Weed distribution along the boundary of the Royal National Park in relation to the cultural and environmental characteristics of the landscape: a GIS approach

Steven Smith
University of Wollongong

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Weed distribution along the boundary of the Royal National Park in relation to the cultural and environmental characteristics of the landscape: A GIS approach.

by

Steven Smith

A thesis submitted in fulfilment of the requirements for a Masters of Science (Hons)

Department of Geosciences
University of Wollongong
Wollongong, NSW Australia

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Abstract

Geographical Information Systems (GIS) have only recently been applied to ecological research and environmental management applications. GIS provide opportunities for exploring spatial relationships between plant species and cultural and environmental characters in the landscape that would otherwise be extremely expensive or impossible to investigate (Smith et al. 1995).

This research uses a widely adopted and available GIS in Australia, called Arcview® to analyse cultural and environmental data sets of the landscape, together with weed distribution data for five weed species that occur in the region. The boundary of the Royal National Park (RNP), Sydney was used as an example of an area gazetted for nature conservation and which is fragmented and isolated by human occupation and infrastructure and is therefore, highly vulnerable to weed infestation. The weed species studied included: *Ageratina adenophora* (Crofton weed), *Lantana camara* (common Lantana), *Ligustrum* sp. (Privet), *Senna pendula* (Cassia) and *Rubus vulgaris* (Blackberry). All of these weed species have the ability to invade natural bushland (each has be classified as an ‘environmental weed’ in other regions), and all have been in the RNP region for at least twenty years.

Cultural characters in the landscape associated with all of the weed species were, the presence of a disturbance, riparian zones and what land-use is adjacent to the park boundary. Where stormwater run-off was present and sites were adjacent to urban areas, higher levels of weed occurrence were recorded. Landscapes that are undisturbed and adjacent to native bush usually did not contain weeds.

The environmental characters analysed were more interesting as these data sets covered the entire RNP region and modeling of weed distribution was possible. The environmental characters included ‘soil’, ‘vegetation’, ‘geology’, ‘slope’, ‘aspect’ and ‘fire frequency’. Due to rare levels of Privet, Cassia and Blackberry along the park boundary, only the weed occurrence data for Lantana and Crofton could be analysed with the environmental data. The attributes southwest and west from the environmental character, ‘aspect’, were found to prevent Crofton weed from establishing.
No other environmental attribute had any significant association to Crofton weed. Lantana's current distribution, however, may suggest that this weed is suited to a specific set of environmental attributes. The Watagan 'soil', shale gully forest 'vegetation type', Narrabeen shale 'geology' when combined, regularly had Lantana present. Lantana was also the only weed to regularly show the ability to invade landscapes along the park boundary without the aid of a disturbance and in this region is living up to its reputation of being an 'environmental weed'.

Accompanied with expert knowledge on the topic of weed ecology, the GIS is useful in identifying and illustrating relationships between weed species distribution to the cultural and environmental attributes present in the landscape. If we can identify such attributes then changes to the landscape may be possible to minimise weed impacts and establishment in the future. For some weed species, as in Lantana's distribution, natural areas can also be mapped showing sites of potential or likely sites of weed occurrence. If this is so time required in the field can be reduced and more time and resources can be put towards effective and lasting weed management actions on the ground. Weed control measures are recommended for those sections of the RNP boundary that are adjacent to urban areas, were the vegetation type shale gully forest is found, and sites, which absorb or accommodate stormwater run-off and infrastructure. The creation of a native plant buffer screen along all but undisturbed sections of the park boundary is also highly recommended. The methods and applications used in this research could be applied to any type of weed species on any type of landscape.
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Chapter One
Problems with weeds

1.1 Introduction

Weed infestation is unfortunately a problem that is not confined to recently abandoned lands. There would be very few Australians that are not familiar with or are not in close approximation to a weed. Weeds occur over most landscape types and are found across a range of different land-uses. The range of land-uses weeds are associated with include small-scale infestations in residential gardens to large-scale infestations on agricultural lands. Areas gazetted for nature conservation are also not exempt from weed invasion.

Fragmented and isolated natural habitats are usually at greater risk of weed invasion than large tracts of intact (or relatively intact) natural vegetation (Muyt 2001). Weeds readily invade open spaces were there is bare soft soil, high nutrient availability, moist conditions and high light intensity (Michael 1970, Buchanan 1989). Fox and Fox (1986) come to the conclusion that there is no weed invasion in Australia of native bushlands without a disturbance. This is unfortunate as the majority of areas set aside for nature conservation are becoming increasingly isolated and exposed along their edges to human habitation and infrastructure. 'Weeds should not be accepted in areas gazetted for nature conservation'. Although the weeds themselves are generally not the cause of the problem, they are what are left, to remind us of our responsibility to , and negative impact on, our surrounding natural environment and areas gazetted for nature conservation.

Amor and Stevens (1975) and Edwards (1989) showed how weed frequency generally declines with increasing distance from a disturbance. A disturbance can be either human or natural. A human induced disturbance on the landscape may include the removal of vegetation and topsoil, the alteration of drainage load and quality, or the illegal dumping of foreign material. A natural disturbance on the landscape may include incidences of fire, flood or wind. Although a disturbance will usually result in weed establishment, weed establishment is not possible unless weed propagules and the necessary resources (eg. light, nutrients) are present in the landscape (Hobbs 1991). If present and establishment occurs, weeds can be considered invasive if further recruitment to its local populations is possible without a regular disturbance. Weeds that
demonstrate an ability to invade both disturbed and undisturbed bushlands are generally classified as a 'environmental weed' (Usher et al. 1988, Humphries et al. 1991, Muyt 2001).

Plants that have the potential to become a 'environmental weed' on any continent show similarities in life cycle and form. They tend to be competitive (growth is at full capacity) and can adapt to change. They have the ability to multiply rapidly as propagule numbers are high and can occur quickly after establishment. Their propagules (seeds, rhizomes, bulbs, corms and tubers) are dispersed by humans (intentionally or accidentally), animals (externally or internally) or by physical means (e.g. wind, water). Dispersal frequently occurs over considerable distances and for most species is usually not limited to just one process. They also usually lack natural predators and are pollinated nonspecifically. (Baker 1965, Auld and Medd 1992, Muyt 2001).

If the natural diversity and richness of any conservation area is to be correctly preserved effective weed control programs need to be implemented. Once a weed is established it can become naturalised in the landscape and if unchecked its detrimental impact on the native vegetation and landscape will be anywhere from immediate and widespread to slow and localised. However if we can identify accurately over large areas of land the cultural, and also the environmental attributes in the landscape that are promoting a disturbance or a weed infestation, then it may be possible restrict weed invasions better in the future. This will be possible as areas of current and potential weed infestation sites can be mapped quicker and weed control techniques can be directed to those attributes in the landscape shown to continually encourage weed invasion and infestation.

The objectives of this research are to:
- Provide a map of sites currently infested or not infested by five 'environmental' weeds along parts of the terrestrial boundary of the Royal National Park (RNP), Sydney.
- Develop a weed database for a GIS to investigate associations between weed species presence and absence to the cultural and environmental attributes present at each site.
- To assess each weed species ability to invade undisturbed landscapes in this region.
- Develop a GIS model (using environmental data layers only) for likely or potential weed invasion and occurrence.

GIS Weeds Steven Smith
• To use this information as a decision support system to identify areas along and within the RNP that require weed control action.

The weed species studied were *Ageratina adenophora* (Crofton weed), *Lantana camara* (common Lantana), *Ligustrum* sp. (Privet), *Senna pendula* (Cassia) and *Rubus vulgaris* (Blackberry). All of these species can invade natural bushlands (Humphries et al. 1991, Muyt 2001) and all have been in the region for at least the last twenty years.

1.2 History of weeds in Australia

Since European settlement thousands of plant species introduced intentionally or unintentionally from all parts of the world have successfully become weeds in Australia (Humphries et al. 1991). As Parsons and Cutherbertson (1992) point out, ‘Although the native plants and animals had supported the needs of Australian Aborigines for food and clothing over thousands of years, the first European settlers found the Australian flora and fauna particularly unsuited for their purposes’. The European settlers introduced many plants and 15 years after the arrival of the first fleet, Governor King had listed 292 introduced plants then growing in the colony and requested a further 82 be sent from England (Parsons and Cutherbertson 1992).

Since this time and as Australia matured as a nation, plant introductions from all parts of the world were inevitable. At first there was little knowledge of or restriction to which plants were introduced, and Australia’s natural vegetation was being rapidly cleared. The introduced plants were strongly promoted for gardens, food, medicinal reasons, and pasture and as a management tool (that is for erosion control and protecting livestock from the weather). Others simply escaped or arrived in Australia accidentally or by unknown means. Today there are approximately 2,200 species of naturalised plants in Australia (Csurches and Edwards 1998) and today in Sydney for example one quarter of all its living plants have been introduced (Buchanan 1989).
1.3 Weeds impact on native bushlands

Weed research and control in native bushlands has only been active since the early 1980's. As reserves of natural bushland become remnants of indigenous vegetation types, the control of weeds is becoming more urgent. The fact that it is now considered important to control weeds in these areas indicates a broadening of weed research from the purely agricultural and economic aspects of weed control to the environmental impacts weed species have in natural ecosystems (Good 1987).

Native bushlands include all areas managed primarily for the conservation of wildlife. They all contain significant components of indigenous plants and animals and any introduced plant, in such an area, should be considered a weed. Native bushlands are recognised as having high conservation values and are important in protecting natural ecological patterns, genetic resources and threatened species. They are also a source of education and recreation for the whole community (Smith 1983, Leys 1996).

Although actual quantitative measures of weed invasion are rare in natural bushlands, in nearly all cases their impacts are associated with a decline in native species richness and/or diversity. There are too few examples of a weed species presence actually contributing to a natural ecosystem. An example may include a degraded piece of land were the weeds may act as ‘nurse plants’ for the regeneration of the native overstorey components (Adair and Groves 1998). A weed can have several impacts on a natural bushlands ecosystem function. These may include the competition for resources with indigenous plant species, harbouring undesirable organisms, altering the hydrological regime and reducing the value of natural bushlands.

1.3.1 Weeds may compete for resources with indigenous plant species

By occupying areas of natural bushland a weed will compete for resources such as moisture, soil fertility and light. Weed growth in most cases is exceptionally fast and can be extremely vigorous because the weeds usually do not suffer significant damage from Australian insects, fungi or other organisms (Csurches and Edwards 1998). As a result they can quickly occupy all available space and in doing so can successfully prevent the growth and establishment of indigenous plant
species. For example, Lantana is believed to inhibit the regeneration of native temperate forest understorey species in South Eastern Australia by creating dense shade (Allan and Britton 1987).

Although there are no known documented instances of species extinctions caused by weed invasions, local extinctions caused by weed invasion in fragmented systems may constitute a serious loss of genetic diversity. Where introductions change the relative abundance of species but do not cause extinctions the system is not likely to be in equilibrium and changes to the recruitment potential of native plants may eventually lead to their extinction (Humphries et al. 1991).

1.3.2 Weeds may harbour undesirable organisms
Weeds may be the hosts for parasitic insects or diseases of native plants. They may also influence animal distributions and richness by providing sufficient food and shelter. Where weeds modify and in some cases replace native plant communities the reduction and replacement of native animal species is likely. This is evident in cases where indigenous animals rely heavily on native plants for food, breeding sites and shelter and in instances where weed infestation suit feral animal habitation. For example Blackberry is known to provide a suitable shelter and food for foxes (Parsons and Cutherbertson 1992, Csurches and Edwards 1998).

1.3.3 Weeds may alter the natural hydrological regime
Weed species in Australia tend to thrive where water is readily available and where increased levels of nutrients are found in the soil (Buchanan 1989). If weeds are invading these areas they may then be responsible for alterations to the hydrological regime. Water resources to those native plants further down the catchment area may be reduced and the physical presence of the weeds themselves may also be responsible for redirecting the natural flow of the watercourses (Csurches and Edwards 1998).

1.3.4 Weeds may reduce the value of natural bushlands
Weeds are in most cases aesthetically unpleasing to the eye. They can also reduce biodiversity and some are responsible for health problems to both humans and domestic animals. For example, broad-leafed Privet can cause health problems for those people who are allergic to and breathe in its pollen, whilst Crofton weed if eaten by horses can cause breathing difficulties which
may eventually lead to the animals death. Also weeds may substantially restrict access to desired areas and encourage fire. Weeds are also responsible for reducing the natural diversity of bushlands, which may eventually lead to a decline in the natural genetic diversity of an area and thus its conservation value (Humphries et al. 1991).
Chapter Two
Weeds and GIS

2.1 Weeds

Information on each weed, its origin, status, distribution, life cycle, preferred habitat and control techniques has been gathered from the literature. Although not all the information was available (gaps are apparent in some parts of the literature), this information was used to describe each weed and the environment where it is usually found. This information was later used to compare the digital and field data collected for the following project. The weed species studied are; Crofton, Lantana, Privet, Cassia and Blackberry. All are common weeds in Sydney and a summary on each weed species is given below.

2.2 Crofton weed

2.2.1 Origin and status

*Agaritina adenophora* (Spreng.) King and Robinson (Crofton weed) is a native of Mexico and is a member of the Asteraceae Family. It was introduced into Australia as an ornamental plant and escaped in 1900. It is declared noxious in 21 local government areas of coastal New South Wales from Gosford to the Queensland border. Its reason for its noxious status is because of its ability to invade and dominant degraded agricultural land and disturbed unused lands. In Sydney it has spread rapidly since the 1970’s (Dyason 1986), and is currently common throughout but is yet to be declared noxious. Refer to Appendix D for noxious weed legislation.

2.2.2 Distribution and preferred habitat

In Australia Crofton weed occurs in coastal and elevated hinterland areas of NSW and South Eastern Queensland where rainfall exceeds 1500 mm a year. Wollongong is its southern boundary (Dyason 1986, Auld and Medd 1992). Throughout these areas Crofton is principally found in creek beds, along transport routes, forest clearings, and in areas where steep (>20°) frost-free slopes occur (Parsons and Cuthbertson 1992). Buchanan (1989) also suggests that Crofton prefer a nutrient rich moist soil and will flourish in both sunlight and fairly deep shade.
2.2.3 Description and ecology
Crofton weed is a perennial herb 1 to 2 m high with opposite, triangular to rhomboidal leaves with toothed margins, numerous upright stems and branches. It has a cluster of white flowers and its buds appear in late winter and are shed between October and mid-January, with the lower leaves of the plant dropping after seed fall. A mature plant can set seed apomictically, that is without pollination or fertilisation and can produce 10,000 to 100,000 seeds per year of which 70% are viable. The seeds have a pappus and make it both easily windborne or floated over long distances. Its seeds germinate in minimal light (deep shade, at or below 2% of full daylight, however will result in their death) at any time between December and September, with peak of germination (>80% of viable seeds) in February and March. New growth occurs with the first major summer rain in both seedlings and mature plants, usually in January, and growth remains high during summer but tapers off in the cooler winter months. It can form large stands of individual and layered plants. Also if individual branches of the plant have contact with the ground, buds from the crown not from the roots may take root and re-establish (Buchanan 1989, Parsons and Cuthbertson 1992).

2.2.4 Factors responsible for its persistence in Sydney
Apart from Crofton’s weedy nature in parts of Australia a number of other reasons seem responsible for its persistence in Sydney’s bushland. The environmental preference of the weed itself, especially along drainage lines and steeply sloping frost free lands, is a major factor in limiting mechanical and high volume chemical treatments (Parsons and Cuthbertson 1992). Also it is usually associated with semi-abandoned lands or along borders/ fringes of public lands managed by different government bodies (Personal Observation 2000).
Plate 1: (a) Crofton in flower (After McLoughlin and Rawling 1995). (b) A population of Crofton weed adjacent to a roadside.

2.2.5 Present control strategies

Physical removal is best. Pull out the entire plant making sure all crowns are not left lying around to re-shoot. Mulch the ground heavily and rehabilitate the site with appropriate plant species. This is best achieved in early spring before new growth starts. It will also allow the plants you are using to replace Crofton weed to establish and compete with Crofton.

For effective herbicide control, high volume application of glyphosate (Roundup®) or picloram + triclopyr in late summer or autumn when the weed is actively growing is best. Thoroughly wet the whole plant, particularly the base (Parsons and Cutherbertson 1992). A follow up application will be necessary as will the rehabilitation of other plant types at the sites. A biological control program has had a limited effect at best. An indigenous parasitic insect reduces the impact of the insect by preying on the introduced predators that attack Crofton (Parsons and Cuthbertson 1992).
2.3 Lantana

2.3.1 Origin and status
*Lantana camara* L. (Lantana) is a native of North, Central and South America. It is a member of the Verbenaceae Family. It was introduced to Australia as an ornamental being grown by Macarthur at Camden Park in 1843. Numerous introductions by the horticultural industry since this time have seen the rapid spread of Lantana. By the late 1850's it was naturalised in Australia along the Brisbane River and currently large naturalised populations exist up most parts of the east-coast of Australia (Parsons and Cutherbertson 1992). At present Lantana is gazetted by the N.S.W Agriculture as Noxious (under the *Noxious Weeds Act 1993*) in all parts of the State and is listed as a W2 noxious plant in the Sutherland Shire. It is not listed as a noxious plant in the Wollongong City Council area.

2.3.2 Distribution and preferred habitat
In Australia Lantana is mainly found along the east-coast, from the Cape York Peninsula in Queensland to Ulladulla on the south coast of NSW. It is estimated that almost four million hectares are infested with Lantana (Parsons and Cutherbertson 1992). In Australia it is most prolific in areas receiving an average annual rainfall greater than 750 mm at altitudes below 1300 m. It is susceptible to frosts, and is generally not found on tablelands, ranges or west facing slopes. It is drought resistant and can grow on most soil types but prefers rich loam soils, and is generally not found on heavy clay soils. Lantana is also suppressed by shade. It is a major weed along roadsides, gullies, steep slopes; fringes of forested areas and neglected lands. It also provides food and shelter for many feral animals (Gallaghar 1979, Allan and Britten 1987).

2.3.3 Description and ecology
Lantana is a perennial erect or scrambling shrub three meters high and often forming dense impenetrable thickets. It is much branched and its woody, brittle branches can reach a length of 5 m. Its odorous leaves are opposite and curved, ovate to lanceolate with toothed margins. It has a mixture of white, pink, cream, purple, red and yellow flower heads that may change colour with age. Pink is the usual and predominant colour of its flowers. Flowers are produced during the second growth season in early summer and continue through to March or April. Its fruits are green at first but ripening to a glossy purple-black, which are widely dispersed by birds. Its seeds are
pale straw-coloured, hard and stony, 2 to 4 mm long and are further dispersed by wind and water. Its seeds may germinate at any time of the year provided sufficient moisture is present. The majority of germination however usually occurs after the first summer storm where growth is slow at first until rootstock is established. Once established it is a predominantly summer growing plant and with new branches appearing in early spring. Lantana can also sucker from its extensive shallow root system if they are damaged or broken. Lantana is also thought to alter the environment (possibly because of soil allelopathy) into which it encroaches so it may form a more suitable environment for itself and less suitable for the neighbouring native plant species (Parsons and Cutherbertson 1992).

2.3.4 Factors responsible for its persistence in Sydney

The prominence of Lantana throughout Sydney's disturbed bushland and its extensive use as an ornamental garden plant in Sydney's past has made Lantana almost impossible to prevent from invading disturbed and undisturbed bushlands. In addition Lantana grows regularly on steeply sloping lands that are often inaccessible, and in dense thickets, were large scale eradication is difficult. Steeply sloping areas are also prone to erosion if all the vegetation is removed at once, so removal or poisoning may actually cause greater harm to the environment than good (Allan and Britten 1987).

Although some funds are available for its removal, it is not cheap to remove. It has been estimated that to remove a two hectare site where 100% coverage occurs in difficult terrain will cost as much as $100 000. However it will obviously be a lot cheaper in less difficult terrain and with lower abundance levels (personal comm. Noxious Weed Officer, Sutherland Shire Council 1999).
Plate 2: (a) Lantana in flower. (b) A dense thicket of Lantana.

2.3.5 Present control strategies

Physical removal of Lantana is best practice and in most environments is not difficult. If possible the large surface roots must be removed and the branches must be disposed of. The burning of Lantana is also useful. A mosaic pattern of burn is necessary, and the land must be worked and be regenerated with suitable plant species able to compete with Lantana's high growth rate and prevent erosion (Parsons and Cutherbertson 1992).

Herbicides applied after a burn give effective control. Spot spray the regrowth with glyphosate (Roundup®) or Garlon® when the branches begin to actively grow. For herbicide use without a pre-burn glyphosate at a rate of 1:100 sprayed at any time of the year, covering maximum leaf area is effective. For control in steep terrain where erosion is possible cut the Lantana from the base and paint the cut stem with glyphosate (Allan and Britten 1987).

Biological control results of Lantana have been mixed at best. Leaf-miner insects particularly Uroplata girardi have shown some promise and has reduced the competitiveness of the weed in
many areas. Also a mealy bug, *Phenacoccus parvus* has shown some promise, however it is unfortunately active on a number of useful plant species (e.g. the potato and tomato) and thus is not widely recommended (Swarbrick 1989). There is new promise though with the unveiling by NSW Department of Agriculture of a Mexican bug *Aconophora compressa*. Although no results are available to date the bug was recently released in 38 locations along the NSW coast and has the potential to be very damaging to Lantana.

### 2.4 Cassia

#### 2.4.1 Origin and Status

*Senna pendula* (Willd.) Irwin and Barneby (Cassia) is a native of South America (Buchanan 1981). It is a member of the Caesalpinioideae Family. Its introduction into Australia was most probably as an ornamental plant in the late 1800’s. Its attractive flowering display is present in many urban gardens and specimens are still available in nurseries throughout NSW. In the wild it is a scattered weed of bushlands and disturbed lands. Cassia is not considered noxious in NSW. It is slowly being recognised as an environmental weed of significance but this is mainly due to its associated relationship with other noxious plant species (Humphries *et al.* 1991). A related species *Cassia alata* is declared noxious in the Northern Territory and parts of Queensland where it forms dense thickets in disturbed/ overgrazed areas and in riparian habitats. It is particularly aggressive in areas where there is a high water table (Csurches and Edwards 1998).

#### 2.4.2 Distribution and preferred habitat

*Senna pendula* in Australia occurs in coastal NSW, the northern tablelands and on the Darling Downs in Queensland (Auld and Medd 1992). It is spread throughout the entire Sydney region. It shows no preference of site or soil type and scattered individuals can be found in quite dry Eucalypt forests as well as in moister areas where it can form quite dense stands (Buchanan 1981).

#### 2.4.3 Description and ecology

Cassia is a perennial shrub up to 3.5 m high and sometimes multi-stemmed. Its leaves are alternate, up to 6 cm long with three opposite pairs of leaflets on each leaf. It is a member of the Caesalpinioideae Family, and has bright yellow flowers. The 13 cm long bean-like fruit hold
numerous hard black seeds that ripen in winter (Buchanan 1981). The pods are winged and can be dispersed by water, wind and animals, however most seeds are dropped directly under the parent plant. A parent plant if damaged can sucker from root buds also (Parsons and Cutherbertson 1992).

Plate 3: (a) Cassia with flowers and seedpods. (b) Cassia specimens taking full advantage of stormwater run-off.

2.4.4 Factors responsible for its persistence in Sydney

Cassia was widely introduced and with an attractive flowering display it is common in urban gardens and in nurseries. It is also often confused with the native species Breynia oblongifolia and has in some cases been left accidentally. Also since it is not declared noxious little funding is available to produce a strategic report to effectively remove Cassia from all private and public lands.

(Note: The main distinguishing feature is leaf arrangement. Cassia leaflets are always in pairs arranged opposite each other, and the leaves of Breynia are always alternate).
2.4.5 Present control strategies
Since Cassia is generally found as scattered individuals, it is considered easy to control in bushland settings. Where it occurs, physical removal is best, disposing of all seed pods. It is possible to cut back the shrub and poison the stump with glyphosate (Roundup®). This is best achieved in the summer months of the year when the plant is actively growing. It can be dug out any time of the year (Buchanan 1981) and there is no known biological control available for Senna pendula.

2.5 Blackberry
2.5.1 Origin and status
Rubus fruticosus L. agg. (Blackberry) is a native of Europe. It is a member of the Rosaceae Family. The earliest documentation of the plant in Australia was in 1842, growing in an Adelaide garden. By the 1880s, there was recognition that it was becoming an important weed. Now, unquestionably it is one of the most important environmental weeds in Australia (Parsons and Cutherbertson 1992). At present Blackberry is gazetted by the NSW Agriculture as noxious (under the Noxious Weeds Act 1993) in all parts of the State and is listed as a W2 noxious plant in both the Sutherland and Wollongong local government areas. A W2 noxious plant requires all landholders both private and public to fully and continuously suppress and destroy a weed.

2.5.2 Distribution and preferred habitat
Blackberry is widespread throughout Australia where average annual rainfall is greater than 760 mm. In NSW it is a major problem of pastures and native forests on the tablelands and slopes. It is less significant on the coast and insignificant on the plains. It does however occur commonly along streams and gullies, roadsides and neglected areas on all land types. Although it can be found on all soil types, its growth is more prolific on fertile soils than on sandy or skeletal soils. Blackberry also provides useful food and shelter for feral animals (Mears 1981, Parsons and Cutherbertson 1989). It is an important weed because it is invasive and covers large areas with a dense canopy excluding light from the soil surface. It dominants the vegetation of an area in a very short time but rarely will invade virgin bushland. However it will establish most readily on disturbed sites especially if they are subsequently neglected (Ermert 1998).
2.5.3 Description and ecology

Blackberry is an erect shrub 2 to 3 m high often growing in dense impenetrable thickets. Its stems can be as long as seven metres and are green to reddish purple, with numerous prickles 3 to 12 mm long. Its leaves are dark green, alternate and consist of 3 or 5 toothed oval to ovate leaflets, which are usually shed in winter. Its flowers appear in summer and are either white or pink. Its fruit is an edible berry and is produced from January to March and changes from green to red to black as it ripens. Its seed is somewhat triangular, 2 to 3 mm long, deeply and irregularly pitted. The majority of its seeds germinate in spring but few survive. The seedlings that do survive, growth is slow (about 5 cm) in the first year. After several years though, thickets are usually 1 to 2.5 m high but live for only 2 or 3 years. The majority of new growth is increased as first year stems emerge from the crown in late winter. These will then develop roots and daughter plants at its tips in autumn (Parsons and Cutherbertson 1992).

2.5.4 Factors responsible for its persistence in Sydney

Apart from Blackberry's enormous invasive ability in Australia a number of other factors are responsible for its persistence in Sydney's bushland. Blackberry was originally a highly recommended plant for hedges and was grown widely because of its edible berries. Its seeds also are easily digested by birds and animals alike and are spread over a wide region. Although it is declared noxious, and in some parts control has been highly successful, it requires a major effort to remove it from the landscape. Its prickly stems growth structure makes physical removal difficult and if not dug out completely it will readily re-shoot from lignotubers under the ground.
Plate 4: (a) Blackberry in flower (After McLoughlin and Rawling 1995). (b) A Blackberry specimen crawling along the ground.

2.5.5 Present control strategies

Blackberry seedlings generally fail to establish or invade shaded areas. Therefore it is best practice to introduce native plants that can create shade. It may be best to maintain a dense cover of useful vegetation in areas where it favours to prevent seedling establishment of Blackberry.

For existing populations of Blackberry physical removal is possible for small thickets or individual shrubs. It is essential to remove the crowns and the root system. This is possible by mattocking and ripping the roots. Goats are also becoming increasingly important in controlling Blackberry in agricultural areas. They readily eat the plant and can destroy quite large clumps (Parsons and Cuthbertson 1992, Ermert 1998).

Herbicides are also an effective control. Garlon® applied at fruiting time (January to March) and spraying the leaves or cut stems directly is effective. After application other plant species should be encouraged as the ground is often left bare after poisoning and is therefore susceptible to the
re-establishment of Blackberry. A recently developed herbicide, metsulfuron methyl, is proving to be very effective and can be used over a wider range of application times (Parsons and Cutherbertson 1992).

A biological control program has seen the investigation and approval of several rust strains, particularly *Phragmidium violaceum*. It has had moderate success and defoliation has been achieved in summer. Research is continuing on a different strain of the rust and a highly successful biological control agent may eventually be found (Parsons and Cutherbertson 1992).

2.6 Privet

2.6.1 Origin and status

*Ligustrum lucidum* W.T.Ait. (Privet) is a native of China and Japan. It is a member of the Oleaceae Family. Numerous introductions as an ornamental/ hedge plant on both public and private land in Australia has seen it become naturalised in many parts of Australia (Csurches and Edwards 1998).

At present Privet is declared noxious (under the Noxious Weed Act 1993) in certain Shires throughout NSW. It is declared noxious in the Campbelltown Shire but not in the adjoining Sutherland Shire or Wollongong local area (personal comm. Sutherland Shire Noxious Weed Officer 1999). The two main reasons for Privet being declared noxious are its ability to invade native bushlands and its pollen can cause health problems to sensitive people.

2.6.2 Distribution and preferred habitat

In Australia Privet has small, naturalised populations in Victoria but is widespread up much of the east-coast of Australia, inland to west Wyalong. Privet is widespread throughout much of Sydney, showing a preference for moist fertile gullies where it often replaces native species such as *Pittosporum undulatum* and even *Eucalyptus* spp. (Burrows and Kohen 1983). It is also common along creeks especially those that receive drainage from urban areas, or on shale soils (Buchanan 1981).

2.6.3 Description and ecology

Privet is a small tree up to 10 m high. The stems and leaves are without hairs or prickles. The dark green leaves, up to 12 cm long, have wavy edges and are opposite in arrangement along the
stem (Auld and Medd 1992). Its flowers are white, numerous and small with four spreading lobes. Its flowers appear in late summer and the fruit ripen to a purplish-black berry in June and fall from the tree in July and August. Flowering and fruiting is usually very dense and it has been estimated that a single mature specimen may produce 100,000 to 10,000,000 seeds annually. Optimum soil temperature for seed germination is 15 °C and consequently germination in Sydney is favourable in spring and autumn but most likely can occur throughout the entire year (Burrows and Kohen 1983). Also both the roots and branches of Privet can re-shoot if disturbed (Buchanan 1981). Both species have been suspected of being poisonous and *Ligustrum* species are known to cause hayfever (Auld and Medd 1992).

2.6.4 Factors responsible for its persistence in Sydney
Large mature trees exist throughout the older parts of Sydney. It was one of the first plants introduced and was widely used and sold throughout NSW. Privet also produces succulent berries that are widely dispersed by birds both native and introduced. Also, depending on the extent and location of Privet, a high cost in its removal may be involved. For heavily occupied areas the cost may be as much as $3000 a hectare. For these funds to be available and for a control program to be effective Privet must be declared noxious in all shires throughout Sydney.

2.6.5 Present control strategies
Physical removal of Privet is best. The entire root system must be removed and if there are seed or berries present on the tree these must be dispose of appropriately. For areas prone to erosion or when Privet specimens are too big to physically remove, herbicides are effective. Cut the branches back to the stump and paint the stump with herbicide. Glyphosate (Roundup®) or Garlon® are effective herbicides and can be applied any time of the year. Burning the tree or simply cutting the tree down is inappropriate as Privet can re-shoot from its rootstock (Buchanan 1989).

There is no known biological control agent for Privet in Australia.
Plate 5: (a) A large leaved Privet in flower (After McLoughlin and Rawling 1995). (b) A stand of Privet specimens in an area of stormwater run-off.
2.7 Geographical Information Systems (GIS)

A geographical information system (GIS) offers facilities for entering, storing, predicting, manipulating, analysing, and displaying geographic or spatial data. A GIS can recognise and analyse the spatial relationships among mapped phenomena. Conditions of adjacency (what is next to what), containment (what is enclosed by what), and proximity (how close something is to something else) can be determined with a GIS (Aspinall 1994). Therefore its power resides in its ability to associate locations and characteristics, and to cross reference different types of spatial information (Smith et al. 1992, Goodchild et al. 1993). Statistical analysis is generally not required and therefore cartographic modelling should be regarded as a spatial hypothesis, rather than scientific fact (Johnston 1998).

The data is represented in the form of static, two-dimensional objects as points, lines, and polygons. To these you may attach feature information (attributes) that may include a description or characteristics of the land unit that the points, lines, and polygons represent. For example the points may represent a site location and the attributes associated with each point may include, the coverage of the weed species, soil type, aspect, or a description of the current management at the site. Lines may represent roads, rivers, or other linear features, while polygons may represent aerial features (Congalton and Green 1997, Johnston 1998).

Data entered into a GIS must be accurate and at an appropriate scale. Scale is important, as it will determine the detail of the answers required which must address and suit the questions you wish to examine (Pickup 1993). Ground registration is also an important aspect of spatial data and GIS. On a GIS map projections have been developed through mathematical formulas to minimise the problem of representing the Earth's spherical form on a planar surface. A map projection can be envisioned as if a light source in the middle of the Earth were casting shadows onto a giant piece of paper wrapped in a cylinder or cone. Most map projections require the original data to be stored in decimal degrees of longitude and latitude. An example of a map projection that is commonly used on a GIS is the Universal Transverse Mercator (UTM) and is readily available in Australia (Congalton and Green 1987, Johnston 1998).
Every piece of land on the earth's surface can be placed into a GIS and classed as a land unit. Classifying the many land surfaces into land units is a way to organise the land according to its appearance. Classification of land units must be uniform and include a list of features (attributes) that help in the effective description and/or management of the land unit. For example if we were to classify farmland in land units of soil type the features of the soil can include either environmental (moisture level, texture, etc) or cultural data (soil-use, time of fertiliser application, etc). Although this approach to land management has been in existence and used for a long period of time, not since the relatively recent advent of GIS, is it possible to store, display and update this information on a digital database (Kirkby et al. 1996).

A digital database describing characteristics of the land would be particularly useful to any land manager. It would allow the land manager to compare features present on the land giving greater insight about the make up and processes operating over each land unit (Kessell 1990). If it is possible to compare features between each land unit, the land manager will be able to predict the likely location of similar land units and gain a better understanding of what characters exist on each particular land unit. This would also be useful when attempting to recreate a desired landscape or develop a management plan for a particular area. Also, this technique may be useful when defining the boundaries of sensitive areas. Features that are included within a sensitive area can be displayed on a GIS and if replication of these features are observed elsewhere then the boundary of a sensitive area may be defined (Bridgewater 1993, Brown et al. 1998).

Geographic databases on a GIS can be stored and analysed in either of two formats (Figure 2.1). The first, older format is called raster or grid structure. Raster data stores data in a grid or cell that is referenced to the appropriate coordinate system. The size of the grid can vary but must remain consistent between data layer. A small grid size will attain greater accuracy, as less overlapping between the features inside the grids will occur. Raster data is also powerful when overlaying different data layers. With the data stored in same sized cells data layers are easy to match in the overlaying process. With a combination of data layers land units can be reclassified according to what information is required, relevant to a particular project (Pickup 1993, Aspinall 1994, Johnston 1998).
There are disadvantages in working with raster data however. These include that raster data sets require large amount of storage space (need data for each grid cell), the topology is difficult to represent, and they can be graphically unappealing (squares do not look like lines). With this in mind, spatial inaccuracies are likely to be evident but not severe (Congalton and Green 1997).

Geographic data may also be stored and represented on a GIS as vector or polygon data. These types of data sets use a series of points (x, y coordinates) to define the boundary of the object of interest. Vector data requires less storage space and is preferred for display purposes because it has high resolution and accuracy and it maintains a truer rendition of an object's shape. It is however, more complex to operate and overlay and modelling is difficult. Also vector data is inefficient in representing high spatial variability and does not handle satellite imagery, although there are ways to do it (Congalton and Green 1997).
Extracting specific information from a data layer and combining it with other information from another data layer is possible with the use of Boolean algebra. Boolean algebra involves queries in which the operators AND, OR, XOR, and NOT manipulate spatial data by testing to see if a given condition or statement is true or false. Having achieved this the combination of data layers can be used to form a new map layer (refer to Figure 2.2) (Congalton and Green 1987).

Removing or displaying particular combinations of data layers present on the GIS can produce a new map layer. The major drawback to this approach is that all data layers have equal weighting. The implication of this is that all maps are of equal importance whereas some maps, for example Vegetation, may be more important than the other maps e.g. Geology, in determining particular habitat suitability. Although this can be minimised by weighting the map layers in accordance to their influence on what it is that you are studying, the problem will still exist between the classes present on each data layer. The classes could also be weighted but data will become increasingly complex and difficult to manage (Johnston 1998).

Figure 2.2 Examples of Boolean operators used in overlay analysis (After Congalton and Green 1987).
2.8 GIS for plant and animal habitat suitability

Ecological research must eventually address the total environment in which a species or a population functions, and the study of spatial pattern and process is fundamental to such work. Even though ecosystems are not static by nature and it is practically impossible to gather data on every ecological and environmental process or pattern occurring over a landscape (Brown et al. 1998), what data is available should be utilised to its full potential and cross referenced. A geographical information system (GIS) is the perfect tool to analyse, sort, predict and display this type of information. This offers particular potential for application in the study of species-environmental interactions at regional scales. Spatial analysis can be used to interpret and describe geometric properties of the landscape, leading to an understanding of the complex interactions between different landscape components and linking description of environmental and cultural conditions with plant and animal distributions (Levin 1992).

The distribution of plant species depends upon its individual peculiarities of migration and environmental requirements. In other words for a plant species to exist propagules have to be present and the demographic parameters have to be met by characteristics in the environment (Silvertown and Doust 1993). Whittaker’s (1967) conceptualisation of niche differentiation among plants along environmental gradients showed a clear distinction between species distributions in response to one or more environmental, resource, and/or temporal gradients (Johnston 1998). Although he did not include all of the environmental characters in the landscape that may effect plant species distribution, (such as soil type, geology, soil moisture etc), he was able to illustrate species distributions within a stand in response to the same environmental complex (elevation, aspect and topographic position). Whittaker (1967) also used Mediterranean-climate ecosystems not to show global generalisations but to show how local patterns of site history and environment also effect the vegetation. He was able to illustrate how different plant species occur because different combinations of environmental characters exist in the environment. A list of environmental characters which can determine plant distribution may include; the availability of pollinators, elevation, fire, disease, herbivores, soil type, soil moisture, geology, solar radiation, climate, topography and the occurrence, type and density of itself and other plant species (Silvertown and Doust 1993).
The conclusion that plants exist in environmental complexes lead Kessell (1996) to use a GIS to illustrate known environmental conditions to predict vegetation occurrence. He was able to successfully display two-dimensional tree densities of Pinus albicaulis and Abies lasiocarpa in the Glacier National Park relative to elevation, aspect, and topographic position. Other examples of this type of analysis were also found in the literature. Pastor and Broschart (1990) used soils and topography to examine the spatial distributions of a northern conifer-hardwood landscape. Davis and Goetz (1990) used digital maps of geology, topography and clear-sky solar radiation to predict the distribution of coast live oak in California. In Australia Skidmore (1989) produced an expert system to classify a eucalypt forest into seven native eucalypt forest type classes generated by slope, aspect and topographic position. Although the environmental characters are accurate to varying degrees in predicting plant distributions, greater reliability could be achieved if more data sets are available, describing not only the environmental characters but also the cultural features in the landscape. Cultural features that will influence plant distribution may include land use, disturbance history and what is adjacent to the plant population.

GIS has also been applied to predict animal distributions. Since animals are not stationary this type of analysis usually is focused on breeding or nesting sites and areas where regular food sources are available. Donovan et al. (1987) effectively used GIS to show the extent and location of nesting and brood-rearing habitats required for the reintroduced eastern wild turkey (Meleagris gallopavo sylvestris) at Rose Lake Wildlife Research Area, Clinton and Shiawassee counties, Michigan. Pereira and Itami (1991) used a similar prediction technique where they produced a habitat suitability map for the endangered Mt. Graham red squirrel in the Pinalene Mountains of Arizona. Both models found that for a model to be effective it has to be based on its ability to generalise habitat requirements so that the GIS-based variables adequately represent the life requisites of the species. Therefore the GIS in locating probable species habitats is generalising the habitat requirements or characteristics in the environment that are shared with the occurrence and absence of the species studied. A similar methodology was used by Walker and Cocks (1991) were they used climatic parameters to define the potential distribution of red kangaroos in Australia. They suggest that although it was accurate over a large area other types of environmental parameters would have been useful. Walker (unpublished) studied the distribution

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of Koalas in New South Wales using topographic, soil fertility, tree species, nutrient status, climate and slope data in a HABITAT exercise to define an environmental envelope where Koalas can exist.

2.9 GIS for weed management

A geographical information system (GIS) for weed management must help answer questions about the current status of a weed, about likely trends in the future, and offer insight for the future management of weeds in a region. If relationships are evident between the environmental characters and cultural characters present in the landscape to plant species distribution, then there may be clues as to where and why a particular plant is establishing on a particular landscape. A GIS would be a useful tool to analyse and model such data (Pickup1993). Also the use of expert knowledge on weed biology and ecology in a study area will aid in the development of relationships between a weed and its environmental and cultural characters in the landscape being quantified (Everitt and Escobar 1996). Similarly, evidence as to why a particular weed species is invading one area and not the other may be better illustrated.

Examples in the literature of GIS analysis of environmental and weed data include; Chicoine et al. (1985) illustrated the potential to predict weed distribution from basic environmental resource maps. A GIS was successfully used over a large area for weed detection and site suitability in parts of the western and northern rangelands in the USA (Anderson et al. 1996, Everitt and Escobar 1996). Due to the large size of the area it was possible to incorporate satellite imagery and when each land unit characters and plant types were identified on the image, the prediction of current and future weed sites was possible. The Department of Natural Resources and Environment (DNRE, United States of America) also created a database to record the location of plant pests, however the system does not incorporate a mapping component and thus modeling is difficult (Lane et al. 1989). The CSIRO has developed a computer-based model (BIOCLIM®) to predict the spread of plant and animal species throughout climatic regions. Although these systems were effective, especially over large areas, they only incorporated a limited set of environmental characters.
Kerr and Westbrooke (1996) suggest to accurately map and model weed distribution, the cultural characters evident in the landscape also need to be incorporated. With both environmental and cultural data sets, a GIS accompanied with expert knowledge on weed biology and ecology would develop an integrated and more efficient approach to weed monitoring in natural ecosystems. In Australia, Kerr and Westbrooke (1996) used GIS successfully to show localised weed distribution through analysis of many environmental and cultural data layers. It was developed to assist in forming an integrated approach to weed control strategies through a database for record keeping, weed surveying, estimating control tactics and predicting future weed distributions. It allowed for the determination of which conditions within a specified area best suit the survival and successful regeneration of a particular weed species. It was also used to determine if the weed species currently occupies all the sites within the area which the GIS has shown it is capable of occupying. Although it was successful, they failed to include sites where the weed species was absent and therefore may have missed factors in the landscape that are preventing the establishment of the weeds.

By collecting data about the natural environment, the environmental change across the landscape, together with data on weed species abundance and distribution, relationships (or spatial association) between the data sets may be evident. Such relationships assist the determination of causative factors, knowledge of which will greatly enhance weed management. For example if Weed A was almost always associated with a disturbance, then to effectively manage and prevent Weed A establishing itself in the landscape, the disturbance at a site which contains Weed A must be addressed. Another example might be where Weed B is almost always found at sites where there is no disturbance but is present because individuals of this species are always adjacent to the site. Therefore to effectively manage Weed B in its current environment you must also manage the adjacent populations of Weed B.

If characters in the landscape are known to influence weed species distributions and these are visible on aerial photographs, satellite imagery or any other map/information source, prediction of weed distribution will be possible without spending a lot of time and resources carrying out weed surveys. Weed surveys will always be required but be far more cost effective. Database weed
systems could remain permanent and would provide a land manager, not familiar with the regions landscape, a useful database of information on a weeds location, and the characters in the landscape allowing or enhancing the weeds establishment (Solomon and Shugart 1993, Kerr and Westbrooke 1996). If this is possible, weed management can be directed to the identified locations and characters in the landscape that associated to weed establishment. A GIS can therefore record attribute information for each character relevant to a weed species ability to establish itself in a particular area. New information for the area can be updated as data is acquired. If improvements in weed assessment, management and prediction are possible, areas that are currently affected by weed establishment may be reduced and future infestations may be prevented.
Chapter Three

Study Area and Methods

3.1 Study Area

The Royal National Park (RNP) was established in 1879. The 15,068 ha park is triangular in shape, bounded to the north by the Port Hacking River, to the east by the South Pacific Ocean, and to the west by the Princes Highway and the Illawarra Railway line. The north-western portion of the park is contiguous with suburban Sydney (Figure 3.1). It was the first piece of land in Australia and second in the world to be set aside specifically for conservation. It is recognised as amongst the most floristically diverse for its size in the temperate parts of the world. It also contains world class landscapes and areas of cultural significance. Also due to the close proximity of the RNP to Sydney and Wollongong it demonstrates important developments in conservation and recreation philosophy to a wide range of people and has achieved this since its establishment in 1879 (Humphries 1994).

The study area consisted of sites at regular intervals along the majority of the RNP's terrestrial boundary. The RNP's terrestrial boundary is delineated on the Port Hacking, Otford, Appin and Campbelltown 1:25,000 topographic maps, produced by the Land Information Centre (1985). The boundary was chosen as each of the five weed species where known to occur and the boundary dissect a wide range of landscapes and vegetation types some of which are of high conservation value. The boundary is also vulnerable to heavy human activities of different land-use types and objectives and is often the first place weed seeds and propagules enter the park. There was adequate access to most of the 42 km boundary via mainly the public utilities road and rail network. The suburbs of Helensburg, Waterfall, Heathcote, Engadine, Loftus, Kirrawee and Grays Point all directly lie adjacent to the RNP boundary.

General features of climate within the area are warm summers and mild winters. Annual air temperatures range from -1°C to 37°C. Rain occurs on about 40% of the days in the year with periods of summer drought. Annual precipitation ranges from 1 143 to 1 270 mm. Valleys have enhanced precipitation through run-off, lower evaporation and higher humidity than the ridge tops.
Evaporation within the park has been estimated at 890 to 1 016 mm per year on the plateau and 762 mm in the valleys (Gutteridge et al. 1989).

North-east winds prevail during the summer and are modified by sea breezes. There is the occasional passage of cold fronts of south-east to south-west winds. In winter and spring, the southern air dominates, bringing cold westerlies sometimes reaching gale force (Gutteridge et al. 1989).

Figure 3.1 Location of the Royal National Park (After Gutteridge et al. 1989).

The RNP occupies the Woronora Ramp segment of the Sydney Basin, a major structural unit of New South Wales. The ramp is a defined geological feature, which rises southwards from the Cumberland Basin to the Illawarra between the coastal cliffs and the low plain to the west around

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Liverpool, Campbelltown and Picton. This area is part of the much larger Sydney-Bowen Basin and is of Permian and Triassic age (270-180 million years ago). The geology of the RNP consists of three units, the Narrabeen Group at the base, the Hawkesbury Sandstone and the Wianamatta Group at the top. The Hawkesbury Sandstone is the dominant group forming a plateau, which in places is up to 200 m in elevation. The plateau generally slopes downwards to the north and is deeply dissected in the west by the Hacking River system. This landscape is characterised by steep valleys and ridges, rocky outcrops and streams. In the east, the plateau is characterised by broad, gently sloping ridges and small eastward flowing drainage lines. In the south of the park and along the Hacking River valley the Narrabeen Group shales are exposed in the deep gullies. The Wianamatta Group is mainly shaley with the upper half, containing sandstones. This group is very limited in its distribution, with much of it being weathered away (Gutteridge et al. 1989, Humphries 1994). A geology map for the region is shown in Figure 3.2.

Much of the sandstone plateau supports an Eucalypt woodland community, which in the western part of the park grades into sandstone gully forest dominated by *Angophora costata*. In moist and sheltered locations the vegetation is tall open eucalypt forest and contains rainforest elements. Heath and mallee vegetation is also extensive on the sandstone plateau. It is a complex mosaic of open and closed shrub and mallee heath with smaller areas of wet heath.

In the upper catchment of the Hacking River on the Narrabeen shales there are significant stands of subtropical and warm temperate rainforest and Shale gully forests. It is estimated that some 75 per cent of the rainforest of the Illawarra, has been cleared since settlement, and accordingly, that remaining is of high conservation value. It provides a habitat link with the rainforest on the Illawarra escarpment. Other vegetation types of significance include areas were wetlands are present were the tall moist eucalypt forests occur. The RNP also contains populations of 26 rare or threatened plant species. They include trees, shrubs, herbs and orchids from a variety of habitats including rainforest, eucalypt forest, heathland and wetlands. Weeds are estimated to comprise 20% of the total number of local plant species found (Humphries 1994).
The majority of soils present in the RNP are formed from sandstone parent material. On hill and valley slopes the movement of soil downhill, especially where lubricated by water, builds deeper deposits in valley bottoms and is a significant factor in the formation of duplex yellow podzolic soils. On level, plateau land, the soils are less structural. They are stony, shallow, and frequently devoid of a soil profile. These soils are termed skeletal soils or lithosols. In certain river valleys where the underlying Narrabeen geological group has been exposed, deep red earth soils, with high nutrient
availability are found (Gutteridge et al. 1989). A map illustrating the distribution of soil types in the RNP is shown in Figure 3.3.

Figure 3.3 Distribution of soil types in the RNP.
3.2 Methods

3.2.1 Field Survey

A series of sites were randomly chosen when the majority of the parks terrestrial boundary was divided into 500 m intervals, either on the ground or on a 1:25 000 topographic map. The interval between some of the sites was determined on the ground using a measuring wheel. For those sections of the boundary where the terrain limited access of the measuring wheel, physical or land-use features visible on a relevant 1:25 000 topographic map were used to identify the 500 m interval between sites. Physical or land-use features that were included features such as the presence of a drainage channel or where a walking track or road intersected the park boundary. A total of 84 sites were surveyed and the location of these is shown in Figure 3.4. All sites where eventually transferred to the relevant 1:25 000 topographic maps. In the field each site 25 m to the left and 25 m to the right of the original interval point was surveyed. Thus each site was 50 m in length. At each site data was collected describing weed occurrence and abundance. Environmental and cultural characters in the landscape thought to influence weed distribution were also recorded.

For each character a data dictionary was developed to describe all the possible attributes that were present for each character. For example if the character to be described was drainage, then every possible type of drainage that could occur over the entire study region was included in the attribute table. The characters investigated and a list of the attributes used to describe each one is shown in Table 3.1. Coverage of weed species was recorded by estimating the percentage of foliage cover for each weed at each site. The characters 'what is adjacent to the boundary', 'drainage' and 'evidence of a disturbance' where considered cultural characters of the landscape. Although drainage is a natural/environmental feature of the landscape, the majority of the riparian zones along the park boundary is influenced by human habitation and thus was considered to be a cultural character. A field data sheet developed for consistency in data collection is presented in Appendix A.
Figure 3.4 Location of the 84 sites surveyed along the boundary of the RNP.
Table 3.1: Characters (in bold) and their attributes

1. **Site number** – 1 to 84.

2. **What is adjacent to the boundary** – Bitumen road, Dirt road / creek, Urban, Ocean, Sports ground, Bush, Bush / creek, Rail, Rail / dirt road, Carpark, Creek, Cleared land, Fire break / urban, Rail yard.

3. **Easting** – Read off a 1:25,000 topographic map

4. **Northing** – Read off a 1:25,000 topographic map

5. **Drainage** – Natural drainage into the park, Natural drainage out of the park, Natural drainage along the boundary, Artificial drainage into park, Artificial drainage out of park, Artificial drainage along the boundary, Drain easement, Creek.

6. **Soil pH** – 5, 6, 7.

7. **Evidence of a disturbance** – No earthworks, Dumping, Clearing, Artificial gully, Track, Clearing / earthworks, Old earthworks.

8. **Crofton weed** – Very common (>50% coverage), Common (10-50% coverage), Sparse (<10% coverage), Absent.

9. **Lantana** – Very common (>50% coverage), Common (10-50% coverage), Sparse (<10% coverage), Absent.

10. **Privet** – Very common (>50% coverage), Common (10-50% coverage), Sparse (<10% coverage), Absent.

11. **Cassia** – Very common (>50% coverage), Common (10-50% coverage), Sparse (<10% coverage), Absent.

12. **Blackberry** – Very common (>50% coverage), Common (10-50% coverage), Sparse (<10% coverage), Absent.

13. **Distance each weed species has travelled off the boundary and into the park** – 0-5 m, 0-10 m, 0-50 m, 0-100 m, 0-150 m, >200 m.

14. **Do any of the weed species occur within 100 m of the site** – Yes, No.

15. **Other weed species present** – Yes, No.

16. **Cover of native vegetation** – Very common (>50% coverage), Common (10-50% coverage), Sparse (<10% coverage), Absent.
3.2.2 GIS Set-up and Modeling

The use of ArcView®, a PC-based GIS developed by the Environmental Systems Research Institute (ESRI) in 1996, was utilised to assess both the field data collected and some pre-existing digital databases from the National Parks and Wildlife Service (NPWS) of the RNP. With the field data, a table was created in Microsoft Excel® and then saved as a dbf 4 file and imported into Arcview®. The Eastings and Northings are the coordinates of each site and these were used to transfer the ground location of each site onto a digital map of the RNP. A digital map displaying the RNP estate and its surroundings was provided by NPWS. The NPWS also provided cultural data layers illustrating the location of utilities and park infrastructure including data layers displaying the location of roads, rail, recreational, cultural and educational facilities.

The location of each drain easement was determined from maps provided by Sutherland Shire Council and from observations in the field. The maps were digitised using the Environmental Resource Mapping System (E-RMS) developed and provided by the NPWS (Ferrier 1989, Bridgewater 1993). The location of rivers and creeks were also digitised using E-RMS. Their locations were digitised from the relevant 1:125 000 topographic maps and also transferred from E-RMS to Arcview®. Buffer zones for some data layers were also created. A buffer zone of 500 meters was considered adequate around urban areas, considering the distance storm water and wind can carry seed. All these data sets therefore could be analysed together, and the occurrence of the weed species could be illustrated in terms of their association (‘if any’), they have with the cultural and local environmental attributes present at each site.

The GIS was also used as a tool to map potential weed occurrence. If the ability of a plant to grow in a given location is normally governed by more than one factor, the production of composite maps may present a clearer view of the RNP’s vulnerability of invasion by these weeds. Environmental characters covering the entire RNP region were used as potential data types to predict weed occurrence. These included environmental databases on the ‘topography’ (D.E.M-Digital Elevation Model), ‘soils’, ‘vegetation’, ‘geology’ and ‘fire frequency’. The data sets for these characters were large enough to cover the entire RNP region. This data can be produced from digitising basic resource maps, that is existing soil and vegetation maps etc, and the ones used for this research were provided and created by the NPWS GIS unit. Manipulation of these databases
is possible and the 'slope' and 'aspect' characters for the entire region were created from the D.E.M. All databases were collected on their availability and on the relevance each character has on weed distribution. All these environmental characters are considered important for plant establishment and all were given equal weighting. That is each character was considered to have an equal ability in influencing plant establishment. Attributes within each character were also given equal weighting. The literature was used as a guide in determining this. A list of each environmental character used, accompanied with a brief description and source is shown in Table 3.2. Unfortunately the raw data, listing each site's environmental attributes could not be displayed as an Appendix, due to technical restraints.

Table 3.2: Environmental character, description and source.

<table>
<thead>
<tr>
<th>Data layer</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect</td>
<td>Created from 25m pixel D.E.M 9 attributes of aspect</td>
<td>NPWS</td>
</tr>
<tr>
<td>Slope</td>
<td>Created from 25m pixel D.E.M 9 attributes of slope</td>
<td>NPWS</td>
</tr>
<tr>
<td>Vegetation</td>
<td>1:25,000-RBG 33 attributes to vegetation</td>
<td>NPWS</td>
</tr>
<tr>
<td>Soils</td>
<td>1: 100,000 corpdata 14 attributes of soil</td>
<td>NPWS</td>
</tr>
<tr>
<td>Geology</td>
<td>1:100,000-corpdata 4 attributes of geology</td>
<td>NPWS</td>
</tr>
<tr>
<td>Fire frequency</td>
<td>Number of fires in same spot 6 attributes of fire frequency</td>
<td>NPWS</td>
</tr>
</tbody>
</table>

All data was stored as themes. This allows for each character to be represented graphically as a data layer in Arcview®. Themes are listed in the views Table of Contents. Each theme is drawn in the order they appear in the Table of Contents, superimposing those at the top over those below. Once the data is displayed it can be queried and any combination of data layers can make up a new data layer. Each character or its attributes can form a new data layer and each can be

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displayed and queried against itself or other attributes. (Note: a theme is active when it is raised in the Table of contents and displayed when there is a tick in the check box).

Only those attributes that dissected the boundary of the park were relevant in the analysis process. For example the vegetation attribute upland swamp was not relevant to this study as no upland swamps dissected the park boundary and thus were not present in the field survey. There are however, vegetation types that dissect the RNP boundary that are of high conservation value and these need to be identified. ‘Fire frequency’ was also analysed as fire will generally open up an area and encourage the growth of some species whilst restricting the growth and regeneration of others. Fire is a major disturbance to ecosystem structure and function. The environmental character ‘aspect’ was also considered important as the amount of sunlight an area receives and the length of time an area may be exposed to frosts is strongly influenced by its position in the landscape. ‘Slope’ also is important in determining plant growth and establishment, as different degrees of slope will generally have differences in soil depth and water drainage. It will also influence the erodability of the soil with steep sloped areas being highly prone to soil erosion and will be important when attempting to remove a weed from the landscape.

Attribute type and location of the environmental characters, ‘geology’ and ‘soils’ is shown in Figure 3.2 and Figure 3.3 respectively. These data layers along with the environmental character ‘vegetation’ were also overlain with the attribute information collected at each site on weed species distribution. With these data layers covering sites surveyed along the boundary and sites that were not, weed species occurrence, when regularly associated with an environmental attribute represented on these data layers, could be extrapolated to areas outside of the original survey locations. For example if Lantana was always found on a particular soil attribute, then were this soil type occurs Lantana will most likely be present. All weed abundance levels, that is, very common, common, and sparse, were used when analysing this type of association, although greater consideration or weight was given to those sites that contained very high levels of weed coverage. Unfortunately, due to the limited number of sites that contained the weeds Blackberry, Cassia and Privet, potential or likely occurrence of these weeds could not be predicted.
3.2.3 Accuracy of GIS Modeling

To determine the accuracy of the sites predicted as suitable for Crofton and Lantana a further 69 sites were surveyed along the park boundary. All new sites were located in the middle of two previously surveyed sites. Therefore all new sites were 250 m from an original survey site. Not all intervals were surveyed however, and the location of the 69 sites is shown in Figure 3.5. At each site Crofton and Lantana were recorded as either present or absent. No other data was recorded, as this was an exercise to determine whether Crofton and Lantana were present at sites along the boundary where the GIS model developed from the first set of survey sites, suggests they are capable of existing.
Figure 3.5 Distribution of second set of field sites along the boundary of the RNP.
Chapter Four

Results

4.1 GIS Landscape and Field Survey Analysis

An attribute table displaying the results of the fieldwork is presented in Appendix B.

4.1.1 Crofton weed

Forty nine percent of all sites surveyed contained Crofton. Of these 83% had an abundance level either common or very common. Its occurrence was not limited to any one section of the park boundary. Seventy one percent of sites where Crofton was present had some type of disturbance and 66% of all sites, which contained Crofton, where adjacent to urban areas. Distance into the park for Crofton varied. It was usually found around the fringes but could penetrate the park for over 200 meters. From observation alone drain easements or other features in the landscape that increased the flow of water into the park, were the main reasons usually associated with increased distances of Crofton penetrating the park (Figure 4.1).

4.1.2 Lantana

Lantana was present at 25% of sites surveyed and of these 86% contained abundance levels either common or very common. Sixty two percent of sites that had Lantana present were undisturbed and only 40% of these sites were adjacent to urban areas. The majority of sites that contained Lantana where found at the southern end of the park. Lantana did not necessarily require a disturbance or increased levels of drainage to be present or for it to travel further into the park (Figure 4.2).

4.1.3 Cassia

Nineteen percent of sites surveyed had Cassia present. Cassia presence was always associated with urban areas and always had Crofton present. Also 87.5% of sites which contained Cassia were disturbed. Where it was present it could was found to penetrate the park for over 200 m, but only when increased levels of water were flowing into the park (Figure 4.4).
4.1.4 Blackberry

Seventeen percent of sites surveyed had Blackberry present. It was usually associated with urban areas (Figure 4.5) and was always associated with Crofton. Also 87% of sites that contained Blackberry were disturbed. There was not data available for the distance Blackberry is penetrating the park but from observation alone it rarely penetrated the park for more than 10 meters.

4.1.5 Privet

Only 10% of sites surveyed contained Privet. Those that did were all in the northern part of the park where its abundance levels varied from sparse to very common. It was mainly found at sites that had increased levels of water run-off. In these locations Privet could penetrate the park up to 50 meters (Figure 4.3). Also where Privet was present it was always associated with either Crofton or Cassia. Fifty seven percent of sites that contained privet were disturbed.
Figure 4.1 Crofton weed: Distribution, abundance along and distance across the RNP boundary.
Figure 4.2 Lantana: Distribution, abundance along and distance across the RNP boundary.
Figure 4.3 Cassia: Distribution, abundance along and distance across the RNP boundary.
Figure 4.4 Blackberry: Distribution and abundance along the RNP boundary.
Figure 4.5 Privet: Distribution, abundance along and distance across the RNP boundary
Relationships indicated by the GIS suggest that the cultural characters in the environment were strongly associated to all the five weeds current distributions. The cultural characters included 'disturbance', 'what is adjacent to the boundary' and 'drainage'. The location of stormwater run-off was also considered and was included as an attribute of the 'drainage' character. Unfortunately though by using a random sampling technique only 6% of sites surveyed included sites of stormwater run-off. These sites were usually associated with high weed coverage and increased distances the weeds are entering the park. The environmental attributes 'soil pH' and 'cover of native vegetation' did not show any significant association to the five weed species distributions.

The cultural character 'disturbance' was strongly associated to all of the weed species distributions (Figure 4.6). Where sites had been subjected to a disturbance 94% of these sites contained one or all of the five weed species. With the 6% of sites that were subject to a disturbance but did not contain any of the five weeds, 50% of these sites contained other weed species. For sites that were undisturbed, 50% of sites contained at least one or all of the five weed species. For 30% of these, however, coverage of the five weed species was no greater than sparse. It is evident therefore that although the weeds are more likely to found at disturbed sites, all of the weed species studied are capable of establishing at sites which are undisturbed.
Figure 4.6 Influence of a 'disturbance' in relation to weed free sites.
The cultural character, 'what is adjacent to the boundary', was important only for those sites that were adjacent to native bush or adjacent to urban areas. Twenty three percent of sites surveyed were adjacent to native bush and from these only 5% contained any one of the five weed species. For sites adjacent to urban areas the occurrence of the five weed species increased. Seventy percent of sites contained at least one or all of the five weed species. Cassia and Privet were only found when the sites were adjacent to urban areas and of the 41 sites that contained Crofton, 66% were found adjacent to urban areas. For Blackberry, 87% of sites where occurred were adjacent to urban areas. Lantana was the only weed for which a minority of sites at which it occurred, were adjacent to urban areas. Only 40% of sites that contained Lantana were adjacent to urban areas.

Sites adjacent to urban areas also contained a greater variety and abundance of other weed species. All weed species, if present when adjacent to urban areas, had propagules of its kind less than 100 meters away. Instances, however, did occur were a weed species was not present even though it had propagules less than 100 meters away. These sites were generally those that contained no disturbance and were adjacent to native bush. Figure 4.7 illustrates the association between weed free sites and sites adjacent to native bush.
Figure 4.7 Influence of the attribute adjacent to native bush in relation to weed free sites.
4.2 GIS Modeling

4.2.1 Crofton weed.

The set environmental characters used to predict site suitability of Crofton along the boundary and within the Royal National Park (RNP) included ‘soil’, ‘vegetation’, ‘aspect’ and ‘slope’. The attributes for the environmental characters ‘fire frequency’ and ‘geology’ showed no association with the occurrence of Crofton weed. Although the cultural characters in the landscape, such as a ‘disturbance’, were shown to strongly influence Crofton distribution, there were some possible clues of site suitability of Crofton in terms of these broader environmental characters operating over the landscape. Crofton was present on all soil types (attributes) found in the RNP. The soil type Hawkesbury, however, a colluvial, sandy, highly permeable, very low fertility soil, did not contain Crofton for 65% of sites which had this soil type present. For all other soil types Crofton was present on more than 50% of sites.

All vegetation types (attributes) analysed along the boundary contained Crofton. A vegetation type that had a greater number of sites free of Crofton was a sandstone gully forest. These forests typify much of the western section of the RNP. Although this vegetation type did contain Crofton its abundance was never very common and 63% of sites that contained a sandstone gully forest did not contain Crofton.

Crofton was also present in the vegetation types shale gully forest and rainforest, both of which are considered significant and consequently are of high conservation value. Eighteen sites were in the vegetation type shale gully forest and of these 44% contained Crofton. Abundance levels of Crofton at these sites ranged from sparse to very common. Of the ten instances where a rainforest was present, 20% of these sites contained Crofton. All abundance levels recorded in the rainforest vegetation type were very common.

Another broader environmental character of interest was ‘aspect’. The aspects, southwest and west totally restricted the occurrence of Crofton. Twelve percent of sites contained an aspect southwest or west and not one of these sites had Crofton present. The environmental character ‘slope’ was also analysed. Slopes where Crofton was limited included sites of moderate slope.
Moderate slopes were defined as slopes that were greater than 19° but less than 24°. For this degree of slope 88% of sites contained no Crofton.

A composite map representing areas in the park suitable for Crofton establishment is shown in Figure 4.2.1a. This map was produced by overlaying all the environmental attributes available for analysis, except the Hawkesbury soil, sandstone gully forest, west and southwest aspects and slopes that were greater than 19° but less than 24°. These attributes limited Crofton weed establishment and the location of these attributes are excluded from Figure 4.2.1a.

4.2.2 Lantana

The broader environmental characters used to predict potential sites considered capable of supporting Lantana included: ‘soil’, ‘vegetation’ and ‘geology’. Lantana showed no preference for the environmental characters ‘slope’, ‘aspect’ or ‘fire frequency’. Soil considered capable of supporting Lantana included the soil type (attribute) Watagan. Seventy six percent of sites that contained Lantana were associated with a Watagan soil. The distribution of this soil type in the RNP is shown in Figure 4.2.2a. It is a colluvial soil, shallow to deep with good soil fertility. The landscape these soils occur include moderately inclined rolling hills to very steep hills on fine-grained Narrabeen Group sediments. Where this soil type occurred, 50% contained Lantana. Of these 60% were undisturbed. Abundance levels at these sites were usually very common, with only 7% of these sites recording sparse levels of Lantana.
Figure 4.2.1a Crofton weed: Sites suitable along the boundary and within the RNP.
Two other soil types, the Hawkesbury and Gymea, both of which have low soil fertility, also supported Lantana. These two soil types made up 37% of the total sites surveyed but only 13% of these sites contained Lantana, and all, were either disturbed, adjacent to urban areas or adjacent to a road. Only one other soil type, the Lucas Heights type, contained Lantana. Eleven percent, of the total number of sites had a Lucas Heights soil. From this soil type, only 28% contained Lantana, and all are disturbed or adjacent to a bitumen road. Since all other soil types except the Watagan soil type only contained Lantana when a site was disturbed, or adjacent to human infrastructure, the Watagan soil attribute was used to model Lantana distribution. This soil type also contained 76% of the total number of sites that had Lantana present.

Figure 4.2.2a Distribution of the Watagan soil type in the RNP (black areas).

The vegetation type (attribute) that regularly supported Lantana was a shale gully forest. Sixty two percent of sites that had a shale gully forest contained Lantana. Although this vegetation type did not always contain Lantana it did contain 48% of all sites that had Lantana present. The distribution of this vegetation type is shown in Figure 4.2.2b. These forests are of high conservation value and the presence of Lantana is a serious threat to this vegetation type. Other vegetation types that had Lantana present more than once included: sandstone woodland, littoral forest, rainforest and gully rainforest. Shale gully forest however was the only vegetation attribute used to determine vegetation types considered capable of supporting Lantana as it was the only
vegetation type that regularly supported Lantana, and which contained more sites than not of
Lantana presence.

Figure 4.2.2b Distribution of the shale gully forest, vegetation type in the RNP (black areas).

Geology considered capable of supporting Lantana included areas where the Narrabeen shale
geological group was present. Although 50% of the sites that were on this geology type did not
contain Lantana, 63% of all sites that contained Lantana where on this geology type. The
distribution of this geology type in the RNP is shown in Figure 4.2.2c.

Figure 4.2.2c Distribution of the Narrabeen shale geological type in the RNP (black areas).

The overlapping of the Watagan soil type, the shale gully forest vegetation type and the Narrabeen
geological type were used to create a composite map of Lantana distribution in the RNP. This is
illustrated in Figure 4.2.1d. The distribution of Lantana outside of this area, that is, in the top end of the park (refer to Figure 4.3) is directly related to these sites either being disturbed, being adjacent to urban areas or adjacent to road.
Figure 4.2.2d Lantana: Sites suitable along the boundary and within the RNP.
4.3 GIS Analysis of Second Field Survey

4.3.1 Crofton weed

Seventy one percent of sites that had Crofton present in the second survey lay within parts of the park were the combination of environmental attributes from the first survey suggested Crofton is most likely to exist. Also 65% of sites were the environmental attributes suggested Crofton was less likely to exist, did not contain Crofton. However the use of the environmental attributes to create a new site suitability map from the second set of survey sites was not appropriate. This was so as all the environmental attributes displayed within each environmental character, except ‘aspect’, showed no consistent association with Crofton weed occurrence. The environmental attributes that can support Crofton are many and Crofton does seem quite capable of establishing almost everywhere in the RNP except in those areas where a west or southwest aspect is present. Figure 4.3.1 illustrates Crofton weed occurrence as determined from the second set of field sites, with the composite map of Crofton distribution modelled from the first set of field sites overlaid.

4.3.2 Lantana

The data for the second field survey for Lantana however was a little more encouraging. Sixty two percent of sites that had environmental attributes considered suitable for Lantana from the first survey, did actually contain Lantana. Also 89% of sites that were not suitable in terms of the environment attributes displayed if Figure 4.3.2d, did not contain Lantana. Therefore the same set of environmental attributes (i.e Watagan soil type, shale gully forest type and Narrabeen shale geological type) that produced the original site suitability map, were again most often associated with Lantana occurrence, and were therefore used to produce an identical site suitability map for Lantana (Figure 4.3.2). Seventy one percent of sites were Lantana was found in the second survey were on the Watagan soil type. Further for those sites that were on Watagan soil 65% had Lantana present.

Thirty three percent of sites were on the vegetation type, shale gully forest. Although only 44% of this vegetation type contained Lantana, no other vegetation type recorded more than 12% of the total occurrence of Lantana. For geology, the Narrabeen shale geological type was responsible for 66% of sites that contained Lantana. Where this geology type was present 47% of the sites contained Lantana.
Figure 4.3.1 Crofton weed: Second set of survey sites in relation to original site suitability map.

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Figure 4.3.2 Lantana: Second set of survey sites in relation to original site suitability map.
The composite map of Lantana was more useful in that, Lantana may require specialised environmental attributes for it to establish. The attributes 'shale gully forest', 'Watagan soil' and 'Narrabeen shale' were again consistently associated with Lantana. Although not all of the sites that contained Lantana along the park boundary were associated to these attributes, they were responsible for the majority of sites that contained Lantana. Also, where Lantana was present outside of these attributes a disturbance was evident. For sites that contained the above mentioned ‘environmental attributes’ and where Lantana was absent, but expected, these sites were usually adjacent to native bush and no disturbance was recorded. It was however, not uncommon for Lantana to exist in these areas without a disturbance being recorded. Lantana is recognised as an ‘environmental weed’ (Humphries et al. 1991) and thus has the ability to invade areas without human intervention. Also this research suggests its ability to establish in undisturbed areas will increase if a particular set environmental attributes are present in the landscape.
Chapter Five
Discussion

5.1 Cultural Influences in the Landscape

The Geographical Information System (GIS) was useful in identifying cultural characters in the landscape that influence weed infestation along the Royal National Park (RNP) boundary. All of the weed species occurred more often on sites were the landscape had been exposed to a disturbance. A disturbance was defined when either the native vegetation or natural topography of the land surveyed had been altered by human activities. The relationship between a disturbance and weed occurrence is not new and is well documented in the literature (Amor and Stevens 1975, Fox and Fox 1986, Edwards 1989, Muyt 2001), were weed frequency is shown to strongly correlate to human activities. After an initial disturbance, the availability of seed ‘safe sites’ (Harper et al. 1965) will be increased for all plants, and if weed propagules are present or in close proximity to a site, these environments will most likely be infested by weeds. The GIS also highlighted the association between undisturbed sites and no or minimal weed infestation. The native bushland when undisturbed is most likely acting as a buffer, preventing weed seeds and propagules from entering the park.

A disturbance along the boundary was usually associated with the attributes, adjacent to urban areas, stormwater run-off and earthworks. The rarity of Cassia, Blackberry and Privet is encouraging as it indicates that these weeds are not a major problem for the park on its fringe. This is especially the case for those parts of the boundary that are outside the 500 metre buffer zone around the urban area. The low levels along the boundary however does not indicate the level of occurrence throughout the park and if they are present may suggest that the weed seeds are finding other mechanisms to the enter the park besides water or wind dispersal. Privet and Blackberry seeds for example can be dispersed by berry eating birds and animals.

Although the majority of weed species occurrences, apart from Lantana, lay adjacent to the urban areas, a 500 metre buffer zone was chosen as the maximum distance into the park from the urban fringe that would require weed control works. This buffer zone also includes all human
infrastructure adjacent to the urban area. The actual distance of weed control needed in the park would vary, depending on the position of the urban area to the surrounding infrastructure and the position in the landscape of the park boundary. Maximum distance of weed spread into the park would most likely be no more than 250 metres. Two hundred and fifty metres would only be required if a site contained or is adjacent to weed propagules, is disturbed and stormwater run-off is present.

Stormwater run-off from the urban catchment is usually rich in nutrients and often leads to an increase in the amount of phosphorus in the soil. With native soils generally low in phosphorus, the desirable environment for natives to survive becomes less suitable. Stormwater run-off also increases soil moisture and erosion, and transports sediments rich in weed propagules. It also creates alterations to the flow regime and most creeks along the RNP boundary are either directly or indirectly exposed to run-off from the urban development. With the urban area also providing weed propagules and in most cases a physical disturbance to the parks edge, it is no wonder these types of environments contain high concentration of weeds. However since the majority of the parks edge does not contain stormwater run-off, most of the parks edge will require a weed control zone of no more than 50 metres into the park. Disturbances such as road and rail construction, the importation of foreign materials are responsible for the alterations of topsoil and native bushland being cleared. These need to be limited or contained as much as possible. Natural disturbances such as fire will have to be mapped as they occur.

The GIS also identified other relevant weed mapping potential. If the source of weed propagules are shown to be arriving from an area where weed control is difficult or is not likely to occur, then the containment not removal of the weed infestation should be a priority. For instances where coverage of a particular weed is sparse but in a similar environment it is very common, then where it is sparse there is a high probability, if the landscape is not rectified that the weed will become very common at these sites.

If the weeds themselves are generally not the cause of the problem, but rather are a result of a problem then what attributes in the landscape need to be addressed to reduce weed coverage. By identifying areas along the park edge that are promoting weed invasion then by concentrating your
weed management efforts in these areas, weed infestation along the majority of the park boundary will be controlled. Weed management in these areas may include the building of settling ponds to reduce the impacts of stormwater run-off, physical changes to the topography, erection of barriers and by applying relevant weed control techniques on the ground. Control techniques are well established and are reviewed in Appendix C.

When controlling weeds in the natural environment, control methods will vary depending on the type and growth form of the weed you are removing and on the type of environment the weed exists in. Early identification of weed species invasion and autecological studies either carried out in the field or through the literature which determine the timing and potential of each weed species vegetative and reproduction life, will also determine control techniques. Autecological studies have shown that Crofton weed seeds become ripe from October to January, Lantanas from December to June, Cassia and Privet from April to August and Blackberry from January to March (Burrows and Kohen 1983, Dyason 1986, Parsons and Cuthberston 1992, Ermert 1998). All the weed species need to be actively controlled before each has the chance to increase the size of its propagule pool. Also all areas should be surveyed for plant, animal or organisms that may be present and which are of high conservation value. If there are plant, animal or organisms of high conservation value then an alternate weed control techniques need to be developed. An example of matching a control technique to the attributes surveyed will include the use of herbicides or fire to areas which have high weed occurrence and have been disturbed and have no conservation value. Herbicides and fire are effective control techniques as they are relatively cheap (especially were the cost of labour is concerned) and can cover large areas in a short period of time.

A Geographical Information System (GIS) accompanied with field observations of weed occurrence was a useful tool in illustrating areas were weed control works are required. It can display the current distribution of a weed and has the power to associate cultural attributes found in the landscape to weed species location. By combining this type of information with autecological studies of an individual weed species, areas along the park boundary can be divided into areas of weed control zones. Zones could include areas that require immediate weed control works, areas that require extensive weed control work, areas that require minimal weed control works or areas that require no weed control works. Areas that are expected to experience increases in weed
infestation can also be displayed and effective and appropriate control techniques recommended. The databases and maps can be regularly updated as weed control works begins.

5.2 GIS Modeling of Environmental Characters in the Landscape

The number of environmental characters analysed is only governed by the availability of data and the relationship if any, each character has on plant growth. It is not necessary to examine an environmental character in the landscape that does not influence plant establishment or its attributes share similar associations to plant locations. Also it is not necessary when studying a small region, to examine those characters in the environment that are relatively uniform across the entire region. For example a climatic map was not relevant to this research as a similar climatic regime exists over the entire RNP. Were local variations occur they are most probably due to their position in the landscape, which was previously examined in both the field survey and by analysing the environmental characters 'slope' and 'aspect'. Further the ‘fire frequency’ environmental character was also not relevant as the majority of the park was burnt in 1994 and no major fires have been recorded since this time. However, since plant distribution is related either directly or indirectly to most factors operating over a landscape, it is essential to initially analyse all of the available data sets that are available.

With both Cassia and Blackberry occurring at only 19% and Privet at only 10% of sites surveyed, as apposed to Crofton occurring at 50% of sites surveyed, there could be no modeling of potential distribution of these three weeds. No regular association was evident between the environmental characters analysed on the GIS to the occurrence of these three weeds. Also all but one of the occurrences of Cassia, Privet and Blackberry were found inside the 500 metre buffer zone of the urban area indicating that these weeds will generally require a disturbance to establish. Although Lantana also only occurred at a minority of sites (25% of sites), it was evident from the GIS analysis that Lantana occurrence could be directly attributed to a known combination of environmental attributes present on the landscape. Therefore with 50% of sites surveyed containing Crofton weed and the regular association of Lantana to a particular set of environmental attributes displayed on the GIS, meant it was possible to produce maps illustrating potential distributions of these weeds outside of the original survey sites.
When predicting the potential distribution of Crofton weed on the GIS, by displaying the environmental attributes on which it was not regularly associated with, suggested that Crofton weed could potentially occur on more than 50% of the parks landscape. This map however is most likely not an accurate representation of Crofton weed occurrence in the RNP. Crofton weed establishment was strongly associated to the occurrence of the cultural characters, ‘disturbance’ and ‘drainage’ and the majority of environmental characters analysed were at least once associated to Crofton weed occurrence. One environmental character of interest, however, that did directly influence Crofton weed infestation was ‘aspect’. Crofton was not recorded at sites with a southwest or west aspect. These aspects were recorded at 12% of total sites surveyed and not one of these sites recorded Crofton. This is supported in the literature as Crofton is susceptible to frosts (Parsons and Cuthberston 1992), and frosts will remain in the landscape longer in places were these aspects are found. This is a potential management application, but will require the building of temporary structures or the planting of frost resistant native plants that can create shade to prolong the influence of frosts and thus may inhibit Crofton weed establishment.

The composite map of Lantana was more useful in that Lantana may favour a particular combination of environmental attributes for it to establish without the aid of a disturbance. The attributes include the Watagan soil, Narrabeen geology and shale gully forests vegetation type. When these environmental attributes are together Lantana will most likely to be found. Lantana was usually very common and if it was absent, the site was adjacent to native bush and no disturbance was evident. It was however, not uncommon for Lantana to exist on this combination of attributes without a disturbance. Lantana did however require a disturbance to exist outside areas were this combination of environmental attributes are not found. Although Lantana occurrence was minimal outside of this combination, were it was found it was not unusual for it to record high abundance levels.

The GIS analysis of both the environmental and cultural characters illustrate that Lantana propagules, like Crofton weeds, are most probably present throughout the entire RNP region and will establish on most combinations of environmental attributes that occur throughout the region as long as a disturbance is present. Lantana does however favour the environmental attributes Watagan soil, Narrabeen geology and shale gully forests. Its presence especially in shale gully
forests and rainforests (vegetation communities of high conservation values) in the southern section of the park suggests that this weed should be declared noxious (refer to Appendix D) in all local government areas surrounding the RNP.

The majority of weed species studied were not so much associated with the environmental characters in the landscape, but by the cultural characters that exist at each site. For the GIS to accurately predict weed distribution for areas not covered by field survey work the utilisation of aerial photographs or other land-use maps would be required. By mapping the cultural characters in the landscape known to encourage weed invasion from these resource maps it would be possible to identify and map current and probable sites of weed infestation over large areas (Smith et al. 1995). When association between a weed and a land-use feature is determined each relevant feature can be digitised and imported onto a GIS and displayed as a map illustrating weed occurrence.

Although time in the field will always remain an essential part when exploring the natural environment, field survey work is generally expensive and time consuming and any method that can reduce the cost of such work should be explored. Also by reducing the time required in the field more time and resources can be put towards effective and lasting weed management actions on the ground. The cultural attributes in the landscape that promote weed occurrence, for example a disturbance, would most likely be highly visible on aerial photographs. Natural disturbances such as fire and wind would also be easy to map. There will however be instances were it will not be possible to map all areas of disturbance etc, as the area of interest may contain a plant overstorey component making the identification of the weed species difficult at ground level. Unfortunately for this research, current aerial photographs or the relevant resource maps were not available.

Once areas requiring weed control have been detected, weed removal projects in the RNP need to be developed at a catchment level and should involve all relevant private and public landholders. Landholders fringing the RNP include the State Rail Authority, Roads and Traffic Authority and private landholders. Collaboration and consultation between the National Parks and Wildlife Service and these landholders is essential. Appropriate and adequate information and education must also be provided to the broader community. For example an education program may involve
the distribution of pamphlets and the erection of signs identifying the weed species that are being removed and the indigenous plants that are being re-introduced. Ways to prevent or limit a disturbance to the park boundary also need to be discussed in both the professional and broader community.

Once the source of weed seeds and propagules has been managed, when removing the last of the weeds, always work from areas with little or no weeds, towards weed infested areas. This way the spread of the weed is being controlled and the bushlands natural regeneration will also be enhanced. It may also be necessary to let native plant regeneration dictate the rate of weed removal. For example if few weeds and many natives regenerate (or if the ground remains weed free) it is obvious that little time will need to be spent re-weeding a site (Buchanan 1989) and the weed population has been successfully contained. Further the likelihood of weeds returning will be dramatically reduced if native plant species are occupying the landscape or the landscape has been altered to reduce weed invasion. If adequate funding and time is available complete removal of a weed from the landscape is possible. The creation of a native plant screen to absorb weed seeds and propagules along sections of the boundary not adjacent to native bush is highly recommended.
Chapter Six

Conclusion

Geographical Information Systems (GIS) provide opportunities for exploring spatial relationships between plant species location, to the cultural and environmental attributes present in the landscape. Without GIS analysis this exploration may otherwise be extremely time consuming and expensive (Smith et al. 1995). These systems should be utilised in the construction of weed database. With the addition of digital maps containing geographical, cultural and environmental attributes present on the landscape, areas of actual and probable weed occurrence can be accurately illustrated on a scaled geographical map. Arcview®, produced by ESRI (1996), was found to be an effective GIS both in raster and vector formats.

The information presented in this research suggests that all of the weeds studied require a non-specialised landscape to be present along sections of the Royal National Park boundary. If their propagules are present, each weed will establish wherever space is made available. All are not so much influenced by the environmental characters (the data layers, ‘soil’, ‘vegetation’, ‘geology’, ‘fire frequency’ and ‘topography’), but by the cultural characters in the environment, such as a disturbance, stormwater run-off and what land-use is adjacent to the park boundary. Lantana also showed the ability to occur regularly in landscape where these cultural attributes are not found. Lantana’s occurrence could be accurately mapped from its regular association to a combination of environmental attributes present in the region. The combination of environmental attributes included the Watagan soil, Narrabeen shale geology and shale gully forest vegetation type. Where this combination of environmental attributes occur Lantana is expected even if a disturbance is not present.

With the majority of weed infestations, however, associated to the cultural characters in the landscape, these characters and their associated attributes need to be located geographically and entered into a GIS. If they are mapped over the entire RPN region, accurate maps of weed infestation could be produced. The digitising of aerial photographs or land-use maps would in most cases provide this type of information. With this information together with expert knowledge on the topic of investigation (autecological studies on each weed species of interest, as presented in

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Chapter 2), the GIS could also be used an aid in the decision making process. If we understand weed ecology, and can map present and potential weed distribution, and attach attributes responsible for weed infestation, then we will be able to rectify or manage more appropriately these landscapes in the future. Also field time will generally be reduced and more time and resources can be put towards effective and lasting weed management actions on the ground. Also if a disturbance is responsible for the majority of weed invasions along the park boundary, then all disturbances in and adjacent to the RNP need to be limited or contained as much as possible.

With the urban fringe usually providing weed propagules and in most cases a minor physical disturbance on the park edge, a weed control zone of no more than 50 metres into the park is necessary at the majority of weed occurrence sites, along the RNP boundary. Weed control work would only be required up to 250 metres into the park for locations on those parts of the boundary that are adjacent to urban areas, contain a large disturbance or stormwater water run-off is found. Although all of the weed species studied have shown the ability to be 'environmental weeds' in other regions, only Lantana was filling this potential. Crofton occurrence in particular suggested that, although Crofton weed was very common along many sections of the park boundary, its occurrence was usually the result of a disturbance and was not regularly occurring at sites that are undisturbed. It was not regularly associated to any of the environmental attributes studied, although the 'aspects' west and southwest never contained Crofton. Privet, Blackberry and Cassia also did not show any regular association to the environmental characters and also did not occur frequently enough at the sites surveyed.

Figure 6.1 illustrates locations were weed control measures are recommended. They are directed to those sections of the RNP boundary that lie adjacent to urban areas (highlighted by a 500 metre buffer zone), are disturbed, and areas that absorb and accommodate stormwater run-off and infrastructure (riparian zones). The areas where the environmental attributes, Watagan soil, Narrabeen shale geology, and shale gully forest vegetation type overlap is also included as an area recommended for future weed control work. Shale gully forests are considered to be of high conservation value and Lantana needs to be identified early if its establishment and occurrence in these areas is to be limited and contained. The creation of a native plant screen to absorb weed
seeds and propagules along sections of the boundary not adjacent to native bush is highly recommended.

Figure 6.1 Areas recommended for immediate weed control works.
References


Appendix A: Field data collection sheet.

**Data sheet for weed survey of the boundary of the Royal National Park, Sydney.**

<table>
<thead>
<tr>
<th>1. Site no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of collection: Name of collectors:</td>
</tr>
<tr>
<td>2. EASTING:</td>
</tr>
<tr>
<td>3. NORTHING:</td>
</tr>
<tr>
<td>4. What is adjacent to the boundary</td>
</tr>
<tr>
<td>5. Drainage</td>
</tr>
<tr>
<td>6. Soil pH</td>
</tr>
<tr>
<td>7. Evidence of a disturbance</td>
</tr>
<tr>
<td>8. Croton weed present</td>
</tr>
<tr>
<td>9. Lantana present</td>
</tr>
<tr>
<td>10. Privet present</td>
</tr>
<tr>
<td>11. Cassia present</td>
</tr>
<tr>
<td>12. Blackberry present</td>
</tr>
<tr>
<td>13. Distance each weed has traveled into park.</td>
</tr>
<tr>
<td>Croton m</td>
</tr>
<tr>
<td>Lantana m</td>
</tr>
<tr>
<td>Privet m</td>
</tr>
<tr>
<td>Cassia m</td>
</tr>
<tr>
<td>Blackberry m</td>
</tr>
<tr>
<td>14. Do any of the weeds above occur 100m from the site?</td>
</tr>
<tr>
<td>15. Are there other weed species present?</td>
</tr>
<tr>
<td>16. Cover of native vegetation</td>
</tr>
</tbody>
</table>
APPENDIX B: Results of Field Survey
<table>
<thead>
<tr>
<th>SITE NUMBER</th>
<th>SITE LOCATION</th>
<th>SOIL PH</th>
<th>DRAINAGE</th>
<th>EVIDENCE OF DISTURBANCE</th>
<th>WEED SPECIES PRESENT AT SITE</th>
<th>METRES IN THE PLOT AREA</th>
<th>PROPAEDES ADJACENT TO THE PLOT</th>
<th>OTHER WEED HABIT</th>
<th>COVER OF NATIVE VEGETATION</th>
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<td>0</td>
</tr>
<tr>
<td>6</td>
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</tr>
<tr>
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<tr>
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<td>200</td>
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<td>Mixed</td>
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<tr>
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<tr>
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<td>Site W</td>
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</tr>
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</table>

**Legend:**
- **Soil PH:** Natural, Altered
- **DRAINAGE:** Natural, Continuous
- **EVIDENCE OF DISTURBANCE:** No, Absent
- **WEED SPECIES PRESENT AT SITE:** Various species listed
- **METERS IN THE PLOT AREA:** Various values listed
- **PROPAEDES ADJACENT TO THE PLOT:** Various distances listed
- **OTHER WEED HABIT:** Various types listed
- **COVER OF NATIVE VEGETATION:** Various types listed
APPENDIX C: Requirements of weed control

All weed control techniques have the potential to benefit native species at the expense of the introduced species. All of the weed control techniques outlined below are best integrated depending on the location and type of weed infestation and are relatively useless unless rehabilitation or revegetation of the native vegetation occurs. It will be also necessary to follow up weed control work, sometimes as long as 10 years after the initial treatment or at least until the native vegetation is established at ground and overstorey levels. Current weed control techniques available to land managers in natural bushlands include physical removal, spraying with herbicides, biological controls, and the use of competing plants.

Physical removal

Mechanical clearing of weeds in natural bushlands is usually inappropriate unless large independent stands of weeds occur. The individual pulling out of the weeds is often more appropriate, and methods of such techniques were developed by the Bradley sisters (Buchanan 1989). There technique was originally intended for weeds occurring in the coastal heathlands and woodlands of the Sydney region but can be applied to all vegetation types across Australia provided adequate labour is provided (Groves 1991). It involves the hand pulling or mattocking out of all weed species, taking care in minimising the disturbance to the native plants and ground. It is also best practice to bag and remove all of the weed seeds and propagules before attempting to physically remove the weeds. For all of the weed species studied physical removal is possible, although some specimens of Privet can be large trees. Also the dense growth forms of Blackberry and Lantana and the difficult terrain these weeds are often found in may also restrict their physical removal.

Fire can be used to physically reduce the abundance of weed species. It also promotes the growth of native species and limits the regeneration of some weed types. It may also be useful in removing dead weed debris that has had a herbicide applied to it. When using fire a mosaic pattern to a burn is best and the season of the burn is important, as is the frequency and intensity of the burn. For example a high intensity fire will generally favour the regeneration of hard-seeded legumes and
limit the growth of seed-regenerating proteaceous species. High intensity burns will also reduce and in most cases completely remove all the vegetation and biomass. This will increase the availability of seed 'safe sites' (Harper et al. 1965) and as a result fire may actually increase weed infestations. If fire is to be used, it should be integrated with other control techniques and knowledge of its effect on the weed and on the native vegetation should be gathered along with the relevant fire permits and supervision. It must also be noted that fire to control weeds may not be appropriate in some vegetation types such as rainforests.

Physical control of weeds may also include altering the landscape. If weeds are associated with increased water run-off then the weeds will only be effectively managed in the long-term if the drainage of the area is rectified to limit weed infestation. The building of settling ponds or re-contouring the land to minimise water run-off may be a viable option. The building of structures may also inhibit weed establishment. For example if a weed is susceptible to frosts, such as Crofton weed, then the building of a temporary wall etc, to increase the amount of time the weed is exposed to frost may limit its establishment.

The use of boiling water to kill weeds is also possible and would have no long-term effects on the natural landscape, as no chemicals or physical disturbance to the environment is necessary. Soil compaction is another unconventional method to control weeds and involves the compaction of the soil to prevent weed seeds from finding 'safe sites' (Harper et al. 1965). This prevents their roots from penetrating the soil surface. Although this technique is not appropriate within native ecosystems that are to be restored, it is highly appropriate on the fringes of these areas and in places where there is high usage and weed infestation is already common and cannot effectively be reduced. If soil compaction is an option then a native plant buffer zone between the area of compaction and the park is required. Also soil compaction should not be applied to areas where water run-off is common as this will lead to weed propagules and soil erosion moving further down the catchment area.

**Herbicide control**

Whether or not to use herbicides is sometimes a difficult decision. The safety of a particular herbicide to the person spraying the herbicide, its effect on desirable plants, neighboring
properties, soil micro-organisms, fish, birds and mammals should always be a factor in making the decision. However, herbicides should be seriously considered when there are dense stands of weeds or where weeds are growing very rapidly. They are also useful on areas with potential erosion problems and on large trees – when felling or digging up their roots is a dangerous, expensive or a time-consuming exercise (Buchanan 1989). At present herbicides are registered for use on particular weeds and the recommended dosage rate should be followed. For example Roundup® a commonly used herbicide to control weeds in natural bushlands is a systemic, non-selective, knockdown herbicide (Buchanan 1989). Roundup® is comparatively safe for the operator and is inactivated immediately in the soil. It is therefore 'safe' to use carefully in a native bushland, as there is very little chance of it moving through the soil to desirable plants or preventing the germination of native plants. One potential risk of Roundup® to natural ecosystems is, if used regularly in the same environment increased levels of estrogen may buildup in the soil, possibly leading to a decline in male plants and subsequently affect genetic diversity.

Regular herbicide application along the park boundary should be considered to a region 500 m around the areas fringing urban areas, disturbance sites and stormwater infrastructure. The time of herbicide application is important. Most herbicides including Roundup® should only be applied when water and sugars are being rapidly translocated around the plant. This is usually when the weeds are actively growing (this is in the summer months for the five weeds studied) and not suffering from stress, and when transpiration is rapid (Buchanan 1989). Herbicides do not effect the seed or the seed capsules of weeds so before the application of a herbicide, all the ripe propagules should be removed from the weed where practical. Also a herbicide should not be applied if rainfall is expected within six hours of the application time.

**Biological control**

With the exception of Prickly Pear there have been relatively few successes to eradicate and control weeds in Australia using biological control techniques. This is unfortunate as a classical biological control is generally targeting specific and can operate over a large area. However they are expensive to implement (because of the technology and the necessary involvement of international activities) and control if achieved (only 25 to 40% success rate) is usually achieved
only in the long-term. Furthermore they are suited to only some plant groups (Groves 1991, Leys 1996).

At present, a number of biological control programs are in progress for weeds in natural ecosystems. They are usually integrated with other management techniques such as the use of fire and herbicide application (for example Bitou Bush is being treated in Jervis Bay National Park). Biological control results of Lantana have been mixed at best. Leaf miners particularly *Uroplata girardi* have shown some promise and has reduced the competitiveness of the weed in many areas. A mealy bug, *Phenacoccus parvus* has also shown promise, however it is unfortunately active on a number of useful plant species (for example the potato and tomato) and thus is not widely recommended (Swarbrick 1989). NSW Department of Agriculture is testing a Mexican bug (*Aconophora compressa*) on Lantana. Although no results are available to date, the bug was recently released in 38 locations along the NSW coast and has the potential to be very successful.

For the other weed species studied, only Blackberry at present may be controlled with a biological control. The fungus *Phragmidium violaceum* has been released on Blackberry with some success. If a biological control is found to be effective and safe for release on any weed species it should be introduced as soon as possible (Groves 1991).

**Promotion of native plant species**

The promotion of native vegetation or bush regeneration is paramount to the success of any weed control program. It is not possible to have a successful weed control program unless indigenous plant species are put in place of the newly eradicated weed species. Techniques to promote native species may be achieved by simply reintroducing indigenous or native plants back into an area, or by strategically applying nutrients to favour the native species. Both techniques are useful and the effects of competition by native species on weeds should not be overlooked. Some native plants will have the ability to shade out weeds because of differences in growth form, for example *Acacia mearnsii* De Wild. will shade and prevent fennel from re-establishing. They may also prolong the effects of frosts and if a similar root system is evident between a weed and a native, competition for
soil moisture through the summer months may be possible, for example Themeda triandra Forssk. with H. perforatum (Humphries et al. 1991). Furthermore some native species by means of soil alleopathy may be able to change the chemical make-up of the soil and restrict weed establishment. Native pine species, such as the Casuarina's have this ability and may be introduced along drainage channels and stormwater culverts. For these types of approaches to be successful autecological studies on the native plants to be introduced into an area are required. The findings of these studies will need to be compared to autecological studies on the weeds they will be forced to compete against (Humphries et al. 1991).

**Economic requirements of weed control**

Although weed control and bush rehabilitation are considered necessary, funding is usually either not available or inadequate. Economic rationalism is required and unfortunately there is a significant cost involved in controlling weeds in natural bushlands without any real economic gains. With funding limited to those weeds declared noxious, other weed species are simply replacing the noxious weeds. Their establishment is often just as damaging to the environment and they are just as aesthetically unpleasing to the eye. All weed species establishing in areas set aside for nature conservation should be declared noxious (Appendix 2) and until this is accomplished, funding for weed removal in natural ecosystems will remain scarce.

The funding available to local and state agencies supports a wide range of expertise in weed control, from a pest species research officer to a weed spray operator. Private contractors take up the bulk of available funding for weed removal projects and what funding is left is used for ongoing research into weed control (weed surveys etc) or maintaining volunteer bush regeneration programs. Weed surveys are fundamental to weed control and volunteer bush regeneration programs are proving to be highly successful. They have been developed and are operated at both the local and state levels of government and their participation rates are increasing annually. They involve groups of volunteers locating themselves at various sites identified as having a weed problem and remove the weeds and rehabilitate the area with native plants. Once the volunteers are trained they require minimal supervision and provide an opportunity to continually monitor and control weeds at sites.
Appendix D: Noxious Weed legislation in New South Wales

Weed legislation in Australia was first considered necessary in 1851. This was in South Australia and in recognition of what is now known as the variegated thistle and spear thistle. Legislation to prevent weed invasion was introduced to N.S.W some years later (Parsons and Cutherbertson 1992) and if used appropriately can be a useful tool in controlling noxious weeds.

In N.S.W under the Noxious Weeds Act 1993 (NWA), the Minister for Agriculture can, by order published in the Gazette, declare a plant to be a noxious weed, either throughout the whole or part of the State. When considering a native plant species for noxious status the Minister for the Environment must also be consulted (NWAs.7). The provisions of the NWA do not cover prickly pear, which is dealt with separately under the Prickly Pear Act 1987 (Farrier et al 1999).

Plants are declared noxious by the Minister of Agriculture on recommendations from a Noxious Plants Advisory Committee established principally under Part XX11 of the Local Government Act 1919 (No. 41) as amended (Parsons and Cutherbertson 1992). The committee members are appointed by the Minister for Local Government and include:

- A chairperson, nominated by the Minister for Agriculture and Rural Affairs;
- An officer of the Department of Local Government;
- An officer of the Department of Lands;
- A director of a Pastures Protection Board;
- A member or officer of the State Pollution Control Commission;
- A person nominated by the Shires Association of New South Wales;
- A person nominated by the Shires Association of New South Wales who is a member of a county council established for the control of noxious plants; and
- A person nominated by the Water Resources Commission

Although this committee is responsible for having a plant species in N.S.W declared noxious it is not responsible for controlling noxious weeds. Its principle aim is to consider applications submitted by local councils for noxious weed declaration and to consult with landholders and the Minister for Agriculture on matters relating to noxious weeds and recommending the allocation of
funds for noxious weed control. The *Noxious Weed Act 1993* states that the responsibility for controlling noxious weeds lies with:

- Occupiers and owners of private land;
- Occupiers of Crown land, including land held under lease or license;
- Local councils on land they occupy;
- The Western Lands Commission, on any Crown land in the Western Division which it occupies, and which does not fall within any local government area;
- Rural lands protection boards in areas under their control; and
- Public authorities (such as the National Parks And Wildlife Service, State Forests and government departments (Farrier et al 1999)

Under the *NWA 1993* weeds are categorised according to the action required for their control. This takes into consideration the extent of the weed infestation, available control methods, and the threat of further spread or damage. The four categories of control are:

- **W1 (Notifiable).** Landholders must notify their local council within three days and must fully and continuously suppress and destroy the W1 weed.
- **W2.** Landholders must fully and continuously suppress and destroy W2 weeds.
- **W3.** Landholders must prevent the spread and reduce the numbers and distribution of W3 weeds. These weeds are usually so widespread that total suppression and destruction is impractical.
- **W4.** There were no W4 weeds listed in the Act. The action specified in the declaration must be taken in respect of the weed. That is a plant may be identified as a threat to the environment and has the potential for spread but requires specific action other than those listed above. These may include actions to prevent a plant from being sold, propagated or knowingly distributed. It may also aid in the removal of large weed trees or at least aid in preventing them from flowering and fruiting (Farrier et al 1999).

If for some reason funds are not available ministers in charge of a public authority with a weed control notice issued can appeal to the Premier for settlement (NWAs.65). Private land holders who fail to act on a weed control notice can appeal to the Land and Environment Court (NWAs.25) for settlement. Also the Local Control Authority (LCA is usually the local council) or the Minister for
Agriculture can carry out control measures and claim the costs from the occupier if a settlement is not reached. If it is a public authority the Premier's approval must be obtained before action is taken (Farrier et al 1999).

An associated method of legislative control is the federal Quarantine Act 1908. It has been successful in keeping some plants undesirable to agriculture out of this country. At present a revision of the legislation is necessary and gaps in coverage will still occur until our knowledge of species' attributes associated with weediness, especially those that invade natural bushlands is substantially increased (Groves 1991). An allied aspect of legislative action is to prevent the propagation and sale of declared noxious species. Similar controls have been suggested for plants known to be invasive, or potentially so, in natural bushlands and greater education for the whole community is necessary to stop the sale of noxious plants (Carr 1988).

6.1 Problems with weed legislation for controlling weeds in natural bushlands
There are many difficulties in adhering to, or enforcing weed legislation in natural vegetation communities. Difficulties with weed legislation for these areas are listed in the National Weed Strategy (1997) and include:

- The objectives of weed legislation have not always been clear and appropriate to the situation.
- Forcing reluctant landholders to control weeds may be a long slow process. By the time enforcement can be legally implemented, the weed may have already spread to new areas.
- Failure of landholders to report infestations for fear they will be required to undertake control measures which are no obvious benefit to them, at least in the short term.
- Local Control Authorities (LCAs) have not always harmonised legislation to address situations where a weed is declared noxious in one LCA but not in an adjoining LCA.
- Governments have not always provided sufficient personnel to implement weed legislation effectively.
- Weeds legislation has generally focused on weeds of agricultural significance
- There has been an expectation by most stakeholders that weeds legislation alone is sufficient to solve many weed problems. Hence, action taken under weed legislation has generally not been integrated into other land and water management programs or undertaken strategically.
Obviously these shortcomings will have to be addressed if weed legislation is to be effectively used for controlling and minimising weed invasion in natural bushlands in the future.