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An Investigation of the Factors Influencing the Abundance and Species Richness of Introduced Species on Roadsides in the Illawarra

Melissa J. Huntsman
University of Wollongong

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Abstract

Negative impacts associated with the invasion of introduced species necessitates that their establishment and spread into new areas is minimised. Road verges facilitate the spread of introduced species along this disturbed corridor and into adjacent habitats. Revegetation of road verges by the Roads and Traffic Authority (RTA) aims to inhibit the germination of introduced species by the planting and/or seeding of native species and use of herbicide. The presence and spread of introduced species on verges has been widely studied; however there are still gaps in our knowledge of the success of particular treatments (i.e. seeding and planting) in their ability to withstand invasion. This study aimed to: i) determine if, and to what extent, the planting protocols of the RTA influence the abundance and cover of introduced species along road verges; and ii) identify if additional site specific factors and management practices impact the abundance and cover of introduced road verges.

Flora surveys, site condition analysis and soil investigations were conducted on 40 road verge sites in the Illawarra region. Road verges had twice the percentage cover and three times more introduced than native species, with the most abundant natives being those that were planted by the RTA. The percentage cover and species richness of native plants did not vary with the use of either revegetation treatment, whilst the use of seeding decreased introduced species abundance. The age of the road verge revegetation was the strongest indicator of native species richness, with species richness decreasing with increasing age. Introduced and native species composition was significantly related to the age of revegetation. Modification of RTA species selection and revegetation techniques is believed to be responsible for the shift in native species composition, as minimal natural dispersal was observed. Introduced species composition was greatly influenced by the dominance of noxious

Lantana camara on older road verges. The use of imported topsoil increased native species richness and decreased introduced species richness, highlighting the importance of proper management of in -

situ topsoil. The dispersal limitations of native plants necessitates that initial revegetation of road verges must include high diversity and richness of native species to increase road verge ecosystems resistance to invasion. To increase ability of current road verge ecosystems to resist invasion it is recommended that weed infestations within the road network are actively managed and species richness of road verges be manually increased.

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AN INVESTIGATION OF THE FACTORS INFLUENCING THE ABUNDANCE AND SPECIES RICHNESS OF INTRODUCED SPECIES ON ROADSIDES IN THE ILLAWARRA

By

MELISSA J. HUNTSMAN

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Abstract

Negative impacts associated with the invasion of introduced species necessitates that their establishment and spread into new areas is minimised. Road verges facilitate the spread of introduced species along this disturbed corridor and into adjacent habitats. Revegetation of road verges by the Roads and Traffic Authority (RTA) aims to inhibit the germination of introduced species by the planting and/or seeding of native species and use of herbicide. The presence and spread of introduced species on verges has been widely studied; however there are still gaps in our knowledge of the success of particular treatments (i.e. seeding and planting) in their ability to withstand invasion. This study aimed to: i) determine if, and to what extent, the planting protocols of the RTA influence the abundance and cover of introduced species along road verges; and ii) identify if additional site specific factors and management practices impact the abundance and cover of introduced road verges.

Flora surveys, site condition analysis and soil investigations were conducted on 40 road verge sites in the Illawarra region. Road verges had twice the percentage cover and three times more introduced than native species, with the most abundant natives being those that were planted by the RTA. The percentage cover and species richness of native plants did not vary with the use of either revegetation treatment, whilst the use of seeding decreased introduced species abundance. The age of the road verge revegetation was the strongest indicator of native species richness, with species richness decreasing with increasing age. Introduced and native species composition was significantly related to the age of revegetation. Modification of RTA species selection and revegetation techniques is believed to be responsible for the shift in native species composition, as minimal natural dispersal was observed. Introduced species composition was greatly influenced by the dominance of noxious *Lantana camara* on older road verges. The use of imported topsoil increased native species richness and decreased introduced species richness, highlighting the importance of proper management of in-situ topsoil. The dispersal limitations of native plants necessitates that initial revegetation of road verges must include high diversity and richness of native species to increase road verge ecosystems resistance to invasion. To increase ability of current road verge ecosystems to resist invasion it is recommended that weed infestations within the road network are actively managed and species richness of road verges be manually increased.

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Chapter 1. Introduction

1.1 General Introduction

The introduction of non-native and non-indigenous species as a consequence of anthropogenic activities has a negative impact upon both the human and natural environment (Elton 1958), and is identified as one of the major causes of biodiversity loss worldwide (WRI. 1992; Vitousek et al. 1996; Coutts-Smith et al. 2006). The prevalence and impact of introduced species has been studied comprehensively worldwide (Vitousek et al. 1997) and their extent is considerable: in over 184 sites worldwide, an average of 16% of the species present were introduced (Lonsdale 1999). The combined negative impacts and invasive potential of weedy species worldwide has necessitated considerable research focusing on the impact of introduced species upon communities and wider ecosystems and how to best manage these impacts (Davis 2006).

In order to prevent invasion and reduce the impact of weedy species, it is important to understand how these species spread and how humans facilitate this. Road verges are one of the recognised disturbed areas which often facilitate the spread of introduced flora (Forman et al. 2002). In order to manage this disturbed corridor it is important to understand what encourages weed growth in these areas and revegetation methods that limit or prevent the growth of weed species.

The Roads and Traffic Authority (RTA) is the New South Wales government authority responsible for the state's major road network and associated entities. In association with private industry and local councils they design, construct and maintain this vital infrastructure. The RTA is responsible for developing appropriate revegetation guidelines for the road verges and ensuring compliance of these specifications by those constructing the road. The methods and species used for the revegetation of road verges by the RTA have developed over time to reflect scientific knowledge.

1.2. Introduced Species in Australia

The majority of Australia's introduced species were deliberately established and cultivated for agricultural, horticultural or ornamental purposes; some sources suggest that introduced species provide an overall economic benefit to the country (Randal 2007). The most recent figures suggest that there are 26,242 introduced species within Australia, with 96.9% currently being cultivated (Randal 2007); the remaining 3.1% have been introduced both accidentally and purposefully (Randal 2007).

Species introduced with the most positive intentions can still become invasive; *Lantana camara* introduced as an ornamental plant and now classified as a noxious weed is an excellent example of

this (Ensbey 2008). Williamson and Fitter (1996) developed the 1 in 10 rule, which sugests that 1 in 10 species introduced will become naturalised and have a negative impact both economically and environmentally. In Australia, this theory holds true with 2,739 of the 26,242 introduced species classified as naturalised and growing outside their area of introduction (Randal 2007). In agriculture pasture areas in Northern Australia this percentage is higher, with 60% of the exotic grasses introduced for agricultural purposes listed as weed species and less that 1% of these species useful to agriculture and not classified as a weed (Lonsdale 1994).

In Australia, noxious species are the most severe of the weed classifications and are recognised as needing legislative control and management because of their negative impacts upon one or a number of the following; human health, animal health, biodiversity, waterways and agriculture (Noxious Weeds Advisory Committee 2009). In 2004, 370 flora species within Australia were legislatively classified as noxious by State and Territory governments (Siden et al. 2004). That has increased to 482 species currently recognised as noxious in at least one state or territory within Australia, with 192 classified as noxious in NSW and 84 noxious in the Illawarra region (Australian Weeds Committee. 2011).

1.3. Impacts of Introduced Flora

Flora species introduced purposefully and accidentally into non-indigenous locations can cause significant negative impacts. Research into these impacts focuses on the sectors most affected by invasions; the economy, agriculture and the natural environment

Economic impacts

Monitoring, control and eradication programs are required to reduce the impact of introduced species on agriculture, ecosystems and society. The cost of implementing these programs in addition to the economic and ecosystem losses due to weed infestations can be considerable (Thorp et al. 2000; Siden et al. 2004; NSW Government: Industry and Investment 2010).

The total economic loss from agriculture (including losses in output), natural environment, public authorities, indigenous lands and commonwealth research in Australia is estimated to be between $3,554 million and $4,532 million (Siden et al. 2004). There is no published information regarding the direct and indirect economic consequences of weeds within the Illawarra, however noxious weed grants in 2009-2010 for the Illawarra Weeds Authority, (made up of representatives from Kiama, Wollongong and Shellharbour Council areas) received $58,500 for weed control coordination, $14,200 for council administration support and $158,000 for targeted high priority weeds, including $16,000 for the declared noxious weed *Lantana spp.* (NSW Government: Industry and Investment 2010).

Agricultural impacts

While the agricultural industry is responsible for the introduction of flora species, it also suffers significantly from weed invasions. There is a strong focus to reduce the impact of agricultural weeds as the cost of production losses and control of the introduced flora costs the Australian agriculture industry millions of dollars a year (Siden et al. 2004).

The infiltration of naturalised flora into grazing paddocks and crop fields is problematic as they often compete with cultivated agricultural species (Dew 1972), can be poisonous to live stock (Pimentel D et al. 2005) and can contaminate crop and wool that is to be harvested causing significant production losses (Parry et al. 1999; Godfray et al. 2010). In NSW, *Senecio madagascariensis* (fireweed) has spread exponentially through NSW (Sindel et al. 1992), outcompeting pasture grasses (Sindel 1989) and poisoning livestock. *Nassella trichotoma* (serrated tussock) is a Weed of National Significance with major negative impacts upon agricultural production as it contaminates crops and reduces feed for livestock (NSW Government: Industry and Investment. 2010).

Environmental impacts

The negative impacts of weed species upon the environment has been well studied and documented (Vitousek et al. 1996). The spread of introduced species into natural environments can have detrimental impacts on the natural environment as they can disrupt natural processes and cause the decline in indigenous species richness (Mason et al. 2009), with many plant and animal species endangered or threatened due directly to the impact of introduced species (Pimentel D et al. 2005).

Introduced species compete with native species, and can dominate leading to homogenisation of the ecosystem (Thorp et al. 2000; Nentwig 2007). In NSW, 45% of the listed threatened species are placed under stress by the destructive impact of introduced flora (Coutts-Smith et al. 2006). *Lantana camara* and *Chrysanthemoides monilifera* (bitou bush) have been identified as the species that are the most detrimental to listed threatened species in NSW (Coutts-Smith et al. 2006).

As demonstrated in the Northern Territory, Australia (Brooks et al. 2004) and Hawaii (Hughes et al. 1991), invasion by particular species can increase the frequency and intensity of fire, due to changes in species composition and abundance. The invasion of introduced species can lead to the alteration of entire landscapes; for example Northern Territory wetlands have been changed into shrub land due to the noxious weed *Mimosa pigra* (Walden et al. 2008).

Typically research of introduced species in the Illawarra region has focused on particular problematic species such as *Chrysanthemoides monilifera* (Ens et al. 2009) *Lantana camara* (Gooden et al. 2009a; Gooden et al. 2009b) and *Olea europaea* subsp. *Cuspidate* (Cuneo et al. 2006). Additional research of

C. monilifera management has focused on management practices (French et al. 2008) and the impact of these practices upon indigenous communities (Matarczyk et al. 2002).

1.4. Disturbed Environments

Disturbance can affect individuals directly (e.g. damaging or injuring individuals) or indirectly (e.g. altering the type and quantity of required resources), with the flow on effects potentially impacting entire ecosystems (Hobbs et al. 1992). Disturbance (whether natural or anthropogenic) is an important process in ecosystems (Hobbs et al. 1992), opening up resources such as space and light for new plants to germinate. Initial studies focused on vegetative response to disturbance, particularly the stages of vegetative growth, from the disturbance event to a stable climax (Clements 1916). The role of disturbance in ecological communities has shifted, and Clements theory is not widely accepted (Connell et al. 1977). While high levels of disturbance can be detrimental, intermediate levels appear to favour species richness (intermediate disturbance hypothesis (Connell 1978)). Elton (1958) identified that disturbed areas had higher numbers of introduced species in comparison to non disturbed areas, with further studies acknowledging that both natural and anthropogenic forms of disturbance promote successful invasion by introduced species (Baker 1974; Larson 2002). While there are both native and introduced species have the potential to be weedy invasive species, it is regularly the introduced species that dominate anthropogenic forms of disturbance (Larson 2002).

1.5. Characteristics that Enhance Invasion

There are certain life history traits and characteristics of species which are associated with competitive advantage and subsequent successful invasion (Thorp et al. 2000). It was previously hypothesised that characteristics of flora species responsible for their ability to successfully invade areas and could be determined and used to predict which species will be invasive (Baker 1974)(Table 1.1 1.1). Subsequent studies have found that these characteristics can not be used to predict all species that will be invasive (Sutherland 2004) but invasive species will on average possess half of Baker's characteristics (Williamson 1993).

The success of introduced species growing in disturbed habitats is due to characteristics which allow them to prosper in various habitats and ecosystems (Table 1.1), and that these generalist characteristics of weed species provide a competitive advantage over the native species when disturbance occurs (Marvier et al. 2004). Others suggest that the dominance of weed species in disturbed habitats is due to the lack of resources required for native plant growth (Seabloom et al. 2003).

Table 1.1: Specific characteristics of flora species are responsible for their competitive advantage over other species and resulting weed classification (Baker 1974).

	Ideal weed characteristics
1.	1. Germination requirements fulfilled in many environments
2.	2. Discontinuous germination (internally controlled) and greater longevity of seed
3.	3. Rapid growth through vegetative phase to flowering
4.	4. Continuous seed production for as long as growing conditions permit
5.	5. Self-compatible but not completely autogamous or apomictic
6.	6. When cross-pollinated uses unspecialised visitors or wind
7.	7. Very high seed output in favourable environmental circumstances
8.	8. Produces some seed in wide range of environmental conditions; tolerant and plastic
9.	9. Has adaptations for short- and long-distance dispersal
10.	10. If a perennial, has vigorous vegetative reproduction or regeneration from fragments
11.	11. If a perennial, has brittleness, so not easily drawn from ground
12.	12. Has ability to compete interspecifically by special means (rosette, choking growth, allelochemicals)

Introduced species in the Illawarra posses many of the tabled characteristics; *Protasparagus aethiopicus* (asparagus fern) and *Lantana camara* seed are dispersed long distances by birds (Parsons et al. 1992), *Araujia sericifera* (moth vine) can successfully germinate under a wide range of environmental conditions (Vivian-Smith et al. 2005) and allelopathy is utilised by *Chrysanthemoides monilifera* (Bitou bush) to compete indirectly with native flora (Ens et al. 2009).

1.6 Invasive vs Ruderal Introduced Species

As not all weeds are similarly invasive, Baker (1974) coined the terms major and minor weeds to describe the severity of species; these terms have been reclassified with invasive noxious weeds now the most severe weed classification (Richardson et al. 2000).

There are significant differences between the life history traits of invasive and non invasive species (Sutherland 2004), and their evolution in relation to stress, competition and disturbance is of major importance (Grime 1979). Ruderal weed species generally have annual or perennial growth, are often colonising species and can be loosely defined as an 'r' selected species. The distribution of ruderal species is closely related to the presence of natural or anthropogenic disturbance (Frenkel 1970). Invasive weed species are not generally colonial species but have superior dispersal abilities and the capacity to outcompete native species. Invasive species are more likely to have the form of a

tree or shrub (Sutherland 2004). Species which are invasive generally produced seeds in large numbers and have the ability to disperse their seeds large distances or can spread vegetatively (Richardson et al. 2000).

The terminology surrounding introduced species can be confusing, so for the purpose of this thesis the following will be utilised;

- Weed - a plant growing where it is not wanted, it can be introduced from another continent or area in Australia.
- Introduced species – a flora species not native to Australia
- Naturalised species - a weed that reproduces and can sustain a population without human interference.
- Invasive species - a naturalised species that not only grows outside its area of intended distribution but can disperse from the site of introduction also damaging or threatening environmental, agricultural or other social resources (Australian Government: Department of Sustainability Environment Water Population and Communities 2010).
- Noxious species - a flora species that is required to be controlled under the Noxious Weeds Act 1993. A control class from 1 to 5 indicates the level of control required for specific species, which varies depending on the local government area.

1.7 The Road Side Environment

The ecological impacts of road networks has encouraged an increase in research in the ecology of road verges (Spellerburg 1998), with a noticeable escalation in research papers since the 1980's (Forman et al. 2002). The increase in research has lead to a greater understanding of how and why these networks have impacted upon the environment. Road construction affects the abiotic and biotic environments in the area directly modified by construction. Additionally, negative impacts can be experienced in ecosystems in the surrounding area and even those not in close proximity to the road (Coffin 2007). The impact of roads on road kill, habitat fragmentation, edge effects and roadside habitats has been well researched (Forman et al. 2002).

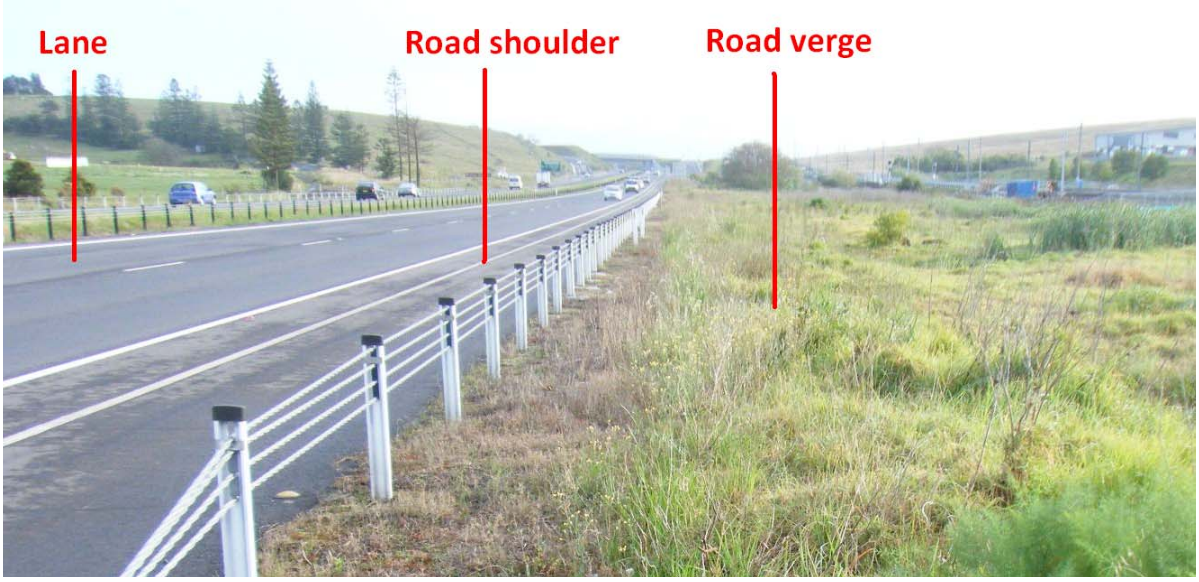

Figure 1.1: The road verge is the vegetated area adjacent to the paved lane and shoulder.

Roads as a disturbed environment

Road verges are widely recognised as highly modified and disturbed environments (Forman et al. 2002)(Figure 1), as a result of severe modification during the road construction process (Forman et al. 1998; Forman et al. 2002). The construction process commonly requires topsoil and sub soil to be completely removed, stockpiled, stored and then re-laid (Faucette et al. 2006), totally restructuring the soil profile. Further disturbance due to erosion is common, particularly in verges that are not compacted correctly, have no vegetation or have a significant slope (Riley 1988). After construction, the presence of the road, associated vehicular traffic and maintenance activities continue the disturbance regime (Forman et al. 1998; Spellerburg 1998; Forman et al. 2002).

The abiotic conditions of road verges vary from the surrounding environments, especially natural bushland (Forman et al. 2002)(Figure 2). The materials and structure of roads contribute to the characteristics of the road verges mircoclimate (Karim et al. 2008) as the ability of the road pavement of absorb and radiate heat, can result in higher temperatures (Forman et al. 2002). Vehicles create localised wind gusts which have the ability to lift soil particles (Forman et al. 2002) and may transport plant seeds (Tikka et al. 2001). During rain events pollution produced by vehicles is washed from the impermeable road surface (Ball et al. 1994) into drains and onto verges with altered surface flow (Forman et al. 1998). These abiotic conditions influence the plant life forms present (Karim et al. 2008) and can be influential in the success of revegetation by seeds (Mola et al. 2011).

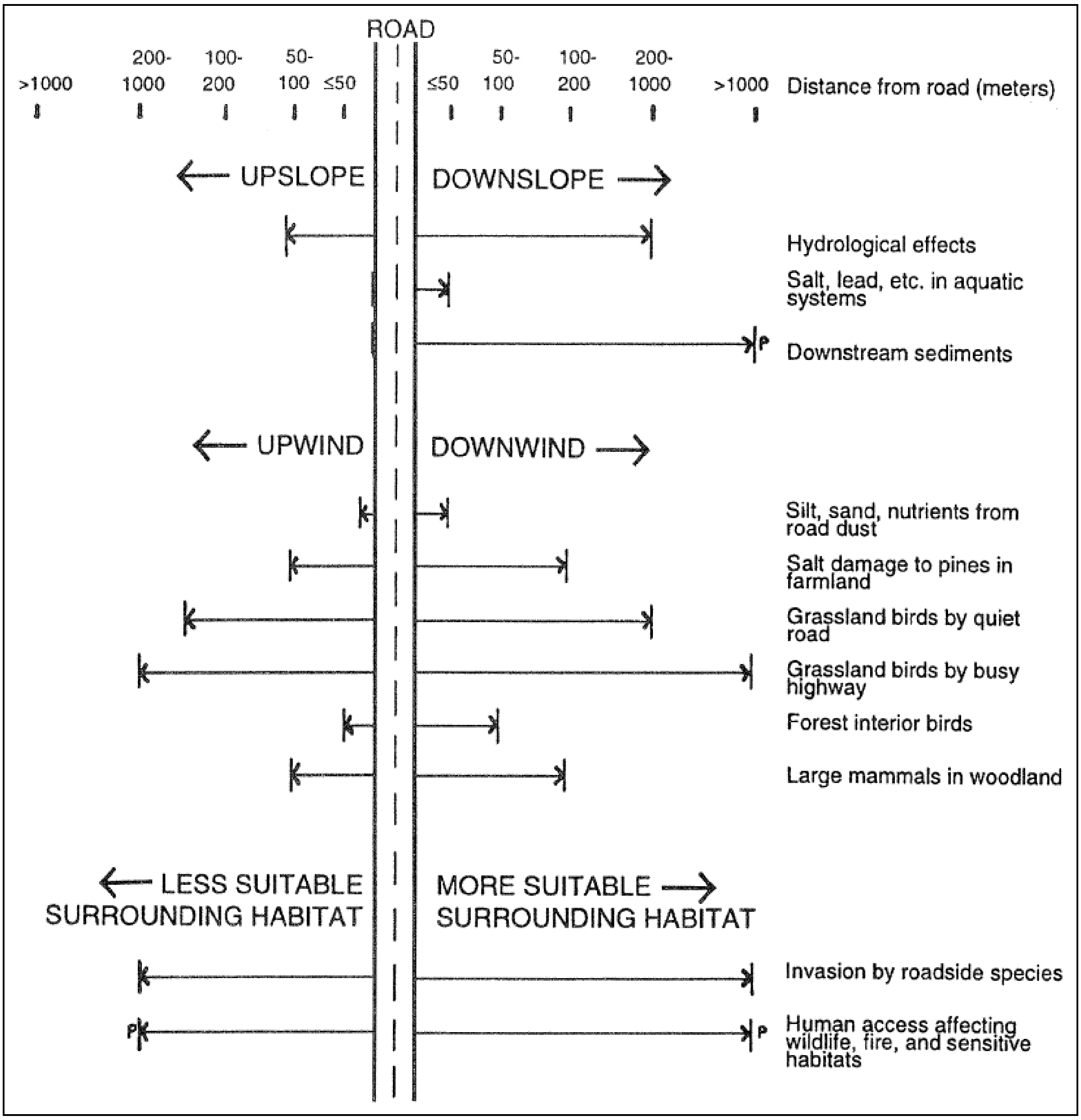

Figure 1.2: Road presence effects vary in distance from the road with slope, wind direction and habitat type. The majority of distances are based on specific research. (P) represents an effect primarily at specific points (Forman et al. 1997).

Roads constructed through areas of indigenous vegetation generally have an overall negative impact upon surrounding areas (Brekke Skrindo et al. 2004) however, the altered road verge environment can be advantageous. For example the concentrated water flows and reduced competition were shown to be beneficial to the native species, *Banksia hookeriana,* with plants growing on road verges significantly larger and producing more seed than those located at least 50m from disturbance (Lamont et al. 1994). In highly modified regions such as agricultural and urbanised areas, road verges may be the only area that is able to provide habitat to indigenous species that are unable to survive

in the surrounding area (Arnold et al. 1990). There has been interest in using road verges for conservation purposes (Way 1977; Cale et al. 1991; Forman et al. 1998; Ranta 2008), particularly in agricultural regions in Western Australian where the road verge provides the only habitat for both native flora and fauna (Arnold et al. 1990)**. T**he constant disturbance due to maintenance activities and limited area and depth of the verge suggests that considerable time and costs would need to be invested in these verges to ensure a high biodiversity.

Abiotic conditions of road verges influence the germination and growth of flora and the continual disturbance of the road verges influences the species able to survive in these conditions (De Wet et al. 1975). The high frequency of disturbance on road verges allows resources such as space and light to be readily available (Mortensen et al. 2009). The frequency of weed species is particularly enhanced by light with high light levels coinciding with high frequencies of weed species (Parendes et al. 2000). Few studies have considered the complexity of the communities created alongside road verges, with most studies concentrating on a particular invasive species and the impact of that on the surrounding community (Dong et al. 2008; Jodoin et al. 2008).

Road verges as a corridor for the spread of invasive introduced flora

The road verge is a starting point from which seeds of both indigenous and introduced species can potentially spread into surrounding ecosystems, agricultural areas and urban gardens. Road verges are known to contain a large number of weedy species (Frenkel 1970) and are one of the anthropogenic corridors that are believed to facilitate the spread of species beyond their traditional and geographical boundaries (Forman et al. 1998; Nentwig 2007). The disturbed nature of road verges results in road verges having a significantly higher frequency of non-native species compared to the surrounding grassland and forest environments (Amor et al. 1975). The rate and distance of spread of flora species has increased due to the development of transport technologies such as trains, motor vehicles and aeroplanes (Mack 2003). The nature of road verges encourages the growth of disturbance tolerant species (Hansen et al. 2005).

The disturbed nature of road verges provides a suitable corridor that facilitates the spread of invasive flora species (Spellerburg 1998; Harrison et al. 2002; Sullivan et al. 2009) allowing seeds to travel twice the distance on road verges than they do in non disturbed areas (Mortensen et al. 2009). Seeds are likely to be transported along the road verge by a range of biotic and abiotic vectors (Lonsdale et al. 1994; Mortensen et al. 2009). Vehicles are one of the vectors that can facilitate the spread of introduced species along road verges and have been shown to regularly transport seeds long distances (Von Der Lippe et al. 2007) Mud trapped in vehicle tread carries small and/or light seeds of pioneer species (Zwaenepoel et al. 2006). Maintenance and construction vehicles and

equipment can facilitate the spread of weed species along the verges (Mortensen et al. 2009), with unpublished data by Rauschert (cited in (Mortensen et al. 2009)) suggesting that these machines may be responsible for the seeds travelling up to 200 times further than natural dispersal.

The density of weed species decreases with increasing distance from the road verge (Watkins et al. 2003; Flory et al. 2006; Dong et al. 2008), with both singular plants and heavily invaded areas proven to be significant seed sources (Harrison et al. 2002). Even more pristine areas are impacted, the abundance of introduced species in natural reserves in New Zealand is significantly influenced by the distance from roads and railways (Timmins et al. 1991). This is problematic as further advancement by competitive invasive species into the surrounding ecosystem can occur as a result of minor natural disturbances (Harrison et al 2002). Agricultural areas are particularly vulnerable to encroachment from the road verge as they experience regular disturbance (Forman et al. 2002). The spread and distribution of road verge weeds has been studied in numerous countries (Arévalo et al. 2005; Sharma et al. 2009; Sullivan et al. 2009), due to inconclusive and opposing research outcomes the spread of introduced species from road verges into surrounding environments requires further investigation (Forman et al. 2002). Further research into these areas is suggested due to studies not producing significant relationships between the abundance of weed species and the distance from the road verge (Christen et al. 2006; Craig et al. 2010), however this may be due to the small initial weed presence on the verges (Craig et al. 2010). In Australian, alpine regions are the focus of road verge studies into the spread of introduced species; with major focus on the species present and the invasive capacity of those species (Pickering et al. 2007).

Road size and associated traffic volume is a significant factor in the abundance of weed species, with large roads with high traffic volumes possessing a higher abundance and frequency of weed species (Dong et al. 2008; Mortensen et al. 2009). The age of the road doesn't produce such clear relationships, with some studies showing higher abundance of weeds at newer roads (Dong et al. 2008) and others at older roads (Jodoin et al. 2008). It is important to note that these studies only considered one species and didn't factor in other introduced species. There is also an increase in introduced species abundance with nearness to urban centres (Arévalo et al. 2005).

1.8 Revegetation

The motivation for revegetation varies but is commonly undertaken with the aim to return the area to a healthy and functioning ecosystem, however, this is not always the primary goal with revegetation often carried out for other purposes including aesthetics, to reduce erosion potential or as a noise barrier.

The revegetation of anthropogenically disturbed areas such as mine sites, agricultural areas, rail and roads provides important information into revegetation of different geographical areas, ecosystems and the success of various techniques. Revegetation by specific species has the ability to remediate contaminated lands (Dickinson et al. 2000; Bleeker et al. 2002), reduce the height of the water table, reduce the impacts of dry land salinity (George et al. 1999) and wind breaks in agricultural areas can successfully reduce the wind speed, soil erosion (Bird et al. 1992). Methods for regrowth of species in these disturbed areas can occur in a number of ways including; growth from propagules in topsoil, the use of a seed mix or planting of species.

Native species selection is an important factor in revegetation, particularly when it has been shown that planted species are the most dominant species even 20 years after revegetation has occurred (Newman et al. 2001). A cover crop of introduced species is sometimes utilised as a colonising species to both stabilise the soil and inhibit the growth of aggressive introduced species, allowing native species to grow. Plantings of introduced species with biological characteristics such as nitrogen fixing can be beneficial in disturbed soils (Zahran 1999), and can facilitate the growth of native species, although this assumes that richer soils will be better for native plants. However, in America this method was found to be counterproductive as it suppressed the growth of the native prairie species it was supposed to facilitate (Wilson 1989). Ideally, native grass species should be utilised as a cover crop to assist revegetation of disturbed sites. Native Australia grass species are successful in providing a cover to disturbed sites; however the sowing rate must be sufficient to prevent introduced species becoming prevalent (Huxtable et al. 2005) and time of sowing should be considered as climatic conditions can influence the success of native species (Huxtable et al. 1999).

The success of revegetation in developing an ecosystem with minimal weed species in these anthroprogenically disturbed areas is varied. A decline in weed species over time has been associated with the quality of the topsoil (Wali 1999; Brekke Skrindo et al. 2004), the thickness of the topsoil (Brekke Skrindo et al. 2004) and the initial revegetation techniques used (Newman et al. 2001). However, it is difficult to return disturbed areas to the standard of the surrounding vegetation. Newman and Redente (2001) found 20 years after the seeding of disturbed areas, the initial seed mixes were the dominant species and the small number of species from the surrounding area suggested that they inhibited colonisation by seeded native species. Maintenance makes a significant impact upon the emergence of weed species in disturbed areas (Gibson-Roy et al. 2010) and the use of short term irrigation on revegetated areas can have a significantly positive influence on species composition 18 years after irrigation has ceased (Newman et al. 2001).

1.9 Revegetation of Road Verges

The RTA's current aim of revegetating road verges is based on positive ecological outcomes, safety and maintenance considerations are also important considerations (Roads and Traffic Authority 2008a). Additionally the area to be revegetated is commonly sloped and therefore one of the initial goals is to protect soil quality and reduce soil erosion (Faucette et al. 2006). The revegetation of verges is challenging because of the extent of disturbance that has occurred (Faucette et al. 2006). Studies conducted overseas have provided a variety of results on the most successful revegetation methods. In Spain, the use of hydro seeding has increased plant diversity (García-Palacios et al. 2010) and cover (Matesanz et al. 2006); however there was no distinction between native and weed species in either of these studies. Seeding of road verges is the most commonly used method to revegetate road verges. When hydro seeding on cut verges is compared to fill verges, fill verges had significantly higher species richness and species cover (Matesanz et al. 2006). In Norway two years after a cover of topsoil was applied with no additional revegetation treatment, the abundance of weed species decreased whereas native species increased (Brekke Skrindo et al. 2004).

Studies have highlighted the current detrimental preference for non-native species as an initial cover crop (Elseroad et al. 2003; Tinsley et al. 2006), when it is known that these introduced species can inhibit the future germination and growth of native species (Wilson 1989).

1.10 Australian Weed Legislation and Policy

The established negative impacts associated with specific weed species necessitate legislated management and control of these species. The following outlines legislation and state policies that have been developed as a means to provide a framework for the management and control of particular species and to allow enforcements of these actions.

Federal legislation

In Australia there is no specific Commonwealth legislation that encompasses the control, management and eradication of invasive introduced species. It is the responsibility of the states and territories to develop and implement legislation regarding weed species. The Commonwealth does have control over the importing of non-native species via the *Quarantine Act 1908* (Cth) and the *Environment Protection and Biodiversity Conservation Act 1999* (Cth). Additionally, the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) manages the use of biological agents for the control of particular species.

Noxious Weeds Act 1993(NSW)

The N*oxious Weeds Act 1993 (NSW)* (NW Act) is the key NSW legislation for the control and management of weed species, although it only applies to classified noxious weed species. The NW

Act classifies noxious weeds as plants that pose a potentially serious threat to primary production or the environment or human health and are likely to spread in the area or to another area (s 8). Through the use of classes it is recognised that the impacts of noxious weeds vary between local government areas. Classifications vary between local government areas, except class 1 which is state wide (Appendix 1).

The NW Act outlines the responsibility for the management of classified noxious weeds (Part 3). The management of declared noxious weeds must be undertaken by owner of the land, whether private or public, and must be carried out in accordance with the procedures outlined in the NW Act. Penalties apply if the obligations are not followed. Additionally, the land owners must notify the local control authority of the presence of a notifiable weed, classified as a Class 1, 2 or 5 weed (s 15).

Section 17 of the NW Act outlines the obligations to control noxious weeds on roads; however this Act does not include State highways, freeways or tollways within this obligation. The RTA is however, obliged to control weeds on its road verges when notified by the local control authority.

Threatened Species Conservation Act 1995 (NSW)

The Threatened Species Conservation Act 1995 (*NSW*) (TSC Act) outlines key threatening processes impacting threatened species. The impacts of a threatening process are eliminated or managed through a threat abatement plan. Of the key threatening process listed in the TSC Act 7 of these are specifically related to introduced flora species, these are; *Lantana camara*, *Chrysanthemoides monilifera*, *Cytisus scoparius* (Scotch broom), *Olea europaea* (African olive), escaped garden plants, exotic perennial grasses and exotic vines and scramblers.

Declaration of Noxious Weeds Policy

The Declaration of Noxious Weeds Policy, developed by the NSW Department of Primary Industries outlines the *Noxious Weeds Act 1993*, specifically describes the requirements for the declaration of noxious weeds in NSW and how to apply for a change in the noxious weed class (NSW Department of Primary Industries. 2009). It mentions the negative impacts placed upon land holders that have a declared noxious weed growing on their land.

NSW Invasive Species Plan 2008-2015

The NSW Invasive Species Plan is an initiative of the NSW Department of Primary Industries that aims to protect biodiversity and primary industries from all invasive species including weed species. The aims of this plan are to prevent the establishment and spread of invasive species, and reduce the impact of already established invasive species (Australian Government: Primary Industries. 2009).

NSW New Weed Incursion Plan 2009-2015

This plan compliments the NSW Invasive Species Plan and aims to prevent the establishment of new weed species (Australian Government: Primary Industries. 2009)

Other NSW strategies

Currently there are strategies covering Alligator Weed (NSW Alligator Weed Strategy), Parthenium (Parthenium Weed Strategy) and a draft Fireweed Strategy.

1.11 RTA Revegetation and Maintenance Policy

The Roads and Traffic Authority (RTA) is the New South Wales government authority responsible for the state's major road network and associated entities**.** In association with private industry and local councils they design, construct and maintain this vital infrastructure. The RTA is responsible for developing appropriate revegetation guidelines for the road verges and ensuring compliance of these specifications by those carrying out the work.

Past RTA Techniques

Historically the aim of revegetation was to establish an aesthetically pleasing and self-sufficient road side environment that would require minimal maintenance. The absence of ecological outcomes as a priority in revegetation meant that species selection for revegetation was based upon the suitability of the species from a safety and maintenance view point (Roads and Traffic Authority 2008a). Species that were recommended to achieve these outcomes included both native and introduced species, with the most notable being the native *Acacia saligna* and the introduced *Fraxinus oxycarpa* which are now both classified as naturalised weed species within NSW (National Herbarium of New South Wales. 2011). As species selection and road verge revegetation was not regarded as important information in comparison to road construction procedures there are few published records kept about the actual techniques used for revegetation and the species used for roads in the Illawarra over 15 years old.

From personal accounts over 13 000 plants were planted along 18km of road on the Southern Freeway in 1996. The main species planted were *Casuarina glauca* and *Callistemon* var. "Kings Park special', and the verge areas were seeded with a native species mix. The actual contents of this seed mix was not recorded, however personal accounts suggest that there was over 30 native species within the mix including *Lomandra longifolia*, *Melaleuca armillaris* and *Cerastium tomentosum* (Daniel Daffara pers. comm. 2011). This mass planting was undertaken as part of the local councils Corridor Strategy that was initially developed in the 1980's, to link the Illawarra Escarpment to Lake Illawarra, providing a movement corridor for fauna species along road verges and river edges (Daniel, pers. comm. 2011).

Present RTA Techniques

The Roads and Traffic Authority Landscape Guidelines, 2008 describe the need for an ecologically sound road corridor that is a reflection or improvement of the surrounding ecosystem. The draft Biodiversity Guidelines state that the purpose of revegetation includes visual screening, air quality improvements, erosion and sediment control, carbon sequestration and biodiversity offsets and recovery (Roads and Traffic Authority 2011a). The present ecological objectives of the built landscape are to mimic the function of a native community providing a wildlife shelter and corridor, a natural water filter and to minimise pollutant outputs in all stages of construction and completion (RTA 2008). In regards to planting and revegetation species choice the design guidelines require that rural and urban verges be evaluated as separate entities. Indigenous species, as opposed to native species are the preferred choice in rural areas, in comparison to urban areas where exotic species are still considered a viable option (RTA 2008).

The RTA utilises 3 forms of vegetation of its road verges; seeds (the application of the seeds can be via hydro seeding, hydro mulching or by hand), turf and planting of saplings. The seed used to revegetate the road verges are required to be 'locally collected native seed'. There are a number of seed mix types and the mixes are matched to the landscape characteristics. Seeded cover crops are also regularly utilised as a means of quickly stabilising the soil and preventing the growth of weed species. The species utilised as a cover crop are both introduced and sterile; clover species, Japanese millet and rye grass (Roads and Traffic Authority 2008b). It is noted in the RTA specifications that clovers used as a cover crop cannot be used in conjunction with native seeds as they may out compete these species (Roads and Traffic Authority 2008b). Indigenous species saplings are regularly planted in urban road verge landscaping and are used sparingly in regional settings.

RTA Topsoil Management

The definition of topsoil in the specifications has been improved over the last 14 years and it is now required that weed contaminated topsoil be disposed of rather than be reused (Roads and Traffic Authority 2011b). Topsoil removed during the clearing of the site is most commonly used in the vegetation of the verges and imported topsoil is only used when the topsoil is contaminated or insufficient amounts are available.

The construction specifications of sites require that all suitable topsoil be treated and stored in a manner to protect the micro organisms within the soil and ensure that weed species do not grow in the soil (Roads and Traffic Authority 2011b). The specifications state that all topsoil should be sprayed with herbicide before vegetation clearing, turned over every couple of weeks and if necessary sprayed before re-laying the stockpile. However, due to cost and time restrictions during

the construction process it is widely believed by those within the RTA that these specifications are not followed correctly, if at all.

Management of introduced species on established road verges in the Illawarra

It is well known that maintenance procedures to manage weed species on road verges influences the flora present within the verge and can been responsible for enhancing the growth of particular weed species (Baker 1974). The RTA recognises that it is important to ensure that maintenance practices carried out do not nullify revegetation work and the publication of weed management guidelines are due in late 2011.

Responsibility of road verge maintenance is divided between the Local Council and the RTA (depending on the road classification and agreements between the organisations). RTA is responsible for entire verge maintenance of Highways, Freeways and others as stated within specific agreements. *The Roads Act 1993* (*NSW*) states that at minimum the RTA is required to maintain 1 m of the verge for safety purposes. In the Illawarra region the control and maintenance of noxious weeds present on RTA verges is contracted out to the Local Council.

Verge maintenance of RTA managed roads changed around 2002. Previous to 2002, the RTA used to mow the entire road verge from road edge to the fence line and target spray any weeds within that area with a glyphosate-based herbicide, often Round Up. The current strategy to maintain the 1m area of responsibility involves non-targeted spraying of the area under wire rope and safety fence using a boom and the trimming of all flora species that have grown into the 1m verge. This maintenance activity is undertaken 3 to 4 times a year. The remainder of the verge is now left to re-grow and will only be maintained for safety reasons by the RTA or noxious weed control by the local council or RTA.

The effectiveness of the continual use of one type of herbicide is under scrutiny. The consistent use of glyphosate-based herbicide has led to glyphosate resistant weeds on road verges in Northern NSW and Southern Queensland (Australian Glyphosate Sustainability Working Group 2011)

1.12 Aims and thesis outline

This study aims to fill gaps in knowledge surrounding the effect of revegetation techniques utilised by the RTA on the abundance and cover of introduced species. I will focus upon factors known to influence plant growth and encourage establishment of alien species.

The aims of this study were to:

- Determine if, and to what extent, the planting protocols of the Roads and Traffic Authority influence the abundance and cover of introduced species along road verges;
- Determine if there were other site specific factors that could be modified to reduce the abundance and cover of introduced species along road verges;
- Provide an understanding of the best management practices to reduce the abundance and cover of introduced species along road verges and encourage native species establishment.

This chapter provides an overview of the impact of introduced species and why some of these species are such successful invaders. The importance of disturbed areas, particularly road verges in facilitating the spread and growth of these species will be discussed. An overview of the methods used for revegetation of disturbed areas and by the RTA for revegetation of road verges, is included.

Chapter 2 describes the methods used to collect and analyse the data, Chapter 3 outlines the results of the study while Chapter 4 discusses the findings of the study in relation to previous research and suggests management applications associated with the study.

Chapter 2. Methods

2.1 Study Area

The Illawarra Region is located on the south coast of NSW, Australia. The sites surveyed were located along three major roads and one minor road within this region, spaced over a distance of approximately 43km. Bulli Pass Road, Bulli was the most northern site (34° 19' 27.6234", 150° 54' 47.2674") and Princes Highway, Kiama Downs the most southern site (34° 38' 5.3514", 150° 49' 58.62"0) (Figure 2.1). The mean average rainfall in the northern section of the study sites, measured at Bellambi, is 1043.4 mm, with the southern section, measured at Kiama, averaging 1258.3 mm of rain per year (Bureau of Meteorology (BOM) 2011).

Site Selection

Bulli Pass Road, Bulli was chosen because it was located on the most northerly road within the Illawarra region that had been constructed by the RTA. The remainder were major roads as classified by their traffic volume and located along Memorial Drive, Southern Freeway and the Princes Highway. All four roads were chosen as site locations on the basis that they were in the Illawarra Region, geographically coastal, constructed by the RTA and continued onto each other forming a continuous road corridor, potentially providing a dispersal passage for introduced species. The distance between survey sites was a minimum 800 metres. Previous research into exotic species along road verges have varied: some used longer distances (Hansen et al. 2005; Jodoin et al. 2008), some shorter distances (Harrison et al. 2002) and some had random selection of sites (Craig et al. 2010). Random site selection was not applicable due to time restrictions of the study and safety requirements associated with working on road verges. The minimum 800 metre distance was chosen as it allowed for a variety of verge conditions to be surveyed while ensuring that revegetation information for most of the sites was available. Site selection was dependent upon safety requirements associated with working on road verges and sites weren't included if they did not fit within the safety measures. Sites were also excluded if there were not immediately adjacent to the road, did not fit the size requirements or if they were located behind an impenetrable barrier such as a noise wall or safety barrier. The location of 14 sites was extended beyond the minimum 800 metre distance due to the above factors. Sites were situated on the road verge; the verge for the purpose of this study is the vegetated area adjacent to the road shoulder (Figure 1.1)

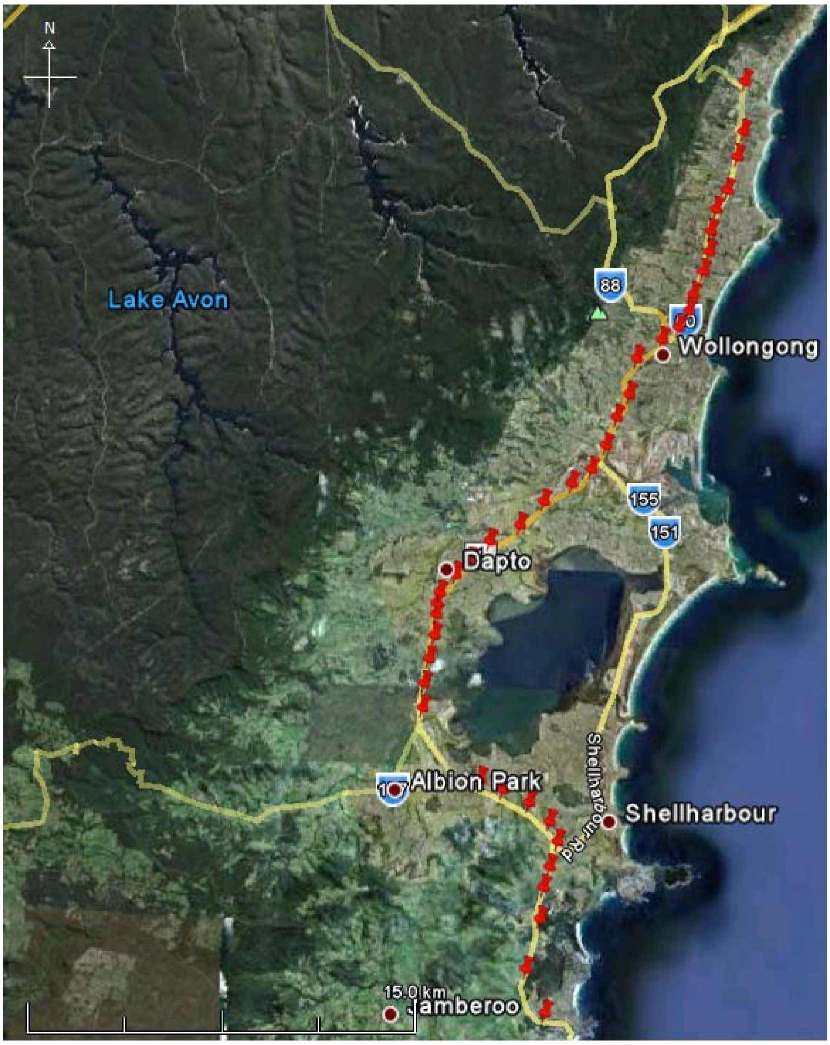

Figure 2.1: The survey sites are located from Bulli Pass Road, Bulli in the north and Princes Highway, Kiama in the south (Google Inc 2011).

Quadrat size

Surveys in 80 m^2 quadrats were undertaken at each site. A quadrat size of variable length and width ensured a large variety of sites would fit the size requirements (Spooner et al. 2009). The 80m^2 quadrat could be 4 m wide x 20 m long, 2 m x 40 m or 1 m x 80 m.

2.2. Sampling

Vegetation Sampling

A survey of the 40 sites was carried out between the middle of April and the end of June 2011, to ensure that annual species and grasses would have sufficient growth in order to be identified and annuals would be present.

All plant species present were recorded using a version of the Braun Blanquet method of vegetation sampling (Table 2.1) (Wilkins et al. 2003). This method was utilised because it is time efficient,

workable and accurate method for surveying flora (Wikum et al. 1978) and is easily adaptable for statistical analysis (Wikum et al. 1978)

The abundance of each species was assessed in relation to its percent cover of the total site area and based upon its abundance was allocated a Braun Blanquet value. To assess the success and survival of plantings carried out by the RTA, trees and shrubs present at the survey sites were assessed using both the Braun Blanquet method and counted individually. Additionally, I determined if the species were planted as part of revegetation works and measured the distance between individuals in any plantings.

Table 2.1: The Braun Blanquet method allows the cover and abundance of species to be calculated quickly and accurately (Wilkins et al. 2003)

Cover – abundance value	Description
1	One- a few individuals
2	Uncommon and under 5%
3	Common and under 5%
4	Very abundant and <5% or 5-20% cover
5	20 - 50% cover
6	50 - 75% cover
7	75 – 100 % cover

Species were identified, where possible on site. Unidentified specimens were collected and identified with the aid of specimens within the Janet Cosh Herbarium and the Janet Cosh Herbarium staff. Each species was classified as introduced or native.

Soil Sampling

The soil structure of road verges is artificially assembled during road construction and as soil conditions influence the growth of plants, it was important to include soil as a contributing factor. As there was little information available from the RTA regarding the state of the soil on its road verges, it was necessary to survey soils. In order to assess the impact that the soil conditions have upon the abundance of weed species present within the study sites a variety of factors were assessed and noted (Appendix 3).

The location of the soil to be sampled was chosen randomly and conducted in at least two areas per site. The surface soil type was identified onsite using a basic flow chart (Figure 2.2**)** as described by (Rengasamy et al. 2010).

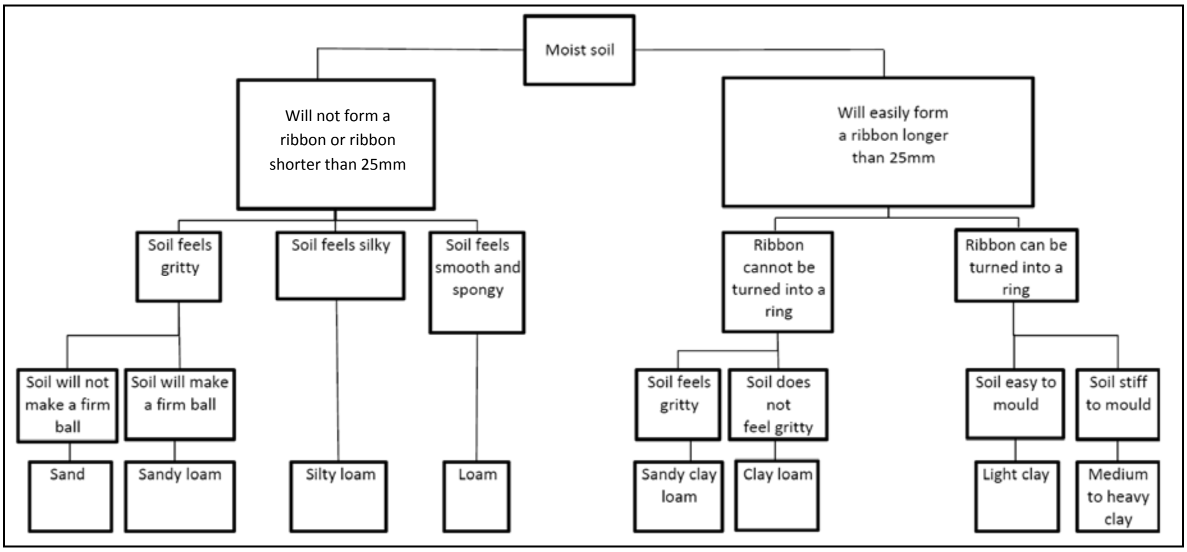

Figure 2.2: The soil texture of each of the 40 road verges was assessed onsite (Rengasamy et al. 2010).

The level of organic matter including depth of the topsoil horizon was recorded. A small bucket auger was used at two locations per site and a tape measure was used to determine the depth of the topsoil layer, while organic matter was assessed visually (Appendix 3).

The depth to the impenetrable layer of the soil influences the depth to which plants can grow and therefore can play a significant role in the species composition of any given area. The depth to the impenetrable of the profile was measured off a metal rod driven into soil at two locations per site, with the average of the two values recorded

The presence of rocks within the topsoil can be an indication of improper construction processes, as according to RTA documents topsoil is meant to be free of clay lumps and stones (RTA 2011) . The presence of rocks can influence the species composition within the road verge. The contents of the soil removed by the bucket auger for the two topsoil measurements were assessed for soil particle size and consolidation (Appendix 3). Soil particle size and consolidation was assessed on a scale of 1 to 7, where 1 was uniform grain size and no rocks and 7 used if the verge surface was all rock.

Site Condition Sampling

A variety of factors were recorded for each site. Composition of vegetation at any given site is constrained by light and the nature of existing ground cover. In order to assess if these factors influenced the abundance of weed species within the survey sites the heights of the tree canopy and shrub layer and the percent of bare ground, litter and live vegetation were classified into categories (Appendix 2). The slope of each road verge was measured as high gradient slopes have high potential for erosion (Riley 1988). The aspect of the slope of the verge was recorded in order to

show which direction the verge was facing, as this influences the amount and timing of the sunlight received by the verge.

Land use adjacent to the road verge was recorded as either urban, industrial, agricultural or bushland. The type of boundary separating the verge from the surrounding land was also noted as noise walls are a potential barrier to the spread of species into and from the road verge.

Analysis of RTA information

Information regarding treatment of the road verges during construction was sourced from RTA documentation and via personal accounts from employees. Revegetation documentation for 12 of the study sites was available due to their recent construction; confirmation that the landscaping plans were an accurate portrayal of the original work was sought and confirmed. Revegetation documentation for the 28 older sites was unavailable but obtained from personal accounts from numerous RTA employees employed within the organisation at the time of the revegetation. Information on other factors was obtained from a combination of personal accounts from RTA employees and internal RTA documentation. Information on topsoil and herbicide treatment is contained within construction specifications; confirmation of the accuracy of these plans was obtained from RTA employees working on the construction of particular roads.

2.3. Statistical Analysis

Data preparation

Species were classified as native or introduced using PlantNET (National Herbarium of New South Wales. 2011) and Herbarium staff advice. Braun Blanquet values for all specimens were transformed into an equivalent percentage cover values (Table 2.2) and specimens with abundance values were reassessed and allocated percentage cover values. Percentage cover values were totalled for each site, producing two response variables; native percentage cover and introduced species cover. The number of native and introduced species present at each individual site was totalled, producing native and introduced species richness response variables.

Investigation of species richness and percentage cover

Univariate and multivariate statistical analysis were conducted using JMP ver. 7.0.1 (JMP 1989-2007). One-way analysis of variance (ANOVA) assessed differences between the response variables amongst the 15 categorical explanatory variables. Simple regression analysis assessed relationships between each of the response variables with the four continuous explanatory variables. Age of revegetation and depth to impenetrable soil layer were tested as both continuous and categorical

variables Data was tested to ensure normality using Sharpiro Wilk W test. Square root data transformations were undertaken to comply with the assumptions of normality.

Table 2.2: For statistical analysis Braun Blanquet values were transformed into an equivalent percentage cover value.

Braun Blanquet value	Equivalent percentage cover
1	1
2	2
3	4
4	15
5	37.5
6	62.5
7	87.5

The majority of statistical analysis were undertaken with a sample size of 40 sites. The use of herbicide was accurately confirmed for 25 sites and age of road verge revegetation for 39 sites; therefore analysis including these variables used a reduced sample size. Significant difference between means was determined using a Tukey's test or a student's t test (when classes had unequal sample sizes). When undertaking 3-way interactions lost degrees of freedom were avoided by altering percentage litter cover categories; 40-80% and 80-100% classes were combined.

In order to reduce the chance of Type 1 error, 2 and 3-way Analyses of Covariance (ANCOVA) were run with explanatory variables that were either previously significant in single factor models and/or likely to vary with the influence of other explanatory variables (Appendix 5).

Species composition

Native and introduced species abundance per site were separately analysed to assess species composition within PRIMER ver. 6 (Clarke 1993). MDS visually compared native or indigenous species composition similarity in planted or seeded sites, age of revegetation classes or soil depth classes (explanatory variables). PERMANOVA statistically tested if species composition was dependent on the explanatory variables. Pair wise analysis indentified species contributing to the difference in composition. Similarity percentage analysis (SIMPER) established which native and introduced species made the highest contribution in classes of road verge age of revegetation.

Chapter 3. Results

3.1. General results

In total, 154 individual vascular plant taxa were recorded from across the 40 road verge sites, averaging 14 species per site. Several specimens were unable to be identified to species level; eight specimens were identified to genus, five to family and eight were recorded as unidentified (Appendix 4). Of the identified species, 53 were native to the study area and 106 were introduced (including specimens identified to family) (The Royal Botanic Gardens and Domain Trust. 2011). The minimum cover of introduced species at a road verge site was 15%, whilst the minimum cover of native species was 0%. Introduced species had comparatively high species richness and percentage cover, on average covering twice the verge area (Table Table 3.1).

Table 3.1: The mean number and mean percentage cover of introduced and native species present on each road verge site. Percentage cover included multiple plant forms therefore some values were higher than 100%. Brackets contain standard deviation.

	Introduced species	Native species
Mean number of species per site	11.8 (5.4)	3.4 (2.6)
Mean percentage cover per site	105.0% (50.2)	52.2% (46.0)

The most abundant introduced species were the grass *Chloris gayana* and woody shrub *Lantana camara*, both of which occurred at approximately 50% of roadside verges In comparison to the two most abundant native species (*Casuarina glauca* and *Melaleuca armillaris*), on average *C. gayana* covered twice the verge area of *C. glauca*, and *L. camara* covered twice the area of *M. armillaris* (Table 3.2). The four native species that were most common were those used by the RTA for revegetation of the road verges; *C. glauca, M. armillaris* and *Callistemon* var. “Kings Park special” were individually planted on the road verges, whilst *Acacia longifolia* was both seeded and planted (Table 3.2).

Introduced species had relatively higher frequencies of occurrence compared with native species (e.g. the introduced herb *Bidens pilosa* was present at 75% of roadside verges, whilst the native tree *C. glauca* occured at about 40%). Generally, the species with the highest percentage cover per site were also the most common across the study region. Three introduced herbs, *Conyza bonariensis*, *Foeniculum vulgare* and *Sonchus oleraceus*, were frequently detected at sites, but at low abundances.

Figure 3.1: Photograph showing a *Lantana camara* dominated road verge.

Lantana camara, the only recorded noxious weed in the study area was present at over 50% of study sites and at 11 of those sites was one of the most dominant species, covering 20-50% of the verge area (Figure 3.1). Additionally, 14 species recorded within this study are classified as noxious weeds in other Local Government areas within NSW (NSW Department of Primary Industries 2009). Two Weeds of National Significance were present on the road verges (Thorp et al. 2000); *L. camara* and *Asparagus asparagoides,* although *A. asparagoides* was detected at low abundances.

Table 3.2: Mean percentage cover and site presence of the 15 most abundant species.

Species	Introduced or native	Mean percentage cover per site (n=40)	Number of sites present
Chloris gayana	Introduced	17.5%	20
Lantana camara	Introduced (Noxious)	15.8%	21
Pennisetum clandistinum	Introduced	9.5%	20
Casurina glauca	Native	8.7%	15
Bidens pilosa	Introduced	6.6%	30
Melaleuca armillaris	Native	6.6%	10
Acacia longifolia	Native	4.2%	12
Callistemon var. "Kings Park special"	Native (hybrid)	3.3%	7
Senecio madagascariensis	Introduced	3.0%	17
Ageratina adenophora	Introduced	2.7%	6
Plantago lanceolata	Introduced	2.6%	13
Araujia sericifera	Introduced	2.5%	22
Sida rhombifolia	Introduced	2.4%	20
Cynodon dactylon	Introduced	2.4%	10
Tagetes minuta	Introduced	2.3%	12

To reduce the chance of making a Type 1 error during statistical analysis, I undertook a restricted set of models incorporating multiple explanatory factors. I was interested in identifying any important interacting factors that might explain native and exotic species richness and cover. Explanatory variables that were significant in single regression and single factor ANOVA's were further analysed in multifactor general linear models. While the F tables for these tests are listed in Appendix 5, here I will cover the overall important significant and non-significant results.

A large number and variety of variables were statistically compared. To reduce the complexity of this chapter, only significant interactions and non-significant results associated with revegetation methodology are examined (Appendix 5).

3.2. Interactions between Native and Introduced Species

Generally, there was a positive relationship between the cover and richness of flora species on the road verges. As expected, the number of native species present on the road verge was positively related to the percentage cover of native species (R^2 = 0.250, F = $_{1,39}$ 13.028, p = 0.001; Figure 3.2) and the species richness of introduced species was positively related to the percentage cover of introduced species the (R^2 = 0.170, $F_{1,38}$ = 7.493, p = 0.009; Figure 3.3).

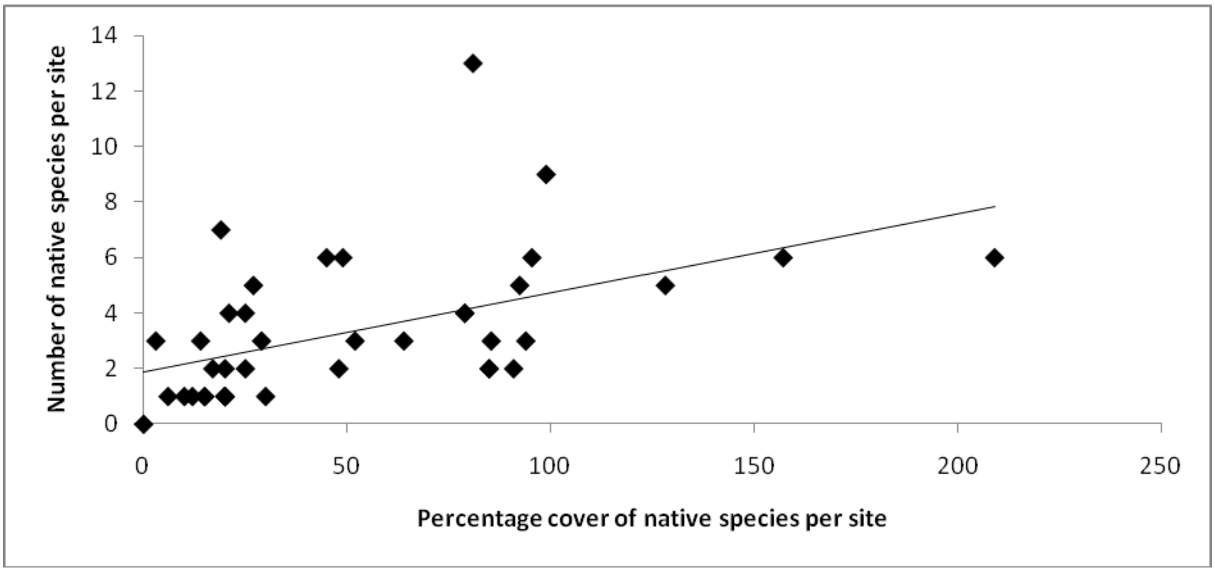

Figure 3.2: Percentage cover of native species in relation to the native species richness on road verges.

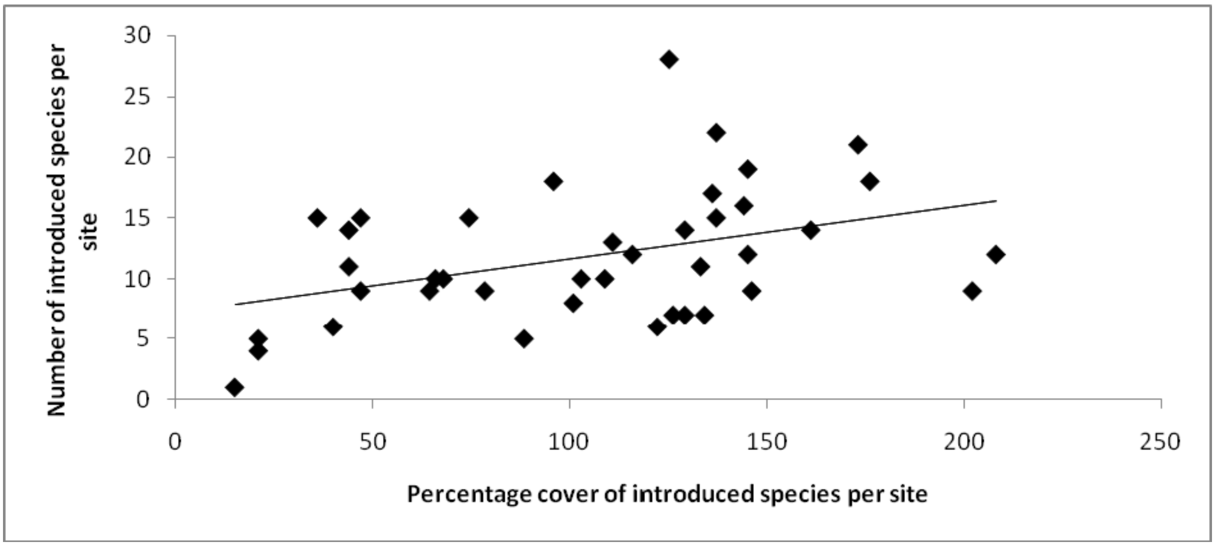

Figure 3.3: Percentage cover of introduced species in relation to introduced species richness on road verges.

It was expected that the cover and species richness of introduced species would vary significantly with the cover and species richness of native species, however no significant relationship was found between the species richness (R^2 = 0.002, F =$_{1,39}$ 0.064, p = 0.800), or the percentage cover (R^2 = 0.094, F = $_{1, 39}$ 4.051, p = 0.051) of native and introduced species. Interestingly the percentage cover of introduced species varied significantly with the number of native species (R^2 = 0.100, F =$_{1, 39}$ 4.366, p = 0.043). The positive relationship demonstrated that the percentage cover of introduced species decreased with increasing native species richness (Figure 3.4).

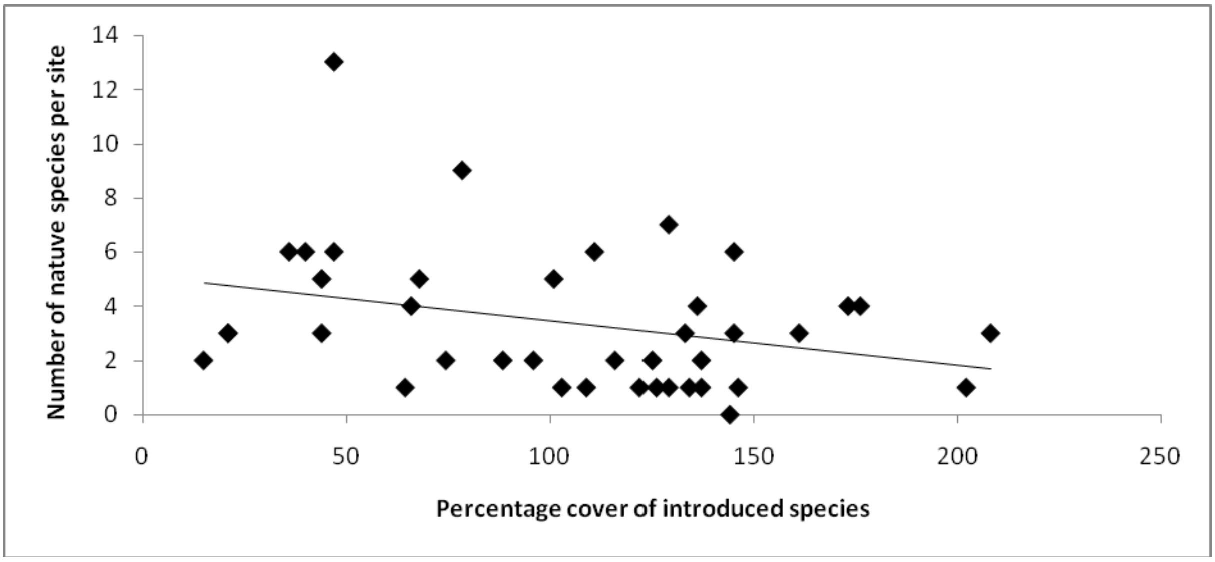

Figure 3.4: Native species richness in relation to percentage cover of introduced species on road verges.

3.3. Native Species and their Relationship with Environmental Variables of Road Verges

Richness and Percentage Cover of Native Species

Overall, the type of revegetation (i.e. whether roadsides had been seeded or revegetation with seedlings) had no discernible impact on the richness or cover of native species: there was no significant difference in either the mean native species richness and cover between seeded versus non-seeded roadsides (richness: $F_{1, 33} = 0.169$, $p = 0.683$; cover: $F_{1, 38} = 1.154$, $p = 0.289$), or between planted versus non-planted roadsides (richness: $F_{1, 38} = >0.001$, $p = 0.988$; percentage cover: $F = _{1, 38} = 0.130$, $p = 0.720$).

The species richness or percentage cover of native species was not related to any factor associated with the road verge environment (aspect, slope, adjacent land use, boundary type, percentage cover of bare ground, percentage litter cover, percentage cover of live vegetation, height of canopy and height of shrub layer) or soil conditions (organic matter, soil texture, soil depth and particle size) (Appendix 5).

Native species richness was significantly influenced by the age of the road verge revegetation. Native species richness decreased as road revegetation aged ($R^2 = 0.120$, $F = 5.065$, $p = 0.030$) (Figure 3.5). The relationship was highly variable; roads built within the last five years had the largest variation.

Figure 3.5: Native species richness in relation to the age road verge revegetation.

I investigated the interaction between native species richness with depth to impenetrable soil layer, age of revegetation and the use of planting as I considered that soil depth may improve the success of planting with time. However, there was no significant three- way interaction ($F_{2, 38} = 3.036$, $p = 0.065$). Nevertheless, the effect of age of revegetation on native species richness varied with the use

of planting (two-way interaction, $R^2 = 0.473$, $F_{2, 38} = 4.156$ $p = 0.020$, Figure 3.6). As the Tukey's test failed to find any significant differences amongst the means, I used t-tests to highlight the most likely differences between the means, despite the concerns of increased Type 1 error rates. On planted road verges, middle-aged road verges (8-14 years) had 65% fewer native species than recently planted road verges (1-7 years). In road verges that had not been planted, middle-aged roads had 62% fewer native species than old-aged revegetation (>15 years). The only consistent relationship between planted and not planted verges was the variation between middle-aged roads, both experiencing the lowest native species richness.

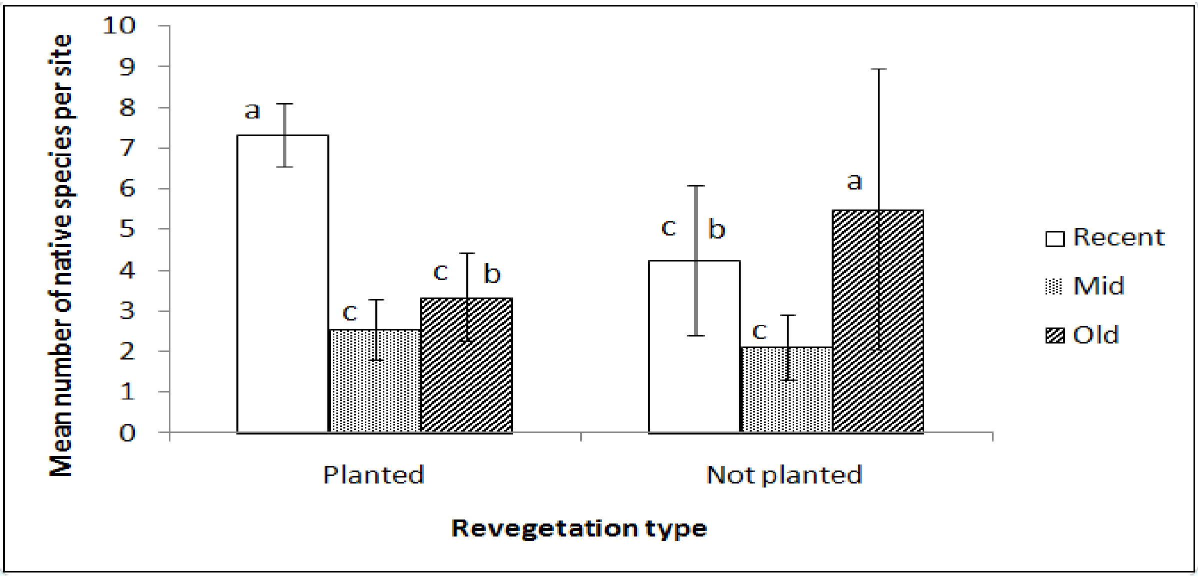

Figure 3.6: Difference in native species richness between different age of road verge revegetation categories and planting categories. Data are means ± SE, n=39.. Different letters denote significant differences (p < 0.05).

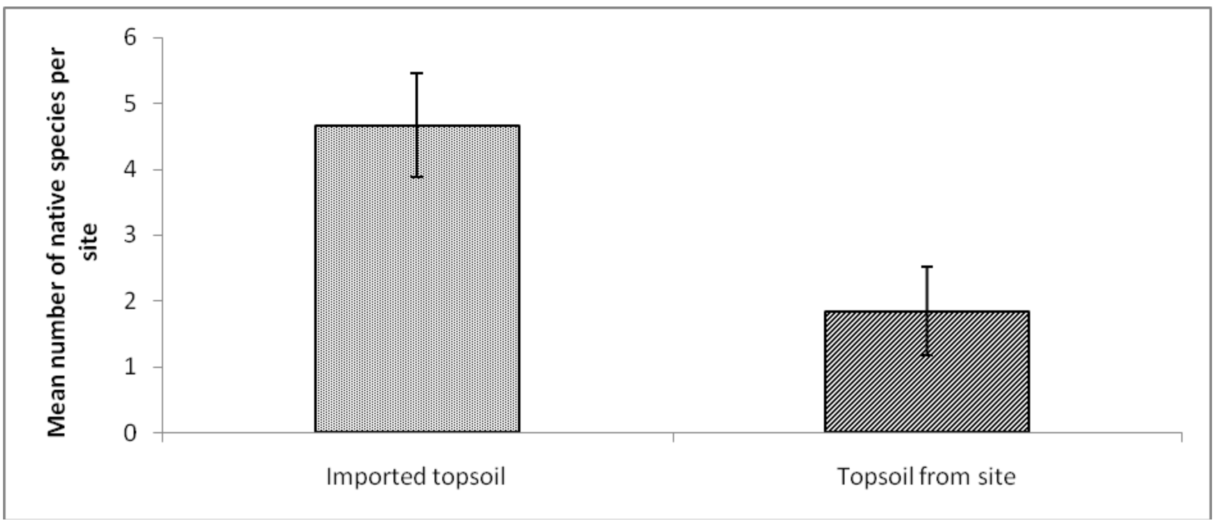

Figure 3.7: Difference in native species richness between topsoil categories. Data are means ± SE, n = 25.

As information on whether sites had imported topsoil or not was unavailable for 15 sites I used the reduced sample of 25 sites to analyse the relationship between the species richness of natives and the use of imported topsoil. Native species richness varied with topsoil ($F_{1, 23} = 8.168$, $p = 0.009$). Imported topsoil sites had higher species richness (Figure 3.7) which was maintained when it was considered in a two-factor model with either seeded or planted sites (Appendix 5). However there was no interaction in any model. Imported topsoil did not influence the percentage cover of natives in any model (Appendix 5).

I investigated a number of three-way interactions; I wanted to determine if percentage cover and species richness of natives was influenced by complex relationships amongst a variety of explanatory variables. Percentage cover or species richness of native species was not influenced by any of the tested three-way interactions (Appendix 5).

Native Species Composition

Native species composition did not significantly vary with either planting (PERMANOVA, Pseudo-$F_{2, 38}$= 1.057, $p = 0.383$) or seeding (PERMANOVA, Pseudo-$F_{2, 38}$= 1.386, $p = 0.091$) classes when the age of road verge revegetation was combined within the model. Interestingly, native species composition did vary amongst seeding classes when analysed with the depth to impenetrable soil layer (PERMANOVA, Pseudo-$F_{1,39}$ = 2.098, $p = 0.003$) and planting (PERMANOVA, Pseudo-$F_{1, 39}$ = 1.880, $p = 0.010$). Such differences are a consequence of the randomisation procedure within PRIMER. I interpreted this variation in importance to suggest that the effect on native species composition was relatively small, further emphasised by the small Pseudo-F ratios.

Native species composition did significantly vary with the age of revegetation (PERMANOVA, Pseudo-$F_{2, 38}$ = 1.440, $p = 0.037$, Figure 3.8) but planting or not planting had no significant interaction on native species composition. Species composition of recently revegetated road verges differed from mid ($p= 0.019$) and old aged roads ($p=0.012$) SIMPER confirmed that the most abundant species in each age class were those utilised by the RTA for revegetation (Table 3.3 and 3.4).

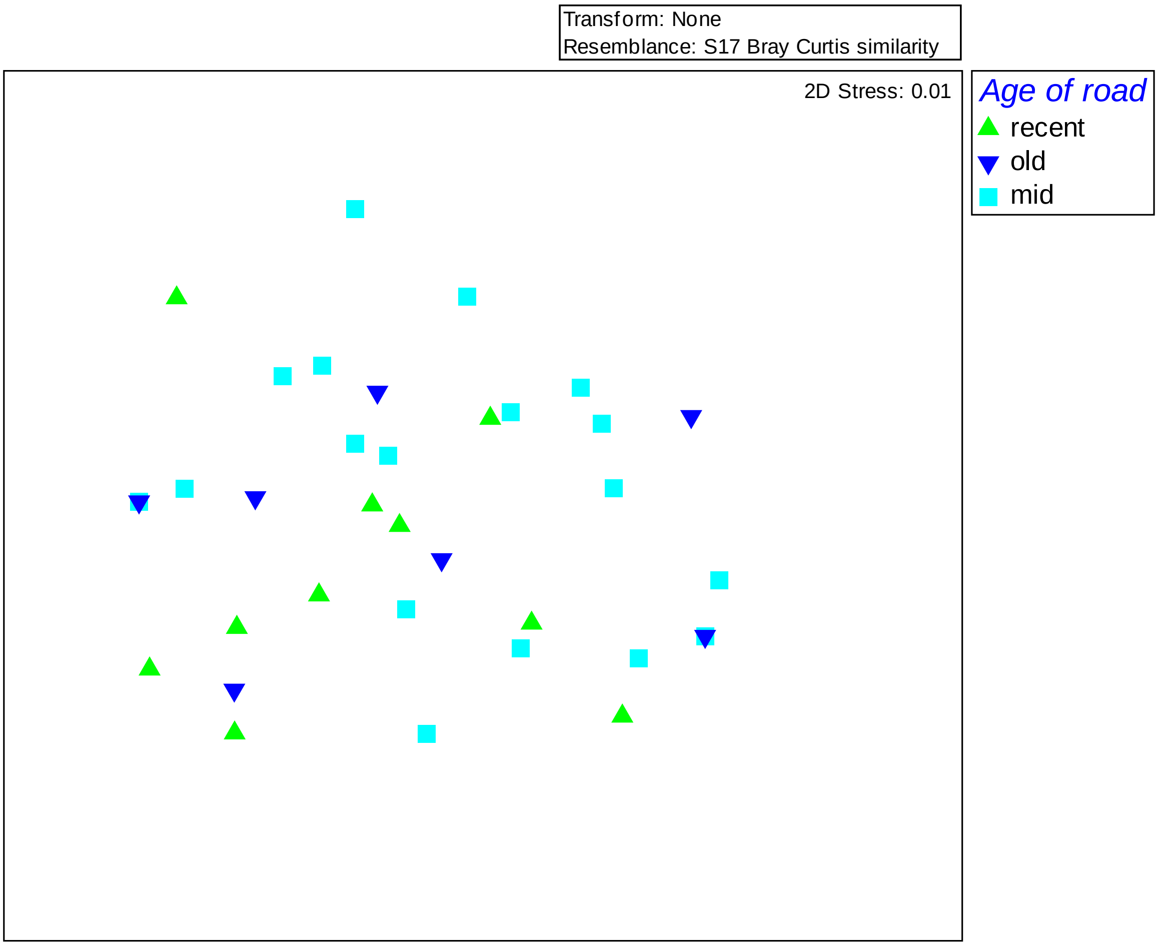

Figure 3.8: MDS comparison of native species composition at recent (green), middle (light blue) and old (dark blue) revegetated road verges. Points closer together represent sites with more similar species composition, Outliers not shown: one recent, two mid and two old.

Table 3.3: Native species composition and average similarity value within each age of road verge revegetation category.

Age	Average Similarity	Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Recent	8.05	*Acacia longifolia*	8.91	4.18	0.51	51.97	51.97
Mid	10.29	*Casuarina glauca*	13.75	4.11	0.33	39.94	39.94
		Melaleuca armillaris	10.75	2.91	0.28	28.30	68.24
Old	7.35	*Casuarina glauca*	7.56	4.94	0.43	67.22	67.22

Table 3.4: Results of SIMPER displaying native species composition with the highest contribution to percentage cover between age of revegetation categories.

Species	Average percentage cover		Contribution (%)
Recent and old age revegetation dissimilarity = 97.28	Recent	Old	
Acacia longifolia	8.91	1.44	10.72
Casuarina glauca	0.36	7.56	8.94
Cynodon dactylon	8.41	0.22	7.00
Celaleuca armillaris	0.00	5.33	6.51
Lomandra tanika	7.95	0.00	6.25
Lomandra longifolia	3.00	4.17	5.96
Acacia binervata	5.73	0.00	5.48
Recent and mid age revegetation dissimilarity = 95.85	Recent	Mid	
Acacia longifolia	8.91	2.85	12.20
Casuarina glauca	0.36	13.75	12.09
Melaleuca armillaris	0.00	10.75	9.50
Cynodon dactylon	8.41	0.10	6.75
Lomandra tanika	7.95	0.00	6.04
Acacia binervata	5.73	0.00	5.18
Old and mid age revegetation dissimilarity = 90.37	Old	Mid	
Casuarina glauca	7.56	13.75	19.56
Melaleuca armillaris	5.33	10.75	15.55
Acacia longifolia	1.44	2.85	7.72
Ficus rubiginosa	4.44	0.00	5.71
Callistemon var. "Kings Park special"	3.11	4.25	5.58

3.4. Introduced Species and their Relationship with Environmental Variables of Road Verges

Species richness and percentage cover of introduced species

In contrast to the cover and abundance of native species, introduced species were influenced by RTA practices. Introduced species richness was positively related to the depth to the impenetrable soil layer (R^2 = 0.150, F =$_{1, 39}$ 6.492, p = 0.015 Table 3.9). It also varied amongst road verge soil textures ($F_{5, 34}$ = 3.630, p = 0.010, Figure 3.10). Sandy-clay soils contained more introduced species than sandy and silty loam. Sand, loam and clay-loam soil textures had similar numbers of introduced species.

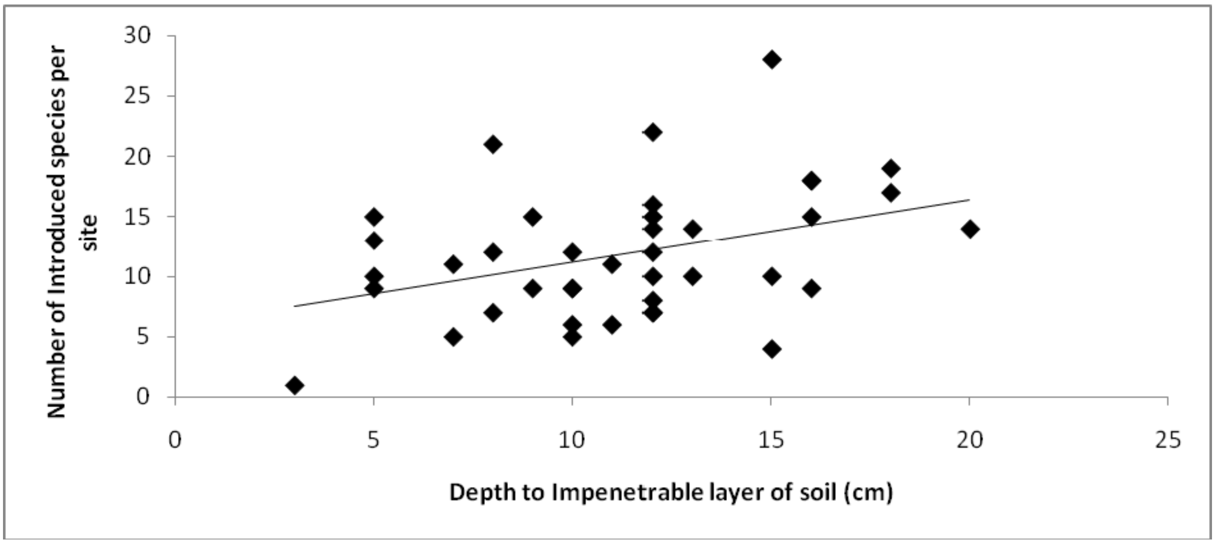

Figure 3.9: Species richness of native species in relation to the depth to impenetrable soil layer on roadside verges.

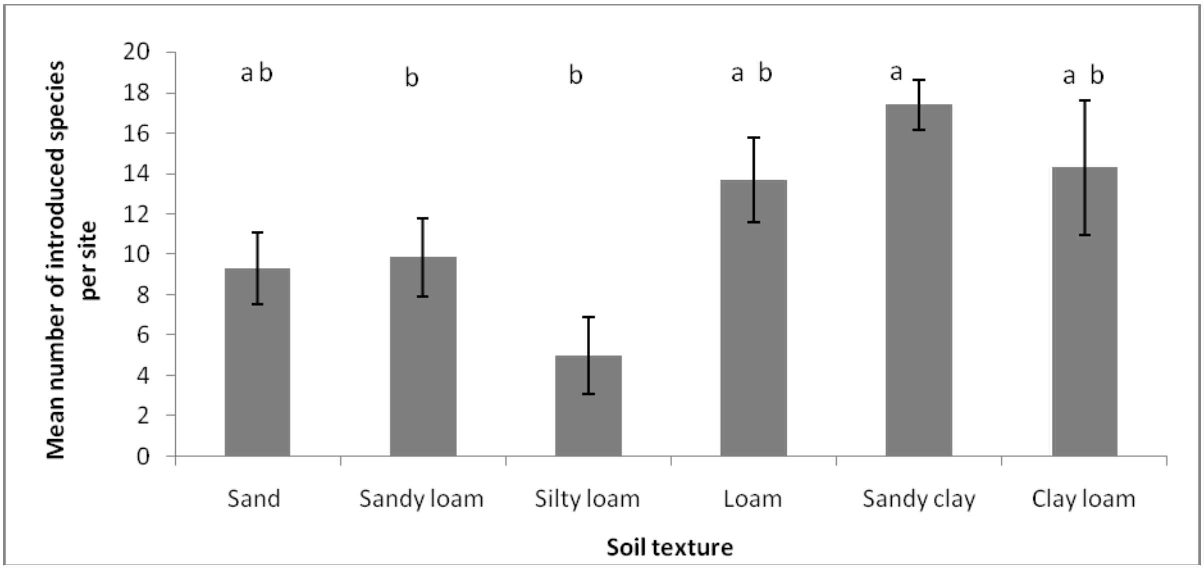

Figure 3.10: Difference in introduced species richness between six soil categories in roadside verges. Data are means ±SE, n=40. Different letters denote significant differences (p < 0.05).

The species richness or percentage cover of introduced species were significantly related to more variables than native species but were not associated with particle size or the majority of measured road verge environment conditions (aspect, slope, adjacent land use, boundary type, percentage cover of bare ground, percentage cover of live vegetation, height of canopy and height of shrub layer) (Appendix 5).

High levels of organic litter were associated with low mean percentage cover of introduced species (single factor ANOVA, $F_{2, 32}$ = 4.700, p = 0.015, Figure 3.11). The highest organic litter class contained 77% fewer introduced species than the other classes. Species richness also varied with organic litter classes (single factor ANOVA, $F_{2, 39}$ = 5.321, p = 0.009). The 80-100% of litter cover was associated with 45% fewer introduced species richness than 0-40% and 65% fewer introduced species richness than 40-80% litter cover .

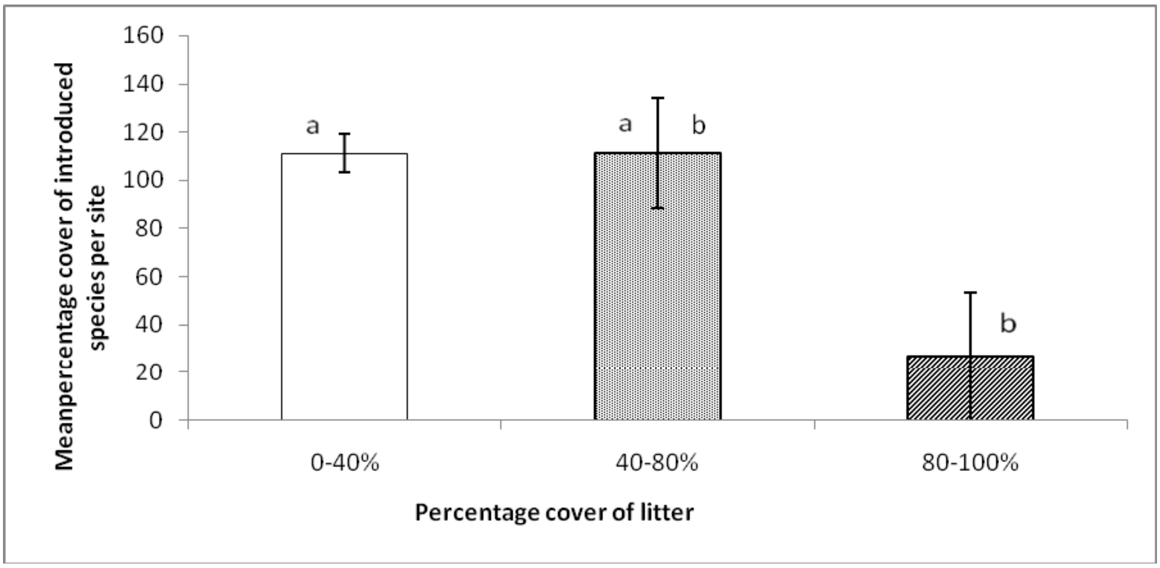

Figure 3.11: Difference in introduced species richness between three organic litter classes on roadside verges. Data are means ± SE, n = 40. Different letters denote significant differences (p < 0.05).

Seeded sites contained significantly fewer introduced species in comparison with non-seeded sites (single factor ANOVA, $F_{2, 39}$ = 4.900, p = 0.033, Figure3.12). Non seeded verges contained 36% more introduced species than seeded verges. The species richness of introduced species did not vary significantly on planted road verges (single factor ANOVA, $F_{1, 38}$ = 1.185, p = 0.283).

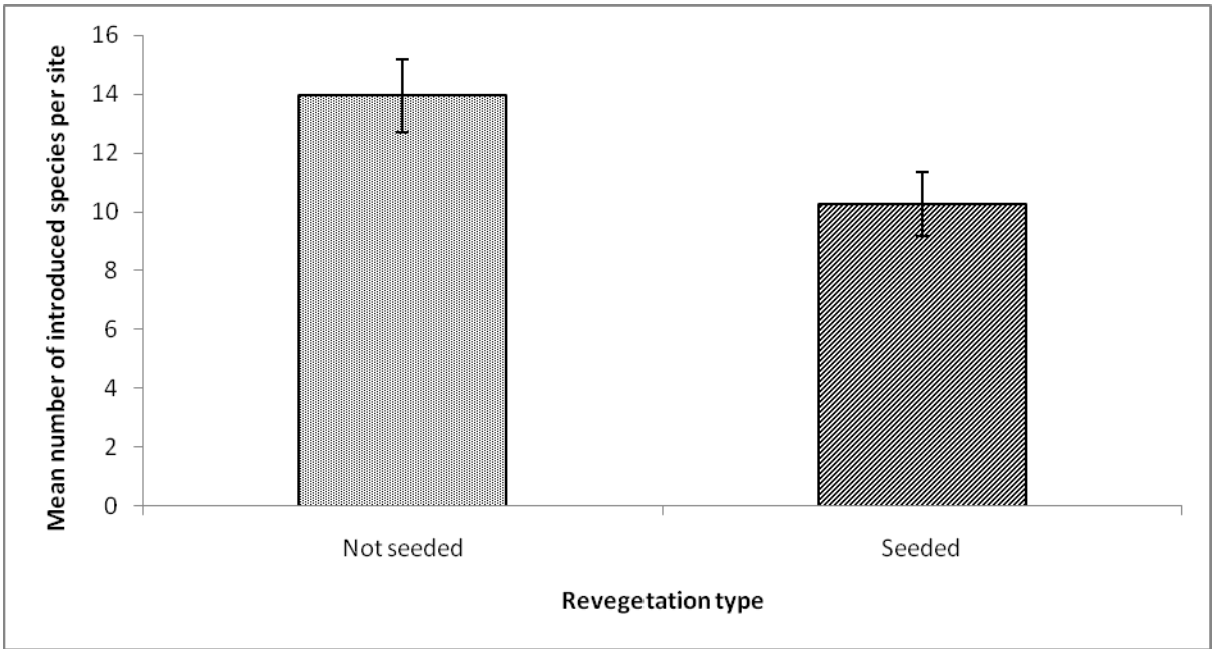

Figure3.12: Difference in introduced species richness between seeding categories. Data are means ± SE, n = 40. Symbol (*) denotes significant difference ($p < 0.05$).

I was interested to investigate whether the advantages of deep soils for introduced species could be ameliorated by the addition of native seed or a deep litter layer. There was a significant interaction ($R^2 = 0.330$, $F_{1, 38} = 4.682$, $p = 0.038$) with depth of litter changing the interaction between depth to impenetrable layer and seeding. In both litter classes, introduced species richness had a positive relationship with seeded verges; however, the small number of points defining the relationship at high litter cover suggests this conclusion maybe equivocal. At low litter cover, increasing depth of soil reduced exotic species in non seeded verges but this relationship was weaker at higher litter levels (c.f. Figure 3.13a and 3.14b).

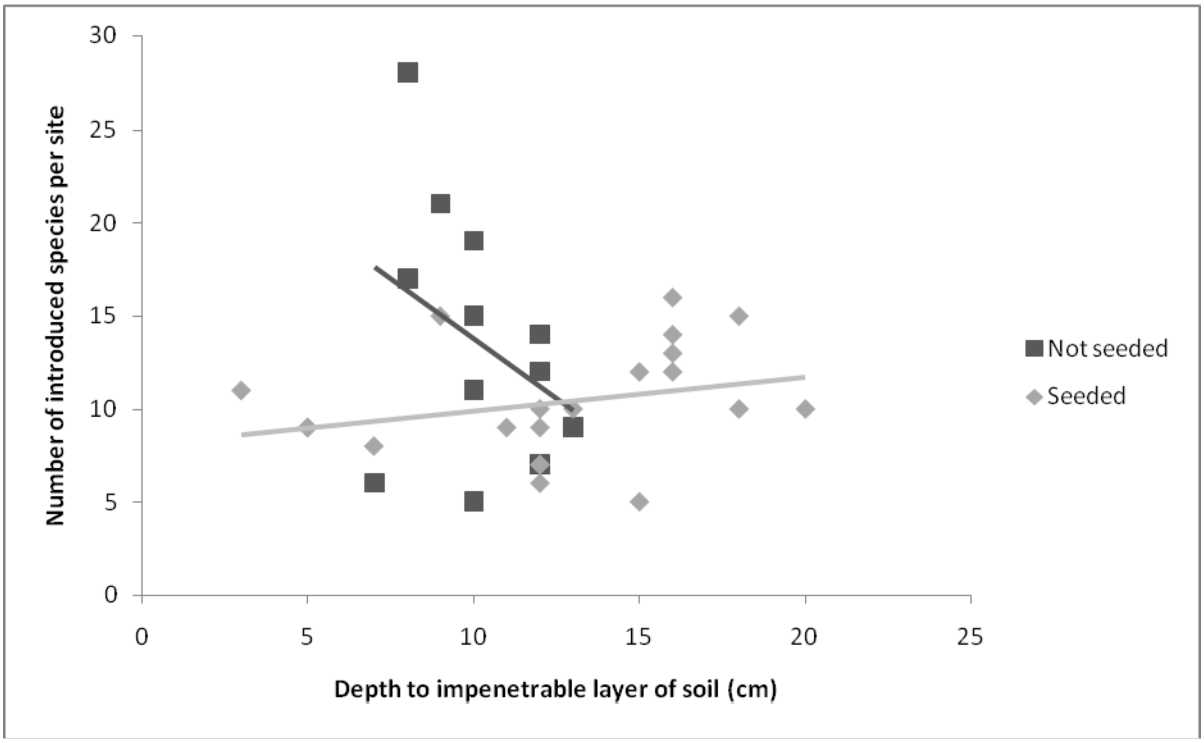

Figure 3.13 a: Difference in introduced species richness on low litter verges (0-40%) between seeded categories and soil depth of the road verge.

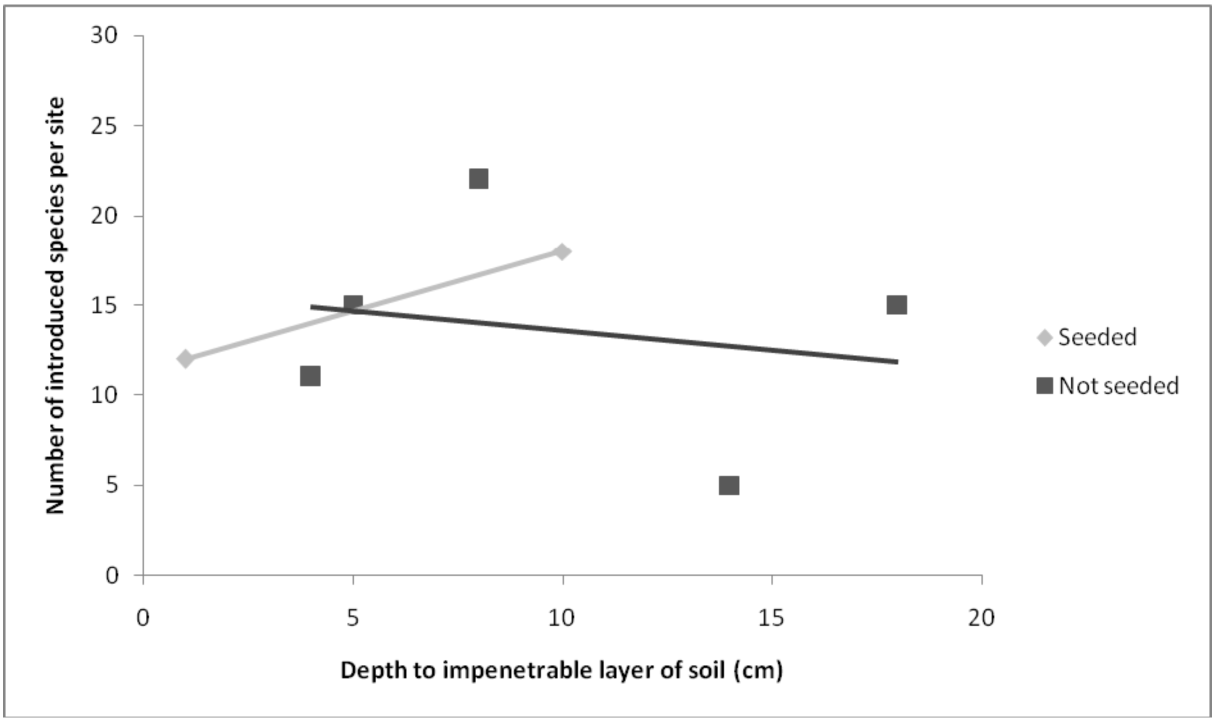

Figure 3.13b: Difference in introduced species richness on high litter verges (40-100%) between seeded categories and soil depth of the road verge.

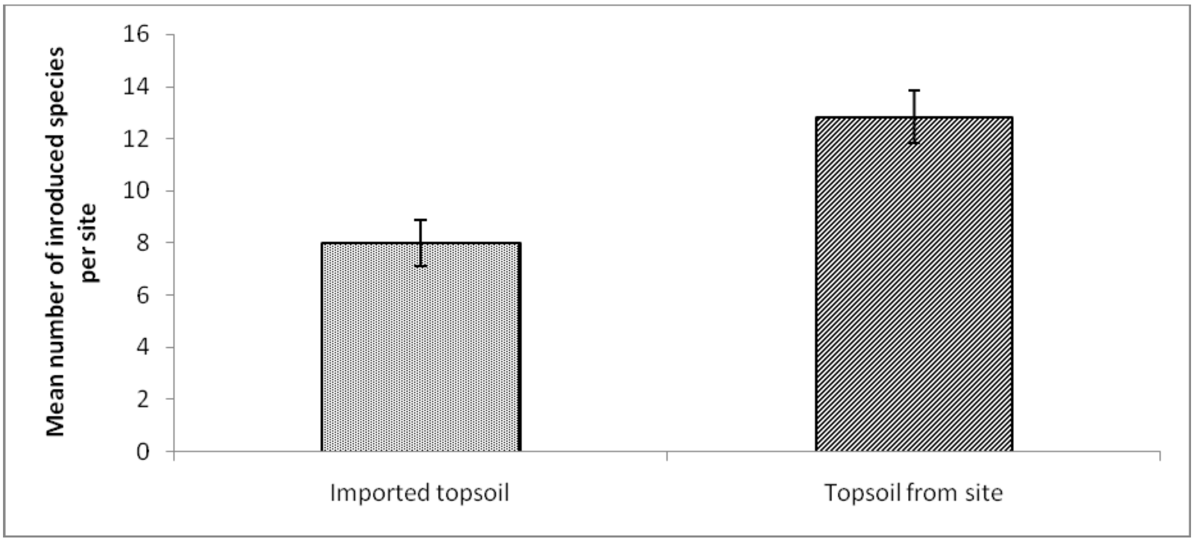

Figure 3.14: Difference in mean introduced species richness between topsoil categories. Data are means ±SE, n = 25.

Road verges with imported topsoil contained a smaller number of introduced species ($F_{1, 23} = 13.220$, $p = 0.001$, Figure 3.14). When included in models with either seeded or planted categories, topsoil maintained its effect on species richness, but did not affect the cover abundance of introduced species in any model (Appendix 5).

I investigated a number of 3-way interactions; I wanted to determine if percentage cover and species richness of introduced species was influenced by complex relationships between a variety of explanatory variables. The above mentioned 3-way interaction (Figure 17a and b) was the only significant result produced (Appendix 5).

Introduced Species Composition

Introduced species composition was not influenced by the use of either seeding (PERMANOVA, Pseudo-$F_{1, 39} = 1.389$, $p = 0.157$) or planting (PERMANOVA, Pseudo-$F_{1, 39} = 1.326$, $p = 0.183$) revegetation techniques. Further, the depth to impenetrable soil layer did not influence the particular species present on the road verges (PERMANOVA, Pseudo-$F_{1, 39} = 0.877$, $p = 0.698$).

While there were no changes in species richness or percentage cover of introduced species with age of the road verge, species composition did significantly vary (PERMANOVA, Pseudo-$F_{2, 38} = 2.170$, $p = 0.003$). Species composition of recently revegetated roads differed from mid (p=0.001) and old aged roads (p=0.001, Figure 3.15). Recently revegetated verges were broadly characterised by pioneer weed species, while older revegetated verges had a high presence of problematic invasive introduced shrubs and vines (Table 3.5 and 3.6).

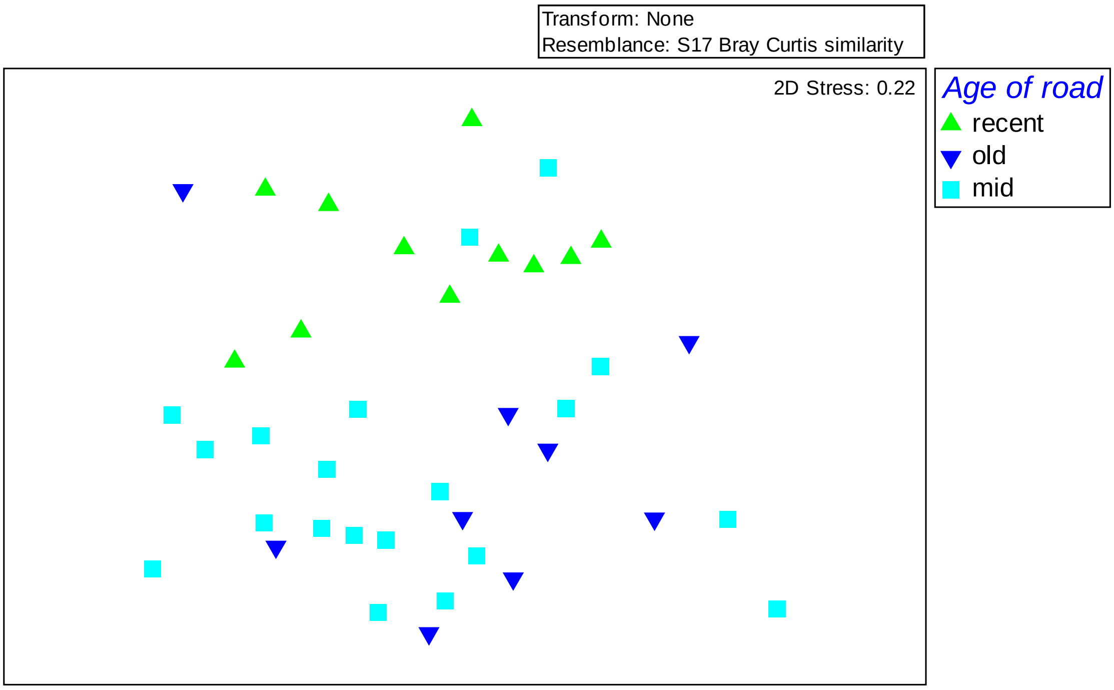

Figure 3.15: MDS comparison of introduced species composition at recent (green), middle (light blue) and old (dark blue) revegetated road verges. Points closer together represent sites with more similar species composition, Outliers not shown: one recent, two mid and two old.

Table 3.5: Introduced species composition within each age of road verge revegetation category.

Age	Average similarity	Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Recent	19.06	*Pennisetum clandestinum*	15.36	4.79	0.72	25.14	25.14
		Bidens pilosa	8.14	3.84	0.59	20.14	45.28
		Tagetes minuta	7.23	2.56	0.78	13.41	58.69
Mid	20.71	*Chloris gayana*	28.05	8.01	0.51	38.66	38.66
		Lantana camara	18.15	5.90	0.55	28.51	67.17
Old	17.64	*Lantana camara*	29.94	8.74	0.52	49.54	49.54
		Araujia sericifera	4.56	2.83	0.6	16.02	65.55

Table 3.6: Results of SIMPER displaying native species composition with the highest contribution to percentage cover between age of revegetation categories.

Species	Average percentage cover		Contribution (%)
Recent and old age revegetation dissimilarity = 89.21	Recent	Old	
Lantana Camara	0.00	29.94	18.16
Pennisetum clandestinum	15.36	10.33	11.84
Bidens pilosa	8.14	8.28	9.07
Chloris gayana	6.59	7.50	7.36
Tagetes minuta	7.23	0.00	4.54
Recent and mid age revegetation dissimilarity = 88.43	Recent	Mid	
Chloris gayana	6.59	28.05	17.26
Lantana Camara	0.00	18.15	10.45
Pennisetum clandestinum	15.36	5.95	9.79
Bidens pilosa	8.14	4.98	5.55
Tagetes minuta	7.23	0.65	4.48
Plantago lanceolata	7.55	0.95	4.24
Old and mid age revegetation dissimilarity = 82.10	Old	Mid	
Lantana Camara	29.94	18.15	20.38
Chloris gayana	7.50	28.05	18.49
Pennisetum clandestinum	10.33	5.95	8.01
Bidens pilosa	8.28	4.98	6.97

3.5 The Influence of Herbicide

The use of herbicide on topsoil before its collection and while it was stockpiled was expected to have a negative significant impact on the cover and abundance of weed species present in the road verges. The impact of herbicide use before topsoil collection was not statistically analysed due to a small sample of sites for which this information could be obtained. Herbicide was not sprayed on the topsoil before it was collected for stockpiling at any of the 12 recently constructed sites and this information was not accurately available for the remaining 28 sites. Of the 12 recently constructed sites, the majority had utilised herbicide on the topsoil stockpiles. When this use was statistically analysed, the use of herbicide on the stockpiles did not have a significant impact upon either the abundance ($F_{1,10}$ = 0.279, p = 0.609) or percentage cover ($F_{1,10}$ = 0.015, p = 0.904) of introduced or the abundance ($F_{1,10}$ = 1.899, p = 0.198) or percentage ($F_{1,10}$ = 0.591, p = 0.460) cover of native species.

3.6 The Impact of Maintenance

The impacts of maintenance, though not statistically quantified were apparent at almost all road verge sites. *Casurina glauca* trees had been entirely removed from one road verge site, resulting in *Callestium* var. "Kings Park special" being the only native species present (Figure 3.16). The use of herbicide and mowing for safety maintenance was apparent on the majority of the road verges. The area of the verge regularly maintained contains patchy vegetation and was dominated by pioneer species (Figure 3.17). Further maintenance for aesthetic purposes has occurred on verges around planted vegetation (Figure 3.18).

Figure 3.16: Maintenance activities influence road verge species composition. This photo shows the stumps remaining from the removal of *Casurina glauca*.

Figure 3.17: The area between the red line and concrete drain was the approximate width sprayed with herbicide for safety and maintenance purposes.

Figure 3.18: The area around planted vegetation was mowed for aesthetic and safety purposes.

4. Discussion

4.1 Summary of Results

The central aim of this thesis was to comprehensively describe the patterns of introduced and native vegetation establishment across roadside verges with varying revegetation and management histories. In particular, this study is amongst the first to investigate the interacting effects of soil condition, revegetation protocol, weed control methodology and site age on the composition of introduced vegetation along roadsides, with the subsequent aim of informing best management practices.

In general, I found that none of the Roads and Traffic Authority (RTA) existing methods for establishing and managing roadside verges were successful in preventing the initial establishment of introduced species, or producing native communities able to withstand invasion in the long term (Table 4.1). Further, the revegetation methods (i.e. planting vs. seeding) did not influence the richness or abundance of native species. The lack of significance was unexpected as the most abundant native species were those used for revegetation by the RTA. The high richness of introduced versus native species (even on recently revegetated road verges) implies that the current construction, revegetation and maintenance practices are not sufficient to achieve the RTA's desired road corridor ecological outcome (as specified in their Biodiversity Guidelines). The importance of seeding and planting of native species on road verges is not questioned, but rather this project identifies a need for an improved approach to reduce introduced species establishment and reduce future cost for ongoing management. While some site conditions influenced abundance and richness of introduced species, no factor consistently reduced these levels. It is highly probable that the absence of weed control before and during topsoil stockpiling means that even with sufficient seeding and planting, the introduced and often aggressive colonisers are already present in the topsoil and quickly dominate the verge.

Table4.1: The four measured response variables had various interactions; positive (+), negative (-) and variance (as described). Explanatory variables that produced significant interactions are indicated (*): Native species richness (Planted * Age of revegetation) and Introduced species richness (Soil depth * Planted * Percentage litter cover). The four response variables had no significant interaction with the following measured explanatory variables: aspect, slope, boundary type, adjacent land use, percentage of live vegetation, percentage of bare ground, height of canopy, height of shrub layer, use of herbicide, organic matter and particle size (Appendix 5).

Explanatory variable	Native species richness	Native percentage cover	Introduced species richness	Introduced percentage cover
Planted	*			
Seeded			Non-seeded areas contained higher richness of introduced species.*	
Age of revegetation	-*			
Soil depth			+*	
Soil texture			Introduced species richness was highest in sandy clay and lowest in silty loam.	
Imported topsoil	Verges with imported topsoil had higher richness of native species.		Verges with imported topsoil had lower richness of introduced species.	
Percentage litter cover			Higher litter layers had lower richness of introduced species.*	Higher litter layers had lower introduced species percentage cover.
Native species richness		+		-
Native percentage cover	+			
Introduced species richness				+
Introduced percentage cover	-		+	

4.2 Patterns of Introduced Species Abundance and Richness

The high richness of introduced species relative to native species richness was an expected outcome, as the dominance of weeds in disturbed areas (Mack et al. 2000) and on road verges (Forman et al. 1998; Abd El-Ghani et al. 2005; Sharma et al. 2009) is well documented worldwide. Further, the high abundance and site presence of the most abundant weeds is not surprising as *Bidens pilosa* (Grombone-Guaratini et al. 2004), *Pennisetum clandistinum* (Cilliers et al. 2000), *Senecio madagascariensis* (Radford et al. 2000), *Lantana camara* (Lin 2007) and *Chloris gayana* (Fensham 1998) are all known to invade road verges. The high site presence of *Araujia sericifera* is particularly concerning as it is classified as noxious elsewhere in NSW (Pittwater Council 2011) and appears to be becoming a more significant weed in the Illawarra. Furthermore its wind dispersed seeds (Thorp et al. 1998) will continue to be spread by wind gusts associated with the road verge micro climate (Forman et al. 2002).

Plant biomass (used to measure percentage cover) has a close relationship with species richness (Qinfeng 2003), reinforced by the positive, linear relationship between the richness and abundance of introduced species typical of this survey. The productivity diversity hypothesis reinforces that increased biomass is an indicator of species richness (Cardinale et al. 2009), resulting in species richness and percentage cover regarded as predictors for each other. Furthermore, the relationship indicates that species abundance is driven by the addition of new species, rather than the increasing dominance of one or a few species. The implications of this from a management perspective is that control of introduced species will need to be targeted at reducing the number of species occupying a site, rather than targeting one or a few dominant species. This will be relatively more difficult since control techniques vary widely among species.

The comparatively low native species richness may be increasing the susceptibility of the road verges to invasion by introduced species. The ability of native communities to resist invasion is greater in ecosystems with high species richness (Elton 1958), as decreasing native species richness increases the susceptibility of ecosystems to invasion (Zavaleta et al. 2004). Davis et al (2000) hypothesised that the presence of unused resources in an environment will increase the vulnerability of that area to invasion (Figure 4.1); however, areas of high native diversity can resist invasion by introduced species when essential resources are available (Maron et al. 2007). The low species richness of road verges and high availability of resources such as light and space have produced areas of low resistance to invasion. In order to reduce available resources, a variety of native flora forms (ground covers, shrubs, grasses etc) would be recommended to ensure the highest number of niches are filled.

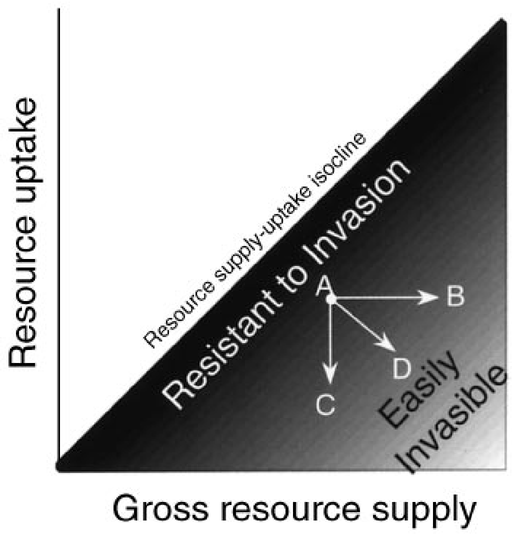

Figure 4.1: The theory of fluctuating resource availability suggests that a community's ability to resist invasion is dependent on resource availability and increasing resource availability results in reduced invasion resistant (Davis et al. 2000).

The depth of the soil profile was found to influence the establishment of introduced species, with deeper soil profiles generally associated with an increased number of introduced species occupying a roadside verge. The classification of soil depth that was used in this study was based on the magnitude of soil compaction. The probable mechanism underpinning this result, therefore, is the poor rates of root growth in highly compacted soil profiles which typically contain low oxygen levels (Letey 1985). Furthermore, introduced species established in deeper soils are better able to withstand droughts due to greater rates of water penetration and deeper root profiles within the soil (Padilla et al. 2007). A similar positive relationship between richness and soil depth was not exhibited by native species, although this has been shown to be true in other studies (e.g. Holmes 2001). In addition, shallower soils are likely to be more prone to erosion of what little soil is available. Despite the addition of native seed; if the soil profile is too shallow, the rapid erosion of soil from a site would remove the seed, in turn preventing germination and establishment. Thus, in order to establish vegetation on a verge (especially where seeding is used instead of planting with tubestock) the soil should be decompacted or additional topsoil should be brought into the site.

Topsoil imported for use on road construction sites is required to be free of both native and introduced seed. The initial absence of weed propagules in imported topsoil is likely to be responsible for the smaller recorded introduced species richness in sites that utilised this soil type, as the presence of propagules is one of the three factors influencing the invasion of a habitat by introduced species (Lonsdale 1999) . This pattern validates the protocol for topsoil stripped from the construction site to be treated as recommended by the RTA (i.e. topsoil sprayed with herbicide before vegetation clearing and during stockpiling) to reduce viable weed propagules within the soil.

The recorded presence of introduced species at these sites indicates that while weed free topsoil is important in reducing initial introduced species richness and produces overall reduced species abundance, it doesn't prevent future establishment by these unwanted plants. The use of unsprayed and therefore potentially weed contaminated topsoil is likely to have a lasting impact on the future species richness. It is also important to note that the majority of areas utilising imported topsoil were planted with the native *C. glauca*; which produces a large amount of slowly decomposing litter (Clarke et al. 1996), thus blanketing the soil and probably reducing the establishment of native and introduced species.

There was a significant decline in the abundance of weeds as the number of native species increased at road verge sites. This pattern may indicate that native species are directly suppressing the amount of weeds through increased competition for resources such as light, water and nutrients (Lonsdale 1999). This theory of invisibility was first proposed by Elton (1958) and posits that as the number of native species increases, the number of suitable niches available for additional species to occupy becomes smaller (i.e. species saturation) and competition, in turn, becomes strong enough to inhibit further colonisation of a site by introduced species. Thus, a fundamental, sustainable protocol to control weed invasion might be to enhance the number of native species revegetated at a site, rather than simply promoting a high abundance of just a few native species.

The high abundance of introduced species present in road verges with soil classified as sandy clay and low abundance in silty loam is possibly an effect from the importation of topsoil. Imported topsoil must conform to RTA specifications including the absence of clay lumps, suggesting that sandy clay is in-situ soil (and possibly eroded of topsoil). Alternatively, the presence of clay inhibited the effectiveness of glyphosate during herbicide spraying (Glass 1987), both during spraying of vegetation before clearing and subsequent maintenance .

Patterns of Introduced Species Composition

The composition of the introduced species assemblage changed substantially as the age of the road verge increased. Recently constructed verges (0-7 years) were characterised by the presence of pioneer weeds, many of which are wind-dispersed annual herbs that thrive in disturbed, sunny locations. As the age of the road increased, these herbs were replaced by robust, shade-tolerant shrubs (in particular *Lantana camara*), suggesting that the decreasing introduced species richness with increasing age of revegetation is a result of a move from pioneer to large competitive introduced species. *Lantana camara* (a slow growing noxious shrub) is likely to be responsible for

lower introduced species richness in old revegetated verges, perhaps due to its allelopathic abilities (Gentle et al. 1997), or competitive ability.

Road verges that were revegetated by seeding had a smaller number of introduced species than sites that were not seeded. Typically, the use of seeding is known to increase the species richness in comparison to areas where no revegetation (seeding or planting) treatments have taken place (Brekke Skrindo et al. 2004). The use of a native seed mixture increases the density of native species (Elseroad et al. 2003), reducing the potential for invasion (the diversity resistance hypothesis (Elton 1958; Case 1990)). Currently, native seed mixtures utilised by the RTA contain a higher number of species than are used by the RTA for planting of the road verges.

The abundance of *Lantana camara* on the studied road verges indicates that maintenance practices will need to be increased to control the growth and spread of the current infestations, as specified in the Noxious Weeds Act 1993 (*NSW*). The increased focus by Local Weed Authorities on high risk pathways including road verges will require future action to control specific introduced species (Southern Rivers Catchment Management Authority et al. 2011).

4.3 Patterns of Native Species Abundance and Richness

The most abundant native species were those widely planted by the RTA; planted species are known to dominate the verges for up to 20 years after revegetation (Newman et al. 2001). Road verges in urban areas are commonly behind tall noise walls and isolated from the native seed source of bushland, inhibiting natural recruitment of native species onto the verges. A large proportion of native Australian flora including *Eucalyptus* (Yates et al. 1994) and *Acacia* species (Berg 1975) are adapted for short range dispersal (Berg 1975; Westoby et al. 1990; French et al. 2011). Coupled with the urban and rural location of studied road verges this explains the majority of native species present were those manually planted or seeded by the RTA. Consequently, to increase native species richness seeding and/or planting needs to be conducted manually.

The variation of native species richness within age and planting classes is related to the alteration in revegetation practices over time. Species richness of roads verges is a direct result of RTA revegetation practices and native propagules present in the topsoil, with limited natural native recruitment (Berg 1975; Yates et al. 1994). The reduction of species richness in middle age planted roads is due to the high use of *C. glauca* and *Callistemon* var. "Kings Park special" for the revegetation of verges in 1996. *Casuarina glauca* were placed in augured holes filled with topsoil in selected sites in 1996. The surrounding material was not replaced and consists of construction aggregate, effectively inhibiting additional flora germination. The increase in species richness on recently planted verges is a reflection of improved RTA practices, as an increased number of native species are utilised instead of the previously preferred method of two alternating species.

The negative relationship between native species richness and the continuous age of road verge revegetation could be explained by the above discussed reasons; alternatively, the reduction in native species may indicate an inability of individuals present to successfully seed and replace themselves once the original populations begin to decline. This may be due to the lack of pollinators present on the fragmented road verge habitat (Cunningham 2000) and compounded by the disturbed conditions of the road verge (Spellerburg 1998). The relatively young age of all studied verges could be responsible for the difference in species composition. A comparison of remnant vegetation on rural road verges since around 1830 to the present found that species composition was similar between road age classes, but age of road did impact upon the structure of the communities (Spooner et al. 2009). Interestingly, the species richness or abundance of introduced species was not influenced by the age of revegetation, yet it did influence the composition of both introduced and native species.

Road verges that utilised imported topsoil contained a higher mean native species richness than sites that used non topsoil (i.e. utilised in-situ topsoil stripped from the construction site). In comparison, introduced species richness was lower on verges that utilised imported topsoil. Imported topsoil used on verges is required to be free from native and introduced propagules (RTA 2011); yet studied road verges with imported topsoil had higher native species presence opposing many findings that suggest that topsoil is an important native seed source (Ward et al. 1996). Sites that utilised in-situ topsoil (RTA's preferred soil option) had lower numbers of native species. This difference is likely to be due to the urban and rural location of the verges and lack of native seed within soil, as in natural bushland areas species present within stripped topsoil can be adequate for revegetation (Ward et al. 1996) and road verge weeds typically reflect those present on adjacent land (Sullivan et al. 2009). The absence of herbicide treatment before vegetation clearing and stockpiling is likely to contribute to this relationship, as viable introduced species seed and rhizomes present would germinate quickly after topsoil is re-laid on the road verge.

The resilience of an environment such as a road verge can be responsible for the invasion of introduced species (Lonsdale 1999) and can be impacted by multiple factors including the nature of disturbance at the site and the ability of the flora species present to outcompete the introduced species (Lonsdale 1999). The seeding and/or planting of native species to cover the highest number of niches is regarded as the best way to prevent the establishment of introduced species. Due to the limited natural recruitment ability of natives and recorded low native abundance, the lack of variables explaining native abundance was not surprising. This further highlights that the major contributing fact in native species abundance on road verges is successful recruitment and germination.

While no other site condition or soil variables influenced the species richness or abundance of native species, this does not discount the importance of these factors. It is likely that if a fraction of studied verges were located in bushland, there would be a significant difference in native species abundance between boundary conditions as verges located in natural areas can successfully regenerate without much anthropogenic assistance (Brekke Skrindo et al. 2004). The positive relationship between introduced species richness and soil depth was not exhibited by native species, although this has been shown to be true in other studies (e.g. Holmes 2001). This may have been caused by the lack of adequate native planting or seeding following the addition of top soil to a site, which was then monopolised by introduced species that were more successful than natives at recruiting to a site. Considering the negative relationship between native species richness and weed abundance and the positive effects of soil depth on weed richness, it is recommended that native species are planted at

all sites following top soil incorporation. The absence of variation in abundance or species richness of native species with revegetation treatments (planting or seeding) is possibly due to the alternation of seeding and planting between sites. Of the 40 sites studied, only 1 was neither seeded nor planted; the remaining had either or both treatments. Whilst no significance was found between revegetation treatments it is likely that this is due to the low native species diversity of the verges, resulting in low variations.

Patterns of Native Species Composition

The change in native species composition over time is one of the most significant findings of this study. It demonstrates the changing RTA method of planting and species selection over time, with the dissimilarity accounted for by species known to be used by the RTA for revegetation (Table 3.2), is reflected by the results. The plant forms utilised has also changed, with the most abundant native species on old aged verges being tree species, while in recent and middle aged road verge revegetation the herb *Lomanda* spp. contributed to the dissimilarity.

4.4 Maintenance

RTA specifications require herbicide spraying before the clearing of vegetation, yet no recently constructed sites received this treatment and it is unlikely that older constructions followed this specification. While the glyphosate based herbicide utilised is absorbed by the stems and leaves of plants and can be translocated below ground within the plant (Roberts et al. 1999), due to the deactivation of glyphosate by soil (particularly clay)(Cheminova Inc. 2004), it is rarely absorbed by the roots of plants (Roberts et al. 1999). Glyphosate has the ability to kill seed and fruit contained on a plant at the time of spraying (Isaacs et al. 1989). Whilst little research has been undertaken, it is unlikely that viable seed present within topsoil would be impacted upon by glyphosate application. Road verges constructed in natural areas do not necessarily require herbicide use for native species to be dominant (Brekke Skrindo et al. 2004), studied road verges were located in urban, industrial and rural locations which generally have considerably higher weed abundance. All studied roads were constructed through urban or agricultural areas and it is likely that propagules of introduced species were present in the utilised topsoil. On recently constructed roads, topsoil was sprayed with herbicide after it had been stockpiled, decreasing the sprayed surface area and the positive impact of the herbicide (in comparison to spraying of the topsoil before collection). This may explain the small mean species richness per site.

The presence of populations of established introduced species within the road corridor complicates the goal of a weed free verge. The invasive vine *Araujia sericifera* (with fine windblown seeds) and noxious *Lantana camara* (whose seeds can be distributed long distances by birds) are established on the studied road verges. Continual maintenance of infested areas will be required to prevent further spread of these species as the disturbed corridor allows for introduced species to easily spread from invaded areas into the recently constructed verge. In order to prevent the establishment of these species on verges revegetated recently and in the future, species richness should be increased in conjunction with weed control in adjacent areas to provide native species with the opportunity to dominate the road verge before these species invade the area.

The presence of roads means that vehicles will always be vectors for species growing on the verges, particularly species with light and/or windblown seeds. It has been established that the best way to combat the spread of introduced species via vehicles is to reduce infestations, thereby decreasing seeds with the potential to spread (Lonsdale et al. 1994). Maintenance and construction vehicles can spread introduced species seed from areas of infestation into non infested areas (DiTomaso et al. 2006). To reduce the likelihood of this occurring, careful and thorough cleaning is required. In Australia systems are being developed to increase awareness and improve the efficiency of this process (Hanson 2004).

4.5 Management applications

It is apparent that past revegetation aims did not include the production of an ecologically functioning ecosystem with studied verges not showing evidence that species utilised for middle and old aged revegetation had reproduced. The majority of the older and middle aged roads may need to be replanted or reseeded with native species once the current plants reach the end of their life cycle. In order to prevent this expensive exercise it is recommended that reproductive ability be considered when species are considered for future road verge vegetation.

The difference in introduced species composition between road age classes allows weed maintenance techniques to be altered to account for this variation. A general herbicide could be utilised to reduce the abundance of weed species on recently revegetated roads and older *Lantana camara* invaded roads would require an integrated approach to control this noxious weed. The publication *Lantana Best Practice Manual and Decision Support Tool* (Stock et al. 2009) is a recommended resource to aid in the establishment of a *Lantana camara* control program. Further, the RTA is recommended to take an active approach in controlling this noxious species by seeking infestations instead of the current re-active method which relies on the local council informing them of areas required to be controlled.

The ability of native species richness to reduce the percentage cover of introduced species is one of the most significant findings of this study. For future revegetation, an increase in the quantity and diversity of seed will build the resilience of these areas to invasion, while already established verges would benefit from a combination of weed control followed by a manual increase of native species by either seeding or planting.

4.6 Further research directions

It was difficult to establish which native species growing on the road verges had germinated from seed mixes or via natural dispersal. It would be useful to conduct a long term study to accurately analyse topsoil treatment, species seeded/planted, the time of introduced species invasions and how the native species reacted to the invasion. This would allow for identification of native species that germinated from the topsoil without anthropogenic influences and determine preferred verge conditions by comparing germination success between sites.

While many road verge studies investigate the success of one revegetation treatment over time (Brekke Skrindo et al. 2004), this study provided a snap shot of current species richness and road verge conditions. This study could be advanced by surveying the verges, particularly those recently revegetated over time to observe succession of particular revegetation treatments and how the vegetation communities respond to maintenance.

The abundance of introduced species present on road verges has been shown to be positively influenced by the average daily traffic of roadways (Mortensen et al. 2009). Investigation into this variable on Illawarra road verges would be beneficial as a positive relationship could aid in maintenance applications. A positive relationship could be utilised to indicate areas that will require the most weed control management.

4.7 Conclusion and Recommendations

The time and cost constraints associated with road construction result in environmental considerations not being strictly enforced. The enforcement of environmental specifications can potentially reduce future maintenance costs and provide more favoured ecological outcomes. The increasing focus on roads and railways as high priority corridors for introduced species invasion will require continued action by the RTA to manage and prevent infestation on its road verges. The release of the RTA's Weed Management Guidelines will provide a standard of control, it is important to ensure measures are enforced and accurately undertaken. A working partnership between local councils and the RTA to actively manage all introduced species and promote a diverse native road verge, would benefit both organisations. Prevention of introduced species establishment is regarded as the most cost effective management practice (Wittenberg et al. 2001), with eradication and management significantly more time consuming and expensive (Wittenberg et al. 2001). To prevent the spread and establishment of introduced species along road verges in the Illawarra it is recommended that the RTA implement the future construction and revegetation recommendations.

Recommendations for future construction and revegetation:

- Ensure that project managers enforce the spraying of topsoil with an approved herbicide before vegetation clearing.
- Increase the quantity of seed within the spray mixtures and the number of individuals planted.
- Increase the species richness of seeding and planting, including species from a range of forms (ground cover, shrubs, grasses and trees).
- Where possible minimise the slope of road verges to reduce the erosion of topsoil.
- Monitor new plantings to ensure that a healthy native plant cover is achieved as quickly as possible and to control any growth of introduced species.
- Ensure road verges whose future maintenance will be the responsibility of the local council, have an appropriate cover of native vegetation before the transfer occurs.

Recommendations for already established road verges:

- Actively manage known infestations of introduced species, to reduce the expansion of these plants.

- Actively reduce the abundance of *Lantana camara*, with the goal of eradicating infestations from the road verges.
- Increase the resilience of already revegetated verges by removing introduced species present and re-seeding the verges with native species.

Legislation

Environmental Protection and Biodiversity Conservation Act 1999 (Cth)

Quarantine Act 1908 (Cth)

Noxious Weed Act 1993 (NSW)

The Roads Act 1993 (NSW)

Threatened Species Conservation Act 1995 (NSW)

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Appendices

Appendix 1

***Noxious Weeds Act 1993* – Section 8**

Weed control classes

(1) The following weed control classes may be applied to a plant by a weed control order:

(a) Class 1, State Prohibited Weeds,

(b) Class 2, Regionally Prohibited Weeds,

(c) Class 3, Regionally Controlled Weeds,

(d) Class 4, Locally Controlled Weeds,

(e) Class 5, Restricted Plants.

(2) The characteristics of each class are as follows:

(a) Class 1 noxious weeds are plants that pose a potentially serious threat to primary production or the environment and are not present in the State or are present only to a limited extent.

(b) Class 2 noxious weeds are plants that pose a potentially serious threat to primary production or the environment of a region to which the order applies and are not present in the region or are present only to a limited extent.

(c) Class 3 noxious weeds are plants that pose a serious threat to primary production or the environment of an area to which the order applies, are not widely distributed in the area and are likely to spread in the area or to another area.

(d) Class 4 noxious weeds are plants that pose a threat to primary production, the environment or human health, are widely distributed in an area to which the order applies and are likely to spread in the area or to another area.

(e) Class 5 noxious weeds are plants that are likely, by their sale or the sale of their seeds or movement within the State or an area of the State, to spread in the State or outside the State.

(3) A noxious weed that is classified as a Class 1, 2 or 5 noxious weed is referred to in this Act as a "notifiable weed".

Appendix 2

Vegetation sampling survey sheet

Site #					
Size	4x20m	2x40m	1x80m		
Slope					
Aspect					
Soil	Clay	Sand	Rubble	Loam	Other:
Evidence of topsoil or litter content					
Adjacent land use	Urban	Industrial	Farm	Natural	
Boundary Type	Fence	Noise Wall	Barrier	No Barrier	
% Bare Ground	0-40	40-80	80-100		
% cover litter	0-40	40-80	80-100		
% cover of live veg	0-40	40-80	80-100		
Shade (from sources outside site)					
Height of Canopy (m)	0-1	1-2.	2-3.	>3	
Height of shrub layer (m)	0-2	1-2.	2-3.		
Evidence of maintenance. If yes explain.					

Braun Blanquet

Cover abundance value	Description			
1	One- a few individuals			
2	Uncommon and under 5%			5% = 4m 2m2
3	Common and under 5%			20% = 16m 4m2
4	Very abundant and <5% or 5-20% cover			50% = 40m
5	20 - 50% cover			75% - 56m
6	50 - 75% cover			100% = 80m
7	75 - 100% cover			

Plant Species / Number	Abundance (if large tree or shrub)	Braun Blanquet Value (ground covers)	Artificially planted?	Distance between plantings	Notes plant on

Appendix 3

Soil classification survey sheet

	Organic Matter	Texture of moist soil	Soil Depth / Depth to impenetrable layer	Particle size and consolidation
1	Well formed, dark, soil with obvious organic matter – horizon depth:~15cm	Medium to heavy clay	Deep: 1.0 - < 1.5m	No rocks, grains all relatively the same size.
2	Obvious organic matter – horizon depth:~10cm	Light clay		Soil particles mostly uniform small pebbles throughout.
3	Small width of actual soil organic layer: ~5cm, litter on top to form larger layer.	Sand	Moderate: 0.5 - <1.0m	Un consolidated soil, pebbles throughout.
4	Organic matter in the process of breaking down to form layer – temporary	Sandy clay loam		Equal combination of rocks and soil.
4.5	Organic matter in the process of breaking down to form layer – permanent (Casuarina spines)	Clay loam		
5	Organic matter on surface has not formed humus as yet	Sandy loam	Shallow: 0.25 - < 0.5m	Large percentage of rocks or clay, and small percentage of soil. >50 % rock cover
6	Small number of leaves on surface, large bare areas.	Silty loam		>70 % rock cover
7	No organic matter	Loam	Very shallow : <0.25m	All rock
			Actual Depth:	

Other features	Description
Relative elevation	
Drainage	
Erosion	
Is it a point of high moisture	
Soil Structure	

The purpose of the soil classification is to have an average rank of the soil condition of an 80m^2 site. It will be used as a possible factor influencing the prevalence of weeds and as an indicator of the extent of previous disturbance.

Appendix 4

Summary of flora species recorded on the studied road verge sites. (*) indicates an introduced species.

Family	Species	
Acanthaceae	Thunbergia alata	*
Amaranthaceae	Amaranthus viridis	*
Apiaceae	Cyclospermum leptophyllum	*
	Foeniculum vulgare	*
	Hydrocotyle bonariensis	*
	Unidentified Apiaceae	*
	Trachymene incisa	
Apocynaceae	Araujia sericifera	*
	Gomphocarpus fruticosus	*
Arecaceae	Phoenix canariensis	*
Asparagaceae	Asparagus aethiopicus	*
	Asparagus asparagoides	*
Asphodelaceae	Asphodelus fistulosus	*
Asteraceae	Ageratina adenophora	*
	Aster subulatus	*
	Bidens pilosa	*
	Cirsium vulgare	*
	Conyza bilbaoana	*
	Conyza bonariensis	*
	Delairea odorata	*
	Galinsoga parviflora	*
	Gamochaeta spicata	*
	Hypochaeris radicata	*
	Leontodon taraxacoides	*
	Senecio madagascariensis	*
	Senecio pinnatifolius	*
	Silybum marianum	*
	Soliva sessilis	*
	Sonchus oleraceus	*
	Tagetes minuta	*

Family	Species	
	Taraxacum officinale	*
	Unidentified Asteraceae	*
Bignoniaceae	Pandorea pandorana	
Brassicaceae	Hirschfeldia incana	*
Caryophyllaceae	Arenaria leptoclados	*
	Cerastium	*
Casuarinaceae	Casuarina glauca	
Chenopodiaceae	Chenopodium album	*
	Einadia hastata	*
Cirsium	Unidentified Cirsium	*
Commelinaceae	Tradescantia fluminensis	*
	Commelina cyanea	
Convolvulaceae	Ipomoea indica	*
	Dichondra repens	
Crassulaceae	Crassula spp.	*
Cyperaceae	Cyperus eragrostis	*
	Carex appressa	
Davalliaceae	Nephrolepis cordifolia	
Dilleniaceae	Hibbertia scandens	
Ericaceae	Leucopogon lanceolatus	
Euphorbiaceae	Euphorbia peplus	*
	Ricinus communis	*
	Unidentified Euphorbiaceae	*
	Chamaesyce dallachyana	
Fabaceae	Chamaecytisus palmensis	*
	Genista monspessulana	*
	Medicago lupulina	*
	Psoralea pinnata	*
	Senna pendula	*
	Trifolium pratense	*
	Trifolium repens	*
	Trifolium resupinatum	*
	Trifolium tomentosum	*

Family	Species	
	Unidentified Fabaceae	*
	Vicia sativa	*
	Glycine microphylla	
	Indigofera australis	
	Kennedia rubicunda	
	Medicago spp.	
Geraniaceae	Geranium homeanum	
Iridaceae	Watsonia meriana	*
Juncaceae	Juncus continuus	
Lamiaceae	Plectranthus ciliatus	*
	Plectranthus spp.	*
	Westringia fruticosa	
Lomandraceae	Lomandra fluviatilis	
	Lomandra longifolia	
	Lomandra tanika	
Malvaceae	Malva neglecta	*
	Malva parviflora	*
	Sida rhombifolia	*
	Modiola caroliniana	
Meliaceae	Melia azedarach	
Mimosaceae	Acacia baileyana	
	Acacia binervata	
	Acacia irrorata	
	Acacia longifolia	
	Acacia mearnsii	
	Acacia melanoxylon	
	Acacia saligna	
Moraceae	Ficus rubiginosa	
Myrsinaceae	Anagallis arvensis	*
Myrtaceae	Callistemon citrinus	
	Callistemon var. kings park speicial	
	Callistemon spp.	
	Eucalyptus spp.	

Family	Species	
	Eucalyptus canaliculata	
	Eucalyptus piperita	
	Eucalyptus punctata	
	Leptospermum polygalifolium	
	Melaleuca armillaris	
	Melaleuca decora	
	Melaleuca ericifolia	
	Melaleuca linariifolia	
	Melaluca spp.	
	Syzygium spp.	
Ochnaceae	Ochna serrulata	*
Oleaceae	Ligustrum sinense	*
Onagraceae	Oenothera mollissima	*
Oxalidaceae	Oxalis corniculata	*
	Oxalis purpurea	*
Passifloraceae	Passiflora subpeltata	*
Phytolaccaceae	Phytolacca octandra	*
Pittosporaceae	Pittosporum undulatum	
Plantaginaceae	Plantago lanceolata	*
Poaceae	Axonopus fissifolius	*
	Briza subaristata	*
	Bromus catharticus	*
	Chloris gayana	*
	Chloris virgata	*
	Cynodon incompletus	*
	Digitaria sanguinalis	*
	Echinochloa esculenta	*
	Ehrharta erecta	*
	Eleusine indica	*
	Eleusine tristachya	*
	Eragrostis curvula	*
	Megathyrsus maximus	*
	Melinis repens	*

Family	Species	
	Paspalum dilatatum	*
	Paspalum urvillei	*
	Pennisetum clandestinum	*
	Setaria parviflora	*
	Setaria pumila	*
	Sporobolus spp.	*
	Stenotaphrum secundatum	*
	Cynodon dactylon	
	Themeda australis	
Polygonaceae	Acetosa sagittata	*
	Polygala virgata	*
	Rumex crispus	*
	Rumex brownii	
Portulacaeae	Portulaca oleracea	
Proteaceae	Grevillea oleoides	
	Grevillea robusta	
Rutaceae	Murraya paniculata	*
Solanaceae	Solanum americanum	*
	Solanum chenopodioides	*
	Solanum nigrum	*
Sterculiaceae	Brachychiton acerifolius	
Tropaeolaceae	Tropaeolum majus	*
Ulmaceae	Celtis occidentalis	*
	Trema tomentosa	
Verbenaceae	Lantana camara	*
	Verbena bonariensis	*
	Verbena incompta	*
	Verbena rigida	*
	Unidentified plant 1	*
	Unidentified plant 2	*
	Unidentified plant 3	*
	Unidentified plant 4	*
	Unidentified plant 5	*

Family	Species	
	Unidentified plant 6	*
	Unidentified plant 7	*
	Unidentified plant 8	*

Appendix 5

F table of results, (*) denotes significant difference.

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
# of introduced	Soil depth (cont)	1	168.647	168.647	6.492	0.015 *
# of introduced	Error	38	987.128	25.977	6.492	0.015 *
# of introduced	Total	39				

# of introduced	Aspect (cont)	1	26.702	26.702	0.899	0.349
# of introduced	Error	38	1129.073	29.712	0.899	0.349
# of introduced	Total	39				

# of introduced	Age of reveg (cont)	1	3.471	3.471	0.112	0.740
# of introduced	Error	37	1144.119	30.922	0.112	0.740
# of introduced	Total	38				

# of introduced	Slope (cont)	1	24.467	24.467	0.822	0.370
# of introduced	Error	38	1131.308	29.771	0.822	0.370
# of introduced	Total	39				

# of introduced	% cover of introduced species (cont)	1	190.354	190.354	7.493	0.009 *
# of introduced	Error	38	965.421	25.406	7.493	0.009 *
# of introduced	Total	39				

# of introduced	% cover of native species (cont)	1	11.028	11.028	0.366	0.549
# of introduced	Error	38	1144.747	30.125	0.366	0.549
# of introduced	Total	39				

# of introduced	# of native species (cont)	1	1.944	1.944	0.064	0.802

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
# of introduced	Error	38	1153.831	30.364	0.064	0.802
# of introduced	Total	39				

# of introduced	Planted (cat)	1	3.963	3.963	1.185	0.283
# of introduced	Error	38	1120.812	29.495		
# of introduced	Total	39				

# of introduced	Seeded (cat)	1	132.399	132.399	4.916	0.033 *
# of introduced	Error	38	1023.376	26.931		
# of introduced	Total	39				

# of introduced	Planted and seeded (cat)	1	10.176	10.176	0.338	0.565
# of introduced	Error	38	1145.599	30.147		
# of introduced	Total	39				

# of introduced	Age of reveg (cat)	2	17.612	17.612	0.281	0.757
# of introduced	Error	36	1129.973	31.388		
# of introduced	Total	38				

# of introduced	Soil texture (cat)	5	402.765	80.553	3.637	0.010 *
# of introduced	Error	34	753.010	22.147		
# of introduced	Total	39				

# of introduced	Soil depth (cat)	3	144.725	48.242	1.718	0.181
# of introduced	Error	36	1011.050	28.085		
# of introduced	Total	39				

# of introduced	Organic matter (cat)	5	112.388	22.478	0.733	0.604

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
# of introduced	Error	34	1043.387	30.688		
# of introduced	Total	39				

# of introduced	Particle size (cat)	4	188.230	47.057	1.702	0.172
# of introduced	Error	35	967.546	27.644		
# of introduced	Total	39				

# of introduced	Adjacent land use (cat)	2	7.508	3.754	0.121	0.886
# of introduced	Error	37	1148.267	31.034		
# of introduced	Total	39				

# of introduced	% of bare ground (cat)	2	8.693	4.346	0.140	0.870
# of introduced	Error	37	1147.082	31.002		
# of introduced	Total	39				

# of introduced	% of litter cover (cat)	2	258.177	129.088	5.321	0.009 *
# of introduced	Error	37	897.599	24.259		
# of introduced	Total	39				

# of introduced	Height of canopy (cat)	3	56.275	18.758	0.614	0.610
# of introduced	Error	36	1099.500	30.542		
# of introduced	Total	39				

# of introduced	Height of shrub layer (cat)	2	66.808	33.404	1.135	0.332
# of introduced	Error	37	1088.967	29.432		
# of introduced	Total	39				

# of introduced	Use of herbicide (cat)	1	2.250	2.250	0.279	0.609

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
# of introduced	Error	10	80.667	8.067	0.279	0.609
# of introduced	Total	11				

# of introduced	Imported topsoil (cat)	1	145.773	145.773	13.217	0.001 *
# of introduced	Error	23	253.667	11.029	13.217	0.001 *
# of introduced	Total	24				

# of introduced	% cover of lantana (cont)	1	24.803	24.803	0.833	0.367
# of introduced	Error	38	1130.972	29.762	0.833	0.367
# of introduced	Total	39				

# of introduced	Planted (cat) * Imported topsoil (cat)	1	9.261	9.261	1.006	0.327
# of introduced	Imported topsoil (cat)	1	169.478	169.478	18.412	0.0003 *
# of introduced	Planted (cat)	1	43.427	43.427	4.718	0.041 *
# of introduced	Error	21	193.297	9.205	7.465	0.001 *
# of introduced	Total	24				

# of introduced	Seeded (cat)	1	43.047	43.047	4.299	0.051
# of introduced	Imported topsoil (cat) * seeded (cat)	1	7.109	7.109	0.710	0.409
# of introduced	Imported topsoil (cat)	1	170.617	170.617	17.041	0.001 *
# of introduced	Error	21	210.257	10.012	6.298	
# of introduced	Total	24				

# of introduced	Seeded (cat)	1	69.911	69.911	2.943	0.098
# of introduced	Age of reveg (cont)	1	19.691	19.691	0.829	0.371
# of introduced	Seeded (cat) * Age of reveg (cont)	1	16.351	16.351	0.688	0.414
# of introduced	Soil depth (cat) * Age of reveg (cont)	2	91.274	45.637	1.921	0.166
# of introduced	Soil depth (cat)	2	67.791	33.896	1.431	0.257

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
# of introduced	Seeded (cat) * Soil depth (cat)	2	59.329	29.665	1.249	0.303
# of introduced	Soil depth (cat) * Age of reveg (cont) * Seeded (cat)	2	35.396	17.698	0.745	0.484
# of introduced	Error	27	641.450	18.789	1.937	0.079
# of introduced	Total	38				

# of introduced	Planted (cat) * Age of reveg (cont)	1	17.199	17.199	0.645	0.429
# of introduced	Age of reveg (cont)	1	6.356	6.356	0.238	0.629
# of introduced	Planted (cat)	1	0.000	0.000	0.000	0.998
# of introduced	Soil depth (cat) * Age of reveg (cont)	2	44.912	22.456	0.842	0.442
# of introduced	Planted (cat) * Age of reveg (cont) * Soil depth (cat)	2	36.615	18.307	0.687	0.512
# of introduced	Soil depth (cat)	2	27.371	13.685	0.513	0.604
# of introduced	Planted (cat) * Soil depth (cat)	2	14.800	7.400	0.278	0.760
# of introduced	Error	27	333.583	12.355	1.459	0.204
# of introduced	Total	38				

# of introduced	Seeded (cat)	1	55.512	55.512	2.313	0.138
# of introduced	Soil depth (cont)	1	43.647	43.647	1.818	0.187
# of introduced	Seeded (cat) * Soil depth (cont)	1	35.822	35.822	1.492	0.231
# of introduced	% of litter cover (cat)	1	30.173	30.173	1.257	0.271
# of introduced	Seeded(cat) * % litter cover (cat)	1	8.881	8.881	0.370	0.547
# of introduced	% of litter cover (cat) *Soil depth (cont)	1	5.553	5.553	0.231	0.664
# of introduced	Seeded (cat) * % litter cover (cat) * Soil depth (cont)	1	112.373	112.373	4.682	0.038 *
# of introduced	Error	32	768.117	24.004	2.307	0.051
# of introduced	Total	39				

# of introduced	Soil depth (cont)	1	1.378	1.378	3.540	0.069
# of introduced	Planted (cat) * Soil depth (cont)	1	0.518	0.518	1.330	0.257
# of introduced	% of litter cover (cat)	1	0.421	0.421	1.083	0.306

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
# of introduced	Planted (cat) * % litter cover (cat) * Soil depth (cont)	1	0.174	0.174	0.448	0.508
# of introduced	Planted (cat)	1	0.169	0.169	0.433	0.515
# of introduced	% of litter cover (cat) *Soil depth (cont)	1	0.007	0.007	0.018	0.894
# of introduced	Planted (cat) * % litter cover (cat)	1	4.514	4.514	115972.000	0.002 *
# of introduced	Error	32	12.456	0.389	4.033	0.003 *
# of introduced	Total	39				

# of introduced	Planted (cat) * Soil depth (cont)	1	47.795	47.795	1.934	0.176
# of introduced	Planted (cat)	1	0.468	0.468	0.019	0.892
# of introduced	Soil depth (cont)	1	135.222	135.222	5.472	0.027 *
# of introduced	Age of reveg (cat) * Soil depth (cont)	2	72.243	36.122	1.462	0.250
# of introduced	Age of reveg (cat)	2	24.658	12.329	0.499	0.613
# of introduced	Planted (cat) * Soil depth (cont) * Age of reveg (cat)	2	18.984	9.492	0.384	0.685
# of introduced	Planted (cat) * Age of reveg (cat)	2	0.257	0.128	0.005	0.995
# of introduced	Error	27	667.262	24.713	1.767	0.113
# of introduced	Total	38				

# of native	# of introduced species (cont)	1	0.443	0.443	0.064	0.802
# of native	Error	38	262.932	6.919	0.064	0.802
# of native	Total	39				

# of native	% cover of introduced species (cont)	1	27.139	27.139	4.366	0.043 *
# of native	Error	38	236.236	6.217	4.366	0.043 *
# of native	Total	39				

# of native	% cover of native species (cont)	1	67.244	67.244	13.028	0.001 *
# of native	Error	38	196.131	5.161	13.028	0.001 *
# of native	Total	39				

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
# of native	Age of reveg (cont)	1	31.018	31.018	5.065	0.030 *
# of native	Error	37	226.572	6.124	5.065	0.030 *
# of native	Total	38				
# of native	Soil depth (cont)	1	2.354	2.354	0.343	0.562
# of native	Error	38	261.021	6.869	0.343	0.562
# of native	Total	39				
# of native	Slope (cont)	1	0.228	0.228	0.329	0.857
# of native	Error	38	263.147	6.925	0.329	0.857
# of native	Total	39				
# of native	Aspect (cont)	1	4.268	4.268	0.626	0.434
# of native	Error	38	259.107	6.819	0.626	0.434
# of native	Total	39				
# of native	Planted (cat)	1	0.002	0.002	0.002	0.988
# of native	Error	38	263.373	6.931		
# of native	Total	39				
# of native	Seeded (cat)	1	1.165	1.165	0.169	0.683
# of native	Error	38	262.210	6.900		
# of native	Total	39				
# of native	Planted and seeded (cat)	1	0.988	0.988	0.143	0.707
# of native	Error	38	262.387	6.905		
# of native	Total	39				

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
# of native	Age of reveg (cat)	2	55.256	27.628	4.916	0.013 *
# of native	Error	36	202.334	5.620		
# of native	Total	38				
# of native	Soil texture (cat)	5	9.485	1.897	0.254	0.935
# of native	Error	34	253.890	7.467		
# of native	Total	39				
# of native	Soil depth (cat)	3	14.825	4.942	0.716	0.549
# of native	Error	36	248.550	6.904		
# of native	Total	39				
# of native	Organic matter (cat)	5	66.105	13.221	2.279	0.069
# of native	Error	34	197.270	5.802		
# of native	Total	39				
# of native	Particle size (cat)	4	41.642	10.411	1.643	0.185
# of native	Error	35	221.733	6.335		
# of native	Total	39				
# of native	% of litter cover (cat)	2	0.080	0.040	0.006	0.994
# of native	Error	37	263.295	7.116		
# of native	Total	39				
# of native	Adjacent land use (cat)	2	5.512	2.756	0.366	0.676
# of native	Error	37	257.863	6.969		
# of native	Total	39				

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
# of native	Boundary type (cat)	2	15.283	7.642	1.140	0.331
# of native	Error	37	248.092	6.705		
# of native	Total	39				
# of native	% of bare ground (cat)	2	5.940	2.970	0.427	0.656
# of native	Error	37	257.435	6.958		
# of native	Total	39				
# of native	Height of canopy (cat)	3	8.283	2.761	0.390	0.761
# of native	Error	36	255.092	7.086		
# of native	Total	39				
# of native	Height of shrub layer (cat)	2	11.723	5.861	0.862	0.431
# of native	Error	37	251.652	6.801		
# of native	Total	39				
# of native	Use of herbicide (cat)	1	18.778	18.778	1.899	0.198
# of native	Error	10	98.889	9.889	1.899	0.198
# of native	Total	11				
# of native	Imported topsoil (cat)	1	2.325	2.325	8.161	0.009 *
# of native	Error	23	6.554	0.285	8.161	0.009 *
# of native	Total	24				
# of native	% cover of lantana (cont)	1	12.427	12.427	1.882	0.178
# of native	Error	38	250.948	6.604	1.882	0.178
# of native	Total	39				

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
# of native	Planted (cat)	1	16.022	16.022	2.898	0.103
# of native	Planted (cat) * Imported topsoil (cat)	1	9.553	9.553	1.728	0.203
# of native	Imported topsoil (cat)	1	69.047	69.047	12.490	0.002 *
# of native	Error	21	116.089	5.528	4.336	0.016 *
# of native	Total	24				
# of native	Imported topsoil (cat) * seeded (cat)	1	0.156	0.156	0.521	0.478
# of native	Seeded (cat)	1	0.029	0.029	0.097	0.759
# of native	Imported topsoil (cat)	1	1.401	1.401	4.669	0.042 *
# of native	Error	21	6.300	0.300	2.867	0.061
# of native	Total	24				
# of native	Age of reveg (cont)	1	2.608	2.608	0.348	0.560
# of native	Seeded (cat)	1	1.876	1.876	0.250	0.621
# of native	Seeded (cat) * Age of reveg (cont)	1	1.469	1.469	0.196	0.662
# of native	Soil depth (cat) * Age of reveg (cont)	2	5.484	2.742	0.366	0.697
# of native	Soil depth (cat) * Age of reveg (cont) * Seeded (cat)	2	2.956	1.478	0.197	0.822
# of native	Seeded (cat) * Soil depth (cat)	2	1.437	0.718	0.096	0.909
# of native	Soil depth (cat)	2	0.744	0.372	0.050	0.952
# of native	Error	27	202.412	7.497	0.669	0.754
# of native	Total	38				
# of native	Planted (cat) * Age of reveg (cont)	1	14.172	14.172	2.044	0.164
# of native	Planted (cat)	1	0.201	0.201	0.029	0.866
# of native	Age of reveg (cont)	1	46.317	46.317	6.681	0.016 *
# of native	Soil depth (cat) * Age of reveg (cont)	2	20.607	10.304	1.486	0.244
# of native	Planted (cat) * Age of reveg (cont) * Soil depth (cat)	2	5.444	2.722	0.393	0.679

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
# of native	Soil depth (cat)	2	5.081	2.540	0.366	0.697
# of native	Planted (cat) * Soil depth (cat)	2	0.756	0.378	0.055	0.947
# of native	Error	27	187.174	6.932	0.923	0.533
# of native	Total	38				

# of native	Seeded (cat) * % litter cover (cat) * Soil depth (cont)	1	4.397	4.397	0.556	0.461
# of native	Seeded (cat) * Soil depth (cont)	1	2.871	2.871	0.363	0.551
# of native	Soil depth (cont)	1	2.769	2.769	0.350	0.558
# of native	Seeded(cat) * % litter cover (cat)	1	2.200	2.200	0.278	0.602
# of native	% of litter cover (cat) *Soil depth (cont)	1	1.620	1.620	0.205	0.654
# of native	Seeded (cat) * Soil depth (cont)	1	1.221	1.221	0.154	0.697
# of native	% of litter cover (cat)	1	0.828	0.828	0.105	0.749
# of native	Error	32	253.213	7.913	0.184	0.987
# of native	Total	39				

# of native	Planted (cat) * % litter cover (cat)	1	2.196	2.196	0.274	0.604
# of native	Soil depth (cont)	1	1.936	1.936	0.242	0.626
# of native	Planted (cat) * Soil depth (cont)	1	1.812	1.812	0.226	0.638
# of native	% of litter cover (cat) *Soil depth (cont)	1	0.741	0.741	0.092	0.763
# of native	Planted (cat)	1	0.499	0.499	0.062	0.805
# of native	Planted (cat) * % litter cover (cat) * Soil depth (cont)	1	0.324	0.324	0.041	0.842
# of native	% of litter cover (cat)	1	0.004	0.004	0.001	0.983
# of native	Error	32	256.465	8.015	0.123	0.996
# of native	Total	39				

# of native	Planted (cat) * Soil depth (cont)	1	15.148	15.148	3.011	0.094
# of native	Soil depth (cat)	1	14.472	14.472	2.877	0.101
# of native	Planted (cat)	1	5.921	5.921	1.177	0.288

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
# of native	Planted (cat) * Soil depth (cont) * Age of reveg (cat)	2	30.541	15.270	3.036	0.065
# of native	Age of reveg (cat) * Soil depth (cont)	2	7.122	3.561	0.708	0.502
# of native	Age of reveg (cat)	2	94.139	47.069	9.356	0.001 *
# of native	Planted (cat) * Age of reveg (cat)	2	45.434	22.717	4.516	0.020 *
# of native	Error	27	135.829	5.031	2.200	0.047 *
# of native	Total	38				

% cover of introduced	Age of reveg (cont)	1	271.864	271.864	0.105	0.748
% cover of introduced	Error	38	96215.905	2600.430		
% cover of introduced	Total	39				

% cover of introduced	Soil depth (cont)	1	1727.778	1727.778	0.681	0.415
% cover of introduced	Error	38	96486.197	2539.110		
% cover of introduced	Total	39				

% cover of introduced	Slope (cont)	1	146.565	146.565	0.057	0.813
% cover of introduced	Error	38	98067.410	2580.720		
% cover of introduced	Total	39				

% cover of introduced	Aspect (cont)	1	23.831	23.831	0.009	0.924
% cover of introduced	Error	38	98190.144	2583.950		
% cover of introduced	Total	39				

% cover of introduced	% cover of native species (cont)	1	9462.181	9462.181	4.051	0.051
% cover of introduced	Error	38	88751.794	2335.570		
% cover of introduced	Total	39				

% cover of introduced	# of native species (cont)	1	10120.415	10120.415	4.366	0.043 *

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
% cover of introduced	Error	38	88093.560	2318.300		
% cover of introduced	Total	39				

% cover of introduced	# of introduced species (cont)	1	16175.694	16175.694	7.496	0.009 *
% cover of introduced	Error	38	82038.281	2158.900		
% cover of introduced	Total	39				

% cover of introduced	Planted (cat)	1	436.361	436.361	0.170	0.683
% cover of introduced	Error	38	97777.614	2573.100	0.170	0.683
% cover of introduced	Total	39				

% cover of introduced	Seeded (cat)	1	7.261	7.261	0.003	0.958
% cover of introduced	Error	38	98206.714	2584.390	0.003	0.958
% cover of introduced	Total	39				

% cover of introduced	Planted and seeded (cat)	1	8.556	8.556	0.003	0.954
% cover of introduced	Error	38	98205.419	2584.350	0.003	0.954
% cover of introduced	Total	39				

% cover of introduced	Age of reveg (cat)	2	4477.144	2238.572	0.876	0.425
% cover of introduced	Error	36	92010.625	2555.850		
% cover of introduced	Total	38				

% cover of introduced	Soil texture (cat)	5	17919.487	3583.897	1.518	0.210
% cover of introduced	Error	34	80294.488	2361.600		
% cover of introduced	Total	39				

% cover of introduced	Soil depth (cat)	3	1784.490	594.830	0.222	0.880

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
% cover of introduced	Error	36	96429.485	2678.600		
% cover of introduced	Total	39				
% cover of introduced	Organic matter (cat)	5	23668.051	4733.610	2.159	0.082
% cover of introduced	Error	34	74545.924	2192.530		
% cover of introduced	Total	39				
% cover of introduced	Particle size (cat)	4	16322.160	4080.540	1.744	0.162
% cover of introduced	Error	35	81891.815	2339.770		
% cover of introduced	Total	39				
% cover of introduced	Adjacent land use (cat)	2	6352.708	3176.354	1.279	0.290
% cover of introduced	Error	37	91861.267	2482.740		
% cover of introduced	Total	39				
% cover of introduced	Boundary type (cat)	2	2763.147	1381.574	0.536	0.590
% cover of introduced	Error	37	95450.828	2579.750		
% cover of introduced	Total	39				
% cover of introduced	% of bare ground (cat)	2	3889.879	1944.940	0.763	0.474
% cover of introduced	Error	37	94324.096	2549.300		
% cover of introduced	Total	39				
% cover of introduced	% of litter cover (cat)	2	19888.225	9944.113	4.698	0.015 *
% cover of introduced	Error	37	78325.750	2116.910		
% cover of introduced	Total	39				
% cover of introduced	Height of canopy (cat)	3	550.621	183.540	0.068	0.977

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
% cover of introduced	Error	36	97663.354	2712.870		
% cover of introduced	Total	39				

% cover of introduced	Height of shrub layer (cat)	2	5352.948	2676.474	1.066	0.355
% cover of introduced	Error	37	92861.027	2509.760		
% cover of introduced	Total	39				

% cover of introduced	Use of herbicide (cat)	1	1750.028	1750.028	0.591	0.460
% cover of introduced	Error	10	29592.889	2959.289	0.591	0.460
% cover of introduced	Total	11				

% cover of introduced	Imported topsoil (cat)	1	46.532	46.532	0.016	0.902
% cover of introduced	Error	23	68787308.000	2990752.522	0.016	0.902
% cover of introduced	Total	24				

% cover of introduced	% cover of lantana (cont)	1	13498.361	13498.361	6.055	0.019 *
% cover of introduced	Error	38	84715.614	2229.358	6.055	0.019 *
% cover of introduced	Total	39				

% cover of introduced	Planted (cat)	1	3880.150	3880.150	1.308	0.266
% cover of introduced	Planted (cat) * Imported topsoil (cat)	1	3639.024	3639.024	1.227	0.281
% cover of introduced	Imported topsoil (cat)	1	607.842	607.842	0.205	0.655
% cover of introduced	Error	21	62277.908	2965.615	0.737	0.542
% cover of introduced	Total	24				

% cover of introduced	Seeded (cat)	1	2745.027	2745.027	0.877	0.360
% cover of introduced	Imported topsoil (cat) * seeded (cat)	1	1100.211	1100.211	0.351	0.560
% cover of introduced	Imported topsoil (cat)	1	486.410	486.410	0.155	0.697

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
% cover of introduced	Error	21	65741.433	3130.544	0.329	0.804
% cover of introduced	Total	24				

% cover of introduced	Seeded (cat)	1	3153.879	3153.879	1.237	0.276
% cover of introduced	Seeded (cat) * Age of reveg (cont)	1	648.984	648.984	0.255	0.618
% cover of introduced	Age of reveg (cont)	1	645.753	645.753	0.253	0.619
% cover of introduced	Seeded (cat) * Soil depth (cat)	2	9072.663	4536.332	1.780	0.188
% cover of introduced	Soil depth (cat) * Age of reveg (cont) * Seeded (cat)	2	3503.584	1751.792	0.687	0.516
% cover of introduced	Soil depth (cat) * Age of reveg (cont)	2	2859.233	1429.617	0.561	0.577
% cover of introduced	Soil depth (cat)	2	1550.770	775.385	0.304	0.740
% cover of introduced	Error	27	51495.740	1907.250	0.987	0.481
% cover of introduced	Total	38				

% cover of introduced	Planted (cat) * Age of reveg (cont)	1	9758.423	9758.423	4.136	0.052
% cover of introduced	Age of reveg (cont)	1	2263.184	2263.184	0.959	0.336
% cover of introduced	Planted (cat)	1	933.610	933.610	0.396	0.535
% cover of introduced	Planted (cat) * Soil depth (cat)	2	15267.845	7633.923	3.235	0.055
% cover of introduced	Planted (cat) * Age of reveg (cont) * Soil depth (cat)	2	3479.298	1739.649	0.737	0.488
% cover of introduced	Soil depth (cat) * Age of reveg (cont)	2	748.019	374.010	0.159	0.854
% cover of introduced	Soil depth (cat)	2	554.445	277.223	0.118	0.890
% cover of introduced	Error	27	63707.469	2359.536	1.263	0.297
% cover of introduced	Total	38				

% cover of introduced	Seeded (cat) * % litter cover (cat) * Soil depth (cont)	1	3653.102	3653.102	1.600	0.215
% cover of introduced	Seeded(cat) * % litter cover (cat)	1	2572.269	2572.269	1.127	0.297
% cover of introduced	Seeded (cat)	1	1632.326	1632.326	0.715	0.404
% cover of introduced	Seeded (cat) * Soil depth (cont)	1	1059.174	1059.174	0.480	0.494
% cover of introduced	% of litter cover (cat)	1	818.927	818.927	0.359	0.554

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
% cover of introduced	% of litter cover (cat) *Soil depth (cont)	1	650.366	650.366	0.285	0.597
% cover of introduced	Soil depth (cont)	1	162.338	162.338	0.071	0.792
% cover of introduced	Error	32	73069.919	2283.435	1.573	0.179
% cover of introduced	Total	39				
% cover of introduced	Planted (cat) * % litter cover (cat)	1	2514.862	2514.862	1.105	0.301
% cover of introduced	Planted (cat)	1	2148.391	2148.391	0.944	0.339
% cover of introduced	% of litter cover (cat) *Soil depth (cont)	1	2035.845	2035.845	0.894	0.351
% cover of introduced	Planted (cat) * Soil depth (cont)	1	1933.652	1933.652	0.850	0.364
% cover of introduced	Planted (cat) * % litter cover (cat) * Soil depth (cont)	1	1342.272	1342.272	0.590	0.448
% cover of introduced	Soil depth (cont)	1	804.014	804.014	0.353	0.557
% cover of introduced	% of litter cover (cat)	1	15769.846	15769.846	6.929	0.013 *
% cover of introduced	Error	32	72835.140	2276.098	1.593	0.173
% cover of introduced	Total	39				

% cover of introduced	Planted (cat)	1	1303.736	1303.736	0.492	0.489
% cover of introduced	Planted (cat) * Soil depth (cont)	1	944.543	944.543	0.357	0.555
% cover of introduced	Soil depth (cont)	1	9036746.000	9036746.000	0.034	0.855
% cover of introduced	Age of reveg (cat)	2	6080.530	3040.265	1.148	0.332
% cover of introduced	Planted (cat) * Age of reveg (cat)	2	6041.703	3020.852	1.140	0.335
% cover of introduced	Age of reveg (cat) * Soil depth (cont)	2	1924.935	962.467	0.363	0.699
% cover of introduced	Planted (cat) * Soil depth (cont) * Age of reveg (cat)	2	852.681	426.340	0.161	0.852
% cover of introduced	Error	27	71525.345	2649.087	0.857	0.590
% cover of introduced	Total	38				

% cover of native	Age of reveg (cont)	1	4022.886	4022.886	1.921	0.174
% cover of native	Error	37	77466.858	2093.700	1.921	0.174
% cover of native	Total	38				

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
% cover of native	Soil depth (cont)	1	11.935	11.935	0.006	0.941
% cover of native	Error	38	82538.759	2172.070	0.006	0.941
% cover of native	Total	39				
% cover of native	Slope (cont)	1	1288.638	1288.638	0.603	0.442
% cover of native	Error	38	81262.055	2138.480	0.603	0.442
% cover of native	Total	39				
% cover of native	Aspect (cont)	1	5081.042	5081.042	2.492	0.123
% cover of native	Error	38	77469.652	2038.680	2.492	0.123
% cover of native	Total	39				
% cover of native	% cover of introduced species (cont)	1	7953.141	7953.141	4.051	0.051
% cover of native	Error	38	74597.533	1963.090	4.051	0.051
% cover of native	Total	39				
% cover of native	# of introduced species (cont)	1	787.678	787.678	0.366	0.549
% cover of native	Error	38	81763.016	2151.660		
% cover of native	Total	39				
% cover of native	# of native species (cont)	1	21076.528	21076.528	13.028	0.001 *
% cover of native	Error	38	61474.166	1617.700	13.028	0.001 *
% cover of native	Total	39				
% cover of native	Age of reveg (cat)	2	1965.393	982.697	0.449	0.644
% cover of native	Error	36	79524.351	2209.010		
% cover of native	Total	38				

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
% cover of native	Planted (cat)	1	282.535	282.535	0.131	0.720
% cover of native	Error	38	82268.159	2164.950	0.131	0.720
% cover of native	Total	39				
% cover of native	Seeded (cat)	1	2433.678	2433.678	1.154	0.289
% cover of native	Error	38	80117.015	2108.340	1.154	0.289
% cover of native	Total	39				
% cover of native	Planted and seeded (cat)	1	277.090	277.090	0.128	0.723
% cover of native	Error	38	82273.604	2165.090	0.128	0.723
% cover of native	Total	39				
% cover of native	Soil texture (cat)	5	13470.632	2694.126	1.326	0.277
% cover of native	Error	34	69080.062	2031.770		
% cover of native	Total	39				
% cover of native	Particle size (cat)	4	6645.388	1661.347	0.766	0.555
% cover of native	Error	35	75905.305	2168.720		
% cover of native	Total	39				
% cover of native	Organic matter (cat)	5	1413.228	282.646	1.426	0.240
% cover of native	Error	34	68237.466	2006.980		
% cover of native	Total	39				
% cover of native	Soil depth (cat)	3	2770.856	923.619	0.417	0.742
% cover of native	Error	36	79779.838	2216.110		
% cover of native	Total	39				

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
% cover of native	Adjacent land use (cat)	2	454.294	227.147	0.102	0.903
% cover of native	Error	37	82096.400	2218.820		
% cover of native	Total	39				
% cover of native	Boundary type (cat)	2	4620.556	2310.278	1.097	0.345
% cover of native	Error	37	77930.138	2106.220		
% cover of native	Total	39				
% cover of native	% of bare ground (cat)	2	4941.834	2470.917	1.178	0.319
% cover of native	Error	37	77608.860	2097.540		
% cover of native	Total	39				
% cover of native	% of litter cover (cat)	2	6484.597	3242.299	1.577	0.220
% cover of native	Error	37	76066.097	2055.840		
% cover of native	Total	39				
% cover of native	Height of canopy (cat)	3	7814.256	2604.752	1.255	0.304
% cover of native	Error	36	74736.438	2076.010		
% cover of native	Total	39				
% cover of native	Height of shrub layer (cat)	2	924.152	462.076	0.210	0.812
% cover of native	Error	37	81626.542	2206.120		
% cover of native	Total	39				
% cover of native	Use of herbicide (cat)	1	64.000	64.000	0.015	0.904
% cover of native	Error	10	41766.500	4176.650	0.015	0.931
% cover of native	Total	11				

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
% cover of native	Imported topsoil (cat)	1	1157.308	1157.308	0.472	0.499
% cover of native	Error	23	56373.152	2451.007	0.472	0.499
% cover of native	Total	24				
% cover of native	% cover of lantana (cont)	1	4465.881	4465.881	2.173	0.149
% cover of native	Error	38	78084.813	2054.864	2.173	0.149
% cover of native	Total	39				
% cover of native	Imported topsoil (cat)	1	2608.913	2608.913	1.026	0.323
% cover of native	Planted (cat) * Imported topsoil (cat)	1	1916.812	1916.812	0.754	0.395
% cover of native	Planted (cat)	1	1496.129	1496.129	0.588	0.452
% cover of native	Error	21	53414.685	2543.556	0.539	0.661
% cover of native	Total	24				
% cover of native	Seeded (cat)	1	3588.631	3588.631	1.428	0.245
% cover of native	Imported topsoil (cat)	1	2726.485	2726.485	1.085	0.309
% cover of native	Imported topsoil (cat) * seeded (cat)	1	259.705	259.705	0.103	0.751
% cover of native	Error	21	52774.387	2513.066	0.631	0.603
% cover of native	Total	24				
% cover of native	Age of reveg (cont)	1	1680.189	1680.189	0.735	0.399
% cover of native	Seeded (cat)	1	1379.372	1379.372	0.603	0.444
% cover of native	Seeded (cat) * Age of reveg (cont)	1	1248.927	1248.927	0.546	0.466
% cover of native	Soil depth (cat)	2	1623.955	811.977	0.355	0.704
% cover of native	Soil depth (cat) * Age of reveg (cont)	2	1530.640	765.320	0.335	0.719
% cover of native	Soil depth (cat) * Age of reveg (cont) * Seeded (cat)	2	1354.875	677.437	0.296	0.746
% cover of native	Seeded (cat) * Soil depth (cat)	2	539.477	269.739	0.118	0.889
% cover of native	Error	27	61750.579	2287.058	0.785	0.653

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
% cover of native	Total	38				

% cover of native	Age of reveg (cont)	1	9327.914	9327.914	4.145	0.052
% cover of native	Planted (cat)	1	1778.634	1778.634	0.790	0.382
% cover of native	Planted (cat) * Age of reveg (cont)	1	39.386	39.386	0.018	0.896
% cover of native	Soil depth (cat) * Age of reveg (cont)	2	4026.514	2013.257	0.895	0.421
% cover of native	Planted (cat) * Soil depth (cat)	2	3712.895	1856.447	0.825	0.449
% cover of native	Planted (cat) * Age of reveg (cont) * Soil depth (cat)	2	2197.663	1098.832	0.488	0.619
% cover of native	Soil depth (cat)	2	1954.404	977.202	0.434	0.652
% cover of native	Error	27	60754.955	2250.184	0.838	0.606
% cover of native	Total	38				

% cover of native	Seeded (cat) * Soil depth (cont)	1	3614.480	3614.480	1.642	0.209
% cover of native	% of litter cover (cat)	1	1740.423	1740.423	0.791	0.381
% cover of native	Seeded (cat)	1	1662.933	1662.933	0.755	0.391
% cover of native	Seeded(cat) * % litter cover (cat)	1	1137.225	1137.225	0.516	0.478
% cover of native	% of litter cover (cat) *Soil depth (cont)	1	995.147	995.147	0.452	0.506
% cover of native	Soil depth (cont)	1	678.205	678.205	0.308	0.583
% cover of native	Seeded (cat) * % litter cover (cat) * Soil depth (cont)	1	75.475	75.475	0.034	0.854
% cover of native	Error	32	70450.522	2201.579	0.785	0.605
% cover of native	Total	39				

% cover of native	% of litter cover (cat)	1	2849.394	2849.394	1.251	0.272
% cover of native	Planted (cat) * Soil depth (cont)	1	2590.263	2590.263	1.137	0.294
% cover of native	Planted (cat) * % litter cover (cat)	1	1083.926	1083.926	0.476	0.495
% cover of native	% of litter cover (cat) *Soil depth (cont)	1	729.907	729.907	0.320	0.575
% cover of native	Soil depth (cont)	1	364.359	364.359	0.160	0.692
% cover of native	Planted (cat)	1	304.128	304.128	0.133	0.717

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
% cover of native	Planted (cat) * % litter cover (cat) * Soil depth (cont)	1	0.325	0.325	0.000	0.991
% cover of native	Error	32	72930.965	2279.093	0.603	0.749
% cover of native	Total	39				
% cover of native	Soil depth (cont)	1	1660.905	1660.905	0.745	0.396
% cover of native	Planted (cat)	1	884.320	884.320	0.397	0.534
% cover of native	Planted (cat) * Soil depth (cont)	1	70.711	70.711	0.032	0.860
% cover of native	Planted (cat) * Age of reveg (cat)	2	5421.607	2710.803	1.216	0.312
% cover of native	Age of reveg (cat)	2	4691.612	2345.806	1.053	0.363
% cover of native	Age of reveg (cat) * Soil depth (cont)	2	3996.986	1998.493	0.897	0.420
% cover of native	Planted (cat) * Soil depth (cont) * Age of reveg (cat)	2	3090.553	1545.277	0.693	0.509
% cover of native	Error	27	60179.289	2228.863	0.869	0.579
% cover of native	Total	38				
% Lantana cover	Planted (cat)	1	2314.286	2314.286	4.112	0.050 *
% Lantana cover	Error	38	21385.058	562.765	4.112	0.050 *
% Lantana cover	Total	39				
% Lantana cover	Age of reveg (cat)	2	3112.924	1556.462	3.659	0.036 *
% Lantana cover	Error	36	15315.550	425.432	3.659	0.036 *
% Lantana cover	Total	38				
% Lantana cover	Age of reveg (cont)	1	2543.718	2543.718	5.925	0.020 *
% Lantana cover	Error	37	15884.756	429.318	5.925	0.020 *
% Lantana cover	Total	38				
% Lantana cover	Height of shrub layer (cat)	2	4952.687	2476.343	4.888	0.013 *
% Lantana cover	Error	37	18746.657	506.666	4.888	0.013 *

Response variable	Explanatory variable	D. F.	S.S	M.S.	F ratio	p
% Lantana cover	Total	39				