?

OUTCOMES FROM THE TUART SCIENCE WORKSHOP

Research approach

1. An integrated approach is needed showing causation chains, underlying causes, data overlays and surveys.
2. Study the whole ecological community rather than focus on tuart.
3. Undertake targeted research to test simple vegetation system health models such as Ockham's razor.
4. Comparative ecophysiological research is needed to reveal:
   - if tuarts have declined in some areas more than others,
   - why tuart has declined rather than other species in the ecosystem, and
   - why some tuart trees experience more severe stress than others.
5. Manipulate the system through various thinning, fertiliser, fire (eg. frequency, intensity, season), irrigation, pesticides, and herbicides regimes.
6. Develop operational treatments at a several hundred hectares scale.
7. Take an experimental approach to test hypotheses and identify management options.
8. Examine climate variability and change using trees rings (dendrochronology and fossil paleochronology) records.
9. Survey affected and unaffected areas.
10. Undertake ecohydrology studies such as:
    - seasonality, quality, extraction;
    - tuart health responses to changes in water availability;
    - measurement of traditional plant water status and water use across seasons;
    - advanced analysis of water fluxes, hydraulic architecture; and
    - contrasts between areas with different health status.
11. Study the impact of pests and disease on tuart health. Concentrate on the likeliest agents.
12. Study the role of insects and other invertebrates associated with tuart in recycling nutrients, pollinating plants, and in maintaining ecological balance with pest insects.

APPENDIX 12

SPECIFICATIONS FOR THE DEVELOPMENT OF THE TUART ATLAS

A PROJECT FOR TUART ASSESSMENT OF THE SWAN COASTAL PLAIN IN WESTERN AUSTRALIA

TITLE

A Tuart Atlas of the extent and condition of vegetation occurring on the Swan Coastal Plain of Western Australia.

CONTACT DETAILS

Mr Drew Haswell
Executive Officer, Tuart Response Group
Coordinator, Tuart Conservation Strategy

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Land Management
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Locked Bag 104
BENTLEY DELIVERY CENTRE 6983
Phone: 9334 0337
Fax: 0334 0458
Email drewh@calm.wa.gov.au

GEOGRAPHIC EXTENT—LOCATION OF WORK

The location is within the south west forest region of Western Australia (after Beard and Sprenger, 1984) Attachment 1). Tuart occurs in a 400-kilometre band of the Swan Coastal Plain near the coast from Jurien Bay in the north to the Sabina River, just east of Busselton.

OBJECTIVE

To develop a Tuart Atlas of the Swan Coastal plain region at a scale of 1:50,000.

OUTCOMES

Outcome 1: T The occurrence and condition of tuart

Outcome 2: The occurrence of tuart outside the reserve system.

Outcome 3: Mapping that builds on:

- the earlier broad tuart overstorey structural units mapped by Speck (1952), that were further developed by Beard (1979a,b,c; 1981) and consolidated by Hopkins *et al* (1996), and Smith (1973; 1974;
- the review of the conservation estate within the System 6 area, by the Department of Conservation and Environment (Heddle *et al* 1980);and
- information derived from plots on the regional floristic groupings of tuart (Gibson *et al* 1994; Department of Environmental Protection, 1996).

Outcome 4: Provide an initial basis for refining the present CAR reserve system for tuart conservation and protection.

PROJECT DESCRIPTION AND BACKGROUND

This project will integrate and build on relevant physical, biological and environmental information to produce a comprehensive Tuart Atlas.

STUDY DESIGN AND METHODS

Task A: Assimilate data

This will be done by:

- collating all relevant published and unpublished information,
- acquiring remnant vegetation, soils and physical items (houses, roads, developments, mines) to provide working maps to record aerial and detailed 'ground-truthing' data,
- editing intersection boundaries to provide seamless integrated datasets, and
- arranging high resolution aerial photography the Department of Conservation and Land Management.

Task B: Survey

A survey will:

- use aerial photography to assess the condition of tuart,
- devise appraisal methods that distinguish continuous, patchy or sparse canopies,
- devise appraisal methods to distinguish different degrees of understorey clearing,
- integrate canopy density and understorey data with information about soils, landforms, geomorphologic units and climate zones,
- nominate areas of high conservation value for follow-up ground-assessment,
- use aerial assessment to validate the survey,
- on the ground, validate high potential conservation value areas by tagging each tree in 400 square metre plots for epicormic growth, percentage of live and dead leaves and crown, potential causes of physiological stress, condition of the leaves and insect damage, and
- in 100 metre plots, comparing tuart frequency and presence with previous research.

Task C: Develop the Tuart Atlas

- All information will be put into digital form.
- Maps and explanatory text will be prepared.
- Boundaries that interface with System 6 will be edited and incorporated with comprehensive vegetation mapping undertaken for the Regional Forest Agreement, and other relevant vegetation mapping.

Task D: Prepare Other Reports

- A detailed analysis of the locations of high value tuart occurrence and condition, and recommend areas (i) for inclusion in the secured conservation estate, or (ii) in need of special protection and management programs will be prepared.
- A final report suitable for scientific publication evaluating the distribution of the tuarts' canopy density and condition in relation to soils and landforms, geomorphologic units, climate zones and land use will be prepared.

QUALITY ASSURANCE

The successful contractor and/or employed staff will be experienced and have expertise in plant and forest ecology, botany or environmental sciences, and ensure the reliability of collected data.

DATA RELIABILITY

A reliability code will be assigned to each integrated tuart canopy density and condition class, indicating the degree of confidence in the assessment of its conservation value. Very high reliability will be assigned to tuart classes which have been 'ground-truthed' and have been subject to previous fine scale vegetation mapping. Low reliability will be assigned to tuart classes that have been assessed from aerial photography only, and where remnant vegetation, and soil and landform data is unreliable or not available.

OUTPUT DATA REQUIREMENTS

All information collected will be digitally captured. The Department of Conservation and Land Management will be the owner and custodian of all of this data and information.

New site data will be compatible with existing Department of Conservation and Land Management databases, and the proposed Vegetation Complex Update of the Swan Coastal Plain. Methods for collecting site survey data and allocating tuart occurrence according to tuart canopy density and condition classes will be documented.

INPUT DATA REQUIREMENTS

The Department of Conservation and Land Management's 1:50,000 scale map series will provide base level information for the project. In addition the detailed mapping at 1:10,000 of ground-truthed areas of the region will be used as input to the 1:50,000 scale Atlas mapping. Existing vegetation classification systems, to be used include those referenced in Speck (1952), Beard (1979a,b,c; 1981), Smith (1973; 1974), Hopkins et al (1996); Heddle et al (1980); Gibson et al (1994) and the Department of Environmental Protection (1996), and FMIS types and tree associations. Other essential input GIS datasets available to the successful contractor under licence agreement include:

- remnant vegetation from the Department of Agriculture;
- soils and landform from the Department of Agriculture;
- topographic data layers (roads, hydrography, cultural, relief) from Department of Land Administration (DOLA) and the Department of Conservation and Land Management; and
- cadastre and tenure information (State Cadastral Database) from DOLA and the Department Conservation and Land Management's Tenure Information System.

Digital aerial photography, imagery, maps and other GIS datasets held by the Department will also be provided. Transfer of data between the Department and the successful contractor will be covered by data licensing agreements restricting the use of the data to the project.

All voucher material will be lodged with the State Herbarium.

INDICATIVE TIMEFRAME [24]

Task A:	Assimilate data	Completion date 8 July
Task B:	Survey	Completion date 2 August
Task C:	Develop Tuart Atlas	Completion date 30 August
Task D:	Prepare final reports	Completion date 30 September

MONITORING

The project will be supervised by the Tuart Response Group comprising representatives from the Departments of Conservation and Land Management, Environment; Water Catchment Protection, Planning and Infrastructure and Agriculture, the South West and Peel Development Commissions, the Tuart Coalition and the Lake Clifton Landcare Group. The Tuart Response Group reports to the Minister for Environment and Heritage. Botanical and survey standards will be set and monitored by the Department of Conservation and Land Management's Science Division.

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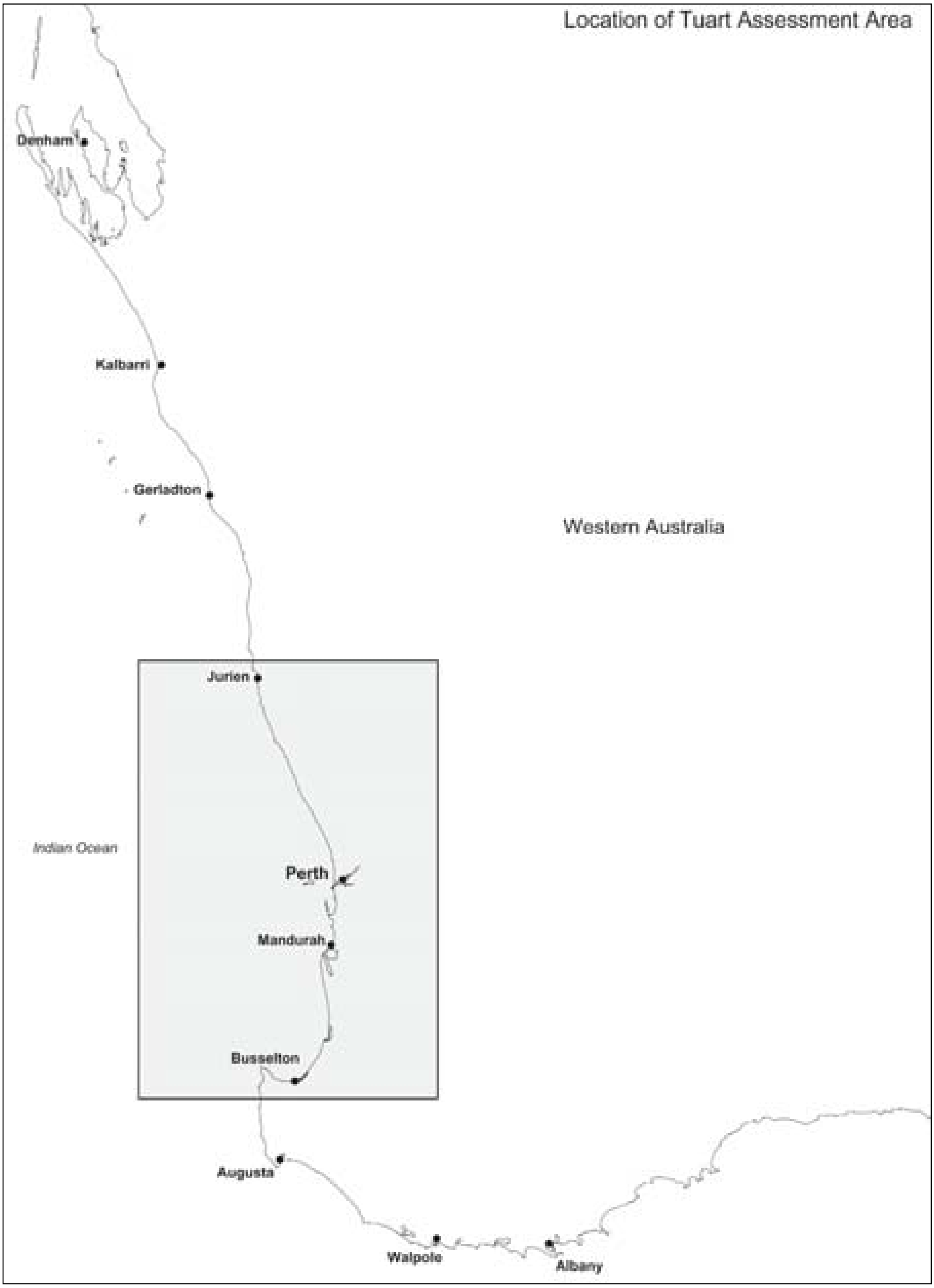
[24] Starting and completion dates to be confirmed on award of the contract.

ATTACHMENT 1: Location map for the development of the Tuart Atlas



DRAFT STRATEGY TO CONSERVE AND PROTECT TUART

VISION

Tuart trees, associated vegetation and ecosystems are valued by the communities of Western Australia for the range of benefits they can provide. They will therefore be conserved, protected and enhanced for future generations to enjoy.

OUTCOMES

1. Knowledge and community awareness of tuart trees, associated vegetation, and ecosystems, and its various values and benefits are improved and shared.

2. Partnerships are built within and between community groups with differing interests in tuart trees, associated vegetation and ecosystems.

3. Tuart ecosystems and associated vegetation are adequately represented, conserved, protected and managed to enhance the variety of benefits they provide, especially for maintaining biodiversity and ecological functioning.

4. Tuart trees and stands are identified and sustainably managed on private lands, and plans are developed and implemented to restore and rehabilitate them.

5. A shared understanding of the role of tuart trees, associated vegetation and ecosystems in the landscape is developed, and demonstrated in plans and processes for State and regional development.

6. Institutional arrangements to conserve and protect tuart trees, associated vegetation and ecosystems are in place, and incentives continually improved to support land owners and land managers.

Existing Actions (for each outcome 1–6)

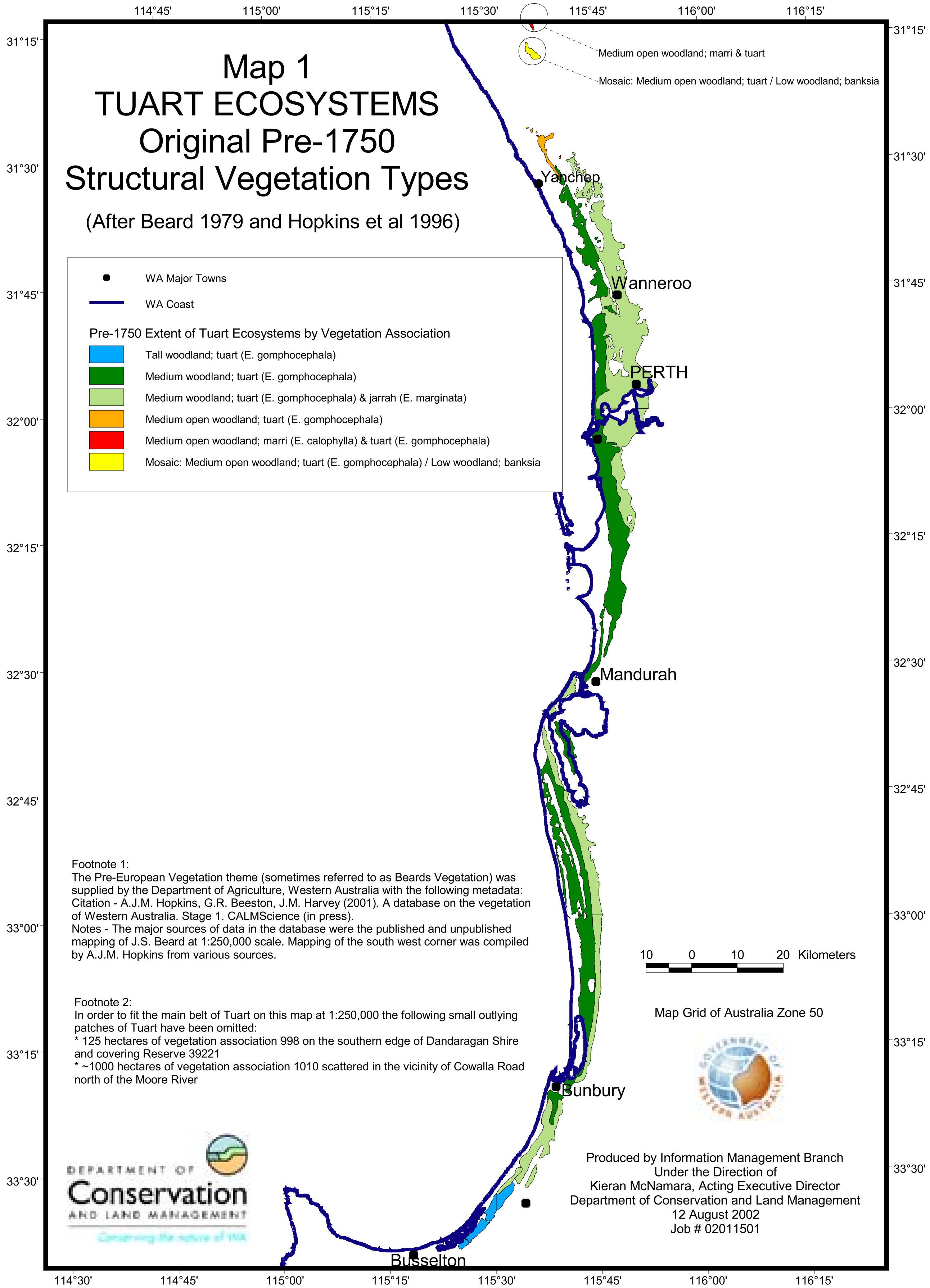
Aims
Options
Strategies
Targets

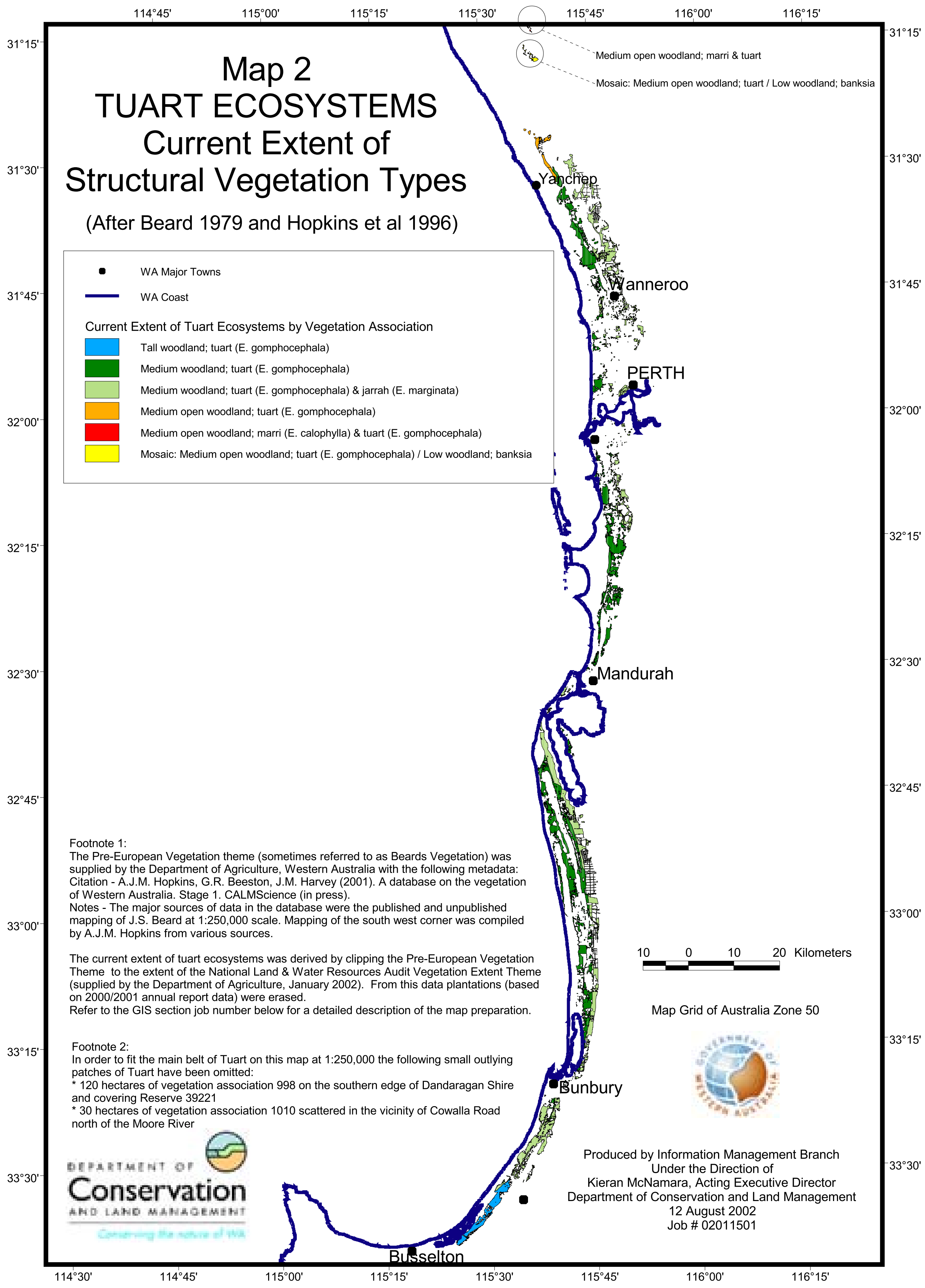
Statements of intent regarding the implementation of the Tuart Conservation Strategy

Adaptive Management

IMPLEMENTATION
PERFORMANCE ASSESSMENT

Adaptive Management


Map 1
TUART ECOSYSTEMS
Original Pre-1750
Structural Vegetation Types
(After Beard 1979 and Hopkins et al 1996)
WA Major Towns
WA Coast
Pre-1750 Extent of Tuart Ecosystems by Vegetation Association
Tall woodland; tuart (E. gomphocephala)
Medium woodland; tuart (E. gomphocephala)
Medium woodland; tuart (E. gomphocephala) & jarrah (E. marginata)
Medium open woodland; tuart (E. gomphocephala)
Medium open woodland; marri (E. calophylla) & tuart (E. gomphocephala)
Mosaic: Medium open woodland; tuart (E. gomphocephala) / Low woodland; banksia
Medium open woodland; marri & tuart
Mosaic: Medium open woodland; tuart / Low woodland; banksia
Yanchep
Wanneroo
PERTH
Mandurah
Bunbury
Busselton
114°30'
114°45'
115°00'
115°15'
115°30'
115°45'
116°00'
116°15'
31°15'
31°30'
31°45'
32°00'
32°15'
32°30'
32°45'
33°00'
33°15'
33°30'
Footnote 1:
The Pre-European Vegetation theme (sometimes referred to as Beards Vegetation) was supplied by the Department of Agriculture, Western Australia with the following metadata:
Citation - A.J.M. Hopkins, G.R. Beeston, J.M. Harvey (2001). A database on the vegetation of Western Australia. Stage 1. CALMScience (in press).
Notes - The major sources of data in the database were the published and unpublished mapping of J.S. Beard at 1:250,000 scale. Mapping of the south west corner was compiled by A.J.M. Hopkins from various sources.
Footnote 2:
In order to fit the main belt of Tuart on this map at 1:250,000 the following small outlying patches of Tuart have been omitted:
* 125 hectares of vegetation association 998 on the southern edge of Dandaragan Shire and covering Reserve 39221
* ~1000 hectares of vegetation association 1010 scattered in the vicinity of Cowalla Road north of the Moore River
10 0 10 20 Kilometers
Map Grid of Australia Zone 50
DEPARTMENT OF Conservation AND LAND MANAGEMENT
Produced by Information Management Branch
Under the Direction of
Kieran McNamara, Acting Executive Director
Department of Conservation and Land Management
12 August 2002
Job # 02011501



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