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“Evaluating the long-term success of native revegetation in the Southern Tablelands, NSW”

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Abstract

Deforestation and degradation of productive lands is an environmental issue facing farming communities worldwide. As a result of past land management practices, biodiversity has been impacted and often irreparably damaged and the resulting landscapes can be devoid of the original functioning ecosystems with impacts across both the biotic and abiotic features of the landscape. Increased knowledge over the past 20-30 years has led to an appreciation and improved effort towards maintaining and preserving remnant ecosystems through fencing and ecological restoration efforts. In some areas however, almost total removal of the original ecosystem has occurred and as such, there is little remnant vegetation to base revegetation efforts on. This lack of a benchmark to work towards has impacted on the subsequent success of revegetation plantings in such regions.

The Southern Rivers Catchment Management Authority (SRCMA) has identified that there is a need to encourage landholders to revegetate at strategic points across properties, however outcomes of previous revegetation has been quite varied. Previous studies have attempted to explain these variations through analysing certain abiotic or biotic components of the revegetation, though few have attempted to investigate the feedbacks between revegetation and soil and the potential link to successful vegetation recruitment. This study examines those potential relationships in an attempt to determine the limitations to persistence and therefore success of revegetation and how this relates to revegetation management in the wider Southern Tablelands area of NSW. Soil and vegetation samples were collected from seven revegetation sites within the Braidwood district and tested for determinable soil and vegetation characteristic correlations. Results revealed little association between soil characteristics and levels of recruitment, rather indicating that particular vegetative components may be more influential in restricting recruitment and continued persistence. These results provide information to decision makers about where best to distribute funding throughout the Southern Tablelands to ensure the benefits of revegetation carried out now continue into the future. The potential for such revegetation to sequester carbon and contribute to future ‘carbon credit’ commodities is also discussed

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“Evaluating the long-term success of native revegetation in the Southern Tablelands, NSW”

By

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The information in this thesis is entirely the result of investigations conducted by the author, unless otherwise acknowledged, and has not been submitted in part, or otherwise, for any other degree or qualification.

- Xanthe Willis

ABSTRACT

Deforestation and degradation of productive lands is an environmental issue facing farming communities worldwide. As a result of past land management practices, biodiversity has been impacted and often irreparably damaged and the resulting landscapes can be devoid of the original functioning ecosystems with impacts across both the biotic and abiotic features of the landscape. Increased knowledge over the past 20-30 years has led to an appreciation and improved effort towards maintaining and preserving remnant ecosystems through fencing and ecological restoration efforts. In some areas however, almost total removal of the original ecosystem has occurred and as such, there is little remnant vegetation to base revegetation efforts on. This lack of a benchmark to work towards has impacted on the subsequent success of revegetation plantings in such regions.

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1 INTRODUCTION

1.1 Context

Throughout the world revegetation is carried out in an attempt to restore habitat (McLoughlin, 1997; Munro *et al.*, 2007), influence and improve water quality (Webb and Erskine, 2003), preserve threatened flora and fauna (McLoughlin, 1997) , control and mitigate soil erosion (Bird *et al.*, 1992), rehabilitate areas devastated by mining (Schwenke *et al.*, 2000) and provide shelter for livestock (McDowell *et al.*, 2006). The removal of woody vegetation has also indirectly led to emission of carbon (Turner *et al.*, 2005) and loss of nutrients (Son *et al.*, 2003) in soils globally and revegetation may provide a pathway to restoring these vital ecological cycles. The potential for revegetation to not only restore habitat but provide carbon sequestration services is a highly relevant topic at this time in the global climate (Specht and West, 2003; Shrestha and Lal, 2006; Yadav *et al.*, 2009; Wang *et al.*, 2011).

Globally, deforestation is identified as one of the major causes of environmental degradation (Food and Agriculture Organisation of the United Nations., 2011). Broad scale rehabilitation and restoration could theoretically stem the progression of deforestation and assist in the restoration of remnant forest and bushland. Restoration is the act of revegetating an area with the intention to return the area to a fully functioning, self sustaining and environmentally resilient ecosystem (Society for Ecological Restoration International Science & Policy Working Group, 2004); the eventual outcome being that the restored area functions as the historic ecosystem would. In contrast rehabilitation aims to revegetate an area to limit degradation but not necessarily with the aim of restoring ecosystem functions (Lake, 2001). Whether the aim of revegetating an area is to return it to a complex ecosystem or to reach another goal, revegetation is a step to re-establishing the extensive forests and bushland that have been modified or lost in the past. This, however, poses the problem of how best to undertake restoration and or rehabilitation efforts and how best to measure if the revegetation has been a success or failure.

Many studies have looked into the best mechanisms to gauge success of rehabilitation through revegetation. Biotic factors such as faunal response to, and use of, restoration plantings (Munro *et al.*, 2007), spider diversity as an indicator of habitat state (Gollan *et al.*, 2010), and ant community structure and species diversity as a measure of restoration progress (Gollan *et al.*, 2011) have all been used in attempts to evaluate the success of rehabilitated and restored areas. Floristic factors have also been extensively investigated in an effort to define the success of rehabilitation plantings. Wilkins *et al* (2003) and Munro *et al* (2008) attempt rehabilitation assessments based on the floristic diversity and structural complexity of restored areas in comparison between remnant, revegetated and untreated pasture. Others have approached the evaluation of success in terms of recruitment and the degree to which a revegetated area is regenerating itself through non-anthropogenic interference (Tucker and Murphy, 1997). Recruitment has also been used as an indicator of revegetation success as it suggests the planting is self sustaining and can persist into the future (Tucker and Murphy, 1997). A functioning healthy ecosystem however includes both the biotic and abiotic factors. Soil and its interactions with revegetation is clearly fundamental to restoring ecosystem processes (Barajas-Guzmán *et al.*, 2006; Farrell *et al.*, 2011). Variations in nutrient values have been attributed to the growth rates of revegetated areas (e.g Schwenke *et al* 2000) and 'breakeven' points in soil organic carbon have been credited to different ages of plantings in Dean *et al* (2012). Wang *et al* (2011) found that there was a positive correlation between revegetation cover and the amount of soil organic carbon sequestered within the sites when compared to untreated cleared land. Though all these parameters are effective, in their own right, at determining some form of success within a revegetated site, there is minimal research which aims to investigate how the abiotic and biotic components of the revegetation system interact and whether there is a positive feedback from this on persistence into the future, in the form of aiding recruitment.

However the revegetation is assessed, using either rehabilitation or restoration values, the need to asses it at an ecosystem level is principle to improving the outcomes of this labour, time and money intensive activity. In response to this is where the aim of this project fits into the picture. Through investigating the benefits to soil from revegetation and assessing this association through the positive feedbacks which may aid recruitment within the revegetation, this project is hoping to provide a range of recommendations which will help to make informed decisions about where revegetation should be located within the landscape to maximise the benefits to the surrounding soil, how revegetation is improving soil characteristics in a way that will add value to a property, how best to distribute funding and labour throughout an area which requires revegetation, and how best to assess the success of revegetation plantings for future improvements in practices, maintenance, sequestration potential and species composition.

Braidwood, a rural community located on the Southern Tablelands of NSW has a number of sites which have been revegetated. The high degree of agricultural modification to the original landscape has highlighted the need to investigate the best methods of encouraging further revegetation on privately owned properties through emphasising the benefits to soil characteristics on a reasonably unproductive sandy soil type and determining if the labour, time and funding put into the revegetation efforts now will continue into the future represented by a healthy, self sustaining, and recruiting ecosystem.

To determine effects on soil from revegetation, a range of soil characteristics will be investigated. The potential to sequester carbon and earn monetary returns from revegetation in the future from ‘carbon farming’ schemes, is an important aspect behind investigating the soil organic carbon levels both within and outside the revegetation sites. The potential for revegetation to influence soil moisture retention both within the site, and through indirect effects of shading and protection, on the surrounding paddocks is the motivation behind measuring trends in soil moisture. The nutrient accumulation capacity of revegetation is investigated through phosphorous analysis to determine whether revegetation in the area improves soil characteristics beneficial to overall property sustainability. The leaf litter biomass is the link between the vegetation and soil characteristics and is investigated in an attempt to determine how the process of litter fall and decomposition positively influences soil characteristics within a site which may in turn facilitate healthier growth and higher recruitment levels. Biotic factors investigated include the actual levels of recruitment and whether they are related to any of the above mentioned parameters to determine if recruitment is occurring currently, possible limitations to recruitment and the potential implications of limited recruitment.

1.2 Aims

The overall aim of this project is to investigate the potential benefits to soil characteristics from revegetation and whether these interactions have any positive feedback benefits in facilitation of recruitment. The broad nature of this aim and the number of associated soil conditions, revegetation parameters and recruitment influences requires a number of specific hypotheses that explore these vegetation-soil interactions. The hypotheses that will be investigated to address the overall aim are:

1. There is a positive relationship between leaf litter biomass, soil organic carbon, soil moisture and available phosphorous within the revegetation sites. This hypothesis investigates the relationship between accumulation of leaf littler biomass in revegetated areas and an increase in positive soil characteristics.
2. There is a positive relationship between leaf litter biomass and the level of recruitment. This directly tests the success of revegetation with regards to self-sustaining native vegetation communities.
3. There is positive relationship between soil moisture and the level of recruitment. This directly tests the success of revegetation with regards to improvement of soil properties positively feeding back to aid recruitment.
4. There is a positive relationship between abiotic factors (SOC, moisture, P and biomass) and revegetation. This hypothesis investigates the relationship between nutrient enrichment and revegetation when compared to the surrounding agricultural areas.

1.3 Thesis Structure

Directly following this introduction is a comprehensive literature review. This chapter attempts to highlight the current situation of revegetation within Australian landscapes and the cost associated with this. Differences in measuring the success of revegetated areas will also be discussed in light of my study which is looking into both biotic and abiotic components of a revegetated area.

An extensive overview of the region in Regional Settings has been included as the topic of the next chapter. The region has been severely altered since European settlement and has only recently (last 20-30 years) had revegetation efforts carried out. In light of this there is a section in the regional settings chapter devoted to the influences and effects of European settlement on the immediate area surrounding the township of Braidwood located in the Southern Tablelands of New South Wales.

The methods chapter will explain the theoretical and practical techniques utilised in the pursuit of the project aims. Each technique will be justified as to the grounds on which it was chosen over other potentially successful methods. The results chapter will summarise raw data in an accessible manner with significant and non significant results highlighted. This is followed by a discussion chapter which will attempt to explain the patterns and associations highlighted within the results. The conclusions and recommendations chapter will draw together this thesis and make suggestions about future research directions in the area of revegetation success studies.

2 LITERATURE REVIEW

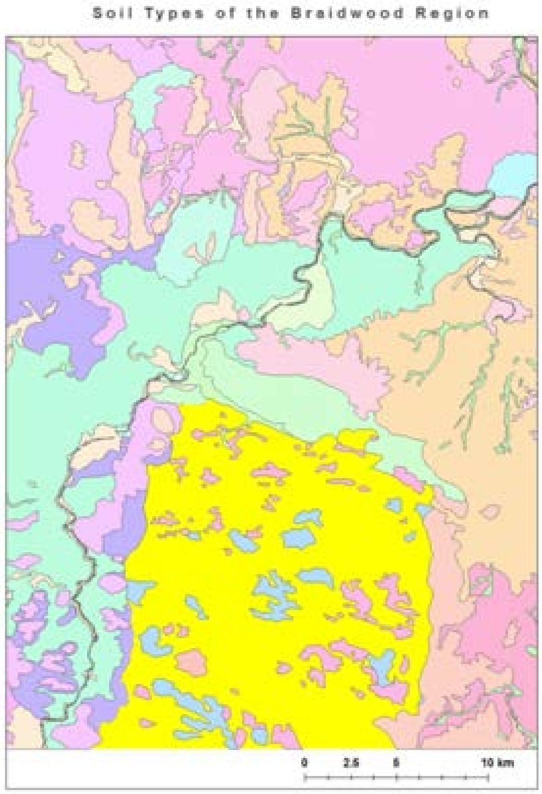
2.1 Introduction

Within Australia the subject of deforestation is a keenly discussed topic among politicians, scientists and the general public. Initially vast swathes of land throughout eastern Australia were clear felled to use as grazing and crop lands by European settlers. Only very recently has the idea of maintaining remnant vegetation within a farming environment become a topic which is even contemplated by the rural and greater community. The advantages of maintaining and rehabilitating vegetation on farms has been clearly discussed in recent autobiographies such as Peter Andrews' 'Back From the Brink' (2006) and John Fenton's 'The Untrained Environmentalist' (2010). As much as some might find these autobiographies potentially un-scientific and certainly representative of the opinions of the authors, they have brought the custom of clear felling and a European style of farming into question among more of the general public than previously. When looking at statistics for rates of deforestation in Australia, in the 10 years to 2010, there has been a net loss of around 160 000 hectares annually with only a small net gain in forested areas since 2007 (Hatton *et al.*, 2011). As the Australian State of the Environment Report 2011 (Hatton *et al.*, 2011) notes however, the environmental worth of revegetation is generally significantly different from the vegetation community that was there previously. Whether there has been a total loss of the original vegetation community, some remnant trees remain or the original environment has been opened to grazing, each represents an altered environment where it is likely that the systems and functions of that community have been disturbed. In an effort to try and re-establish vegetation in the agricultural environment, many farmers have begun to tentatively plant out vegetation onto their land or accept grants and help from government and community groups to revegetate strategic areas of their land.

Braidwood, on the Southern Tablelands of New South Wales, is one such rural area where property owners are beginning to understand the importance of revegetation for retaining moisture, providing habitat and shelter, increasing the amenity and value of their farms, carbon storage and soil cohesiveness. The recently ended drought in the Southern Tablelands has inspired many to invest in revegetation programs to turn bare rocky outcrops or tors which are prominent in the area into vegetated areas. The transformation can be seen in Figure 1 where 1a is the original cleared rocky tor, 1b shows the initial revegetation of the area with hand planted tube stock seedlings and 1c shows the revegetation growth as of February 2012.

Figure 1: The progression from degraded, bare paddocks in 2004 (1a), to being planted out with tube stock seedlings in October 2004 (1b), and the growth visible in February 2012 at Site 8 at 8 years of age (1c). (1a and 1b: G. White 2004, 1c: X. Willis, 2012)

The Braidwood region is a standout for investigation into revegetation and soil interactions as a particular productive soil type in the area (Figure 2a) has been almost totally stripped of any form of remnant vegetation, with any remnants having been influenced directly or by adjacent farming and grazing practices (Figure 2b) (Jenkins, 1996).



a

b

Figure 2: (a) Soil types of the Braidwood region highlighting the granite derived Braidwood soil type in yellow; (b) corresponding aerial photo of the region showing almost total clearance of all native vegetation from that soil type for grazing. (2a: Jenkins, 1996, 2b: Google Earth accessed 24/4/2012).

It is well documented that soil types influence the vegetation and ecosystems which develop on them (Schwenke *et al.*, 2000; Son *et al.*, 2003; Zhang *et al.*, 2006; Bochet *et al.*, 2007; Archibald *et al.*, 2011; Batjes, 2011; Farrell *et al.*, 2011; Wang *et al.*, 2011). In many cases, revegetation efforts are in areas where parts of the original ecosystem still exist on the same soil type (Archibald *et al.*, 2011); therefore there is a benchmark of species diversity, richness and composition to work towards. Revegetation in the Braidwood region is complex due to the almost total lack of remnant vegetation which may have occurred on the specific Braidwood Granites' Soil (Figure 2), therefore there is no benchmark for the revegetation works to pursue. The clearance of this soil type has indirectly indicated that there is a definite boundary between soil types in the area and the assumption is that there would have been a distinct difference in the native vegetation community located on this soil type compared to the surrounding non-cleared vegetation communities. The cleared nature of the area also presents the issue of whether the original community could be recreated and supported in such a modified setting, where original microclimates and ecosystems no longer exist. As such there is no vegetation community benchmark for this particular area and revegetation efforts have tended to focused on what grows efficiently when planted or directly seeded.

2.2 Rehabilitation and Restoration

2.2.1 What is the difference?

Commonly overlooked in the literature and information surrounding revegetation is the definition and original aim of the revegetation being studied and therefore whether the area is actually undergoing restoration or rehabilitation (McLoughlin, 1997; Lake, 2001; McDonald and Williams, 2009). There are distinct and diverse differences between the aims and outcomes of rehabilitation and restoration which are quite often overlooked when the success or merits of revegetation efforts are assessed. It is critical to outline by which standard definition the revegetation is part of, and assessed accordingly. The distinct differences in definitions will impact on whether the revegetation will be determined as a success or failure in the years after planting. It is at this point also that for the purpose of this paper revegetation is clearly defined as the physical planting and growth of any new vegetation on modified landscapes. Revegetation is the process carried out for a number of reasons including farm forestry and forestry operations, ecosystem and biodiversity enrichment, amenity, erosion and water movement control, stock comfort and naturally regenerating vegetation (Atyeo and Thackway, 2009).

There are a number of different terms applied to practices involving revegetation, McLoughlin(1997) has compiled a range of terms which are commonly referred to when the aim of revegetation is discussed. Regeneration is a common expression used and it is generally accepted that it came from the “Bradley method of bush regeneration” (Buchanan, 1989). This method of regeneration involves the removal of weeds from the native vegetation with little other human intervention (Bradley, 1971). Assisted or natural regeneration are terms that have also been interchanged when discussing a method of regeneration which is typical of the Bradley method (McLoughlin, 1997). Enhancement is another expression used when referring to the purpose of revegetation, defined by the Natural Heritage Charter (McLoughlin, 1997) as adding to the natural significance of an area through the introduction of additional seedlings to enhance vegetation and or ecosystem functions within that area . Reinstatement (McLoughlin, 1997), reconstruction (Perkins, 1993), reclamation (Buchanan, 1989) and fabrication (Perkins, 1993) are all alternative names attached to processes, intentions and objectives for revegetation efforts where, fabrication excepted, the main goal is to re-establish a native plant community to return the area to its original standard. Fabrication is the total recreation of a plant community which is tailored to the new site conditions which have arisen since the clearance of the original vegetation (Perkins, 1993). The two main distinctions however need to be made between ecological restoration and rehabilitation.

2.2.2 Ecological Restoration:

Broadly speaking the term 'ecological restoration' has been interpreted to define the processes involved in returning an altered, dysfunctional and or degraded landscape to a functioning healthy ecosystem (McLoughlin, 1997; Clewell *et al.*, 2007; Maron and Cockfield, 2008). Directly defined by the Society for Ecological Restoration; *"Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed"* (Society for Ecological Restoration International Science & Policy Working Group, 2004). The overall aim is to restore a damaged ecosystem to its pre-disturbed condition however the success of restoration is not measured on whether it has achieved its former state but rather that it becomes a functioning, self sustaining and environmentally resilient ecosystem (Society for Ecological Restoration International Science & Policy Working Group, 2004). Restoration is the activity that accelerates the recovery of the ecosystem in terms of the ecological connections and functions of the system, the structure and diversity of species, and the ability of the ecosystem to support biota (Clewell *et al.*, 2007).

As outlined by Dobson *et al* (1997) the use of the word ecosystem implies a greater scope than simply the biotic components and beneficiaries of restoration projects. Thus restoration must recognise the functions and interactions between the biotic and abiotic environment and encompass an understanding of these processes into any restoration works carried out. Should the extent of the restoration be limited to single outcomes, it should not be referred to as ecological restoration but instead perhaps habitat restoration when the aim is to restore a place not the processes within it, or perhaps community and species restoration when referring to a single species or plants and animals only in a particular place (Dobson *et al.*, 1997). Soil and water restoration is also a vital component of true restoration and quality is often a word used when referring to such abiotic factors (Society for Ecological Restoration International Science & Policy Working Group, 2004).

2.2.3 Rehabilitation

The words rehabilitation and restoration are often, and incorrectly, interchanged when referring to revegetation. Rehabilitation is any act which seeks to improve a landscape from a degraded state but not necessarily to a functioning, healthy ecosystem (Dobson *et al.*, 1997; Lake, 2001). Catalysts for rehabilitation include the lowering of water tables, providing shelter for livestock and crops (Bird *et al.*, 1992), improving water quality, improving aesthetic conditions (Lake, 2001), providing habitat (Munro *et al.*, 2008), re-establishing native vegetation to a previously denuded landscape (Dorrough and Moxham, 2005), producing timber (Fenton, 2010), carbon sequestration (Yadav *et al.*, 2009) and land stabilisation (Maron and Cockfield, 2008; Smith, 2008). A study conducted by Smith (2008) found that of the landholders who revegetated parts of their land do so due to two main motives; salinity mitigation and nature conservation, but soil erosion and aesthetics were also factors which determined the choice of landholders to revegetate sections of their properties.

2.3 Australian Expenditure: Australia Goes Green!

Over the previous two centuries of agriculture in Australia, inappropriate farming practices have led to vast areas of land becoming degraded including the removal of many ecological communities. A recognition of this has lead to large scale government investment in natural resource management (NRM) from the 1980's (Atyeo and Thackway, 2009). Since 1990 the Australian Federal Government has introduced seven major NRM projects collectively worth A$6.51 billion with a general trend of increasing the investment into NRM projects common across Federal, State and Territory and Local government (Figure 3). In comparison to other developed nations, the ratio of NRM expenditure to agricultural land area in Australia shows a lower investment than both Europe and the United States (Hajkowicz, 2009).

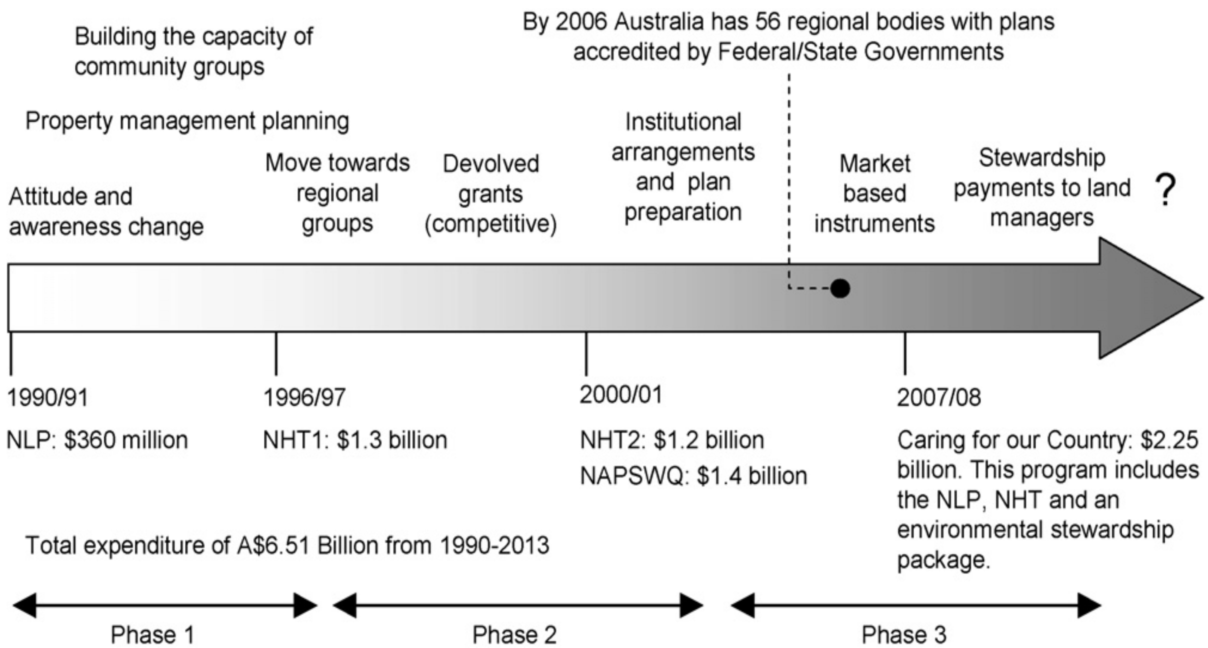


Figure 3: The evolving focus of Australian natural resource management programs. (NLP =National Landcare Program; NHT=Natural Heritage Trust; NAPSWQ= National Action Plan for Salinity and Water Quality) Source: Hajkowicz 2009

The subject of who should supply funding for NRM projects, how these funds should be distributed, how much is being planted for the financial outlay and how much land area has been planted is often overlooked when the funding is divided out. Smith (2008) approaches these questions through a case study in the central 'wheat-belt' region of Western Australia, where the removal of deep rooted trees has led to rising salinity levels and serious environmental degradation. Smith found that of the 37 677ha of the Wallatin Creek and O'Brien Creek catchments, 1750 ha had been revegetated with a total of $3.2 million having been invested. The surprising finding from this study is that of the total amount invested, 77% of that was privately funded by the landholders of the area with the remaining 23% provided by government and other public bodies. This equates to over $1800 per revegetated ha spent on revegetation and with little research or ongoing monitoring of sites except by the landholders themselves, the issue of gauging success has become one which the Australian National Audit Office (ANAO) has highly recommended be rectified (Hajkowicz, 2009). The issue of the area needing to be covered by limited funding is brought to the fore when looking into the unique case of Australian revegetation (Hajkowicz *et al.*, 2005), however this should mean that rigorous effort should be put into monitoring the success of revegetation across all areas so as the limited funding that is available is utilised effectively.

2.4 Gauging Success

Success is a subjective term interpreted in different ways by different people and can be especially subject based when applied to analysing individual aspects of a whole ecosystem (Zedler, 2007). Broadly speaking the term success is defined by the Oxford dictionary as *1. the accomplishment of an aim or purpose, 2. the good or bad outcome of an undertaking* (Oxford Dictionaries, 2010). From this definition and when placed within the context of assessment of revegetation, the revegetation should begin with clearly defined aims and or purposes for comparison along a timeline, and can also be assessed as either a success or failure on account of the outcomes which were defined at the beginning of the revegetation.

The difficulty when gauging success in a multi-faceted system such as an ecosystem is the aspect on which you are gauging success. When applied to restoration of grassy woodlands of the Cumberland Plain, Wilkins *et al* (2003) gauged success through an audit style floristic comparison of revegetated areas to remnant vegetation using untreated pasture as the control. Through comparison of the floristic composition and structure of the restored sites Wilkins found that the restoration works proved somewhat ineffectual at providing a successional pathway towards reaching the floristic goal of restoring the ecosystem to the remnant condition. Interestingly when the planted species where removed from the statistical analysis, the revegetated sites showed no difference in the number of exotics and natives than the untreated pasture and also had significantly more exotic species and less than half of the native species of the remnant sites (Wilkins *et al.*, 2003). This study in particular only assessed the floristic success of revegetation with no attempt to identify potentially contributing soil conditions or faunal responses to the rehabilitation.

Ants provide a unique service to ecosystems and as such they have been viewed as an ideal indicator of restoration success (Fagan *et al.*, 2010) providing clear trends throughout the progression from mine site to rehabilitated ecosystem (Andersen and Sparling, 1997). Though when applied to a revegetation setting through the progression from degraded ecosystems, to young revegetation, older revegetation then mature woodland, species richness of ants did not show as clear a trend as in mine site rehabilitation. The difference between functional ant groups occurred between sites with no significant trend between replicate sites (Gollan *et al.*, 2011). The use of a bioindicator as a measure of success is one approach to determining the success of revegetation and rehabilitation efforts. Though trends in ant communities could provide information about the structural complexity and main species within revegetation (Fagan *et al.*, 2010), they provide little information about the condition of the soil and the effectiveness of the revegetation to stabilise erosion or add to the visual amenity of an area.

2.5 Recruitment

The self propagation of a species is inherent to that species success and persistence in an area (Tucker and Murphy, 1997) and the assumption is therefore made that if revegetation is to become a long term success that continues past the lifespan of the original planted species, seedling recruitment of that planted species is the first step towards this goal. Therefore the initial gauge of success or future success of any revegetation relies on the self propagation of a species within, and hopefully outside, the initially revegetated area. Many factors combine to limit the ability of native species to recruit effectively. Fecundity of the species (Vesk *et al.*, 2010), current and previous land uses (Dorrough and Moxham, 2005; Aleman and Tiver, 2008), the spatial distribution of potential remnant seed sources (Tucker and Murphy, 1997; Vesk *et al.*, 2010), the surrounding exotic or native groundcover vegetation status (Spooner *et al.*, 2002), and the proximity to remnant vegetation (Tucker and Murphy, 1997) are all factors which could influence the vegetation recruitment levels within revegetation.

Seed supply is an essential element in the recruitment process as without a viable seed supply there would be no germination and therefore vegetation recruitment (Vesk *et al.*, 2010). Reduced seed production has been found to occur on relatively isolated plants in fragmented landscapes (Burrows, 2000). This is potentially a function of the reduction in supply of pollen due to the reduced mate density and lower frequency of mates (Duncan *et al.*, 2004; Knight *et al.*, 2005; González-Varo *et al.*, 2009). For those species with the potential to self pollinate, there may not be an issue in pollination in an isolated setting, however for most Australian *Eucalyptus* species there is only a small potential for self-compatibility and this therefore tends to lead to a reduction in seed production and reduced seedling vigour (Vesk *et al.*, 2010). Out-crossing is preferential for breeding success and specifically so within grassy woodlands where a 50m distance of isolation is significantly correlated with a drop in fecundity (Burrows, 2000).

As well as isolation, livestock grazing is recognised as a major limiting factor in the recruitment of new seedlings (Pettit and Froend, 2001; Spooner *et al.*, 2002; Dorrough and Moxham, 2005). Seedling germination has been found to be similar in grazed and ungrazed areas, however livestock herbivory significantly decreases seedling survival due to defoliation, trampling and outright removal of the plant (Pettit and Froend, 2001).

In a study conducted by Spooner *et al* (2002), the exclusion of livestock was found to be one of the most influential factors on successful recruitment in the revegetated sites, where 59% of fenced sites had recruitment occurring compared to 13% of unfenced sites. Tree recruitment has been found to more likely occur in areas where there was greater native perennial grass cover and less where there was a dominance of exotic annual grass cover or dense crown cover and there is evidence to suggest that exclusion of stock also leads to improvements in native ground cover composition and a reduction in common exotic species (Spooner *et al.*, 2002).

The above are all factors influencing the recruitment potential of a rehabilitated site. However there is a vital component missing from the mix of studies and that is the influence of the abiotic environment on the potential for recruitment within a rehabilitated site. Specifically the influence of soil conditions on levels of recruitment and success of revegetation efforts.

2.6 Rehabilitation and the Abiotic Environment

2.6.1 Soil – Vegetation interactions

As stated previously, the lack of research conducted into the effects of soil on revegetation success is conspicuous in its absence. There is a variety of research available on the carbon sequestration potential of diverse types of revegetation and with those comes minor analysis of other variables such as moisture and nutrient enrichment, but the lack of a whole body of literature is an interesting observation (Yadav *et al.*, 2009; Wang *et al.*, 2011; Dean *et al.*, 2012). From anecdotal and observational analysis it is clear that there is a relationship between soils and vegetation, however again there is a lack of synthesis of this relationship in regards to the interactions of soil condition and revegetation efforts. There appears to be no attempts to gauge the success of a planting based simply on the changes in soil conditions over time and it would seem that this is a necessary aspect of assessment when approaching a planting from an ecological restoration perspective as the whole ecosystem must function as it once did, abiotic factors included.

In a study by Wilson (2007), the effect of scattered paddock trees on surface soil properties was examined. Key findings of Wilson's study included observations that there was a significant decrease in pH, carbon, nitrogen and extractable phosphorous systematically with distance from individual trees. This indicates the potential influence vegetation can have on soil properties.

2.6.2 Biomass

In the context of this project, biomass is the dry, dead, and decomposing layer of organic matter lying on the ground surface, or leaf litter biomass. This layer of leaf litter is recognised as a vital feature of a functioning healthy ecosystem as leaf litter is part of both biotic and abiotic functions within an ecosystem (Cortez, 1998; Todd *et al.*, 2000). Farrel *et al* (2011) have found that leaf litter covered areas showed a significant drop in salinity levels from severe to moderate and the areas where there was leaf litter covering the soil surface, vegetation recruitment was favoured. Farrel *et al* (2011) also found that due to the insulating effects of leaf litter, moisture was higher and temperature less extreme than bare soil. Leaf litter, specifically from leguminous shrubs (of which *Acacia spp.* are), increases the nitrogen and organic carbon levels and consequently enhances soil biological activity (Alegre *et al.*, 2004).

The allometric assumption is thus that a relationship may exist between vegetation recruitment and leaf litter biomass amounts due to the influence of biomass on nutrient and carbon cycles, specifically within the topmost layer of soil, which in turn provides favourable germination and establishment conditions. This is the link which will hopefully be examined through this project.

2.6.3 Soil Carbon

The storage of carbon within soil and decaying vegetation is a topic which has come to the fore of scientific research currently as society searches for innovative ways to remove carbon from the atmosphere and store it in a stable form (Shrestha and Lal, 2006; Yadav *et al.*, 2009; Batjes, 2011). A large body of literature exists on a number of variations in soil organic carbon (SOC) storage under plantations (Turner and Lambert, 2000; Turner *et al.*, 2005; Kasel and Bennett, 2007), under native grasslands and woodlands (Jonson and Freudenberger, 2011; Pringle *et al.*, 2011; Dean *et al.*, 2012; Dean *et al.*, 2012), the potential to store carbon in reclaimed mine sites (Shrestha and Lal, 2006), and the effects of vegetation restoration and rehabilitation on soil carbon amounts (Wilson, 2002; Son *et al.*, 2003; Wang *et al.*, 2011).

The gradient of change in soil carbon has been mapped as agricultural landscapes return to native vegetation (Alberti *et al.*, 2011; Wang *et al.*, 2011), though notably absent is assessment of Australian soils. The potential for the accumulation pattern to be detectable means that SOC accumulation could be a valuable method of rehabilitation assessment whilst also providing information about the possibility of carbon off-set schemes based on revegetation and restoration. Contradiction however exists within the literature on this topic. Dean *et al* (2012) discusses this through suggesting that a 'breakeven' point in carbon soil dynamics may occur whereby there is a net emission directly after revegetation, a time lapse where soil carbon turns from emission to accumulation which then reaches the 'breakeven' point where the soil has returned to pre-revegetation carbon levels and only after which net sequestration occurs. This could suggest a reason for some of the contradictions in the literature, hence sampling done before the breakeven point would show a decrease in soil organic carbon (Turner and Lambert, 2000) and those sampled afterwards would show an increase (Wang *et al.*, 2011).

2.6.4 Soil Moisture and Nutrients

As with all things within an ecosystem, even one which has been highly modified, the interaction of vegetation with soil cannot be overlooked. It has been recognised that leguminous species provide litter fall which is low in lignin and high in degradable organic carbon and nitrogen (Alegre *et al.*, 2004). As such these species are recognised as being primary boosters of soil nutrients (typically N) within rehabilitation environments (Alegre *et al.*, 2004). The deficiencies in nutrients has been recognised as a key factor affecting revegetation success (Schwenke *et al.*, 2000). A decline in N in conventionally ploughed and rehabilitated sites at a Bauxite mine near Weipa, Western Australia was observed in sites with poorly performing rehabilitation. Losses of up to 69% in mineralised N within the top 0-10cm of soil occurred in the first 18 months after rehabilitation, this was attributed to the highly disturbed nature of mine site rehabilitation locations (Schwenke *et al.*, 2000). In an exceptional study conducted by Alberti *et al* (2011) the effect of rainfall on organic carbon content was inextricably linked to the types of vegetation which persisted in particular areas and the amount of N retained within the soil. 70% of the variation in their data was explained by the amount of precipitation within an area, where dry sites (<750mm annually) gained SOC after colonisation of native species, and wet sites lost SOC. The trend in carbon dynamics was linked to the nitrogen dynamics in the area as carbon losses occurred only when there was a decrease in soil nitrogen stocks, which occurs in wetter sites due to leaching.

Soil moisture is also another particularly relevant topic when looking into limiting factors affecting the potential success of revegetation sites. It is unquestionable that moisture is needed in some form within the soil profile for vegetation to survive. There is however little information as to the effects of soil moisture on rehabilitation, past looking into local rainfall. Similarly there is little information on rehabilitation and the effects of it on soil moisture both within the rehabilitated site and outside of it. It is evident that soil moisture retention does influence the recruitment potential of rehabilitated sites due to it becoming a limiting factor in germination rates, especially in areas where conditions are harsh with little time for moisture to become available to the seed (Bochet *et al.*, 2007). The presence of moisture within the soil is generally related to the decomposition rates of leaf litter within rehabilitation sites (Cortez, 1998). This process works by the assumption that if a site has leaf litter, this insulates the soil from desiccation, the presence of moisture and leaf litter helps to provide a favourable environment for decomposing fungi and microorganisms, which in turn influences the levels of nutrients within the top layer of soil which directly comes into contact with any viable seed dropped from revegetated species. The question that arises after this observation is whether this assumed relationship actually occurs and is there a way of measuring this that will enable each aspect to show a potential correlation with another aspect within this system.

2.6.5 Soil Fauna and Microorganisms

Though soil fauna is not a component of this project it is important to discuss the significance soil microbes have on soil condition and therefore vegetation and in turn revegetation. Bourne *et al* (2008) have suggested from the results of their study into the effect of soil biota on growth of *Eucalypt microcarpa*, that variation in soil fauna has the potential to greatly influence the growth rates of revegetation on retired agricultural lands, such as those being revegetated in the Braidwood district. Bourne *et al* (2008) also found that soil fauna provided benefits in terms of release of nitrogen and support of decomposition rates, but also to leaf robustness and biomass increases overall. Conversely Jouquet *et al* (2010) have found that though the addition of compost and vermicompost (worm castings) both improved soil parameters (increased nutrients, C and pH) and seedling growth and biomass amounts, the interaction of local endogenic earthworms with these additions can have a negative effect on soil parameters and plant growth through leaching of the soil nutrients.

A major part of rehabilitation within Australia takes place within the mining industry as mine spoil and impacted lands are rehabilitated as part of general practice within mine leasehold areas. As is the nature of private companies, the rehabilitation costs of regenerating these areas are limited and needing to be spent on the best possible method of rehabilitation. In this sense mining has been a driving force behind research into finding the best possible methods for ensuring revegetation success. One such comprehensive study was conducted on the importance of inoculation to increase the numbers of filamentous and non-filamentous bacteria and fungi within the soil (Wildman 2009). It was recognised that these microorganisms provide beneficial decompositional services within the leaf litter biomass and top soil layers and therefore it is advantageous to improve numbers of these microorganisms to improve revegetation success (Wildman, 2009). Inoculation of the soil to be revegetated results in an increase in actinomycetes (filamentous microbe spp.) and fungi in a measureable gradient from disturbed state to rehabilitated state. Hence this progression in soil microorganisms could provide an assessable gradient for decomposition rates, soil nutrient rates and therefore increases in vegetation development.

2.7 Conclusion

When looking at the success of revegetated, rehabilitated or restored landscapes, success is a term that needs to be clearly defined and subject based. Success of revegetation through recruitment, establishment, soil improvement, or through habitat improvement could all become instruments to gauge success by, but a revegetated site must only be gauged a success or failure based on the motivations for which the revegetation was undertaken. A site may be successful at stabilising soil erosion and improving the organic content of the soil, and on that scale the revegetation is a success, but what if this site was a planting of willow trees (e.g *Salix salix*) or a monoculture of acacias (e.g *Acacia melanoxylon*) with little floristic structure and minimal habitat value. The literature has shown that there are some very specific indicators of success however few studies have attempted to incorporate both biotic and abiotic indicators.

3 REGIONAL SETTING

3.1 Location

Braidwood is located on the eastern edge of the southern tablelands of NSW, approximately 95km east of Canberra and 60km west of Batemans Bay (Figure 4). Braidwood is situated along the Kings Highway between Canberra and Batemans Bay and is the major township within the area, servicing smaller satellite villages including Majors Creek, Bombay, Mulloon and Mongarlowe. Braidwood is 643m above mean sea level at 35.45 degrees south and 149.80 degrees east (Eyles, 1977; Bureau of Meteorology, 2011)

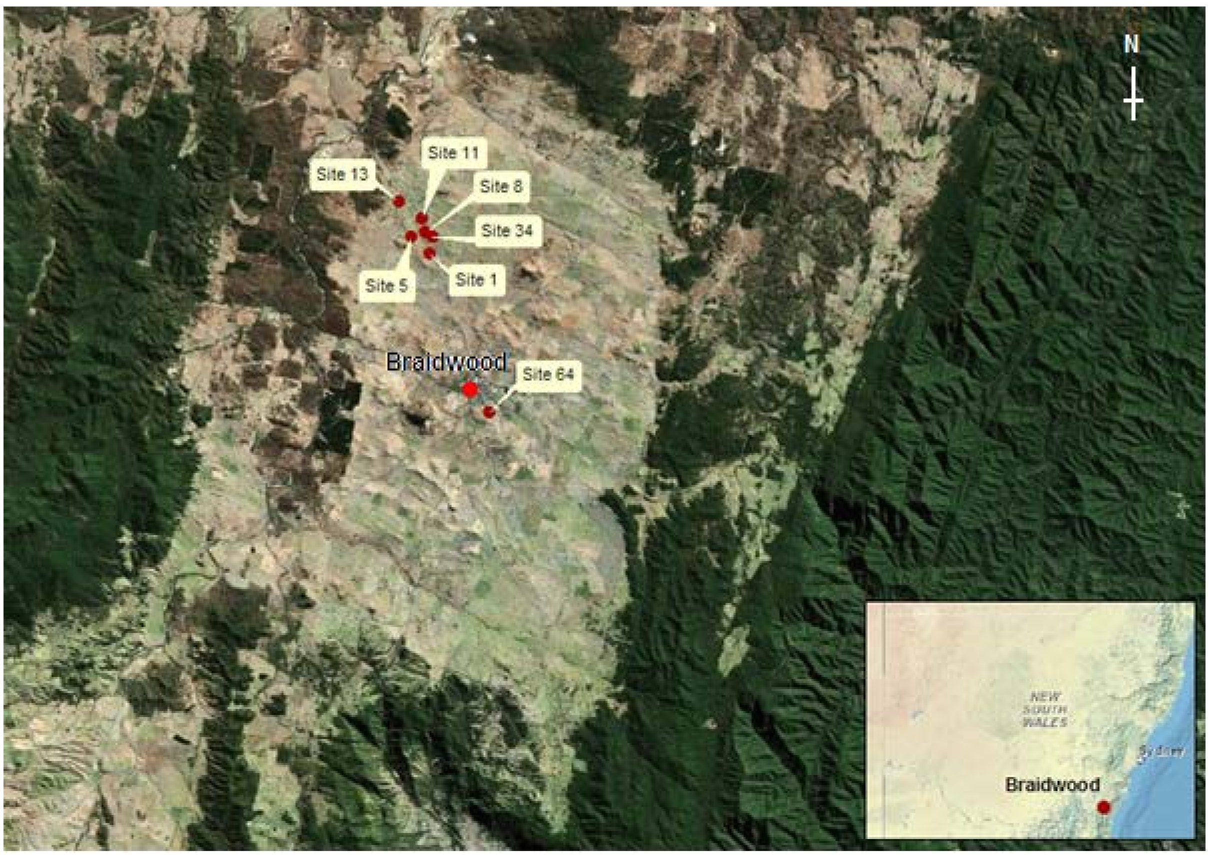


Figure 4: Location of Braidwood and the final sites used for sampling. (ArcGIS Online Basemaps, 2012)

The Southern Tablelands are located at the southern end of the Lachlan Fold Belt, and is part of the Great Dividing Range (Eyles, 1977; Jenkins, 1996). The Southern Tablelands region lies on a plateau that is bounded by the western slopes and the eastern coastal escarpment (Hazell *et al.*, 2003).

This plateau ranges between 600m to 750m, is covered in small rolling hills and generally insignificant drainage networks. The highest point within the Braidwood district is Mount Gillamatong to the south west of the township and is at a height of approximately 900m above sea level.

To the east of Braidwood there is the Budawang National Park, to the west Tallaganda State Forest between Braidwood and the ACT. South of Braidwood is the Araluen River and Araluen township and the Deua National Park. To the North of Braidwood the Shoalhaven River meanders towards the ocean and Lake Bathurst is off to the NW on the route to Goulburn.

3.2 Climate

Weather data for the Braidwood area is collected on Wallace Street at a station that has been recording rainfall data since 1887 and temperature data since 1907 (Bureau of Meteorology, 2011).

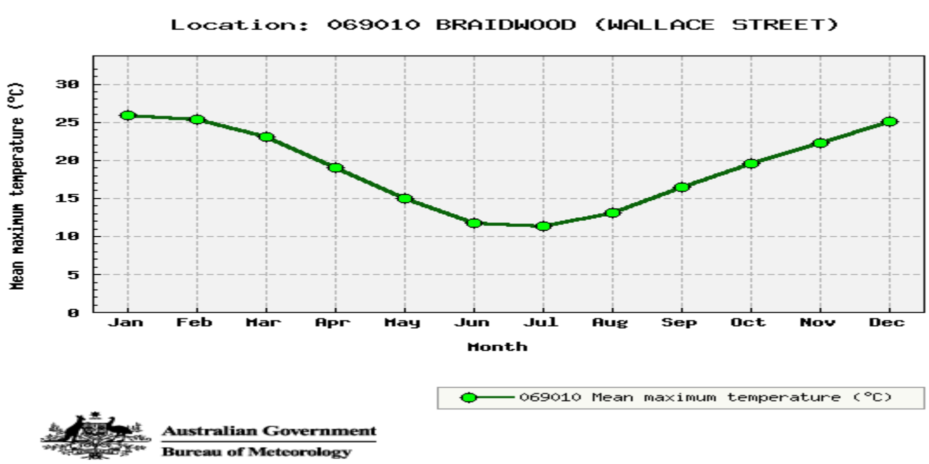


Figure 5: Mean maximum temperature (°C) in Braidwood for years 1887 to 2012 (Bureau of Meteorology 2011)

Maximum temperatures are mild (Figure 5) with average monthly maximums not exceeding 27˚C in the 12 months prior to September 2011 with the highest recorded temperature being 37.1 in January 2011. The area is prone to heavy frosts in the winter and temperatures fall below freezing regularly, with minimum temperatures as low as -8˚C in July 2011 and the average minimum daytime temperature -0.4˚C also in July (Figure 6) (Bureau of Meteorology, 2011).

Figure 6: Mean minimum temperature (°C) in Braidwood from years 1887 to 2012 (Bureau of Meteorology, 2011)

The climate of the area is classified as temperate to subhumid generally tending to be cool and moderately dry (Jenkins, 1996; Johnston and Brierley, 2006). The average annual rainfall is approximately 720mm with mean days of rain >= 1mm ranging between 5.5 days to 6.9 days per month (Bureau of Meteorology, 2011) with minimal seasonal variation in rainfall (Figure 7).

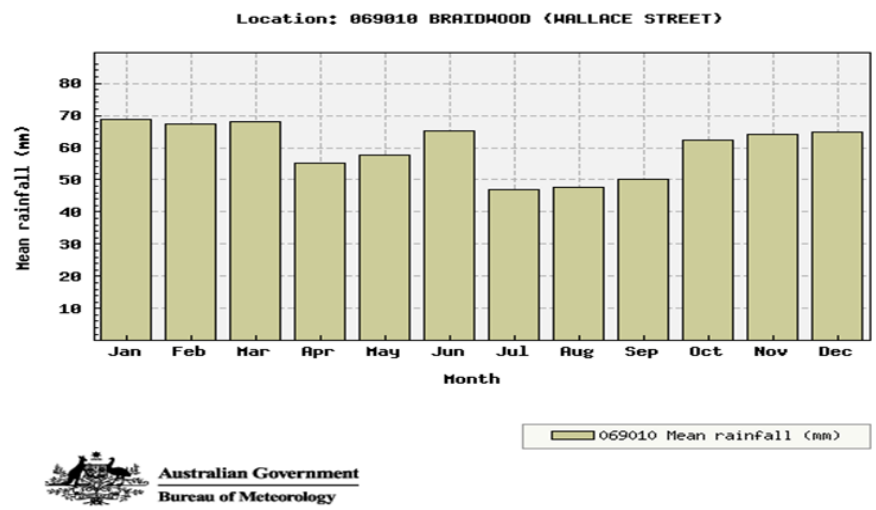


Figure 7: Mean annual rainfall (mm) in Braidwood for years 1887 to 2012 (Bureau of Meteorology, 2011)

Strong winds in the Braidwood area generally originate from the West to North West bringing harsh cold gusts to the north western sides of revegetation sites and hot gusts during the summer months (Figure 8) (Bureau of Meteorology, 2011).

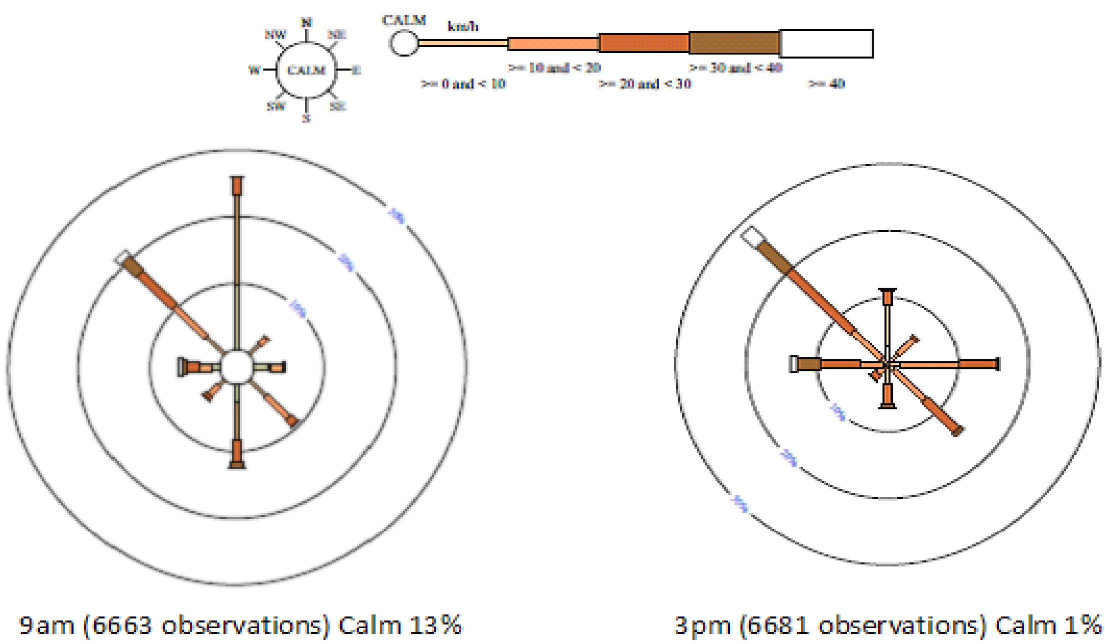


Figure 8: Roses of Wind direction versus Wind speed in km/h for 1 Dec 1991 to 30 Sep 2010, Braidwood Racecourse (Bureau of Meteorology 2011).

3.3 Geology

The township of Braidwood, and the immediate surrounding farmland, lie on the Braidwood Rises, identified as a key physiographic region within the *Braidwood 1:100,000 Soil Landscapes* map sheet (Jenkins, 1996). This region is characterized by insignificant drainage patterns and low, undulating rises which are often topped with granite tors (Jenkins, 1996)

The Braidwood map sheet covers a geological region characterised by broad structural groupings present in the southern end of the Lachlan Fold Belt (Figure 9). These include the Molong-South Coast Anticlinorial Zone, the Captains Flat-Goulburn Synclinorial Zone and the Budawang Synclinorium in the south east of the mapped area (Felton and Huleatt, 1976; Jenkins, 1996). The geology particular to this study is part of the Molong – South Coast Anticlionrial Zone.

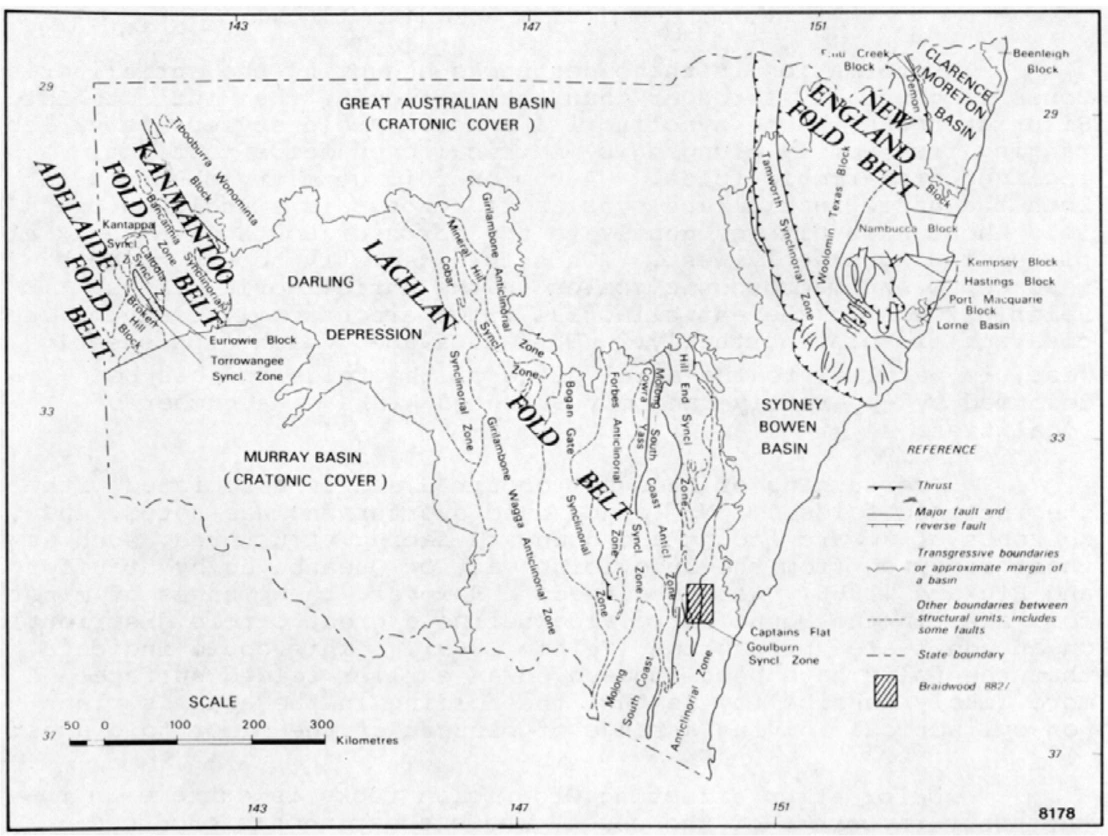


Figure 9: The Location of the Braidwood 1:100,000 map sheet in relation to the Lachlan Fold Belt and the geology of NSW. (Felton and Huleatt, 1976)

The geology underlying the Braidwood district, and therefore having the most pronounced influence in the overlying soils is the Braidwood Granite which consists of a Devonian horneblende-biotite granodioirite, adamellite and granite. The extent of this geological unit is from 30km south to 14km north of the Braidwood Township (Figure 10). This particular geological unit intrudes strongly folded Ordovician sediments along the northern, eastern and southern boundaries of the unit. To the west the unit intrudes Silurian acid volcanics (Felton and Huleatt, 1976; Jenkins, 1996).

The Braidwood Granite is described as generally massive with slightly foliated margins (Jenkins, 1996). The aureole surrounding the granite in both the Ordovician and Silurian margins is not high-grade and it has a lower greenschist facies metamorphic grade. The observation that the grain size of the Braidwood Granite is only slightly finer at the margins than in the centre of the intrusion suggest that the granite was in an advanced state of cooling when emplacement occurred (Felton and Huleatt, 1976).

The Braidwood Granite is cut by numerous dykes, with outcroppings visible along the Nerriga Road cuttings. The dykes specifically associated with the Braidwood Granites are generally quartz microdiorite, sulphide-bearing microdiorite and analcite microdiabase. These dykes are regarded as coeval and therefore of Early Devonian age, the same as the Braidwood Granites (Felton and Huleatt, 1976).

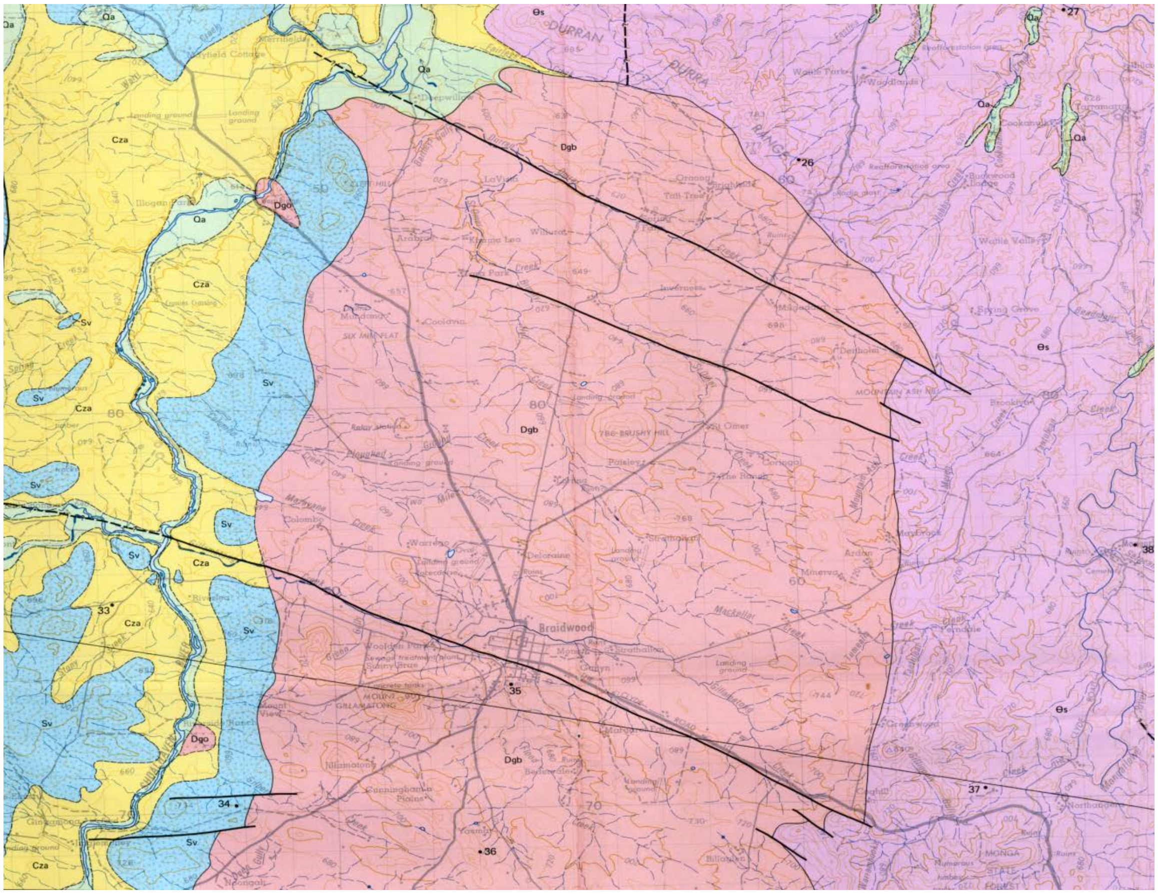


Figure 10: The geology of the Braidwood region. The pink section is the Braidwood Granites. Faults running through the Braidwood Granites are represented by the thick black lines; from top to bottom they are the Durran Durra fault, the St Omar fault and the Gillamatong Fault. (Felton and Huleatt, 1976)

Three major faults are associated with the Braidwood Granites (Figure 10), all trending northwest to southeast. The faults are identified as the Durran Durra Fault in the north section of the Granites, just south of that fault is the St Omer Fault and running through the township of Braidwood is the largest fault to intersect this unit, the Gillamatong Fault. As with the other smaller faults, the block to the north of the fault has been uplifted relative to the southern block. The eastern edge of both the Durran Durra and the Gillamatong fault has appeared to offset the eastern margin of the granite which has possibly then been associated with a number of smaller marginal faults to the south of both of these faults. The St Omer fault does not appear to have had this effect on the margin of the granite (Felton and Huleatt, 1976).

3.4 Soil

There are a number of soil landscapes specific to Braidwood described in the Soil Landscapes of Braidwood (Jenkins, 1996). The soil with which this study is mainly concerned is the residual Braidwood soil landscape, described in more detail below.

The main soil landscapes within the region which are residual landscapes are identified as the Braidwood, Hollow Wood, Morass and Tomboye soil landscapes. A residual soil is one which has formed *in situ* from weathering of the parent material, as witnessed on the plains surrounding Braidwood, these soils generally form level to undulating topography.

Generally surrounding the township of Braidwood, the Braidwood soil type has long been recognised as the most useful for human purposes in the area (F. Sturgiss, pers. comm. 2011), and has been extensively cleared in the region as a result (see Figure 4). In excess of 90% of this soil type has been cleared for grazing or cropping since European arrival (Jenkins, 1996) .The soil type is almost exclusively located on Devonian horneblende - biotite granodiorite, adamellite and granites, broadly named the Braidwood Granites (see Figure 2, Chapter 2 and Figure 10, this Chapter). There are common local tors (granite outcrops) throughout the region and drainage lines off the undulating rises are inconsequential.

The soils identified within the Braidwood type include earthy sands, lithosols and siliceous sands which are shallow (<15cm), rapidly drained and found on the crest and upper slopes of the topography. Non-calcic brown boils which are identified as shallow to moderately deep and reasonably well draining are also found on crests and upper slopes. Yellow podzolic soils which are moderately to poorly drained with a moderate depth (<100cm) are found on side slopes. Moderately deep to deep soils are generally of the poorly drained solodic soil type which is found on lower slopes. Along drainage lines, poorly drained black earths, solodic soils and alluvial soils can be found with variable depth depending on drainage line.

There are distinct changes in the soil horizons down profile depending upon topography (Figure 11). The A1 horizon (bw1 in Figure 11) is found across all topographical regions in the Braidwood soils landscape. It is described as a brown to dark brown coarse sandy loam ranging from massive to single grained. When this horizon is moist it is non-plastic and non-sticky and when it is dry it sets hard but is easily crumbled, and has high permeability.

There are two kinds of A2 horizons depending on slope positioning. The upper slope A2 horizon (identified as bw2 in Figure 11) and the downslope variant (identified as bw4 in Figure 11). Both of these profiles are highly permeable. As with the A2 horizons, the B2 horizons are variable depending on slope positioning. The upper slope B2 horizon (bw3 in Figure 11) is moderately permeable and the downslope B2 horizon has low to moderate permability. The C horizon (bw6 in Figure 11) is present in the downslope soils only; permeability is low to moderate.

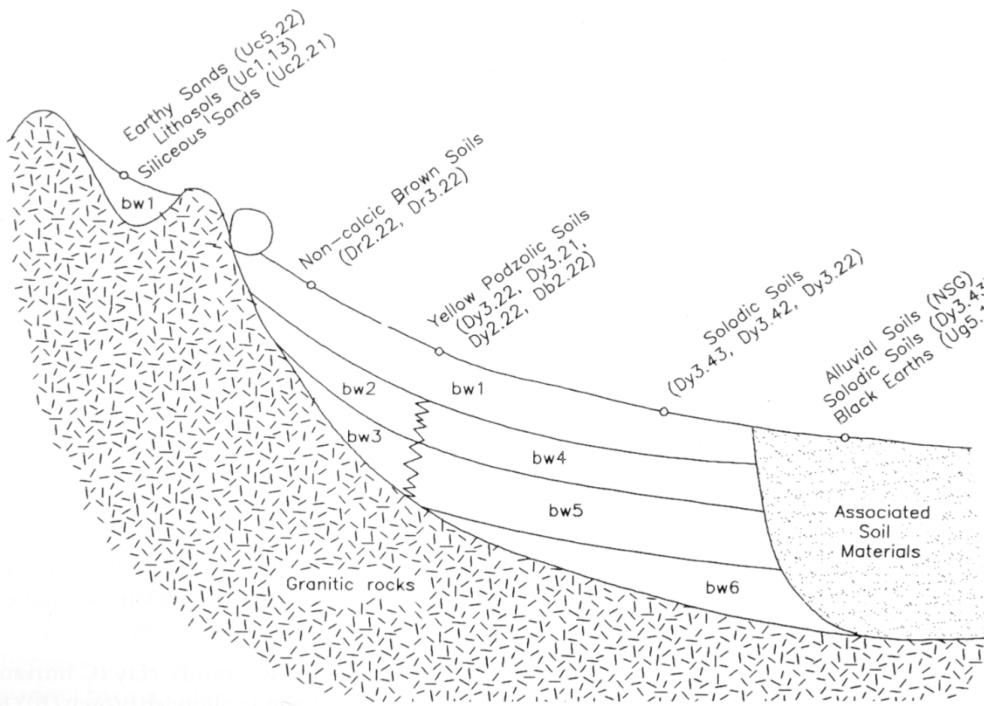


Figure 11: Schematic cross section of the Braidwood soil landscape illustrating the occurrence and relationship of the dominant soil materials. (Jenkins, 1996)

Typically soil depth increases downslope with often <60cm coverage on crest and upper slopes where the first A1 and B2 soils are found. The side slopes have a soil covering of <100cm and the lower slopes typically have a soil layer >80cm. All associated horizons are clear to abrupt throughout this soil type (Jenkins, 1996).

There are a number of key qualities and limitations associated with the Braidwood soil type and the specific soils which make up this type. High permeability and low wet bearing strength lead to generally high erodibility from both wind and water. Strong acidity is associated with all horizons and low fertility is also common in four of the six horizons. On the side slopes to lower slopes there is a high potential for aluminium toxicity in the upper two horizons and locally there is a permanently high water table leading to waterlogging of soils in the soil landscape (Jenkins, 1996).

Ridley *et al* (1990) suggests that due to the already inherently high acidity of the topsoils in this region, acidity could be exacerbated by the application of fertilisers in conjunction with improved pastures. Rural capabilities are classified as very limited for cultivation and moderately limited for grazing purposes however there is only minor erosion noted throughout the region as a result of some sheet, wind and gully erosion (Jenkins, 1996).

For soils of this type it is recommended that ploughing should not occur regularly, if at all, as it will break up the topsoil and increase erodibility. Vegetation cover should be maintained at 100% due to high wind erodibility and stock should be removed from pastures should the vegetation cover fall below 70%. Shelter belts are recommended to reduce strong winds and excess water use should be limited so as not to raise the water table (Jenkins, 1996).

3.5 Vegetation

As the area immediately surrounding the Braidwood township has been largely cleared of remnant vegetation it is speculated that the former vegetation may have included dry sclerophyll woodland with occasional frost hollows containing some more specialist species such *Eucalyptus pauciflora* (Snow gums)(Keith D., 2004) or taken on a savannah woodland vegetation type (Jenkins, 1996). Vegetation throughout the broader Braidwood region covers a variety of classification types from heathland to wet sclerophyll forest (tall closed-forest). Eucalypts are the dominant species throughout the region (Jenkins, 1996) and distribution of species and vegetation communities is shaped by exposure to climatic conditions such as frosts, heat and harsh westerly winds (Kodela and Foster, 1990).

The vegetation on the ranges to the east and south west of the Braidwood district are affected more by aspect, rainfall, elevation and exposure than on the tablelands. The orographic effect of the Great Dividing Range influences the vegetation growth and species on these slopes with southerly and easterly aspects being considerably cooler with greater moisture than the surrounding slopes and valley floors (Jenkins, 1996).This type of moist forest is classified as a Southern Escarpment Wet Sclerophyll Forest in Keith (2004). These types of forests exist most extensively on semi-fertile granitic soils such as around the Braidwood district (Keith D., 2004). Species common to this type of vegetation community include *Eucalyptus fastigata* (brown barrel), *E. viminalis* (ribbon gum), *E. cypellocarpa* (grey gum) with an understorey dominated by *Dicksonia antarctica* (soft tree fern) and *Pteridium esculentum* (bracken fern).

As mentioned the vegetation immediately surrounding Braidwood has been extensively cleared and altered and as such only small patches of remnant stands of trees remain with rapidly senescing remnant paddock trees common in the area (pers. comm. F. Sturgiss 2011, Jenkins 1996). On the Braidwood granite soils *Eucalyptus viminalis* (ribbon gum) and *E.pauciflora* (snow gum) are the common remnant species often interspersed with other eucalypts varieties including *E. melliodora* (yellow box), *E. stellulata* (black sally) and *E. dives*(broadleaved peppermint). There are also rare patches of swamp gum (*E. ovata*) that may be remnants of what was once a more common woodland community. It is so rare now that the community has only been recently recognised (Crooks *et al.*, 2008).

Due to the altered nature of the granite sands Braidwood soil type, local revegetation efforts begun with incorporating species both native (though not necessarily indigenous) and non native species that would grow in the harsh conditions created by the highly altered microclimate and increased exposure to extremes that come with over cleared landscapes.

3.6 Land Use

Humans have resided in the Braidwood area between 17 000 to 20 000 years before present, with stone flakes at Lake George approximately 40km away, indicating evidence for this habitation (Singh and Geissler, 1985). The aboriginal tribes of Walbanga and Wandandian were in the Braidwood region at the time of European settlement. There is minimal evidence to suggest that aboriginal use of fire modified the landscape or altered the eucalypt forests of the area (Johnston and Brierley, 2006).

Since European discovery of Lake George in 1820 and the exploration of the Braidwood region in 1821 there have been numerous and often negative influences on the environment (Jenkins, 1996; Johnston and Brierley, 2006). In 1851 gold was discovered in the region and there was an influx of people into the region related to the discovery. The alluvial deposits of Braidwood proved highly profitable with the goldfields being the most productive in NSW from 1858 to 1862. The panning of the alluvial gold resulted in highly modified water courses as stream banks and beds were panned, with the tailings deposited in large piles surrounding the creeks, these piles of tailings are still visible today along Majors Creek in the township of Majors Creek to the south west of Braidwood. The need for timber to fuel the steam driven dredges would have also resulted in extensive clearing during this gold mining era well beyond the alluvial gold deposits (McGowan, 2004). After the initial rush for the easily accessible gold, reef and quartz crushing operations were taken up by larger companies and gold dredging of creek beds of the area was profitable up to WWII (Jenkins 1996).

During the commercial gold mining operations and following WWII, the region was generally extensively cleared to allow for early agriculture which included raising beef cattle and sheep for wool. Cropping of wheat historically occurred however the practice in the area is now discouraged due to the low moisture retaining properties of the soil, whereby leading to erosion control issues (Jenkins 1996). Where the land is used today as grazing, wheat production would have occurred historically. Generally grazing in the area is on pasture which has been converted from native to exotic pasture species (pers. comm. Hazell, D. 2011).

Since European settlement, hydrological impacts have also occurred affecting drainage patterns, channels, creeks and the Shoalhaven River. Most prevalent is the occurrence of gully erosion which has caused a reduction in water quality, namely from the increase in sediment and nutrient load (Wasson R.J. *et al.*, 1998) as well as the loss of the chain-of-ponds environments (Eyles, 1977). The loss of chain-of-ponds habitat in the area has resulted in physical changes in pond and stream characteristics, resulting in the swift removal of flood waters which would naturally infiltrate the soil and replenish groundwater (Hazell *et al.*, 2003). There has been an overall decrease in the structural complexity of the drainage network in the region due to European modification (Hazell *et al.*, 2003).

Hardwood logging of the native forest of Monga and Tallaganda State Forest is a natural economic resource of the region, as are pine plantations in the area. Most vegetation remnants have been influenced in the recent past by understory grazing, and the most common remaining remnants are the rapidly senescing ‘paddock trees’ scattered throughout the landscape. Stock grazing has a variety of documented effects including defoliation, prevention of regeneration, introduction of weeds, altering the understorey conditions and compaction of the soil (Spooner *et al.*, 2002). It is unlikely that the remnant paddock trees in the area will naturally replace themselves due to the pressures from grazing (Wilson, 2002).

In the last two decades the Braidwood office of the Southern Rivers Catchment Management Authority (SRCMA) has provided support to the surrounding farms within the area to revegetate and rehabilitate strategic parts of the landscape based on stock comfort, preservation of remnants, stabilisation of erosional landscapes, property protection from wind blown weed seed and effective use of agricultural land on properties. A number of programs have been introduced to assist property owners with revegetating areas of their land, these include the ‘Trees on Rocky Knobs’ and ‘Farming for the Long-Haul’ programs which encourage sustainable faming, incorporating strategic revegetation across properties (pers. comm. Sturgiss, F. 2011).

4 METHODS

4.1 GIS Analysis

Preliminary analysis identifying possible revegetation sites using Google Earth. Eighty-eight initial revegetation sites were identified by the SRCMA which were sites they had been involved with in some way, on both public and private lands. No differentiation was made between sites at that stage except to distinguish between native revegetation and non-native revegetation (e.g. pine plantations (*Pinus radiata*) and willow trees (*Salix spp.*)). Of the 88 sites originally identified, each site was traced individually and digitised in ArcGIS to create a revegetation site layer. These polygons of the revegetation sites were checked against high quality (50cm) ortho-rectified aerial imagery. Revegetation sites were then selected through a process of GIS based queries on the parameters deemed the most influential on revegetation sites.

A Data Elevation Model (DEM) of the Braidwood district provided the basis for the spatial analysis undertaken to determine site characteristics. Several layers were derived from the DEM:

- A slope layer divided into 2˚ increments.
- An aspect layer divided into 8 categories (N, NE, E, SE, S, SW, W, NW)
- A classified elevation layer (10m intervals)

Slope was deemed a necessary selection parameter due to the differing drainage capacity of soils depending upon slope angle (Cheng *et al.*, 2008), soil nutrient leaching (Son *et al.*, 2003), soil depth relationship (Hopp and McDonnell, 2009) and the properties of the particular soil type in the area.

As indicated by many authors (Auslander *et al.*, 2003; Wilkinson and Humphreys, 2005) plant growth is affected by the orientation of the slope towards the sun. The greatest variation in temperate parts of Australia is naturally the difference in sunlight received by plants on a north versus south facing slope (Cano *et al.*, 2002). It was thus assumed that on the selected sites, aspect would be a critical influence on the ability of vegetation to grow and therefore influence the success of the planting.

Elevation had been identified as an important parameter in determining what species grow in the area and which vegetation communities may have covered the granite soils before European settlement and clear felling of the area (Keith D., 2004). It was not considered a critical parameter in the Braidwood district, as the area is predominantly flat, only varying between the elevations of 600m – 750m above mean sea level.

Soils were identified as a critical parameter influencing the growth and success of revegetated sites due to well documented symbiotic relationships between soil fauna and plants, nutrient availability, soil properties including texture, structure, pH, permeability, and nutrients (Kodela and Foster, 1990; Bird *et al.*, 1992; Schwenke *et al.*, 2000; Wang *et al.*, 2011). Soil data for the study region was obtained from the Braidwood Soils 1:100 000 map sheet. Key soil types were identified and used to refine the sites chosen for further analysis.

The proposed study sites are all located within Map Grid Australia 1994, Zone 55 (MGA94z55) and much of the source data was in raster format. All data used in the analysis was translated into MGA94z55 and preliminary analysis identified that key raster layers were either not sufficiently aligned and/or were not of a high enough resolution to capture smaller revegetation sites that had been identified as areas of research interest. In response, the raster analysis methodology was translated into a vector model, and the classifications within each raster dataset were converted to polygons in shapefiles that retained the name of the original raster layer. To reflect the raster model of the original data and maintain the integrity of the original data model, the smoothing function was suppressed.

4.1.1 Site Selection Process

Site selection was carried out using the above mentioned layers of Aspect, Slope, Elevation and Soil type. The process used to categorise sites into those with similar characteristics is outlined in Figure 12. At each stage of GIS queries, sites which did not meet the defined criteria were removed from the selection process. From the initial 88 revegetation sites identified, 14 had the same site characteristics as defined by slope, aspect, elevation, soil type and size. After the spatial analysis of the sites, two of the 14 final sites were found to have been directly seeded rather than directly planted tube stock. Comparison of revegetation methods is not part of this study and therefore these two sites were excluded. The eventual number of sites earmarked for sample collection was 12 at conclusion of the theoretical site selection. Due to the budget and scale of this project the final number of sites sampled in the field was seven.

The parameters by which sites were excluded were chosen in an attempt to limit effects of independent variables which may have an influence on soil properties and revegetation success. The slope exclusion of >20˚ was chosen to limit the potential influence of nutrient and moisture mobility through the soil (Wilkinson and Humphreys, 2005; Cheng *et al.*, 2008; Hopp and McDonnell, 2009). Elevation was not critical, but any sites not lying within the 600-700m asl could have previously hosted a different vegetative community. North facing aspects were chosen as slopes facing the north receive more light than south facing slopes and were expected to display similar soil moisture characteristics.

Only sites which were located entirely on the Braidwood Soil Type were included for ease of analysis and due to it being the dominant soil type in the area. This soil type is the extensively cleared and the soil type on which the majority of revegetation in the Braidwood region takes place.

As a standard representative sample plot size was needed to be replicated across all sites, the size of the revegetated sites had to be greater than $600m^2$ to accommodate the 400 m^2 sample plot in the centre of the planting and not be influenced by edge effects.

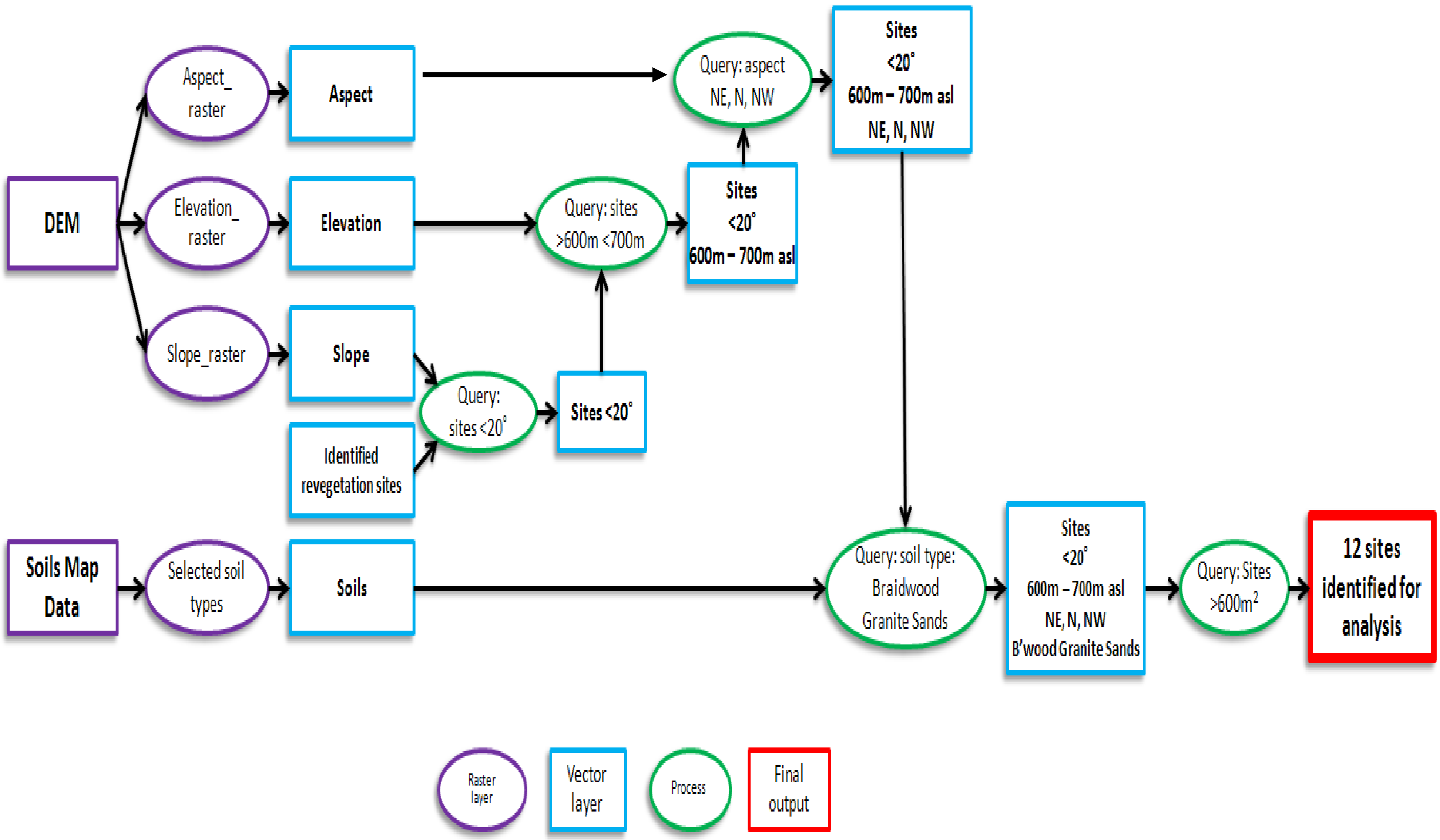


Figure 12: The processes and queries used to classify each site.

4.2 Fieldwork

4.2.1 Soil Sample Collection

At each site, soil samples were collected to evaluate soil organic carbon (SOC), soil moisture and total phosphorous (TP) and plant available phosphorous (PAP) amounts at specific sample locations across the seven revegetated sites (see Appendix 1). In total 34 samples were analysed for SOC and moisture and 27 samples were analysed for leaf litter biomass, PAP and TP.

The placement of specific sample plots was selected on the basis of identifying potential robust trends in variations of soil characteristics and vegetation between the revegetation sites and the adjacent paddocks. The sample plot within each revegetation site (referred to hereafter as the interior plot) was 400m^2 to enable a vigorous sample suite to be collected for both the soils analysis section of this project and the floristic analysis. Within the interior plot two soil samples were taken, each consisted of seven auger hole volumes (approximately 530cm^3) combined to give an overall indication of soil conditions at the sites. A common sampling pattern was followed in the collection of all interior samples; two overlapping 'V's were constructed within the sample plot and samples were collected randomly along these transects within the interior plot (Figure 13).

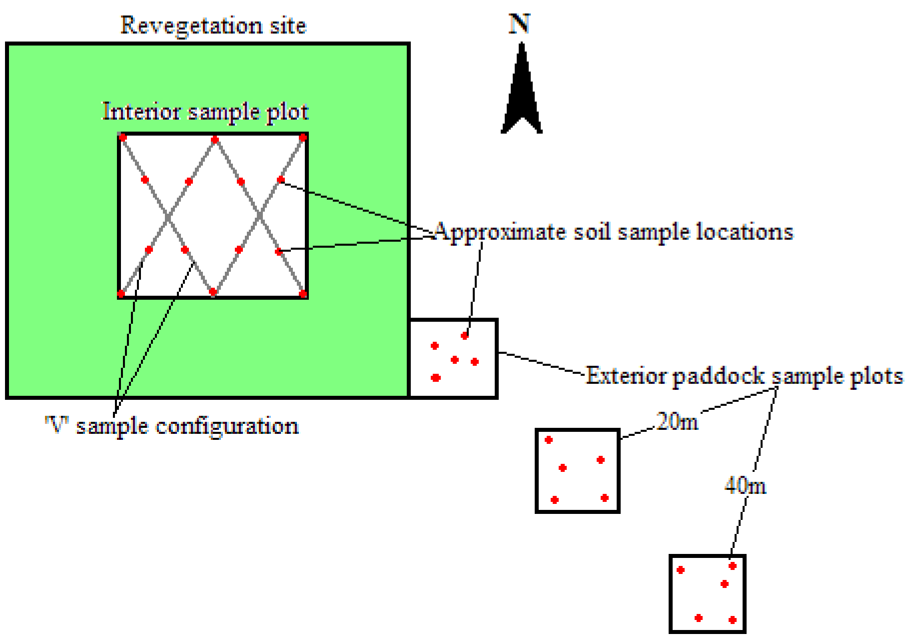


Figure 13: The layout of the sample plots for soil sampling at each site.

For the soils, three external 200m^2 plots were also sampled. These plots were situated on the south east side of the planting as this was deemed the most protected side (Bureau of Meteorology, 2011) and therefore assumed to show the biggest variation in soil characteristics (Hazell. D., pers. comm. 2011). The first exterior 200m^2 plot was situated along the boundary fence line of the revegetated site within the “shade reach” of the revegetation as it was expected that this area would show similar soil characteristics as within the revegetation. The next plot was placed 20m out from the revegetated site where shading would be at a minimum, though protection from prevailing winds provided by the planting could influence soil characteristics. The furthest plot was situated 40m out into the adjacent paddock (Figure 13). It was assumed that at this distance there would be negligible influence from the revegetation planting on soil properties and it could give a reasonable impression of conditions in the adjacent paddock. Each of these exterior plots had 5 random soil samples collected which were mixed into a composite sample to represent the each plot. This method of mixing the soil to obtain a composite sample is a common method of sampling where an overall trend is being investigated (Morrison and Lawrie, 2012).

For SOC and soil moisture, two samples were collected from within the revegetated plot, and one each at the edge, 20m out from the revegetated site and 40m out from the revegetated site. Leaf litter biomass (referred to hereafter as simply biomass) was collected once each from within the revegetated site plot, within the edge plot, 20m out from the revegetated site and 40m out from the revegetated site. Biomass amounts were collected from within the limits of the auger ($52cm^2$). In an attempt to pick up the widest variation in phosphorous changes, only the two composite samples from within the revegetation plot, one from the edge of the revegetated site and one at 40m out from the revegetation site were sampled. All sites were exposed to the same antecedent conditions and were sampled in the same week with similar climatic conditions throughout the week (overcast, 15˚C to 20˚C, no precipitation).

4.2.2 Vegetation Sampling

Sites which were sampled for soil analysis were also sampled to asses vegetation structure. Information was collected about the dominant species' of ground vegetation, % ground cover (vegetation, bare ground, leaf litter or bare rock), canopy cover, the number of vegetation recruits, and general site observations and sketches (see Appendix 2).

As part of the aim of this study was to look into the relationship between vegetation recruitment and soil conditions, sampling outside the revegetation areas was not necessary except to pick up potential edge effects. Thus two $400m^2$ plots were used to sample vegetation. One plot was located in the same area as the interior soil collection plot, and the other $400m^2$ plot was located along the south east edge of the site in an attempt to capture any variation presented across the sites from interior to the edge. The potential for edge effects was hopefully minimised by the inclusion of the edge plot extending out into the adjacent paddock (2m) where there would be more space, light and germination potential away from competing revegetated species within the plot. (Alberti *et al.*, 2011).

After the plots were marked out, each plot was systematically walked to search for any vegetation recruits. As each recruit was found, photographs were taken and a small sample (if the plant was large and healthy enough to do so) was taken for identification purposes. If the recruit was too small to take a sample from, surrounding larger species were searched and sampled in an attempt to identify the recruit. The recruits which were searched for included woody shrub and tree recruits as these are the species which were originally planted in the revegetation therefore these are the recruit numbers analysed to determine whether the original vegetation planted is now self sustaining and will persist into the future.

Hereafter when position is referred to in reference to vegetation analysis, it is indicating an interior sample plot and an edge sample plot. As part of the vegetation analysis, original species were either positively identified or records detailed which species were planted.

4.3 Soil Sample Preparation and Testing

Within seven days of collection, the soil samples were coned and quartered down to approximately 20g individual samples and placed in cans to be dried at 105°C for >24 hours. Coning and quartering is the recommended method for obtaining a representative sample from a large amount of sample material (Morrison and Lawrie, 2012). This method of minimising the sample was used to obtain another representative sample for air drying then oven drying to obtain the figures to calculate the moisture factor required for the following soil organic carbon analysis.

The method followed for the soil organic carbon analysis was the standard procedure for the Walkley-Black method. This method was utilised as it is a standard analysis to determine total soil organic carbon (Blakemore *et al.*, 1981). The Walkley-Black method of organic carbon analysis involves the thermal digestion of concentrated H_2SO_4 added to the soil sample and aqueous $K_2Cr_2O_7$. The heat generated induces the majority of the oxidation of the dichromate, and then a back titration is done using ferrous sulphate. The difference in added $FeSO_4$ compared to the blank titration determines the easily oxidisable organic carbon. The percentage Walkley-Black carbon (referred to as % Soil Organic Carbon in this study project), is given by the formula:

$$\mathrm{WBC} = M \times \frac{(V_1 - V_2)}{W} \times 0.30 \times \mathrm{CF}$$

Equation 1: Walkley-Black percentage SOC equation. (De Vos *et al.*, 2007)

where M is the molarity of the $FeSO_4$ solution (from blank titration), V_1 is the volume (mL) of $FeSO_4$ required in blank titration, V_2 is the volume (mL) of FeSO4 required in actual titration, W is the weight (g) of the oven-dried soil sample and CF is the correction factor. The CF is a compensation for the incomplete oxidation and is the inverse of the recovery. The CF was set by Walkley & Black in 1934 to 1.32 (recovery of 76%) (De Vos *et al.*, 2007)

Plant Available Phosphorous (PAP) was analysed using the Olsen phosphorous method. This method involves the extraction of P from air-dry soil with 0.5 M $NaHCO_3$, adjusted to pH 8.5 with NaOH. Extraction is for 30 minutes at a soil/solution ratio of 1:20. There is no prior adjustment of soil pH, and there is no attempt to remove possible interferences such as arsenate and silicate (Rayment and Lyons, 2011).

Total Phosphorous (TP) was determined via the Rayment and Lyons, Kjeldahl-P IC-POES method. The Kjeldahl digestion uses 18 M H_2SO_4 with sodium sulphate ($NaSO_4$) to raise the boiling point, and copper as a catalyst. All or most P in the sample is converted to orthophosphate. This orthophosphate is determined by inductively coupled plasma optical emission spectrometry (ICP-OES) using the appropriate wavelength for P (Rayment and Lyons, 2011).

4.4 Statistical Analysis

Differences amongst sites and positions for SOC, soil moisture, biomass and phosphorous were all tested for variation using an unreplicated block analysis of variance. Relationships amongst theses soil properties were tested with regression. To check that the data represented a normal distribution, a Shapiro-Wilks Goodness-of-Fit test was performed on the residuals from each ANOVA test and data was transformed where necessary. A Student's t-test was performed where tests showed significant results to identify where differences occurred.

Following log transformation to make the data normal, differences in vegetation recruitment between the interior and edge were analysed using a blocked ANOVA. The relationship between recruitment and soil parameters and % groundcover was tested using regression analyses.

5 RESULTS

5.1 Soil – Position Dynamics

5.1.1 General results

Overall 34 soil organic carbon (SOC) and % moisture, and 27 plant available phosphorous (PAP) and total phosphorous (TP) samples were analysed to determine trends between top soil parameters and vegetation characteristics. All values fell in the lower spectrum of soil levels (J. Morrison, pers. comm. 2012) which was expected for the soil type of the area, with high quartz sand content derived from the underlying lithology. There was a great deal of variation amongst sites indicating that other unidentified factors are likely to be influencing both top soil and vegetation processes at the sites (Table 1).

Table 1: Average of all abiotic parameters and the standard deviation across all seven sites.

	Biomass Kg/m2	% Organic Carbon	% Moisture	Phosphorous (mg/kg)	Total Phosphorous (mg/kg)
Average all sites	0.68	2.55	14.53	19.1	302.33
Standard Deviation all sites	0.5	0.82	6.0	9.95	76.9

No single site exhibited a greater number of extreme values than another (Table 2). Leaf litter biomass varies from over 1000 g m^{-2} to less than 400 g m^{-2} with the highest value coming from the smallest revegetation site. The % SOC fluctuated from 3% to 1.8% which is not unexpected for this soil type. Moisture varied from approximately 8% to 23% and the site with the lowest moisture had the highest average PAP. PAP and TP did not follow the same trends. The PAP fluctuated from 12 mg/kg to 28 mg/kg which is in the low to medium levels for Australian topsoils (Bruce and Rayment, 1982) as expected, and TP varied from 192 mg/kg to 382mg/kg.

Table 2: Average results of all abiotic parameters across each site.

Site	Average Biomass kg/m^2	Average % Organic Carbon	Average % Moisture	Average Plant Available Phosphorous (mg/kg)	Average Total Phosphorous (mg/kg)	Total area of revegetated site (m^2)
1	0.75	2.09	7.64	28.06	276.0	4264.4
5	0.42	2.01	13.18	23.44	307.5	8494.5
8	0.39	3.12	16.60	23.99	382.0	6016.9
11	0.42	3.07	13.42	19.68	359.7	7523.6
13	0.83	1.84	7.99	13.84	192.8	10725.7
34	1.18	3.19	19.95	11.79	280.5	2283.5
64	0.88	2.66	22.73	12.83	332.3	8416.0

Due to the large number of different soil and vegetation parameters being analysed statistically, only significant and non significant relationships which are directly related to soil revegetation characteristics are investigated at greater depth.

5.1.2 Carbon

SOC differed significantly between sites ($F_{(6,23)} = 3.58$, $p = 0.12$) (Figure 14). The Student's t-test indicated that sites 34 and 8 had higher values and sites 5 and 13 had lower values than other sites. All other sites indicated intermediate SOC levels.

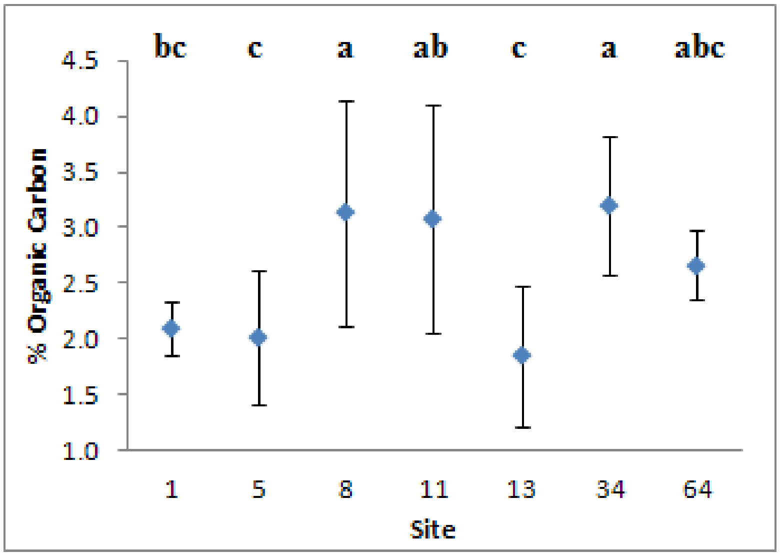


Figure 14: The variations between % SOC with revegetation site. Error bars represent the standard deviations within the data for each sites' SOC samples. Same letters above points showed no significant difference in multiple comparisons.

It was expected that SOC would vary significantly with vegetation cover as represented by a comparison between revegetated sites and the adjacent paddocks. However there was no significant relationship found between the position of the samples and the amount of SOC ($F_{(4,23)} = 1.26$, $p=0.315$; Figure 15), indicating no variation in SOC in topsoil between revegetated sites and adjacent agricultural paddocks.

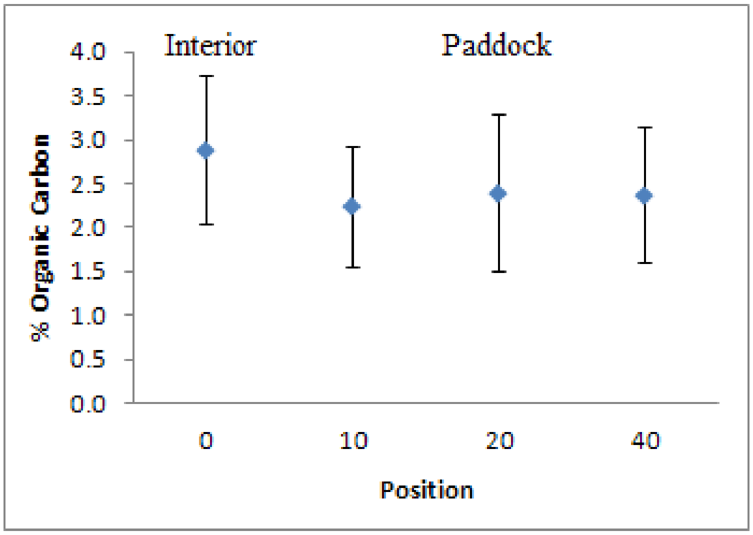


Figure 15: % SOC levels by position. Where 0 indicates the interior of the revegetation site, 10 indicates the edge of the revegetation plot, 20 indicates 20m out from the site and 40 indicates 40m out from the site. Error bars represent the standard deviations across all sites at those positions.

A potential relationship between soil moisture and SOC was investigated as it was thought these parameters might interact through enhanced facilitation of biomass decomposition at damper sites (Cortez, 1998). Unexpectedly there was no relationship found between soil organic carbon and soil moisture (R^2=0.047, $F_{(1,11)}$=0.5462, p=0.4753). There was an indication that %SOC might increase with % moisture but more sites would need to be sampled to confirm this trend.

5.1.3 Moisture

Generally the sandy, well drained soils within the Braidwood region demonstrated highly variable moisture values between sites, despite site selection being aimed at removing any extreme site specific variables such as slope and aspect. The unanticipated non significant relationship between % moisture and position ($F_{(4, 23)}$ = 0.252, p = 0.9054) is a key finding (Figure 16). This indicates that the revegetation has a non-detectable influence on topsoil for this soil characteristic.

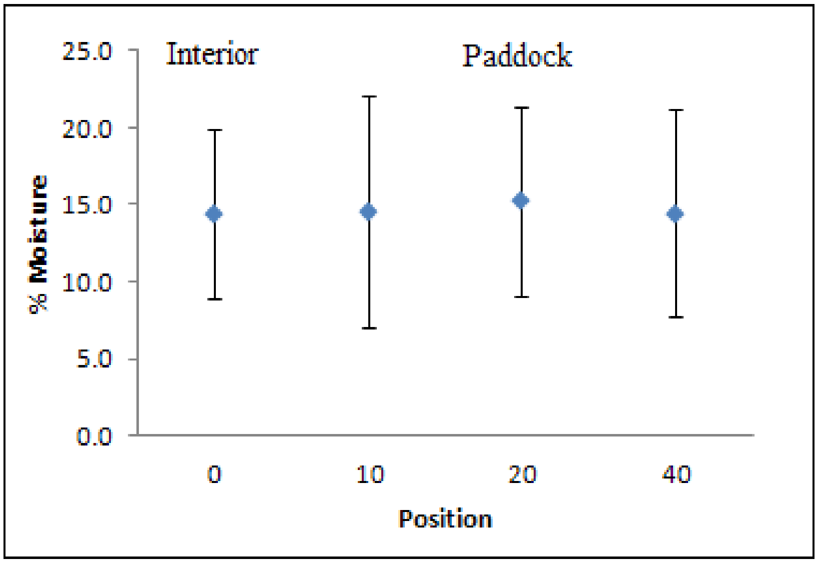


Figure 16: Variation between sample positions and % soil moisture. Error bars represent the standard deviations across all sites at those particular positions.

Sites differed significantly by % moisture ($F_{(6,23)} = 18.5665$, $p = <0.0001$). This indicates that other variables than those excluded through the initial site selection were influencing % moisture at the revegetation sites. Site 64 had significantly higher moisture values and sites 13 and 1 had significantly less soil moisture. All other sites showed intermediate values (Figure 17). This indicates the considerable impact of local site conditions in determining moisture characteristics of topsoil.

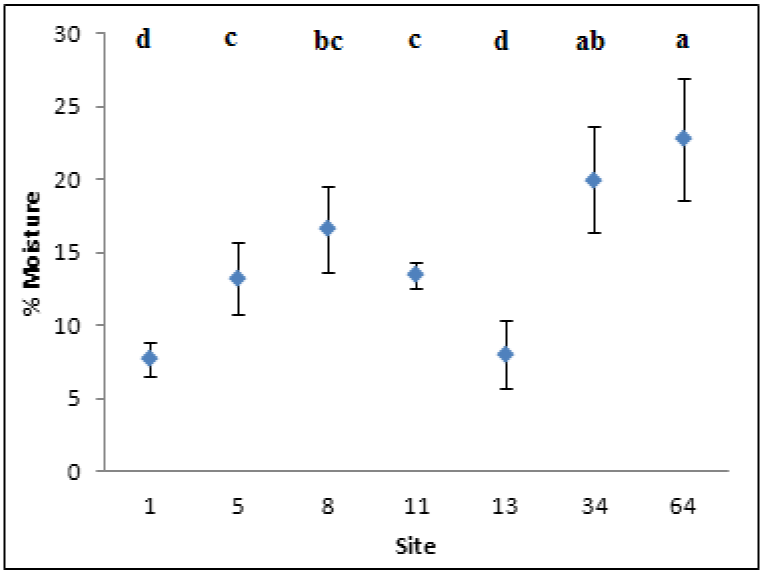


Figure 17: % Soil Moisture variation between sites. Error bars represent the standard deviations within the data for each sites' % moisture values. Same letters above points showed no significant difference in multiple comparisons.

It was expected that biomass and moisture would show a relationship which would indicate an association between these parameters. However no significant relationship between soil moisture and biomass (R^2=0.05427, $F_{(1,11)}$=0.6313, p=0.4437) was found.

5.1.4 Leaf Litter Biomass

Predictably, leaf litter biomass differed significantly with position ($F_{(6, 17)}$ = 10.8538, p =0.0003) (Figure 18) but not with site ($F_{(4, 23)}$ = 1.1487, p = 0.3775). Interior samples had higher amounts of litter than the paddock samples (edge, 20m and 40m plots).

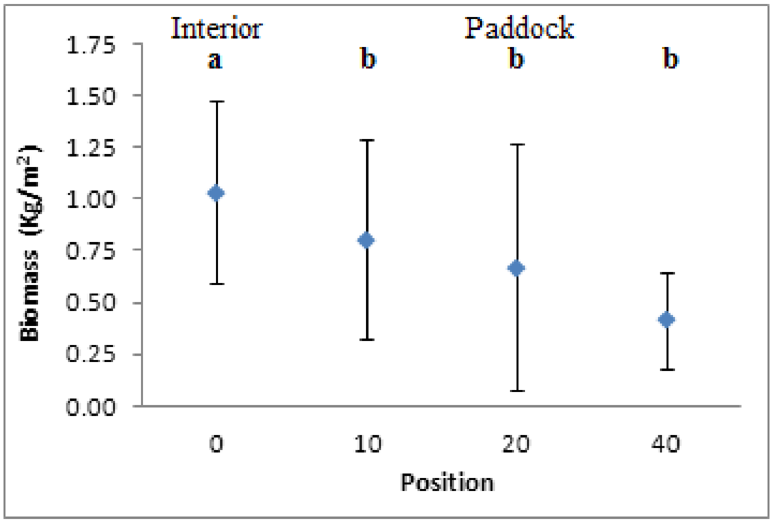


Figure 18: Biomass kg/m^2 variation with position. Error bars represent the standard deviations. Same letters above points showed no significant difference in multiple comparisons.

As with moisture and leaf litter biomass, it was expected that SOC and leaf litter biomass would show a correlation between the two parameters. However as with biomass and moisture, there was no significant relationship between SOC and biomass (R^2=0.1675, $F_{(1,11)}$=0.2.2136, p=0.1649; Figure 19).

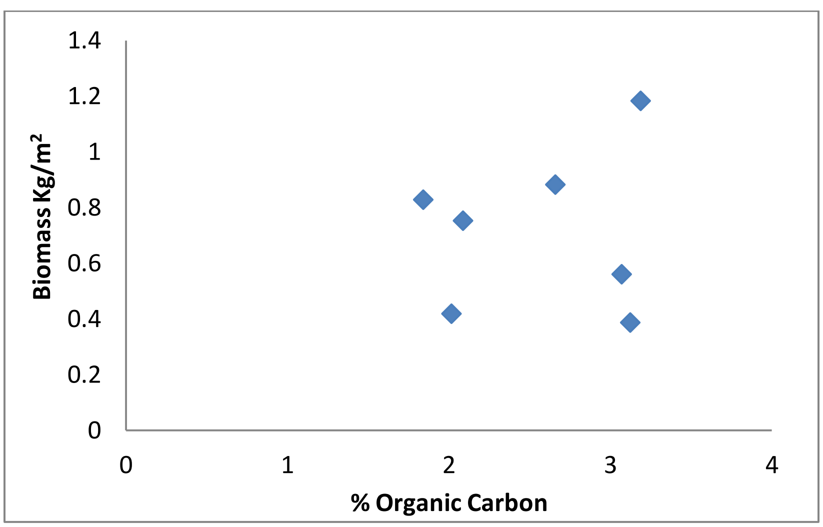


Figure 19: The relationship between biomass and % SOC.

5.1.5 Phosphorous

It was anticipated that phosphorous would differ by position. Two types of phosphorous were sampled, plant available phosphorous (PAP) and total phosphorous (TP).

Unlike SOC, PAP differed significantly with position ($F_{(3, 18)}$ = 8.2966, p =0.0011) (Figure 20) and with site ($F_{(6, 18)}$ = 3.2966, p =0.0109) (Figure 21) which is a key finding. Site 1 and 8 had higher PAP than all other sites whilst site 34 had lower PAP values. All other sites were intermediate.

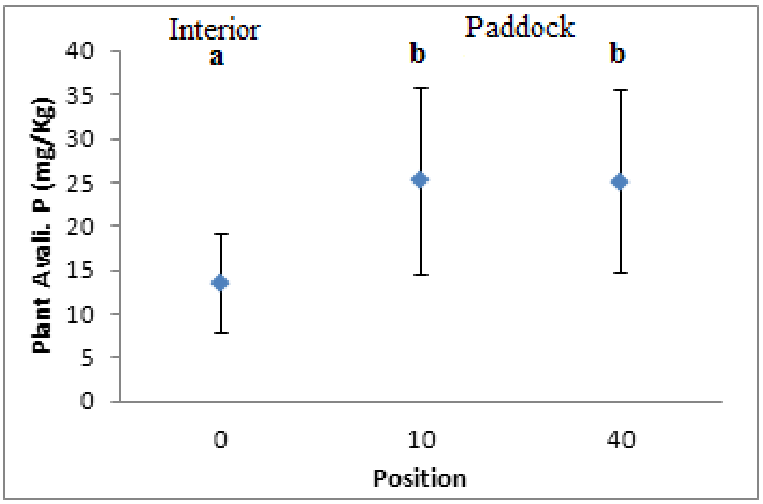


Figure 20: Variation of PAP by position. Error bars represent the standard deviations across all sites at those particular positions. Same letters above points showed no significant difference in multiple comparisons.

Unexpectedly PAP decreased under revegetation with a marked difference immediately between the transition from revegetation (Position 0) and the adjacent paddock (Position 10) with little variation between the exterior positions (Figure 20).

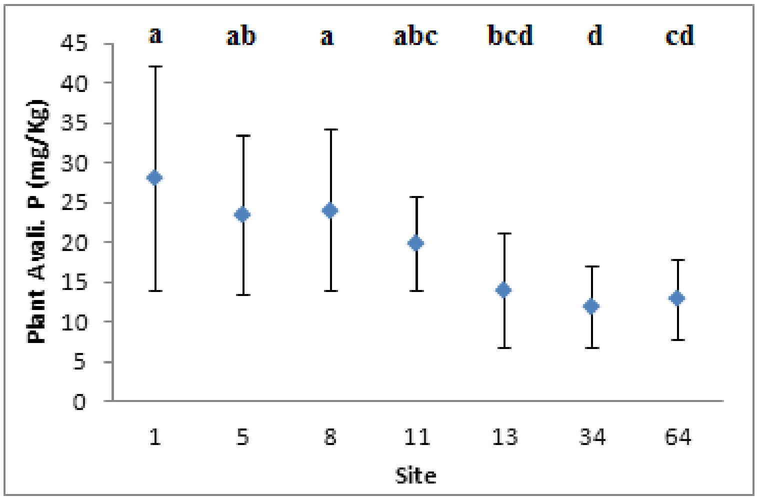


Figure 21: Variation in PAP with site. Error bars represent the standard deviations within the data for each sites' PAP values. Same letters above points showed no significant difference in multiple comparisons.

Unlike PAP, TP differed significantly with site ($F_{(6, 18)}$ = 10.0646, p =<0.0001) but not by position ($F_{(3, 18)}$ = 2.3887, p =0.1027) (Figure 22) which was unexpected as it is tended to be assumed the same nutrient will follow similar patterns even in different forms. Site 8 and 11 had significantly higher values than other sites. Site 13 had significantly lower values than all other sites.

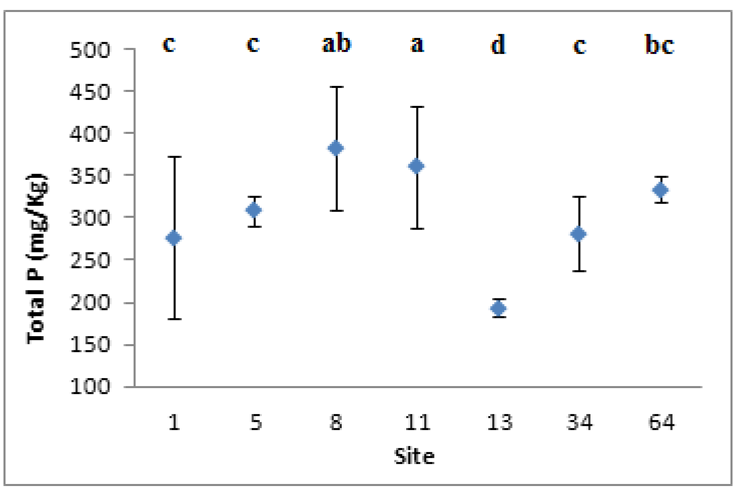


Figure 22: Total Phosphorous variation by site. Error bars represent the standard deviations within the data for each sites' TP values. Same letters above points showed no significant difference in multiple comparisons.

There was no significant relationship between TP and SOC (R^2=0.0996, $F_{(1,25)}$=2.7645, p=0.1089) however the regression plot (Figure 23) suggests that there could be a relationship and further sampling would be needed to clarify this relationship.

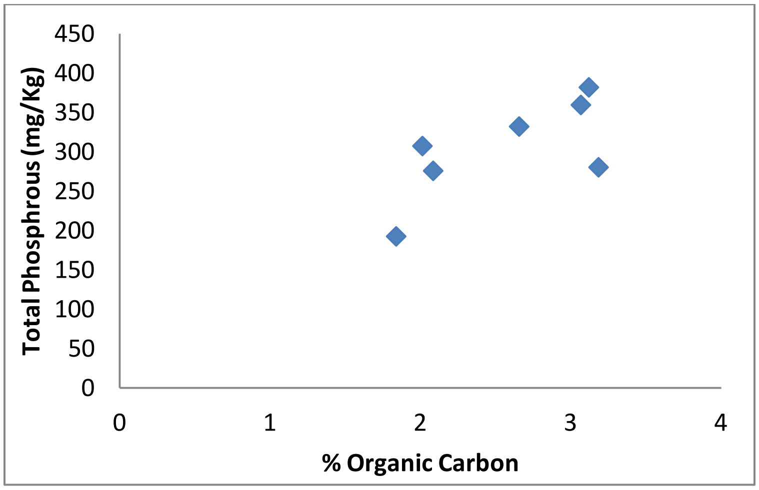


Figure 23: The relationship between OC and TP shows a slight correlation between results.

As with SOC it was assumed that there would be a relationship between TP and biomass. There was a non-significant relationship between biomass and TP (R^2=0.1641, $F_{(1,18)}$=3.5336, p=0.0764). However there was a significant negative relationship between PAP and biomass (R^2=0.2831, $F_{(1,18)}$=7.1093, p=0.0157) (Figure 24). It is a key finding that PAP was negatively related to biomass.

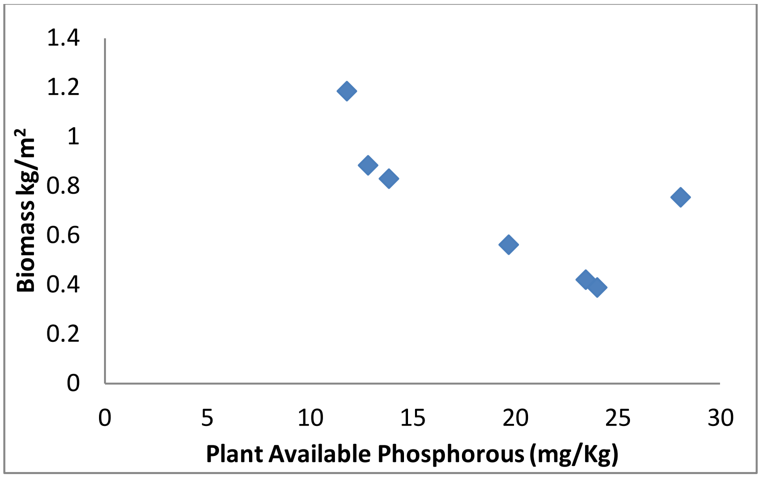


Figure 24: The relationship between biomass and plant available phosphorous shows a trend that suggest phosphorous decreases with increasing biomass amounts.

5.2 Vegetation Dynamics

Detailed historic records were only available for five of the seven sites which were sampled, therefore the following table (Table 3) is a summary of originally planted species in these five sites and established species positively identified within the other two sites, these are marked with an asterisk*. The species listed in Table 3 is an incomplete list of the variety of species utilised in revegetation works throughout the Braidwood region.

Table 3: The species recorded as having been planted within the revegetation sites. The * represents sites where no detailed records exist about what was planted and these species were positively identified at the sites during fieldwork. Highlighted species are those which have had positively identified recruits. All eucalypt and acacia species are native to Australia but the range of other species are marked with an (N) for native species and (Ex) for exotic species.

Species		**Site**
Scientific name	**Common name**	
Eucalyptus *acaciiformis*	Wattle leaved Peppermint	8, 13
E. aggregata	Black Gum	1, 8, 13
E. dives	Broad-leaved Peppermint	5
E. kessellii	Salmon Gum	13*
E. macarthurii	Paddy's River Box	1, 5, 8, 13
E. mannifera	Brittle Gum	5
E. mannifera ssp. maculosa	Red Spotted gum	13
E. melliodora	Yellow Box	8, 13
E. nicholii	Narrow-leaved Black Peppermint	8
E. ovata	Swamp Gum	13
E. parvula	Small-leaved Gum	5
E. pauciflora	Snow Gum	1, 5, 8, 13, 34*, 64*
E. radiata	Narrow-leaved Peppermint	8, 13
E. smithii	Ironbark Peppermint, Gully Gum	8
E. stellulata	Black Sallee	1, 5, 13
E. viminalis	Ribbon Gum, Manna Gum	8

***Acacia** dealbata*	Silver wattle	1, 5
A. elongata	Swamp Wattle	13
A. mearnsii	Black wattle	1, 5, 8
A. melanoxylon	Blackwattle	13
A. pravissima	Ovens wattle	1, 5
A. rubida	Red Stemmed Wattle	1, 5, 64*
A. verniciflora	Varnish Wattle	13
Banksia ericifolia (N)	Heath-leaved Banksia	13
Banksia marginata (N)	Silver Banksia	5
Bursaria spinosa (N)	Blackthorn, Boxthorn, Sweet Bursaria	8
Callistermon citrinus (N)	Crimson Bottlebrush	5, 13
Callitris endlicheri (N)	Black Cypress Pine	5
Cedus deodara (Ex)	Deodar cedar	8
Gleditsia triacanthos (Ex)	Honey Locust	8
Hakea dactyloides (N)	Finger Hakea, Broad-leaved Hakea	5
Pinus radiata (Ex)	Radiata pine	8
Quercus spp. (Ex)	Oak family	8

The vegetation survey indicated that four of the seven sample sites contained juvenile woody tree and shrub recruits and *Acacia spp.* were the most prolific recruiters. The large number of the acacia recruits of a similar age indicates that a recruitment event may have occurred in the recent past. The recruits found at all sites appeared to be between one to five years in age, however *Acacia spp* grow rapidly in the correct conditions and exact germination dates are unknown. In all cases the recruits were clearly not part of the original planting events, nor had they been planted since. The majority of observed recruits were *Acacia spp.* (103) (Figure 26) with only minimal numbers of *Eucalyptus spp.*(12) (Figure 25) recorded (Table 4).

Table 4: The number of recruits observed by site and the species of those recruits.

Site		Number of recruits	Species
1	**Interior**	0	-
	Edge	0	-
5	**Interior**	51	*Acacia dealbata*
	Edge	36	*Acacia dealbata*
8	**Interior**	0	-
	Edge	0	-
11	**Interior**	10	*Acacia dealbata*
	Edge	0	-
13	**Interior**	6	*Eucalyptus pauciflora (2), Acacia rubida (4).*
	Edge	10	*Eucalyptus kessellii (2), Eucalyptus ovata (8)*
34	**Interior**	2	*Acacia pravissima*
	Edge	0	-
64	**Interior**	0	-
	Edge	0	-

Figure 25: A *Eucalyptus pauciflora* recruit as observed in Site 13 interior plot. The blue pen is 15cm long with the nib at the base of the seedling. (X. Willis 2012)

Figure 26: An *Acacia dealbata* recruit observed in site 5 interior plot. Height is approximately 1.5m. (X. Willis 2012)

Site 5 had higher recruitment values than all other sites. Sites 1, 64 and 8 had no recruitment and all others exhibited intermediate recruitment values. Generally, where recruitment did occur it tended to occur more often within the planting (Figure 27, Figure 28). Of the four sites in which recruitment was recorded, only two of those sites had recruits recorded in the edge plot. A much larger sample set would be needed to draw any robust conclusions about this observation however.

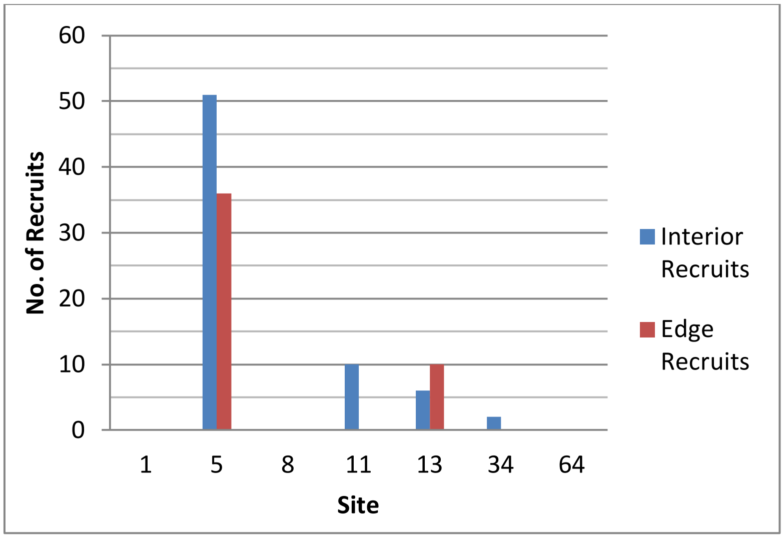


Figure 27: Number of vegetation recruits by site.

Figure 28: *Acacia pravissima* recruit observed at Site 34 interior plot. (X. Willis 2012)

5.3 Recruitment Relationships

5.3.1 Site and Position

It was expected that due to edge effects, position would influence the level of recruitment. However recruitment did not differ with position ($F_{(1,6)}$=1.7411, p=0.2351) but it differed by site ($F_{(6,6)}$= 8.7090, p=0.0093) (Figure 27).

5.3.2 Total Groundcover

There was a significant negative relationship between recruitment and groundcover (R^2=0.32, $F_{(1,12)}$=5.5484, p=0.0363). This is a key finding as it potentially indicates a link between groundcover and the ability of species to recruit within a revegetation setting (Figure 29).

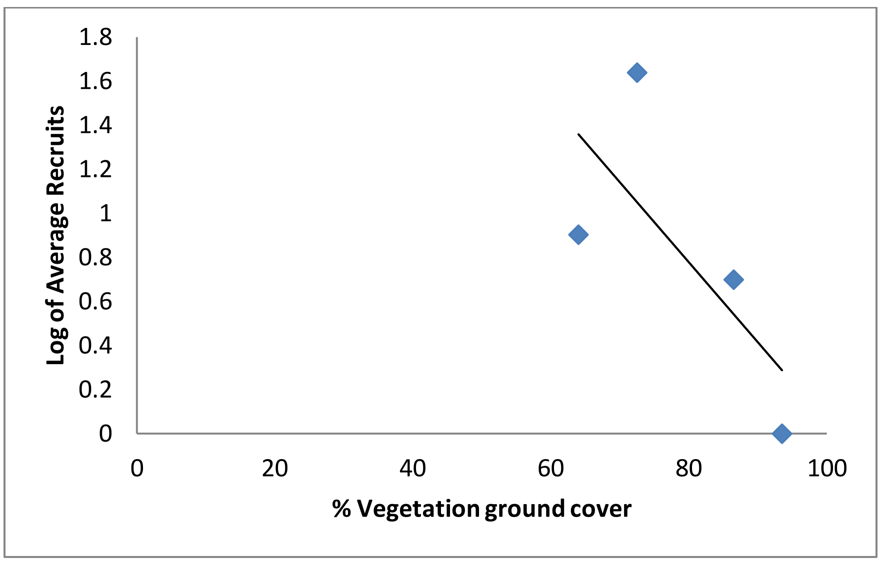


Figure 29: Site vegetation recruits by % groundcover.

The dominant species of groundcover were sampled in an attempt to identify whether exotic or native groundcover could be related to the degree of recruitment within a sampled site. It was postulated that the origin of the groundcover species (either native or exotic) may have an effect on the levels of recruitment and as Table 5 indicates, the majority of groundcovers were exotic pasture grasses and weeds probably establishing when the sites were grazed pasture.

Table 5: Table showing the total amount of ground cover and the breakdown of whether this groundcover was exotic (Ex) or native (N). The difference is made up by species either unidentified or a relatively insignificant percentage of the groundcover.

Site	% Groundcover- Interior	% Groundcover - Edge
1	85 - Ex (91%), N (5%)	96 - Ex (95%)
5	55 - Ex (99%)	90 - Ex (25%), N (5%), Juvenile shoots (70%)
8	75 - Ex (85%)	85 - Ex (75%)
11	80 - Ex (80%)	93 - Ex (95%)
13	50 - Ex (90%)	78 - Ex (98%)
34	90 - Ex (90%)	97 - Ex (65%), N (20%)
64	87 - Ex (80%)	97 - Ex (95%)

The most common exotic species were Phalaris *Phalaris aquatic* (all sites) (Figure 30), Soft Brome *Bromus racemosus* (3 sites), Cocksfoot *Dactylis glomerata* (3 sites), Scotch Thistle *Onopordum acanthium* (3 sites) (Figure 31), Sheep Sorrel *Acetosella vulgaris* (3 sites), and Yorkshire Fog *Holcus lanatus.* at 2 sites. Other exotic species occurring include Brome *Bromus spp.*, Prickly lettuce *Lactuca serriola*, Paspalum *Paspalum dilatatum,* Shivery grass *Briza minor* and Tall Fescue *Festuca elatior.* Native species encountered include Tall Windmill Grass *Chloris ventricosa* (Site 5), Hairy Panic *Panicum effusum* (Site 5), and Wallaby grass *Austrodanthonia spp.* (Site 34).

Figure 30: A *Phalaris aquatica* clump observed within Site 1 interior plot. (X. Willis 2012.)

Figure 31: Scotch thistle *Onopordum acanthium* was a prominent weed in some of the revegetation sites. (X. Willis 2012)

As there were minimal native groundcover species observed in plots, and little recruitment, no statistical analyses were undertaken to determine the impact of native versus exotic groundcover on recruitment.

5.3.3 Recruitment – Abiotic Interactions

There were no significant relationships found between recruitment and soil parameters or biomass results. Recruitment was not related to leaf litter biomass (R^2=0.02, $F_{(11,1)}$=0.2505, p=0.6266), or SOC (R^2=0.1, $F_{(11,1)}$=1.1699, p=0.3026). Furthermore, recruitment was not related to soil moisture (R^2=0.09, $F_{(11,1)}$=1.0769, p=0.3217), TP (R^2=0.062791, $F_{(12,1)}$=0.8040, p=0.3875) or PAP (R^2=0.0081, $F_{(12,1)}$=0.0974, p=0.7603).

5.4 Key Findings

There were a number of unexpected results highlighted through the analysis of the biotic and abiotic factors within and adjacent to revegetation sites. Key findings include:

- Overall all abiotic factors vary considerably with site.
- SOC, % moisture and TP did not differ with position.
- SOC, % moisture and TP are not related to leaf litter biomass.
- PAP differed by position, showing increased values outside of the revegetation site.
- PAP and biomass were significantly related in a negative trend of biomass to PAP.
- Recruitment is not related to position and differs among sites.
- Recruitment and % groundcover are negatively related
- Recruitment was not related to any other abiotic parameters (SOC, % moisture, PAP and TP) in this study.

6 DISCUSSION

The fundamental aim of this thesis was to investigate the long term viability of revegetated sites in the Southern Tablelands. In particular the thesis set out to examine the self propagating nature of directly planted revegetated areas (i.e. levels of vegetation recruitment). It also set out to test the potential benefits to soil characteristics from revegetation and whether these interactions have any positive feedback benefits in facilitation of vegetation recruitment. This study is one of the few which attempts to gauge the success of revegetation by examining the feedbacks between soil and leaf litter biomass characteristics, groundcover characteristics and levels of vegetation recruitment. The wider implications include increased information about revegetation success to further help regional decision makers assess where, when and what to fund in relation to revegetation. The results have implications for potential 'carbon farming' schemes and revegetation projects in the Braidwood region which highlights the need to investigate better ways of quantifying SOC accumulation within the Southern Tablelands.

6.1 Soil – Revegetation Interactions

In general the results suggest that there is limited effect from revegetation on the soil surrounding and within the revegetation site. There appeared to be no trend in % soil organic carbon (SOC) and moisture either within the revegetation site, at the edge or out into the paddock. This suggests that there is a negligible impact on SOC or soil moisture from the vegetation change between revegetation and agricultural paddocks further implying that revegetation may not aid the accumulation of soil nutrients, nor in the retention of soil moisture. Though many authors have found this not to be that case (e.g Wilson 2002, Alberti *et al* 2011, Cortez 1998), there is little information about the ability of the Braidwood Soil Type to retain SOC and moisture except that provided by Jenkins (1996), who identifies the A_1, A_2 and B_1 soil horizons of the region as having high permeability, and low fertility. This may suggest that moisture is either carried down profile and/or down slope, away from the topsoil immediately after wetting. This high moisture mobility could leach the accumulating nutrients from the topsoil (Alberti *et al.*, 2011) with the potential outcome of this leaching being the accumulation of nutrients and moisture further down the soil profile or downslope of the revegetation. As this study did not look into the potential movement of nutrients and moisture through the soil profile, it can only be recommended as an important area for further investigation (see Recommendations). Accumulation of soil moisture and SOC may well be within the B_2-horizon in the bw5 medium heavy clay, which has a low permeability (unlike the three horizons above it) (refer to Figure 11 in Chapter 3) (Jenkins, 1996).

Interestingly, neither SOC nor moisture were significantly related to the amounts of leaf litter biomass suggesting that it cannot be used as an indicator to predict such soil characteristics. The type of leaf litter which is being dropped onto the soil, and the amounts of decomposition which are occurring may also explain why leaf litter biomass is not showing an association with SOC and moisture. The type of leaf litter falling and decomposing is often the driving influence on untreated soil nutrient characteristics as different species leaves have different levels of accessible nutrients within them (Kasel and Bennett, 2007) and decompose at different rates (Alegre *et al.*, 2004), which is also in turn dependant on moisture availability (Cortez, 1998). This might also be dependent on soil fungus and microorganism activity (Hill, 1985; Shetty *et al.*, 1994; Barrett *et al.*, 2009; Wildman, 2009) not quantified in this study.

The soils analysis indicated that plant available phosphorous (PAP) varied significantly with position, showing a strong trend of higher phosphorous levels in the surrounding agricultural paddocks than the revegetation suggesting that revegetation is neither accumulating nor retaining levels of phosphorous within the topsoil. This result must be treated with caution due to other potentially confounding factors including the application of phosphorous-containing fertiliser to the adjacent paddocks. As with SOC and moisture, there is a potential for vertical and lateral movement of nutrients through the soil, and thus away from the topsoil. This may be aided by the deeper rooted tress and shrubs of the revegetation sites as opposed to the shallow rooted grass species dominating the surrounding paddocks (Duncan *et al.*, 2008). If vertical and/or lateral translocation of nutrients is a real phenomena in the Braidwood soils then it may suggest that the original vegetation communities were adapted to low levels of phosphorous. It may also suggest that the revegetation is removing the excess phosphorous from the soil within an 8 year timeframe (all sites were > 8 years of age) to pre-European levels of 15 mg/Kg (Jenkins, 1996).

Though this seems a plausible explanation, the application of phosphate containing fertilisers to the soil in the past is more likely having a greater influence on the PAP results than species selection and nutrient translocation. European methods of agriculture are common throughout Australia, and as discussed in Chapter 3, Braidwood has been cultivated for wheat production and subsequently grazed since it was settled in the 1850's, equating to potentially over 150 years of fertiliser application and build-up within the agricultural paddock topsoils (Dorrough and Moxham, 2005). Anecdotal evidence of phosphorous application suggest that within the last 10 years there has been some application of phosphorous to the surrounding paddocks at all sites with a number of them yearly applications, though exact amounts are not known (G. White, V. Royds and P. Rylands, pers. comm. 2012). This is more likely the cause of the immediate jump in available phosphorous levels between the revegetation and the surrounding paddocks (Ozturkmen and Kavdir, 2012), though it does not explain the leaching of it from the soil under the revegetation. This loss potentially indicates that phosphorous levels in the revegetation sites are returning to pre-European levels as a feedback from the native vegetation community developing.

The negative trend between leaf litter biomass and phosphorous supports the suggestion that phosphorous levels in the adjacent paddocks have been altered externally. Combining this with the result that neither SOC nor soil moisture are related to biomass further reinforces that leaf litter biomass is not a determining factor in topsoil nutrient availability, though this conclusion contradicts many studies (e.g Schwenke *et al* 2000, Todd *et al* 2000, Specht and West 2003, Kasel and Bennett 2007).

6.1.1 Recruitment as a Feedback Indicator

The unexpected result that vegetation recruitment was not significantly influenced by any of the tested abiotic parameters (SOC, moisture, PAP, TP and leaf litter biomass) suggests that there is no positive, or negative feedback, occurring between the abiotic parameters and vegetation recruitment. This implies that recruitment occurs independently of these factors, and it may be more related to other factors such as local disturbance or local growth conditions. The inference from this then is that though recruitment has been found to occur preferentially in sites with increased moisture (Bochet *et al.*, 2007; Farrell *et al.*, 2011), that does not occur on this soil type which may reflect the high permeability and potential nutrient translocation discussed earlier.

The key constraints to recruitment and therefore continued persistence of revegetation into the future, is further supported by the overall lack of vegetation recruitment by the originally planted trees and shrubs in the sites studied. This could be an outcome of the inherent lack of remnant vegetation throughout the region whereby viable seed is not produced in enough quantities within revegetation due to the lack of pollination, as distance from remnant seed sources directly effects the viable seed drop as part of the pollination requirements for eucalypt species planted is not met (Burrows, 2000; Broadhurst *et al.*, 2006; Vesk *et al.*, 2010). This in turn limits the ability of the species to produce a big enough, viable seed fall to ensure some germinate on a suitable seed bed, in appropriate weather conditions for that species (Lawrence *et al.*, 1998). It is recognised that suitable conditions may only occur very infrequently within the 10-20 year timeframe these revegetation sites have been planted, and potentially compounded with the lack of remnant vegetation, the overall absence of recruitment may simply reflect that not enough time has passed for these conditions to occur simultaneously (Spooner *et al.*, 2002). This then leads to the question of whether this study encapsulated enough age variation to account for this time lag and may indicate that the revegetation in this area needs more time to mature before producing seed which will germinate and ensure persistence into the future (Tucker and Murphy, 1997). Anecdotal evidence suggests that the oldest revegetation within the region was captured by this study (Site 13 at 21 years old) and therefore this theory is not testable at this time (F. Sturgiss pers. comm. 2011).

The unexpected biotic constraint to recruitment found across all sites was the well established exotic groundcover. Exotic groundcover has been found to significantly limit eucalypt recruit establishment (Dorrough and Moxham, 2005) through competition for nutrients, water and light (Eliason and Allen, 1997). This is supported by the significant negative trend of recruitment levels with percent groundcover across all sites studied. Though not a measured parameter, the density of the exotic groundcover has also been found to limit recruitment (Lindsay and Cunningham, 2012) and dense exotic groundcover was observed at all sites (Figure 32a and 32b) except the oldest (Site 13) (Figure 33). Again indicating that perhaps 6 of the 7 revegetation sites studied were not old enough to be influencing their environment to allow vegetation recruitment, rather their environment was influencing vegetation recruitment.

Figure 32: (a) Grass matt observed at Site 34 within the edge sample plot. The pen is 15cm long. (b) Exotic grasses in the interior of Site 1, showing thick matting and little opportunity for seedling establishment. (X. Willis 2012)

Figure 33: Groundcover was still dominated by exotic species but it was much less dense and had a greater proportion of leaf litter at the oldest site studied, at 21 years since being planted. (X.Willis 2012)

The restriction of vegetation recruitment by levels of exotic groundcover suggests that to increase the potential for recruitment, exotic groundcover should be removed or thinned periodically to allow viable seed a path to the soil with reduced competition overall. The removal of all groundcover is a recommended treatment before initial revegetation takes place (Greening Australia, 1997), yet after this initial removal there is no recommendations to continue disturbing or to replace exotic species with native groundcovers. The results of this study indicate that this could be beneficial to improving recruitment potential and should be a key aspect of revegetation maintenance occurring up until the revegetation is mature enough to limit groundcover growth itself (see Figure 33).

The age of the revegetation appears to be a major influence on the levels of recruitment observed and in the context of this study, indicates that revegetation within such a highly modified landscape takes time to mature enough to be positively influencing its surrounding environment to allow recruitment to occur. In light of these findings it could be anticipated that the minimum age for revegetation to reach maturity, indicated by the recruitment of the longer lived Eucalypt species (Burrows, 2000; Dorrough and Moxham, 2005; Graham *et al.*, 2009), is 20 years in this region and as such should influence the level of expectations for progress at different timeframes in the assessment of success. This in turn indicates an association with changes in soil characteristics over time as the revegetation matures and influences on the soil characteristics would become more apparent. Thus the levels of recruitment may not be a direct feedback of soil characteristic changes but rather the maturing of the entire ecosystem.

6.2 Implications for future Revegetation in the Southern Tablelands

Of the total expenditure in the 2011 financial period for the Southern Rivers Catchment Management Authority (SRCMA), $2.17 million was spent on various grants and subsidies to encourage and support revegetation throughout the region (Southern Rivers Catchment Management Authority, 2011). The SRCMA covers an area which stretches from Stanwell Park, north of Wollongong, to the Victorian border and as far west as Thredbo (Figure 34), covering 32 000 km^2 in which there is intensive agriculture, urban development, industrial areas and rural lifestyle residential developments (Southern Rivers Catchment Management Authority, 2011). Of the 32 000 km^2, 65% of that is publicly owned and a mix of national parks or state forests and

Crown Lands, the other 35% (11,200km^2) is privately managed urban, agriculture and other land uses (Southern Rivers Catchment Management Authority, 2011). If the assumption is that 60% of the privately owned 11,200 km^2 is agricultural land (6720km2) and 25% of this requires restoration or revegetation work, then the funding spreads to approximately \$1300/km^2. When these grants have to encompass the whole revegetation works, from initial assessment to providing tube stock seedlings or seed and then fencing the revegetation area, the funding must be spent productively and on revegetation that is going to be healthy and persist into the future, requiring little ongoing maintenance.

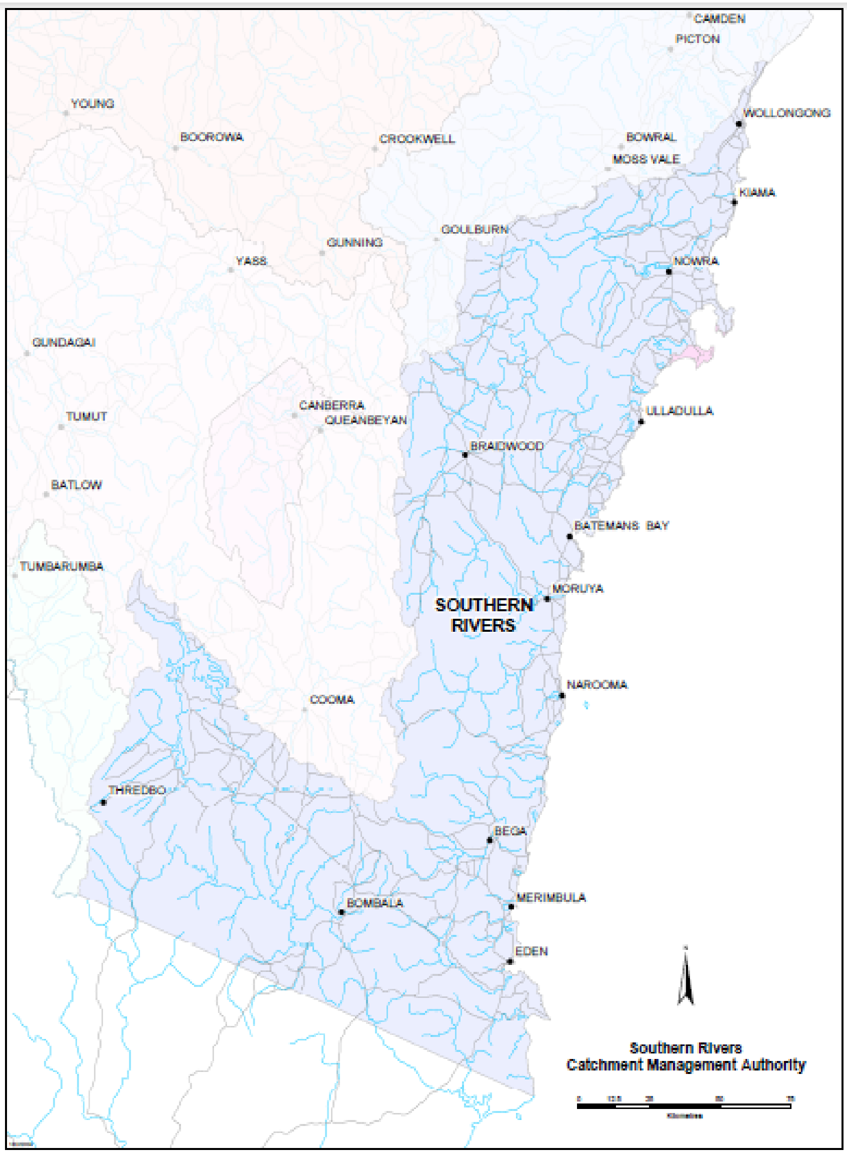


Figure 34: Southern Rivers Catchment Management Authority area. (SRCMA 2012)

Where the results of this study come into this is on the assessment of the long term effectiveness of the revegetation undertaken in the catchment as part of these subsidies and grants and how best to be distributing the funds through the various programs to provide the longest lasting and greatest benefits to the environment. The question which arises here is, if the timeframe for revegetation to mature and start recruiting is 20 years or longer, and various factors such as the distance to remnant vegetation, and the potentially negative influences from previous agricultural practices increase this timeframe indefinitely, wouldn't it then be more effective to preserve what remnant vegetation there is, which is currently persisting in that agricultural environment, through encouraging fencing around remnant paddock trees and stands of trees? Whereby encouraging natural regeneration of the original ecosystem, rather than attempting to recreate it?

The benefits of paddock trees on soil (Wilson, 2002) and the more immediate ecological benefits should potentially be assessed on a site by site basis to determine where the funding should be spent. When the benefits of fencing remnant areas and remnant paddock trees directly includes increased recruitment (Spooner *et al.*, 2002), less soil compaction (Bassett *et al.*, 2005) and a variety of beneficial soil characteristics (Wilson, 2002) the overall need to revegetate an area from scratch is brought into question and should only potentially occur where and when there is no remnants to expand from. Various authors (Spooner *et al.*, 2002; Bassett *et al.*, 2005; Dorrough and Moxham, 2005; Ottewell *et al.*, 2010) advocate active intervention, particularly in the Southern Tablelands, to preserve such remnants and encourage persistence into the future, through fencing and removal of exotic groundcovers, which is supported in this region by the findings of this study.

However as stated in Chapter 3, the Braidwood region has been almost exclusively cleared of the vegetation type which would have been located on the particular soil type of the region. With less than 100 ha of fragmented remnant vegetation on that soil type (Greening Australia, 1997), the need to support remnant vegetation and encourage the expansion of this should be a key assessment tool for funding dispersal throughout the region. The outcomes of this study indicate that to increase current revegetation recruitment, ongoing removal of exotic groundcover is required and replacement with native groundcover would be preferential. However again this occurs naturally within a shorter timeframe in fenced remnant vegetation (Spooner *et al.*, 2002) and further supports the need to recover these areas and the genetic diversity within them for future ecological benefits to both the natural environment and the sustainability of farming within the region.

6.3 Carbon Farming and the Future Use of Revegetation in Sequestration

In the current climate change situation, governments are being pressured to make decisions about the potential for implementing a state wide ‘carbon farming’ scheme where revegetation sequestration of carbon can be sold as credits to offset others emissions (NSW Department of Primary Industries, 2011). This scheme was brought in with the Clean Energy Future program in July 2011 from the Australian federal government and encapsulates the carbon tax, the Carbon Farming Initiative, Carbon Farming Futures funding, and the Biodiversity Fund. What this potentially equates to within the Southern Tablelands and further afield, is that revegetation has the potential to become a source of income for property owners and may provide more of an incentive for revegetation works to be carried out. It is at this point though that the results of this study bring into question the ability to put forward the revegetation works that have already taken place throughout the region for such schemes due to the general lack of SOC accumulation across the revegetation sites observed.

The potential for the leaching of nutrients from this particular soil type has been discussed earlier and this may impact on the ability to accurately measure the amount of carbon being sequestered. This hypothesis would need to be tested to determine if this was the case and not simply that mixed revegetation (as opposed to specifically planted native monoculture plantations) is sequestering carbon at a rate which is lower than expected. Regional assessment of mixed revegetation carbon sequestration should take place if the region is highlighted to become part of a future ‘carbon farming’ market as there is clearly a divide between plantation carbon sequestration and revegetation sequestration (Batjes, 2011).

What is of most relevance to carbon farming under revegetation throughout the region is the time lag between vegetation establishment and the move from net loss of SOC, to accumulation. This is a recognised trend throughout a number of studies on native acacia plantation rotations (e.g Turner and Lambert 2000, Turner *et al* 2005) where net loss of SOC occurs immediately after vegetation removal and accretion may not occur for another 5-20 years, by which time the revegetation may have only reached a net effect of zero. Though revegetation is not working to a plantation rotation scheme, the same principles should be applicable to a cleared agricultural landscape where pasture grasses have been the only feature for at least 50 years. This lapse period has been coined as the ‘breakeven’ point by Dean *et al* (2012) and it appears that the revegetation within the region may follow this trend as the maturation process incorporates SOC transitions from emission to neutral to accretion. The wider implications of this occurring in the Southern Tablelands, are whether or not then, revegetation younger than 20 years should be included in the carbon farming schemes.

The spatial variability of revegetation sites (Figure 35) and in turn SOC could be offset through increasing the number of sites sampled and coming up with an overall regional carbon sequestration potential for the type of mixed revegetation which occurs commonly in the region. This method is recommended to reduce the variation across data (Dean *et al.*, 2012) and could be a viable option for decision makers to reach a less general but still attainable estimate of carbon sequestration within the Southern Tablelands. This general amount could then be applied and used as a monetary incentive for property owners to increase their levels of revegetation, therefore benefitting themselves, the catchment and sustainability outcomes.

Figure 35: Site 34, showing the changes in variations of vegetation success even within the same revegetation site. *Acacia spp.* are thriving on the left, a broadleaf *Eucalyptus spp.* in the centre is struggling with insect attacks and stunting, and the *Eucalyptus acaciiformis* is maturing into healthy, resilient trees to the right. (X.Willis 2012)

7 CONCLUSIONS

The broad aim of this project was to determine the long term viability and self propagating nature (i.e. vegetation recruitment) of revegetation in the Southern Tablelands. The potential positive feedbacks from the influence of revegetation on soil were examined in an attempt to assess the restrictions to revegetation persistence through self propagation. This study has highlighted a number of potential explanations for the overall lack of vegetation recruitment observed within revegetation in the Southern Tablelands and examined possible reasons for these trends. This study drew attention to the influence of groundcover composition and density as a key limitation to self propagation and indicated that continued management of groundcover should occur if persistence of revegetation is to be encouraged. The lack of influence from revegetation on soil indicates that for this soil type, revegetation is not aiding in accumulation of nutrients and as such any future plans to utilise the revegetation in carbon sequestration markets should be approached with caution and further investigation into the particular properties of this soil type should occur. The overall lack of recruitment in revegetation has also emphasised the need to encourage fencing and rehabilitation of remnant vegetation and remnant paddock trees in the region to retain the ecological benefits of such vegetation. This option could also be more financially viable than revegetation straight from agricultural land, though it is recognised this may not always be possible in the Braidwood region.

7.1 Recommendations

Key recommendations for future studies and management of revegetation for persistence highlighted through this study include:

- Further investigation into the potential for nutrient, and specifically SOC, translocation through the soil profile of this soil type to determine the carbon sequestration potential accurately in the region.
- Continued management of exotic groundcover should be added as a key process in revegetation management.
- Revegetation in the region should not be assessed on whether it is a success or not until maturity is reached, which in this particular region appears to be 20+ years.
- Investment into the protection and enhancement of remnant vegetation in the region should be a high priority to protect the ecological benefits of such areas.
- Fencing and rehabilitation of remnant areas could be a more financially viable option than revegetation from bare agricultural land and it is recommended that more funding and research be directed towards this.
- A study similar to this one should be extended over a number of years in an attempt to pick up the key conditions which aid recruitment and therefore the age to be expected before consistent vegetation recruitment occurs.

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8.1 Spatial analysis data layers

Soil types layer:

"Soil Landscapes of the Braidwood 1:100,000 Map Sheet (8827)", ©NSW Department of Environment, Climate Change & Water 1996

SRTM Digital Elevation Model:

Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org.

Location map imagery:

Site map created using ArcGIS Online Basemaps on 04/04/2012.

Main Map Image Source: (c) 2010 Microsoft Corporation and its data suppliers

Inset Map Image Source: http://goto.arcgisonline.com/maps/World_Physical_Map

Aerial imagery used in site selection:

Ortho-rectified aerial photo mosaic, 50cm pixels, Jan 2009. (c) NSW Land and Property Information

9 APPENDICES

Appendix 1

Soil sampling survey sheet.

Property and Property owner:		Site name / number:
GPS (SE corner of site)	Easting: Southing:	Date of Survey:
Current surrounding land use:		Approx age of planting:

Sample Labels say: Site #___, Sample #___, "V" point direction:_______, Date ___/___/____, E:________, S:________, Xanthe Willis

Sample Plot Dimensions: (20x20m, 8x50m, 4x100m, 2x200m, 8x50, other:)

Soil Carbon and Moisture Sampling

1. Assess topsoil variability of site and if deemed not particularly variable (expected), sample as below. Otherwise sample areas with similar topsoil characteristics.
2. Set up the 2 "V" transects to sample along.
3. Using the auger as sample area dimensions, trace around the inside of the auger with a knife to separate inside leaf litter from outside leaf litter.
4. Collect all leaf litter down to soil and place in sample bag.
5. Collect field moisture and pH after collecting leaf litter from the surface.
6. Using the auger drill down to the top most section of the auger (~15cm) and collect the soil sample from the soil augered. There should be ~7 samples per "V". So **14 samples per Main plot**.
7. Bag the sample and label it. Ensure enough sample for carbon and soil moisture analysis is taken and also potentially P and N testing.
8. Gaffa tape up the bag to seal it and retain moisture.
9. Sample edge, mid and paddock plots also using the above method, if it is deemed a practical way of collecting the samples.
10. Samples will be combined back at the lab for a representative sample.

Leaf Litter Samples – numbers correlate with soil samples.

Sample #	Collection area	Label
1		
2		
3		
4		

Main Plot Soil Samples

Sample #	"V" point direction	Field Moisture reading	Field pH reading	Label
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				

Edge Plot Soil Samples

Sample #	"V" point direction	Field Moisture reading	Field pH reading	Label
1				
2				
3				
4				
5				

Mid Section Plot Soil Samples

1				
2				
3				
4				
5				

Outer Plot Soil Samples

1				
2				
3				
4				
5				

Appendix 2

Vegetation sampling survey sheet.

Property and Property owner:		**Site name/number:**
GPS (NW corner of site)	**Easting:** **Southing:**	**Date of survey**
Current surrounding land use:		**Approx. age of planting:**

Sample Labels say:

Sample Plot Dimensions (circle): (20x20m, 8x50m, 4x100m, 2x200m)

Recruits

- Sample within the specified plot size of $400m^2$
- Note species name if known, if unknown: collect sample where possible, bag it and number it. Take a photo of every sample/species.

Species (# if unknown, get BIG sample and photo otherwise)	**Photo #**	**Count**	**Sample label**
	Total Count		

Canopy Cover/Structure

- Assess canopy cover amounts using comparison to the biogeography sheet.
- Record heights of most mature species and what the species is.

Part of structure	% amount
Canopy (>2m)	
Shrubs (<2m)	
Groundcover (<.5m)	

Groundcover

- What are the dominant 4 or so ground covering species (grasses, herbs, shrubs, etc)
- Are they exotic or native grasses
- Record how covered the ground is by the few species.
- Bag and label a sample of each of the grasses/ground coverings

% rock:	% bare ground:	% ground vegetation:	% leaf litter:
Species	**% of each species covering the ground**	**Exotic or Native**	**Label**

Planted Species within the plot

- Identify the species within each plot
- * asterisk the main species which is dominant
- Circle or otherwise identify species which appear to be recruiting

Species	Count within plot	Health

Additional notes about the site: (sketch here to demonstrate what the planting is like structure wise)

Appendix 3

Soil chemical analysis results and leaf litter biomass volumes.

Site	Sample Location	% Organic Carbon	Plant Available Phosphorous (mg/kg)	Total Phosphorous (mg/kg)	% Moisture	Leaf Litter Biomass kg/m^2
1	**Interior**	2.06	18.2368	211	6.94	1.70
	Interior	2.29	16.5968	221	7.60	
	Exterior 10m	2.09	30.1	254	6.56	0.53
	Exterior 20m	2.29			9.47	0.45
	Exterior 40m	1.69	47.3	418	7.65	0.34
5	**Interior**	2.13	13.7104	293	12.12	0.58
	Interior	1.98	16.728	331	11.17	
	Exterior 10m	1.33	35.5	312	11.38	0.26
	Exterior 20m	1.68			16.88	0.48
	Exterior 40m	2.94	27.8	294	14.37	0.36
8	**Interior**	4.77	26.4368	388	19.08	0.97
	Interior	3.37	13.5136	282	11.69	
	Exterior 10m	2.80	37.1296	456	18.37	0.35
	Exterior 20m	2.37			16.23	0.11
	Exterior 40m	2.29	18.8928	402	17.61	0.13
11	**Interior**	3.68	19.4832	410	14.57	0.80
	Interior	4.18	13.9072	392	13.55	
	Exterior 10m					
	Exterior 20m	2.14			12.50	0.44
	Exterior 40m	2.27	25.6496	277	13.07	0.45
13	**Interior**	2.29	6.8224	194	11.03	1.60
	Interior	2.67	8.528	197	9.55	
	Exterior 10m	1.73	21.32	202	7.36	1.20
	Exterior 20m	1.31			6.67	0.34
	Exterior 40m	1.19	18.696	178	5.33	0.18
34	**Interior**	2.51	9.3808	266	21.28	0.77
	Interior	2.70	6.0352	230	25.50	
	Exterior 10m	3.17	14.432	291	16.77	1.39
	Exterior 20m	4.05			19.05	1.89
	Exterior 40m	3.50	17.3184	335	17.12	0.68
64	**Interior**	3.04	10.824	336	19.51	0.76
	Interior	2.47	8.3312	311	16.97	
	Exterior 10m	2.24	12.2016	333	26.43	1.08
	Exterior 20m	2.88			25.17	0.95
	Exterior 40m	2.66	19.9424	349	25.55	0.73

Appendix 4

Statistical results – regression unreplicated block design ANOVA. * indicates a significant relationship

Tested parameter	Error - D.F	Source	D.F	F-Ratio	p
Carbon	23	Site	6	3.5788	0.0119*
		Position	4	1.2591	0.3145
Plant Available Phosphorous	18	Site	6	3.9336	0.0109*
		Position	3	8.2966	0.0011*
Total Phosphorous	18	Site	6	10.0646	<0.0001*
		Position	3	2.3887	0.1027
Moisture	23	Site	6	18.5665	<0.0001*
		Position	4	0.252	0.9054
Biomass	17	Site	6	1.1487	0.3775
		Position	3	10.8538	0.0003*
Vegetation Recruits	6	Site	6	8.709	0.0093*
		Position	1	1.7411	0.2351

Appendix 5

Statistical results – blocked ANOVA. * indicates a significant relationship.

Tested Relationship	**Rsquare**	**Error - D.F**	**D.F**	**F-Ratio**	**p**
Recruits with Leaf Litter Biomass	0.022265	11	1	0.2505	0.6266
Recruits with % Groundcover	0.31618	12	1	5.5484	0.0363*
Recruits with Carbon	0.096132	11	1	1.1699	0.3026
Recruits with PAP	0.00805	12	1	0.0974	0.7603
Recruits with Total P	0.062791	12	1	0.804	0.3875
Recruits with Moisture	0.08917	11	1	1.0769	0.3217
Carbon with Moisture	0.04731	11	1	0.5462	0.4753
Moisture with Biomass	0.05427	11	1	0.6313	0.4437
Biomass with Carbon	0.1675	11	1	2.2136	0.1649
Carbon with Total P	0.099568	25	1	2.7645	0.1089
Total P with Biomass	0.16409	18	1	3.5336	0.0764
Biomass with PAP	0.283133	18	1	7.1093	0.0157*