Management of *Acacia* species seed banks in the Table Mountain National Park, Cape Peninsula, South Africa

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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Abstract

Within the Table Mountain National Park (TMNP), Western Cape, South Africa, various management practices have been undertaken in the removal of alien vegetation. While considerable success in the control of alien plants is evident from the removal of standing plants, it is not known if this effort has actually made any long-term difference in the effort to eliminate alien vegetation from the TMNP. This is because no coordinated effort has been made to assess the extent of the alien seed bank, nor the effect that clearing (including the use of fire) has on this seed store.

This study investigates the extent of pre- and post-fire *Acacia saligna* seed banks under differing stand ages, differing clearing techniques and different habitats in the Cape Peninsula National Park. Firstly, the focus is on two alien plant management techniques: The first technique involves clearing and stacking of biomass for burning during winter (stack burn technique), the second technique involves burning of standing alien plants (standing/block burn technique) to decrease heat release at the surface. Secondly, the extent of *Acacia* species seed banks along the Silvermine River is also investigated with the aim of determining the extent of alien seed stores in this habitat and therefore the long-term restoration potential of the riparian corridor.

The primary question addressed in the first study is: “Under what clearing technique will most of the alien seed bank be reduced?” The secondary question reads: “Is seed bank density and distribution directly related to age of dense infestation of the alien vegetation stand and habitat?” The primary question addressed in the second study is: “What is the vertical, lateral and longitudinal distribution and density of *Acacia* species seed banks along the Silvermine River?” The secondary question reads: “Is seed density and distribution influenced by above ground density of alien vegetation?”

In both riparian and terrestrial systems, alien soil seed banks accumulate in high densities where aboveground alien *Acacia* vegetation is dense. Most of the seed occurs in the upper soil layer, but seed density decreases with depth with an exception of a high seed density at a low depth in one of the samples in the riparian system. Intense fires are most effective in reducing seed stores and removing aboveground alien vegetation in both riparian and terrestrial fynbos systems.

After burns, both stack and stand burns have shown a significant decrease in seed density especially in the upper layers but there is still much seed that remained in the matrix area between stacks. The cooler winter burns resulted in less destructive, lower temperatures that aided higher seedling recruitment. Mature stands of *Acacia saligna* tend to have greater seed stores than immature stands and habitats with deep colluvial soils have a greater density and also greater vertical distribution of seeds.

The vertical distribution of the riparian system differed from the fynbos terrestrial system in that seeds were found down to lower depths. Along the river, seed density also increased laterally with more seeds occurring in the terrrestrial sections than in the channel. Seed density increased with longitudinal distribution with more seeds occurring at the sites in the lower catchment than upper catchment.

Managers should be aware that fire is needed to reduce the seed bank in both riparian and terrestrial fynbos systems. The cooler winter stack burns is the best option as it results in less destructive, lower temperatures that aids higher seedling recruitment. It is important to know the site history as age of dense infestation, number of fires and geology of site could influence seed bank density. In riparian systems the vertical distribution of seed is deeper than in the fynbos area. In order for clearing to be effective it is imperative that follow-up takes place and should be done prior to flowering to stop reseeding.

Keywords: alien plant management techniques, fire, Fynbos, riparian systems, soil seed banks

Uittreksel

Die Tafelberg Nasionale Park, Wes-kaap, Suid- Afrika gebruik verskeie metodes om ontslae te raak van die uitheemse indringer plante. Alhoewel suksesvolle beheer van hierdie plante sigbaar is, word ’n langtermyn verskil betwyfel. Die rede hiervoor is dat daar geen moeite gemaak word om vastestel wat die grootte van die saadbank is nie, of wat die effek van die verwydering van die plante (insluitend die gebruik van vuur) op die saadbank is nie.

Hierdie projek bestudeer die invloed van vuur op die saadbank van *Acacia saligna* onder verskei verwyderings metodes en verskillende stand ouderdomme binne die Tafelberg Nasionale Park. Die klem lê op twee eksotiese plant bestuur metodes: Die eerste metode is waar skoongekapte uitheemse plante in hope gestapel word en gedurende winter onder kontrole verbrand word; die tweede metode is waar staande uitheemse plante gedurende winter onder kontrole verbrand word. Die hoeveelheid van *Acacia* spesies saadbank langs die Silvermyn Rivier word ook vasgestel met die doel om die restorasie potensiaal van die rivier te bepaal.

Die primêre vraag in die eerste studie is: Watter metode sal die meeste van die saadbank verwyder? Die sekondere vraag lui: Is die saad bank direk gekoppel aan ouderdom van eksotiese standdigtheid en houplek? Die primêre vraag in die tweede studie is: Wat is die vertikale en laterale en horizontale voorkoms en digtheid van *Acacia* spesies saadbank langs die Silvermyn Rivier en word saadbank digtheid en voorkoms direk beïnvloed deur digtheid van die bogrondse uitheemse plante?

In beide fynbos en rivier sisteme, akkumuleer eksotiese saad banke in groot mate waar bogrondse uitheemse *Acacia* plantegroei dig is. Meeste van die saad kom voor in die boonste grond laag and saad digtheid neem af met diepte maar daar was `n uitsodering in een van die monsters in die rivier sisteem waar `n groot hoeveelheid saad diep in die grond gevind is. Vuur met hoër temperature is meer effektief vir die vermindering van die saad bank sovel as die verwydering van die bogrondse uitheemse plante.

Beide metodes, waar gestapelde hope uitheemse plante gebrand is en waar staande uitheemse plante gebrand is, het gelei tot `n afname in die hoeveelheid saad in die grond maar baie saad het nog oorgebly in the areas tussen gestapelde hope uitheemse plante. Die brand van gestapelde hope uitheemse plante in winter ly tot minder hitteskade en lae temperature, wat veroorsaak dat meer saailinge ontkiem. In stande met hoër ouderdome kom daar meer saad voor en in stande waar die houplek dieper sand het kom daar ook meer saad voor en saad word gevind dieper in die grond.

Die vertikale voorkoms van saad in rivier sisteme is verskillend omdat meer saad hier voorkom tot diep in die grond as in fynbos areas. Langs die rivier is daar `n laterale toeneem van saad digtheid waar meer saad voorkom op die wal van die rivier as in die kanaal.

In beide fynbos en rivier sisteme, is vuur nodig vir die bestuur van *Acacia* om effektief die saad bank te verminder Die verbranding van gestapelde hope eksotiese plante in winter ly tot lae temperature wat veroorsaak dat meer saaiplante onkiem. Dite is belangrik om die geskiedenis van die studie area te ken want ouderdom van stand digtheid, hoeveelheid vuur en geologie van die houplek het `n invloed op die digtheid van die saadbank. In rivier sisteme is die vertikale voorkoms van saad dieper in die grond as in fynbos areas. Saad beweeg van die booste opnvangebied na die onderste opvanggebied.

Sleutelwoorde: Eksotiese plante bestuur metodes, vuur, Fynbos, rivier sisteme, grond saad banke

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CHAPTER 1: GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 Thesis structure

The thesis is divided into four chapters. The first is a general introductory chapter, which includes motivation for this thesis, outline of key questions and a literature review. Chapter two investigates the extent of pre- and post fire *Acacia saligna* seed banks under various stand ages and various clearing techniques in the Table Mountain National Park. Chapter three looks at the distribution and density of *Acacia species* seed banks along the Silvermine River, Cape Peninsula National Park. Chapter four is the concluding chapter.

1.2 Rationale and motivation

In South Africa one of the biggest tasks reserve managers face is clearing of alien plants (van Wilgen *et al.* 1992). In the Cape Floristic Region alien plants are one of the major threats to biodiversity (Rebelo 1992) as they result in ecosystem processes being altered and local biodiversity being reduced (Richardson *et al.* 1992). Unlike most of the rest of the country where riparian invasions tend to dominate, the Western Cape differs in that both landscapes and rivers are invaded (Versfeld *et al.* 1998).

Stands of alien trees also reduce total annual and low-season stream flow (Bosch and Hewlett 1982, Dye and Jarmain 2004) and increase evaporation, thus leading to reduced mean annual runoff. Riparian areas are the most impacted ecosystems in southern Africa (Macdonald and Richardson 1986) as they are particularly vulnerable to invasions. This vulnerability results from the physically dynamic nature of riparian areas with changes in flows especially floods, altering riverbeds and exposing bare soil for the colonisation by weeds (Versfeld *et al.* 1998).

In the South Western Cape of South Africa, within the fynbos biome, *Acacia saligna (Andr.) Willd.*, *Acacia cyclops* A. Cunn. Ex G.Donn., and *Acacia longifolia* (Andr.) Willd. are the most important invaders, particularly in the lowlands (MacDonald and Jarman 1984). Clearing of these alien plants is not an easy task though, the major reason being that these *Acacia*s produce hard impermeable seeds and have large soil stored seed banks (Milton and Hall 1981, Holmes *et al.* 1987, Pieterse and Boucher 1997). *Acacia* seeds have the potential to remain viable in the soil for long periods of time, with *Acacia saligna* being very long-lived (> 50 years, Holmes and Moll 1990). Fire plays a major role in maintaining fynbos biodiversity and ecosystem functioning and under natural conditions, heat from a fire breaks *Acacia* seed dormancy resulting in germination, sometimes on a massive scale (Jeffery *et al.* 1988).

Fire is beneficial for the germination of hard-coated seeds in the soil and has been proposed as a process that can be used as a management tool to control the large soil stored seed bank in the soil under Australian *Acacias* (Milton and Hall 1981, Henry and van Staden 1982, Holmes *et al.* 1987, Pieterse and Cairns 1987, Holmes 1989).

The current practice of stacking leads to a higher concentration of dead fuel (Scott *et al.* 2000) concentrated close to the surface which increases heat release and leads to increased soil temperatures developing during fires (Holmes 1989, Scott *et al.* 2000, Euston-Brown 2001). Such fires have been shown to have adverse effects on soil, vegetation and fauna (Breytenbach 1989, Macdonald *et al.* 1989, Martens 1997, Euston-Brown 2001, Holmes *et al.* 2001, Scott *et al.* 2000). Thus the method of burning aliens standing is being used in order to decrease heat release at the soil surface (Holmes 2001). Even after clearing though, there is still much seed that remains in the seed bank. It is therefore important to assess the extent of the alien seed bank, and the effect that clearing (including the use of fire) has on this seed store. The management techniques should not only be focused on reducing alien seed banks but should also focus on ensuring minimal damage to soil, fauna and flora.

1. 3 Research objectives

There are two components to the study:

1. An investigation into the extent of pre- and- post *Acacia saligna* seed banks under differing stand ages and differing clearing techniques

The following key questions were asked in this study:

- 1.1 Does the method of alien clearing (stack burn vs standing burn) influence the density or proportion of alien seeds available for regeneration in a post-clearing, post-burn environment?
- 1.2 Does seed bank size change with soil depth?
- 1.3 To what extent does age of dense infestation influence seed bank distribution and density?
- 1.4 To what extent does habitat (shallow mountain soils versus deep colluvial valley soils) influence seed bank distribution and density?

2. An investigation into the extent of *Acacia* species' seed banks along the Silvermine River

The following key questions were asked in this study:

- 2.1 What is the distribution and density of the *Acacia* seed bank in:
  - a) areas along the river that have been cleared successfully (as indicated by good natural vegetation recovery or decrease in alien species present) compared to:
  - b) areas still requiring active follow-up clearance (indicated by poor natural vegetation recovery or where the alien vegetation density has not declined much)
- 2.2. How variable in size are the seed banks longitudinally (from top of the catchment to the bottom) and laterally (from the river channel to the dry terrestrial banks) and vertically (with soil depth)?

1.4 Literature review

1.4.1 Ecological impacts

Fynbos shrublands are a major component of the floristically distinctive Cape Floristic Region: a region with high species endemism and the highest recorded plant species density for any temperate or tropical region in the world (Cowling *et al.* 1992). The Cape Floristic Region contains between 9000 and 9550 indigenous vascular plant species, almost 69% of which are endemic. Of this 69%, 7.5% are endemic to the Cape Peninsula alone an area of approximately 4.7 x 10^3 km ^{2} containing 2250 species (Goldblatt and Manning 2000). Many of the species are endemic and a large number of these species occur in the Red Data list of rare and endangered species. According to the IUCN criteria, 141 plant taxa are classified as threatened with at least 39 that have become extinct on the Cape Peninsula in the 20^{th} century (Trinder-Smith *et al.* 1996). The survival of this unique floral diversity of the Cape Floristic Region is threatened, due in part to the successful invasion of natural habitats by alien plant invaders (Hall and Boucher 1977, Stirton 1978, Macdonald *et al.* 1989).

Once established, woody alien plants significantly modify community structure, alter ecosystem processes, reduce local biodiversity and subsequently threaten numerous taxa with extinction (Macdonald and Richardson 1986, Richardson *et al.* 1992, Holmes and Cowling 1997, Fleitman and Boucher 2001). The loss of populations of indigenous plants is a serious threat as many fynbos species occur in isolated, small populations (Trinder-Smith *et al.* 1996), but it is also important to protect common taxa and widespread populations as they contain vital reservoirs of genetic diversity Monotonous alien stands replace diverse indigenous flora, decreasing the diversity and beauty of the landscape (Hall and Boucher 1977), resulting in lowered aesthetic, recreational and scientific value of fynbos (Kruger and Bigalke 1984, Marais 1998).

Indigenous fynbos species are generally adapted to conditions of low soil nutrients (Macdonald and Richardson 1986) and compete unsuccessfully on enriched soils (Specht 1963). Habitat modification by the *Acacias* has thus been one of the main attributes resulting in displacement of fynbos by these aliens. This includes the mineral enrichment of soils (Musil and Midgley 1990) through the mycorrizhal associations formed where *Acacia saligna* has been shown to accumulate more phosphorous than indigenous plants (Hoffman and Mitchell 1986). Under *Acacia* plots higher concentrations of available nitrogen have also been found (Yelenik *et al.* 2004) as these leguminous plants may fix atmospheric nitrogen. This mineral enrichment is associated with an increased litterfall mass (Milton 1981) and litter decomposition rate (Witkowski 1991), where litterfall under *Acacias* are much higher than that under indigenous vegetation and the resulting phosphorous and nitrogen increase is about nine times that of fynbos (Milton 1980). Other factors contributing to the successful invasion of *Acacia* species include copious production of hard leguminous seeds with large soil stored seed banks (Milton and Hall 1981, Macdonald *et al.* 1989, Pieterse and Boucher 1997). They also have high seed longevity, high percentage seed viability and the seeds germinate after fire (Milton and Hall 1981, Pieterse and Cairns 1987, Holmes 1989, Richardson *et al.* 1992, Pieterse and Boucher 1997, Fleitman and Boucher 2001). *Acacia* species are well adapted to the soils of the South Western Cape, which is sandy and poor in trace elements (Milton 1980).

In South Africa, invasive alien trees and shrubs do not only threaten the floristically distinctive fynbos vegetation but also water resources (Richardson *et al.* 1997), with riparian zones being the most impacted ecosystems

(Wells *et al.* 1986). Dense and sometimes impenetrable thickets of alien plants that invade catchment areas increase the biomass thus drawing far more water than the natural vegetation, and as a consequence decrease runoff to a level lower than under indigenous vegetation (Bosch and Hewlett 1982, Dye and Jarmain 2004). In Cape Town, invading woody species are estimated to reduce the total water supply by 30% (Le Maitre *et al.* 1996). The incremental water use of alien invaders in South Africa is an estimated 3300m^3 per year or 6.67% of the mean annual runoff (Le Maitre *et al.* 2000). The excessive use of water by invading alien plants causes reduced usable water supplies for human needs and detrimental effects for the river environment. Where rivers dry up or where flow is seriously curbed, devastating effects on riverine ecology are experienced. Reduced waterflow in critical months causes salinity in some rivers to increase due to the absence of the dilution effect beyond tolerable levels for native plants or for agricultural use (Marais 1998).

Macdonald and Richardson (1986) consider invading woody plant species to severely affect soil erosion and degradation of soils. Accelerated bank erosion has been associated with *Acacia mearnsii, A. longifolia*, *A. saligna*, *Lantana camara* and *Pinus pinaster* (Macdonald and Richardson 1986, Versfeld and van Wilgen 1986, Wells *et al.* 1986). These species establish and grow through the indigenous vegetation that is better adapted to the flash floods that occur in most fynbos catchments. Alien species however have shallow rooting systems which are unable to withstand flash floods that rip out trees or cause bank collapse, often dislodging mats of indigenous riparian vegetation. The exposed mineral soils are then subjected to accelerated erosion, especially on the riverbanks. Dislodged trees may be transported downstream where they form blockages, which in turn lead to further erosion and widening of the riverbed (Enright 2000). Increased erosion has also been noted in terrestrial areas dominated by living alien trees, after burning and especially after clearing followed by burning (Richardson and Van Wilgen 1992). The eradication of invading alien plants can restore a more natural hydrological regime (Enright 2000) but it may take several years before stream flow recovery approaches pre-invasion levels (van Lill *et al.* 1980).

1.4.2 Seed bank dynamics

A seed bank can be defined as an aggregation of detached potentially viable seeds, including seeds present both above and below the soil surface (Thompson and Grime 1979) that are capable of replacing adult plants (Baker 1989). Very little is known about the vertical (Holmes 1990a) or lateral movement of seeds especially in riparian systems (Goodson *et al.* 2001). Much research has been done on the movement of seed by animals (Milton and Hall 1981, Holmes 1990b, Pieterse 1997) which all play a role in the spatial distribution of seeds within certain areas, but the dominant transport medium for seeds in the riparian environment, is water (Davind and Nilson 1997, Goodson *et al.* 2001). Studies have shown that seed density is greatest near the surface, because this is where recent accretion takes place and density then declines rapidly with an increase in depth (Milton and Hall 1981, Fenner 1985, Holmes 1990a) but this may not be the case in riparian systems where there are certain processes, such as erosion and deposition due to flooding which affect the distribution with depth and the composition of seed banks (Goodson *et al.* 2001). It is assumed that due to the dynamic nature of riparian habitats, the propagules of *Acacia* species are rapidly distributed downstream of the initial invasion (Galatowitsch and Richardson 2005).

Longitudinal movement of seeds downstream in river systems can occur, but the distance downstream depends on the floating ability of the propagules (Schneider and Sharitz 1988, Davind and Nilson 1997, Imbert and Lefèvre 2003). While lateral movement is mainly assumed to occur via water, a study done by Bornette *et al.* (1998) showed that rarely flooded habitats suffered from lower species imports, with the lower likelihood of invasion by alien species and relied more upon other means of propagule import such as wind and animal transport. Although invasions by alien invasive plant species along rivers can have negative effects on the diversity of the riparian plant community, it does reveal underlying patterns in the redistribution of seeds by water. Along invaded rivers the vegetation can be reduced to a virtual monoculture that is an indication of the linear dispersal of propagules and if this is the case then one would predict that propagule pressure would be greatest in lower catchment areas and downstream reaches (Galatowitsch and Richardson 2005).

Vertical movement of seed is assumed to occur via the burrowing and seed- caching activities of animals, in percolating rainwater and down wetting and drying fractures or decomposed root channels (Harper 1977). Added to this in river systems, deposition of mineral sediments and litter during floods can affect seed bank composition and recruitment of seedlings in a density of ways (Goodson *et al.* 2001). Greater sediment loads result in lowered and selective recruitment of seeds from the seed bank and burial of more seeds (Nilsson *et al.* 1993). Deposition of litter contains large densities of seeds, which may germinate or be deposited at any given place but at the same time bury other seeds and prevent recruitment (Nilsson *et al.* 1993). In riparian systems deep burial of seeds can occur with seeds being found down to depths of up to 1m (Esler and Boucher 2004). In sand plain fynbos vegetation, burrowing rodents play a significant role in the dynamics of soil-stored seeds, both in exhuming buried seeds and in burying surface seeds (Holmes 1990a). Dispersal of seeds to depths of 35 cm in loose sand may be aided by the burrowing of the dune molerat, *Bathyergus sullius,* and moles, snakes, frogs and insects that are common in sandy areas (Milton and Hall 1981). Ants have been found to be involved in the dispersal of *Acacia* seeds especially *Acacia saligna* (Holmes 1990b, Pieterse 1997) where the burial of seeds may be as a result of indigenous ants (Bond and Slingsby 1983) but may also be important in the shallow burial of *A. cyclops* and *A. saligna* (Holmes 1989). Myrmechory is therefore partly responsible for the build up of seed banks in the upper 10 cm of soil. Wind can also act as an agent in the shallow burial of seeds, especially in and around dunes, and rain can have a slow effect on the downward movement of seed (Holmes 1990a).

Various factors are responsible for the loss of seed. The greater part of the seed bank will probably die *in situ* (Harper 1977). Losses from the seed bank occur through predation, germination, deep burial, attacks by pathogens, physiological death, decay (microbial action) and dispersal to other parts (Harper 1977, Fenner 1985, Holmes and Moll 1990). In riparian systems erosion resulting from flooding, removes a section of the riverbank, exposes new soils and seed banks, resulting in mass germination from existing seed banks (Komulainen *et al.* 1995, Goodson *et al.* 2001). Rodents consume large amounts of seed, which can make up about 50% of their daily diet (Holmes 1990b). Species with persistent seed banks, such as *Acacia saligna*, produce seeds with water-impermeable testae that remain viable for many years in the soil (Bewly and Black 1984, Simpson *et al.* 1989). The density of individuals present as dormant propagules vastly exceeds the densities present as growing plants (Harper 1977). Some seeds may remain viable after 50 years (Holmes and Moll 1990). The seeds remain dormant until conditions are favourable for germination. Although *Acacia* seeds have a high degree of initial hardness in the first year, loss of dormancy and/or pathogenic attacks on seeds does occur (Holmes 1989). Holmes and Moll (1990) found that for *Acacia saligna*, the percentage decay of buried fresh *A. saligna* seeds was 45.4% for year one and 14.9% for year two.

The seed's moisture content also affects seed coat impermeability in legumes, and depends on climatic conditions prevailing during the late stages of maturation (Tran and Cavanagh 1984). Maturing seeds must desiccate below a critical level before the seed coat becomes impermeable, therefore atmospheric conditions of high temperature and/or low relative humidity must prevail at seed maturation time (Rolston 1978). Above this critical level seeds may be conditionally hard but retain the ability to imbibe water (Rolston 1978). Once *Acacia* seeds have become impermeable, they become more persistent in the soil as germination may occur only following abrasion of the testa (Holmes 1989).

1.4.3 The role of fire in managing *Acacia* seeds banks

Fire plays a major role in breaking dormancy in *Acacia* species, by denaturing the testa of the hard-coated seeds in the soil, which allows the seed to imbibe moisture and germinate, sometimes on a massive scale (Cavanagh 1980, Jeffery *et al.* 1988). It has thus been proposed that fire be used as a tool to reduce the large soil-stored seed banks under Australian *Acacia*s (Milton and Hall 1981, Henry and van Staden 1982, Holmes *et al.* 1987, Pieterse and Cairns 1987, Holmes 1989). Arguments against fire have been presented (Breytenbach 1989) because fire has been implicated as the main disturbance factor that can create "invasion windows" allowing alien invasive plants to establish in natural fynbos (Richardson *et al.* 1992). Alien stands also have higher fuel loads that result in higher intensity burns than would occur in uninvaded fynbos (Holmes and Cowling 1997, Holmes and Richardson 1999, Euston-Brown 2001). This is because the degree of soil heating during a fire is strongly related to the amount of fine fuel on the surface (Bradstock and Auld 1995).

Fire intensity is variable and is further influenced by vegetation moisture content, vegetation age, season of burn, site topography and weather conditions on the day of fire (Van Wilgen 1984, Van Wilgen and Van Hensberggen 1992, Van Wilgen *et al.* 1992). The extent of soil heating during fire depends on fire intensity and duration, fuel type and vertical structure, moisture, load, packing as well as on soil water content (Christensen 1994, Euston- Brown 2001, Holmes 2001). Fire intensity, converted into heat pulses belowground, stimulates seed germination but also determines survival of plants and plant parts and seed survival (Manders and Cunliffe 1987). Changes in fire intensity, associated with woody alien plant invasion, changes the heat pulse into the soil (Van Wilgen and Holmes 1986, Van Wilgen 1987, Bond *et al.* 1999). In areas with extensive fuel accumulation, smouldering fires can heat the soil profile to a depth of 20 cm to 30 cm, resulting in considerable chemical changes and soil sterilisation (Christensen 1994). Thus high intensity burns in alien stands have damaging effects on the soil, increasing water repellency (Euston-Brown 2001), and on indigenous soil-stored seed and on resprouting species persisting in alien stands (Musil and Midgley 1990, Holmes *et al.* 2001). Measured soil temperatures under piles of slashed *A. cyclops* exceeded 260°C and 240°C at 1cm and 4cm below the soil surface respectively (Van Wilgen and Holmes 1986). Seeds of *Acacia saligna* reach maximum germination following heating between 80°C and 100°C with reduced germination at 60°C (Jeffery *et al.* 1988). At 40°C most seeds remain dormant and temperatures above 120°C are fatal (Tozer 1998) depending on the duration of the high temperature.

Fire also plays a major role in maintaining fynbos flora and prescribed burning has been a standard fynbos management tool since the early 1970's (Mitchell 1987). The variability of fire intensity is critical for the maintenance of overall diversity in fynbos. Fire is thus an important tool for maintaining fynbos flora and for managing *Acacia* stands and seed banks provided that fire intensity levels and heat transfer belowground remain within natural range. Good management practices are necessary to reduce the negative effects of fire on soil and indigenous vegetation.

1.4.4 Description and management of selected alien plant species including the use of fire.

1.4.4.1 *Acacia saligna*

Port Jackson is the common name for *Acacia saligna* (Labill.) H.L.Wendl (Henderson 2001). It is an evergreen shrub or tree 3 – 7 m high with a willow-like appearance (Stirton 1978, Henderson 2001). The age to flowering is two years (Milton 1980) and it has bright yellow, globular flowerheads that flower from August to November (Henderson 2001). The plant produces brown fruit pods with hardened whitish margins (Henderson 2001), copious amounts of seeds are produced, which accumulate to form large soil seed banks (11 920 seeds/m^2, Milton 1980) that germinate profusely after fire (Milton and Hall 1981, Cronk and Fuller 1995). The mean seed production per anum was found to be, 530 ± 31 seeds/m^2 for saplings and 5443 ± 11 seeds/m^2 for mature stands (Milton and Hall 1981). Eradication is difficult because Port jackson plants coppice rapidly after fires or mechanical severing.

Port jackson was brought from its native country Southwest Australia for dune reclamation, shelter, tanbark and fodder and has become invasive (Stirton 1978, Henderson 2001). It has invaded Lowland Fynbos, Mountain Fynbos, Eastern Cape Forest, Southern Forest, Succulent Karoo, Grassland and has spread into the southern margins of the Karoo. It invades mountain and coastal fynbos, coastal dunes and river courses (Stirton 1978, Henderson 2001).

1.4.4.2 *Acacia longifolia*

The long-leaved wattle, *Acacia longifolia* (Andr.) Willd. is an evergreen shrub or spreading tree 2 - 6m high (Henderson 2001). The cylindrical flowerheads in the axil of the leaves are bright yellow and fruits are pale brown pods constricted between seeds (Henderson 2001). Age to flowering is two years (Milton 1980) and the flowering months are July to September (Henderson 2001). The plant produces large quantities of seeds ranging between 2901 ± 415 seeds/m^2 (Pieterse and Cairns 1986) and 7646 seeds/m^2 (Milton 1980). The survival and spread of this species is due to its high production of seeds and prolific regeneration after fire (Milton and Hall 1981, Pieterse and Cairns 1986, Cronk and Fuller 1995).

It has become invasive in many areas in fynbos and related vegetation types in the southern and southwestern Cape Province (Cronk and Fuller 1995) and survives on both drier mountain slopes and watercourses. It is native to South-eastern Australia and Tasmania and was brought here for dune stabilization, shade and as an ornamental tree (Stirton 1978, Henderson 2001)

1.4.4.3 Management of alien plant species

The management of alien plant species includes various mechanical, chemical and biological control measures. Mechanical control options include the physical felling or uprooting of plants, their removal from the site, often in combination with burning. Mature plants are cut down, stimulating the release of seeds in serotinous species such as hakeas and pines. Once all the seeds have germinated the stand is burnt in order to kill all the seedlings prior to first flowering. Management suggests burning while green, under moist, cool conditions, to ensure lowest possible fire temperatures (Anonymous 2000). A controlled burn is undertaken through a particular area of felled invasive alien plants (winter burn), usually during the first or second year following stacking or a burnt standing block of dense invasive alien plants, during late summer to early autumn, (Anonymous 2000). The stems of *A.longifolia* and *A. saligna* are manually clear-cut, close to the ground and the manually cut remains are piled into small, scattered stacks and burnt under cool, moist conditions to ensure lowest possible fire temperatures.

For resprouting species the use of herbicides is required to complement the mechanical control. Trees are felled close to the ground and immediately treated with herbicide. Mature *Acacia saligna* is a resprouting species and once it is manually clear-cut the stems are immediately sprayed with 3% Lumberjack (*Triclopyr amine*) mixed with a wetting agent (e.g. Actipron) to kill them, thus preventing resprouting. A blue dye (e.g. Ecoguard) is added to the herbicide to clearly mark the stems. Mechanical control is labour-intensive and thus expensive to use in extensive and dense infestations, or in remote or rugged areas (Anonymous 2002).

Various biological control agents have been brought in as a managent practice to control the spread of alien plants especially *Acacias*. Biological control involves the introduction of host specific pathogens and insects onto a plant and is a tremendously cost effective way to control the plant because after introduction of the biological agent no further action is needed (Zimmerman *et al.* 2004).

The infection of *Acacia saligna* by the biological agent *Uromycladium tepperianum* involves the formation of galls either anually or perennially. Heavily infected plants may bear several hundred galls. The fungal pathogen on *Acacia saligna* has greatly reduced the density of this weed over wide areas and is currently effective in controlling *A. saligna* plants in South Africa (Morris 1991, 1997, 1999, Zimmerman *et al.* 2004).

Although no monitoring has been done on the efect of *Trichilogaster acaciaelongifoliae* on the population dynamics of *A. longifolia*, the biological control of *Acacia longifolia* is believed to be complete, which means that no other control methods are needed to reduce the seed to acceptable levels, but this is only the case in areas where the agents have been established (Hoffman *et al.* 2002, Zimmerman *et.al.* 2004). The bud-gall forming wasp *Trichilogaster acaciaelongifoliae* markedly reduces the reproductive potential of *A. longifolia* and more recently the seed weevil *Melanterius ventralis* Lea (Coleoptera: Curculionidae), which destroys seeds, have brought *A.longifolia* under complete biological control (Dennill *et al.* 1999).

1.4.4.4 Description of stack burns

Stacks should be situated at least 10m away from a river course, a fence, a road, a track or footpath, and this distance could be increased to 20m, for larger amounts of biomass or proximity to an urban edge. Stacks should be at least 5m wide, 5m high and at least 5m apart. Each stack is ignited one at a time by using drip torches (petrol/diesel mix) (L. Mossop pers. comm. 2005).

1.4.4.5 Description of stand burns

In the case of the burning standing technique, a block burn has to take place. The Fire and Technical Services officer will decide on a manageable block size. A firebreak 5 - 15m wide (depending on the local risk factors) must be identified (e.g. Road, river, dam, and recently burnt piece of veld), otherwise a firebreak must be cut to facilitate the control of the block burn. The fire is then ignited using drip torches (diesel/petrol mix), by starting the burn on the firebreak on the upwind side of the block to slowly burn as a back-burn into the block, then the fire is ignited from the downwind side so that the two fronts meet inside the block and extinguish each other (L. Mossop Pers. comm. 2005).

1.4.4.6 Follow-up after both stack burn and stand burn techniques

Most invasive species set seed from two years old thus follow-up clearing of plants is a necessity. In an area of plants recently cleared, follow-up control should occur within this 2-year window period (Anonymous 2002). Appropriate eradication techniques need to be applied where necessary, and the area regularly inspected for survivors. Seedlings can be spot sprayed with herbicide where there is extensive seedling regeneration and little indigenous regeneration, using a foliar application (e.g. 0.5% Triclon (Triclopyr ester solution) of herbicide mixed with a wetting agent (e.g. Actipron). Colouring with dye can be used on saplings (Anonymous 2000, Cillier 2002). Spot spraying is very cost effective while foliar spray is an environmentally high-risk activity that requires stringent controls. Foliar sprays are generally conducted on wind free days to avoid contamination of non-target plants. Juvenile trees can also be removed by manually pulling or with the use of a tree-popper (Anonymous 2002).

1.5 Hypotheses and Predictions

The primary hypothesis is that seed bank density would be greater under dense mature alien stands, with the highest age of dense infestation and that fire would reduce seed banks significantly irrespective of the clearing technique used. The secondary hypothesis is that seed distribution and density would be greater in areas where more alien vegetation occurs above ground.

Several predictions are made concerning the management techniques used and seed bank dynamics:

In stack burn footprints there would be a greater decline in seed stores than for block burn techniques. However distribution of seeds in stack burn areas would be heterogeneous (patchy) because large densities of seeds would still remain in areas where stacks did not occur.

With block burns, decline in seed stores after fire will be less than under stack footprints but distribution and removal of seeds will be more homogenous.

Seed density will decline with depth. Stands with a high age of dense infestation as well as stands with deep colluvial valley soils should have greater seed bank depth distribution and density.

Several predictions are made concerning seed bank dynamics along the river:

The seed density will be greater in areas where more alien vegetation occurs above ground. Areas that had high covers of alien vegetation would still have large densities of seed remaining in the post-clearing environment.

The density of the seeds would increase from the channel to the terrestrial area and from the top of the catchment to the bottom. Most of the seed will be found in the upper layer and seed density will decline with depth but significant seed densities could still be found at lower depths than in terrestrial fynbos areas.

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CHAPTER 2

An investigation to determine optimal clearing techniques for removal of *Acacia saligna* seed banks in the Table Mountain National Park, Cape Peninsula, South Africa

2.1 Abstract

This study investigates the extent of pre- and post fire seed banks of the invasive alien species *Acacia saligna* under different stand ages and clearing techniques in the Table Mountain National Park, with the aim of informing best management practices. Four sites, Noordhoek, Sunvalley, Steenberg and Simonstown were sampled. Three of the sites (Sunvalley, Steenberg and Simonstown) had been cleared and the biomass stacked (stack burn clearing technique) for burning during winter. At the fourth site (Noordhoek) the standing – burn clearing technique was used and burning took place in autumn. Four key questions were posed:

1. Does the method of alien clearing (stacked vs burnt standing) influence the density of alien seeds available for regeneration in the post-clearing, post-burn environment?
2. Does seed bank size change with soil depth?
3. To what extent does age of dense infestation influence seed bank distribution and density?
4. To what extent does habitat (shallow mountain soils versus deep colluvial valley soils) influence seed bank distribution and density?

The seed densities prior to burning were high, under the *Acacia saligna* stands, with the Noordhoek site having the highest seed density across all depth classes between all sites. The highest density of seeds was found in the 0-15 cm depth class layer at Noordhoek with 38 714 ± 4006 seeds/m^2, while Simonstown had the lowest density of seeds, 3158 ± 1537 seeds/m^2 within this depth class. Seed density decreased with depth, with the lowest density of seeds found at the 15-30 cm depth class at Simonstown (391 ± 303 seeds/m$^{2)}$. The densities of seeds were reduced significantly at all four sites after burning, regardless of the clearing technique, with a total percentage reduction of 71.7%, averaged across sites. There was, however, a significant difference in seed density between the stack- and standing burn clearing techniques with the percentage reduction in total site seed density after burns being 63.1% and 97.6% respectively. There were more seeds remaining in the stack burn site than at the stand burn site after burns. The lower reduction in the stack burn clearing technique was due to the unburnt matrix adjacent to the stacks where seeds persisted. Although not statistically tested, age of dense infestation and habitat appear to have an effect on the seed bank distribution and density. Mature stands of *Acacia saligna* tend to have a greater seed stores than immature stands and habitats with deep colluvial soils have a greater density and also greater vertical distribution of seeds. Cumulative mean percentage viability of *Acacia saligna* seeds remaining in the soil was relatively high, with an average across all the sites of 85% in the pre-burn environment and 86% in the post-burn environment. The post-fire seedling density was relatively low at all four sites, in comparison to alien seed bank reduction. The stand burn clearing technique was the better clearing techniques in terms of alien seed bank reduction, although enough seeds always remained in the soil to regenerate new *Acacia* stands.

Keywords: *Acacia saligna*, clearing technique, fire, invasive alien plant, alien management, soil seed banks

2.2 Introduction

Due to the successful invasion of natural habitats by alien plant invaders, the unique floral diversity and long-term survival of the Cape Floristic Region is under threat (Boucher and Hall 1977, Stirton 1978, Macdonald *et al.* 1986, Holmes and Richardson 1999). *Acacia saligna* is one of the most dominant invaders in the south- western Cape (Macdonald and Jarman 1984). This species produce large quantities of hard-coated, water-impermeable seed, which accumulate in the soil and pose a major obstacle to their effective control (Holmes *et al.* 1987, Milton and Hall 1981). As a result of large densities of viable seeds persisting in the soil, many legumes have become weeds (Rolston 1978).

Seed longevity is an important factor in assessing the seriousness of a weed problem (Egley and Chandler 1978), and it is often associated with water-impermeability of the testa (Rolston 1978). Fire plays a major role in breaking dormancy in *Acacia* species, whereby the testa is denatured, allowing the seed to imbibe moisture and germinate (Cavanagh 1980, Jeffery *et al.* 1988). It is the heat pulse through the soil that breaks dormancy (Jeffery *et al.* 1988). The soil temperature under a fire varies as a function of soil depth, as well as fuel bed characteristics, thus, the probability of germination is influenced by the depth at which seeds are buried (Bradstock and Auld 1995). Fewer than 4% of buried *Acacia saligna* seeds have been shown to germinate without treatment (Milton and Hall 1981).

Fire plays a major role in maintaining fynbos floral diversity and prescribed burning has been a standard fynbos management tool since the early 1970`s (Mitchell 1987). The current management of fynbos still consists largely of controlling and applying fire, and is also used in the integrated control of invasions of woody weed species (Van Wilgen and Richardson 1985). The common method of stacking slash leads to a higher concentration of dead and cured fuel (Scott *et al*. 2000) concentrated close to the surface, resulting in increased soil temperatures developing during fires (Holmes and Richardson 1999, Euston-Brown 2001, Scott *et al.* 2000). Such fires have been shown to have adverse effects on soil, vegetation and fauna (Breytenbach 1989, Macdonald *et al.* 1989, Martens 1997, Scott *et al.* 2000, Euston-Brown 2001, Holmes *et al.* 2001,)

An alternative management approach to burning stacks is to burn aliens standing to decrease heat release at the soil (Holmes 2001). It has also been suggested to be more economical (Pieterse and Cairns 1987, Holmes 1989). The major problem with *Acacia saligna* is that it does not only have massive seed production, but also after fire it resprouts from the base and its seeds germinate rapidly, giving it access to the nutrient pool created by the fire (Richardson *et al*.1992). A study done on *Acacia mearnsii* showed that burning of aliens standing was not feasible because the regeneration resulting post-fire was unacceptably high (Pieterse an Boucher 1997).
Seed bank reduction thus provides a potential key to the successful control of invasive alien plants and burning is especially important in reducing *Acacia saligna* seed banks. Burning reduces the seed bank but invariably stimulates germination and therefore clearing of seedlings needs to take place before flowering in order to prevent the seed bank from being replenished. Clearing techniques should not effectively reduce the seed bank but should also have the least possible impact on the environment.

This study investigates the extent of pre-and post fire *Acacia saligna* seed banks under differing stand ages and differing clearing techniques in the Table Mountain National Park, with the aim of informing best management practices.

The following key questions were asked in this study:

1. Does the method of alien clearing (stack-burn vs standing burn) influence the density or proportion of alien seeds available for regeneration in a post-clearing, post-burn environment?
2. Does seed bank size change with soil depth?
3. To what extent does age of dense infestation influence seed bank distribution and density?
4. To what extent does habitat (shallow mountain soils versus deep colluvial valley soils) influence seed bank distribution and density?

2.3 Materials and methods

2.3.1 Study Areas

The Table Mountain National Park (mapping grid-square 3418AB14), which is situated on the South Peninsula Mountain Chain, close to the suburb of Noordhoek, Cape Town, South Africa, was the study area for this project. Four sites, Noordhoek, Sunvalley, Steenberg and Simonstown undergoing clearing were sampled (Figure 2.1). All the stands were closed (i.e. 75-100% canopy cover) stands.

Three of the sites (Sunvalley, Steenberg and Simonstown) had been cleared and the biomass stacked (stack burn clearing treatment) for burning during winter. The fourth site (Noordhoek) received a standing burn treatment in autumn. Each of these sites varied in soil depth, topography, hydrology as well as history of invasion (Table 2.1).

Figure 2.1: The location of the four study sites taken from a 1:50 000 map of the Cape Peninsula. The black dots indicate the proximity within which the four sites are situated that were samples

Table 2.1: Characteristics of the four sites selected for sampling in the Silvermine section of the Table Mountain National Park

Site characteristics	**Sites**			
	Sunvalley	Steenberg	Simonstown	Noordhoek
GPS reading at the centre of the site	S 034° 07' 30.4" E 018° 24' 14.2"	S 034° 05' 14.2" E 018° 26' 52.7"	S 034° 11' 58.3" E 018° 26' 43.1"	S 034° 08' 00.0" E 18° 22' 00.0"
Age of dense infestation	12 Years	25 years	± 25 years	+>80 years
Soil	Deep Sands	Shallow Sand Stone soils	Shallow Sand stone soils	Deep Sands
Geographical features	Sand Dune	Mountain slope	Mountain slope	Wetland
Management	Stack burning	Stack burning	Stack burning	Stand/ block burning
Date of last fire	July/August 2003	July/August 2003	July/August 2004	April 2003
Pre-burn sampling date	March/April 2003	March/April 2003	March/April 2004	March/April 2003
Post-burn sampling date	September/October2003	September/October2003	September/October2004	September/October2003

Age of dense infestation was determined by studying historical aerial photographs. Stratified random sampling was conducted at each site. In the stack burn sites: prior to burning three areas were sampled: the first was next to stacks in the "matrix" (i.e. where aliens were felled, stump-treated with herbicide and biomass was removed), and seed banks in this area were assumed to be similar to the areas under the stacks in the pre-burn environment. In the post-burn environment, sampling was done in the "matrix" area again and in the "stacked" area where alien biomass had been accumulated in piles and burnt. At the standing burn site, samples were collected randomly prior to burning and again post-fire. The samples at the standing burn site were similar to the matrix in the stack burn site. Sampling was done after winter rains when seedlings had emerged.

2.3.2 Sampling method

At each site, 30 random samples were taken in pre-burn areas and another 30 in post-burn areas at the same site. An optimal sample size of N=30 was determined by collecting seeds from random samples in a site, the coefficient of variation was determined and values plotted on a graph with numberdensity of samples along the x-axis. Where the graph started levelling off was determined as the optimal density of samples to be taken. For each sample, soil cores, 5 cm diameter by 15 cm were extracted from two depths (Sub-samples: 0 – 15 cm; 15 – 30 cm) if soil depth allowed. Seed banks were expressed on a per square metre basis. Where relevant, the litter layer was included as a third sub-sample. Soil samples were sieved in the field, and seeds of each sub-sample clearly labelled and bagged separately for counting and viability testing in the laboratory. Where wet soil was collected, the soil was bagged and taken back to be dried in an open plastic container after which the dry soil was sieved.

Seedling counts were also quantified in post-burn environments (depending on time elapsed since burn) by laying out 30, 1m^2 plots in the burnt areas where seedlings were recruiting and counting the density of seedlings within each plot. Aerial photos were used to determine which proportion of the area at each site was taken up by stacks and which by the matrix. On average the stacks covered a proportional area of 40% and the matrix 60%.

2.3.3 Viability tests

Viability tests were conducted on the soil-stored seed. A sample size of a 100 seeds was taken from each depth class for each site, pre- and post burn and five replicates of 20 seeds taken were tested. Where there were fewer than 100 seeds in the sample, all the seeds were tested. In order to break dormancy, seeds were scarified by clipping, placed on moist filter paper in covered germination trays and kept in a growth chamber at a constant day and night temperature of 20 - 25^{o}C (Milton and Hall 1981). The fungicide, Captan, was sprayed regularly on the seeds to prevent fungal contamination (Clemens *et al.* 1977). The seeds were examined regularly, and those with a radicle protruding 1mm or more were recorded as having germinated and were removed. After 60 days seeds that had not germinated were assumed to be non-viable.

2.3.4 Statistical analysis

Descriptive statistics were calculated in *MS* Excel. The Mann-Whitney U-test in Statistica was used to determine significant differences in seed stores between sites and between pre- and post burn seed densities. Cumulative mean percentage germination was calculated in MS Excel and graphs drawn. A chi-square test in Statistica was used to determine significant differences between pre- and post burn seed viabilities within and between sites at all depth classes.

2.4 Results

Influence of clearing technique and soil depth on the seed bank size.

Prior to burning, within the soil profile, most seeds were found in the top layer (0 – 15 cm, including the litter layer), averaging 84% of the measured seed bank. Seed densities decreased with soil depth, with the 15-30 cm layer constituting only 16% of the seed bank (Table 2.2, Figures 2.2a-d). Irrespective of the clearing method at all four sites seed density decreased significantly after burns, in the 0-15 cm depth class (U-test, p<0.05), (Table 2.2).

The Noordhoek (stand burn clearing technique) and Sunvalley (stack burn clearing technique) sites, which are both on deep sands, were used to determine differences between the clearing methods. These were the only sites with litter layers and deeper soil, which included the 15-30 cm depth class layer. Prior to burning, Noordhoek (stand burn clearing technique) had 7641 $\pm$ 2795 seeds/m^2 and Sunvalley (stack burn clearing technique) had 6350 $\pm$ 2253 seeds/m^2 in the litter layer and these densities were not significantly different (U=test, p>0.05). After burns, litter layers were completely consumed in the fire at both sites (Table 2.2, Figures 2.2a and b). Prior to burning there was a significant difference in seed densities between Noordhoek and Sunvalley in both the 0 – 15 cm and 15 – 30 cm layer (U-test, p<0.05) with Noordhoek having the highest seed density (Table 2.2, Figures 2.2a and b). However after burns there was still a significant difference in seed densities in the 0-15 cm depth class but not in the 15-30 cm depth class. After burning, seed densities had decreased significantly across Noordhoek (stand burn clearing technique) and Sunvalley (stack burn clearing technique) sites in the 0 – 15 cm depth class but not in the 15 – 30 cm depth classes. After burning the Sunvalley site had more seeds remaining than at Noordhoek (Table 2.2, Figures 2.2a and b).

When comparing the four sites, after burns there was still a significant difference between seed densities in the 0 – 15 cm layer (U-test, $p<0.05$) but not for the 15 – 30 cm layer (U-test, $p>0.05$)(Table 2.2).

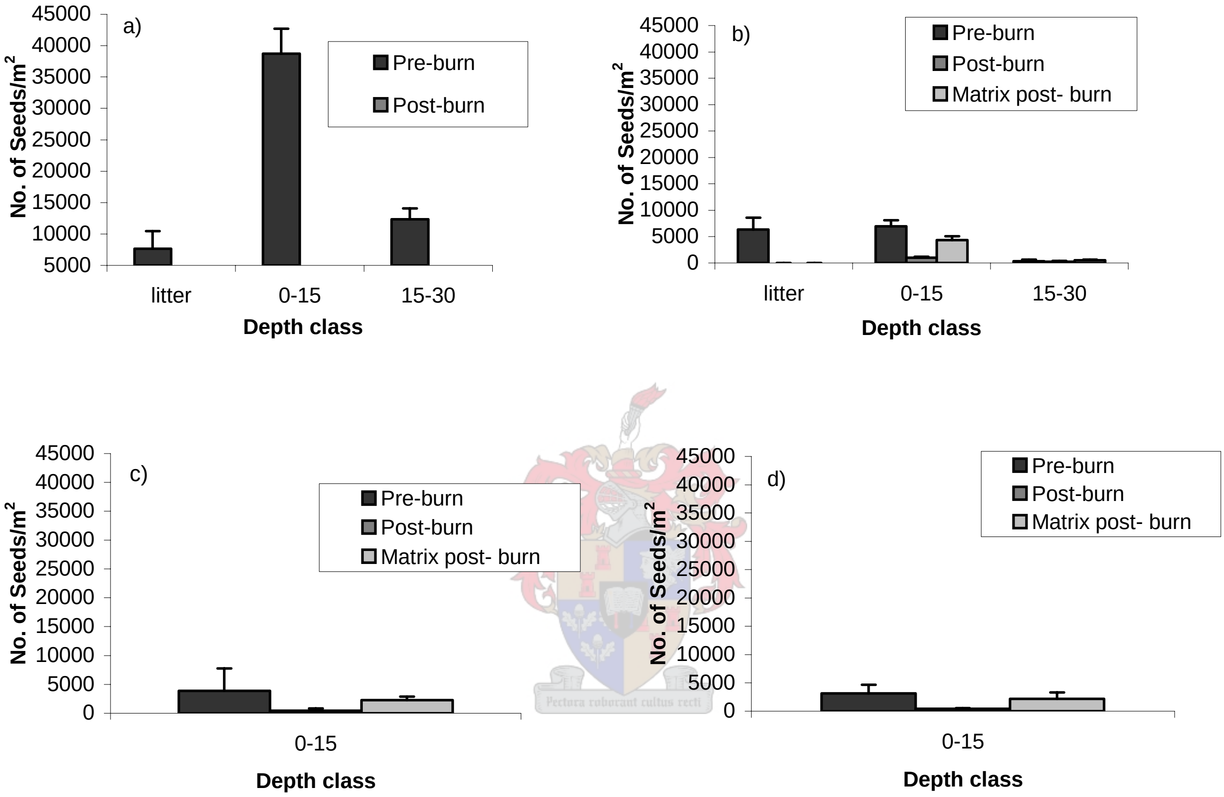

Figure 2.2: Density and distribution of seeds pre-and post burn across all depth classes (litter, 0 – 15 cm, 15 – 30 cm) and for all four sites a) Noordhoek with a stand burn treatment, b) Sunvalley with a stack burn treatment, c) Steenberg with a stack burn treatment and, d) Simonstown with a stack burn treatment. In the key post-burn and pre-burn refer to areas under the stacks and matrix post-burn and matrix-pre-burn refers to areas between the stacks.

Table 2.2: Density of *Acacia saligna* (mean ± standard error, N=30) seeds per square metre of soil surface in the different soil depth classes in pre- and post burn samples for all the sites. For the stack burn treatment it was assumed that the pre-burn matrix seed banks were equivalent to those under the stacks. The total percentage reduction in seed banks was calculated for the stack burn treatment using reductions for the stacks and matrices and their respective surface areas. Sample size (n) is indicated in parentheses. N/A = not applicable

Sites/ Clearing treatment	Depth classes	Pre-burn	Post-burn Seeds/m^2	Post-burn Matrix Seeds/m^2	Total site % Reduction
Sunvalley (Stack burn treatment)	Litter	6350 ± 2253(30)	0	0	75.7%
	0 – 15 cm	6945 ± 1144(30)	1036 ± 782(30) *	4363 ± 708(30) *	
	15 – 30 cm	391 ± 303(30)	255 ± 167(30)	323 ± 140(30)	
Noordhoek (Stand burn treatment)	Litter	7641 ± 2795(30)	0	N/A	97.6%
	0 – 15 cm	38714 ± 4006(30)	1002 ± 627(30) *	N/A	
	15 – 30 cm	12361 ± 1690(30)	391 ± 177(30) *	N/A	
Steenberg (Stack burn treatment)	0 – 15 cm	3888 ± 1194(30)	425 ± 181(30) *	2258 ± 610(30) *	60.8%
Simonstown (Stack burn treatment)	0 – 15 cm	3158 ± 1537(30)	425 ± 145(30)*	2207 ± 1129(30) *	52.7%

* Significant reduction in seed bank (U-test, P<0.05) compared to density before burning

Effect of age of dense infestation and habitat on seed density and distribution

Noordhoek and Sunvalley with similar habitats (deep aeolian sandy soils) had greater seed densities than Steenberg and Simonstown with shallow colluvial mountain soils (Tables 2.1 and 2.2). Although Noordhoek and Sunvalley had similar habitats, their age of dense infestation differed and this is the likely explanation for the difference in their seed densities, with higher densities recorded in the older stand (Tables 2.1 and 2.2). Habitat as well as age of dense infestation was similar at both Steenberg and Simonstown and their seed densities were also similar with Steenberg on average only having 10% more seeds than Simonstown (Table 2.2).

Seed viability and seedling emergence

Cumulative mean percentage viability in the laboratory ranged from 65 - 100% (Table 2.3). Significant increase or decrease in percentage viabilities did not occur for seeds of the depth class 0-15 cm at any of the four sites (Table 2.3). At the depth class 15-30 cm a significant increase in percentage viability occurred at the Sunvalley site (χ^2 =4.32, df=1, p<0.05) (Table 2.3). The highest percentage viability across all sites occurred for the pre-burn litter layers, averaging 88% (Table 2.3). The highest total percentage viability for the pre-burn per site was at Noordhoek (92%) and the lowest total percentage was for the post-burn at Steenberg (77%) (Table 2.3). The highest average percentage viability for the post-burn per site was at Sunvalley (97%) and the lowest average percentage viability was for the post-burn at Simonstown (80%) (Table 2.3).

Percentage viabilities were only significantly different between sites in the 0-15 cm depth class (χ^2 =20.00, df =3, p<0.05) and 15-30cm depth class (χ^2 =9.39, df=1, p<0.05) of the post-burn environment (Table 2.4).

Simonstown had the highest mean density of seedlings that emerged in the field (59 ± 5 seedlings/m^2) and Sunvalley had the lowest mean densities of seedlings that emerged 22 ± 2 seedlings/m^2 (Table 2.5). Noordhoek had the lowest density of viable seeds 1142 ± 528 seeds/m^2 with only 2% of viable seeds that produced seedlings, while Sunvalley had the lowest percentage (1%) of viable seeds that produced seedlings but the highest density of viable seeds 3195 ± 566 seeds/m^2 (Table 2.5).

Table 2.3: Cumulative percentage viability, means ± SE (after 60 days) pre-and post burn for the all the sites and all depth classes. Chi-square (χ^2) values showing the effects of depth and burning techniques on the percentage viability of the *Acacia saligna* seeds within each site. The symbol (-) signifies missing data. Sample size (n) in indicated in parentheses. The significant p-values are indicated with an asterix (* =p<0.05) and the non-significant values are indicated by *NS*. N/A = not applicable.

Sites	Depth classes	Pre-burn % Viability	Post-burn % Viability	df	χ^2	Significance (P-value)
Sunvalley	Litter	88 ± 3(100)	-			N/A
	0 - 15cm	88 ± 6(100)	91± 5 (23)	1	0.3127126	*NS*
	15 – 30 cm	65 ± 19(61)	100± 0(15)	1	4.319980	*
Noordhoek	Litter	87 ± 5 (100)	-			N/A
	0 – 15 cm	93 ± 3(100)	93 ± 3 (59)	1	0.9741312	*NS*
	15 – 30 cm	97 ± (100)	70 ± 12 (23)	1	3.762898	*NS*
Steenberg	0 – 15 cm	77 ± 4 (100)	84 ± 7(25)	1	2.128911	*NS*
Simonstown	0 – 15 cm	84 ± 5 (100)	80 ± 9 (25)	1	3.323080	*NS*

Table 2.4: The Chi-square (χ^2) values showing the effects of depth and burning techniques on the percentage viability of the *Acacia saligna* seeds. The significant p-values are indicated with an asterix (*= p<0.05) and the non-significant values are indicated by *NS*. N/A = not applicable.

	df	χ^2	Significance (P-value)
Litter layer Sunvalley vs Noordhoek	1	0.8898432	*NS*
0-15 cm pre-burn	3	5.820168	*NS*
0-15 cm post-burn	3	5.820168	*NS*
15-30 cm pre-burn	1	0.0262152	*NS*
15-30 cm post-burn	1	9.393477	*

Table 2.5: Total (mean ± standard error) density of viable seeds/ m2across all soil depths remaining post-treatment (mean ± standard error), average density of seedlings/ m^2 that emerged after treatment (in stack treatment calculated proportionately based on aerial extent of stacks and matrix) and the % of the viable seed bank that produced seedlings in the post - burn environment averaged across the site.

Sites	Viable Seeds/ m2	% Viable seeds that produced seedlings	Seedlings/ m^{-2}
Noordhoek (stand burn)	1142 ± 528	2%	19 ± 1
Sunvalley(stack burn)	3195 ± 566	1%	22 ± 2
Steenberg (stack burn)	1281 ± 302	2%	24 ± 2
Simonstown (stack burn	1195 ± 535	5%	59 ± 5

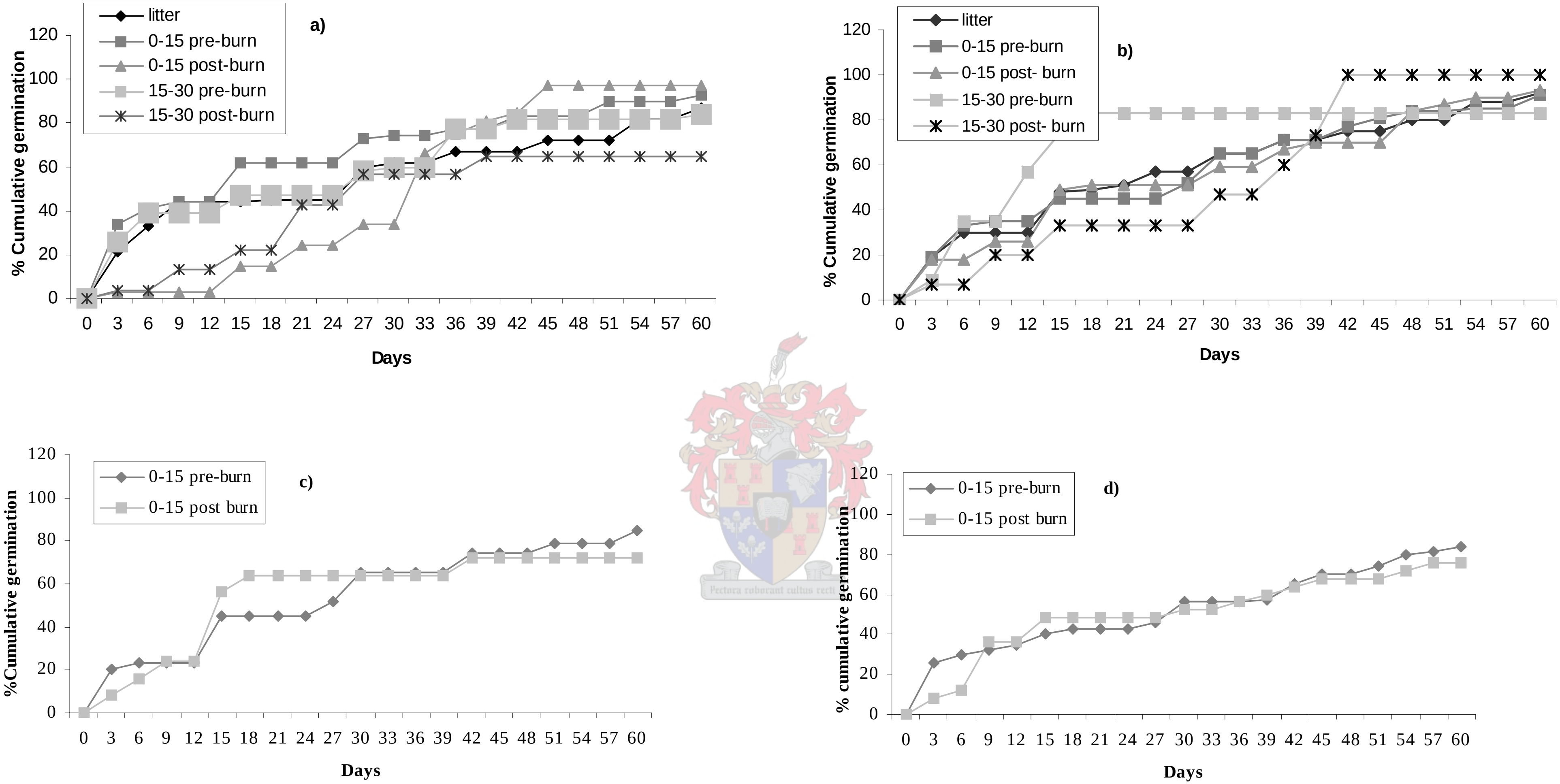

Figure 2.3: Cumulative mean percentage germination of seeds following scarification for pre- and post burn across the all depth classes (litter, 0 – 15 cm, 15 – 30 cm) and for all sites a) Noordhoek, b) Sunvalley, c) Steenberg, d) Simonstown

2.5 Discussion

Influence of clearing technique and soil depth on the seed bank size.

At all four sites irrespective of the clearing technique, burning resulted in a reduction of the seed bank. Thus fire can be used as a tool to reduce the soil seed reserves of alien invasive *Acacias* and this finding corroborates with other studies done by several researchers (Milton and Hall 1981, Pieterse 1986, Pieterse and Cairns 1986, Holmes *et al*. 1987, Holmes 1989).

Effects of the different clearing techniques on seed density could only be tested between Sunvalley (stack burn clearing technique) and Noordhoek (stand burn clearing technique) because of their similar habitats. Greater reduction in seed density occurred at the stand burn treatment site as the remaining seed in the matrix area of the stack burn treatment was still high compared to densities under the stacks even after fire. Seeds were reduced significant at the lower depth for Noordhoek and this could be due to moist soil in the Noordhoek wetland site could have aided germination. A study done by Holmes and Moll (1990) showed that for *A.saligna* water-impermeable dormancy is more readily broken in moist than in dry soil. The greater reduction in seed density even at the deeper 15 – 30 cm layer, as well as the complete removal of litter layers at the stand burn treatment could be an indication of hotter fires than for the stack burn treatment. At the Sunvalley site I observed logs still remaing after fire and recruitment of indigenous seedlings taking place, which is an indication that the stack burns, had not been as a intense as the stand burns.

Seedling emergence

The density of seedlings that emerged after fire, across the four sites was quite low and represented a small proportion of viable seeds that remained in the soil after fire. The stand burn technique yielded the lowest seedling recruitment. The low level of seedling recruitment is an indication that fewer seeds survived the fire. As mentioned above, this is another indication that the stand burn treatment was more severe in its effects than the stack burn treatments. Heat penetration into soil is greater in summer than winter and hot summer fires have resulted in greater *Acacia* seedling recruitment (Holmes 2001) as high seed coat imposed dormany in *A.saligna* (Jeffery *et al.* 1988) is usually readily broken by heat (Milton and Hall 1981; Jeffery *et al.* 1988). This was not the case in this study as seedling recruitment was lower for the autumn burns than the winter burns as fires were too hot and killed most seeds. Usually in stack burn treatments as dead fuel is concentrated close to the soil surface, the amount of heat released is greatly increased and intensified especially in summer, killing most of the seeds with adverse effects on the soil, fauna and flora (Breytenbach 1989, Holmes *et.al* 2001, Richardson an van Wilgen 1986). The effects of fire on soil temperature are greatly affected by various factors such as soil moisture content, fuel type, fire intensity and duration, load and packing (Christensen 1994, Euston-Brown 2000, Scott *et. al.* 2000) and evidence of this was seen in this study when the Simonstown stack burn treatment yielded a higher seedling density after fire compared to the other stack burn sites. Thus the burning of slash under cool winter conditions results in lowered recruitment, as found in this study and is less damaging to the soil. Another reason for the low densities of emerged seedlings post-fire, counted across the four sites could also be as a result of seedling counts that were done to soon after burns as a study done by Holmes (1987) illustrated that only 70% of the remaining viable seed bank had germinated in 6 months following an accidental fire. Thus the period between fire and seedling counts should have been longer than three months in this study.

Seed viability

Viability of seeds was high as expected, both before and after burns (65 - 100%) although the 65% germination for the post-burn 15 – 30 cm for Noordhoek was quite low. The degree of seed dormancy may vary from year to year and between stands (Cavanagh 1980, Jeffery *et al.* 1988). It may be that undamaged seeds had been killed in the fire and did not rot immediately. Seeds tested for viability after the burns represent those remaining in the seed bank that did not germinate directly after the fire, as evidenced by counts of seedlings, thus they remain a significant threat in future invasion potential. There was also no significant difference in viability of seeds across the different sites. The uniformity of *A. saligna* seed viability among sites may reflect the absence of associated seed-feeding insects in South Africa (Van den Berg 1980). Germination rates were very slow in contrast to other studies done. In a study done by Fleitman and Boucher (2001), all seeds had germinated after six days and they were 100% viable regardless of degree of stand maturity or depth of burial. Slow germination rates could have been due to conditions within the germination trays.

Effect of age of dense infestation and habitat on seed density and distribution

Several studies indicate that most accretion of seeds occur in the upper layers and decreases with increasing depth (Milton and Hall 1981, Tozer 1998, Holmes 2002) and this coincides with the results from this study. The Noordhoek infestation with its greater age of dense infestation and high seed density indicates that seeds of *A.saligna* accumulate over time in the soil seed bank. Previous studies on the annual seed-fall indicate that mature trees of *A.saligna* produce a mean density of 5 443 seeds/m^2/year and sapling/juvenile trees 530 seeds/m^2/year (Milton and Hall 1981). Holmes (2002) found higher *Acacia* seed densities in long-invaded stands, compared to recently invaded stands. The lack of a significant difference in seed banks between Sunvalley and Steenberg may indicate that different site factors, for example, fire history and prominence of the biological control fungus, have resulted in Steenberg with a greater age of dense infestation not accumulating more seeds than the younger site. In relation to habitat, there is a tendency for the Noordhoek and Sunvalley sites on deep sandy soils to have higher seed densities than the Simonstown and Steenberg sites on shallow mountain soils. Holmes (2002) found that *Acacia saligna* seed density was similair in deep sand plain and shallow mountain soils but at one Sand plain site there was less change in the seed density with depth(up to 9 cm). In sand plain fynbos vegetation burrowing rodents play a significant role in the dynamics of soil-stored seeds, both in exhuming buried seeds and in burying surface seeds (Holmes 1990) and myrmecochory is also partly responsible for the build up of shallow seed banks (Pieterse 1997). Vertical movement of seeds in the soil may also occur via percolating rainwater and down wetting and drying fractures or decomposed root channels (Harper 1977).

Shallower soils result in the concentration of the seed bank closer to the soil surface, which among other factors renders the seeds more susceptible to fires. Thus over the longer-term fewer seeds will accumulate in shallow compared to deep soils in relation to surface area. Thus the effectiveness of burning treatments on reducing the seed banks in deeper soils will be decreased because burning may only kill the seeds to depths of about 4 cm (Holmes 1989), although germination may be stimulated down to 8.5 cm (Cunningham and Cremer 1965, Floyd 1966). Thus anything below this depth may remain dormant. *A. saligna* potentially may germinate from depths of 10 cm H(olmes and Moll 1990). Seeds germinating below this depth do not have sufficient resources to emerge at the soil surface. Thus reduction of seed density below 15 cm suggests that the treatment stimulated germination that resulted in mortality of the seedlings. The burial of considerable densities of viable seeds indicates that stock will survive for many years even if all the parent plants are removed. There are other forms of seed loss from the soil. Holmes (1988) found that some seeds are lost from the seed bank due to breaking of dormancy and/or pathogenic attack, particularly in the first year. However, loss of viability through physiological ageing is considered to be much reduced in seeds with coat-imposed dormancy as in the case of *Acacia saligna*. Irrespective of stand age or habitat, most of the seeds were found in the upper layers of soil. Thus it is understandable that the top layer of soil had the highest density of seed, as this is where recent accretion occurs. In this study seeds were removed down to a depth of 30 cm with decrease in seed density being more significant in the stand burn technique than the stack burn technique. This coincides with other studies where burning of standing *Acacias* produced seedlings from lower depths than in stack burn techniques (Pieterse 1986, Holmes 1989). As most accretion of seeds occur in the top layer both clearing techniques can be used to reduce seeds in the upper layers of soil but stand burns seemingly reduce seeds at lower depths.

2.6 Conclusion

Both stack and stand burns have shown a significant decrease in seed density of burns especially in the upper layers but there is still much seed that remained in the matrix area between stacks. Stack burns result in higher intensity burns in local patches, and potentially have greater adverse effects on the soil than stand burns. However in this study the stand burn seemed to cause a more severe fire owing to dry soil conditions during the autumn burns. Thus for this study the stand burning clearing technique that was done in autumn resulted in greater heat transfer below ground, killing more seeds than for the cool winter stack burn clearing techniques when the soil was moist.Thus the cooler winter burns resulted in less destructive, lower temperatures which aided higher seedling recruitment. This treatment results in less destruction of indigenous seed banks (although not measured) and higher recruitment of indigenous seedbanks (Holmes 2001) but more intensive follow-up control of *Acacia* species.

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CHAPTER 3

An investigation into the density and distribution of alien *Acacia* seed banks along the Silvermine River, Table Mountain National Park

3.1 Abstract

This study looks at the extent of seed banks of alien *Acacia* species along the Silvermine River, in the Table Mountain National Park, Western Cape Province. This river has been the focus of intensive alien vegetation clearing from 1999 until the present. Four study sites were chosen along the river from the top to the bottom of the catchment. The following key questions were posed:

1. What is the distribution and density of the *Acacia* seed bank in areas along the river that have been cleared successfully, compared to areas still requiring active follow-up clearance?
2. How variable in size are the seed banks longitudinally and laterally and vertically along the river?

In this study all sites have been cleared quite successfully of both *Acacia saligna* and *Acacia longifolia*, but despite this, a substantial amount of viable *Acacia* seed still remains in the soil-seed bank. The densities of seeds found range between 306 ± 176 seeds/m^2 to 7845 ± 3602 seeds/m^2 on the left bank and 917 ± 529 seeds/m^2 to 11 920 ± 6376 seeds/m^2 on the right bank for *Acacia saligna*. Fewer *Acacia longifolia* seeds were found, ranging from 204 ± 72 seeds/m^2 on the left bank and 611 ± 144 seeds/m^2 to 815 ± 273 seeds/m^2 on the right bank. Overall seeds were buried deeper on the right bank than the left bank along the river for both *Acacia saligna* and *Acacia longifolia* and this was significant for *Acacia saligna* but not for *Acacia longifolia*. Across the four sites, seed density declined vertically with depth and most of the seeds were concentrated in the top 0-15 cm layer on both right and left banks, with the exception of a significantly high *A.saligna* seed density 18 678 ± 16 682 seeds/m^2 found at the 60-70 cm depth class at one of the samples for Site 4. Seed density decreased from the terrestrial area to the channel with the exception of a significantly high *A.saligna* seed density 10 867 ± 10 867 seeds/m^2 found in the channel at one of the samples for Site 4. There appears to be a longitudinal movement of seeds downstream. The relationship between the seed bank and aboveground vegetation for both *Acacia saligna* and *Acacia longifolia* was not found to be significant. All seeds germinated within 6 days after breaking dormancy. Indigenous vegetation recovery and the remaining lowered percentage alien vegetation is an indication of some success in the clearing programme but the remaining alien seed bank indicates that follow-up clearing should be scheduled at all sites.

Keywords: *Acacia saligna*, *Acacia longifolia*, alien management, riparian ecosystem, soil seed banks

3.2 Introduction

In South Africa, invasive alien trees and shrubs threaten both the floristically distinctive fynbos vegetation and water resources (Richardson *et al.* 1997), with riparian zones being the most impacted ecosystems (Wells *et al.* 1986). Riparian zones are diverse, complex and dynamic ecosystems that comprise the fringes of vegetation alongside rivers or streams that form the interface between aquatic and terrestrial ecosystems, where vegetation is influenced by flooding or elevated water tables (Naiman *et al.* 1993; Naiman and Decamps 1997). Riparian ecosystems are prone to invasion by alien plants because of periodic exposure to natural (e.g. flooding) and human related disturbances, the perennial availability of moisture, reliable dispersal of propagules by water and the role of stream banks as a reservoir for seeds to be stored (Rowntree 1991, Cronk and Fuller 1995, Pysek and Prach 1995).

In riparian habitats in the Fynbos Biome, alien invaders are most likely to be long-lived woody species, with *Acacia* species being key invaders (Henderson 1998). *Acacia* species regularly produce copious amounts of seeds, which accumulate in the seed bank (Milton and Hall 1981). Alien seed banks are thus a major management problem. A primary concern when restoring rivers is clearing of alien stands (Stromberg 2001). Managing aliens is a key concern for the national Working for Water programme. They have adopted a strategy to focus on invaded riparian corridors and their adjacent subcatchments in order to increase water production, conserve biodiversity, and improve water quality (Van Wilgen *et al*. 1998). Removal of invasive alien woody plants in riparian zones involves felling, usually combined with herbicide application, and prescribed burning. Removal of reinvading seedlings is usually done for two to four follow-up techniques after the initial clearing. This process is intended to deplete remnant propagules and to aid recovery of riparian indigenous vegetation (Galatowitsch and Richardson 2005). However, little is known about the extent of remaining seed banks, and whether the follow-up techniques are sufficient to remove or deplete them.

It is assumed that, due to the dynamic nature of riparian habitats, the propagules of *Acacia* species are rapidly distributed downstream of the initial invasion (Galatowitsch and Richardson 2005). Studies on seed dispersal in river systems have shown that downstream dispersal of propagules does occur, but the distance downstream, depends on the floating ability of the propagules (Schneider and Sharitz 1988, Davind and Nilson 1997, Imbert and Lefèvre 2003). If this is the case then one would predict that propagule pressure would be greater in lower catchment areas and downstream reaches than upper catchment reaches (Galatowitsch and Richardson 2005). Not only is longitudinal movement of seeds a potential problem, but there is also a concern surrounding burial of seeds by sediments. In terrestrial fynbos ecosystems, soil-stored seeds generally occur at depths of three to thirty-five centimetres (Milton and Hall 1981, Holmes 1990, Holmes 2002). However, in dunes and riparian areas, seeds are buried deeper and have been recovered from depths of up to one metre (Esler and Boucher 2004). The primary reason is that in these habitats sedimentation occurs, and on banks where sediment is being actively deposited, seeds are deposited deep into the soil profile (Nilson *et. al.* 1993).

Therefore besides the density of the above-ground vegetation the density of seeds found at a specific area is the result of various processes within riparian systems. This study looks at the extent of seed banks of alien *Acacia* species along the Silvermine River, in the Table Mountain National Park, Cape Peninsula. This river has been extensively managed to aid recovery of indigenous species from 1999 until present.

The research was aimed at answering the following questions:

3.1. What is the distribution and density of the *Acacia* seed bank in:

a) areas along the river that have been cleared successfully (as indicated by good natural vegetation recovery or decrease in alien species present) compared to

b) areas still requiring active follow-up clearance (indicated by poor natural vegetation recovery or where the alien vegetation density has not declined).

3.2. How variable in size are the seed banks longitudinally (from top of the catchment to the bottom), laterally (from the river channel to the dry terrestrial banks) and vertically (with soil depth)?

3.3 Materials and Methods

3.3.1 Site description

The Silvermine River rises at an altitude of 640m in the Steenberg Mountains at 34°07'S and 18°27'E, 10km South of Cape Town. It is a short, naturally perennial river approximately 12km long, with a catchment area of ca. 21km^2 (Figure 3.1). Four study sites were chosen along the river from the top to the bottom of the catchment (Table 3.1, Figure 3.1). These sites are part of a larger study investigating the natural rehabilitation of the river following clearing (Reinecke and King 2003, Reinecke pers. comm. 2005), and the site densities correspond to this study. Extensive mountain fires in January 2000 burned vegetation in all areas upstream of site 6 in this study, excluding site six (Reinecke and King 2003). Pre-fire alien densities were either medium (25-50% canopy cover) or dense (>50% canopy cover).

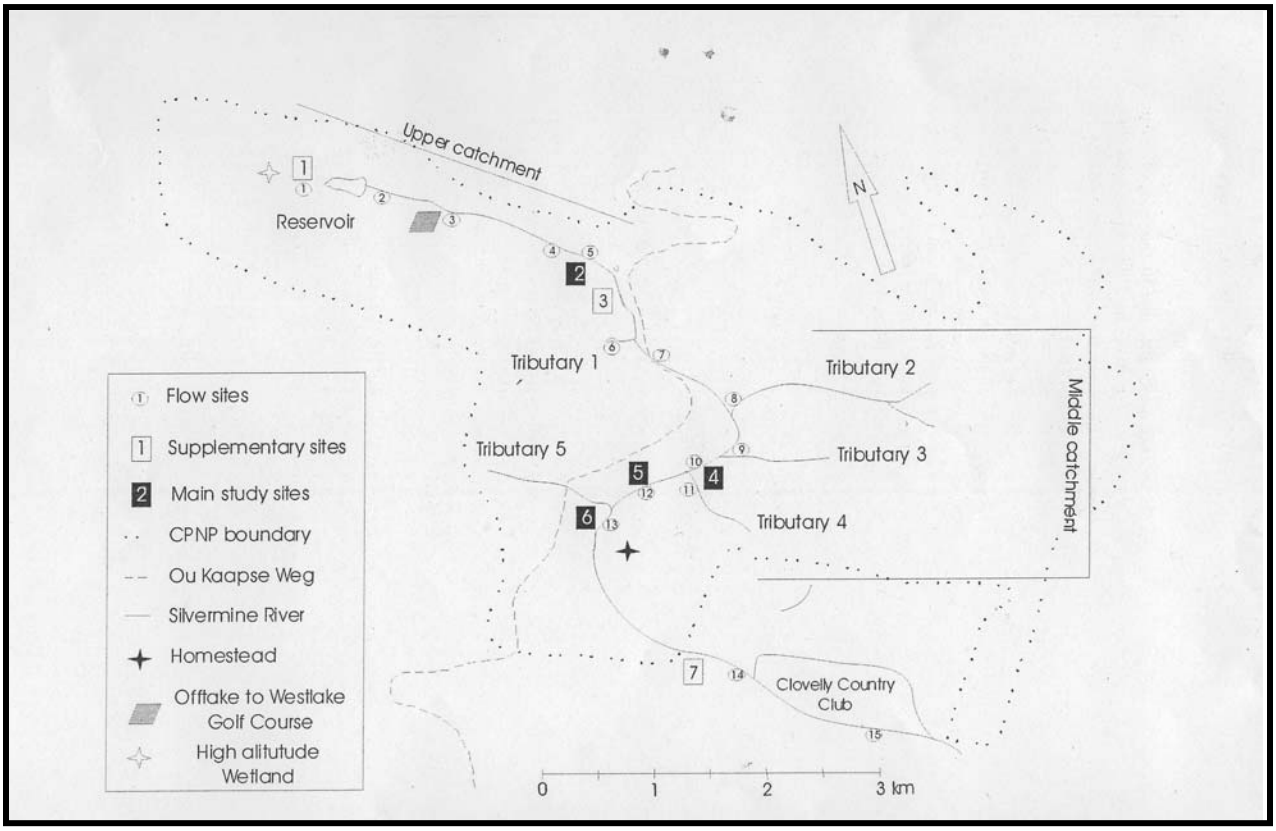

Figure 3.1: The Silvermine River within the Silvermine Section of the Table Mountain National Park (Figure adapted from Reinecke and King 2003). The main study sites indicated in the figure (originally used by Reinecke and King 2003) are the ones used in this study

Table 3.1: Characteristics of the four sites selected for sampling along the Silvermine River.

Site characteristics	**Sites** (site numbers correspond to those of Reinecke and King (2003))			
	Site 2	**Site 4**	**Site 5**	**Site 6**
GPS reading at the centre of the site	S 34 05’ 20.4" E 018 25’ 08.4"	S 34 06’ 15.5" E 018 24’ 55.9"	S 34 06’ 17.6" E 018 24’ 46.9"	S 34 06’ 25.1" E 018 24’ 37.6"
Initial infestation	Medium	Dense	Dense	Medium
Geology	Quartzitic sandstones of the Table Mountain Group	Wind-blown (Aeolian) sands, which overlay weathered Cape Granite	Wind-blown (Aeolian) sands, which overlay weathered Cape Granite	Organically rich, sandy materials
Longitudinal River zone	Mountain stream	Foothill	Foothill	Transitional

3.3.2. Seed bank sampling method

Sampling was done on the right and left banks of the river. On each bank four soil samples, were extracted vertically down the soil profile from different depths, consisting of three replicate soil cores of 5 cm diameter by 15 cm. These four soil samples were taken vertically down the soil profile at 1m above the major flood line (terrestrial area) and were comprised of different sub-samples (sub-samples: 0 – 15 cm; 30 - 45 cm; 60 – 75 cm and 90 – 105 cm) (Figure 3.2). The three replicates were taken along each of three transects, orientated perpendicular and crossing the river to sample both banks. Due to unique characteristics of the river at each site, the length of these transects varied from 22 m to 98 m. Sampling was also done 1m vertically above the winter low point of the river in the river channel, where in order to adequately capture the spatial variation in seed banks, an additional five samples for the 0 – 15 cm depth were taken within a 1m^2 plot and then bulked together as one sample. Soil samples were sieved in the field, and seeds of each sub-sample clearly labelled and bagged separately for counting and viability testing in the laboratory. Where wet soil was collected, the soil was bagged and taken back to be dried in an open plastic container after which the dry soil was sieved.

3.3.3. Vegetation sampling

Alien *Acacia* abundance, pre- -and –post- clearance was estimated using percentage canopy cover data obtained from the Table Mountain National Park (Chad Cheney Pers. Comm. 2005) and also per transect data from a study by Karl Reinecke (Reinecke and King 2003, Reinecke pers. comm. 2005). The latter data (incorporating both indigenous and alien vegetation) had been sampled earlier along the same three transects used for seed bank sampling at each site. The vegetation data was collected from contiguous, square metre, groundcover vegetation plots along the complete length of each transect. A total of 576 m^2 plots were sampled across the four sites (Reinecke and King 2003).

3.3.4 Viability tests

Viability tests were conducted on the soil-stored seed to assess seed viability. Five replicates of 20 seeds were taken from each soil sample. Seeds were scarified by clipping to break dormancy imposed by the hard seed coats, placed on moist filter paper in separate, covered germination trays and kept in a growth chamber at a constant day and night temperature of 20 - 25°C (Milton and Hall 1981). The fungicide, Captan, was regularly sprayed onto the seeds to prevent fungal contamination (Clemens *et al.* 1977). The seeds were examined regularly and those with a radicle protruding 1mm or more were recorded as having germinated and were removed.

3.3.5 Statistical analysis

Descriptive statistics were calculated in *MS* Excel. To test for significant differences in seed density between the right and left banks ANOVA in Statistica was used. A regression analysis was used to determine whether there was a relationship between the seed density and aboveground alien vegetation after clearing. The vegetation cover per transect was used as the seeds were collected along the same transects per site.

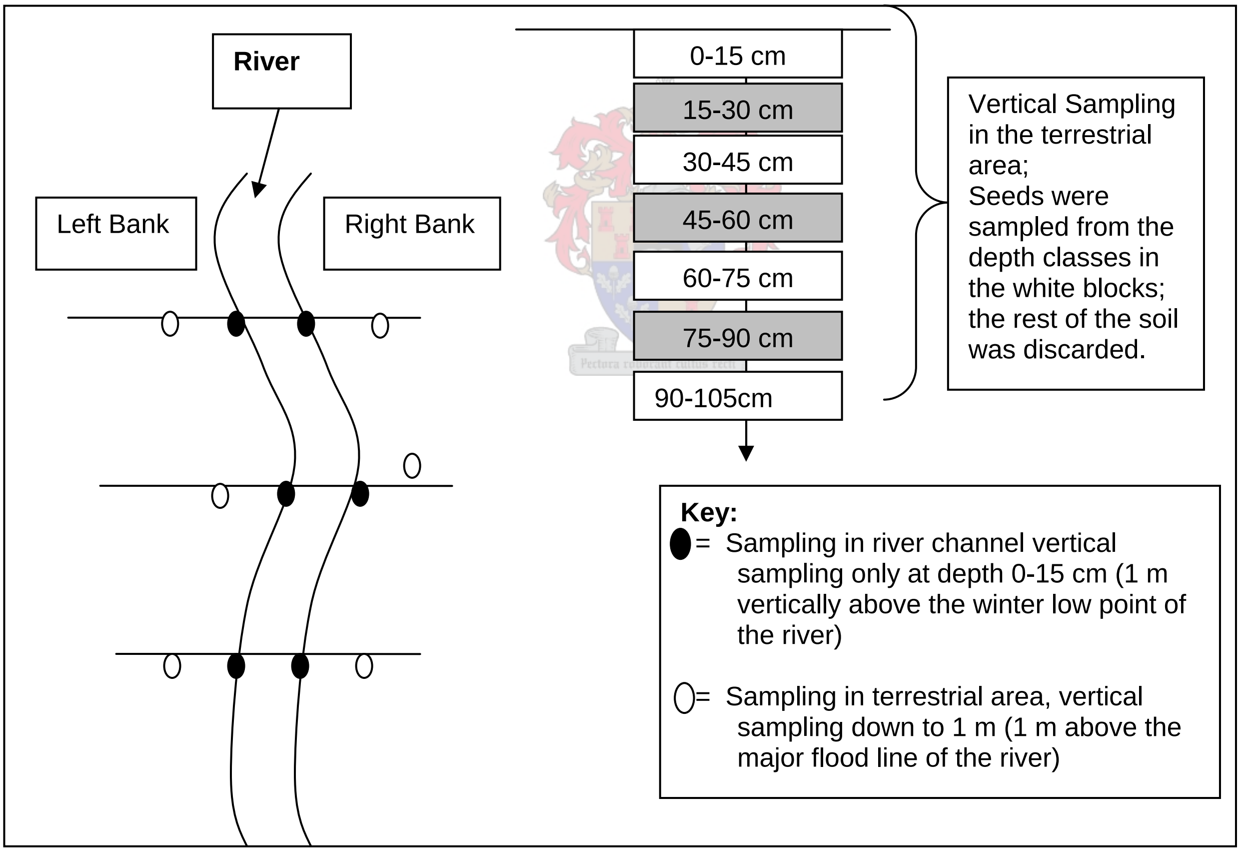

Figure 3.2: Sketch detailing the lateral and vertical method of sampling done per site.

3.4. Background information on Study Site

3.4.1 History of clearing and follow-up control at each site

Accurate information on history of clearing and follow-up initiatives is only available from 1998 since this is when the area was incorporated into the new Table Mountain National Park (TMNP; previously known as Cape Peninsula National Park). In January 2000, mountain fires burned vegetation in all areas upstream of site 6 excluding site 6 (Figure 3.1). After these fires the TMNP implemented new fire policies which led to regular clearing as well as annual follow-up until present (Reinecke and King 2003, C. Cheney pers. comm. 2005). Besides the unplanned fire in 2000, Sites 4 and 5 underwent a planned burn (1999) to remove slash, as part of the alien-clearing programme. Both the fires extended into the riparian zones. The seed bank was stimulated to germinate after each fire, as indicated by peaks in percentage alien vegetation cover (Figure 3.3). After 2001, a decline in alien vegetation cover was recorded (Figure 3.3). This is an indication of the degree of success in the clearing programme. The aerial photographs taken prior to (1996) and post clearing (2003) operations along the Silvermine River give an indication of the success of this clearing programme (Figure 3.4a and b, Appendix A). *A. saligna* and *A. longifolia* were historically present (since the 1940`s) at all the sites along the Silvermine River (Figure 3.5, Appendix A).

Table 3.2: History of clearing of *A. saligna* and *A. longifolia* at each site along the Silvermine River. Area cleared represents felling and stacking as well as the use of herbicide in the case of *Acacia saligna*. No data means that the clearing technique was not recorded.

Site / Year	Site 2	Site 4	Site 5	Site 6
1998	No data	No data	Area cleared (clearing technique unknown)	No data
1999	No data	• Stacks burnt (management burn); • Area cleared (clearing technique unknown)	• Stacks burnt (management burn); • Area cleared after the burn (technique unknown)	No data
2000	Entire area burnt in January 2000 Mountain fires	• Entire area burnt in January 2000 Mountain fires • Area cleared twice (felling,stacking with herbicide application for *A.saligna*)	• Entire area burnt in January 2000 Mountain fires • Area cleared (felling,stacking with herbicide application for *A.saligna*)	Not burnt
2001	No data	• Follow-up after clearing in 2000; • Area cleared (felling,stacking with herbicide application for *A.saligna*); then follow-up took place • Area cleared again that year (felling, stacking with herbicide application for *A.saligna*)	• Follow-up after clearing in 2000; • Area cleared (felling,stacking with herbicide application for *A.saligna*); then follow-up took place • Area cleared (felling, stacking with herbicide application for *A.saligna*) again that year	Area cleared (felling,stacking with herbicide application for *A.saligna*)
2002	No data	Follow-up after last clearing in 2001	Follow-up after last clearing in 2001	Follow-up after clearing in 2001
2003	• Follow-up after clearing previous years; • Area cleared (foliar application)	Area cleared (felling, stacking with herbicide application for *A.saligna*)	Area cleared (felling,stacking with herbicide application for *A.saligna*)	Area cleared (felling,stacking with herbicide application for *A.saligna*)
2004	Follow-up after clearing in 2003	Follow-up after clearing in 2003	Follow-up after clearing in 2003	Follow-up after clearing in 2003

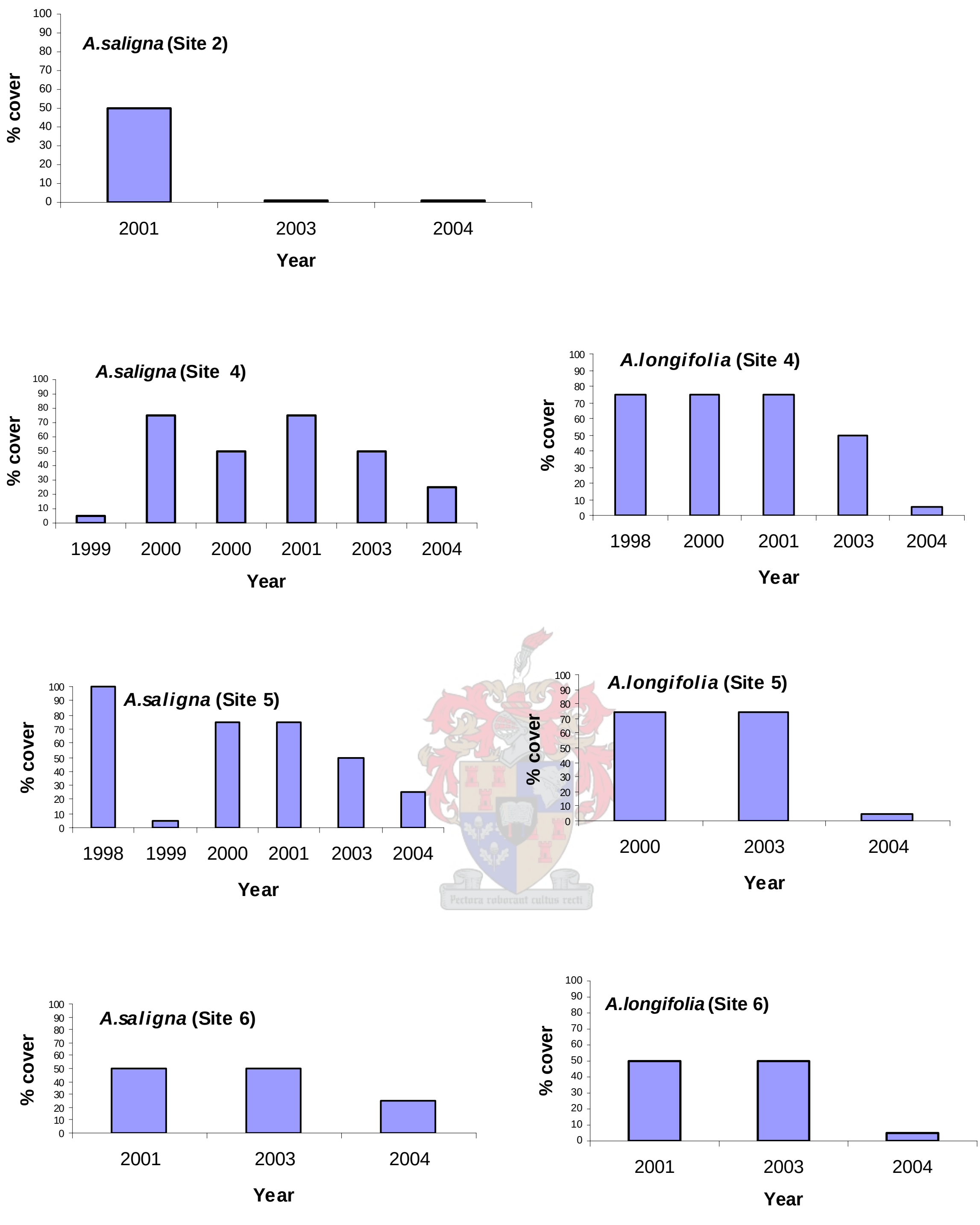

Figure 3.3: The annual percentage vegetation cover of *A. saligna* and *A. longifolia* at Sites 2, 4, 5 and 6. Clearing took place each year prior to the assessment of vegetation cover of *A. saligna* and *A. longifolia*. Refer to table 3.2 for details of clearing history. The key for percentage alien cover classes as used in management: closed >75%, dense 50-75%, medium 25-50%, scattered 5-25%, very scattered <5%, occasional and rare 0.1% (data from C. Cheney pers. com. 2005)

3.5 Results

The distribution and density of *Acacia* seeds and the comparison to the above-ground alien and indigenous vegetation

There was considerable variation in the densities of seeds found across the different sites and sampling points. The seeds of *Acacia saligna* were the more abundant of the two *Acacia* species sampled along the Silvermine River (Table 3.3 and 3.4). This coincides with the historical distribution of the two species (C. Cheney pers. com. 2005). A substantial density of *A. saligna* seeds were found in the channel (1m above the winter low point, but below the major floodline) at sites 4 and 5, with more seeds found on the left bank than the right bank (Table 3.3). By contrast, no *A. saligna* seeds were found in the channel at sites 2 and 6 (Table 3.3). In the terrestrial sampling point (1 m above the maximum flood line), most seeds were found in the top 0 - 15 cm soil layer and they were present at all the sites (Table 3.3). The seeds of *A. longifolia* were not present at sites 2 and 6 at all, and no seeds were found on the left banks of sites 4 and 5 (Table 3.4). Sites 4 and 5 had greater alien seed density in the terrestrial area than in the channel (Table 3.4).

Overall greater seed densities were found in the terrestrial area compared to the channel and this was found at all the sites and for both *Acacia* species (Table 3.3 and 3.4). Below the maximum flood line, seeds were more abundant on the right bank than the left bank (Table 3.3) and this was significant for *Acacia saligna* (ANOVA, p=0.05) but not for *A. longifolia* (ANOVA, p=0.22). Noteworthy was the presence of the highest density of seeds recorded in any one sample in a deeper soil layer (60 – 75 cm depth class) at site 4 on the right bank (Table 3.3). No seeds were found below the 60 – 75 cm depth class at any of the sites (Table 3.3). Overall, most seeds were found at the lower three sites, coinciding with the greater abundance of alien *Acacias* historically (C. Cheney, pers. com.2005) and recently of aliens above ground (Figure 3.3).

Of the lower three sites, site 6 had the lowest seed density but it also had a lower initial alien vegetation cover compared to sites 4 and 6 (Table 3.3, Figure 3.3). The above-ground vegetation of *Acacia saligna* were the same initially for sites 2 and 6 but post-clearing results showed site 6 with a greater seed density and above-ground vegetation cover than site 2 (Table 3.3, Figure 3.3). Post clearing results also showed site 6 to have the same alien vegetation density as sites 4 and 5 where initially these two sites had double the percentage cover of site 6 (Figure 3.3). Similar trends were found for *A. longifolia*, however fewer seeds of this species were found at each of the sites (Table 3.3). All alien *Acacia* seeds in the seed bank were viable as determined in the germination trials (Table 3.3 and 3.4).

No statistically significant relationship was found between the seed bank and the percentage vegetation cover for *Acacia saligna* in the post clearing environment for Year 2000(r^2=0.83, df=4, p>0.05) and Year 2004 (r^2=0.72,df=4, p>0.05)(Table 3.5) as well as for *Acacia longifolia* in the post clearing environment for Year 2000(r^2=0.82,df=4, p>0.05) and for Year 2004 (r^2=0.58,df=4, p>0.05) (Table 3.5).

Reasonable post-clearing recovery of indigenous vegetation has taken place as seen at the sites where initially alien infestation was dense and now, several different indigenous species are present in these sites (Table 3.6; Figure 3.3). Site 2 had the highest density of indigenous plant species while site 5 and 6 had the same density of indigenous plant species, even though initially site 5 had a higher percentage infestation than site 6 (Table

3.6; Figure 3.3). Interestingly, site 4, which had been the most heavily infested initially, had more indigenous species than site 5 and 6, indicating good recovery after clearing (Table 3.5). It must be noted that the data provided in Table 3.6 only gives an indication of what species were present and not of their abundances. All alien *Acacia* seeds in the seed bank were viable as determined in the germination trials (Table 3.3 and 3.4).

Table 3.3: The mean (± standard error, n=6 per depth class per bank) of *A. saligna* seed density (density/m^2) found in the channel (1m above the winter low point) and along the terrestrial banks (1m above the maximum flood line) of the Silvermine River. The latter was sampled at four soil depth classes. Along the river, the percentage above ground vegetation cover of *A. saligna* per bank was also sampled. Percentage viability is indicated in brackets next to the totals for the average seed density across all depth classes.

		Channel Seed bank	Terrestrial					Above-ground *Acacia* cover
Site	Bank	0 – 15 cm	0 – 15 cm	30 – 45 cm	60 – 75 cm	90 - 1.05 cm	Average seed density across all depth classes (viability)	Percentage vegetation cover per bank
Site 2	Right	0	1528 ± 1281	0	0	0	917 ± 529 (100%)	0
	Left	0	509 ± 509	0		0	306 ± 176 (100%)	0
Site 4	Right	1019 ± 588	849 ± 849	1358 ± 13 580	18 678 ± 16 682	0	11 920 ± 6376 (100%)	7
	Left	10867 ± 10867	167 ± 167			0	7845 ± 3602 (100%)	3
Site 5	Right	1358 ± 1358	11 207 ± 11 207	1358 ± 1358	0	0	8354 ± 3685(100%)	5
	Left	4075 ± 4075	0	0	0	0	2445 ± 1412 (100%)	2
Site 6	Right	0	6113 ± 3056	0	2377 ± 2377	0	5094 ± 2071 (100%)	1
	Left	0	2717 ± 2717	340 ± 340	0	0	1834 ± 919 (100%)	0

Table 3.4: The mean (± standard error, n=3 per depth class per bank) of *A. longifolia* seed density (density/m^2) found in the channel (1m above the winter low point) and along the terrestrial banks (1m above the maximum floodline) of the Silvermine River. The latter was sampled at four soil depth classes. Along the river the percentage above ground vegetation cover of *A. longifolia* per bank was also sampled. Percentage viability is indicated in brackets next to the totals for the average seed density across all depth classes.

Site	Bank	Channel	Terrestrial					
		Seed bank						Above- ground *Acacia* cover
		0 – 15 cm	0 – 15 cm	30 – 45 cm	60 – 75 cm	90 - 1.05 cm	Average seed density across all depth classes (viability	Percentage vegetation cover per bank
Site 2	Right	0	0	0	0	0	0	0
	Left	0	0	0	0	0	0	0
Site 4	Right	170 ± 170	170 ± 170	0	509 ± 509	0	611 ± 144 (100%)	4
	Left	0	170 ± 170	170 ± 170		0	204 ± 72 (100%)	2
Site 5	Right	0	849 ± 849	340 ± 340	170 ± 170	0	815 ± 273 (100%)	3
	Left	0	0	0	0	0	0	2
Site 6	Right	0	0	0	0	0	0	0
	Left	0	0	0	0	0	0	0

Table 3.5: Regression coefficients of the two parameters obtained from the four study sites.

Parameter	DF	Equation	r^2	P-value
Acacia saligna seed bank vs vegetation cover at year 2000	4	Y=47.65054 + 0.0003*X	0.83	p >0.05
Acacia saligna seed bank vs vegetation cover at year 2004	4	Y=8.211 + 0.0002*X	0.72	p >0.05
A.longifolia seed bank vs vegetation cover at year 2000	4	Y=25+ 0.0123*X	0.82	p >0.05
A.longifolia seed bank vs vegetation cover at year 2004	4	Y=2.5 + 0.0006*X	0.58	p >0.05

Table 3.6: Density of indigenous and alien species found at each site after clearing initiated in 2000 (Data obtained from Reinecke and King (2003).

	Density of species per site				
	Total	Site 2	Site 4	Site 5	Site 6
Total	147	71	57	38	33
Indigenous plant species	113	59	45	26	26
Alien plant species	34	12	12	12	7

3.6 Discussion

The longitudinal, lateral and vertical distribution of seeds

We need to quantify the extent of alien seed banks in order to adequately manage the problem of alien vegetation. Riparian seed bank studies has been a neglected area of river research and recently has been shown to be quite an important aspect in understanding riparian ecosystems (Goodson *et al.* 2001), as well as in the management of alien vegetation in riparian systems.

The densities of seeds found ranged between 306 ± 176 seeds/m^2 to 7845 ± 3602 seeds/m^2 on the left bank and 917 ± 529 seeds/m^2 to 11920 ± 6376 seeds/m^2 on the right bank for *Acacia saligna*. Fewer *A.longifolia* seeds were found, with 204 ± 72 seeds/m^2 on the left bank and 611± 144 seeds/m^2 to 815 ± 273 seeds/m^2 on the right bank. In chapter two of this thesis I looked at the extent of *A. saligna* seed banks in terrestrial areas and found 38 714 ± 4006 seeds/m^2 in the top 0-15 cm layer only and this does not even include the litter layers or the deeper 15-30 cm layer. Although fewer *Acacia* seeds were found in the riparian study,, this is not always the case with all alien species and riparian systems, as riparian systems are continuously susceptible to renewed invasion by water-dispersed alien species (Goodson *et al.* 2001, Galatowitsch and Richardson 2005). In this case the smaller seed bank could be the result of flushing of seeds after fire and the intensive follow-up that took place after fire, before plants flowered. The shorter invasion period compared to the sites sampled in chapter two could also be the reason for lower seed densities.

A further problem with riparian systems is, that dynamic fluvial processes such as sedimentation and erosion associated with flood events influence riparian seed banks (Goodson *et al.* 2001). These processes either lead to deeper burial of seed or flushing of the seed bank. It is assumed that in erosional areas fewer seeds would be found than in depositional sections of a river system. The effects of these processes was especially prominent at site 4 in the middle catchment, where the highest density of seeds recorded (10 867 ± 10 867seeds/ $m^{2)}$ in this study, was found in a deeper 60 – 75 cm depth class soil layer., which suggests sediment accumulation after the *Acacias* were well established. A study in the United Kingdom on riparian seed banks revealed a low abundance of viable seeds on unvegetated eroding bank sections, while a very substantial seed bank was found in an old channel within a local depositional environment (Goodson *et al.* 2002). In this study, seeds were generally found to be buried deeper on the right bank than the left bank along the river for both *A. saligna* and *A. longifolia.* During this study I observed the right bank to have high vertical sandy banks while the left bank was eroding and this was especially prominent in the middle catchment, which constituted sites 4 and 5 of this study.

Besides the significanty high seed density recorded at the 60-75 cm depth class at site 4, across the four sites seed density generally declined with depth. Most of the *Acacia* seeds were present in the top 0 – 15 cm on both right and left bank. Similar trends were recorded for other studies on three *Acacia* species (*Acacia saligna, A. cyclops* and *A. mearnsii*) with most seeds being recorded in the top layers regardless of habitat, with a decline in abundance with soil depth, but in riparian systems significant densities of seeds were recorded deep down the profile (Esler and Boucher 2004). Seed density was also higher in the terrestrial area (1m above major floodline) than in the channel. Seeds in the channel could also have been lost through decay and rotting, with the exception of the high seed density recorded for Site 4 at one sampling point in the channel. In another study, newly buried populations 45% of *A. saligna* seeds and 97% of *A. cyclops* seeds either germinated or rotted in the first year of burial (Holmes and Moll 1990). Decay rates declined significantly after the first year of burial, as those seeds that were not water-impermeable either germinated or decayed in the first year. The remaining cohort is “hardseeded” and can persist for decades. This poses a problem as removal of this seed bank is difficult at this depth because disturbances like fire can remove the top layers of seed, as shown in this study and in other studies, where seeds were removed down to 4 cm and germination stimulated down to 8.5 cm (Beadle 1940, Cunningham and Cremer 1965, Floyd 1966, Holmes 1989). Fire can thus be used as a management tool, but even if fire is used as a management tool, follow-up clearing programmes are a necessity in these habitats, as the seed banks even deep down in the soil profile can be exposed due to the dynamic nature of riparian habitats. Fire does not only aid mortality but also results in mass germination (Pieterse and Cairns 1986, Holmes *et al.* 1987, Pieterse and Boucher 1997). If follow-up does not take place, the developing stand could restore the seed bank to its pre-clearance size (Holmes *et al.* 1987, Galatowitsch and Richardson 2005). Thus wild fires result in flushing of alien seedlings as Van Wilgen and Richardson (1985) recorded 9 800 stems/ha of *A. saligna* resulting from prolific germination. Intensive follow-up is then required as resprouting plants do not only make control difficult, but is also more expensive (Macdonald and Wissel 1992). Thus seed-attacking biological control agents such as the gall-forming rust fungus, *Uromycladium tepperianum*, on an invasive tree *Acacia saligna* (Morris 1997, 1999, Zimmerman *et.al.* 2004) and the bud-galling wasp *Trichilogaster acaciaelongifoliae* on *Acacia longifolia* can be used as a long-term control strategy to stabilize the soil seed bank and eventually reduce population densities (Hoffman *et al.* 2002, Zimmerman *et.al.* 2004).

The distribution and density of seeds in relation to the remaning cleared above-ground alien vegetation

In this study all sites have been cleared successfully of dense *A. saligna* and *A. longifolia* stands. But despite this, a substantial amount of viable *Acacia* seed still remains in the soil-seed bank. The location of *Acacia* plants can be used to predict where seeds are likely to be abundant in the seed bank. Although the relationship between the above-ground vegetation and seed bank was not significant, areas that had higher alien vegetation density initially had higher seed density. This indicates that clearing of above ground vegetation alone will not reduce the seed bank, thus other management option as mentioned above, such as fire or seed-attacking biological control agents could be used. In a study on *Chromolaena odorata* seed densities were found to increase with an increase in invasion of this species (Witskowski and Wilson 2001). In this study the majority of *Acacia* seeds were found in the middle catchment at site 4 and 5 where initially density was higher than for the other two study sites. Site 2 and 6 had similair initial aboveground alien vegetation densities but I found less seeds at site 2 in the mountain stream than at site 6 in the lower catchment. A reason for this could be that, site 2 is situated in the headwater reaches, and this is where influx of propagules is limited, but site 6 is situated in the lower catchment and downstream propagule movement is very effective along rivers, even for short floating seeds (Anderson *et al.* 2000, Nilsson and Svedmark 2002). Thus alien propagule influx has been higher in downstream sites 4, 5 and 6. This is also the case for indigenous propagules, thus potentially facilitating recovery of invaded riparian sites downstream from influx of propagules. As seed movement downstream is a major factor which could result in lower reaches having higher rates of invasions by alien species, clearing of headwater streams should be favoured to limit influx of alien propagules. This clearing strategy has already been implemented in South Africa (CSIR 1999). Depositional and erosional processes could also have resulted in the larger density of seeds downstream, as the dominant geomorphological process in the foothill zone is deposition, in contrast to the mountain stream zone where it is erosion (Davies and Day 1998).

Despite the high densities of alien seeds found across the four sites, regeneration of indigenous vegetation has occurred, especially at Site 4 and 5, which had almost closed alien stands prior to clearing, with no indigenous vegetation occurring there (Chad Cheney pers comm. 2005). Indigenous vegetation recovery and the remaining lowered percentage alien vegetation is an indication of some success in the clearing programme but the extensive seed bank should not be forgotten. The presence of several indigenous vegetation at sites where initially alien infestation was dense as well as the reduced percentage alien density from 50-75% initially to 5-25% and even<25% at Site 2 is an indication of a successful clearing programme.

3.7 Conclusion

Overall seed density decreased as soil depth increased with an exception of a high seed density at a low depth in one of the samples, likely a result of the dynamic nature of riparian systems. Seed density also increased laterally with less seeds occurring in the channel than in the terrrestrial sections. Seed density increased with longitudinal distribution with more seeds occurring at the sites in the lower catchment than upper catchment. This study also showed that regular clearing in combination with fire is necessary to reduce seedbanks as large seed densities were still remaining in areas where above ground alien vegetation had been cleared quite successfully. The emergence of indigenous vegetation post-clearance and lowered above-ground alien density is an indication, that with intensive clearing and proper management of invaded areas, success or control of invaded areas can be obtained, however follow-up work has to continue due to the presence of a seed bank.

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CHAPTER 4

General Conclusions

4.1 Introduction

The findings and recommendations made in this thesis can be applied to the management of woody alien plants with long-lived, hard-coated seeds, both within the Table Mountain National Park and elsewhere in the Fynbos Biome. The seed bank study along the Silvermine River is the first to be done in fynbos riparian ecosystems and it should help to make managers aware of the extent of seed banks after aboveground vegetation clearance.

This chapter is a review of the predictions outlined in Chapter 1 as well as a summary of problems and shortcomings of this study, future recommendations and implications for management of alien invasive species.

4.2 Realisation of research predictions and objectives

4.2.1 The extent of pre- and post-fire *Acacia saligna* seed banks under differing stand ages and differing clearing techniques

The principal aim of this study was to investigate the extent of pre- and post-fire *Acacia saligna* seed banks under differing stand ages and differing clearing techniques in the Silvermine section of the Table Mountain National Park, focusing on the following components: the effects of alien clearing (stack burn vs standing burn) on the density and proportion of alien seeds available for regeneration in a post-clearing, post-burn environment; the effect of soil depth, age of dense infestation and habitat (shallow mountain soils vs deep sandy valley soils) on seed bank distribution and density. Data was collected on all these components and presented in earlier chapters.

The primary hypotheses that seed bank density would be greater in alien stands with areas of a greater age of dense infestation, in deep sandy soils and that fire would reduce seed banks significantly irrespective of the clearing technique used were upheld by this study. The prediction that stack burn techniques would result in a greater decline in seed banks under stacks than standing burn techniques was upheld, as was the prediction that stack burn distribution of seeds would be heterogeneous (patchy) compared to standing burn technique, because large densities of seeds would still remain in areas where stacks did not occur. As a result of this patchy distribution, the stand burn technique had a greater decrease in seed densities across the whole site than did the stack burn technique. The results obtained from this study corroborate previous studies that found that regardless of the pre-burn technique the seed bank is significantly reduced after fire (Milton and Hall 1981, Pieterse 1986, Holmes *et al.* 1987, Pieterse and Cairns 1987, Holmes 1989) suggested burning standing populations would be more economical. A study done by Pieterse and Boucher (1997) found burning *of A. mearnsii* not to be feasible because of the high regeneration by coppicing and seedling emergence after fires. In this study though, block burns did not result in high regeneration after fire.

Seed density declined with depth as predicted and and although not statitically tested mature stands of aliens as well as stands with deep valley soils had greater seed bank distribution and density than younger stands and also compared to areas with shallow mountain soils. As found in this study and other studies seed density is greatest near the surface, because this is where recent accretion takes place and density then declines rapidly with an increase in depth (Milton and Hall 1981, Fenner 1985, Holmes 1990). Previous studies have also shown greater seed bank distribution and density in mature alien stands (Milton and Hall 1981, Holmes 2002).

4.2.2 The extent of seed banks of alien *Acacia species* along the Silvermine River

The main goal of this study was to investigate the extent of seed banks of alien *Acacia* species along the Silvermine River, in the Table Mountain National Park. The research was aimed at answering the following question: What is the distribution and density of the *Acacia* seed bank in areas that have been cleared successfully to areas that still require active follow-up? We looked at the density and distribution of the seed bank longitudinally, laterally and vertically along the river. These research questions were addressed in Chapter 3.

It was predicted that areas that had dense alien vegetation initially would still have large densities of alien seed remaining post-clearing, even if most of the vegetation had been cleared. This is true as *Acacias* produce copious amounts of hard leguminous seeds resulting in large soil stored seed banks (Milton and Hall 1981, Pieterse and Boucher 1997) and clearing of vegetation alone does not deplete the seed bank because fire is needed to denature the testa of the hard-coated *Acacia* seeds in the soil to allow for germination to take place (Cavanagh 1980, Jeffery *et al.* 1988). In this study no significant relationship was found between the seed bank and the above-ground vegetation.

Movement of seed also plays a role in the seed bank as seeds tend to move downstream and thus accumulate to form greater seed bank densities. This coincides with our prediction that seed density would be greater in the lower catchment compared to the top catchment. Studies have shown that lateral movement of seeds in river systems downstream do occur (Schneider and Sharitz 1988, Davind and Nilson 1997, Imbert and Lefèvre 2003) due to the dynamic nature of riparian systems, it is assumed that the propagules of *Acacia* species are rapidly distributed downstream of the initial invasion (Galatowitsch and Richardson 2005). Predictions that more seeds would be found in the terrestrial section of the riparian zone compared to channel were realised with the exception of high seed density found at one sample at Site 4 of this study. As the terrestrial section has deeper soils more seeds tend to accumulate there. When looking at the vertical distribution of seeds most of the seeds were found in the upper layers decreasing with depth and significant seed densities were still found at low depths as predicted.

4.3 Shortcomings and future recommendations

4.3.1 The extent of pre- and post-fire *Acacia saligna* seed banks under differing stand ages and differing clearing techniques

Only four sites were used in this study and these sites varied in soil depth, topography, hydrology as well as history of invasion. Ideally more sites were needed for sampling, representing the same techniques over a wider range of sites, but were unfortunately not available. As a result I did not have sufficient replication and statistical comparisons could not be made of all the questions posed. Instead, trends were identified and inferences made. For example, in relation to stand age and habitat there is a trend that they have an effect on the seed bank distribution and density.

4.3.2 The extent of seed banks of alien *Acacia* spp. along the Silvermine River

At each site the density of samples taken was chosen in accordance to vegetation transects that were detailed in a previous study done on the river (Reinecke and King 2003). This was done because we used the vegetation data in our study. Our results revealed though that too few samples were taken as standard errors were quite high. Thus for future studies more samples should be taken at a site. Samples do not necessarily have to be taken exactly on vegetation lines as the seed banks are dynamic and movement takes place all the time. Thus the seed bank at a particular point may not necessarily be from the local source. Further studies could entail looking at the indigenous seed bank that could help determine the restoration potential of the river.

4.4 Management implications of this study:

4.4.1 The extent of pre- and post-fire *Acacia saligna* seed banks under differing stand ages and differing clearing techniques

Although both stack and standing burn techniques significantly reduced seed banks, the ultimate success of a clearance project depends on whether a sustainable cover of fynbos vegetation can be restored after the completion of alien clearance operations (Holmes and Foden 2001). Stack burns usually lead to more intense fires, because of residual burning of surface fuels that could have adverse effects on soil, vegetation and fauna (Richardson and van Wilgen 1986, Breytenbach 1989), including indigenous soil-stored seed and on resprouting species persisting in alien stands (Musil and Midgley 1990). Indigenous seed banks in the upper 4 cm of soil may be killed during alien slash fire resulting in lowered regeneration capacity and poor recovery of fynbos vegetation following alien clearance (Holmes 2001).

Alternatively burning of aliens standing to decrease heat release at the soil has been suggested (Holmes 2001) but this could lead to flushing of the seed bank with prolific germination resulting in high seedling recruitment in the range of 9 800 stems/ha of *A. saligna* as recorded by Van Wilgen and Richardson (1985). In an event like this intensive follow-up is necessary in order to stop reseeding. Resprouting plants do not only make control difficult, but is also more expensive to control by using a foliar herbicide application (e.g. 0.5% Triclon, a Triclopyr ester solution) during follow-up (Macdonald and Wissel 1992). In this study however stand burns because of season of burn (autumn), was more intense and this was witnessed by the total removal of the litter layer and low seedling regeneration in the post-burn environment.

The cool, less destructive winter stack burns resulted in greater alien seedling regeneration and alternatively a good recruitment of indigenous seedlings could also occur although not measured in this study indigenous recruitment was observed at one of the stack burn sites. Thus burning of stacks in winter is a good management option in order to reduce adverse effects on the environment (Holmes 2001).

As age of dense infestation and habitat seem to be correlated to size of seed bank it is important for managers to know the site history. The numerous seeds remaining in the soil have high percentage viability. Managers should always be alert when regeneration takes places so that seedlings can be removed before they mature and set seed. If proper follow-up does not take place then burning as a means to reduce the seed bank is fruitless because the seed bank will then be replenished again. This was seen in another study where as a result of negligible follow-up after fire, the developing stand could restore the seed bank to its pre-clearance size (Holmes *et al.* 1987). Block burning seems to be better than stack burning for removal of aliens but irrespective of clearing techniques, enough seeds always remained in the soil to regenerate new *Acacia* stands.

Although the hot autumn stand burn resulted in a greater reuction of the seed bank the cool winter stack burns are a better option in order to reduce adverse ecological effects on the soil and will result in a greater recruitment of indigenous seed. Fire is necessary in order to deplete the soil seed banks under *Acacia saligna* stands. Follow-up work should be done after seedlings have emerged but it shoud be done within the frsti two years before flowering takes place

Main management recommendations for *A.saligna* control are as follows:

- Fire should be used as a tool to reduce the seed bank.
- It is important for mangers to know site history as more seeds are likely to be found in areas with a greater stand age and in sites with deeper soil.
- In deeper soils, seeds are likely to be found at lower depths, especially in previously mature stands.
- Cool winter stack burns are the better options for management in comparison to autumn burns as heat release is lowered causing less soil damage and greater seedling emergence takes place.
- With the greater seedling emergence more intensive follow-up to clear alien seedling should take place.
- Follow-up should take place within the two year window period after germination, before *Acacias* mature and set seed.
- Herbicide application of *A.saligna* is necessary as it is a resprouting species.

4.4.2 The extent of seed banks of alien *Acacia* spp. along the Silvermine River

In riparian systems, as in terrestrial fynbos areas, we always need to be aware of the seed bank in order to manage the aliens effectively, bearing in mind that as a result of the dynamic processes in riparian systems, it has its own set of management problems. As mentioned above for terrestrial fynbos systems, site history is also important in riparian systems in order to manage clearing programs. In this study it was shown, that initial densities prior to clearing should give a good idea of what is in the soil seed bank as high soil seed densities were found in areas where initially above-ground vegetation cover had been dense.

Observations on river geomorphology could also assist in predicting locations of dense alien seed banks as fluvial processes such as sedimentation or erosion influences burial or exposure of soil seed banks (Goodson *et al.* 2001). Dominant geomorphological process in the foothill zone is deposition, in contrast to the mountain stream zone where it is erosion (Davies and Day 1998). Sedimentation leads to burial of seeds as shown in this study and others (Goodson *et al.* 2002) where as erosion exposes new soils and seed banks reulting in flushing of the soil seed bank (Komulainen *et al.* 1994, Goodson *et al.* 2001). Thus in riparian systems we should be aware that seeds are buried deep in the soil in depositional areas. Thus, although most of the seeds have accumulated in the top layer, in riparian systems if sedimentation takes place it could lead to deeper burial of seeds as was found in this study. Thus if there is evidence of sediment accumulation under the alien stand facilitation of erosion to remove seed banks has been suggested as a management option as erosion exposes seed banks resulting in loss of seeds (Esler and Boucher 2004). More seeds occur in the terrestrial areas in the riparian system thus this should be a focus when managing the seed bank.

It is also important to remember that because of longitudinal movement downstream; most of the seeds should have accumulated in the lower catchment. Thus managers should focus attention on upper catchments by removing aliens there, so that the chance of downstream movement of seeds and influx of propagules are limited. Seeds found in riparian systems are also viable and is also an indication that the stock will survive for many years even if all the parent plants are removed. The 2000 fires led to an increase in overall percentage alien vegetation cover by stimulating seeds thus facilitating germination (Kruger and Bigalke 1984, Milton and Hall 1981), but may also have killed much of the seed bank. Thus the follow-up that took place after this was important to reduce the regeneration of the new stands.

Although the clearing programme seems to be successful, the extensive seed bank should not be forgotten. Higher soil seed densities are also more likely to be found in the lower catchment as movement of seed is usually downstream and fluvial processes such as sedimentation is more likely to occur in lower catchments.

4.5 Conclusion

Both studies show that regardless of habitat (riparian or terrestrial fynbos) that even if above ground vegetation is cleared vast densities of propagules always remain in the soil. The seed bank is only reduced by means of fire. Thus fire plays an important role in reducing seed banks. At the same time follow-up should take place regularly in order to reduce or stop replenishment of the seed bank by the seedlings that do come up. Seed density in *Acacia* will only decrease very slowly unless triggered to germinate by a stimulus such as fire. So contingencies should be in place for intensive follow-up operations after the next fire.

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5. APPENDIX A

Aerial photographs for the years 2003, 1996 and 1945 depicting the presence of alien vegetation along the Silvermine River

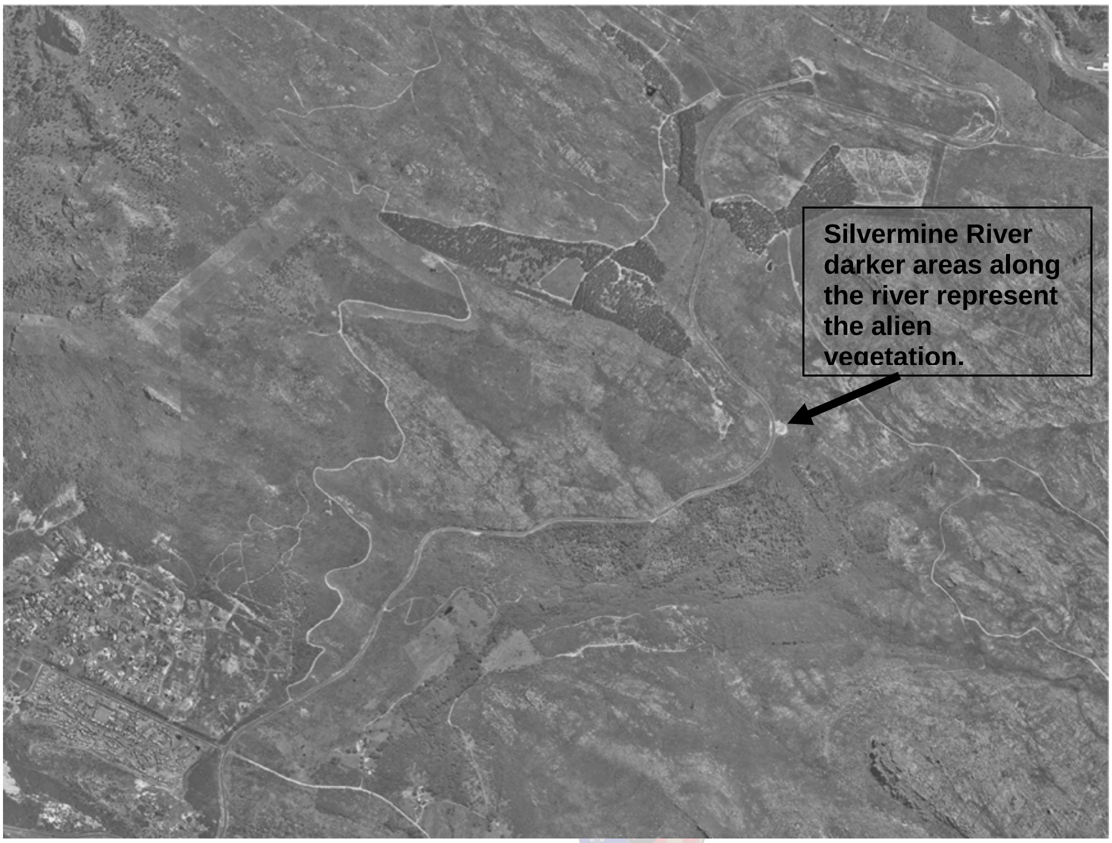

Figure 3.3a: Aerial photograph of the Silvermine River for the year 1996 (Chad Cheney pers. comm. 2005)

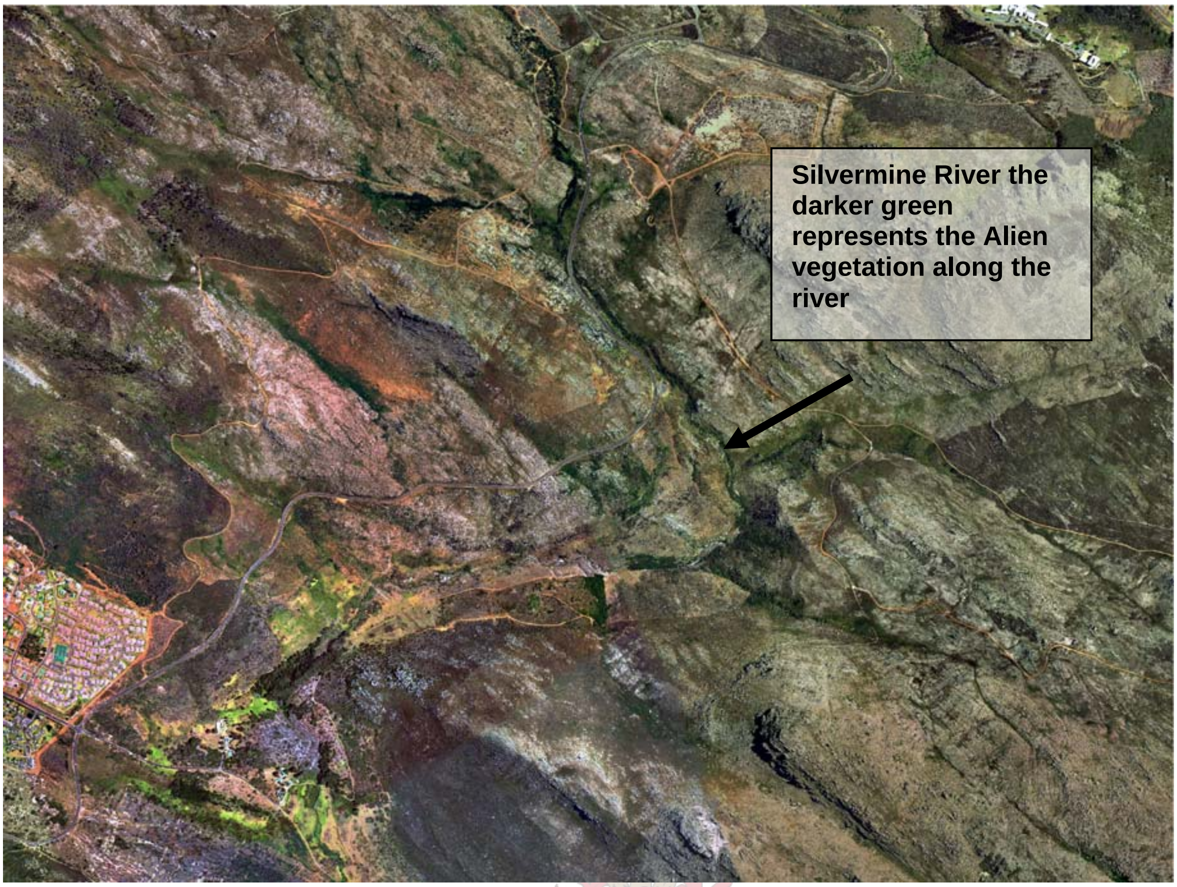

Figure 3.3b: Aerial photograph of the Silvermine River for the year 2003 (Chad Cheney pers. comm. 2005)

Figure 3.4: Aerial photograph of the Silvermine River Year the year194 (Chad Cheney pers. comm. 2005)