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Review and synthesis

The Tree Decline Recovery Seesaw; a conceptual model of the decline and recovery of drought stressed plantation trees

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ABSTRACT

Worldwide tree plantations face prolonged drought periods that are predicted to increase in duration and intensity under climate change scenarios. Trees stressed by drought are susceptible to secondary stressors including pests and pathogens. Depending on the timing and intensity of these stressors, their impact may be persistent or acute, with varied temporal and spatial responses by different hosts. There are complex processes involved in tree performance and mortality, and often it can be difficult to identify the leading cause of growth decline and death. However, it is important to recognise that often death can be a gradual process with periods of recovery. While previous models have focussed on the decline of the tree in response to stress, there has been little focus on the recovery from stress. Hence, the development here of the Tree Decline Recovery Seesaw model. This conceptual model is based on the premise that drought stressed trees may alternate between different stages of health through time, particularly those facing intermittent drought over extended periods. This approach takes into account that recovery periods allow for the tree to regain health, and potentially create new opportunities for pest and disease outbreaks. The *Tree Decline Recovery Seesaw* model provides researchers with the understanding of the complexity of drought/pest/pathogen interactions, allowing them to assess the order and severity of the stressors to determine the likely outcome. This paper provides a vital step towards the development of predictive tools for plantation managers. While our model has focussed on eucalypt plantation trees, there is potential to apply the model to other tree species and forms of plant stress.

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1. Introduction

There are complex processes involved in tree performance and mortality, and often it can be difficult to identify the leading cause of growth decline and death (Amoroso et al., 2012). Trees face a diverse range of abiotic and biotic stressors, and based on the order, timing and intensity of these stressors, their impact may be persistent or acute, with varied temporal and spatial expression (Mitchell et al., 2013a). Often death can be a gradual process (Waring, 1987). Response to stress, and subsequent recovery, reflects the history of stressors on growth (Bansal et al., 2013), which may influence the severity of future stressors on survivorship (Niinemets, 2010). However, while the effect of an individual stressor can be predicted, it is very difficult to extrapolate the interactive and the potential additive impact of multiple stressors, which may occur sequentially or simultaneously (Niinemets, 2010). Bansal et al. (2013) examined the role of independent stressors and the combined impact of drought and herbivory, and demonstrated that the impacts of multiple stressors can be antagonistic so are not always equal to the sum of the impacts of the individual stressors. They showed the influence of multiple stressors was dependent on the stress intensity of one or both of the stressors, for example, the combined impacts of drought and herbivory at moderate intensity reduced radial growth in *Pinus* to a larger extent than when either of these stressors affected the host independently (Bansal et al., 2013). Furthermore, acclimation to previous stress can alter plant response to subsequent stressors, for example heat stress tolerance can be enhanced after trees suffer drought stress, or drought stress tolerance can be increased after mild drought if there is sufficient recovery time to enhance root growth, however multifactor tolerance to environmental factors is rare in trees (Niinemets, 2010).

Several conceptual models have been developed to elucidate reasons for tree death. However, the lack of knowledge of tree decline limits the ability of models to predict tree mortality events. The decline spiral model, a multi-factor sequential decline model, divided the interactions into predisposing, inciting and contributing factors (Manion, 1991). Manion's model only considers the "negative influences that predispose, contribute to or incite tree death" and does not account for environmental change (Wang

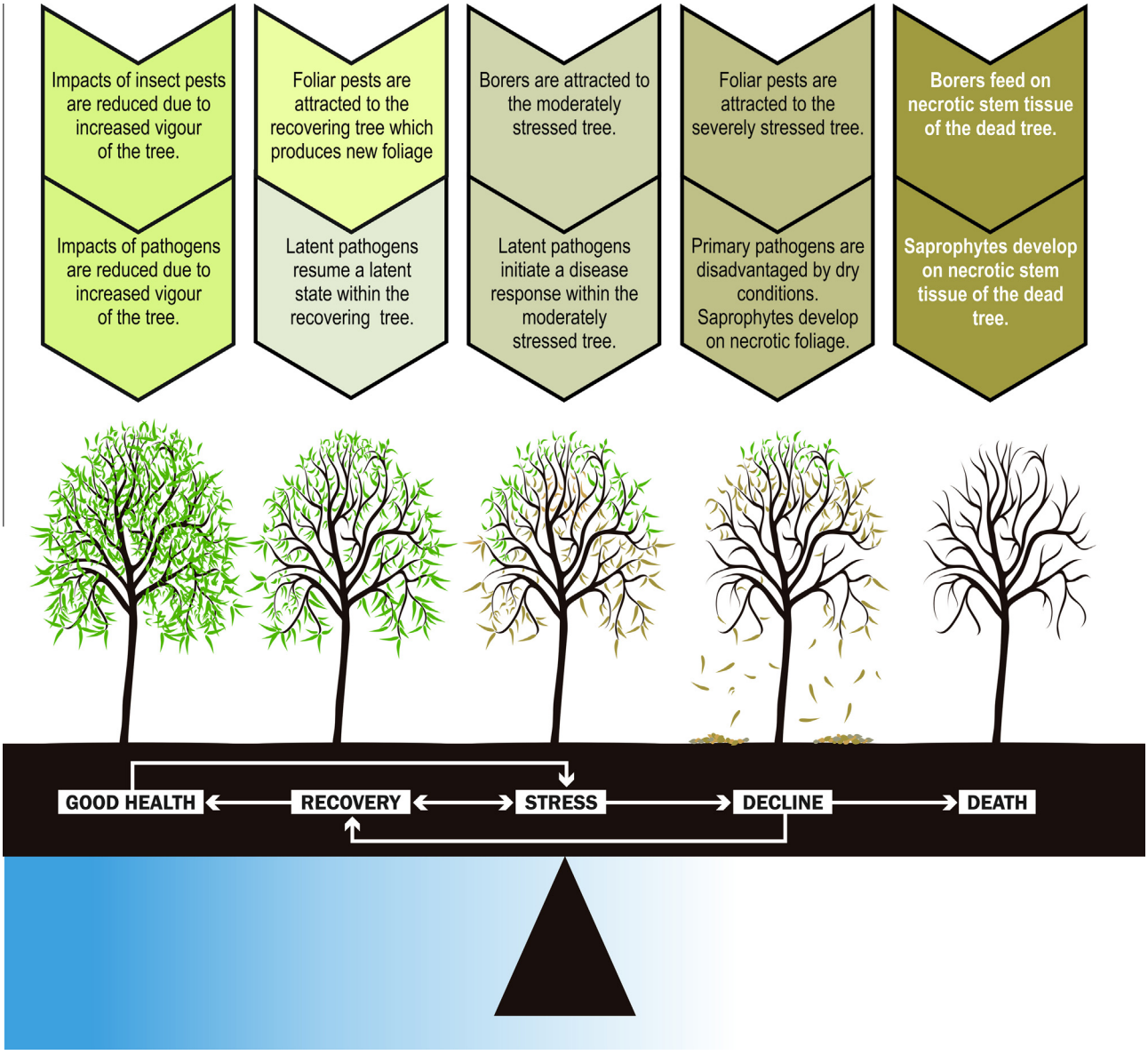

Fig. 1. The Tree Decline Recovery Seesaw model showing a drought stressed tree which may shift between different stages of health, where physical changes occur such as leaf regrowth (recovery), stress or leaf loss (decline), which determines the types of insect pests and pathogens that may exploit the tree.