Research into the causes and management of tuart decline

Report of Phase 1 Activity (July 2003 – June 2006) and Phase 2 Objectives (March 2006 – Feb 2009)

Editors: Paul Barber and Giles Hardy

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FOREWORD

Decline of our woodlands of great concern

Tree declines are now a common phenomenon across a wide range of eucalypt species throughout Australia. There is considerable concern about the rate of spread and intensity of these declines and the subsequent impact they are having on ecosystem function and health.

In Western Australia the most prominent declines occur in *Eucalyptus gomphocephala* (tuart) and *Eucalyptus wandoo* (wandoo), although *E. loxophleba* (York gum), *E. marginata* (jarrah), *E. rudis* (river gum), *E. salmonophloia* (salmon gum) and *Corymbia calophylla* (marri) are also impacted upon. Most of these tree declines appear to be due to complex interactions of biotic and abiotic factors with no single cause. These include: (i) habitat loss and fragmentation, (ii) changes in land management, e.g. fire management, forestry practices, (iii) changes in hydrology, (iv) pests and pathogens and (v) climate change.

In order to bring about the effective mitigation and management of these declines it is critical to conduct well planned and integrated research across a range of scientific disciplines. Without a coordinated approach, research activities will be *ad hoc* and short term.

Since 2003, the Tuart Health Research Group (THRG) has set in place a coordinated research approach to tuart decline with an emphasis on the Yalgorup National Park, where the decline is extremely severe. The THRG is made up of a number of university, agency and industry partners and has implemented research into tuart water relations, soil hydrology, soil and plant nutrition, mycorrhizal fungi, insect pests, soil-borne and foliar pathogens, fire and competition and the use of Geographical Information Systems to monitor and database the different factors involved in tuart decline. While conducting this research, the THRG has also looked at a range of management options – this includes tree injections with phosphite, nutrients and insecticides to provide managers and landholders with the potential to halt the decline of trees while the research determines the possible cause(s). Preliminary results are very encouraging.

Since its inception in 2003 the THRG has grown substantially in its research activities, its collaboration between research groups and its involvement with industry, agencies and community groups. In 2006, the THRG started its second phase of research and management activities. These are reinforcing what was started in 2003 with additional research into tuart restoration, soil microbial biodiversity, multi-spectral imagery and the impact of tuart decline on fauna.

In order to ensure the outcomes of its research activities reach managers, landcare groups and small landholders, the THRG has also implemented a communication strategy. The communication strategy includes a website, regular bulletins, signage to be placed in strategic locations throughout the tuart range and a Woodland Decline Symposium to be held in November 2006.

We are very excited about the diversity of integrated research activities that are being undertaken by the THRG and the huge amount of support it has and is receiving. Effective research is critical in order to understand what is driving the decline of tuart. We believe that the THRG has put in place a comprehensive and well integrated research program to start understanding the processes involved in tuart decline. The THRG with its communication strategy is also ensuring that research findings will be rapidly disseminated to the wider community in an effective manner. More importantly, the research of the THRG has huge regional and national relevance for tree declines throughout Australia.

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We believe that the THRG has been extremely successful in a very short time considering limited funding to date. This success is due to the effective collaboration between universities, agencies, landcare groups, industry and landholders. The following report outlines the activities of the THRG and provides a brief overview of some of the findings to date. We welcome any feedback on this report especially if it will help assist us in obtaining our goal of controlling tuart and other tree declines in Australia.

Associate Professor Giles Hardy
Chairman, Tuart Health Research Group (THRG)

BACKGROUND

Tuart (*Eucalyptus gomphocephala*) is a woodland tree endemic to the Swan Coastal Plain of Western Australia, and is one of the few eucalypts that is adapted to calcareous soil profiles (Eldridge *et al.* 1994).

Prior to European settlement there were more than 111,600 ha of tuart woodlands (Hopkins *et al.* 1996) but this has been reduced to 30,311 ha (Government of WA 2003). In the Yalgorup region, ca. 100 km south of Perth, tuart is undergoing a severe decline. These woodlands were noted to be "mostly in very good condition" in 1993 (Portlock 1993).

In the early 1990s the decline of tuart woodlands in Yalgorup became severe causing public awareness and concern. In 1997, a major dieback occurred near Preston Beach, 30 km south of Mandurah, where tuart trees across all age classes declined and mortality was more than 90 per cent (Government of Western Australia 2002). Aerial mapping and Landsat imagery have shown a dramatic increase in the extent of the decline in Yalgorup since 1999 (Government of Western Australia 2002).

The loss of tuart will have a severe impact on fauna. For example, the western ringtail possum (*Pseudocheirus occidentalis*), classed as vulnerable, lives in tuart woodlands in the northern part of its range (Maxwell *et al.* 1996). Further, it is expected that loss of tuart woodlands will cause loss of invertebrate biodiversity (Majer, Recher and Ganesh 2000; Recher, Majer and Ganesh 1996). The Yalgorup Lake system is so significant for waterbirds that it is recognised under the international Ramsar Convention (http://www.calm.wa.gov.au/national_parks/previous_parks_month/yalgorup.html). Some of the tuart understorey plants are threatened species [e.g. *Acacia benthamii* (Priority 2), *Jacksonia sericea*, *Lasiopetalum membranaceum* (Priority 3), *Dodonaea hackettiana* (Priority 4)].

Tuart decline is one of a number of recent declines of *Eucalyptus* in Western Australia. A large number of physical and biological factors have been suggested as primary causes of these declines. It is likely that more than one factor is involved, and interactions between two or more factors may be responsible for triggering tree decline (Yates and Hobbs 1997). Some research has suggested predisposing environmental factors include declining water tables, salinity, declining annual rainfall over the last 20 years, increased nutrient enrichment of soils and water-bodies from agricultural practices and urban development, increased use of herbicides, fungicides and insecticides, long periods without fire, and drought stress caused by overstocking of understorey species. Overlying these possible predisposing environmental factors is the presence of insect infestations and possible pathogens (Shearer 1992; Abbott 1992).

Climatic perturbations to forests do result in stress (Ayers and Lombardero 2000). It has been suggested that as a result of one or more of the factors listed above, biological factors such as opportunistic pathogens and insects contribute to and exacerbate the decline syndrome of eucalypts in eastern Australia (Clarke and Schedvin 1999). The environmental and climatic perturbations brought about by natural and anthropogenic perturbations may be gradual and of low intensity but can lead to substantial shifts in biotic factors that may or may not be detrimental. The biotic factors only emerge as threats after the trees have been predisposed by the environmental factors to their attack. Therefore, it is likely that we are observing a complex disease etiology in tuart decline. For example, annual rainfall in Western Australia has been declining over the last 20 years (Indian Ocean Climate Initiative 2002). This decline in rainfall will change ambient and soil temperatures, soil moisture conditions, and relative humidity, all of which have been shown to influence the sporulation and colonisation of some forest pathogens (Brasier 1996; Chakraborty, Murray and Magarey 1998; Londsdale and Gibbs 1996). Phase 1 of the ARC funded (Linkage Project LP0346931) research was the first comprehensive study into the causes of tuart decline, examining a range of predisposing and inciting factors and their relationship(s) to the decline (Fig. 1).

Government and community based action, using study results, have devised a Tuart Conservation and Management Strategy draft (Government of Western Australia 2002). Phase 2 of the ARC funded (Linkage

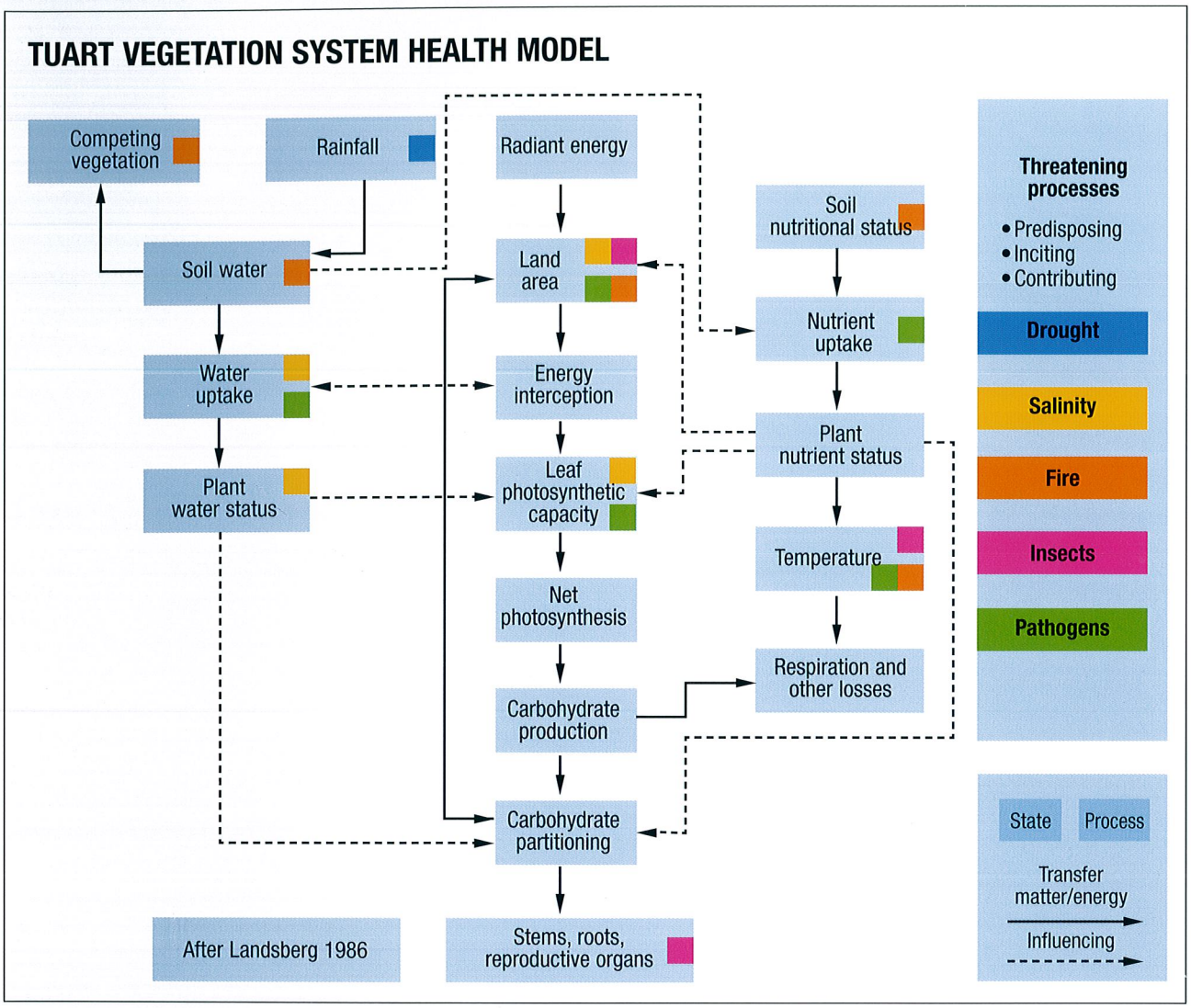

Fig. 1. Tuart Vegetation System Health Model (Government of Western Australia 2002).

Project 0668195) research will build upon research findings from Phase 1 and aim to determine the cause(s) of tuart decline and develop strategies to manage the decline.

PHASE 1 (July 2003 – June 2006)

Aims

Phase 1 of the research program set about determining the cause(s) of tuart decline by:

- developing an understanding of the physiology of tuart in relation to water and nutrient use under different environmental parameters;
- developing a model to describe the morphological/physiological condition of tuart in relation to edaphic (soil type, salinity, water tables), factors across its natural range;
- determining whether pathogens are associated with tree decline and if these are related to predisposing environmental factors;
- describing the insect fauna of healthy and diseased tuart and determine whether systemic insecticides can be used to halt or reverse the decline;
- developing strategies to reduce the impact of decline in tuart based on achievement of the aims above; and
- providing land managers and community groups with appropriate tools to manage tuart decline.

Summary of progress on research activities

Sub-project 1 – Develop a database to analyze the possible environmental and biotic causes of tuart decline

This sub-project will develop a tuart decline database to link the possible interactions between environmental and biotic factors with tuart decline, and establish a permanent and accessible database to monitor and analyse tuart decline over time.

A range of data (climatic, hydrology, geomorphology and soil, pollution, vegetation attributes) have been collected from relevant Government agencies and linked to the health status of the tuart forest across its geographic range. The health status has been collected as a result of establishment of sites (46) throughout the range and assessment of canopy condition of trees at each site as part of sub-project 2. In addition, canopy trend data has been acquired over the past 15 years as a result of spectral data from the LandSat sensor. Aerial photographs at each site have been used to measure features such as fragmentation and subsequent 'ground-truthing' has enabled the tuart forest to be categorised into a series of health categories based on canopy completeness.

All the information acquired externally and by means of ground-based assessments has been compiled into a database and analysed for any possible relationships or interactions with tuart decline (sub-project 2). The 46 sites are now permanent plots that can be assessed for canopy health to monitor their change over time. These plots form the basis for a sub-project within Phase 2 of research into the cause(s) and management of tuart decline.

Sub-project 2 – Environmental correlates and associations of tuart decline

This sub-project will characterise and categorise the spatial patterns of tuart decline across its range and identify relationships between these patterns and abiotic and biotic variables (in order to formulate causation hypotheses).

Field data were collected from 46 sites across the tuart range to include trees of all health categories, ranging from healthy through to severely declining. Together with data from sub-project 1 and other research activities, relationships between canopy decline and environmental conditions were explored. At each study site the canopy condition of no less than 20 trees was assessed using estimations of canopy completeness, measures of canopy size reduction, and through the scoring of canopy condition indices.

The second phase of the study involved collecting data on a wide selection of environmental factors considered to be important to canopy condition. These included factors of stand structure, understorey composition, landform (soil type, geology, topography, and geography), climate (gradients and change), hydrology (depth, depth change and chemistry), fire regimes, pollution and anthropogenic disturbance (fragmentation and site disturbance).

Correlations and associations between variables were explored using standard correlation coefficients and cross-tabulations. Statistical models were established between the measures of tuart decline and environmental variables. Spatial statistics were explored to characterise spatial patterns of the decline. The data acquired in this sub-project helped to target sites for subsequent research activities and also formulate causation hypotheses.

Sub-project 3 – Characterisation of tuart woodland hydrological support mechanisms and predisposition to decline

This sub-project will identify the spatial and temporal variability in hydrological support mechanisms in healthy and declining tuart woodlands and determine the water requirements of tuart and selected dominant understorey species.

Plant water source utilisation was determined by comparing ratios of the stable isotopes of hydrogen (deuterium, δ^2H) in plant vascular water with measurements in rainwater, soil water and groundwater. Rainfall samples were collected monthly and meteorological stations logged rainfall, air temperature and evaporation throughout the study. The soil profile was sampled quarterly at each site and δ^2H measured on extracted water. Soil moisture content was measured with a neutron probe or gravimetrically depending on depth to water table. Groundwater samples were taken quarterly and water table levels measured monthly from monitoring bores installed at each site.

Plant xylem water samples were obtained from trees of different size classes at each site on a quarterly basis for the duration of the project. A time course of the ^{2}H composition of xylem sap water in tuart was plotted with ^{2}H composition of groundwater and soil water to illustrate the seasonal changes in source water utilisation and highlight any differences between healthy and declining trees. A three-component water-source mixing model was then applied to the data to determine the relative contributions of the potential water sources to the xylem-water of the study species.

Predawn shoot water potentials (MPa) were measured in tuart to assess plant water relations in healthy and declining trees. Data were collected monthly over an 18 month period at each site to encompass differences in depth to water table and also size class. Water use (sap flow) was measured quarterly (continuous for a fortnight) on two tuart trees per site using the compensation heat-pulse technique. The sap flow velocity was determined using a Sapflow Sensor unit. Stomatal conductance was measured to determine differences and changes in stomatal control with a portable gas-exchange measurement system.

Sub-project 4 – Isolation and identification of pests and pathogens associated with tuart

This sub-project will determine if potential pathogens and/or insect pests are associated with tuart decline.

Sixteen trees, paired according to their size class and health status (declining, healthy), were excavated and intensively sampled. Prior to felling the selected trees, a range of tree health and growth characteristics were measured. Trees were then felled at ground level and cut into billets at every 50 cm and examined for potential pathogens and pests.

Billets were assessed for lesions and incipient rots and root systems were exposed using an AirSpade®. This exposed the major lateral roots allowing careful examination of secondary and fine roots for decay and necrosis. Potential fungal pathogens were isolated from stems and roots using a variety of techniques. Isolates of interest were characterised using a combination of morphological and DNA-based techniques and placed in long term storage for future reference. Pathogenicity testing of putative pathogens was conducted in the glasshouse. A range of inoculation trials and soil bioassays were conducted on tuart seedlings in the glasshouse and field.

Insects were collected, counted and identified from branch and trunk galleries and foliage. The internal and external surfaces of the billets were assessed for damage by borers (*Phoracantha* spp.) and other insects by recording the presence of galleries, lateral tracks, frass, vents, kino stains, cracks and swellings.

Sub-project 5 – The role of competition in the health and vitality of tuart

This sub-project will determine if the removal of understorey reduces the competition for water and nutrients to tuart.

Sites were selected where tuart was already exposed to severe competition from a dense understorey. The understorey was removed by mechanical and combined mechanical and fire methods. A controlled burn was completed and pre and post-burn canopy health and tree vitality of tuart and understorey species was assessed. A separate ashbed regeneration trial was established to determine the ashbed effect and also the effect of competition with the mid-storey species, *Agonis flexuosa* (Western Australia peppermint). Sites featuring dense peppermint, moderate peppermint and no peppermint, as well as sites with removed ashbed litter and those with ashbeds were selected. Growth and vitality of tuart seedlings was assessed over 12 months and foliar nutrient status and mycorrhizal association of seedlings determined.

Sub-project 6 – Determine if insecticides and fertiliser usage can be used to reduce the rate of tree decline

This sub-project will determine whether insect attack can be halted through the integrated use of insecticides and fertilizer applications, and provide community groups and land managers with appropriate knowledge on fertilizer usage and methods and rates to inject trees with insecticides, if appropriate.

A suitable site on private property containing mature tuart in severe canopy decline was chosen for a cross-classified designed injection trial. Traditional fertiliser application to the ground was not pursued due to the error associated with localising treatments to individual trees and also the high possibility that trees with roots of such poor health would be unable to uptake the required nutrients. A cross-classified design was incorporated to allow the testing of a wide range of treatments, including three rates of potassium phosphonate, a systemic insecticide (Acecap 97® ai:

acephate), a Complete Nutrient (N, P, K, Zn, Mn, Fe), iron, and zinc. Prior to injection trees were assessed for their canopy condition and foliage was analysed for its nutrient status. Canopy health was monitored every three months for a period of 12 months and the foliar nutrient status was assessed six months after the injection.

Other related research activities

The THRG is aware that the cause(s) of the decline of tuart is likely to be complex and will require an adaptive, collaborative and integrated approach to the research. Where opportunities have arisen, new research studies have been established and adopted by talented students at Murdoch University.

Nutrition and mycorrhizae

A preliminary study identified some unusually low levels of particular nutrients in the foliage of tuart occurring in Yalgorup. This study was expanded to include a more detailed research project investigating the role of zinc in the decline. Nutrition of eucalypts is directly related to their association with beneficial mycorrhizal fungi. Again, a study was established to conduct a survey of these mycorrhizal fungi at one of the declining sites and a separate study has documented the abundance of mycorrhizal fungi associated with fine roots of tuart after exposure of root systems using the Air-Spade®.

Foliar and stem fungi

Relative to those *Eucalyptus* species which are utilised as a valuable source of pulp and timber, very little is known about the fungi that are associated with tuart. One of the original hypothesis put forward for the cause of tuart decline in Yalgorup in the early 1990s was a group of stem-infecting fungi known as *Botryosphaeria* species. Some species within this genus are regarded as important pathogens of woody hosts. A survey was conducted to identify *Botryosphaeria* species occurring in declining tuart woodlands.

Field observations conducted in Phase 1 also identified an aggressive foliar pathogen, *Mycosphaerella cryptica*, causing damage to regenerating stands of tuart in Yalgorup. Wider surveys have since been conducted to determine its presence and impact. Pathogenicity trials have also been conducted in the glasshouse with this species and others of the same genus on tuart seedlings to determine mode of infection and symptom development. A study was also conducted on the incidence and severity of *M. cryptica* on tuart seedlings as part of the ashbed trial (Sub-project 5).

Key findings of Phase 1

The following are the major findings from research carried out in Phase 1.

- The disease syndrome of unknown cause(s) labeled as tuart decline by the THRG is at present confined to Yalgorup, although levels of less severe decline of differing cause(s) occur outside the national park (sub-projects 1 and 2).
- Compared to other tuart regions, the decline in YNP shows a high correlation with higher rainfall, finer and shallower soil, higher groundwater alkalinity and salinity, and greater rates of groundwater salinity increase. These findings are still preliminary and require further research to determine whether this hypothesis holds (sub-projects 1 andand 2).
- A conceptual model of tuart canopy decline with hypothesized processes of regional scale canopy decline, and severe canopy decline in the Yalgorup region has been developed (sub-projects 1 and 2).
- Tuart uses a combination of capillary fringe and shallow soil water, with no apparent water source partitioning occurring between size classes. Seedlings are more susceptible to loss of xylem function with the onset of water stress than saplings or mature trees. Nevertheless, critical water potentials for loss of xylem function were rarely breached in any size class or location over an 18 month period (sub-project 3). This 18 month period included one of the driest years on record.
- Fine feeder root necrosis is associated with declining trees within Yalgorup and *Pythiaceous* organisms are recovered frequently from these roots (sub-project 4).
- There appear to be fewer mycorrhizal pads associated with declining trees than healthy trees and this observation is closely associated with fine feeder root necrosis (sub-project 4).
- Seedlings exhibit greater rates of survival and growth on ashbeds compared to off ashbeds. *Agonis flexuosa* is not alleopathic to tuart and does not significantly alter the growth of tuart seedlings due to competition (sub-project 5).
- Trees respond well to systemic injection with zinc, complete nutrients either separately or in combination with low rates of potassium phosphonate (sub-project 6).

- Trees growing in Yalgorup with symptoms of severe decline have different foliar nutrient profiles than trees growing outside the partk that are in good health (Other Related Research Activites).
- Trees growing in Yalgorup show low levels of nutrients, in particular, zinc and nitrogen (Other Related Research Activites).
- Seedlings and saplings are infected with a range of pathogens, including *Mycosphaerella cryptica*, which appear to have a significant impact on their survival and growth (Other Related Research Activities).
- GIS mapping has shown that the decline is spreading rapidly through Yalgorup and has been occurring since 1991.

Overall, this work has shown that severe decline of tuart, labeled as 'tuart decline' by the THRG, is confined at present to YNP and is complex with a range of biotic and abiotic factors likely to be involved.

Early research led to the hypothesis that higher rainfall, finer and shallower soil, higher groundwater alkalinity and salinity, and greater rates of groundwater salinity increase, may be key abiotic factors associated with the decline. Water stress, while not being disregarded as a basal element of the decline syndrome, has not been sufficient to cause death during recent seasonal fluctuations. Fire is an important requirement for the successful regeneration of tuart.

Trees suffering from severe canopy decline in YNP exhibit poor root health, in particular fine roots, and a lack of association with mycorrhizal fungi. This may be reflected in the low levels of nutrients observed in the foliage of tuart occurring in the park and the positive response observed after systemic trunk injection with nutrients.

We will now use this knowledge to focus on specific areas of research to determine the cause(s) and provide management solutions. These research areas are outlined in Phase 2 below.

PHASE 2 (March 2006 – Feb 2009)

Aims

Phase 2 of the research program aims to determine the cause(s) of tuart decline and develop management strategies by:

- using remote sensing and GIS technologies to quantitatively map the extent and spread of the decline, provide tools to detect changes in individual tree canopy health, and determine correlations between declining canopy health and edaphic factors;
- determining, through the establishment of a large scale injection trial, whether injections of phosphite and nutrient supplements can halt or slow the rate of decline, and in doing so, provide land managers, community groups, and government organisations with practical and appropriate tools to manage tuart health;
- developing a greater understanding of the physiology of tuart in relation to water use under different environmental parameters;
- understanding the nutrition of tuart in relation to fire, soils, mycorrhizal fungi and tree decline;
- isolating, identifying and determining the impact of Pythiaceous micro-organisms on tuart health;
- determining the relationships between tuart ecosystem health, biodiversity, recruitment, and edaphic factors to ensure development of vegetation management plans for tuart woodlands, and protocols for the restoration of tuart communities; and
- assessing fauna utilisation of tuarts so that the impact of tuart decline on invertebrate and vertebrate fauna may be understood.

Summary of objectives of research activities

Sub-project 1 – Use LandsatTM data to accurately map the extent and spread of tuart decline, and GIS techniques to determine correlations with environmental and biotic factors.

This sub-project will analyse and classify spectral data from the Landsat sensors acquired since 1988 until present to accurately map the extent and spread of tuart decline, and use the classified imagery derived from the Landsat, GIS terrain and soil data as well as spatial registered field data to find correlations between declining canopy health and edaphic factors.

Final outcomes will include:

- an accurate map of the annual spread of tuart decline in YNP since its inception and
- a determination of which edaphic and biotic factors at a stand scale are strongly correlated with declining canopy health of tuart in Yalgorup.

Sub-project 2: Use ground-based methods, and multi-temporal, multi-spectral, high resolution airborne imagery to determine speciation in tuart woodlands and detect changes in moisture status and foliar densities (e.g. LAI) of tuart canopies

This sub-project will provide government agencies and councils with the protocols to accurately map tuart and associated tree species, and will determine whether high-resolution airborne imagery can be used as a tool to detect changes in canopy condition (forest health).

Final outcomes will include the development of high-spatial, remote sensing techniques to accurately map the distribution of tuart and detect changes in canopy health of tuart.

Sub-project 3. Can systemic trunk injections of nutrients and phosphite, singularly or in combination restore canopy health?

This sub-project will determine whether nutrients, and phosphite, have a positive effect on the canopy health of tuart, and provide management options to ensure a high level of survivability of tuart in the future.

Final outcomes will include:

- the development of a trunk injection treatment to halt and reverse decline symptoms in tuart;
- a greater understanding of the likely cause(s) of the decline due to the response of trees to injection with certain chemicals; and
- the preservation of trees before their likely death in the near future.

Sub-project 4. Develop a greater understanding of the physiology of tuart in relation to water use under different environmental parameters.

This sub-project will broaden the existing knowledge on carbon isotope discrimination in tuart to establish a chronology of tuart water use-efficiency and understand the interplay between past environmental variables and the current pattern of canopy decline. It will also increase our understanding of the effect of severe water stress on tuart physiology by lowering the water table underlying a tuart stand.

Final outcomes will include:

- a knowledge of water use efficiency and relationship to canopy decline in tuart.
- information on the response of tuart to severe water deficit in the field; and
- training of a PhD student with strong skills in tree water use efficiency and hydrology.

Sub-project 5. Develop an understanding of the importance of mycorrhizal fungal associations for growth/survival of tuart in calcareous soils

This sub-project will document the biodiversity of mycorrhizal fungi found occurring in association with tuart, determine the dependency of tuart on mycorrhizal fungi for obtaining limiting nutrients such as Fe and Zn in calcareous soils and, finally, determine the impact of fire on mycorrhizal associations in tuart seedling recruitment.

Final outcomes will include:

- the identification of which mycorrhizal fungal groups are important for tuart establishment and growth, and
- the production of spore inocula to be used in conjunction with re-establishment of tuart.

Sub-project 6. Understand factors important for the regeneration of tuart

This sub-project will determine the site and plant characteristics required for natural recruitment of tuart communities, and determine methods to ensure optimal survival of tuart in disturbed sites. It will also develop tools to assist the control of weeds in tuart restoration.

Final outcomes will include:

- the development of protocols for the restoration of tuart communities for landowners, community associations and government agencies.

Sub-project 7. Understand the impact of canopy decline on biodiversity and ecosystem health

This sub-project will determine the status of fauna as a basis of assessing future trends in canopy decline, and assess which and to what extent species and tuart ecological communities are threatened.

Final outcomes will include:

- the development of spatial analytical tools to assist the development of vegetation management plans for preventative and adaptive actions in declining tuart woodlands and ecosystem maintenance in healthy tuart woodland; and
- training a PhD student with strong skills in vegetation and land management.

Other related work

Understand the composition of soil microbial communities between healthy and declining sites

This project will use fatty acid methyl esters and molecular tools to characterise microbial communities and biomass in the soils of healthy and declining tuart.

Final outcomes will include:

- an understanding of soil microbial biodiversity and function in tuart stands of different health status.

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