The ecological impacts of invasive *Pinus radiata* in eucalypt vegetation: pattern and process

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PREFACE

This thesis examines the ecology of invasive *Pinus radiata* and is presented in three sections addressing three major themes in invasion biology; Pattern of invasion, Process of invasion and Mechanisms of invasion impact. The research was motivated by three simple questions; How much invasion has occurred? Which factors are important for pine success? and What is the impact of pines once they have established? An initial introduction to the thesis places invasion biology in the context of broader ecological literature and introduces *Pinus* as a model system for studying invasions. It also outlines the major hypothesis addressed by each chapter. The first section, Pattern of invasion, aims to document the current extent of pine spread in Australia and is composed of a literature review and results of a field survey of plantation sites in New South Wales. The review of *Pinus radiata* invasion in Australia was an early aim of the research and has been accepted for publication. The chapter introduces the study species and provides motivation for the key hypotheses addressed in the remainder of the thesis. The second section, Process of invasion, examines some of the factors facilitating invasion with a specific focus on propagule pressure. This section reports the major vegetation types invaded and considers the role of fire in the invasion process. The findings of this section will be rewritten in a more concise format for submission to a scientific journal at a later date. The final section addresses the Mechanisms of impact and is composed of two chapters. The chapter reporting pine litterfall rates is in press and the second chapter examining the influence of pine litter and shade on native and pine germination has been submitted for publication. The header of each page notes the current chapter and the footer highlights the current section. The aims of each section are outlined at the beginning of the section and the hypotheses addressed are restated.

Because three chapters of this thesis have been written as stand-alone pieces of work for publication, some repetition between chapters was unavoidable. For example the review repeats some of the introductory material and includes some of the information obtained during a questionnaire of relevant personnel outlined in chapter 3. It also contains concluding comments and policy recommendations that are re-iterated in the general discussion at the end of the thesis. As the review outlines measures for pine control they were not considered in any other part of the thesis. The hypotheses stated in the introduction are, more or less, a specific subset of the research questions posed in the review. Chapters 5 and 6 contain introductory material and site details

covered in earlier chapters. While the content remains the same, minor changes have been made to the formatting of each submitted manuscript for general presentation consistency within the thesis. Citation details and acknowledgements of these submissions are provided at the beginning of the chapters. Glenda Wardle was the principal supervisor of this research project and the sole co-author of all submitted manuscripts. She made a contribution to all parts of this thesis through assistance with the conceptual development of the research, experimental design and analysis and helpful discussions and editorial comments on earlier drafts. Data collected as part of my honours project in 2003 was included in some data analyses. In all instances this inclusion has been acknowledged.

The questionnaire presented in chapter 3 received approval from the Human Research Ethics Committee at the University of Sydney prior to distribution. Permission to conduct this research was provided by Forestry NSW and the Department of Environment and Conservation and Climate Change (DECC). Both agencies have undergone name changes during the course of this study. DECC was formerly known as the Department of Environment and Conservation and prior to this, the National Parks and Wildlife Service (NPWS). Forestry NSW was formerly known as State Forests.

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ABSTRACT

Early recognition of plant invaders is key to their successful management. Yet knowledge of the ecological impacts of species before they become widespread is poor. This thesis examines the ecology of invasive *Pinus radiata,* a species which is known to spread from introduced plantings in Australia but is currently a low profile invader. *Pinus* invasions are considered major ecological problems in New Zealand and South Africa where wildlings are beginning to dominate natural areas and suppress native vegetation. Invasion success elsewhere and the large softwood estate in Australia suggest that pines may begin to dominate native eucalypt forests bordering large commercial plantations. This research focused on three components of impact of *P. radiata*; extent, abundance and effect per individual. The borders of 29 *P. radiata* plantations in NSW were surveyed in order to quantify the current level of invasion and to identify factors facilitating pine spread. Of particular interest was the role of propagule pressure, vegetation type and fire in the invasion process.

The area of land in NSW currently invaded by *P. radiata* was estimated at almost 4 500 ha, although this is likely to be an underestimate due to an inability to detect wildlings (self-sown pines) at long distances from the plantation. Twenty six of the 29 plantations produced wild pines, however most of the sites are in the very early stages of invasion. Noticeable wildling populations were recorded at nine sites indicating that *P. radiata* is capable of establishing within native vegetation. Pine spread was most severe in the world heritage listed Blue Mountains region where pine densities reached up to 2000 per hectare in areas adjacent to the plantation and isolated pines were recorded up to 4 km from the source. The presence of isolated pines within intact native vegetation suggests that disturbance is not required for pine establishment in forested environments. Furthermore, high pine emergence and survival rates in eucalypt woodland and evidence of self reproduction by wildlings suggest that in the absence of adequate control measures pines may become established invaders in the Australian landscape.

While low levels of current invasion at many sites hindered the ability to examine the factors facilitating invasion some variables that appear to be driving pine success were identified. At the landscape scale plantation size and residence time were significant predictors of the level of invasion at a site. Areas of native vegetation

adjacent to plantations less than 40 years experienced very low levels of invasion suggesting a lag period between plantation establishment and invasion. However, pines with diameters up to 60 cm were observed growing adjacent to plantations younger than 40 years implying that the first colonisers are capable of establishing soon after plantation trees become reproductive. Propagule pressure was also found to have a strong influence on invasion success on a smaller scale manifesting in a significant positive relationship between the age of a plantation compartment and the likelihood of invasion.

A negative relationship between plantation size and level of invasion was a surprising result and was influenced by just two large sites that happened to be located in areas of high rainfall. All sites receiving more than 1300 mm annual rainfall experienced low levels of invasion suggesting that this is a limiting factor for pine spread in NSW. There were significant differences in the level of invasion between vegetation types implying that some communities are more susceptible to invasion. Patterns of spread confirmed ideas regarding the facilitative effect of disturbance in the invasion process and the resistance of wet sclerophyll forest to invasion in Australia. An absence of wildlings in cleared land and areas of remnant bushland was attributed to high levels of grazing pressure. Wind direction did not appear to influence the distribution of pines close to the plantation, but evidence of long distance wind dispersal of pines was provided by an investigation of pine spread from the air at one site where large pines were found growing 10 km downwind from a mature plantation.

Fire was found to have both a positive and negative influence on the invasion process. High intensity wildfires are capable of destroying large pines with diameters exceeding 50 cm. However, fire can stimulate seed release from cones resulting in large post-fire recruitment pulses. Seedling densities of up to 3050 per hectare were recorded almost 3 years after wildfire, suggesting that follow up control prior to recruits reaching coning age, i.e. within 5 years, would be beneficial. Surveys of wildling pines exposed to low intensity hazard reduction burns suggest that the majority of pines greater than 3 m in height and with a diameter of more than 10 cm will survive the fire. Low intensity prescribed fires that are carried out after pines have reached this size will fail to control wildling populations.

To examine the influence of *P. radiata* once it has established in the native community this study focused on two mechanisms of impact, the addition of pine litter and increased shade due to an increase in canopy cover. Collection of pine litterfall

within an invaded eucalypt woodland over a 2 year period recorded rates of up to 1400 kg/ha/year in the most heavily invaded area with a pine basal area of 11.3m^2/ha. More than 70 % of pine litter fell directly below the pine canopy suggesting that the most severe litter effects will be limited to these areas. Glasshouse and field experiments were conducted to examine the influence of this increased litter load on the emergence of *P. radiata* and two native species. Recruitment of native plant species was impeded by litter levels of 6000 kg/ha, the equivalent of approximately 4 years of pine litterfall. Both *P. radiata* and the two natives responded similarly to pine and eucalypt litter suggesting the two litter types are influencing the recruitment phase equally. However, where pines are added to the system, increased litterfall rates could potentially result in the doubling of the litter load and hence a greater barrier to seedling establishment. Pine invaded eucalypt woodlands are also subjected to three fold increases in canopy cover. Trends in reduced emergence of native species under a pine canopy suggest that the addition of pines to eucalypt forests is likely to have a negative influence on native recruitment and may result in a shift towards a shade tolerant community. However, reversal of trends in emergence below pine canopy between seasons implies that quantifying invasion impacts requires a consideration of temporal variation.

Increased levels of disturbance, forest fragmentation and an increasing pine estate are likely to lead to the infestation of new areas. Furthermore the lag phase associated with pine spread means that even if no new plantations are established the number of invasion events will increase. This study has identified a number of risk factors that can be used to guide plantation establishment and the management of invasion events. Minimising disturbance at plantation borders and increasing the 'no planting' zone will help to reduce the impacts of pines. Where possible new plantations should be established upwind of cleared land or at least, wet sclerophyll forest. Frequent monitoring of the borders of plantations yet to source invasions, particularly those greater than 40 years of age, will help identify problem areas before control becomes difficult and costly. Maps of the 29 plantations marked with areas of pine infestation will help prioritise sites for control and provide base level knowledge for future monitoring of pine spread. Stringent legislation that binds plantation managers to control wildlings beyond their boundaries is critical for the effective management of pine invasions.

With infinite numbers of invaders and limited funds to dedicate to their control, a method of triaging species for management is critical. This is particularly difficult

when information is typically biased towards invaders that are already widespread. By focussing on the ecological impacts of invaders it becomes possible to rank species on the basis of the threat they pose to native communities. Ecological research is capable of providing the knowledge to quantify invasion impacts and must remain at the centre of policy decisions.

STATEMENT OF AUTHORSHIP

Except where reference is made in the text, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma.

No other person's work has been used without due acknowledgement in the main text of the thesis.

The thesis has not been submitted for the award of any degree or diploma in any other tertiary institution.

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27 August 2007

STATEMENT OF CO-AUTHORSHIP

Glenda Wardle was the primary supervisor of the project. Glenda assisted with conceptual development of the project, experimental design and statistical analysis. She also provided useful comments on earlier drafts of the thesis.

Glenda Wardle

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