AN INVESTIGATION OF RIPARIAN VEGETATION RECOVERY FOLLOWING INVASIVE ALIEN TREE CLEARING IN THE WESTERN CAPE.

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2008

A thesis submitted in partial fulfilment of the degree of Master of Science, at the University of Cape Town

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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.

Signature.. Date..

Acknowledgments

I thank my supervisors Dr Pat Holmes, Prof Timm Hoffman as well as Prof Dave Richardson for their help, guidance and motivation regarding research ideas, the manuscript structure and insightful comments. A special thanks to Dr Pat Holmes for her support and time spent keeping the focus of the manuscript in line with research objections, time in the field and assistance in plant identification.

Financial support was provided through the national research project: "Targets for Ecosystem Repair in Riparian Vegetation" for the Working for Water programme, Department of Water Affairs and Forestry (DWAF).

I thank the Plant Conservation Unit for support and for being my home for the duration of the project. Comments and suggestions provided by colleagues within the Unit have all contributed to improvements in the final manuscript.

Thanks to the Working for Water and CapeNature staff for helping with site selection and site information. I am indebted to the time they took to show me around and to make the fieldwork seem as easy as it did. I thank my friends Clement Arendse, Kishan Sankar and Wayne Hendricks for their assistance in the field. I would also like to thank Terry Trinder-Smith, in the Bolus Herbarium, Dr Tony Verboom, Dave Gwinn-Evans, as well as Karl Reinecke for helping with plant identification. Finally I'd like to thank my family and Amy Trout for their emotional support and understanding while completing this project.

Summary

Riparian zones are dynamic, as a result of varying levels of disturbance from natural flooding regimes, and this makes them particularly susceptible habitats to invasion by alien plants. In South Africa, particularly the Fynbos Biome, closed-stand invasions by alien *Acacia* and *Eucalyptus* species have been able to develop within riparian areas. Their impacts on water resources and biodiversity have been countered by manual clearing in order to protect the valuable ecosystem services provided by intact riparian zones, as well as the biodiversity of indigenous communities. The Working for Water programme is tasked with the important role of controlling invasive alien plants with an assumption that indigenous vegetation will recover naturally. Current management objectives are to reduce above ground biomass of invasive alien plants by labour intensive means, after which indigenous vegetation is usually left to recover without further intervention. However, it is unclear to what extent natural recovery can be achieved.

The main aims of this study were to ascertain the nature of riparian vegetation recovery, as well as determine which clearing treatment was most successful in promoting recovery. This was achieved by focusing on: 1) the recovery of species composition and biodiversity, 2) recovery of vegetation structure (assumed to be a surrogate for ecosystem function) and 3) whether a particular clearing treatment best promoted indigenous riparian vegetation recovery.

Reference sites (control), as determined by Prins et al., (2004), were compared to alien-impacted sites in order to analyse variation among vegetation variables. Three initial clearing treatments were identified, namely: Fell Only (trees are felled and slash left on site), Fell & Remove (slash is removed from the riparian zone) and Fell & Burn (the slash is left for six months to a year before it is burnt).

Study sites were selected based on invasion history and method of clearing as described by Working for Water and CapeNature clearing records. Sites of moderate to dense alien infestation (25-75% canopy cover) generally have sufficient indigenous vegetation

remaining to facilitate unaided recovery (Galatowitsch and Richardson, 2005), so the focus of this study was on the closed-stand alien invasion (> 75% canopy cover), where natural recovery may be protracted. Only sites cleared at least two years prior to sampling and with complete management histories were chosen to provide sufficient time for some post-clearance recovery. Seventy-eight vegetation plots were sampled in a total of 15 rivers.

One of the most important conclusions from this work is that the clearing treatment used can have a significant impact on the recovery of indigenous vegetation with regard to species composition, species richness, growth form structure and vegetation structure. The impacts of both increased slash and burning within the riparian zone may compromise or prolong the recovery time of indigenous vegetation. The most important difference between cleared and Reference plots was in terms of their species composition. The loss of key riparian species (namely: 3-10 m trees, including, *Brachylaena neriifolia, Metrosideros angustifolia; and other fynbos scrub elements, including: Elegia capensis, Cannomois virgata, Berzelia lanuginosa, Leucadendron salicifolium, Erica caffra)* in some cleared plots is the main reason for their dissimilarity to Reference plots as determined by a Detrended Correspondence Analysis.

Although the Fell and Burn treatment proved to be best treatment to reduce woody alien species, secondary invasion by alien herbaceous species occurred where natural riparian vegetation did not re-establish. The Fell & Remove treatment is recommended as the best to use in promoting indigenous vegetation recovery, and together with continued alien follow-up control, is able to minimize alien re-invasion of riparian ecosystems. Managers are advised to consider actively restoring riparian areas where recovery is likely to be protracted, in order to facilitate the recovery process. Areas where active intervention and species re-introduction may be anticipated are: areas where large slash piles are left *in situ*, areas where large slash piles have been burnt generating excessive heat and a lack of important riparian species emerging following clearing.

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Chapter 1. Introduction

1.1 Problem statement

South Africa has had a long history of invasion by alien plants (van Wilgen et al., 1998). Invasive alien trees and shrubs threaten biodiversity and water resources generated within mountain catchment areas. The realization that closed-stand invasions can reduce the water yield of a catchment prompted the initiation of the national Working for Water programme in 1995. Initially concerning itself with the management of catchment areas and riparian zones, the Working for Water programme has now grown into the world's largest programme dealing with invasive alien species, extending to providing assistance to private land owners (Richardson and van Wilgen, 2004). Riparian zones, which are usually densely invaded, have been the focus of many clearing projects. To this end, the current national management objectives are to reduce above ground biomass of invasive alien plants by labour intensive means, after which indigenous vegetation is usually left to recover without further intervention. This approach works well in some cases (Derek Malan pers. comm. 2006), and the resultant plant assemblages appear to reinstate appropriate ecosystem services. In other cases, however, large-scale erosion can occur after the removal of invasive plants, or the remaining and regenerating indigenous vegetation is unable to restore the desired ecosystem functioning. By promoting vegetation recovery the costs attributed to follow-up control of alien plant species could be potentially reduced.

Clearing operations can succeed or fail to stimulate vegetation recovery and previous reports have called for improved understanding of the effects of clearing operations on the recovery of indigenous vegetation (e.g. Holmes et al., 2005; Versfeld et al., 1998). Except in transformed landscapes, the success of any alien clearing operation depends on the recovery of indigenous vegetation. However, research is required regarding the level of ecosystem repair following alien clearing. By utilising clearing methods that facilitate indigenous vegetation recovery, a more cost-effective restoration technique could be developed in order to reduce the time taken from the initial clearing phase to successful vegetation recovery.

This study is part of a Working for Water funded initiative entitled: "Targets for ecosystem repair in riparian vegetation in Fynbos, Grassland & Savanna biomes". This national project aims to provide baseline information on the impacts of alien plant invasions and clearing methods on riparian vegetation recovery, while assessing the level of ecosystem repair following alien clearing. This study addresses these aims within the Fynbos Biome by investigating the impacts of control operations on natural recovery in riparian zones in the southwestern part of the Western Cape.

1.2 Rationale & objectives of study

This study aims to provide baseline information on alien-invaded riparian areas that have been previously cleared by the Working for Water programme. I focused on areas that have had closed-stand invasions, where the canopy cover of invasive alien trees was >75%, and most likely to compromise natural recovery (Holmes and Cowling, 1997a, 1997b). The different initial clearing methods that have been used in the past decade include felling and leaving slash in situ (Fell Only), felling and removing slash from the cleared area (Fell & Remove) and felling and burning slash (Fell & Burn). Follow-up control generally includes chemical control of alien regrowth. These various methods differentially affect the recruitment environment for indigenous species. A survey-based sampling technique was chosen to compare areas that had been cleared by the three different clearing treatments. Sampling above-ground vegetation accumulated at least two years after the initial clearing treatment would reveal any relevant patterns of succession resulting in a trajectory towards recovery. The trajectory was evaluated based on similarities of common features with uninvaded (Reference) riparian sites. Results from this study will provide Working for Water with valuable insights into natural recovery potential of cleared alien closed-stand sites as well as highlighting potential differences among the clearing treatments used in riparian zones.

The timing of this survey, with Working for Water entering its final ten-year plan, enables feedback to managers on an assessment of the ecological impacts of clearing operations undertaken thus far. Studies of this nature are lacking in riparian ecosystems and need to be done in order to fully understand the effects of invasive alien plants and clearance on indigenous ecosystems. Since no active restoration practices are formally part of the Working for Water clearing programme there is a need to know how well vegetation is able to recover naturally and whether additional recovery strategies should be considered for the restoration of invaded ecosystems e.g. active plant re-introduction. It is also imperative to find optimal alien clearing techniques that not only promote indigenous vegetation recovery but are as cost effective as possible. Here it is assumed that biotic resistance will inhibit further invasion, thus reducing the intensity of future follow-up control. Thus the central research question identified for this study is: "To what extent do current alien clearing methods influence vegetation recovery in fynbos riparian ecosystems?" Results are intended to guide management on best clearing practices and indicate possible situations in which additional restoration actions may be required.

The following specific questions were addressed in this study:

- What is the difference in floristic and growth form composition between reference vegetation and cleared vegetation?
- Are there differences between plots cleared using different methods?
- Which clearing method best facilitates indigenous vegetation recovery?

1.3 Literature review

1.3.1 Riparian zones

The area of land adjacent to a stream or river is often known as the riparian zone. The riparian zone is the focal point of many studies from different disciplines, including biological and physical aspects relating to biodiversity, conservation, plant invasions, restoration, hydrology and geomorphology to name but a few (see Gregory et al., 1991). As a result, some differences exist in defining the riparian zone as the limits vary depending on the nature of the study (Gregory et al., 1991; Naiman and Décamps, 1997; Wissmar and Beschta, 1998). Adding to the confusion is the heterogeneity of geographical locations, differences in species assemblages and composition, as well as seasonal variations in flooding regimes, which have contributed to a variety of interpretations and definitions of the riparian zone. Coupled with this, is the variety of terminologies used to describe the riparian zone which include alluvial floodplain, floodplain forest, phreatophytic (water table dependent) and riparian buffer zone. For this study I used the definition proposed by Gregory et al. (1991) who define the riparian zone as the vegetation interface (or ecotone) between terrestrial and aquatic ecosystems. Occupying the area adjacent to the active water channel, the riparian zone occurs between the low and high-water marks of the adjacent stream and is consequently subjected to seasonal inundation (Naiman et al., 1993; Naiman and Décamps, 1997). Boundaries of the riparian zone extend outward from the stream bank, including part of the terrestrial landscape influenced by an elevated water table, and are limited by the extent of flooding and the soil's ability to hold water (Gregory et al., 1991; Naiman et al., 1993; Naiman and Décamps, 1997). Varying in width, as determined by both the hydraulic and topographical nature of the catchment, this zone could encompass narrow strips of vegetation on low order streams of the steeper mountain slopes or large floodplain forests in more open lowland areas. Typically riparian zone formation is related to elevated water tables, hydrological flow paths and heterogeneous sedimentary structures associated with erosion and deposition processes (Huggenberger et al., 1998).

Riparian zones are dynamic, diverse and complex, and plant communities are affected by both terrestrial and aquatic forces. Disturbance patterns in the riparian zone are the major driving forces for determining community diversity, often resulting in a unique mosaic of plant assemblages that differ in structure and function to that of surrounding terrestrial vegetation (Boucher, 1978; Gregory et al., 1991; Jungwirth et al., 2002). Plant species that are frequent in riparian communities are well adapted to exploit the increase in water resources and as a result, water supply is also a regulating factor for many riparian species (Buijse, 2002; Stromberg et al., 1996). The shallow water table at the stream fringe allows some plants to utilise ground water which is able to sustain communities in periods of low water flow (Stromberg et al., 1996). Further traits of riparian vegetation include morphological adaptations increasing resilience to withstand flooding, sediment deposition, physical abrasion and stem breakage during disturbance events (Naiman et al., 1993).

The principle disturbance in riverine channels and the adjacent riparian zones stems from flooding events, which vary in frequency and intensity (Stromberg et al., 1996). Flooding events and annual flow regimes are equally important in influencing establishment, mortality, and patch structure as well as the successional patterns of riparian vegetation and in-stream communities (Hampe, 2004; Nilsson and Svedmark 2002; Shafroth et al., 2002). Large floods typically remove established vegetation creating the conditions required for new individuals to establish (Gregory et al., 1991; Naiman and Décamps, 1997). These processes are also important in the distribution of materials and sediments throughout the catchment.

International research has shown that the complexity of processes affecting the riparian zone may result in increased species richness when compared to terrestrial landscapes (Naiman et al., 1993). However, this might not be applicable to the two distinct riparian groups of the Fynbos Biome of the Western Cape, namely Afrotemperate forests and riparian Closed-Scrub Fynbos (Cowling and Holmes, 1992). Although a minor component of riparian vegetation, tall Afrotemperate Forests that occur in the upper reaches of fynbos streams and protected kloofs are known to be species poor when compared to surrounding landscapes (van Wilgen and Mcdonald, 1992). The more widespread riparian scrub has fewer species restricted to the wetter soils of the Fynbos Biome than surrounding terrestrial vegetation. Although the riparian vegetation is fairly distinctive from surrounding fynbos vegetation, terrestrial species can occur within the riparian areas increasing local species richness, if only for short periods of time (Boucher, 1977; Reinecke et al., 2007).

1.3.1.1 Rivers in the landscape

This section describes the basic features of riverine systems and how they influence the formation of riparian vegetation communities. Generally all the waterways leading to the main drainage river of terrestrial systems is known as the catchment or watershed (Davies and Day, 1998). Rivers are linear and longitudinal in nature and are considered integrated ecological systems (Ward et al., 2002). The main drivers of this ecosystem are the hydrologic regime, geology and geomorphology of the surrounding catchment (Naiman and Décamps, 1997). As the flow of water follows a descending altitudinal gradient, originating from headwater systems, changes to both hydrology and geomorphology affect the adjacent riparian zone. The longitudinal gradient of the river can be broadly classified into mountain stream (steeper gradients associated with erosion), foothill (less steep, associated with both erosion and deposition) and lowland zones which fall into the six geomorphological zones described by Rowntree and Wadeson (2000). Steep, hard rock and high-energy environments can usually be found in constrained single-channel mountain streams (headwaters) of the river. As the streams accumulate in the foothills and lowland zones, a flatter and more expansive section of the river is found. Here slower flowing water increases deposition of alluvial deposits allowing for deeper mixed soils (Davies and Day, 1998).

The river is generally the source of major disturbances affecting riparian communities. These can occur on varying temporal and spatial scales. Geomorphological influences for example, have either localised or basin wide implications (Gregory et al., 1991). Further disturbances that act over differing spatial and temporal scales include floods, landslides, debris torrents and fires (Boucher, 2002; Naiman et al., 1993). Floods are responsible for the removal and deposition of topsoil and debris, re-shaping of channels and also the dispersal of vegetative propagules within the riparian zone (Sedell et al., 1990). These processes may act over different scales, but have an important function in regulating ecological diversity (Richards et al., 2002). Therefore only when the river corridor is viewed as a complex ecological system and part of the landscape, can one begin to understand the dynamics involved and processes required to maintain ecological integrity. The complex interactions between the river and adjacent landscapes, has forced researchers to consider rivers and riparian zones in an ecosystem and landscape perspective (Gregory et al., 1991; Malard et al., 2002; Wiens, 2002).

Rivers in the Fynbos Biome are short and steep, with few exceptions (Holmes et al., 2005; Davies and Day, 1998). Rainwater entering the streams usually does so via surface runoff in heavy rainfall events or via the generally porous soils in the region. Mountain streams are fast flowing streams through relatively undisturbed landscapes with narrow riparian areas, foothill and lowland reaches are characteristic of widening channels and increasing riparian areas, while lowland reaches pass through a variety of transformed landscapes generally resulting in a reduction of the riparian zone and lower water quality (Brown, 1998). The winter rainfall region of the Fynbos Biome is dominated by the Cape Fold Belt mountains. The mountains are comprised mainly of sandstone that yields nutrient-poor substrata which greatly influences the surrounding geomorphology. Material along Western Cape rivers are mostly sand based, derived from the Table Mountain sandstone or clayey where Malmesbury shale is present in the catchment (Theron et al., 1992). The proximity of soils to rivers, streams and seepages creates numerous habitats where moist soils support a variety of plant species with associated functional adaptations.

1.3.1.2 Importance of riparian zones

Riparian zones and the vegetation therein fulfil important geomorphological, ecological and social roles, many of which have been well documented (Hood and Naiman, 2000; Kemper, 2001). The position of the riparian zone allows for inputs from terrestrial and aquatic origins. This means that any flows of energy, water and nutrients will pass through the riparian zone making it an important buffer in the functioning of riverine ecosystems. The health of the riparian system can affect the way in which ecosystem services (e.g., productivity, nutrient inputs) are delivered as well as relationships between landscape components. Although few of the relationships between plant diversity and ecosystem function have been quantified, studies have revealed that a decline in species diversity leads to a reduction in ecosystem functioning (Hooper et al., 2005; Richardson et al., 2007).

Riparian vegetation interacts with various ecological processes by influencing temperature and light regimes, sediment control and filtration as well as by producing organic matter (Hood and Naiman, 2000; Ward et al., 2002). Apart from acting as a barrier between terrestrial and aquatic landscapes, riparian zones also make a significant contribution to the nutritional components of aquatic ecosystems. Nutrient inputs from riparian vegetation in the form of allochthonous material are important in sustaining aquatic invertebrate communities (Gregory et al., 1991). During intermediate disturbance events (e.g. periodic floods) the debris caused by destroyed vegetation provides inputs (i.e. food and nutrients) to the riverine ecosystem. For the fauna that occupies adjacent waters these inputs are important in regulating food chains (Davies and Day, 1998). Overhanging vegetation cover regulates water temperature, which has been shown to influence both fish and invertebrate species (Davies and Day, 1998; Ward et al., 2002). The presence of riparian trees or indigenous riparian root systems, vastly increases the stability of bank sections reducing the possibility of mass wasting (Abernethy and Rutherford, 2000).

From an anthropogenic point of view, rivers and riparian areas have numerous benefits. Human activities have long been associated with riparian zones and have had many negative impacts related to various land use requirements resulting in often degraded environments (Jungwirth et al., 2002; Richardson et al., 2007). Logging and clearfelling of riparian forests for farming, grazing and timber transport are some of the main reasons for their degradation (Davies et al., 2005; Muotka and Laasonen, 2002). Hydrological alteration by canalisation and dams alter the extent and composition of riparian areas. Reduced propagule dispersal as well sediment and material transport can greatly influence vegetation patterns. Although channelization maximizes adjacent land use, by constraining river flow and increases the manageability of rivers by creating simple flow patterns, the ecological losses are significant. In some parts of the world restoration/rehabilitation projects have been initiated to reverse this ecological degradation (Stromberg, 2001).

Healthy river systems that provide good water quality are not only ecologically important but have benefits for human consumers as well. Zaimes et al. (2006) showed that a stream community vegetated with indigenous riparian forest can reduce soil erosion by 77-97% compared to unvegetated banks, thereby reducing suspended sediments found in drinking water as well as the costs of removing such sediments. Likewise, riparian vegetation has been known to reduce the impacts of flooding and increase the stability of adjacent banks. The goods and services provided by an ecologically intact riparian zone are clearly beneficial for human society. But one should not ascribe value to riparian systems based purely on the ecological and economical services they provide. Instead the conservation of healthy intact systems should be cause enough for the restoration and rehabilitation of degraded ecosystems. The fact that healthy riparian zones can have economic benefits increases the need for consumers to consider conservation and restoration of these areas.

1.3.1.3 Classification of riparian zones

Plant distribution patterns in riparian corridors are influenced by hydrological processes. The main determinants of lateral vegetation gradients are the elevation up the channel bank and period of inundation from bank overflow (Boucher, 2002; van Coller et al., 2000). Thus understanding lateral zonation within riparian zones allows categorisation of vegetation patterns, thereby increasing management potential and monitoring of environmental degradation (Kemper, 2001; Smith, 1992). The application of instream flow requirements in impounded rivers would need to be regulated in order to prevent lateral vegetation patterns from changing (Busch and Smith, 1995; Nilsson and Svedmark, 2002).

Research on South African fynbos rivers identified three main lateral zones: the aquatic zone, wetbank zone and drybank zone, described as follows:
The *aquatic zone* contains rooted aquatic plants that require inundation at least 50% of the year. The *wetbank zone* substratum remains moist during most of the year and contains a sedge/moss and shrub/*Prionium* subzone. The *drybank zone* exists mainly on the alluvial deposits caused by the deposition of eroded material. This area contains plants able to access water via deeper root systems. Long-lived vegetation forms the main tree-shrub zone while it can also contain transitional elements when moving from the wetbank to the dry-bank (lower dynamic) and also on the outer edge from the drybank to the main terrestrial vegetation (back dynamic).

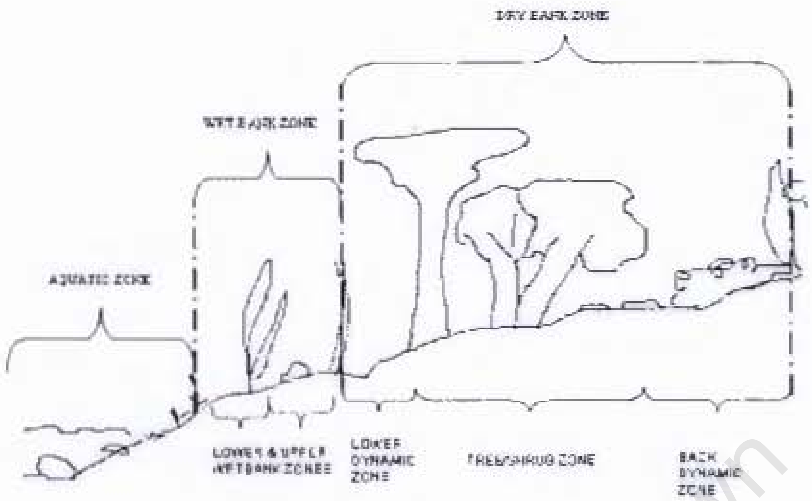

Figure 1. 1. Zonation patterns of riparian areas within South Africa. (from Boucher, 2002)

Figure 1. 2. Image of the Jakkals River with wet bank in the foreground and invasive *Acacia* species occupying the dry bank.

Although other classifications exist for riparian zones the common denominator is the change in species as the distance from the water's edge increases. The classification system used by Boucher (2002) was developed primarily in the Fynbos Biome. It is this classification that was used in the design of the vegetation survey of cleared plots.

1.3.1.4 Riparian vegetation structure

Riparian zones exhibit a high degree of structural and compositional diversity (Gregory et al., 1991) as successional pathways fluctuate between pioneer and later seral assemblages. Due to frequent disturbance by flooding, it is not uncommon for a riparian zone to be occupied by a mixture of age classes. Flood damage can create colonisation gaps resulting from uprooted plants and cause the removal of sediments (erosion) as well as create new sands banks for colonisation (deposition). Natural disturbances caused by flooding are important in regulating vegetation patterns. The elimination of annual flooding in regulated rivers often leads to the encroachment of forest vegetation towards the waterline (Johnson, 1994). However, in dry regions reduction in flows downstream of large dams may cause a decline of floodplain forests because of water scarcity (Pettit and Froend, 2001; Rood and Heinze-Milne, 1989; Stromberg, 2001). Modelling by Richter and Richter (2000) indicates that low to medium-sized floods are important in reshaping banks due to sufficient sediment loads and thus providing suitable open habitats for cottonwood seedlings in the Yampa River, Colorado, USA. The frequency, intensity and specific timing of these events are important as many riparian plant species utilise flooding events to deposit seeds as water levels increase and recede over time (Hood and Naiman, 2000; Pettit and Froend, 2001). The location of seed deposition within the riparian zone is an important determinant of a plant's survival. Water availability through soil moisture and the water-table along free-flowing rivers, helps in maintaining lateral zonation patterns of riparian vegetation (Boucher, 2002; Stromberg, 1997).

Riparian plant species are able to enter the system either by seed, vegetative propagules, or by vegetative expansion from neighbouring populations (Bowden et al., 2006; Honnay et al., 2001; Karrenberg et al., 2003). As a result, plant life history strategies (resprouting vs. reseeding) that tend to dominate in these areas favour intermediate disturbance i.e. periodic floods. Poor recruitment from the seed bank in Australian riparian areas has added to the importance of flow requirements and seed release by resident riparian species (Pettit and Froend, 2001). However, seeds are short-lived in many tree species and germination requires adequate site conditions (Karrenberg et al., 2002; Pettit and Froend, 2001). For example, the short-lived seeds of cottonwood species rely on appropriate water flow, draw down and soil moisture to establish successfully in order to survive drier summer months that follow (Rood et al., 2003). Similarly four Australian overstorey tree species were shown to be well adapted to hydrological regimes when required to germinate from seed (Pettit and Froend, 2001). In the Fynbos Biome, vertebrate (e.g. *Ilex mites*) and water-dispersed (*Brabejum stellatifolium*) tree species have short-lived seeds that do not enter the soil seed bank. These need to germinate before the hot dry summer season if recruitment is to be successful (Prins, 2004; Vosse, 2007).

The presence of existing vegetation able to disperse seed and vegetative material into new locations during flood periods is an important recruitment mechanism (Hulme and Bremner, 2006; Sedell et al., 1990). Following disturbance, the soil seed bank is usually the source of new species colonizing the riparian area. However, seedlings of tree species are often rare in forested environments and regeneration by sprouting is an important life history trait in riparian communities (Midgley and Cowling, 1993). Thus species that do not possess persistant seed banks, or suffer from reduced seed output will have diminished capacity within novel environments. This often leads to an increase in herbaceous, graminoid and low shrub species. Although certain riparian areas do not have tall tree canopies (see Sieben, 2002), in areas where this is not the case, the natural succession of tree species is often dependent on the transport of seed or vegetative plant materials (Karrenberg et al., 2003). The recovery of vegetation structure following disturbance is important as this can be used as a surrogate for monitoring the delivery of ecosystem services (King and Hobbs, 2006).

In the Fynbos Biome, two types of riparian communities have been described (Cowling & Holmes, 1992; Rebelo et al., 2006; Van Wilgen and Mcdonald, 1992). In the headwater reaches that are protected from fire, usually in deep gorges or kloofs, Afrotemperate Forest communities persist, which usually form the dominant vegetation in these riparian zones (Cowling and Holmes, 1992). The community dominants include *Ilex mitis, Cassine schinoides, Podocarpus elongatus, Cunonia capensis, Halleria lucida, Maytenus acuminata* and *Rapanea melanophloeos.* Although soil accumulation in these areas is not substantial, tall forests persist and usually form separate communities to lowland riparian systems, which have similar affinities to fynbos vegetation (see Cowling and Holmes, 1992; Taylor, 1978). Where fire is able to influence headwater communities, riparian zones contain predominantly herbaceous species (Sieben, 2002). Dense Closed Scrub Fynbos communities usually develop as the gradient and water velocity decreases allowing the increase of alluvium (Boucher, 1978). The communities are also generally shorter than Afrotemperate Forests. Riparian closed scrub vegetation occupies the adjacent banks of streams and is dominated by common species such as *Brabejum stellatifolium, Metrosideros angustifolia, Brachylaena neriifolia, Prionium serratum, Elegia capensis, Cannomois virgata* and *Erica caffra*. European and American rivers seem to differ to fynbos rivers, as tall floodplain forests, often described in the literature, are often absent in the foothill and lowland sections (see Ward et al., 2002).

1.3.2 Invasion in riparian zones

1.3.2.1 Extent and impact worldwide

Invasive alien plants are a major problem around the world, causing costly impacts to ecosystems (Mooney and Hobbs, 2001; Richardson, 1998; van Wilgen et al., 2000). Released from natural predators and able to utilise available resources more efficiently than indigenous plants (Macdonald and Jarman, 1984; Richardson et al., 1997), invasive alien plants can quickly dominate an area if left uncontrolled. The most damaging invaders are able to transform ecosystems at the trophic (by using above normal amounts of resources or adding resources to environments) and ecological levels (by displacing indigenous species) (Richardson et al., 2000). The extent of the problem is massive as highlighted by a recent global review revealing that invading species (plant, animal and microbe species) cost (including control and damages) in the order of US$314 billion per year (Pimentel, 2002). In the US alone, government agencies spend US$ 631.5 million on invasive species issues per annum (Harms and Hiebert, 2006).

Riparian zones all over the world are favoured habitats for alien plants both woody and herbaceous (Hood and Naiman, 2000). The dynamic nature of rivers increases the chances for aliens to become established, because rivers act as a medium of propagule transportation as well as supplying open spaces for colonization (Deferrari and Naiman, 1994). The removal of established vegetation by periodic floods provides space, light and nutrients for indigenous, as well as alien species (Davies et al., 2005). Plants that are able to invade habitats outcompete indigenous species for light, water, nutrients and other resources. Their ability to establish quickly in new areas and the lack of important environmental cues, as required by indigenous vegetation, are some reasons that invasive species are opportunistic and successful. Additional disturbance through anthropogenic influence in riparian zones further increases the chances of alien propagules entering the system (Planty-Tabacchi et al., 1996) and often acts as a trigger in the dispersal and proliferation of alien plant species (Richardson et al., 2007). Once established the alien species are able to take advantage of natural conditions and facilitate spread via the natural disturbance regimes. Major concerns ascribed to invasive alien plants are changes to species composition and structure of the vegetation that alien plants replace and their considerable impacts on ecosystem function (Richardson et al., 2007). For example, indigenous riparian vegetation has been replaced in many parts of arid, western USA by the invasion of salt cedar (*Tamarix* species.) trees (Friedman et al., 2005), leading to estimated costs of billions of dollars in economic losses over the next 50 years (Cohn, 2001; McDaniel and Taylor, 2003; Zavaleta, 2000).

As riparian plants influence many properties of riparian zones, changes to vegetation composition and structure can cause numerous impacts, affecting the physical environment and biological pathways (Hobbs et al., 2006). For example, invasive species may alter characteristic features of riverine areas by consuming large quantities of water (alien *Acacia* or *Eucalyptus* species in South Africa and *Tamarix* species in the USA) and by changing channel morphology through altered sediment processes (Pienaar and Boucher, 1998, Richardson et al., 2007, Zavaleta et al., 2001). Another example would be invasive *Tamarix* species invading riparian communities in the arid southwestern United States where much degradation has been attributed to their invasion (Harms and Hiebert, 2006). The large *Tamarix* forests that form are capable of replacing indigenous vegetation, increasing water consumption, reducing width of channels, salinizing soils and decreasing biodiversity (Zavaleta et al., 2001). However, this invasion can be attributed to changes in the river hydrology by river damming and flood suppression (Stromberg, 2001), reducing disturbance events and creating the more stable conditions required for *Tamarix* to succeed. In these invaded areas where *Tamarix* alone is targeted, alien species that co-exist are likely to take over if the dominant species is removed (Harms and Hiebert, 2006). Closed-stand invasions also have the ability to disrupt established trophic pathways and other processes and compromise the ability of indigenous species to colonise and area (Cohn 2001; Ladd et al., 2005; Muotka and Laasonen, 2002).

1.3.2.2 Extent and impacts of aliens in South Africa and the Fynbos Biome

In South Africa it is estimated that 10 million hectares are invaded to some extent by invasive alien trees and shrubs (Versfeld et al., 1998). Although some species are well established and many others are at the early stages of invasion (Nel et al., 2004), the limited resources available to tackle invasive alien species is cause for concern (Dye et al., 2001). It is estimated that alien plants cost South Africa tens of billions of Rand annually in lost agricultural productivity as well as resources spent on alien control (van Wilgen et al., 2001).

Riverine areas throughout South Africa are heavily invaded, particularly in the Fynbos Biome (Macdonald and Jarman, 1984; Holmes et al., 2005; Richardson and van Wilgen, 2004). The invasion of river channels by invasive alien plants in catchment areas has been one of the main focal points for removal of such vegetation. Riparian vegetation in the winter rainfall region of the Western Cape is mainly impacted by trees and shrubs namely Australian *Acacia* (e.g. *Acacia mearnsii*, *A. longifolia, A. saligna*) and *Eucalyptus* (e.g. *E. camuldulensis*) species (Forsyth et al., 2004; Nel et al., 2004; Richardson and van Wilgen, 2004), which is usually distinct from surrounding fynbos vegetation. These invasive alien plants have been identified as excessive water consumers when compared to indigenous species (Le Maitre et al., 2000). Studies have shown that invasion by alien tree species in mountain catchments reduces water run-off by 7% and affects hydrological processes within the area (Dye and Poulter, 1995; Higgins et al., 2000). The greatest impacts on water resources occur when evergreen plants (*Acacia* species) replace seasonally dormant vegetation, such as the fynbos (Dye and Jermain, 2004; Enright, 2000). As a result, increased evapotranspiration affects the overall water balance within a river system, especially in the more arid environments (Mack and D'Antonio, 1998; Wiens, 2002).

Indigenous riparian shrubs and trees do not readily burn and are able to withstand natural fires (Boucher, 2002), but with increased woody alien vegetation in riparian zones the resultant greater fuel loads can cause mortality to indigenous trees and lead to a change in fringing riparian vegetation after fires. The shallow root systems of the dominant invaders of the region, *Acacia mearnsii*, allow it to be easily uprooted in high-flow floods. The exposed banks are then subjected to accelerated erosion and soil loss (Macdonald and Richardson, 1986; Enright, 2000; Mack and D'Antonio, 1998). Impacts to landscape appearance (Le Maitre et al., 1996), biodiversity and potential eco-tourism revenues are further reasons to remove invasive alien plants from the landscape.

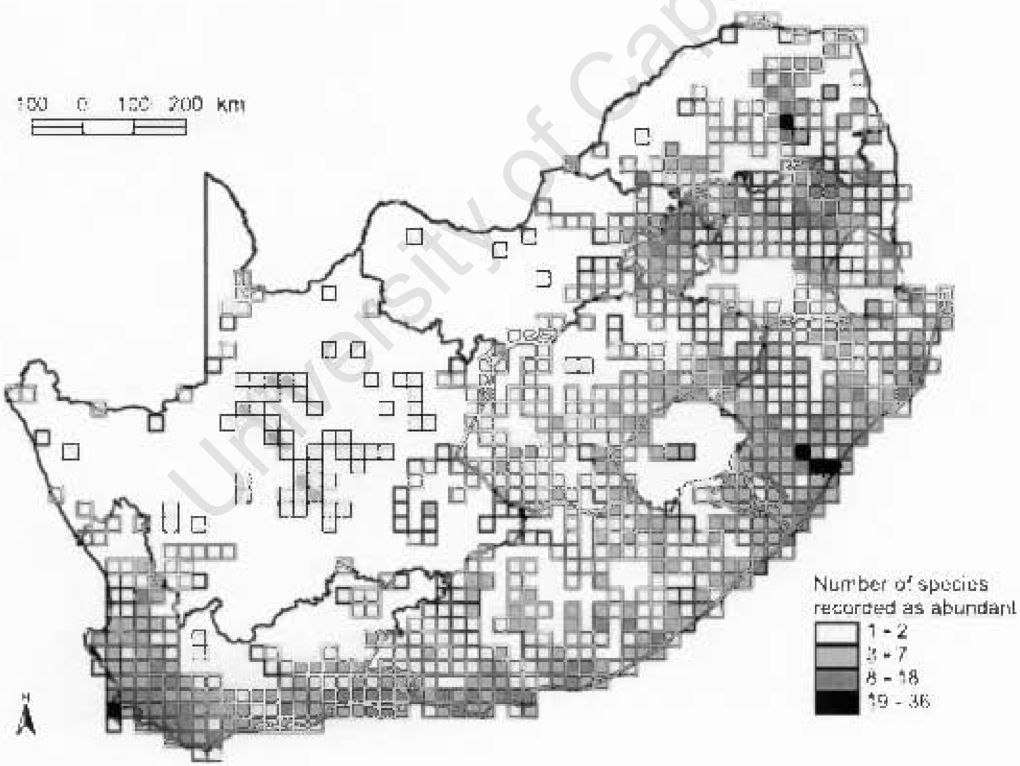

Figure 1. 3. The distribution of invasive alien plant species in South Africa. Data are taken from the South African Plant Invaders Atlas. Shading indicates the number of species listed as 'abundant' in each quarter-degree cell (from Richardson and van Wilgen, 2004)

1.3.2.3 Mechanisms of invasion in riparian systems

For an invasion process to be seen as detrimental to the ecosystem, alien plants should be able to spread and maintain viable populations (Richardson and van Wilgen, 2004). Riparian zones are particularly susceptible to plant invasions (Pyšek and Prach, 1993) and are known to act as havens and provide corridors for source population to spread within the catchment area (Stohlgren et al., 1998). Hood and Naiman (2000) suggest that regular floods decrease the strength of competitive interactions in riparian zones and return portions of the zone to an early successional stage. Also alterations to natural flow regimes in impounded rivers allows for a reduction in indigenous species creating openings for alien species (Cohn, 2001; Vitousek, 1990). Thus, the removal of above-ground vegetation increases invasion potential as resources become readily available to alien propagules (Davis et al., 2000; Deferrari and Naiman, 1994).

Invasion of new environments is influenced by 1) number of propagules entering the site; 2) characteristics of invading species; 3) susceptibility of new environment to invasion (Lonsdale, 1999). Where alien populations increase and become dominant, the connectivity of riverine systems facilitates the flow and spread of seeds downstream and occasionally upstream, from initial colonisation (Décamps et al., 1995; Planty-Tabacchi et al., 1996). Furthermore, the lack of water stress and a propagule's ability to be dispersed by water are two enabling mechanisms for alien plant proliferation (Ferrar et al., 1988).

Apart from natural disturbances, anthropogenic influences in the landscape can also increase susceptibility to invasion. Bunn et al. (1998) describe how the removal of indigenous vegetation (for agriculture) opens pathways for non-native species to become established and succeed in riparian systems. Similar observations were made in the USA when the exotic "tall whitetop" (*Lepidium latifolium*) increased in abundance after streamflow reduction resulted in a decrease in native riparian flora, notably indigenous cottonwood populations (Rood et al., 2003).

In South Africa, poor management has led to commercial forestry species being among the main invaders (Nel et al., 1999; Richardson, 1998). The spread of alien species from plantations has resulted in forestry organisations committing themselves to reducing their spread. Species such as *Acacia mearnsii, A. longifolia, A. saligna* and *Pinus pinaster* are able to recruit and become established within indigenous riparian vegetation, often replacing a mixed riparian community with a woody monoculture, which may lead to altered channel morphology (Rowntree, 1991). The large seed banks generated by *Acacia* species are generally persistent and accumulate in the soil as a result of numerous seeds produced each year. The dormancy of hard coated *Acacia* seeds is usually broken by fire (Holmes, 1989), which is followed by the germination of *Acacia* seedlings (Pieterse and Boucher, 1997). This trait is shared with indigenous fynbos vegetation although the short maturation period and rapid growth of *Acacia* species usually allows it to out-compete indigenous vegetation.

Recruitment by indigenous vegetation is often limited to the soil stored seed bank, colonization from seed rain of nearby plants and vegetative expansion from plants outside disturbed community, as well those within (Hulme and Bremner, 2006). Species that do not possess persistent seed banks, or suffer from reduced seed output, will have diminished capacity within novel environments. These gaps are quickly colonised by alien species, especially in riparian areas where seeds are easily transported and deposited by hydrological fluctuations.

1.3.3 Alien plant control and the Working for Water Programme

The South African alien clearing initiative, the Working for Water programme, has been dubbed one of the biggest invasive alien control programmes in the world (Macdonald, 2004). During its first seven years, Working for Water invested R1.59 billion in clearing programmes (van Wilgen, 2004). Falling under the wing of the Department of Water Affairs and Forestry (DWAF), the national programme has a mission to enhance water supplies by empowering local communities to carry out catchment level projects that focus on the eradication of invasive alien plants (van Wilgen et al., 1998). It works together with a variety of implementing agents, local authorities and consultants to achieve its aims of establishing and maintaining a programme of clearing invading alien plants and restoring natural vegetation. Through the co-ordination of various government departments the project aims to tackle a number of important issues via a single mandate.

Its primary objectives are linked to water resource management objectives including: water security and sustainable runoff from catchments, protecting the productive use of land, conservation of biological diversity, reduction of the intensity and frequency of fires and floods, employment and creation of secondary industries to empower impoverished communities and the effective eradication of invading alien species (Enright, 2000; van Wilgen et al., 1998). The programme relies heavily on its approach to maximise social benefits by utilising a labour force that stems from the poorer previously disadvantaged communities in South Africa (Enright, 2000). Aside from ecological objectives, the Working for Water programme aims to include the upliftment of socially marginalized communities in its mandate by utilising community-based labour-intensive methods of alien plant control. With a strong gender focus, women make up about 50% of the workforce including clearing team members and team leaders (Magadlela and Mdzeke, 2004). This has led to remarkable delivery of social services and community upliftment. In the 2000/1-budget, five years after its inception, the cumulative amount allocated to the Working for Water programme surpassed the one billion Rand mark. The latest financial figures indicate that over 400 million Rand was spent in 2003/4 bringing the total expenditure of Working for Water programme up to approximately R2.4 billion (Anon, 2004).

Workers are employed through Emerging Contractor Programmes. These also provide education in small business management. Contracts are issued locally, to competing contractor groups, enabling business-like enterprises to become established. Unfortunately this aspect is also one of the shortcomings of the Working for Water programme, since employment is short-term (two years) thereafter people are left to compete for limited resources. For this reason the turnover of people is likely to affect the quality of clearing operations. However, it should be noted that about 92% of the budget is spent on labour expenses (52% of which was spent on women, 20% on the youth and 1% on disabled workers) (Anon, 2004).

The direct economic benefits of the Working for Water programme was certainly one of the major factors that allowed its continued support by National Government. By increasing the amount of surface runoff that reaches existing dams the need for new water schemes is reduced. Likewise, the cost-effectiveness of the efficient control of invading plants would likely be cheaper than increasing water yielding infrastructure e.g. dams and water supply schemes (Van Wilgen et al., 1998). In an attempt to understand plant invasions and the impacts thereof, Working for Water has dedicated resources to scientific research. In 2000 about 5% of the budget was spent on biological control research (discussed below). Further developments by the Working for Water programme include a public awareness campaign (The Weed Buster Campaign) regarding the threats of invasive plants and the challenges faced when dealing with them (Magadlela and Mdzeke, 2004). As Working for Water provides clearing support to private landowners with invasive alien plants on their property, the education aspect has greatly facilitated a mutual role of tackling the problem of alien plant invasions. Research is still ongoing and understanding of the dynamics of alien plant invasions remains relatively poor (Marais et al., 2004).

Much focus has been directed to clearing riparian areas and their immediate sub-catchments. Understanding the effects of different clearing methods on the recovery of indigenous vegetation still, however, needs to be investigated (Holmes et al., 2005). Work by Galatowitsch and Richardson (2005) has shown that areas cleared as early as 1999 had not fully recovered after clearing. Some of these areas were revisited and used in the analysis to assess vegetation recovery. Popular clearing methods used by Working for Water are thus investigated further in this study to aid in the management of invasive alien species and water catchments.

1.3.4 Removal of aliens from riparian zones (current management tools)

The rationale for alien plant control in riparian zones in South Africa is sound on both ecological and economic grounds as the impact of widespread invasion on our water supplies is increasingly recognised. In an experiment, pines were removed from the riverbanks for 30 m on each side of the stream in a small catchment in Jonkershoek, in the Western Cape Province. This resulted in a 44% increase in streamflow for every 10 % of the catchment area cleared (Scott and Lesch, 1996). Similar results were experienced in the Grassland Biome: after invading pines and wattles were removed from catchments a 120% increase in streamflow resulted (Dye and Poulter, 1995). The increase in runoff to streams is a major incentive to remove alien plants from catchments. Charged as the primary implementing agent to manage invasive alien plants, Working for Water utilises a number of tested methods to reduce alien biomass. Below I present a summary of the clearing process and methods used to control invasion of alien woody species.

1.3.4.1 Management methods (history)

Alien plant species in the Western Cape were recorded as early as 1685 for European *Pinus pinaster* and in the early 19th century for Australian *Acacia* species (Shaughnessy 1980). The plants were brought in to perform a number of functions not provided by fynbos species. Some of the reasons for introductions include forestry, dune stabilisation, to provide windbreaks and shade as well as for aesthetic purposes (Schonegevel, 2001). The long history of alien species being cultivated to increase the Cape's resources has resulted in the spread of some alien species in the Western Cape. Today alien species are still utilized to sustain whole industries. However, numerous species have increased their range by spreading of their own accord. A historical review by van Wilgen et al. (1997) on alien clearing, shows that botanists were concerned about the spread of alien species and potential replacement of indigenous vegetation as early as 1888 (Peter MacOwan) and 1908 (Rudolf Marloth). Hydrological experiments by Professor C.L Wicht indicated large impacts of pine plantations on water resources. Further results, by both Wicht and his student, Fred Kruger, finally quantified the impacts of alien plants on a catchment level and the reduction of runoff to streams. The review also demonstrated the degree of alien clearing projects in the 1980's, although much of it was uncoordinated. Sadly, the reduction in funding and restructuring of the Department of Forestry led to a decline in alien plant control during the late 1980's and early 1990's. The crux of the matter is that the areas cleared, were once again reinvaded by uncontrolled alien plants. Even though alien plant clearing was undertaken for a number of years, the nature of execution resulted in little impact on invasive alien abundance in some areas and was a wasted investment. The current knowledge of alien plant management stems from past management practices and subsequent research. Thus management of invasive species is not a new concept and there are still many challenges ahead (van Wilgen, 2004). However management practices can always be improved up on.

1.3.4.2 Management tools

Any clearing programme would be accompanied by a clearing strategy consisting of three important elements. **Initial clearing** would result in a massive reduction in above ground biomass. This stage would remove large amounts of invading plants (depending on the density). A number of methods for initial reduction will be discussed below. **Follow-up control** is an important aspect to any clearing project. In the case of alien *Acacia* species, long-term invasion and persistent closed canopies results in a massive soil-stored seed bank that is likely to germinate after the initial clearing has been done. This regrowth flush is sometimes induced by fire, as is the case of *Acacia mearnsii* in the Western Cape (Pieterse and Boucher, 1997). By removing germinating young alien vegetation in the follow-up control the seed bank is depleted allowing indigenous recruitment to resume, provided seedlings are not damaged by herbicide application. **Maintenance control** is a long-term commitment to prevent any future possibility of alien plants re-invading the landscape. The best means for reducing alien cover is to have an effective and strict clearing plan in operation. Not intending to do so would result in a waste of resources and time for initial clearing. Unfortunately too many clearing projects fall behind after the initial and follow-up processes. This negates the hard work that has been put in to the area to reduce alien cover and in doing so increases the potential for re-invasion by the same or secondary alien species (Holmes et al., 2005).

The types of clearing methods available for all stages of control may be divided into three groups: mechanical, chemical and biological (See Anon, 2000; Anon, 2006).

- *Mechanical* methods of control are labour-intensive and include hand pulling, felling, brush cutting, hacking and ring-barking. Felling is one of the main methods of initial clearing used by the Working for Water clearing teams. Burning may also be used as a tool to kill non-resprouting aliens, or to remove excessive aboveground biomass (slash) and initiate vegetation recovery in fire-prone ecosystems such as in the Fynbos Biome. However heavy fuel loads may result in fires that damage remaining vegetation. The results of mechanical control are easily visible yet there are some issues which are not well understood, such as the timing and intensity of felling. The effectiveness of this method is dependent on the worker, as poor execution can result in alien plants resprouting or accidental removal of neighbouring indigenous plants (Reinecke et al., 2007). Where alien species are able to coppice, herbicide is applied to the stumps. The effectiveness of this also relies on the height at which the stump was cut, which is recommended to be as close to the ground as possible.

- *Chemical* methods use herbicides to reduce resprouting of felled trees and to kill seedlings and saplings. It is applied either as a foliar spray, by spraying young woody plants or herbaceous alien plants (if the plants are below knee height) or to the stumps of older stumps after cutting, via stem injection (frilling). In the Western Cape, Working for Water projects use herbicides after felling and during follow-up control. The herbicide most often used is a triclopyr, water and diesel mixture, coloured with a blue dye to indicate treated areas. Herbicides can kill both alien and indigenous plants. The overuse of herbicide, although regulated, has been known to reduce indigenous vegetation cover (Parker-Allie, 2004). However, Working for Water training programmes ensure the supervisors of clearing teams are well informed of the procedures required for safe and effective application of herbicides (Anon, 2006).
- *Biological* control is a longer-term method for controlling an alien species. It relies on the plant's natural enemies in the form of species-specific insects and diseases to control invading plants. These agents either affect the seed production of alien plants or reduce the plant's fitness, ultimately killing the plant. While it is an effective means of control, concern over its impact on non-target plants and invasive plants with commercial value has slowed down the release of agents into problem areas. Most of the alien *Acacia* species that invade Fynbos Biome riparian zones have biological control agents established on them (Versfeld et al., 1998). However, these mainly reduce the viable seed output of aliens and reduce their rate of spread (van Wilgen, 2004; Zimmermann et al., 2004). The degree of control achieved by these biocontrol agent ranges from negligible to complete. The dominant riparian invader in the fynbos biome, *Acacia mearnsii*, has a seed-attacking biocontrol agent, but the impact of the agent currently is unknown. In the case of "complete control", viable seed production is reduced to the extent that plants are no longer invasive. However, existing stands generally still require mechanical or chemical control (Zimmermann et al., 2004). Biological control has been recognised as the only long-term solution to keeping alien numbers low.

The manner in which clearing is planned is important and needs to be carefully considered. Prior to clearing, decision-making regarding the next planned land use, the resources available and site geography usually determine the clearing method used. At the very least the following actions are required for strategic planning:

- Areas should be cleared that reduce the risk of re-invasion. For example, the location of the areas which need to be cleared should be carefully planned so that upstream areas are cleared before clearing downstream takes place.
- Work is carried out from outer areas (less dense) to more dense areas.
- In densely invaded areas work should be done section by section to avoid erosion in the catchment.

The planning of alien clearing is not always easy and much invaded land falls outside of governmental control. Although private landowners are required to clear their land of aliens, the laws are not readily enforced resulting in patchy clearing efforts along river systems.

Table 1. 1. Alien control methods designed to promote recovery of indigenous vegetation (Anon, 2000)

Major Groups	Species	Initial (preferred)	Follow-up
Serotinous non-sprouters	Hakeas & pines	Fell & burn	Hand pull or fell older plants before they reach maturity
Thicket resprouters	Wattles (*A. mearnsii, A. saligna, A. longifolia)*, mesquite & gums	Fell close to ground and treat stump with herbicide; or frilling	Hand pull while still small or spot spray herbicide
Thicket non-resprouters	*Acacia cyclops* (Rooikrans)	Fell & leave slash; fell & burn; or burn standing	Hand pull or fell before maturity
Subtropical resprouters and scramblers	*Lantana*, *Pereskia aculeata*, *Caesalpinia* spp.	Dig out with hand pick; where larger use a bulldozer; fell close to ground & treat stump with herbicide.	Hand pull

Clearing methods are often integrated for effective control (Richardson, 1998), depending on resources available. Integrated control is usually species-specific and knowledge of invading species is important as shown in Table 1.1. By combining a range of clearing techniques (e.g. both mechanical and chemical methods) resprouting aliens can be eradicated by killing the plant effectively and by reducing plant biomass and excessive seed production. It is during the follow-up treatments that alien infestations are usually brought under control. Funds need to be available for achieving a balance between new clearing operations and follow-up operations on previously cleared areas. During the financial year 2003/2004 Working for Water spent more resources on follow-up clearing than initial clearing treatments (194 440 hectares of initial clearing, 598 135 hectares of follow-up clearing). This indicates the level of commitment by Working for Water as well as the escalating resources required to fully manage invasive alien plants. Focusing on follow-up control maximizes the results achieved since an inability to sustain reduced alien levels means a waste of resources and effort put in (Stromberg, 2001). Clearing itself should not cause too many disturbances in early successional communities naturally exposed to high levels of disturbance (Hulme and Bremner, 2006). Unfortunately the increased follow-up required usually means an increase in herbicide applications. Likewise, clearing should not be seen as an end in itself as the ultimate goal should be the recovery of indigenous vegetation (Harms and Hiebert, 2006; Holmes and Richardson, 1999). Thus reducing the impacts of alien clearing methods on natural vegetation recovery should be a priority for clearing agents.

1.3.5 Restoration of riparian zones

The international literature on riparian restoration is dominated by the restoration of riparian landscapes that have been affected by anthropogenic interferences and mechanical alterations e.g. channelisation or damming of streams (see Cohn, 2001; Shafroth et al., 2002). The loss of habitat, biodiversity and ecological benefits of riparian zones (e.g. in reducing flood risk, reducing point pollution sites) has prompted local communities and governments to invest in restoration of river and riparian areas. Currently, millions of dollars are being spent across the world in restoration efforts by recreating artificial habitat through boulder placement or vegetation planting (Rood et al., 2003), dam removal, or regulating instream flow requirements.

The main concern among restoration ecologists is the degree to which areas should be restored resulting in divisionary terms such as *restoration* and *rehabilitation*. King et al. (2003) attempt to clarify these terms through an extensive literature review, which is briefly summarised here. The two concepts are similar yet have significantly different end products. *Restoration* implies the return of a degraded area to some historical condition (e.g. in the USA, Rutherford et al., 2000) or condition prior to disturbance. This includes restoring population biology attributes, natural levels of species diversity and processes allowing the restored communities to function in the long term through dynamic situations while containing all the ecological elements able to facilitate adaptive evolutionary change (Montlavo et al., 1997; Palmer et al., 1997). The *rehabilitation* of habitats aims at "…making the land useful again after a disturbance" (Fogg and Wells, 1998). Although one might not achieve a historical condition, allowing the degraded area to function as a sustainable environment is an improvement. Provided that some structural characteristics are in place that will allow the system to function in the long term, the requirements for rehabilitation will have been served. Similarly, the recovery of vegetation structure can be assumed to result in the appropriate delivery of ecosystem services (King and Hobbs, 2006).

Difficulties have been acknowledged in attaining these goals as the duration of degradation and the degree of modification to the channel have significant impacts (Meier, 1998). Further problems lie in the dearth of historical records and ecological states to guide restoration projects (Prins et al., 2004). Higgs (1997) suggests this lack of knowledge leads to perceived states of restoration goals and that both social and scientific expectations can be met by restoration definitions. Because most riparian ecosystems have a long history of use by humans, they should be considered as part of the general landscape (Richardson et al., 2007) and it would be necessary to achieve restoration goals that are realistic and serve the needs of stakeholders within the degraded ecosystem.

The Society for Ecological Restoration (SER, 2004) defines restoration as the process of assisting recovery of an ecosystem that has been degraded, damaged or destroyed. Restoration objectives have been clarified into nine guideline principles by the SER. A survey on ecological restoration measurements, by Ruiz-Jaen and Mitchell Aide (2005), highlights that most studies measure three out of the nine main attributes; namely 1) diversity, 2) vegetation structure, 3) ecological processes, as essential for long-term persistence of an ecosystem. These are considered the technical performance criteria that all restoration projects should include (Higgs, 1997). The other guidelines require restoration studies to include long-term monitoring or data collection outside of the study areas, which is often not possible given the short time-frame of research projects (Ruiz-Jaen and Mitchell Aide, 2005). Higgs (1997) also admits that site-specific knowledge would ensure a more effective restoration project, allowing stakeholders to link ecological and social needs.

South African rivers, which are smaller in comparison to North American and European rivers, have not undergone much human alteration in the headwater regions. Restoration objectives here stem mainly from alien plant invasion impacts and in some areas exacerbated by the effect of impoundments. Alien vegetation removal is usually only a precursor for any restoration project (Wissmar and Beschta, 1998), as the elimination of other threats is important before restoration can be considered (Ruiz-Jaen and Aide, 2005). However, the removal of aliens might not be enough to promote indigenous vegetation recovery (Harms and Hiebert, 2006; Holmes et al., 2000). The re-establishment of indigenous vegetation by natural means can be hindered by a lack of propagules in areas with a long history of impact by alien species, both standing and cleared (Callaway and Maron, 2006; Galatowitsch and Richardson, 2005; Holmes et al., 2005). In uninvaded rivers, flooding increases plant species richness through the delivery of propagules (Jansson et al., 2005), but if the higher catchment is degraded, then fewer propagules may be supplied to promote vegetation recovery post-clearance, possibly indicating the need for a more active intervention in the recovery of cleared areas (Holmes et al., 2005). Maintaining refugia allows for minimal restoration intervention, as propagules are likely to seed denuded landscapes, provided the hydrological flow is not interrupted. However, a species ability to fill vacant ranges is limited by its dispersal properties, colonization and persistence ability (Schurr et al. 2007). Initial vegetation recovery following most disturbances (i.e. flooding and fire) can be attributed to the soil seed bank (Goodson *et al.,* 2001; Le Maitre and Midgley, 1992), although research in both terrestrial and riparian ecosystems has shown this to be severely depleted during long-term alien occupation (Holmes and Cowling, 1997a, 1997 b; Vosse, 2007). Where the resilience (ability of an ecosystem to return to its former state following disturbance) of riparian areas to disturbance has been compromised then active planting as a restoration tool should be considered in areas where vegetation recovery is poor (Holmes et al., 2005; Richardson et al., 2007; Wali, 1999). Where available, reference conditions can be used as a benchmark for monitoring the intactness of the environment after aliens have been cleared from the system. The use of reference sites will be discussed in Chapter 2.

1.4 Significance of study

Clearing of invasive alien species is the first step towards the recovery of degraded areas. Although alien clearing has had a long history, little attention has been paid to the recovery of cleared areas and riparian areas in particular. For this study I focus on the natural recovery of recently cleared areas. Here three initial clearing techniques are compared to provide Working for Water with information regarding the optimal method to best promote natural vegetation recovery after alien clearing. By comparing the cleared areas to Reference (uninvaded) vegetation, baseline data on the success of Working for Water clearing operations to date will be provided. The degree of natural recovery will be measured in relation to vegetation structure, composition and diversity. In situations where the objective of alien plant clearance is to restore ecological integrity, deficiency in any of the measures could indicate that active intervention should be considered to further promote recovery of these disturbed sites.

1.5 Limitations and mitigations

As stated in the Riverine Vegetation Index report by Kemper (2001), vegetation monitoring is notoriously difficult. The slow growth of trees and diversity of species and growth forms as well as varying vegetation response to influences can make this process seem unwieldy. In assessing whether a restoration trajectory is achieved can be complicated by complex interactions of physical and biological processes of riparian systems. Problems regarding management histories and differential site histories can further complicate the interpretation of the results.

Sampling in this study covers a large area within the Fynbos Biome and samples different catchments. The data are pooled, thereby increasing the variability as well as increasing overall species richness. It is anticipated that a large sample size will compensate for the noise of natural variation and help to tease out real differences that may exist among clearing methods. A field experiment testing different initial and follow-up clearing methods was planned to coincide with the field survey to test the data surveyed in the field. However, the experimental burn was not done in time for plant recruitment to be monitored in this study. A second experiment to test the efficacy of using different plant re-introduction methods as a speedy restoration tool was also interrupted due to the site being washed away during heavy rains.

1.6 Thesis outline

The thesis sets out to determine baseline information on the impacts of current clearing methods used on the natural recovery potential of riparian zones. Chapter 1 consists of a literature review of key issues relating to riparian zones and the impact of alien plants in these systems. This review highlights the work achieved by the Working for Water programme as well as examples of invasive alien species within riparian areas. Chapter 2 contains the site description of all the rivers sampled as well as site requirements and sampling techniques. Two data chapters follow the general methodology chapter. Chapter 3 is the first of the data chapters, assessing the species composition and diversity within cleared riparian areas. This chapter deals with a baseline assessment of the recovery of cleared areas and uses species composition and diversity as a measure of recovery. Chapter 4 uses the same dataset and compares vegetation structure to quantify the success of restoration. Chapter 5 concludes the study with a general discussion of the main results pertaining to management implications and restoration and ends with recommendations for future research. Appendix 1 and 2 contain the species list and vegetation plot details. Appendix 3 provides the experimental design of the experiment meant to coincide with the field survey. Although this experiment was not completed, the information was included as an appendix so as not to lose the data. Appendix 4 provides preliminary results of the second experiment which was terminated due to flood damage.

Chapter 2. Study Areas

The South African flora, especially the Cape Floristic Region, is known worldwide for its high levels of endemism and diversity (Cowling and Hilton-Taylor, 1994). Classified as a semi-arid country, South Africa receives an average of 500mm of rain per annum which is not evenly distributed, with some regions receiving more rain and others considerably less than the average (Hoffman and Ashwell, 2001). The mediterranean-type climate of the Western Cape supports unique vegetation types which have been highly prioritized for the conservation of biodiversity (Goldblatt and Manning, 2000; Rebelo et al., 2007; Pressey et al., 2003). The region experiences a winter-rainfall climate while the summer months are notably hot and dry, resulting in periodic water shortages (Deacon et al., 1992). Climatic gradients in the fynbos biome can be experienced from west-east and north-south (Deacon et al., 1992). The west-east gradient affects rainfall patterns, where the west experiences winter rainfall patterns and the east spring-autumn rainfall peaks. Rainfall declines rapidly to the north with less than 400 mm per annum on the coastal forelands to the North of Langebaan. Rainfall also declines as one moves inland and eastward of the Cape Fold Belt mountains. The highest rainfall is recorded in mountain ranges of the Cape Fold belt. The average rainfall for the Cape Fold Belt ranges from 1000 mm to 2000 mm per annum with the Hottentots Holland Mountains receiving up to 3000 mm in some places (Sieben et al., 2004). This is in contrast to the rest of the low-lying regions which receive up to 750 mm at the coast and 400 mm in the intermontane valleys (Fuggle and Ashton, 1979). The wettest months are between June and September, which account for sixty percent of precipitation, most of which falls in the form of rain (Fuggle and Ashton, 1979).

A characteristic feature of the Cape Fold Belt mountains is the hard, resistant quartzitic rocks belonging to either the Table Mountain Group or occasionally to the Witteberg Group. Two main broad groups of dominant rock types, shales and sandstones, dictate differences in soil types, habitat types and also vegetation types in the region. Riparian zones differ in substrata from adjacent terrestrial systems as mixing of sediment occurs more frequently than in terrestrial environments. The continual erosion and deposition of sediments creates a mosaic of sediments which riparian vegetation are able to colonise. In

Mountain Fynbos the increased soil moisture along rivers, seepages and drainage lines provides habitat for numerous riparian plant species (Taylor, 1978).

2.1 Site selection process

2.1.1 Study design

The ideal experiment would allow for sufficient long-term monitoring of changes from pristine vegetation to dense invasion and then recovery following clearing by different methods. However, the time and money that would be required to set up such an extended experiment are not available. An alternative approach is to use a retrospective inferential method that allows us to use existing reference sites and compare them to disturbed areas further downstream (Davies et al., 2005). This approach has many flaws and one should consider the implication of inferences and also the dynamic nature of the study areas. Any differences between floristic compositions of clearing treatments and controls may be obscured since important variables were not observed or monitored as they occurred. Also, since there is considerable natural variation in species composition over space in the region, it is also problematic to separate differences attributed to treatments from natural variation. However, determining the recovery of diversity, species richness and ecological processes by comparisons to reference sites is a widely used method for gauging restoration success (Hejda and Pyšek, 2006; Ruis-Jaen and Mitchell Aide, 2005a).

The focus of my study is the mountain stream and foothill segments where both dense invasion and reference sites may be found. Sample plots were located based on invasion densities and previous management histories (Figure 2.1). Sites of moderate to dense alien infestation (25-75% canopy cover) generally have sufficient indigenous vegetation remaining to facilitate unaided recovery (Galatowitsch and Richardson, 2005; Hejda and Pyšek, 2006). Therefore the focus of this study was on the closed alien stands (>75% canopy cover) where natural recovery may not occur, or may be protracted (Holmes and Cowling, 1997b). These areas would be most affected by bad management since the regeneration potential of indigenous vegetation has already been impacted on by competitive exclusion from invasive alien species. For this study, three different initial clearing methods were identified namely, felling and leaving slash in situ (Fell Only), felling and removing slash from the cleared area (Fell & Remove) and felling and burning slash (Fell & Burn) (see Figure 2.2). Possible sites and management histories were located using the WIMS (Working for Water Information Management System) database and CapeNature records. The management histories were confirmed by discussions with managers from CapeNature and the Department of Water Affairs and Forestry (DWAF). Clearing records obtained from Working for Water offices comprised the actual contract issued to the contractors used to remove alien vegetation. This included the initial clearing method, alien plant species and densities, dates of initial clearance, follow-up methods and dates. To confirm burning as part of the initial treatment other databases were consulted as the contractor was not responsible for burning and this information therefore, was not be recorded in the Working for Water database. It was planned that the vegetation plots be made permanent for future sampling, with the completed database being housed in the Plant Conservation Unit at the University of Cape Town. The information gathered in this initial study will hopefully be the first of many to fully understand the recovery process following clearing in riparian areas of the Western Cape.

2.1.2 Working for Water mapping techniques

Before explaining the data extraction process from the Working for Water database, I will provide a brief summary of the mapping methods used by Working for Water to create the GIS database. Working for Water has standardised its data collection of invaded areas and ensures that data collected by various organisations can be compared directly. Guidelines and mapping procedures can be found in "*STANDARDS FOR MAPPING AND MANAGEMENT OF ALIEN VEGETATION AND OPERATIONAL DATA*" (Anon, 2003). Alien vegetation data is mapped into GIS software as polygons directly from orthophotographs (called Heads-up Digitising) or by GPS-based field mapping and data capture techniques. The data are entered using specific codes as designed for the GIS (WIMS) programme. In the Western Cape, the polygon identity codes are related to the quaternary catchment (Midgley et al., 1994) within which the clearing project falls. Each polygon is associated with a metadatafile which includes important information regarding invasive alien species, densities and clearing costs. Each project is divided into coverage of alien species grouped into NBAL's (NB =Natural environment - Biological AL=Alien), which is categorised by specific identity numbers, recording information regarding site and clearing information. Recorded information includes: area treated (size of NBAL), density class of infestation (divided into seven density classes based on aerial canopy cover and recorded for each alien species present in the NBAL. The classes are: 0.1-1%, 1-5%, 5-25%, 25-50%, 50-75% and 75-100%), workload (expressed in persondays per hectare) and contract value (as tendered by contractor). The WIMS database is able to record information for each stage/phase of a clearing operation within the relative NBAL. This makes it an effective monitoring tool to note changes in alien species and corresponding density, while recording the all-important financial costs. However, this data needs to be used with caution since not all the clearing information has been entered (Marais et al., 2004). The data files associated with the clearing project are also linked to the contracts generated for clearing operators. As each phase of clearing is updated so too is the project database. An example of how this data can be used is provided in Marais et al. (2004), where total area cleared and associated costs of clearing are analysed. Also recorded is the main species targeted, methods used for clearing, herbicide use and the amount of time spent working in particular area.

2.1.3 Site selection and data extraction

The clearing of invasive aliens occurred prior to the Working for Water programme's initiation in 1995 (see Holmes et al., 1987) although records of these early clearing projects either are not readily accessible or have been lost entirely (Derek Malan DWAF, pers. comm.). The scientific nature behind Working for Water's mandate allowed for better and more detailed records to be kept. However, it was only in 1999 that an effective GIS database (WIMS) was developed (Marais et al., 2004). It was only implemented in 2000 in the Western Cape.

For the purpose of this study, Working for Water projects, within the Western Cape, were loaded into ARCVIEW where the data files (.dbf) containing the NBAL identification number could be viewed. Where possible the Western Cape river layer was used to intersect riparian areas. The extracted data file was sorted according to alien density to identify NBAL's of closed-stand (75-100%) infestation. Where map projections differed, aerial photographs were used to digitise rivers in order to intersect the NBAL's, as mentioned above. Since the NBAL's on their own make no distinction between terrestrial and riparian habitats, aerial photographs were important in locating the exact position of rivers and alien stands.

Many of the areas had been worked prior to 1999 and the initial clearing treatments were not recorded. Thus the first clearing entry in the accompanying data file was from one of the follow-up procedures carried out after the year 2000. These locations were excluded for a lack of site history information. NBAL's were only chosen where a complete site history could be constructed. Sites were first located in this manner prior to further investigation, which included a site visit and a meeting with the project leaders. Some sites used in this study overlapped with previous studies carried out in the fynbos riparian systems (see Galatowitsch and Richardson, 2005). From these site locations a varying number of sample plots could be sampled, depending on the size of the area cleared (i.e. NBAL). It was decided that a distance of 200 m should separate plots on the same river to provide some independence between samples (Galatowitsch and Richardson, 2005).

Further cleared areas were located using CapeNature's GIS clearing information. CapeNature has its own method of data storage, providing information for sites dating back further than the WIMS database. The two databases are somewhat different in that only the latest clearing treatment can be viewed in the CapeNature database with relative ease, whereas the Working for Water database allows the entire record for the NBAL to be viewed. The apparent difficulty at extracting information could hinder research aimed at the follow-up treatments for instance. However, since CapeNature was also an implementing agent for Working for Water, the methods for clearing followed similar guidelines. Additional information obtained from CapeNature includes fire records for each site sampled.

The site selection process allowed the study area to cover large distances between sites (Figure 2.1). The overall study conformed to a control versus impacted analysis where variations between basic community indicators could be tested. Environmental variables were also included to help determine the natural variation among sites. It was understood from the beginning of the project that it would be difficult to relate any aboveground situation solely to the clearing treatment used in the area. There are a number of important factors influencing basic plant colonization and establishment and riparian zones are no different. However by using a large sample size it was intended to test whether the impact of different clearing methods and time since clearance would exceed the noise of variation among rivers and catchments. The trajectory of vegetation towards the reference condition would thus be an indicator of healthy recovery (Hejda and Pyšek, 2006). As a measure of this successful recovery community and structural characteristics were compared to reference sites. Looking at the broader structural components, including growth forms and guilds, allows for comment on clearing treatments that are detrimental to natural recovery rates. Situations may be identified where active restoration is required to facilitate a trajectory towards a healthy, functioning riparian system.

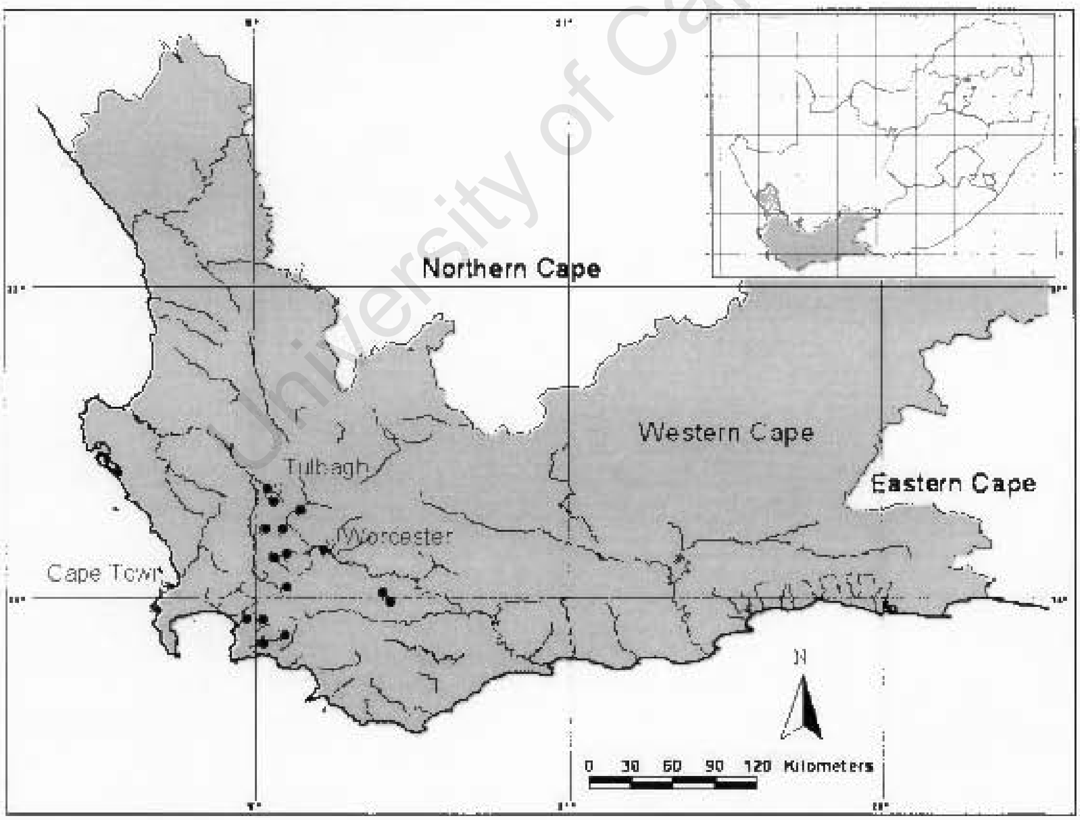

Figure 2. 1. Map of the Western Cape, South Africa, showing the fifteen rivers sampled (•) that fall within the winter rainfall region of the Fynbos Biome. Characteristics of rivers and the number of study plots are provided in Table 3.1.

2.1.4. Site requirements

The first requirement was to locate only closed-stand invasions in the riparian zone with a mean alien canopy cover of 75-100%. The initial clearing treatment should have been conducted at least two years prior to sampling to provide sufficient time for vegetation to have colonized cleared banks. All sites should have sufficient clearing information as recorded by Working for Water and CapeNature. Important information includes: initial clearing date and clearing method, whether the site was burnt or not (as part of the clearing treatment and additional fires), subsequent follow-up treatment dates and methods and whether herbicides were used. Sites should ideally be situated within the mountain stream and foothill segments of the river, limiting disturbance to invasion and clearing treatment. A further requirement was that each cleared site had a suitable reference condition for comparison. This will be discussed further in the next section.

2.2 Reference Sites

2.2.1 Definition and importance

All restoration projects require specific goals in order to identify appropriate guidelines for restoration. A useful way to measure the success of vegetation recovery is by comparing the trajectory of different variables with reference sites (Ruiz-Jaen and Aide, 2005). Reference sites are useful in determining changes to degraded systems as well as attaining direction for restoration goals. A reference site is one that displays a more-or-less natural condition, i.e., one that has not undergone obvious intensive human interference. It acts as a standard of comparison and evaluation to degraded areas (Aronson et al., 1993; Aronson et al., 1995). Many restoration projects use reference sites as their target. This provides structural information on historical disturbance conditions (Eekhout et al., 1997; Rutherford et al., 2000). Much of the current debate on the use of reference sites for setting restoration targets has centred on their relevance in times of global change, landuse and human involvement in riparian areas (Hobbs et al., 2006; Richardson et al., 2007). In these instances historical assemblages may become difficult to re-instate and may even be inappropriate. However, riparian reference sites in the Fynbos Biome of South Africa are likely to remain useful in relation to restoration, as riparian communities extend over a fairly wide range of climatic conditions in this biome. The real problem would occur if the restoration of low-lying rivers within coastal areas were to become a reality, as much of this area has been transformed by agriculture and urbanization and historical conditions are largely unknown in some cases. The use of reference sites at higher altitudes might be applicable to these systems. Unfortunately reference sites are few and far between, as the alteration of lowland landscapes by humans and invasive alien plants has occurred on a large scale (Brown, 1998).

2.2.1 Reference conditions used in this study

Data on reference sites and target vegetation were obtained from Prins (2004), who determined reference characteristics for riparian vegetation from six rivers in the Western Cape in areas with no previous history of invasion and <25% presence of alien vegetation cover. This included the Witte, Molenaars and Palmiet rivers for which invaded sites were sampled in the current study. Examples of Reference sites used can be seen in Figure 2.3. Due to the current sampling requirements not all the rivers could be used for which reference conditions have already been determined. Where the Prins study did not supply reference data for a particular river, additional reference plots were sampled during 2005 in rivers that had suitable uninvaded habitat remaining (Table 3.1). Each invaded and cleared river had a reference site which was located, in most cases, above the cleared plots with the exception of the Palmiet River. These reference plots were sampled at lower altitudes to the cleared plots since the only pristine riparian vegetation occurred in the Kogelberg Nature Reserve (Prins et al., 2004). Prins et al. (2004) identified five riparian communities within fynbos riparian areas which were mainly influenced by geology.

Figure 2. 2 Examples of indigenous riparian vegetation recovery for the three clearing treatments sampled: **Row A**, the Fell & Remove treatment; **Row B**, the Fell Only treatment *Pteridium aquilinum* in foreground; **Row C**, the Fell & Burn treatment

Figure 2. 3 Examples of indigenous riparian vegetation Reference sites used in this study

2.3 Catchments and Rivers in the Fynbos Biome

The rivers presented here are grouped according to the Water Management Areas into which they fall (Midgley et al., 1994; Nel et al., 2007). The following river systems are represented in the study: Berg, Breede, Bot, Palmiet, and Sir Lowry's. In the text below a brief description is provided of the sites sampled including the river name and map reference number followed by 1) geology, 2) vegetation, 3) invasion history (e.g. alien species, dominants, density) 4) Working for Water and other clearing that has occurred in the river sub-catchments as well as an indication of the time since clearance.

2.3.1 Breede River System

2.3.1.1 Molenaars River and Du Toits River 3319CA

The geology of upper reaches of the Molenaars River consists of Peninsula, Wellington pluton granite outcrops and recent Quaternary deposits (scree, tallus, alluvium). Further downstream the alluvium deposits make up most of the riverbanks. The major vegetation type within the catchment valley consists of Hawequas Sandstone Fynbos interspersed with Boland Granite Fynbos and Western Coastal Shale Band vegetation (Rebelo et al., 2006). Clearing is evident in the riparian areas and records indicate *Acacia mearnsii* as the dominant alien species targeted in the area. Follow-up records reveal that other alien species are also present, namely: *Acacia longifolia*, *Acacia saligna* and *Rubus* species. The upper reaches of the Du Toits River (plots 82 - 87) were sampled at an altitudinal range of 560-590 m, whereas the foothill section of the Molenaars River (plots 49 - 52) had an altitudinal range 300-340 m above sea level (Figure 2.4). The initial clearing method for both sites was Fell & Remove, where slash was stacked out of the riparian zone < 5 years ago.

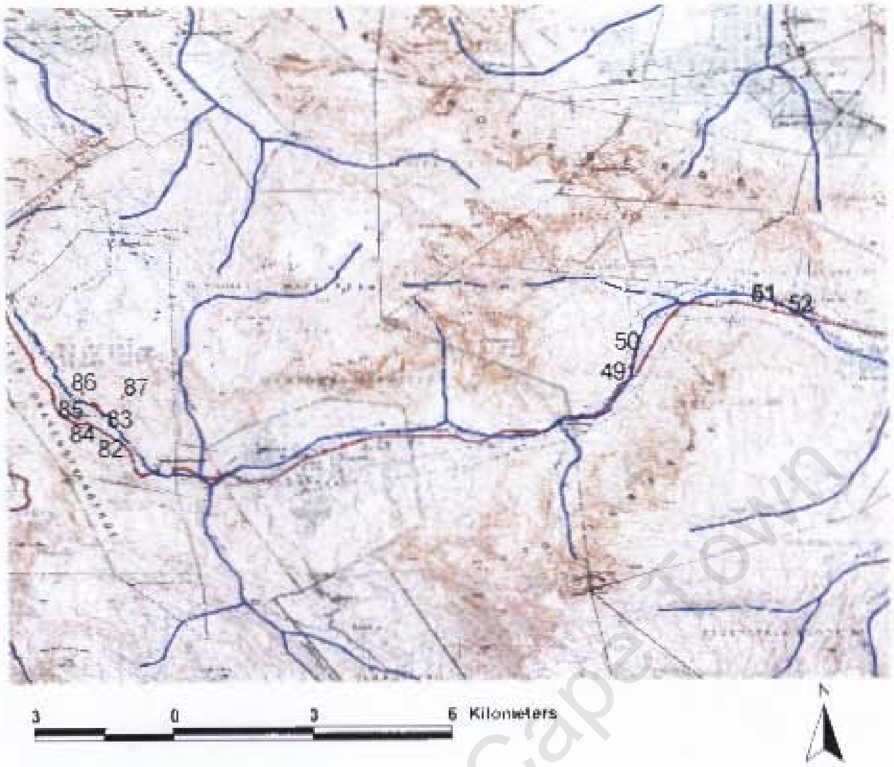

Figure 2. 4. Vegetation plots along the Molenaars (49 - 52) and Du Toits (82 - 87) Rivers.

2.3.1.2 Wit River 3319CA

The geology of the Wit River catchment consists mainly of the Peninsula formation supporting the Hawequas Sandstone Fynbos vegetation type (Rebelo et al., 2006). Campbell (1985) described the "Witrivier" riparian community to include common species *Metrosideros angustifolia, Brachylaena neriifolia, Brabejum stellatifolium, Elegia capensis* and *Erica caffra*. The "Witrivier" riparian community is common to the West and southern interior of the Cape Fold Belt mountains. The foothill areas of the Wit River are covered by closed-stand invasion of tall *Acacia mearnsii* trees. Clearing has been carried out in sections and is ongoing (Currie, 1989; Prins, 2004). Vegetation plots (30 - 33) were located below the Steenboks Nature Reserve Park (Figure 2.5). Clearing was carried out by the Waterval CapeNature team in whose office records were collected. Initial clearing was Fell & Remove done >5 years ago. A fire was reported to have swept through the area in 2001, although no evidence of burning was noted in the plots sampled.

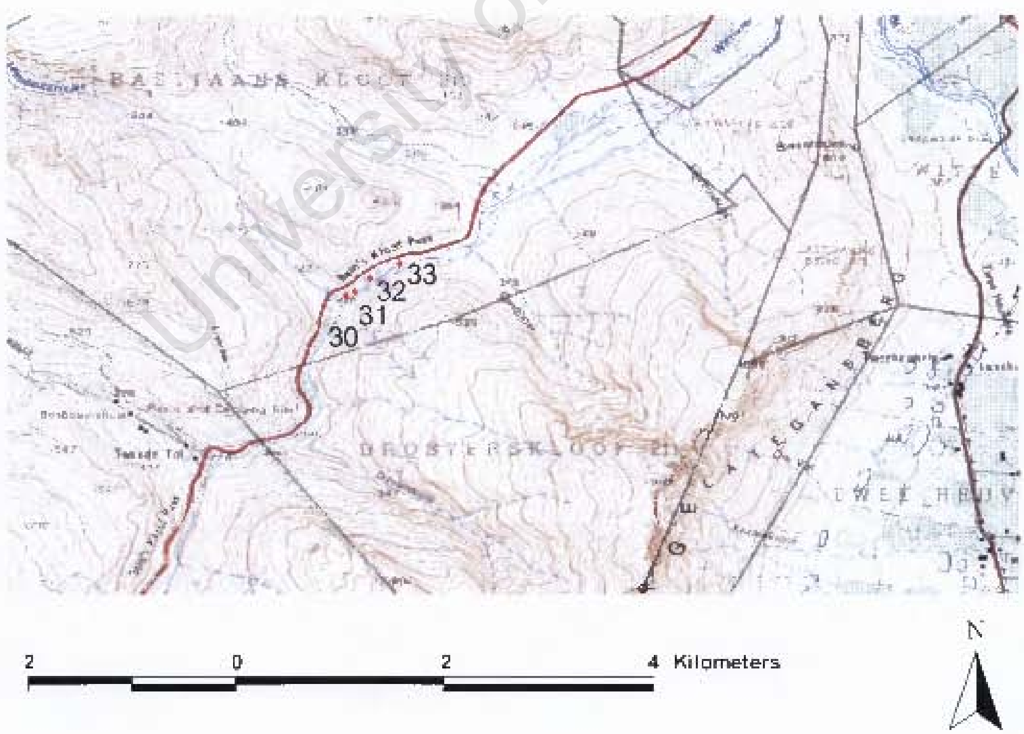

Figure 2. 5. Vegetation plots (30 - 33) along the Wit River below Tweede Tol.

2.3.1.3 Upper Breede River 3319AD

The upper Breede River runs along Mitchells Pass before meeting up with the Wit River below Bainskloof Pass. The geology is of the Peninsula formation with quaternary alluvial deposits and supports Breede Alluvium Fynbos vegetation (Rebelo et al., 2006). The main channel is fairly braided and islands form during the winter months. Vegetation plots (1 - 10) were located in the foothill segment of the river, situated below more recently cleared areas further up the river (Figure 2.6). The vegetation along the river channel is mixed with *Prionium serratum* forming dense clumps in some locations. Alien invasion comprising dense *Acacia mearnsii* and *Acacia longifolia* was reported to have been cleared. Initial clearing was Fell & Burn done >5 years prior to sampling. Follow-up clearing is still ongoing as teams were noted on site during sampling.

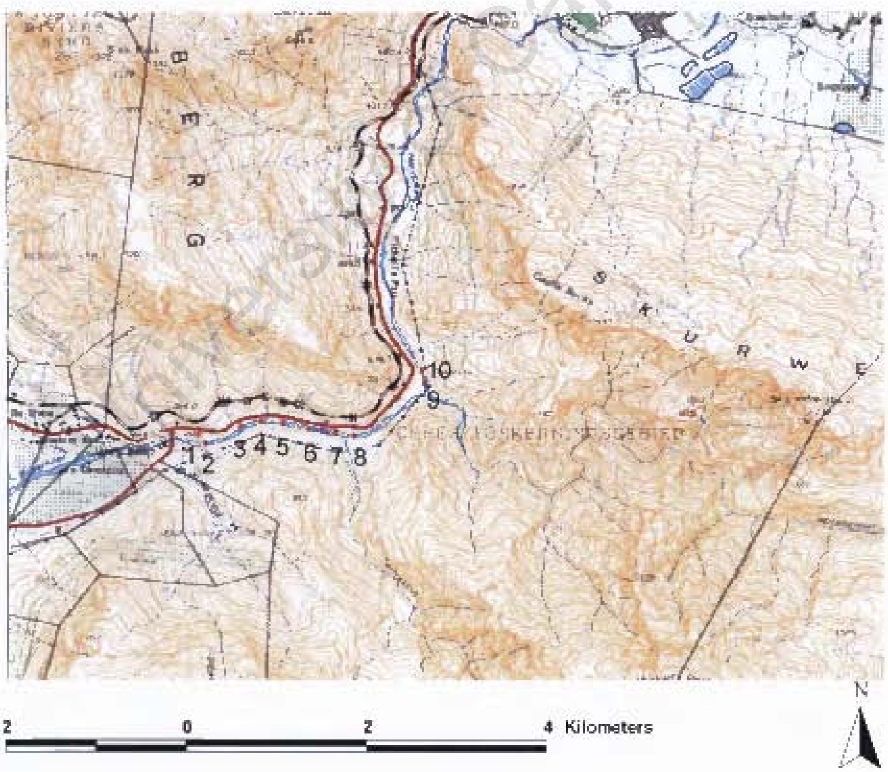

Figure 2. 6. Vegetation plots (1 - 10) along the Upper Breede River below Mitchells Pass.

2.3.1.4 Breede river 3319CB

The Breede river site is situated below the Nekkies resort on the eastern bank (71 - 72) with four sites (73 - 76) occurring further downstream (Figure 2.7). The river traverses shale and mudstone hills which are adjacent to the river. Other geological features found in the area include quartzitic sandstone and siltstone layers within the overall formation. The surrounding vegetation type is Breede Alluvium Fynbos (Rebelo et al., 2006). Invasive plants dominant here are mixed *Acacia* and *Eucalyptus* species. These areas have been recently targeted by the Worcester Working for Water teams and as a result the area does not have a long history of alien clearing. The initial clearing method is a Fell Only which occurred <5 years ago. Slash is left within the riparian zone however the area can be accessed by road relatively easily.

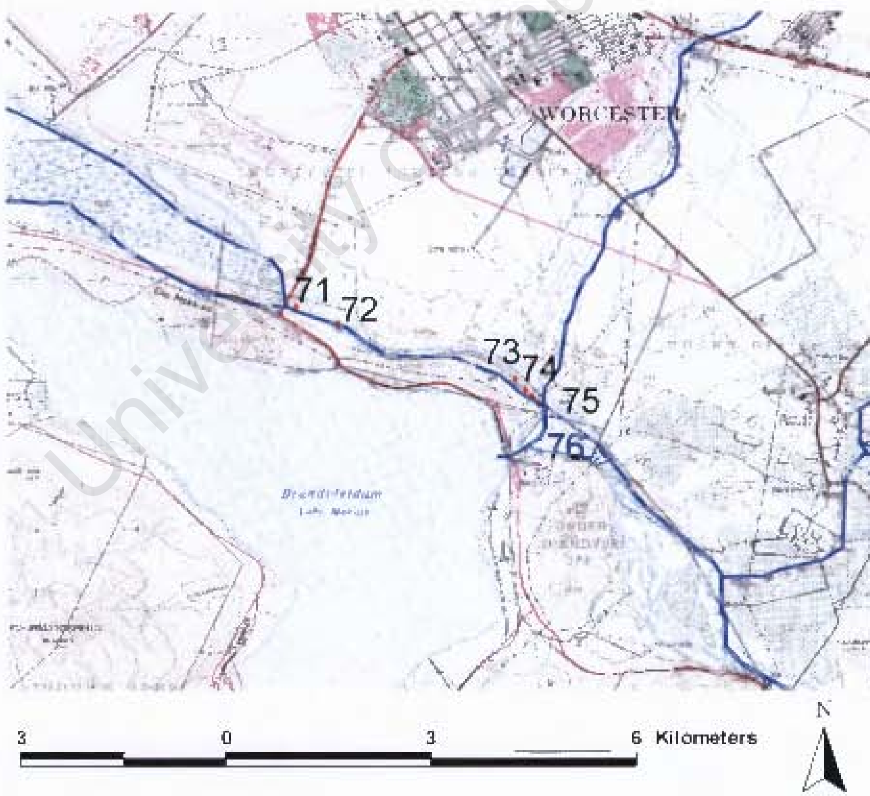

Figure 2. 7. Vegetation plots (71 - 76) along the Breede River below the Nekkies Resort

2.3.1.5 Houtbaais and Hoeks River 3319DD

The source of the two rivers stems from the Riviersonderend mountains. Geology in the region of the Rietvlei formation is comprised mainly of white feldspathic sandstone with mudstone interspersed. The two river channels are similar in that both are made up of large white cobbles and alluvium soils line the banks. The vegetation changes from North Sonderend Sandstone Fynbos to Breede Alluvium Renosterveld as you move further downstream (Rebelo et al., 2006). Alien plants prominent in the area include *Eucalyptus* and *Acacia* species. Alien plant management is undertaken by CapeNature at the Vrolijkheid Nature Reserve. Closed-stand invasions were cleared using a Fell & Burn treatment done <5 years prior to sampling along the Houtbaais (plots 53 - 58) and Hoeks (plots 59 - 61) River (Figure 2.8). The fire was an especially hot one as burn scars are still apparent in the riparian area.

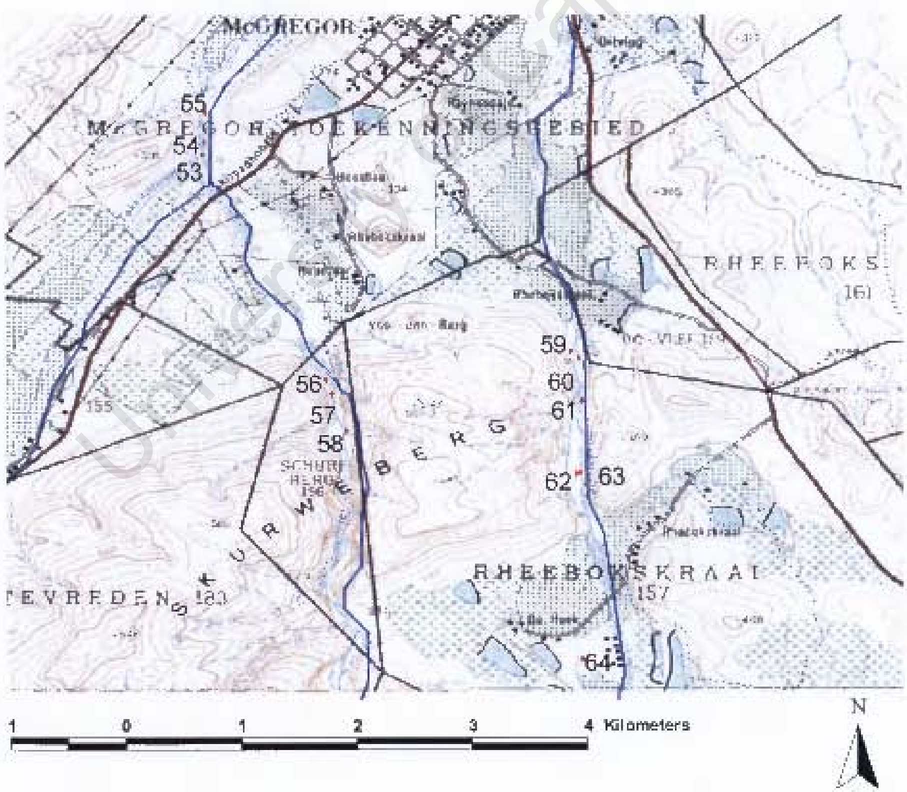

Figure 2. 8. Vegetation plots along the Houtbaais (53 - 58) and Hoeks (59 - 61) River near McGregor

2.3.2. Palmiet River System

2.3.2.1. Palmiet River 3419AC

Vegetation plots (14 - 16) were sampled is within the Arieskraal area situated below a measuring weir (Figure 2.9). Geology is predominantly of the Rietvlei formation, white silicaceous sandstone, and Gydo formation, mudrock and siltsone, makes up the surrounding hills. The vegetation type is Kogelberg Sandstone Fynbos (Rebelo et al., 2006). The dominant alien species is *Acacia longifolia*, but during the current sampling period of 2005 large amounts of emerging *Eucalyptus camuldulensis* saplings were recorded. The initial treatment was a Fell & Remove occurring >5 years prior to sampling, where the contractor was reported to have removed most of the slash.

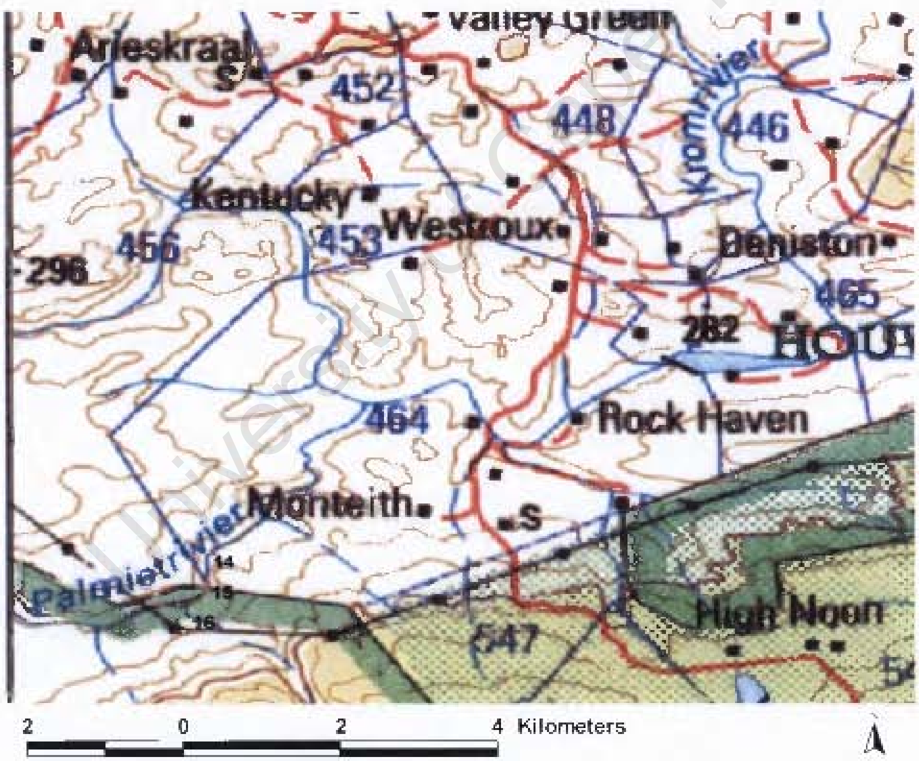

Figure 2. 9. Vegetation plots (14 - 16) along the Palmiet River in the Arieskraal area.

2.3.2.2. Wesselsgat 3419AA

The Wesselsgat River is situated in the Hottentots Holland Reserve which is surrounded by SAFCOL pine plantations. Geology includes Skurweberg, Goudini, Cedarberg and Pakhuis formations. Vegetation type is Kogelberg Sandstone Fynbos (Rebelo et al., 2006). Vegetation plots (77 - 81) were sampled below the pump station of the Wesselsgat River (Figure 2.10). Plots were cleared using a Fell Only treatment where mixed *Acacia* species and *Pinus* species were cleared. This was done >5 years prior to sampling.

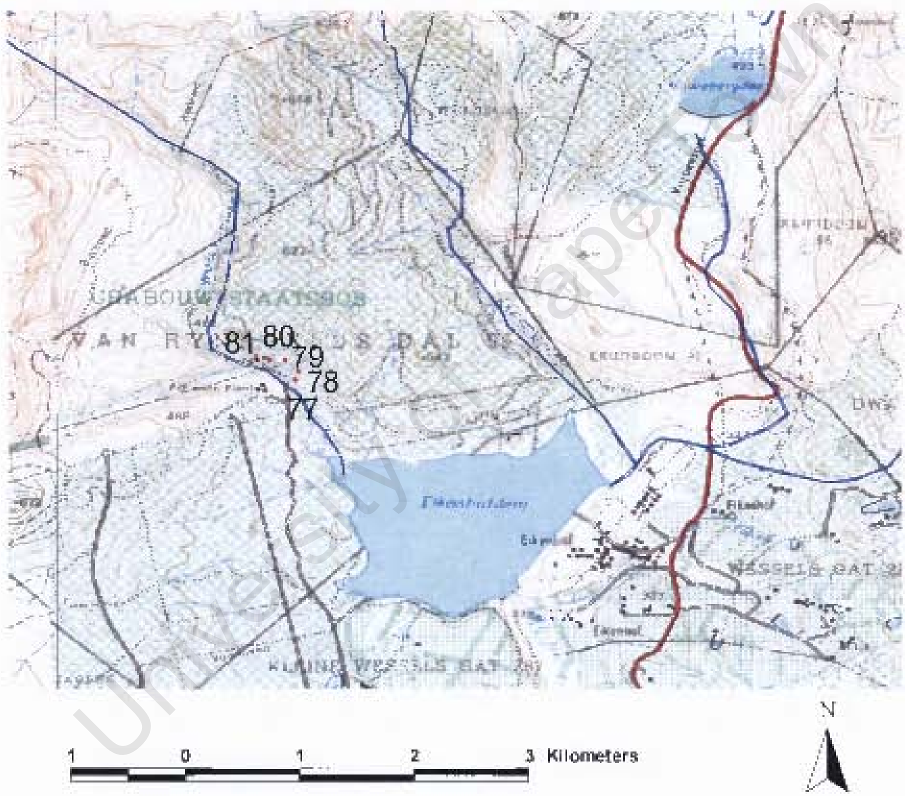

Figure 2. 10. Vegetation plots (77 - 81) along the Wesselsgat River in the Hottentots Holland Forestry reserve.

2.3.2.3 Viljoens River 3319CC

The Viljoens River flows into the Theewaters kloof dam. Geology of the area consists of a shale band running through Peninsula Sandstone formation. This supports the Western Coast Shale Band and Hawequas Sandstone Fynbos vegetation types (Rebelo et al., 2006). The area was cleared of closed-stand *Acacia mearnsii* although large *Eucalyptus* tree species remain further downstream of the sampling site. Only one vegetation plot was sampled in this region (plot 88). It was kept in the analysis as it fell within the Palmiet river system. The fire record of the area indicates two fires, one in 1999 and another in 2004. The initial clearing treatment was a Fell & Burn done >5 prior to sampling (Figure 2.11).

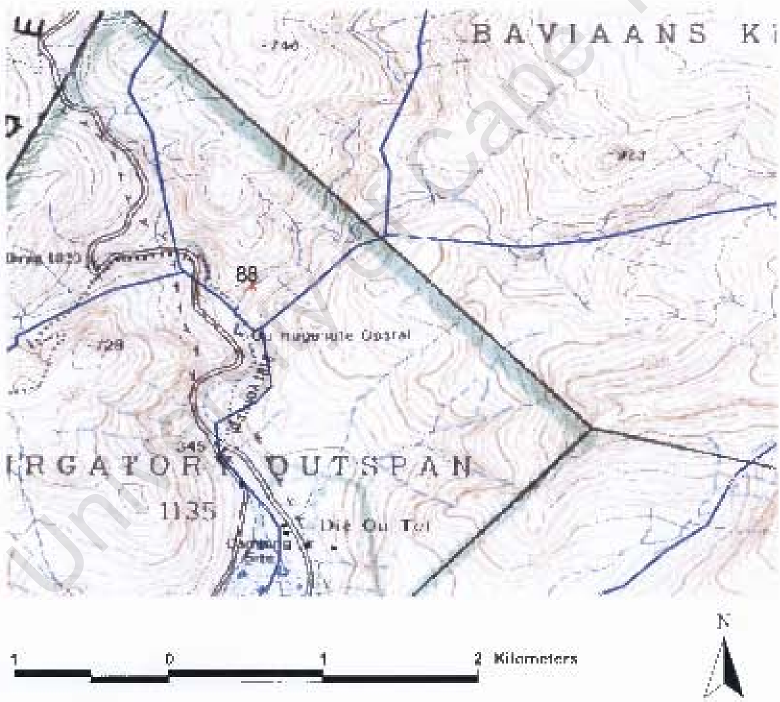

Figure 2. 11. Vegetation plots (88) along the Viljoens River.

2.3.3. Berg River System

2.3.3.1. Berg River 3319CA

The sample area falls in the Assegaaibos reserve close to Franschoek. The area was managed as a pine plantation and was heavily invaded with *Pinus* and *Acacia* species. Geology in the region is reported to be Quaternary sediments attributed to the low gradient of the river channel. Vegetation type is Swartland Alluvium Fynbos (Rebelo et al., 2006). Working for Water records indicate that *Pinus* species, *Acacia longifolia* and *Acacia mearnsii* were removed from the riparian areas. Vegetation plots (11 - 13) were cleared using an initial Fell & Burn treatment done < 5 years prior to sampling (Figure 2.12).

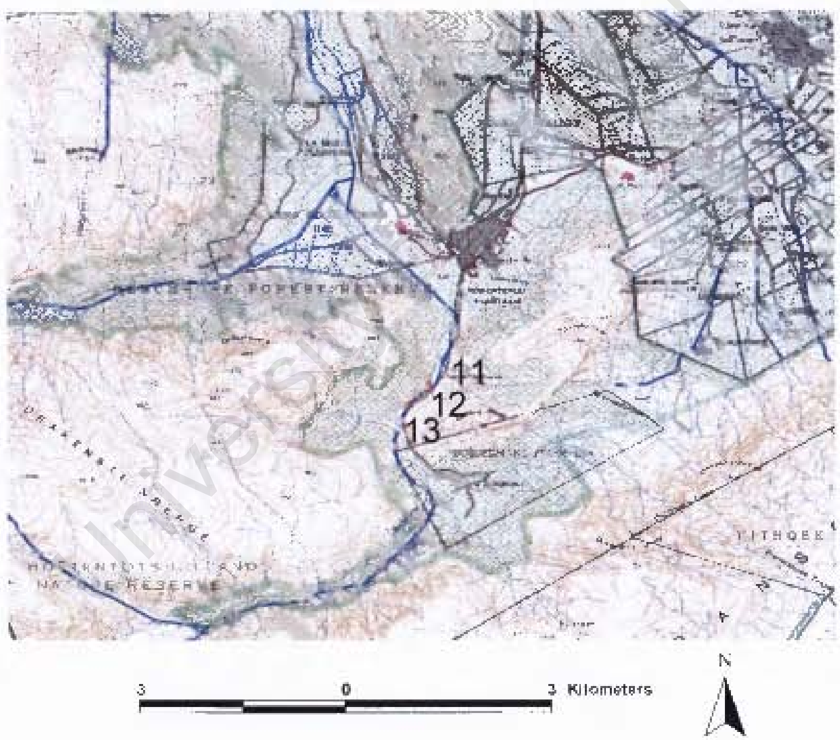

Figure 2. 12. Vegetation plots (11 - 13) along the Berg River in the Assegaibos Reserve.

2.3.3.2. Waterval River and Kleinberg River 3319AC

The geology along the Waterval River is complex and consists of the Skurweberg (white-weathering, quartzitic sandstone), Goudini (quartzitic sandstone, shale and siltstone) and Cedarberg (shale, siltstone, subordinate sandstone) formations. The major vegetation type in the valley consists of Hawequas Sandstone Fynbos interspersed with Western Coastal Shale band vegetation (Rebelo et al., 2006). The Waterval CapeNature offices are situated in the area and are responsible for the clearing operations in the region. The plots sampled (35 - 41) were cleared in 1999 where a mix of closed-stand *Acacia longifolia* and *Pinus pinaster* was removed (Figure 2.13). The Kleinberg River runs adjacent to the Nuwekloof Pass. The geology forms part of the Peninsula formation characterised by Quartzitic sandstone and shale. The vegetation type sees a shift from Hawequas Sandstone Fynbos to Winterhoek Sandstone Fynbos as you move further north (Rebelo et al., 2006). The plots sampled (65 - 70) were cleared of alien plant species by the Waterval CapeNature and started in 1998 (Figure 2.13). It has seen some 8 follow-ups namely using felling as a method.

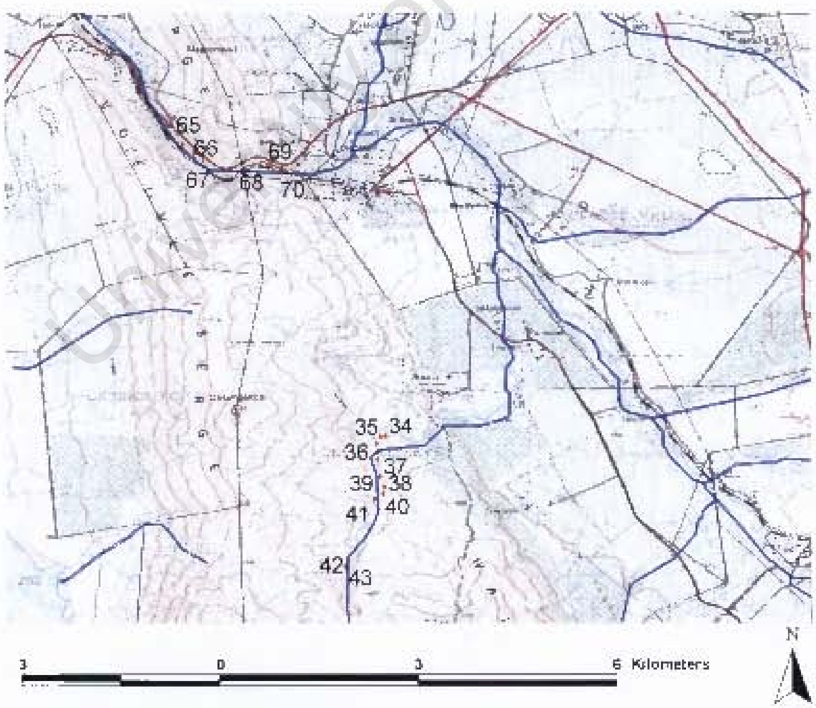

Figure 2. 13. Vegetation plots sampled along the Waterval (35 - 41) and Kleinberg (68 - 70) Rivers.

2.3.4. Sir Lowry River System

2.3.4.1. Sir Lowry River 3418BB

The site is located on the Wedderwill Estate, a small area adjacent to pine plantations. Geology of the area is made up of Quaternary sediments with Granite of the Stellenbosch Batholith occurring upstream. The predominant vegetation type of the area is Boland Granite Fynbos (Rebelo et al., 2006). Closed-stand invasion consiting of 30 years old *Hakea, Pinus pinaster, Acacia mearnsii, Acacia longifolia* and *Acacia saligna* were cleared (Di Marais pers. comm., 2005). Vegetation plots (44 - 48) were cleared <5 years prior to sampling using a Fell & Burn treatment (Figure 2.14).

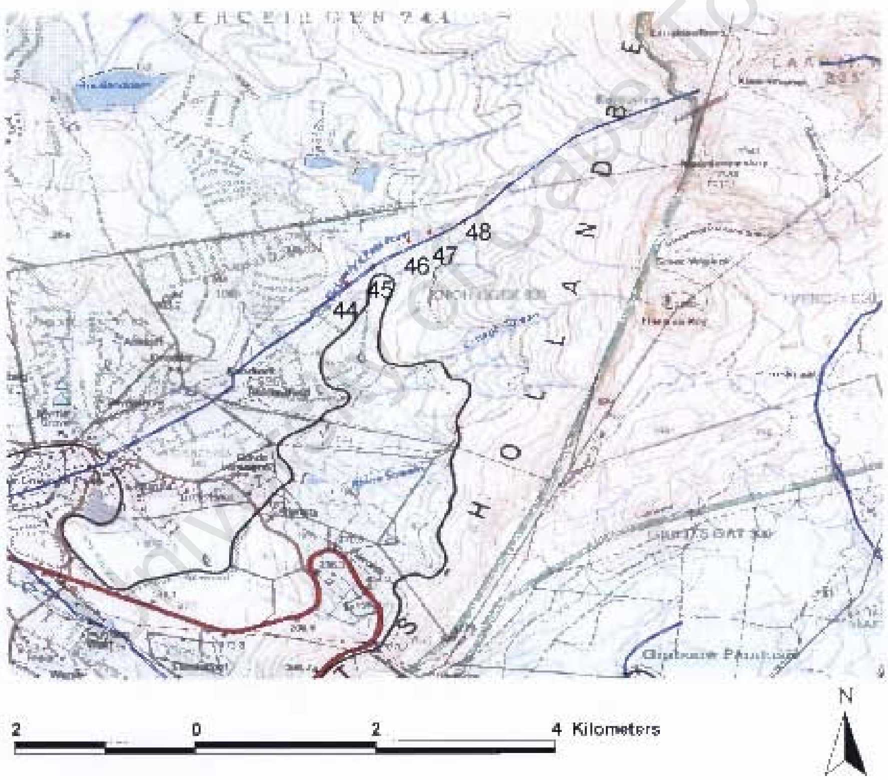

Figure 2. 14. Vegetation plots (44 - 48) along the Sir Lowry River.

2.3.5. Bot River System

2.3.5.1. Jakkals River 3419AA

The Jakkals River runs along the Houhoek Pass and eventually flows into the Bot River. The geology of the region is complex and consists of the Skurweberg, Goudini, Cedarberg and Rietvlei formations. The vegetation type is Kogelberg Sandstone Fynbos with Elgin Shale Fynbos occurring further upstream (Rebelo et al., 2006). The plots sampled (17 - 25) were first cleared in 1996 and 1997 (Figure 2.15). Alien species comprised various *Acacia* species although *Acacia mearnsii* was the dominant alien in many along the river. Alien trees were felled and burned 1997. Two follow-ups were recorded yearly after the initial clearing.

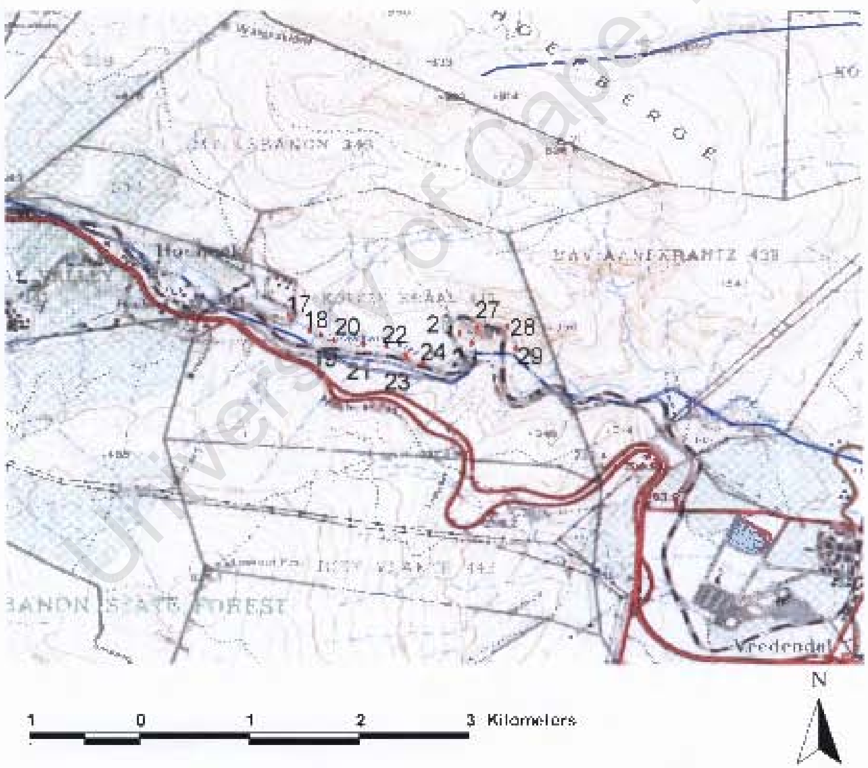

Figure 2. 15. Vegetation plots (17 - 29) along the Jakkals River.

Chapter 3. The effects of different alien control methods on the recovery of riparian vegetation composition and diversity

3.1 Introduction

It is understood that riparian areas are generally susceptible to invasion by alien plants (Hood and Naiman, 2000; Planty-Tabacchi et al., 1996; Stohlgren et al., 1998). Changes induced by flooding or human induced disturbances allow for the creation of gaps, propagule transport (both indigenous and alien), as well as changes to flow regimes or nutrient availability that can favour alien species becoming established within the riparian zone (Décamps, 1995; Galatowitsch and Richardson, 2005). The past few decades have seen a global increase in research directed at the restoration of disturbed riverine systems. The realization of the importance of ecosystem resources and services, including biodiversity, to be obtained from indigenous systems has prompted this move (Nilsson et al. 2007; Patten, 1998; Turpie, 2004; van Wilgen et al., 1998).

In South Africa the infestation of riverine channels by invasive alien plants in catchment areas has been one of the main focal points for the removal of such vegetation. It is widely accepted that invading species are a major threat to natural biota (Richardson and van Wilgen, 2004) and the ecosystem services they provide (Zavaleta et al., 2001). Alien species (e.g. *Pinus, Acacia* and *Eucalyptus* species) used in commercial forestry prompted whole-catchment experiments as early as 1936 to determine impacts on water resources (van Wilgen, 2004). These species are able to increase their range by forming closed-canopy stands in catchment areas, thereby increasing their invasive potential (Richardson et al., 2000). Studies have linked invasion by alien species, usually as dense closed-canopy stands in mountain catchments, to a reduction in surface water run-off, catchment yield and as well as to altered hydrological processes within the catchment (Dye and Jarmain, 2004; Higgins et al., 2000; Le Maitre et al., 2000).

In the Fynbos Biome all lowland rivers have been transformed to some extent (Brown, 1998). Landuse changes and riverine modifications, aimed to serve human needs, have reduced the ecological integrity of these systems the closer they get to the sea. The headwater regions of fynbos rivers, however, are mainly threatened by invasive alien plants and this is one of the main reasons for land degradation in these areas. The Working for Water programme has therefore initially targeted riparian areas and their immediate sub-catchments (Marais, 2004; Holmes et al., 2005).

Currently, trees and shrubs are the most important alien invaders in the Fynbos Biome, with Australian wattles acting as important riparian invaders in the Western Cape, namely: *Acacia saligna, A. longifolia* and *A. mearnsii (*Nel et al., 2004). These species invade both riparian and terrestrial ecosystems with the latter receiving more research attention. Mature closed-canopy alien vegetation (*Pinus, Acacia* and *Eucalyptus* species) stands change the light regime thereby shading out indigenous vegetation, resulting in a reduction in species richness, local diversity and indigenous vegetation cover (Holmes and Cowling, 1997).

Invasive alien plants have been shown to outcompete indigenous species and transform environments (Richardson et al., 2000). However, in addition to this, alien clearing methods potentially may be destructive to the environment (Parker-Allie et al., 2004). Field studies show variation among clearing methods in their impacts on soil and vegetation recovery (e.g., Breytenbach, 1989; Korb et al., 2004; Holmes, 2001; Holmes and Marais, 2000; Holmes et al., 2001). As an example, Breytenbach (1989) tested the slash and burn technique used in the removal of *Hakea sericea.* This treatment was shown to have negative impacts on indigenous recruitment, following the burn, owing to the unnaturally high temperatures the soil was subjected to. For this reason summer burns in dense alien slash are not recommended in catchment areas (Richardson and van Wilgen, 1986). Holmes et al. (2001) showed a negative relationship between fire intensity and density of fynbos recruits following alien clearance, whereas in the United States the use of fire in the removal of *Tamarix* species showed no difference when compared to the vegetation recovery of non-burning methods (Harms and Hiebert, 2006). Thus, manipulating disturbance regimes (especially fire cycles) can help in reducing alien infestation and biomass (Richardson, 1998). The concern comes from the recovery of indigenous systems after fire has been used. Fire management has been modified accordingly to allow vegetation to reach maturity. Unfortunately frequent rogue wild fires may prevent this from happening.

In the Western Cape portion of South Africa, alien clearing from catchment areas has been implemented for several decades to remove both closed and emerging stands of invasive alien vegetation. Unfortunately there has been little monitoring of past clearing projects, particularly in riparian zones, in relation to the impacts of the methods used on natural vegetation recovery. Prins (2004) identified several plant communities in pristine riparian habitats along fynbos rivers to be used as a reference for restoration targets following the removal of invasive alien species. These can also be used to assess the natural recovery of invaded and cleared riparian areas. The potential exists for invasive alien species removal to have negative impacts on natural vegetation. Therefore, in this chapter I investigate two aspects of riparian communities: 1) natural recovery of indigenous riparian ecosystems following invasive alien clearing and 2) the impacts of the initial clearing method applied in riparian zones during the past ten years in the Western Cape, namely: felling (with or without the removal of slash), and felling in combination with burning. Owing to large-scale transformations in lowland river systems (Brown, 1998), and the lack of reference systems there, this study focused on mountain stream and foothill segments where both closed-stand invasions and reference vegetation may be found (Galatowitsch and Richardson, 2005; Prins, 2004). The aim of this study was to investigate which initial alien clearing method best facilitates the recovery of natural riparian vegetation composition. I assume that although there is a difference between clearing methods with regard to the rate and degree of recovery, natural recovery of riparian systems is possible. The underlying premise is that recovering vegetation, that most closely resembles the composition of uninvaded, reference vegetation will indicate the optimal clearing method. I pose the following questions:

1. Is there a significant difference in floristic composition and diversity between reference vegetation and cleared vegetation?
2. Is there a significant difference in floristic composition and diversity among recovering vegetation stands following different clearing treatments?
3. Which of the more commonly used clearing treatments best facilitates vegetation recovery in the riparian zone?

3.2 Methods

Historical land-use has transformed most of the lowland riparian zones to some extent and reference sites to guide restoration targets are lacking. Therefore, the focus of our study was on mountain stream and foothill segments where both dense invasion and reference sites may be found.

Fifteen rivers were sampled, (see Chapter 2 for site requirements), from which 78 vegetation plots were obtained (Figure 2.1; Table 3.1). Vegetation plots measuring 10 x 5 m, which is a commonly used size for phytosociological studies in fynbos shrubland vegetation (Boucher, 1977), were set up in the riparian zone, with the long edge parallel to the river. Although different lateral riparian zones have been identified in fynbos rivers (Boucher, 2002), I chose to locate the sample plots in the major (dry bank) zone. This zone is subjected to episodic flooding and is generally dominated by riparian scrub (shrubs and small trees), however it may also incorporate some elements of neighbouring fynbos communities. The wet bank zone close to the river is seasonally inundated and is often very narrow or, in mountain streams, non-existent. The upstream top corner (furthest from the waters' edge) of each plot was marked by a steel peg to help locate the plot for future sampling. The GPS reading was taken from this location using a Garmin GPS IV.

Within each plot, total indigenous vegetation cover was estimated as a percentage of the entire plot (50 m^2), while vegetation composition was measured using estimated percentage projected canopy cover values for individual perennial plant species (indigenous and alien) present within the plot. This was later converted to Braun-Blanquet cover-abundance scores for analysis (Werger, 1974). Indigenous perennial species richness was recorded in three 1 m^2 quadrats within the plot, as well as for the entire 50 m^2 plot. The two scales were chosen to determine species richness and vegetation recovery at different scales within a plot. Floristic data were gathered by recording all recognizable species in the field and taking specimens for later identification of unknown species. Species identifications were carried out in the Guthrie and Bolus herbaria situated at the University of Cape Town. Data on target vegetation were obtained from Prins (2004), who determined reference characteristics for riparian vegetation in areas with no previous history of invasion and <25% presence of alien vegetation. Where the Prins study did not supply reference plots for a particular river, additional reference plots were sampled during 2005 in rivers that had suitable uninvaded habitat remaining (Table 3.1).

Table 3. 1. Locations of study plots for each of the three clearing treatments and Reference plots along Western Cape rivers. Numerals (i-iv) indicate the reference sites used for cleared areas.

Clearing treatment	River name	No. of plots sampled	Reference plots	Map reference	Altitudinal range (m)	Mean annual rainfall (mm)	Year of initial treatment
Fell & Remove	Molenaars	4	21 (i)	3319CA	300-340	889	2002-2003
	Waterval	8	2* (ii)	3319CA	220-300	600	1998-1999
	DuToits Kloof	6	(i)	3319CA	560-590	1477	1997-1998
	Witte	4	26 (iii)	3319CA	260	833	1998
Total		**22**					
Fell Only	Palmiet	2	14 (iv)	3419AC	130	817	1997
	Wesselsgat (Palmiet upper)	5	(iv)	3419AA	330	1285	1999
	Breede	6	(i, iii)	3319AC	200	299	2003
	Klein Berg	6	ii	3319AC	90-120	552	1998
Total		**19**					
Fell & Burn	Jakkals	13	(iv)	3419AA	190-250	875	1997-1998
	Hoeks	4	2*	3319DD	240-280	263	2001
	Houtbaais	3	2*	3319DD	250-280	247	2001
	Assegaaibos	2	1*	3319CA	300	531	2003
	Viljoens	1	(iv)	3319CC	360	901	1999
	Titus	10	(i, iii)	3319AD	290-320	655	1998-1999
	Sir Lowry	4	1*	3418BB	220-290	966	2002
Total		**37**					

Notes: * indicates additional reference plots sampled in 2005. The numbers in parenthesis indicate the reference plot group the cleared plots were compared to.

3.2.1 Data analysis

The effects of the three different clearing treatments (Fell Only, Fell & Remove, Fell & Burn) on vegetation variables (total indigenous cover, indigenous species richness and diversity, alien cover) were compared to the control (Reference plots) using one-way ANOVA. All statistical analyses described below were done in STATISTICA (Version. 7, Statsoft, Inc., 2004). In order to determine any differences between treatments the data were first assessed to see if they met the criteria of normality as required for analysis of variance (ANOVA). Levene's Test was used to test for homogeneity of variances between samples and the Kolmogorov-Smirnov Test was used to test for normality in data. Where data were not normally distributed appropriate transformations were applied. Indigenous vegetation cover percentages were Arcsin transformed. Species richness (50 m^2 and 1 m^2) and Shannon Weiner diversity indices were square-root transformed. Where ANOVA's were significant, Tukey's unequal N post-hoc test was used to further investigate differences among means.

Additional variables were sampled in this survey that were not included in the Prins (2004) survey supplying the majority of data for reference plots. Thus only Reference plots (n = 8) surveyed in this study could be used for comparisons with cleared pots (n = 78) for species richness at the 1 m^2 scale.

The Kruskal-Wallis test is the non-parametric equivalent of one-way ANOVA. It makes no assumptions about the homogeneity of variance or the normal distribution of data (Dytham, 2005; Zar, 1996). This test was used to test differences between diversity indices for clearing treatments, which failed to conform to ANOVA assumptions.

The effect of age since clearance on vegetation recovery was examined by dividing the cleared plots into two age groups (those cleared <5 years ago and those cleared ≥ 5 years ago). Vegetation variables (species richness and vegetation cover) were tested to see whether there was any difference between the two age classes using one-way ANOVA as described above. This was further investigated using a two-way ANOVA to determine any interaction between age since clearance and clearing treatment. Where relationships were significant multiple range tests was used to assess the differences.

Diversity per 50 m^2 plot was assessed using cover values per species as a proportion of the total vegetation cover calculated for the Shannon Weiner (H') index and Evenness using "Pielou's J" (McCune and Grace, 2002; Zar, 1996).

$$H' = -\sum_{i=1}^{k} p_i * \ln p_i$$

where k = number of species and pi = the proportion of species found in plot i.

$$J = \frac{H'}{H'_{\max}} \qquad \text{and} \qquad H'_{\max} = \log k$$

The community analysis package, Primer (version 5.2.2), was used to provide Bray Curtis Similarity coefficients for clearing treatments and Reference plots. Ordinations were created using PC-Ord 4.0 (MjM Software Design, 1999). PC-Ord contains the updated version for the algorithm used in the Detrended Correspondence Analysis (DCA) ordination (McCune and Grace, 2002). Ordinations have been successfully used in testing the recovery of diversity in restoration experiments (Rui-Jaen and Mitchell Aide, 2005a). The distance between communities in ordination space is a measure of their compositional dissimilarity (Shaw, 2003), making it possible to note the direction and extent of changes in composition. The eigenvalues are an indication of the strength of ordination. However, PC-Ord has the ability to further test the strength using after-the-fact correlation of ordination data with real data using the relative Euclidean distance measure. Using a second matrix containing environmental or categorical variables the DCA can therefore be used to show relationships between numerous variables. PC-Ord was also used to run a Canonical Correspondence Analysis (CCA) in order to determine which environmental variables are important in plot distribution.

3.3 Results

3.3.1 Vegetation cover

One-way ANOVA revealed significant cover differences for indigenous perennial vegetation among the treatments ($F = 39.9$; d.f. = 3,144; $p<0.001$; Table 3.2). Reference plots contained significantly higher indigenous vegetation cover than the cleared plots. Clearing treatments differed as Fell & Remove plots had significantly higher vegetation cover than Fell Only plots, with Fell & Burn as an intermediate between the two (Table 3.2). The average cover for cleared plots was 60% of Reference plots average. The lowest canopy cover recorded for the cleared plots was 6% of the Reference. If the lowest Reference plot canopy cover of 50% is used as an arbitrary cut-off point for vegetation recovery, then 37 of the 78 cleared plots belonging to various clearing treatments have low vegetation cover. This accounted for 74% of Fell Only plots, 27% Fell & Remove and 46% of Fell & Burn plots.

3.3.2 Species richness

The analysis of species richness in different clearing treatments was shown to be significant at the plot scale ($F = 6.1$; d.f. = 3,144; $p<0.001$; Table 3.2). The highest species richness was recorded for the Fell & Remove treatment while the Fell Only treatment exhibited the lowest richness (Table 3.2). Further investigation by Tukey Tests revealed the high species richness for Fell & Remove plots to be significantly greater than Fell Only, Fell & Burn and Reference plots (Table 3.2). No clearing treatment exhibited significantly lower results than the Reference plots at the 50 m^2 scale.

Species richness at the 1 m^2 scale was also significantly different, ($F = 15.0$; d.f. = 3,82; $p<0.01$; Tables 3.2), with Reference plots having the highest mean richness. Post-hoc tests revealed Reference plots to be significantly higher than Fell Only and Fell & Burn treatments. Fell & Remove plots had significantly higher species richness than Fell Only plots.

3.3.3 *Diversity*

The non-parametric Kruskal-Wallis test revealed significant differences for both Shannon-Weiner diversity (χ^2 = 14.9; d.f. = 3; p<0.001) and Evenness scores (χ^2 = 23.6; d.f. = 3; p<0.001) among clearing treatments (Table 3.2). The Fell & Remove treatment recorded the highest Shannon-Weiner diversity score and was significantly different from the other clearing treatments (Fell Only and Fell & Burn), but was not significantly different from the Reference condition. The Fell Only treatment was the only cleared treatment to have significantly lower diversity than the Reference condition. Evenness (*J*) scores for Reference plots were significantly different to Fell Only and Fell & Burn plots, but not to Fell & Remove plots.

3.3.4 *Age since clearance*

Indigenous vegetation cover was significantly higher in older plots than younger plots (F = 12.9; d.f. = 1,76; p< 0.001, Tables 3.3). Unlike the combined age plots there was no difference in species richness between the two age classes (<5 years and $\geq$5 years) at the plot scale (50 m^2). However, species richness at the 1 m^2 scale was significantly different among treatments (F = 7.05; d.f. = 1,76; p<0.01; Table 3.3). Two way ANOVA using age since clearance and clearing treatment as factors showed no difference for vegetation cover (F = 0.604; d.f. = 2,72; p>0.5) and significant difference for species richness at the plot scale (F = 6.67; d.f. = 2,72; p<0.01) and the 1 m^2 scale (F = 13.5; d.f. = 2,72; p<0.001; Figures 3.1, 3.2 and 3.3). Multiple range tests showed that, at the plot scale, species richness did not differ between age groups within a clearing treatment. However, differences were apparent for the same age classes among different clearing treatments. Species richness in young Fell & Burn plots was significantly higher than in young Fell Only plots. Older Fell & Remove plots were significantly richer than older Fell & Burn plots (Figure 3.2). Looking across age groups revealed older Fell & Remove plots to be significantly richer than Young Fell Only plots. Similar trends were noted at the 1 m^2 scale as for the larger plot scale. The only difference was the significant increase in richness over time for the Fell & Remove treatment, but not for the other two treatments (Figure 3.3). This scale also showed that young Fell & Burn plots had significantly higher richness than young Fell Only plots. However as the plots increased in age the difference ceased to exist. Older Fell & Remove plots were also significantly richer than the old Fell & Burn plots.

Table 3. 2. Vegetation variables (means ± standard error) for three clearing treatments and the Reference condition. Within each variable, columns with different letter superscripts are significantly different based on one way ANOVA. χ^2 is for the Kruskall Wallace ANOVA test.

Vegetation Variables	Fell Only	Fell & Remove	Fell & Burn	Reference	Effect MS (d.f.)	Error MS (d.f.)	*F*	*P*
N	19	22	37	70				
Indigenous Vegetation % Cover	41.3 ± 5.96^{a}	66.89 ± 4.39^{b}	54.2 ± 4.23^{ab}	73.1 ± 1.40^{c}	8603.2 (3)	215.5 (144)	39.9	<0.001
Species Richness *1 m^2	1.72 ± 0.21^{a}	3.10 ± 0.31^{bc}	2.16 ± 0.13^{ab}	4.48 ± 1.19^{c}	1.7 (3)	0.1 (82)	15.0	<0.001
Species Richness 50 m^2	9.11 ± 0.98^{b}	15.5 ± 1.29^{a}	11.2 ± 0.70^{b}	11.0 ± 0.57^{b}	3.1 (3)	0.5 (144)	6.1	<0.001
							χ^2	***P***
Diversity (*H'*)	1.34 ± 0.13^{a}	1.88 ± 0.08^{c}	1.51 ± 0.05^{ab}	1.70 ± 0.05^{cb}			14.9 (3)	<0.01
Evenness (*J*)	0.58 ± 0.06^{a}	0.81 ± 0.04^{ab}	0.66 ± 0.02^{a}	0.74 ± 0.03^{b}			23.6 (3)	<0.001

* Note: 1 m^2 plots were only measured for plots sampled in the current survey (N=8). These exclude the reference plots surveyed by N. Prins (2004).

Table 3. 3. Vegetation variables (means ± standard error) using age since clearance as the main factors.

Vegetation Variables	<5 Years	≥5 Years	Effect MS (d.f.)	Error MS (d.f.)	*F*	*P*
N	28	50				
Indigenous Vegetation % Cover	41.8 ± 4.60^{a}	62.1 ± 3.36^{b}	3348.3 (1)	260.3 (76)	12.9	<0.001
Species Richness 50 m^2	11.2 ± 0.88	12.2 ± 0.81	0.318 (1)	0.566 (76)	0.56	>0.05
Species Richness *1 m^2	1.82 ± 0.17^{a}	2.57 ± 0.16^{b}	0.938 (1)	0.132 (76)	7.05	<0.01

*Note: 1m^2 plots were only measured for plots sampled in the current survey (N=8). These exclude the reference plots surveyed by N. Prins (2004).

Table 3. 4. Two-way Analysis of variance table for the variables of vegetation cover and species richness, with age since clearance and clearing treatment as the two factors.

Factor	d.f.	SS	*P*	*F*
Vegetation cover				
Age since clearance	1	2200.5	<0.05	8.82
Clearing treatment	2	8.78.8	0.179	1.76
Interaction	2	301.4	0.549	150.7
Error	72	179584.4		
Species richness (50 m^2)				
Age since clearance	1	0.1543	0.538	0.382
Clearing treatment	2	4.60	<0.05	5.703
Interaction	2	5.39	<0.05	6.676
Error	72	29.07		
Species richness (1 m^2)				
Age since clearance	1	11.47	<0.05	14.24
Clearing treatment	2	3.23	<0.05	2.00
Interaction	2	19.37	<0.05	12.02
Error	72	27.19		

*Note: 1m^2 plots were only measured for plots sampled in the current survey (N=8). These exclude the reference plots surveyed by N. Prins (2004).

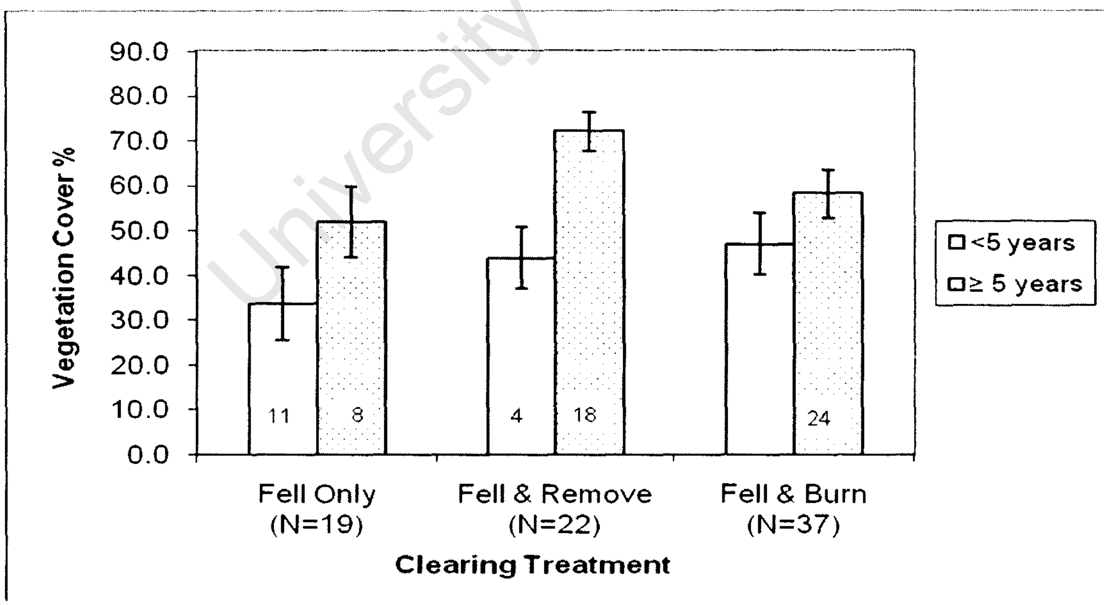

Figure 3. 1. Indigenous vegetation cover (mean ± standard error) following different clearing methods, divided into two time since clearance classes. (<5 years, ≥5 years) (differences non significant, Table 3.4). Sample sizes are indicated in graph above.

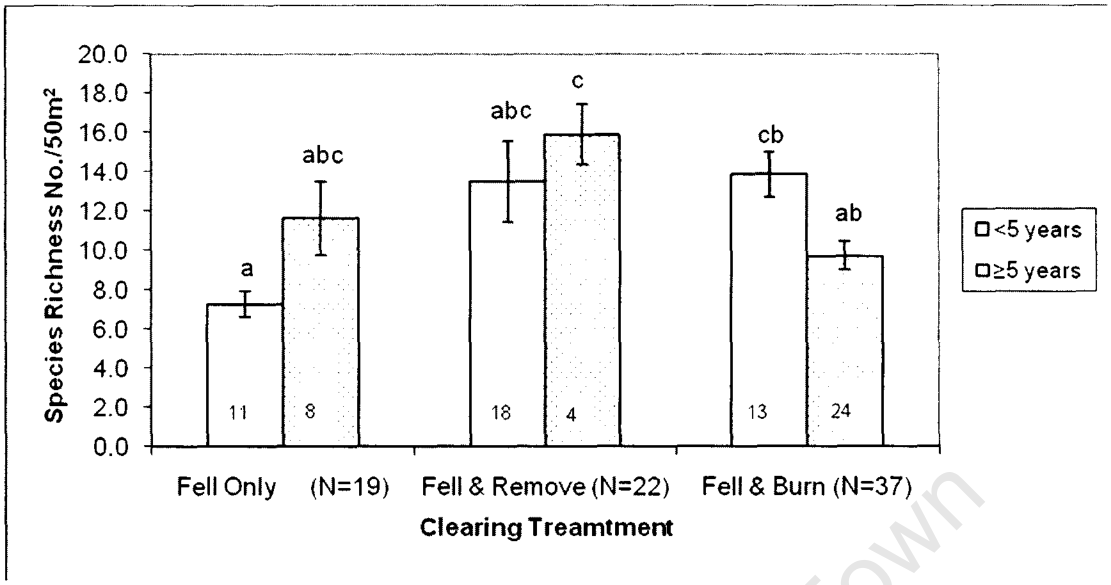

Figure 3. 2. Species richness (50 m^2) (mean $\pm$ standard error) following different clearing methods, divided into two time since clearance classes. (<5 years, ≥5 years) (differences non significant, Table 3.4). Different letter combinations above bars indicate a significant difference at P < 0.05 based on two way ANOVA. Sample sizes are indicated in graph above.

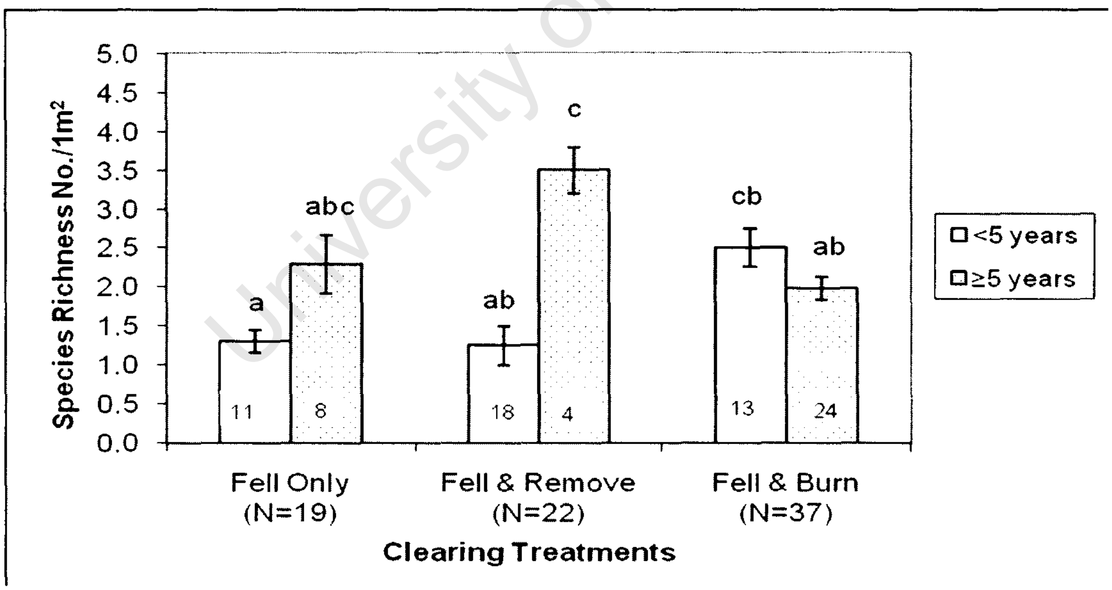

Figure 3. 3. Species richness (1 m^2) (mean $\pm$ standard error) following different clearing methods, divided into two time since clearance classes. (<5 years, ≥5 years) (differences non significant, Table 3.4). Different letter combinations above bars indicate a significant difference at P < 0.05 based on two way ANOVA. Sample sizes are indicated in graph above.

3.3.5 Community composition

Braun Blanquet cover classes are represented in a Detrended Correspondence Analysis (DCA) using species occurring in more than 2 plots, where rare species were down-weighted (Figure 3.4). The DCA indicates species compositional differences among plots and treatments. DCA axis 1 and 2, which are associated with 57.0% and 34.0% of the variance, respectively, were useful in organizing the clearing treatments to note a trajectory towards the reference condition. The total variance or "inertia" in species dataset was 9.47 reducing the robustness of the total variance explained by the ordination (Shaw, 2003).

The degree of species relatedness and vegetation cover is an important factor in determining the level of vegetation recovery. As a visual tool, Figure 3.4 allows for an inspection of which clearing treatment best facilitates recovery towards a composition displayed by the reference plots.

The first axis is associated with six of the twelve environmental variables (Table 3.5). It is negatively correlated with species richness and % vegetation cover, and positively correlated with % fine sand, soil depth, number of follow-ups and % alien cover. Because plots in higher altitudes were least invaded it could be said the first axis is primarily associated with altitude and probability of alien cover. The negative correlation with species richness and vegetation cover suggests that reference plots have higher values for both variables and these are reduced in cleared plots. There is a fairly high degree of colinearity among environmental variables for the first axis, thus making it difficult to determine which factors strongly influence plant species patterns. The second axis is poorly associated with all environmental variables except pH, which has a weak positive correlation.

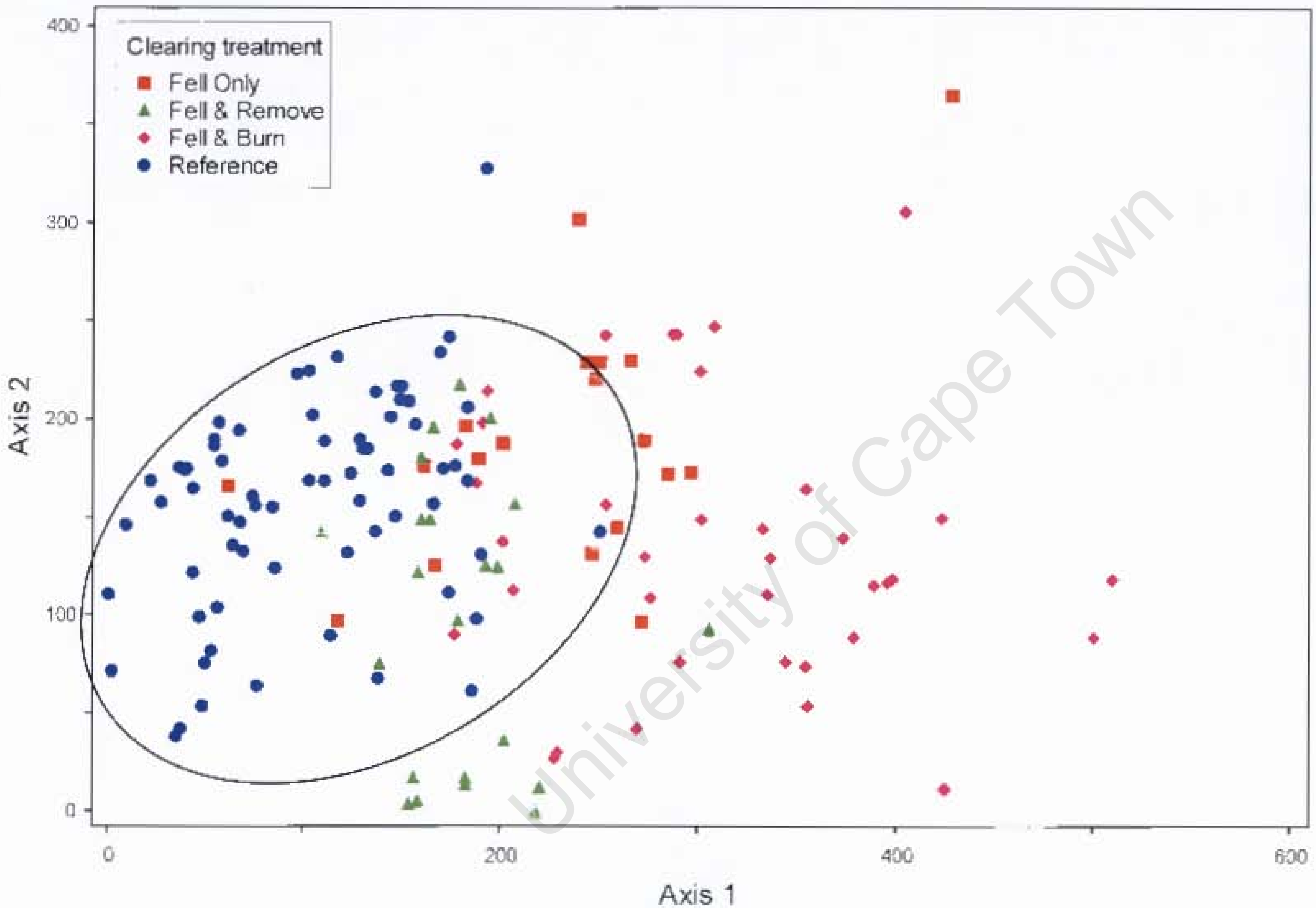

Figure 3. 4. DCA ordination depicting plots based on 361 species with rare species down-weighted. The clearing treatments are used as grouping variables with the treatments explained in the accompanying legend. The ellipse indicates 98% of Reference plots.

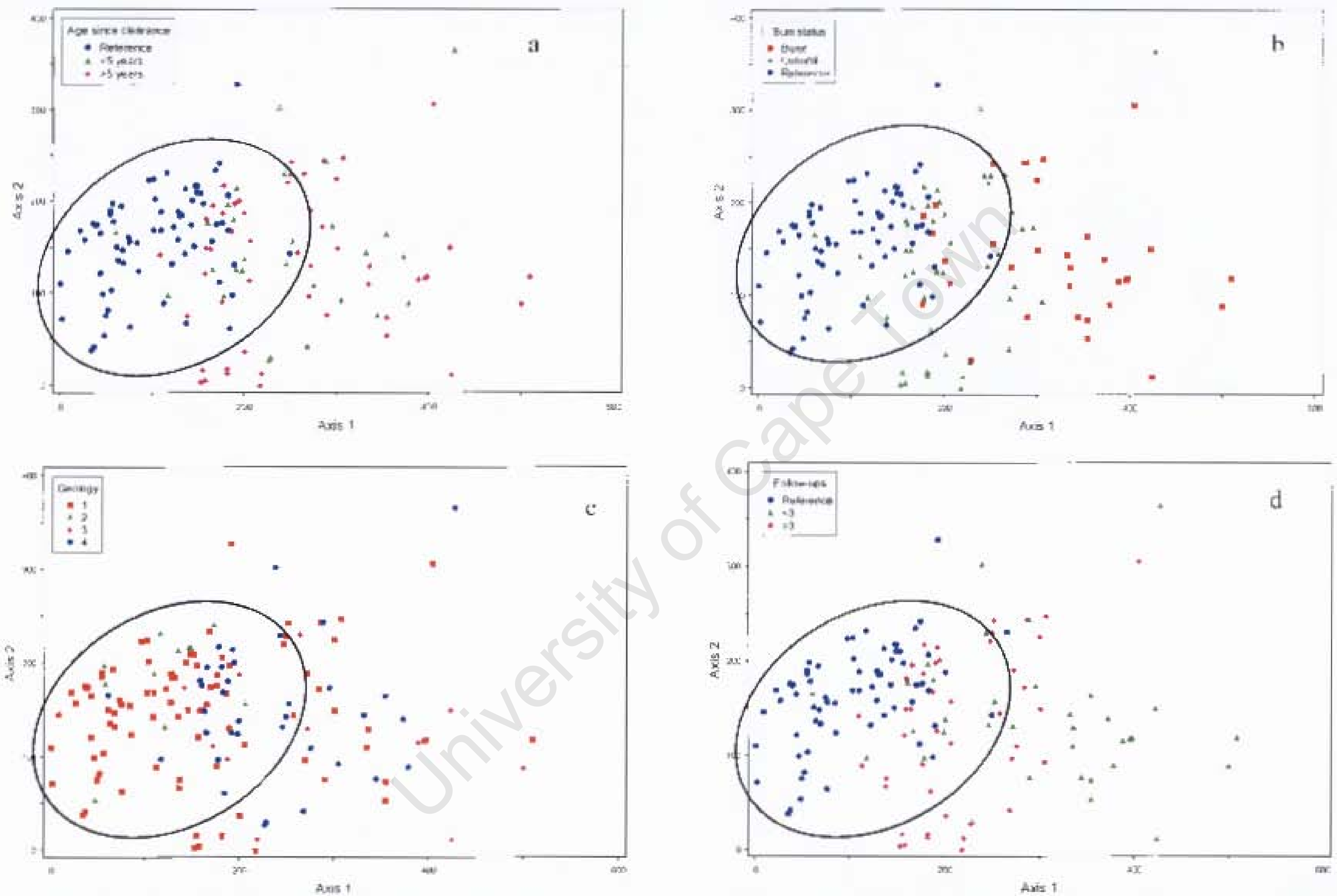

Figure 3. 5. The same DCA ordination as Figure 3.4 using different grouping variables: a) Age since clearance, b) Burn status, c) Geology (1=sandstone; 2=granite; 3=mixed; 4=alluvium), d) Number of follows-ups received after initial clearing. The ellipse indicate 98% of Reference plots.

The DCA axis 1 and 2 are useful in delineating the similarity of species composition within each clearing treatment. The overlap between different groups suggests that common species are likely to exist within all three treatments. According to the Pearson and Kendall correlation coefficients, species associated with the Reference group (negative correlation with axis 1) include, *Brachylaena neriifolia, Metrosideros angustifolia, Elegia capensis, Berzelia lanuginosa, Leucadendron salicifolium, Erica caffra, Restio perplexis* and *Cannamois virgata,* while the cleared side (positive correlation with axis 1) is associated with *Cliffortia strobilifera, Erharta ramosa, Chryanthemoides monolifera, Athanasia trifurcata, Helichrysum* species and *Rhus* species. Where clearing treatments overlap with the Reference, these can be accounted for by the presence of the dominant riparian scrub species. The low axis score of Fell & Remove plots allow for more overlap with the Reference condition, more so than the other clearing treatments. The high axis scores for Fell & Burn plots indicate dissimilarity in species composition with regard to the Reference plots. Fell Only plots tended to have intermediate axis scores and variable response to clearance and indigenous vegetation recovery. Bray Curtis similarity indices confirm the ordination results by revealing that the Fell & Remove treatment is most similar in species composition to the Reference, with Fell & Burn most dissimilar and Fell Only an intermediate between the two (Table 3.6). A list of the species occurring within 10 or more plots is shown in Table 3.7, indicating presence or absence in a treatment.

The grouping variables used in Figure 3.5 include, Age since clearance, Burn status (whether a plot was burnt or not), Geology and the number of follow-up treatments a cleared plot has received. Of the four grouping variables used, only Burn status was able to explain the pattern expressed. The use of Follow-up treatments was variable where both few and many treatments resulted in plots closely associated with the Reference. However burnt plots with few follow-up treatments were most dissimilar to the Reference.

Table 3. 5. Pearson Correlations of environmental variables with DCA ordination axes.

Variables	Axis 1	Axis 2	Axis 3
pH	0.269	0.387	0.194
Species richness	-0.531	-0.037	-0.037
% Vegetation cover	-0.529	-0.025	-0.034
% Fine sand	0.640	-0.028	0.058
% Medium sand	0.2224	-0.017	-0.046
% Coarse sand	-0.311	-0.106	-0.089
Soil depth (m)	0.457	-0.169	0.045
Altitude (m)	-0.239	0.251	0.114
% Rock cover	-0.057	0.124	-0.008
Aspect	-0.120	0.138	-0.138
Number of Follow-ups	0.461	-0.245	-0.213
Alien Cover	0.416	0.048	0.138
Eigenvalues	0.575	0.342	0.276

Table 3. 6. Bray Curtis similarity data of top ten species between clearing treatments and Reference.

	Fell Only	Fell & Remove	Fell & Burn
Fell Only			
Fell & Remove	36.2		
Fell & Burn	27.4	37.5	
Reference	39.2	51.5	27.3

The Canonical Correspondence Analysis (Figure 3.6) shows that pH, altitude, % fine sand, soil depth and % coarse sand are important explanatory variables in the distribution of Reference and cleared plots. There is still a degree of separation among clearing treatments, although some overlap exists. Altitude separates Reference plots and cleared plots, with the latter occurring on deeper soils with more fine and medium sand.

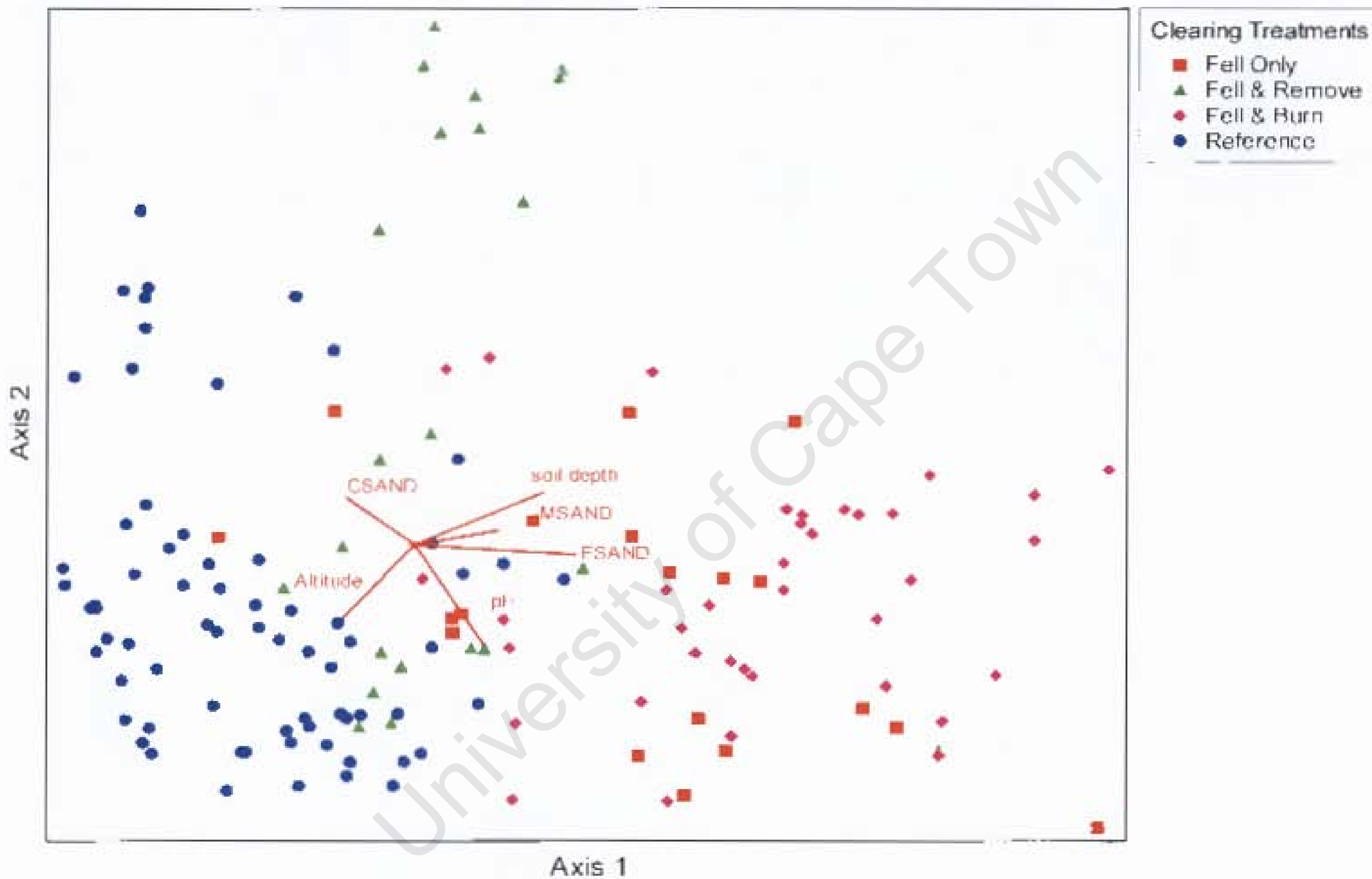

Figure 3. 6. A Canonical Correspondence Analysis relating environmental variables to species composition.

Table 3. 7. A list of common species sampled in the study indicating presence and absence in clearing treatments. x = species absent from clearing treatment and F = frequency. Nomenclature follows Goldblatt and Manning (2000).

Species	F	Fell Only	Fell & Remove	Fell & Burn	Reference
Anacardiaceae					
Rhus angustifolia	42				
Asteraceae					
Metalasia densa	12	x			x
Cullumia ciliaris	12	x		x	
Athanasia trifurcata	13	x	x		x
Chrsyanthemoides monolifera	14	x			x
Stoebe plumosa	25				
Stoebe cinerea	26				
Berzelia lanuginosa	30	x			
Brachylaena neriifolia	55				
Celastraceae					
Cassine schinoides	10				
Cunoniaceae					
Cunonia capensis	10				
Dennstaedtiaceae					
Pteridium aquilinum	47				
Dryopteridaceae					
Dryopterus inaequalis	13	x		x	
Ebenaceae					
Diospyros glabra	83				
Ericaceae					
Erica caffra	26				
Fabaceae					
Psoralea pinnata	22				
Iridaceae					
Nivenia corymbosa	12	x		x	
Lauraceae					
Cassytha ciliolata	13			x	
Myricaceae					
Morella serrata	13				x
Mytaceae					
Metrosideros angustifolia	85				
Poaceae					
Cynodon dactylon	15		x		
Pennisetum macrourum	24				
Ehrharta ramosa	36				
Podocarpaceae					
Podocarpus latifolius	14	x			
Prioniaceae					
Prionium serratum	34				
Proteaceae					
Leucadendron salicifolium	27				
Brabejum stellatifolium	79				
Restionaceae					
Platycaulos callistachyus	10	x		x	
Restio perplexus	20	x		x	
Calopsis paniculata	33				
Elegia capensis	34			x	
Cannomois virgata	37	x		x	
Rosaceae					
Cliffortia ruscifolia	19	x			
Cliffortia strobilifera	23		x		
Saliaceae					
Salix mucronata	11			x	
Thymelaeceae					
Passerina vulgaris	14				

3.4 Discussion

3.4.1 Vegetation cover

Average indigenous vegetation cover of cleared plots did not recover to the Reference condition in the short time (<10 years) since initial clearing, regardless of the clearing treatment used. The significantly lower cover for cleared plots is consistent with other riparian (e.g. Harms and Hiebert, 2006) and terrestrial studies (Holmes and Marais, 2000) following alien vegetation removal. Differences in clearing treatments are, however, apparent as the Fell & Remove treatment had significantly higher vegetation cover than the Fell Only treatment. The lower vegetation cover for both Fell Only and Fell & Burn treatments suggests that increased biomass (via slash) and burning in the riparian zone, negatively affects indigenous vegetation cover in the short term (2-10 years). Age since clearance indicated that older plots, regardless of clearing treatment, had higher vegetation cover than young plots, thus there is good potential for recovery of indigenous vegetation cover after a further 5-10 years.

3.4.2 Species richness

Plant species richness at the plot scale was not lower than the Reference condition for all cleared plots. The Fell & Remove treatment however, had significantly higher species richness than all other treatments, possibly as a response to disturbance of topsoil by caused by the physical removal of slash . This is not uncommon, and other studies have reported increases in species richness post-disturbance attributed to short-lived pioneer and surviving resprouter species (Davies et al., 2005; Holmes, 2001; Wolters et al., 2005). Although species richness was comparable to the Reference at the plot scale, a lower species richness at the 1 m^2 scale for Fell Only and Fell & Burn treatments could indicate an elimination of more sensitive species following clearing (Holmes and Cowling, 1997a). The results suggest that differences between species richness at the plot and 1 m^2 scale could be a function scale or species' composition, as reflected by the diversity and evenness index. For example, the Fell & Remove plots support relatively high numbers of species (presumably small) species with low individual cover, whereas Reference plots have fewer species, and the individuals cover a larger area. This Reference condition is typical of riparian scrub vegetation composed mainly of large shrubs and small trees which form dense thickets allowing less space for the co-existence of early successional species (McDonald, 1988; Reinecke et al., 2007; Taylor, 1978).

In burnt plots, species richness and diversity were comparable to that of the Reference condition, at the plot scale. Although pre-fire biomass was not measured in this study, changes in soil properties and damage to soil-stored banks (caused by an increase in fuel load and therefore, hotter fires) could be a cause for poor species richness measured at the quadrat scale. Similar effects for species richness reduction have been reported from Ponderosa pine plantations, where slash piles are accumulated and burnt (Korb et al., 2004). This suggests that fires should be avoided where unnaturally high fuel loads are present (Breytenbach, 1989). Although most fynbos seeds are dependent on fire, burning intensity is important as fires that are too hot, or not hot enough, will affect seedling recruitment accordingly (Holmes, 2001).

3.4.3 Species composition

Riparian vegetation of the Fynbos Biome is often fairly similar in composition, as few species that make up successional communities occur throughout the region (Taylor, 1978). This is supported by the close association of Reference plots in the ordination. This pattern is not seen in cleared plots, where differences in species composition may be associated with the clearing treatment. However, the overlap in ordination space of cleared and Reference plots, in particular the Fell & Remove treatment, suggests that riparian zones are capable of recovery following alien clearing. Scrutiny of species composition for Reference plots and those cleared plots overlapping with Reference indicates a similarity of common indigenous riparian scrub species, such as *Metrosideros angustifolia* and *Brabejum stellatifolium.* Additional species to those found in Reference plots (Table 3.7) were *Athanasia trifurcata*, *Metalasia muricata* and *Chrysanthemoides monilifera*. These Asteraceous species are likely to be dispersed by wind and birds from the surrounding fynbos landscape. Their germination is likely to be dependent on the availability of vacant land as none of the species were found in the Fell Only treatment, where space is occupied by the slash cover.

The species composition of burnt plots differed most from the Reference condition, even though some plots had been cleared for more than five years. Although species richness and vegetation cover were similar to that of the Fell Only treatment, burning in the riparian zone clearly alters species composition. An increase in pioneer species (*Asteraceae* and *Poaceae*) is partly responsible for composition shifts. Plots along the Viljoens, Hout and Hoeks Rivers received repeated fire within a short interval (<5 years), where five year old vegetation was burnt. It is known that frequent burning of terrestrial fynbos eliminates seed producing shrubs, altering composition of vegetation (van Wilgen, 1981). However, similar compositional shifts are seen along the Jakkals and Mitchells Pass Rivers where plots were burnt only once. These results are contradictory to those found by Harms and Hiebert (2006) in the southern USA where they found no significant difference between the clearing methods of burning or not burning for both species richness or vegetation composition. The succession of terrestrial fynbos communities is triggered by fire and is relatively constant following the initial post-fire flush of annuals, geophytes and pioneer species (Bond and van Wilgen, 1996). Although fire does play an important role in structuring riparian communities (Taylor, 1978), the extended absence of late-successional species in the burnt plots sampled, indicates a disruption to processes promoting recovery.

The Fell Only treatment, based on species composition, could be seen as a viable method to remove alien vegetation, as there is relatively high overlap of the cleared plots with the Reference. Clearing costs are also lower owing to slash not having to be removed. However, low species richness and vegetation cover associated with Fell Only treatments suggests that this treatment could be improved on. Further research is probably required to explain the variability in results and the effects of slash on recruiting species that sometimes results in poor recovery following this treatment. Excess slash on riparian banks also increases the potential for higher economic and environmental costs, as slash being washed downstream in floods could cause logjams, destabilization of banks and damage to bridges. A compromise may be to remove slash above 1:20 year flood lines, or stack on sandbars and burn before the rainy season flows submerge the sandbars (Holmes, et al., 2005).

Since all cleared plots had follow-up treatments using herbicide, the notion that increased herbicide reduces the species richness of cleared areas could not be tested. However, critics of the Working for Water programme feel that unregulated herbicide treatments, following alien clearing, kills regenerating indigenous species (Parker-

Allie et al., 2004). The results indicate that continued follow-up is important to give the indigenous community a chance to recover. As seen in Figure 3.5, older plots that have had numerous follow-ups also overlap with the Reference condition more than plots that have not had regular follow-up treatments. It can only be recommended that follow-up treatments take indigenous vegetation into consideration, reducing the threats of overuse of herbicides.

3.4.4 Environmental variables

Although riparian zones are known for their heterogeneous habitats as a result of lateral and longitudinal variations in geology, geomorphology and hydrology (Gregory et al., 1991), this study revealed no correlation between geology and species composition of cleared riparian sites. This is in contrast to Prins (2004) who found geology to influence community composition in undisturbed fynbos riparian vegetation. However, in cleared alien vegetation in which aliens disrupt geomorphological processes, geological influences may be masked (Mack and D'Antonio, 1998).

An alternative hypothesis could be that the invasion of alien trees reduces the presence and potential recovery of rare or specialized species (Holmes and Cowling, 1997a, 1997b; Washitani, 2001), thus geological gradients will not be teased out by environmental analysis. Although altitude seemed to be an important factor, contributing to the clustering of Reference plots in ordination space, many riparian species are not restricted to particular altitudinal zones and could occur in any of the cleared plots (Goldblatt and Manning, 2000). Because of riverine degradation in the lowlands (Brown, 1998), intact riparian systems are most likely to be found higher up in the catchment area, where most protected areas are found. A recent study, however, revealed the poor conservation status of rivers and riparian areas, even higher in the catchment area (Nel et al., 2007). The presence of alien stands further degrades the status of riparian areas and reduces the propagule pressure of indigenous species required to seed downstream areas (Jansson et al., 2005; Richardson et al., 2007). Although many Reference plots were located at a higher altitude the proximity of these areas to cleared sites should be taken into account. For instance, the Palmiet River System reference plots were located 40 m above sea level, as upstream the riparian areas are affected by agriculture, dams and plantations. The propagule supply for cleared areas is likely to depend on surviving patches of indigenous vegetation higher up the catchment and where these are lacking, greatly reducing the natural recovery potential (Boedeltjie et al., 2004; Sedell et al., 1990).

The alien cleared plots were, for the most part, found at lower altitudes than the reference plots and at lower gradient reaches associated with increased deposition over erosion. Most of the cleared plots had an increase in % fine sand and soil depth. This needs to be investigated further to test the hypothesis that sediment gets trapped beneath alien *Acacia* species. This will have implications for the management of erosion within riparian banks. The complexity of riparian ecosystems goes beyond the variables measured in this study. It is possible that important environmental variables relating to the geomorphological or hydrological nature of the study areas were excluded from the analysis.

3.5 Conclusions

The clearing treatment had a significant effect on the recovery potential of indigenous vegetation, where the proportion of cleared plots that resulted in species assemblages most similar to the Reference condition is as follows: Fell & Remove (51.5%), Fell Only (39.2%) and Fell & Burn (27.3%). When taking species richness, diversity and indigenous vegetation cover into account, the Fell & Remove treatment proved to be the best clearing treatment to facilitate indigenous riparian recovery. Clearing treatments that overlap with the Reference can be accounted for by the presence of the dominant riparian scrub species, which survive both invasion and clearing. Common riparian scrub species within cleared plots that allow for overlap with the Reference condition include: *Brachylaena neriifolia, Metrosideros angustifolia* and *Brabejum stellatifolium.* Plots that lack these common riparian scrub species fall outside of the Reference group. In this study the Fell & Burn treatment had the most dissimilar species composition to Reference including an addition of species like *Chrysanthemoides monilifera* and *Athanasia trifurcata* and an abundance of *Cliffortia strobilifera, Ehrharta ramosa, , Helichrysum* species and *Rhus* species.

The removal of slash from the riparian zone is enough to promote the recovery of common riparian scrub species, whereas excessive slash and severe fires does not always provide the conditions for this to occur. Considering that riparian areas are dynamic landscapes and are primarily acted on by hydrological fluctuations, the time between extreme events could probably prolong the recovery of riparian areas (Boucher, 2002; Jansson et al., 2005). Therefore, given sufficient time and the continuation of follow-up treatments, it appears that most cleared plots can follow a trajectory towards recovery, especially where riparian scrub species has been protected from invasion and clearing. However, in some cases where riparian scrub species has been completely removed (e.g. after burning) plots as old as ten years have not yet managed to resemble the Reference condition. This indicates a potential decrease in the resilience in riparian areas following burning. However, further research on propagule dispersal and riparian scrub germination requirements is required before this statement can be fully accepted.

Unfortunately the limitation of national resources and the uncertainty surrounding future support for alien clearing requires immediate results regarding the recovery of cleared areas, to provide some biological resistance against further invasion. The level of recovery achieved thus far highlights the differences in indigenous vegetation response to a particular clearing treatment used, as not all cleared areas respond in the same manner. Alien species management has been shown to require specific treatments to effectively reduce the threat of the invasive species. However, the impacts of such should be factored in for what is required following the clearing of alien species. As our main assumption is the total recovery of cleared areas sampled, the results suggest that active restoration should be considered in areas where recovery appears to be protracted. This is similar to areas such as Sand Plain Fynbos, where low persistence of long-lived species in the soil seed bank of riparian ecosystems indicates the recovery of riparian areas cannot rely on the seed bank alone (Holmes, 2002; Vosse, 2007). It is, however, advised that natural recovery be given a chance prior to the initiation of any active restoration strategies. The shift in community composition for Fell & Burn plots suggests that burning with slash present sets the succession back by increasing the proportion of pioneer species present. The following chapter examines the vegetation structure and the presence of alien species within cleared plots in order to provide a better understanding of the recovery process.

Chapter 4. The impact of different alien plant clearing methods on vegetation structure, regeneration and dispersal modes in riparian zones

4.1 Introduction

Alien plant invasions in riverine ecosystems of the Western Cape are dominated by woody species, predominantly trees (Holmes et al., 2005). These alien trees are able to outgrow and shade indigenous vegetation, eventually eliminating sensitive species (Holmes and Cowling, 1997a). Dense alien vegetation can alter species and growth form composition as well as the overall vegetation structure of indigenous habitats (Holmes and Cowling, 1997a; Galatowitsch and Richardson, 2005). This is achieved through a disruption of processes that determine vegetation structure e.g. changes in light regimes and soil nutrient status, extent of flood disturbance, changes in seed input from surrounding sources and soil seed bank composition (Holmes, 2002; Petit and Froend, 2001; Vosse, 2007).

The Working for Water programme is tasked with the fundamental role of controlling invasive alien species, and it is assumed that indigenous species recovery occurs naturally. The ultimate success of the programme depends on restoring appropriate vegetation cover, in most cases, following alien clearing operations (Holmes and Foden, 2001). To date few studies have evaluated the work done by Working for Water, particularly in riparian ecosystems. Vegetation assessments should therefore determine whether natural recovery has succeeded in restoring indigenous components to the landscape. Where natural recovery is not possible, alternative means of recovery via active restoration should be considered (Wissmar and Beschta, 1998).

Vegetation recovery assessments, apart from considering diversity, also consider vegetation structure using growth forms (e.g. forbs, shrubs, trees) and regeneration modes, as these are useful in predicting the direction of plant succession within a community (see Holmes and Cowling, 1997a; Ruiz-Jaen and Aide, 2005; Toniato and Filho, 2004). The recovery of vegetation structure can be assumed to result in the appropriate delivery of ecosystem services (King and Hobbs, 2006).

Previous research on vegetation structure includes work done by Holmes (see Holmes, 2002; Holmes and Cowling, 1997a), who investigated terrestrial fynbos vegetation response to invasion. Their results showed dense invasion by alien plant species to have a negative impact on vegetation structure by reducing the coverage of certain guilds, and in some cases eliminating them completely. This approach was used to identify changes to vegetation structure in riparian ecosystems recovering from invasion, as well as to assess differences resulting from alien clearing treatments.

The aim of this study was to investigate recovery of growth form composition regeneration mode as well as to assess the natural recovery potential of sites cleared by different initial treatments. The null hypothesis, that all clearing treatments investigated result in recovery of indigenous riparian vegetation structure, was tested. In particular I asked the following questions: 1) How does vegetation structure of cleared sites differ from that of uninvaded reference sites? 2) Are there differences in clearing treatments with regard to growth form composition? 3) Do cleared plots have all the vegetation components which are necessary to initiate a trajectory towards recovery?

4.2 Methods

Within each plot, cover of indigenous perennial plant species was measured using an estimate of projected canopy cover, details of which are described in Chapter 3. Species cover within a plot was assigned to growth forms based on morphology and maximum height reached, as described by Goldblatt and Manning (2000). Species cover was separated firstly into four (broad) growth form classes then divided into eight (narrow) growth form classes to discern detailed differences among clearing treatments and Reference vegetation.

The broad growth form classes are forbs (herbaceous dicotyledonous plants), graminoids, shrubs and trees. The narrow growth form classes comprised forbs, graminoids (divided into restioids and other graminoids: including sedges, rushes and grasses), shrubs (divided into three height classes: <1 m shrubs, 1-2 m shrubs, and >2 m shrubs) and trees (divided into two height classes: 3-10 m trees and >10 m trees). It was decided that restioids (species belonging to the Restionaceae family) be separated from other graminoids, as they are an important descriptive feature of riparian zones in the Fynbos Biome (Taylor, 1978).

To understand height distribution of cleared areas, indigenous vegetation cover was assessed in four vertical strata (m): <0.5, 0.5-2.0, 2-5, >5. This was measured directly in the field and not corrected for individual species' potential maximum height. This variable was not measured in the Prins (2004) survey, which supplied the majority of data for Reference plots. Thus only Reference plots (n = 8) surveyed in this study could be used for comparisons with cleared pots (n = 78).

Indigenous species were further classified according to regeneration mode (resprouter, short-lived (<5 years) seeder, long-lived (≥5 years) seeder) and dispersal mode (wind, ant, passive, vertebrate, other) following Holmes and Cowling (1997b) and with the help of the expert knowledge of P. M. Holmes and T. Trinder-Smith. Values were obtained using the average cover of growth forms within each treatment adjusted to three significant figures.

The presence of alien vegetation was also considered in this chapter. The proportion of woody and herbaceous alien species cover was assessed and compared among clearing treatments.

4.2.1 Data analysis

Differences among groups were assessed using the Chi square (χ^2) statistic in contingency table analyses. The Chi square null hypothesis is that the relative frequencies for each growth form will be the same for each clearing treatment as compared to the Reference plots (Zar, 1996). Thus an equal distribution is expected for growth forms within each treatment. The analysis is used to show differences in ratios experienced for growth form composition within each treatment. It can also be used to show which growth forms are over- or under-represented or missing entirely from a treatment. The analysis compares observed values (as measured in different clearing treatments) to expected values (as measured in the Reference plots). The Reference plots are considered to be the "ecological" expected values against which cleared treatments are measured. Major alterations to growth form proportions will result in significant differences between clearing treatments and the Reference condition. The structure of the contingency table analysis allows for significance to be calculated for an individual clearing treatment (as shown in the table columns) and for individual growth form cover (as shown in the table rows) against the Reference condition. Regeneration and dispersal modes were also analysed using χ^2 analysis and compared to the Reference condition.

To explore further differences in growth form composition a Detrended Correspondence Analysis (DCA) ordination of growth forms was created using PC-Ord 4.0 (MjM Software Design, 1999) as described in Chapter 3. Changes to growth form composition over time was assessed by dividing the database into two groups, namely those cleared ≥5 years ago and those cleared <5 years ago. For each age group the average cover was calculated per growth form within a clearing treatment and represented as a proportion of the total cover.

4.3 Results

4.3.1 Vertical strata

Reference plots were well vegetated in all vertical strata and had >60% cover in each of the two strata below 2 m (Figure 4.1). Reference plots also displayed higher canopy cover in the >5 m stratum compared to their cleared counterparts. Of the unburned treatments, Fell Only plots had the lowest cover (<30%) in each vertical stratum while Fell & Remove plots were well vegetated up to 2 m (≈ 50% in each vertical stratum). Fell & Burn plots had 30-50% indigenous vegetation cover below 2 m with most cover occurring below 0.5 m. The tallest class was the most impacted by invasion and clearance as few large trees were present in cleared areas.

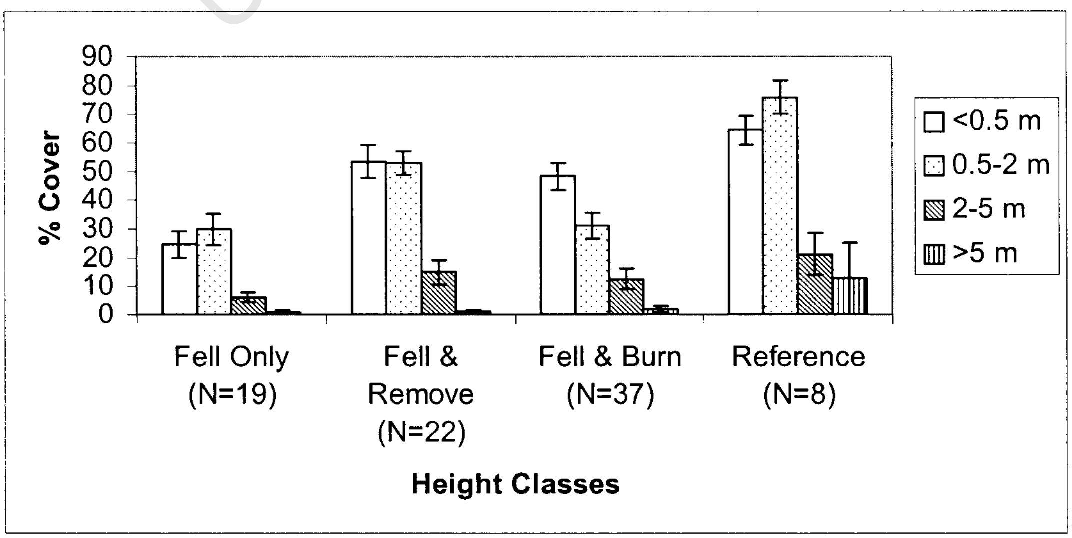

Figure 4. 1. Indigenous vegetation height structure (mean ± standard error) in four vertical strata for cleared and Reference plots

4.3.2 Broad growth forms

Species belonging to the four major growth forms were present in all cleared treatments, but the proportion of cover per growth form varied significantly among clearing treatments (Table 4.1 & Figure 4.2; χ^2 = 105.6 D.F. = 6, P<0.001). All cleared treatments displayed significantly different overall growth form proportions to that of the Reference values. However, there were no significant differences in the proportion of graminoid and shrub cover, whereas forb and tree cover were significantly different compared to the Reference condition. The unburned treatments (Fell Only and Fell & Remove) had higher forb cover than the Reference plots, while all clearing treatments had lower tree cover than the Reference plots.

Most growth forms occupied over 10% projected canopy cover, except for tree cover within Fell Only and forb cover within Fell & Burn and Reference plots. Within the Reference plots each growth form was exceeded by he next one, with trees having the highest cover. This pattern was not replicated in Fell Only and Fell & Burn treatments where shrub cover exceeded tree cover.

Table 4. 1. Average cover of broad growth forms per treatment analysed in a contingency table using the Reference as the expected values. χ^2 analysis was used to calculate difference in growth form proportions.

Growth form	**Clearing Treatments**				χ^2
	Fell Only	**Fell & Remove**	**Fell & Burn**	**Reference**	
Forb	16.2	11.8	2.96	5.08	33.9***
Graminoid	12.3	26.7	18.8	21.0	5.38 ^{ns}
Shrub	17.6	17.9	25.2	27.6	7.28 ^{ns}
Tree	6.56	33.2	15.2	46.4	58.9***
χ^2	65.7***	17.6***	22.3***		105.6***

Note: Degrees of freedom = 2 for rows and = 3 for column values, whereas the total degrees of freedom = 6. NS denotes Not significant; * denotes P < 0.05; ** denotes P < 0.01; *** denotes P < 0.001.

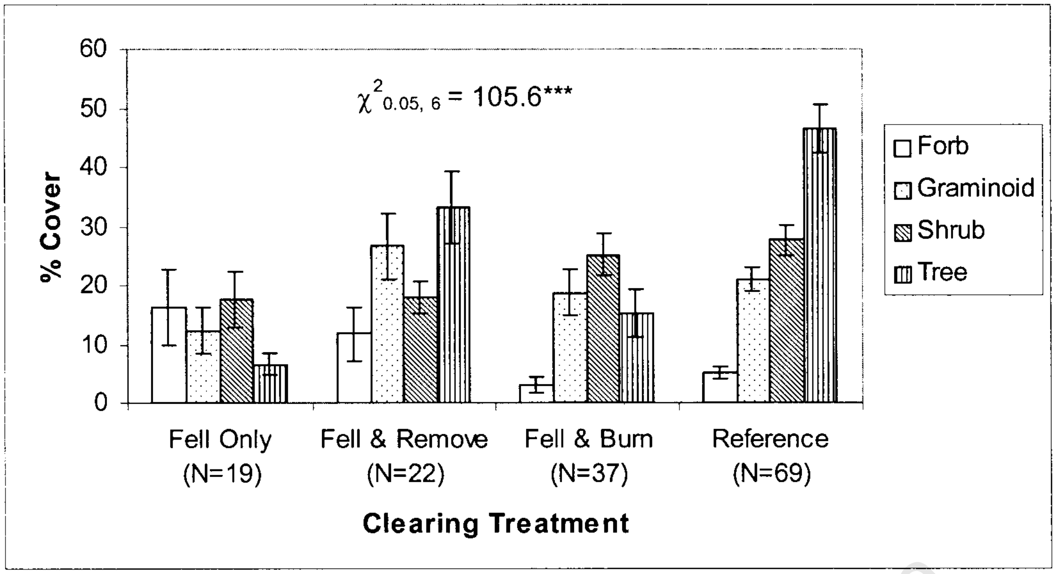

Figure 4. 2. Cover (mean $\pm$ standard error) of the broad growth forms in cleared and Reference plots. The χ^2 analysis was calculated using contingency tables with the Reference as expected values.

4.3.3 Narrower growth forms

The results from Table 4.1 were repeated by dividing the growth forms into eight classes (Tables 4.2 & 4.3, Figure 4.3). Varying proportions of species' cover were present within the eight growth form classes. However these were significantly different to the Reference (Table 4.2, Figure 4.3; $\chi^2 = 190.4$, D.F. = 14, $P<0.001$). The unburnt treatments had higher forb cover compared to Fell & Burn and Reference, and the latter two had similar cover of 1-2 m tall shrubs. The three prominent cover groups in Reference plots were: restioid, 1-2 m tall shrubs and 3-10 m tall trees. Restioid cover in the Fell & Remove treatment was not significantly different to the Reference plots, whereas the Fell Only and Fell & Burn treatments had considerably less restioid cover. The Fell & Burn treatment had an increase in other graminoids (namely *Poaceae* species), far exceeding the other clearing treatments (Table 4.2). Tree cover (3-10 m and >10 m) was lower in all cleared treatments compared to the Reference. Although the Fell & Remove treatment had the highest average cover (>30%) for 3-10 m tall trees, it also had the lowest cover among clearing treatments for >10 m tall trees. The Fell Only treatment had the lowest cover of 3-10 m tall trees. No difference was found for low and tall shrub cover between cleared and Reference plots.

Table 4. 2. Average cover of narrow growth forms for cleared and Reference plots analysed in a contingency table using the Reference as expected.

Growth form	**Clearing Treatment**				χ^2
	Fell Only	**Fell & Remove**	**Fell & Burn**	**Reference**	
Forb	16.2	11.8	2.96	5.08	58.11***
Restioid	2.64	18.5	1.12	16.2	25.72***
Other Graminoid	9.67	8.18	17.5	4.85	27.04***
<1 m Shrub	1.34	2.23	2.58	3.61	1.29 ^{ns}
1-2 m Shrub	8.32	9.77	16.7	17.4	14.99**
>2 m Shrub	7.95	5.93	5.88	6.75	1.53 ^{ns}
3-10 m Tree	3.51	31.8	13.1	40.0	53.10***
>10 m Tree	3.06	1.37	2.14	6.43	8.59*
χ^2	91.0***	36.6**	62.8***		190.4***

Note: Degrees of freedom = 2 for rows, and = 7 for columns where as the total degrees of freedom = 14. NS denotes Not significant; * denotes P < 0.05; ** denotes P < 0.01; *** denotes P < 0.001.

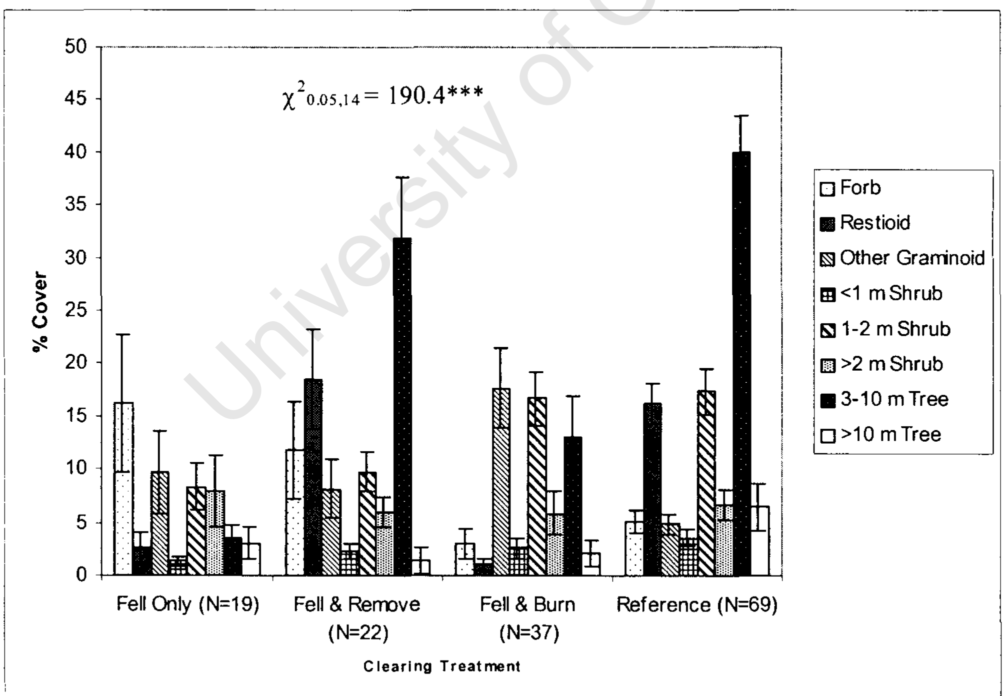

Figure 4. 3. Cover for narrow growth forms (mean $\pm$ standard error) in cleared and Reference plots. The χ^2 analysis was calculated using contingency tables with Reference as the expected values.

4.3.4 Alien cover

Alien species accounted for a larger proportion of cover in cleared plots compared to Reference plots, with <2% alien cover occurring in the latter (Table 4.3). The Fell Only treatment had the highest alien cover and highest woody alien cover among the cleared treatments (Figure 4.4). Fell & Burn plots had the lowest woody alien component whilst supporting the highest herbaceous alien species cover. Fell Only plots included both woody and herbaceous alien elements. On average the similar woody cover for the Fell Only and Fell & Remove treatments were significantly higher than the Fell & Burn woody alien cover. Fell & Remove treatments had significantly less herbaceous alien cover than Fell Only and Fell & Burn which also had the highest herbaceous alien cover.

Table 4. 3. Alien cover (mean ± standard error) for cleared and Reference plots.

Vegetation Variables	Fell Only	Fell & Remove	Fell & Burn	Reference
% canopy cover woody species	21.7 ± 6.18[a]	17.5 ± 4.24[a]	5.03 ± 1.25[b]	1.92 ± 0.50[b]
% canopy cover herbaceous species	7.87 ± 2.83[abc]	2.30 ± 1.57[a]	14.4 ± 3.73[bc]	0.05 ± 0.03[a]

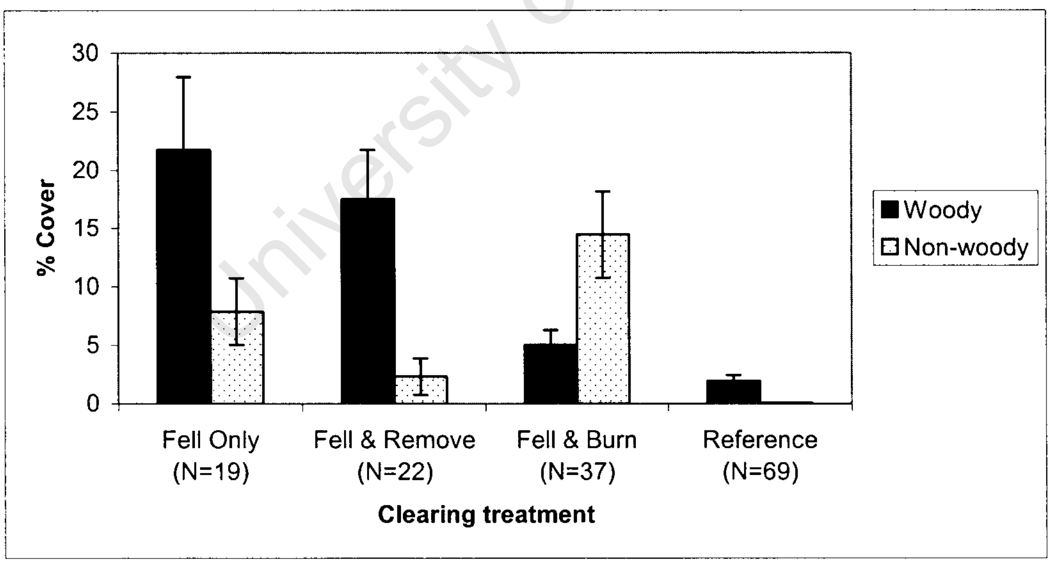

Figure 4. 4. Alien cover within each of the clearing treatments indicating proportions of woody and herbaceous aliens.

4.3.5 Regeneration and Dispersal mode

The relative importance of resprouters in riparian communities is indicated in Figure 4.5 as this guild had the highest cover in all treatments. However, regeneration guild structure in cleared plots differed significantly to Reference plots (Table 4.4; χ^2= 193.6 D.F. = 4, *P*<0.001). Long-lived obligate re-seeders were under-represented in cleared plots when compared to the Reference, with Fell & Remove having the highest cover of this guild among clearing treatments. Short-lived obligate re-seeder species comprised a relatively small proportion of vegetation cover in Reference riparian plots but this increased in Fell Only and Fell & Burn plots and decreased in Fell & Remove plots.

Passive dispersal was the best-represented dispersal mode in all treatments, including Reference plots (Table 4.5, Figure 4.6). All treatments had similar representation of wind dispersed species whereas ant dispersal was highest in Fell & Remove and Reference plots.

Table 4. 4. Regeneration mode (mean ± standard error) of indigenous vegetation for both cleared and Reference plots. The χ^2 analysis was calculated using contingency tables with Reference as the expected values

Regeneration mode	**Clearing Treatment**				χ^2
	Fell Only	**Fell & Remove**	**Fell & Burn**	**Reference**	
Reseeders short-lived	8.98	2.00	7.21	4.46	19.6***
Reseeders long-lived	11.07	28.9	21.5	38.1	7.64*
Resprouters	32.2	50.3	32.2	55.4	29.2***
	33.7***	4.03^{NS}	18.7***		56.4***

Note: Degrees of freedom = 2 for rows and columns where-as the total degrees of freedom = 4. NS denotes Not significant; * denotes P < 0.05; ** denotes P < 0.01; *** denotes P < 0.001.

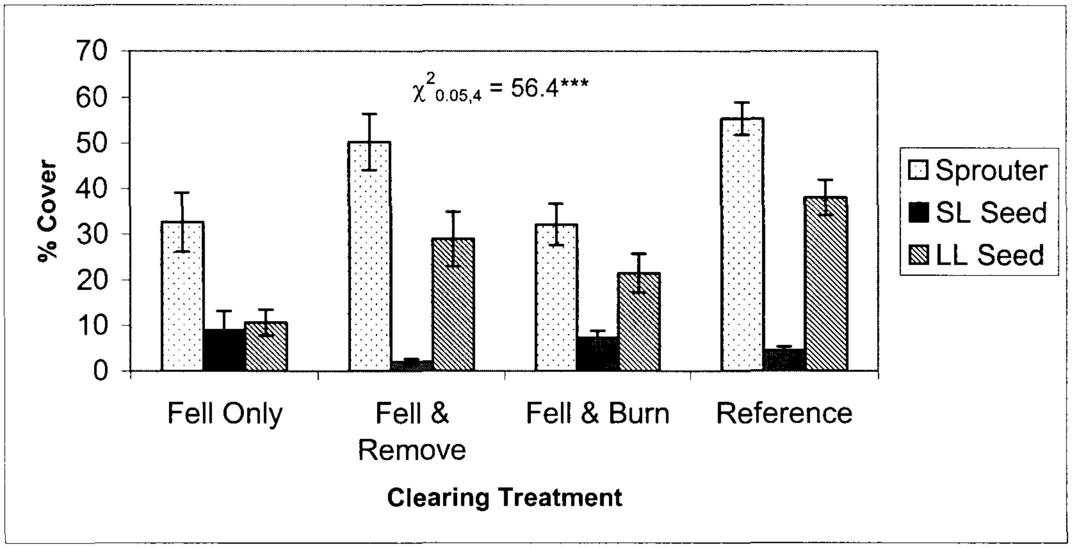

Figure 4. 5. Regeneration mode guild structure for cleared and Reference plots (mean $\pm$ standard error). Where: SL=short-lived obligate re-seeder ($\leq$4 years), LL=long-lived obligate re-seeder ($\geq$5 years).

Table 4. 5. Dispersal mode (mean $\pm$ standard error) of indigenous vegetation in both cleared and Reference plots. The χ^2 analysis was calculated using contingency tables with Reference as the expected values.

Dispersal mode	**Clearing Treatment**				χ^2
	Fell Only	**Fell & Remove**	**Fell & Burn**	**Reference**	
Wind	16.6	16.5	14.9	15.1	0.26^{NS}
Ant	1.70	9.89	4.45	8.93	8.20*
Passive	19.2	51.7	31.1	62.1	46.8***
Animal	12.9	4.01	12.6	8.07	7.42*
Other	2.41	11.7	9.15	22.3	31.2***
	56.3***	9.57*	27.9***		93.8***

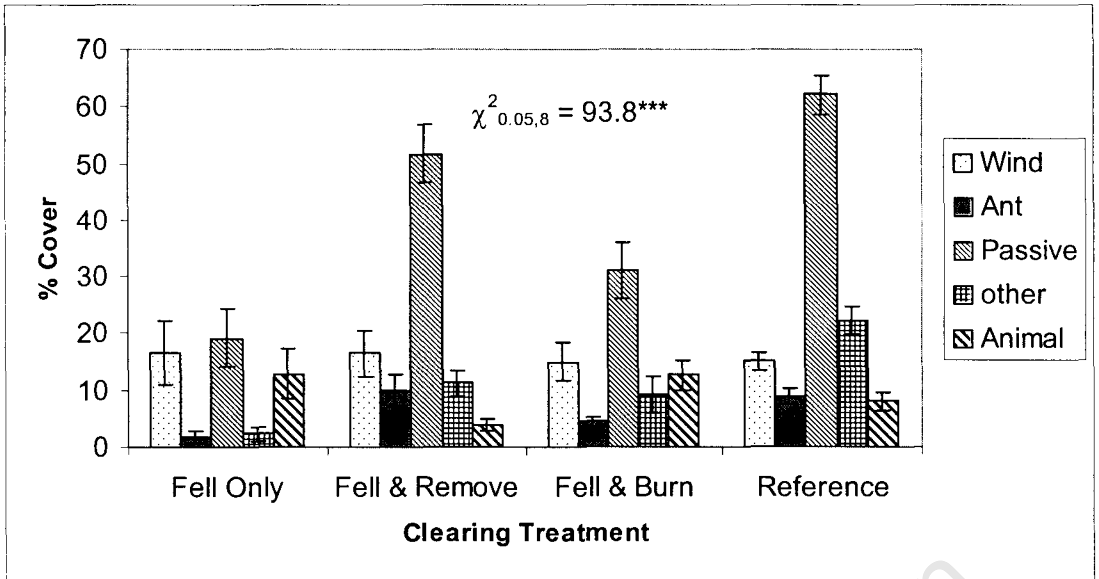

Figure 4. 6. Dispersal mode guild structure for cleared and Reference plots.

4.3.6 Growth form distribution

The DCA ordination was based on four broad growth form categories (Figure 4.7). Pearson's correlation revealed that graminoid and forb cover were correlated with axis 1 ($r = 0.594$ and $r = -4.99$ respectively) while shrubs and trees were correlated with axis 2 ($r = -0.538$ and $r = 0.524$ respectively). The total variance in species data was 2.18. The eigenvalue for axis 1 is 0.363 with a length of 2.8 while axis 2 is 2.77 with a length of 2.68. Axis 1 and 2 captured the variance in the data matrix as $r^2 = 0.408$ as described by relative Euclidean distance. There was good overlap between Reference plots and Fell & Remove plots. The majority of Fell & Burn and many of the Fell Only plots clustered outside the Reference group in ordination space.

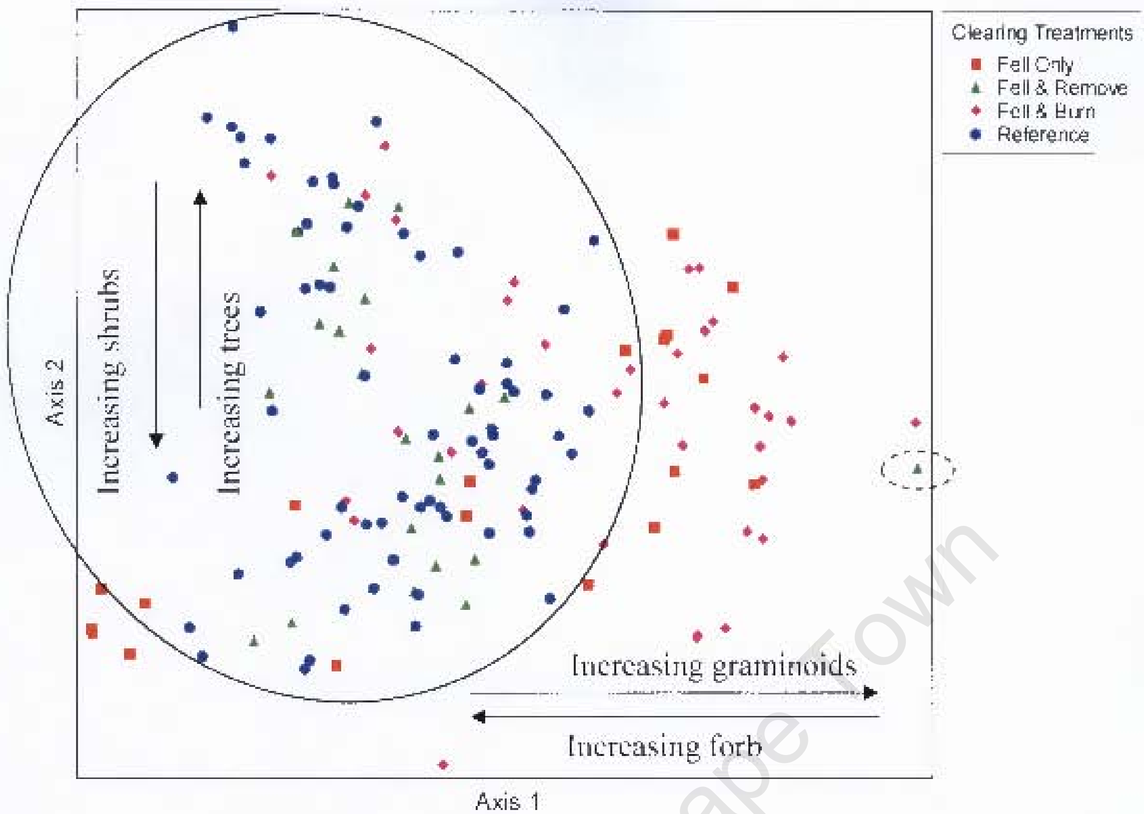

Figure 4. 7. DCA ordination depicting the relationship of plots as defined by broad growth form composition. Plots are grouped according to clearing treatment (see legend). The solid ellipse indicates the Reference plots while the dotted ellipse indicates one Fell & Remove outlier.

4.3.7 Age since clearance

Growth form distribution differed between older and younger cleared plots (Figure 4.8). Generally, vegetation cover was higher in older plots except for the Fell & Burn treatment where older plots exhibited slightly less vegetation cover than younger Fell & Burn plots. In young plots (<5 years) 21% (6 out of 28) were dominated by herbaceous cover, 21% by graminoid cover with small trees and medium shrubs dominating 14% (4 out of 28) and 10% (3 out of 38) respectively. In older plots (≥5 years) 34% (17 out of 50) was dominated by small trees, 18% by graminoids and16% (8 out of 50) by tall shrubs.

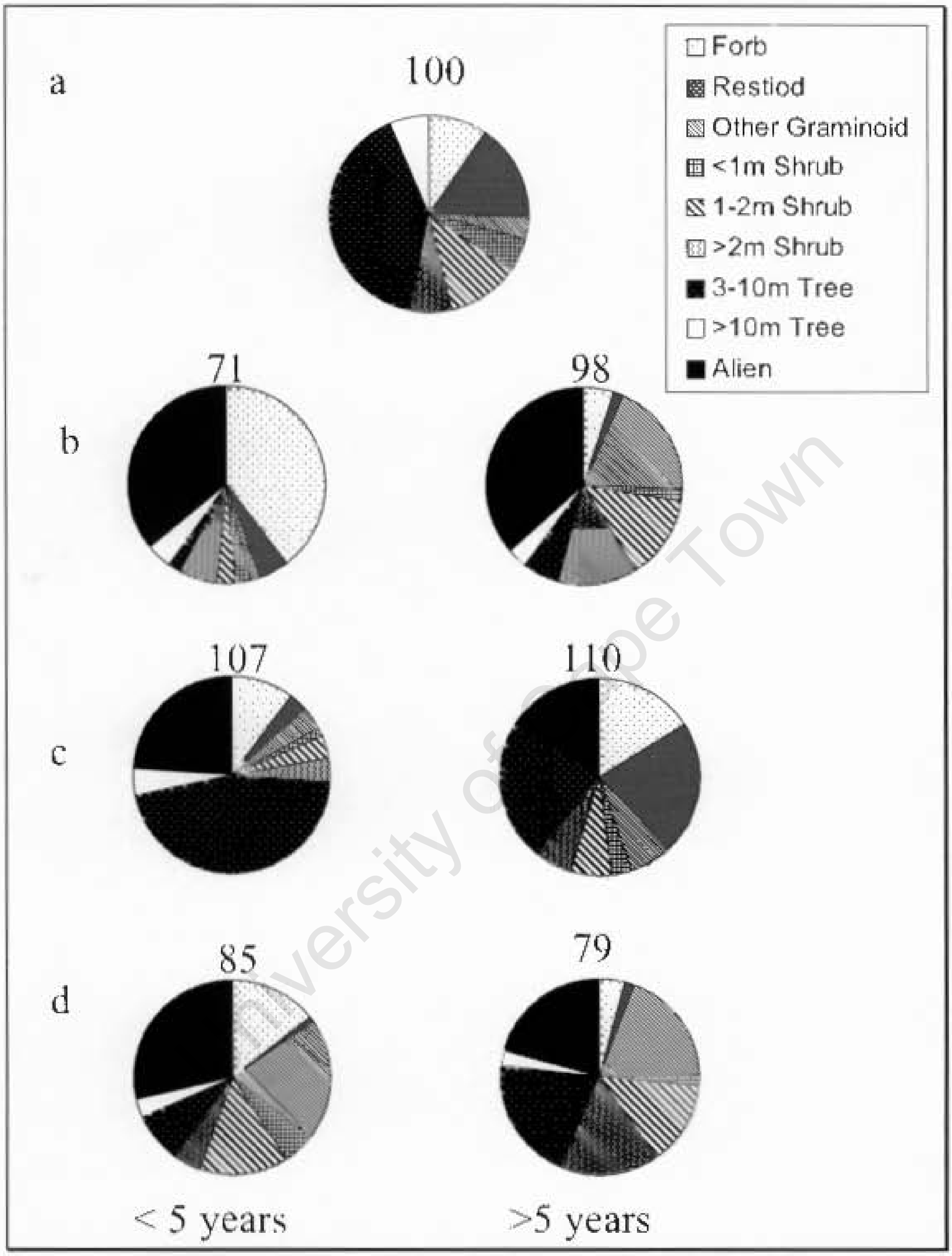

Figure 4. 8. Proportion of average growth form cover per treatment as divided into two age groups (<5 years & ≥5 years). The number above each pie chart indicates average total percentage canopy cover of all growth forms (including alien cover) for each treatment. a) Reference b) Fell Only c) Fell & Remove and d) Fell & Burn.

4.4 Discussion

4.4.1 Differences in vegetation structure between cleared and Reference plots

Although the Reference condition displayed variability in growth form composition among plots, reflecting the natural variation in structure within fynbos riparian vegetation (Taylor, 1978), vegetation height and cover of growth forms were generally higher than in cleared plots. Characteristic growth forms common to Reference plots, namely restioids, 1-2 m tall shrubs and 3-10 m tall trees, were present in cleared plots, but in different proportions. Cleared plots displayed a relative increase in the cover of forbs, non-restioid graminoids and shrubs, with varying degrees of 3-10 m tall tree cover. Reduced vegetation cover in each vertical stratum for cleared plots, especially above 2 m, confirms similar findings by Galatowitsch and Richardson (2005), indicating either that mature trees do not survive invasion (Holmes and Cowling, 1997a) or are cleared indiscriminately during clearing operations.

Taller vegetation can be expected for Reference plots, as increased vegetation cover allows the establishment of the taller, later succession species requiring a closed canopy for recruitment (Van Wilgen and Forsyth, 1992). Such species have Afromontane Forest affinity (Taylor, 1978). Although Afromontane Forest communities are most likely to be found upstream in fire-protected kloofs, some of their component tree species may occur in Fynbos Riparian Scrub after a sufficiently long fire-free interval (Taylor, 1978). However, the presence of this guild was negligible in cleared plots.

Of more relevance to vegetation recovery is the cover of 3-10 m tall trees, as this category contains the prominent riparian scrub species (e.g. *Brabejum stellatifolium, Brachylaena neriifolia, Erica caffra* and *Metrosideros angustifolia*) of the Western Cape (Galatowitsch and Richardson, 2005; Prins et al., 2004; Taylor, 1978). Reference plots contained the highest cover of this mainly resprouting riparian scrub guild (Prins et al., 2004).

4.4.2 Differences in vegetation structure among clearing treatments

Of all the treatments investigated, the Fell & Remove treatment resulted in a vegetation structure most similar to that of the Reference condition. The Fell & Remove treatment had the highest cover of indigenous riparian trees and was the only cleared treatment to contain restioid cover similar to that of the Reference. The removal of slash from cleared areas probably allows species to take advantage of disturbed and open conditions (Dickinson and Kirkpatrick, 1987). Without fire to stimulate germination of alien *Acacia* and other heat-pulse requiring indigenous species (Jeffery et al.,1998; Pieterse and Boucher, 1998), the species stimulated would most likely be those responding to sunlight or increased temperature at the soil surface (Brits, 1986). The possible reduction of alien seedlings following poor germination cues (i.e. burning) could give indigenous resprouting species a chance to recover. However, the large seed bank of alien species would still be present in the system as fires are important in killing buried seeds (Pieterse and Boucher, 1998). This is evident as a large proportion of alien species within Fell & Remove plots are woody and in most cases the target species of the initial clearing treatment.

In contrast, where slash is burnt (i.e. Fell & Burn), the heat pulse stimulates both indigenous and alien hard-seeded species to recruit immediately after the fire (Holmes and Richardson, 1999; Pieterse and Boucher, 1998). The ensuing Working for Water follow-up practice of foliar herbicide application would likely have a negative effect on any recruiting indigenous species. Also, the increased density and abundance of alien plants likely to germinate after a fire (Pieterse and Boucher, 1998) would trigger a 'blanket spray' herbicide treatment of cleared areas with indigenous species being killed in the process (Parker-Allie et al., 2004). An alternative explanation for changes in vegetation structure may be that high fire temperatures, resulting from unnaturally high levels of alien biomass, cause mortality in the indigenous soil-stored seed bank (Euston-Brown et al., 2002; Holmes and Marais, 2000). Fell & Burn plots are possibly on a different recovery trajectory as shown by the separation from Reference plots. The increase in graminoids and herbaceous cover is similar to Sand Plain Fynbos communities where *Poaceae* cover increased following burning, although this cover was expected to be short-lived (Hoffman et al., 1987). The same was found for mountain fynbos after a Fell & Burn treatment was used to clear alien vegetation (Holmes et al., 2000).

The Fell Only treatment had equally low cover among all growth forms. It was observed that residual slash from alien clearance may retard indigenous plant establishment. Similarly, excessive litter can inhibit indigenous seedling germination by increasing shading of soil to direct sunlight and thus dampening temperature fluctuations, as well as physically obstructing seedlings that do germinate (Friedman et al., 1996). In particular, the slash can hinder the recruitment of low shrubs and graminoids common on some riparian banks (Pieterse, 1997). Slash has also been observed to function as bird perches and can thus facilitate the recruitment of bird-dispersed species. Some evidence exists for this, as Fell Only and Fell & Burn (slash is left *in situ* before burning) treatments had higher average cover of bird-dispersed species than Fell & Remove, mainly attributed to increases in cover of *Rhus* species and *Diopspyros glabra*.

The results confirm differences in clearing methods used, similar to that of terrestrial studies by Parker-Allie et al. (2004) and Holmes et al. (2000). However, Harms and Hiebert (2006) reported no ecological difference between two removal techniques of Tamarisk from riparian banks by cutting or burning. They suggest the negative impacts created by Tamarisk invasion overrides the disturbance created by different clearing methods. Thus, poor recovery of indigenous vegetation and low vegetation cover of riparian banks will occur no matter which clearing method is used to clear alien vegetation. They also suggest that restoration plans should be included to promote recovery of indigenous vegetation.

4.4.3 Resilience of cleared plots

Species sensitive to invasion would likely be the first to be excluded from recovering areas unless they have long-lived persistent soil-stored seed banks (Galatowitsch and Richardson, 2005; Holmes and Cowling, 1997a). Although indigenous riparian seed banks can provide an initial ground cover post clearance, especially by herbaceous species (Vosse, 2007), the characteristic riparian scrub species (e.g. *Metrosideros angustifolia, Brabejum stellatifolium, Brachylaena neriifolia, Rhus angustifolia*) do not have soil-stored seed banks and rely on immediate germination following general dispersal mechanisms by water or vertebrates as described in other riparian surveys (Holmes et al., 2005; Johansson et al., 1996; Vosse, 2007). Also, Galatowitsch and Richardson (2005) reported that regeneration of indigenous riparian species was protracted due to invasion of alien species. In areas prone to varying degrees of disturbance such as riparian zones, persistent species such as resprouters tend to dominate (Bellingham and Sparrow, 2000). The importance of the latter was shown as resprouters made up the dominant canopy cover in Reference and cleared plots. This was apparent in areas where overall vegetation cover was low and the dominant cover belonged to resprouters (e.g. Fell Only plots).

Clearing treatments had an impact on the distribution of different life history strategies used by plants in riparian zones. Obligate reseeders, both long-lived and short-lived, appear to be compromised by increased slash cover as indicated by the lack of common reseeder species within the Fell Only treatment. Where these do occur they are scattered among a few plots or restricted to one location. In Fell & Remove plots slash removal increases the potential for reseeder recruitment. However, similar patterns occur as for the Fell Only treatment where reseeders are restricted to few locations and the resprouters are common throughout the treatment. Although burning was shown to reduce the overall height structure of riparian vegetation, this treatment also favoured the recruitment of reseeder species, especially short-lived reseeders. As for terrestrial fynbos ecosystems, fire-stimulated germination is a requirement for many species (Le Maitre and Midgley, 1992). However, the increase of fire ephemerals is usually short-lived. The overlap of species between riparian and terrestrial zones could account for the relative increase in reseeders as many belong to the *Asteraceae* and *Poaceae* families, both of which are prominent in fynbos vegetation.

Dispersal into cleared riparian areas is generally passive and regeneration after disturbance is probably a function of germination from the soil-stored seedbank, in combination with wind and animal dispersal. It is not known to what extent the role that water plays in seed dispersal of riparian species in the Western Cape, although some seeds are capable of floating for long periods of time (pers. obs). Although few seedlings were sampled in the drybank zone, some riparian tree species (e.g. *Metrosideros angustifolia*) were noted to germinate within the active stream channel on suitable substrata. This suggests that seedling establishment of some species is limited in the drybank zone by flooding of adjacent banks as well as by the availability of suitable habitat requirements. Terrestrial dispersal distances are short for fynbos species and their spread is driven by several fire cycles (Holmes and Richardson, 1999). Therefore, where riparian species are removed, opportunistic species with wind and animal dispersal will be favoured, as shown in the Fell & Burn treatment. However, these species might not have the desired attributes to increase biotic resistance to reduce future invasions by alien species. Pieterse and Boucher

(1998) found that graminoid growth forms, although dominant at the time, were not sufficient to reduce the threat of invading *Acacia mearnsii,* suggesting similar growth forms will offer the best resistance to invasion (Bakker and Wilson, 2004). Apart from surviving species, dispersal of propagules, distance to propagule source and potential of overbank flooding could hinder the recovery of the riparian zones. Further research is required to fully understand these dynamics.

Time since clearance does play an important role in the recovery of vegetation cover. These changes extend to changes in growth form composition, as proportions appear to change over time. Given that natural recovery usually requires longer than five years (Richardson and van Wilgen, 1992) the plots that do share features with Reference plots, such as the Fell & Remove treatment, suggest that this treatment facilitates recovery by minimizing additional disturbance. In practise, where Working for Water has only focused on reducing the biotic threat to riverine catchments, lowering the time taken for vegetation to recover is a major advantage in the battle against alien vegetation.

4.4.4 Alien vegetation

Although most of the cleared areas had received the required follow-up treatments (and many have received additional ones), alien vegetation was still present within cleared plots. The removal of alien vegetation has been acknowledged to be a difficult task. The large biomass generated by alien plants has posed a problem for managers. The removal of slash is often expensive and working in mountain catchments makes removal a difficult if not impossible task. However, observations that the removal of slash creates easier working conditions and ensures more effective follow-up control, is a motivating factor for slash removal. Excessive slash caused by previous clearing treatments inhibits the proper execution of felling techniques, as required by resprouting species, such as *Acacia mearnsii.* This can be seen in the Fell Only treatment having the highest woody alien cover of the three clearing treatments. In most cases this was due to previously felled plants being able to resprout below the slash piles. This is one important motivating factor for proper slash management within cleared areas, as resprouting alien species not effectively dealt with will cause further problems in the future. The removal of slash by burning (i.e. Fell & Burn) further stimulates the hard seeded Acacia seeds to germinate thereby reducing their soil stored seeds and increasing mortality (Holmes et. al., 2005).

Good initial control is an important factor as the efficiency of riparian scrub recovery could be delayed by renewed establishment of alien plant species (Galatowitsch and Richardson, 2005; Harms and Hiebert, 2006). Although woody alien species form the main target for Working for Water teams, following initial clearance, secondary invasion by herbaceous alien species potentially adds to the competitive exclusion of indigenous species (Holmes et al., 2005). The dynamic nature of riparian areas makes them suitable habitats for alien species to proliferate even while effort is made to remove them (Deferrari and Naiman, 1994; Zavaleta et al., 2001). This was highlighted in Fell & Burn treatments where the herbaceous alien species increased in abundance in place of the cleared woody alien component. Where alien grasses such as Kikuyu (*Pennisetum clandestinum*) invade following alien tree clearance, especially following burning, the regeneration niche may be usurped, further delaying vegetation recovery (Reinecke et al., 2007). Excluded from the analysis but recorded in a number of cleared plots, was the cover of alien annual grasses such as *Briza maxima* and *Paspalum urvillei*. These grass species dominate disturbed, especially burnt, riparian landscapes with great success. As a control tool for the burning of slash this is a great way to reduce woody alien numbers as reductions to the soil-stored seed bank are significant (Breytenbach, 1989; Pieterse and Boucher, 1997). However, the negative impacts of increased fire temperatures appear to set the succession back further than not burning.

4.5 Conclusions

Growth form analysis provides a means of examining the recovery of structural aspects of vegetation following alien clearance. This study rejects the null hypothesis that recovery of vegetation structure is uniform for all clearing treatments. Clearing treatments have different effects on indigenous vegetation recovery with regard to growth form, regeneration mode and dispersal mode when compared to Reference plots. Vegetation changes include a shorter cover of cleared plots which is also more sparse than when compared to reference plots. The absence of riparian scrub in some plots suggests that appropriate recovery is limited by the lack of recruitment of these species. Also, surviving riparian tree species should be protected from damage during clearance operations as this could potentially increase the rate of recovery at cleared sites.

Characteristic growth forms common to Reference plots (restioids, 1-2 m tall shrubs and 3-10 m tall trees) were present in most cleared plots, but in different proportions. Where the Fell & Remove treatment mirrored the Reference condition with regard to 3-10 m tree cover and restioids, the Fell Only and Fell Burn treatment increased cover of forb and non-graminoid species. The Fell & Remove treatment appeared to be most similar to Reference plots in structure, but this treatment still contained a high proportion of woody alien vegetation. The Fell & Burn treatment appeared to have reduced woody alien cover but succession appeared to have been retarded by the predominance of herbaceous cover, both alien and indigenous.

It is not clear how changes to vegetation structure may alter the delivery of ecosystem services, especially if the dominant riparian scrub species are missing. Managers should therefore concern themselves with the recovery of vegetation structure under the assumption that an intact vegetation structure results in the delivery of appropriate ecosystem services. Although burning proved to have negative impacts on vegetation structure, it is a favoured tool for managers in reducing excess biomass and the alien seed bank. The decision to burn or not should be linked to the conservation goals for the area, the outcomes of which greatly affect the nature of the riparian zone. Should alien reduction be the main priority then burning could be an option, provided excessive temperatures are not reached. Slash should be burnt when soil is wet to minimize heat transfer and damage to soil and indigenous seed bank. On the other hand should the restoration of biodiversity be a priority, the Fell & Remove treatment coupled with continued follow-up would be best to achieve this goal, provided excessive herbicide use is controlled.

Chapter 5. Conclusion and management implications

Riparian areas are generally prone to natural disturbance from hydrological fluctuations in the main riverine channel as well as to human-mediated transformation and are thus particularly susceptible to alien plant invasions. The linear nature of rivers allows them to act as conduits of energy, sediment and nutrients, all of which facilitates the spread of biological material, including alien species. In South Africa, particularly the Fynbos Biome, closed-stand invasions by alien *Acacia* and *Eucalyptus* species have been able to develop within riparian areas (Boucher, 2002; Galatowitsch and Richardson; Holmes et al., 2005). The negative impacts to water resources and biodiversity caused by invasive alien plants are being countered by the Working for Water programme (van Wilgen et al. 1998), which is responsible for managing alien species in order to protect the valuable ecosystem services provided by intact riparian zones.

The effects of invasive alien plants on terrestrial vegetation structure have been well documented by local and international researchers (Holmes and Cowling 1997a, 1997b; Vitousek, 1990; Hejda and Pyšek, 2006). However, South Africa has few studies of the impacts of alien plants on riparian systems that can compare to international research for similar ecosystems. Although acknowledged, alien plant invasion in riparian areas of the Fynbos Biome is poorly understood. Even more so is the response of indigenous vegetation to alien removal as well as the natural recovery potential thereof. Information was therefore required by the Working for Water programme regarding the effectiveness of the current clearing treatments used in riparian zones of the Fynbos Biome and their impacts on indigenous vegetation recovery. The results of this study are among the first to quantitatively examine riparian zones following alien clearing and report on the level of natural vegetation recovery. Although natural vegetation recovery attained from cleared areas has been variable, this study revealed few plots have recovered to the Reference condition.

What follows is a summary of the main findings of this study which are discussed in relation to their implications for management. One of the most important conclusions from this work is that the clearing treatment used can have a significant impact on the recovery of indigenous vegetation with regard to composition, species richness, growth form structure and vegetation structure. The impacts of both increased slash and burning within the riparian zone may compromise or prolong the recovery time of indigenous vegetation. The most important difference between cleared and Reference plots was in terms of their species composition. The loss of key riparian species (namely: 3-10 m trees, including, *Brachylaena neriifolia, Metrosideros angustifolia; and other fynbos scrub elements, including: Elegia capensis, Cannomois virgata, Berzelia lanuginosa, Leucadendron salicifolium, Erica caffra)* in some cleared plots is the main reason for their dissimilarity to Reference plots. The clearing treatment most dissimilar to the Reference condition was the Fell & Burn treatment. Although indigenous vegetation cover was not the lowest, the majority of burnt plots resulted in a species composition dominated by short-lived pioneer species, including wind-dispersed graminoids. Similarity to the Reference can be attributed to surviving common riparian scrub species which are able to co-exist with alien vegetation. Where key riparian species were removed, by invasion and clearing, the riparian zone is likely to remain in an altered vegetation state until natural disturbance regimes are able to influence species succession further. The method which best facilitates indigenous vegetation recovery, regarding species composition and growth form structure, was the Fell & Remove treatment. This method had the highest indigenous vegetation cover, similar species composition and growth form structure to that of Reference plots. Unfortunately the higher clearing costs associated with removing slash could make this method impractical in areas that are not easily accessible by road. The associated benefits of promoting vegetation recovery following clearing, including potential savings to costs in reduced follow-up treatments, could make the removal of slash a viable option in areas where active restoration is not feasible. The cheaper clearing option that Fell Only presents could be seen as a viable method to remove alien vegetation. However, this clearing treatment displayed mixed results and similar species composition, as defined by the DCA ordination, was noted in only a few of the cleared plots. This treatment is also associated with low indigenous vegetation cover, low species richness and high alien presence, possibly resulting from difficult conditions in which to conduct follow-up control operations (resprouting species, e.g. *Acacia mearnsii* and *Eucalyptus* species, cannot be felled close enough to the ground because of increased slash). The low vegetation cover and poor growth form representation associated with the Fell Only treatment suggests that this treatment could be improved upon. The presence of large slash piles provides a physical barrier to recovering and germinating species. The added dangers of runaway wild fires which burn the dried out slash under extreme weather conditions, could further reduce riparian recovery potential and is another reason for removing or reducing the slash left behind. It is surprising that the Fell & Burn treatment resulted in significant differences in composition to that of the Reference, since fire is the regulating feature of adjacent terrestrial fynbos vegetation. Therefore, avoiding fires of high severity, by decreasing slash, is important to reduce the mortality of newly recruited species able to re-establish within the slash.

Several alternative suggestions have been proposed regarding the management of slash from alien clearing operations (e.g. Holmes, 2001; Holmes et al., 2005). Thinning the stacks or stacking the slash out of the riparian zone could increase the chances of recovery or provide habitat for new species entering the riparian zone. Burning the slash on sandbars in the riverbed during low flow periods is another option that could be investigated. Reducing fuel by removing large logs would reduce the severity of any slash fires and facilitate decomposition of remaining slash. Where this is not feasible then burning during moderate weather conditions when the soil is wet should reduce damage to the soil and indigenous seed bank by minimizing heat transfer below ground (Department of Water Affairs and Forestry, 2005; Holmes and Marias, 2000). The benefits of burning following alien clearing have been well documented and these include: removing slash piles while reducing the alien seed bank by triggering *Acacia* seedlings to germinate (Pieterse and Cairns, 1986; Holmes et al., 1987). However, the altered state of the recovering community could be reason enough to reconsider burning in the riparian zone when fuel loads are large.

Where possible, surviving indigenous riparian scrub species should be protected from indiscriminate removal during clearing operations. The results indicate that most of the vegetation cover is made up by resprouting species. Thus in most cases it is assumed that the presence of riparian scrub vegetation in cleared plots can be related to resprouting individuals surviving both invasion and the clearing treatment. Like Fynbos in the lowlands, the low persistence of long-lived species found in the soil seed bank of riparian ecosystems indicates that the recovery of riparian areas cannot rely on the seed bank alone (Holmes, 2002; Vosse, 2007). Protecting the above-ground community from intense fires and the overuse of herbicide, usually following intense fires, should be made a priority. Changes to riparian zone species composition should be considered against the desired management objectives of the catchment, as this can influence the desired outcomes of conservation, water production or other anthropogenic requirements. An increase in short lived species is common following disturbance, however it is uncertain how long before riparian species are introduced especially after clearing. In all cases seeds that rely on passive dispersal, including water dispersal, contributed the most in all clearing treatments. Opportunistic species with wind and animal dispersal modes might easily enter the riparian zone but may not have the desired attributes to increase biotic resistance to reduce future invasions. The loss of dominant community species could result in a change to the ecosystem services provided by the current vegetation (Richardson et al., 2007). Long lasting changes to vegetation structure and composition, as seen in some of the cleared plots, are an indication of reduced resilience of riparian vegetation. The change in vegetation height following clearing and burning in particular, could suggest that riparian areas are prone to a threshold change from tall vegetation to low herbaceous cover (Hobbs and Norton, 1996). Active restoration in these areas generally results in greater costs and is ecologically more challenging (Hobbs and Norton, 1996; Holmes, 2002).

While this study covered many different areas within the Fynbos Biome it is still one of the first to tackle monitoring of Working for Water projects in riparian areas within the last ten years. Identifying realistic recovery goals for different situations, particularly in relation to vegetation type, river order and level of ecosystem degradation could only be achieved to a certain degree. The Working for Water programme aims to enhance sustainability of ecosystems by eliminating invading alien plants, thus enhancing ecological integrity (van Wilgen et al., 1998). The first step in the recovery process is to remove invasive alien species that occupy indigenous riparian communities (Wissmar and Beschta, 1998). On average each clearing treatment seemed to reduce the cover of woody alien species. However, the continued presence of alien species within recently cleared areas gives testament to the difficulty in completely removing invasive alien species. The focus of this thesis was to provide baseline information on the impacts of current clearing treatments used on the natural recovery potential of riparian zones. It was found that the clearing method used in the riparian zone is capable of having a significant effect on the recovery potential of cleared areas. Although the vegetation cover of cleared plots is still lower than the Reference condition, vegetation structure and species composition (of the Fell & Remove treatment) is similar and it appears that most plots are on a trajectory towards recovery. In order to improve the natural recovery process, the removal of invasive alien vegetation should not be seen as an end to itself. The clearing process should be included in a more holistic view of restoring ecological integrity to maintain longitudinal continuity of the catchment in order to protect the ecological functions and services, as well as meet human needs. By placing the cleared area within the context of its surroundings, realistic expectations can be sought from the natural recovery process. However, if the cleared area is isolated by further closed-stand invasion or severe landuse transformations, then active restoration techniques should be implemented in order to restore the riparian zone.

5.1 Recommendations for future research

This study revealed the importance of long-term monitoring especially in areas where natural recovery is expected to take place, such as the riparian areas of the Fynbos Biome. By prioritizing long-term monitoring, a more effective understanding of plant succession in riparian areas, particularly following alien clearing and in relation to wild fires can be achieved.

The influence of the surrounding landscape in supplying propagules is also likely to be important in influencing recovery rates (Galatowitsch and Richardson, 2005; Holmes et al., 2005; Petit and Froend, 2002). For example, riparian seed bank analysis by Vosse (2007) revealed that limited recruitment that can be expected from this source for the dominant riparian scrub species. Therefore, an improved understanding of the dispersal modes (e.g. water versus vertebrate), receiving environment and timing of dispersal events, as well as germination and establishment requirements, of key riparian scrub species is required. Additionally, the role of refugia and intact riparian areas as sources for propagule dispersal should be considered in areas where the poor conservation status of rivers and riparian areas have been highlighted (Nel et al., 2007).

This study also documents the change in vegetation structure from riparian scrub to low graminoid and herbaceous cover which could result in changes to ecosystem services (e.g. water quality) that might be associated with a loss of dominant riparian scrub species (Richardson et al., 2007). Further research in changes to ecosystem services and the need for active restoration should be carefully considered as this can be difficult and expensive (Hobbs and Norton, 1996; Holmes, 2002; Macdonald, 2004). Further studies are also required to investigate the impacts of secondary alien invasions on indigenous vegetation recovery. Where alien grasses such as Kikuyu (*Pennisetum clandestinum*) invade following alien tree clearance, especially following burning, the regeneration niche may be usurped, further delaying vegetation recovery (Reinecke et al., 2007).

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Appendices

River channel choked with *Acacia mearnsii*

Appendix 1: Species list used for this study including regeneration and dispersal modes and rank of species as classified by plots occupied.

			REGENERATION MODE			DISPERSAL				
FAMILY	GROWTH FORM	SPECIES NAME	SPROUTER	SL SEED	LL SEED	WIND	ANT	PASSIVE	ANIMAL	RANK
KIGGELARIACEAE	tree	*Kiggelaria africana*	√						√	122
ANACARDIACEAE	small tree	*Heeria argentea*	√					√		116
ANACARDIACEAE	tall shrub	*Rhus angustifolia*	√						√	6
ANACARDIACEAE	medium shrub	*Rhus laevigata*	√						√	80
ANACARDIACEAE	tall shrub	*Rhus lucida*	√						√	97
ANACARDIACEAE	tall shrub	*Rhus tomentosa*	√						√	78
APIACEAE	herb	*Centella sp.*	√				√			151
APOCYNACEAE	short shrub	*Cynanchum africanum*			√	√				107
ARACEAE	herb	*Zantedeschia aethiopica*		√				√		92
ASPARAGACEAE	medium shrub	*Asparagus rubicundus*	√					√	√	76
ASPARAGACEAE	short shrub	*Asparagus scandens*	√					√	√	86
ASTERACEAE	other	*Asteraceae sp.*		√		√				144
ASTERACEAE	medium shrub	*Athanasia crithmifolia*			√	√				161
ASTERACEAE	medium shrub	*Athanasia trifurcata*		√		√				29
ASTERACEAE	small tree	*Brachylaena neriifolia*	√			√				4
ASTERACEAE	medium shrub	*Chrysanthemoides monolifera*			√				√	22
ASTERACEAE	short shrub	*Chrysochoma sp.*		√		√				127
ASTERACEAE	medium shrub	*Conyza scabrida*		√		√				88
ASTERACEAE	short shrub	*Cullumia ciliaris*			√		√			32
ASTERACEAE	medium shrub	*Elytropappus rhinocerotis*			√	√		√		146
ASTERACEAE	medium shrub	*Euryops abrotanifolius*			√	√				47
ASTERACEAE	short shrub	*Helichrysum cymosum*		√		√				41
ASTERACEAE	herb	*Helichrysum patulum*		√		√				147

			REGENERATION MODE			DISPERSAL				
FAMILY	GROWTH FORM	SPECIES NAME	SPROUTER	SL SEED	LL SEED	WIND	ANT	PASSIVE	ANIMAL	Rank
ASTERACEAE	herb	*Helicrysum pandurifolium*		√		√				162
ASTERACEAE	tall shrub	*Hymenolepis parviflora*			√	√				102
ASTERACEAE	medium shrub	*Metalasia densa*			√	√				31
ASTERACEAE	medium shrub	*Osmitopsis asteriscoides*			√	√				73
ASTERACEAE	short shrub	*Osteospermum ciliatum*		√				√		159
ASTERACEAE	short shrub	*Plecostachys polifolia*		√		√				137
ASTERACEAE	short shrub	*Pseudognaphlium undulatum*		√		√				164
ASTERACEAE	short shrub	*Senecio burcehllii*		√		√				39
ASTERACEAE	short shrub	*Senecio pubigerus*		√		√				160
ASTERACEAE	medium shrub	*Stoebe cinerea*	√			√				15
ASTERACEAE	short shrub	*Stoebe incana*	√			√				156
ASTERACEAE	medium shrub	*Stoebe plumosa*	√			√				16
ASTERACEAE	short shrub	*Stoebe sp.*	√			√				133
ASTERACEAE	short shrub	*Ursinia paleacea*		√		√				74
BLECHNACEAE	herb	*Blechnum sp.*			√	√				111
BRUNIACEAE	medium shrub	*Berzelia lanuginosa*			√			√		12
BRUNIACEAE	tall shrub	*Brunia albiflora*			√			√		108
BRUNIACEAE	tall shrub	*Pseudobaeckia africana*			√			√		40
CELASTRACEAE	small tree	*Cassine schinoides*								37
CELASTRACEAE	small tree	*Maytenus acuminata*			√					53
CELASTRACEAE	small tree	*Maytenus oleoides*			√					89
CORNACEAE	tree	*Curtisia dentata*			√			√		125
CUNONIACEAE	tree	*Cunonia capensis*			√			√		36
CUNONIACEAE	tree	*Platylophus trifoliatus*		√				√		129
CYPERACEAE	graminoid	*Carpha glomerata*	√					√		46

			REGENERATION MODE			DISPERSAL				
FAMILY	GROWTH FORM	SPECIES NAME	SPROUTER	SL SEED	LL SEED	WIND	ANT	PASSIVE	ANIMAL	Rank
CYPERACEAE	graminoid	*Cyperaceae sp. 1*			√			√		58
CYPERACEAE	graminoid	*Cyperaceae sp. 2*			√			√		145
CYPERACEAE	graminoid	*Cyperaceae sp.3*			√			√		119
CYPERACEAE	graminoid	*Cyperus sphaeropermus*			√			√		130
CYPERACEAE	graminoid	*Epischoenus gracilis*			√					64
CYPERACEAE	graminoid	*Ficinia indica*	√				√			103
CYPERACEAE	graminoid	*Ficinia nigrescens*	√				√			77
CYPERACEAE	graminoid	*Ficinia oligantha*		√			√			95
CYPERACEAE	graminoid	*Ficinia trichodes*	√				√			149
CYPERACEAE	graminoid	*Ficinia zeyheri*		√			√			112
CYPERACEAE	graminoid	*Isolepis prolifer*		√				√		56
CYPERACEAE	graminoid herb	*Neesenbeckia punctoria*		√				√		55
CYPERACEAE	graminoid	*Pycreus polystachyos*		√						105
CYPERACEAE	graminoid	*Tetraria thermalis*	√					√		65
CYPERACEAE	graminoid	*Tetraria ustulata*	√							158
DENNSTAEDTIACEAE	herb	*Histiopteris incisa*		√						69
DENNSTAEDTIACEAE	herb	*Pteridium aquilinum*	√			√				5
DROSERACEAE	herb	*Drosera capensis*		√				√		152
DRYOPTERIDACEAE	herb	*Dryopteris inaequalis*		√		√				26
EBENACEAE	medium shrub	*Diospyros glabra*	√						√	2
ERICACEAE	short shrub	*Erica sp. 1-*			√			√		68
ERICACEAE	short shrub	*Erica - sp. 2*			√			√		57
ERICACEAE	medium shrub	*Erica caffra*			√			√		13
ERICACEAE	short shrub	*Erica closed*			√			√		114
ERICACEAE	short shrub	*Erica curvirostris*			√			√		109

			Regeneration mode			Dispersal				
FAMILY	**GROWTH FORM**	**SPECIES NAME**	**SPROUTER**	**SL SEED**	**LL SEED**	**WIND**	**ANT**	**PASSIVE**	**ANIMAL**	**Rank**
ERICACEAE	short shrub	*Erica hirtiflora*			√			√		153
ERICACEAE	short shrub	*Erica inconstans*			√			√		44
ERICACEAE	medium shrub	*Erica sphaeroides*			√			√		134
EUPHORBIACEAE	medium shrub	*Clutia pulchella*	√							79
FABACEAE	short shrub	*Otholobium decumbens*			√			√		154
FABACEAE	tall shrub	*Podalyria calyptrata*						√		38
FABACEAE	tall shrub	*Psoralea aphylla*			√			√		67
FABACEAE	small tree	*Psoralea pinnata*			√			√		19
FABACEAE	tree	*Virgilia oroboides*			√			√		60
GERANIACEAE	short shrub	*Pelargonium cucullatum*			√					124
IRIDACEAE	short shrub	*Nivenia corymbosa*			√			√		33
JUNCACEAE	herb	*Juncus capensis*		√				√		94
JUNCACEAE	herb	*Juncus effusus*		√				√		93
JUNCACEAE	herb	*Juncus lomatophyllus*		√				√		48
JUNCACEAE	herb	*Juncus punctorius*		√				√		106
LAURACEAE	herb parasite	*Cassytha ciliolata*			√			√		28
LAURACEAE	small tree	*Cryptocarya angustifolia*								101
CAMPANULACEAE	herb	*Lobelia setacea*		√				√		96
CAMPANULACEAE	herb	*Lobelia sp.*		√						150
AIZOACEAE	short shrub	*Carpobrotus edulis*			√				√	72
MYRICACEAE	small tree	*Morella serrata*	√		√			√		23
MYRSINACEAE	tall shrub	*Myrsine africana*	√					√	√	104
MYRSINACEAE	tree	*Rapanea melanophloeos*			√			√		81
MYRTACEAE	small tree	*Metrosideros angustifolia*	√					√		1
OSMUNDACEAE	herb	*Todea barbara*			√	√				75

			REGENERATION MODE			DISPERSAL				
FAMILY	**GROWTH FORM**	**SPECIES NAME**	**SPROUTER**	**SL SEED**	**LL SEED**	**WIND**	**ANT**	**PASSIVE**	**ANIMAL**	**RANK**
POACEAE	graminoid	*Aristida junciformis*			√					62
POACEAE	graminoid	*Poaceae sp. 1*		√		√				66
POACEAE	graminoid	*Cynodon dactylon*	√					√		24
POACEAE	graminoid	*Ehrharta erecta*	√				√			84
POACEAE	graminoid	*Ehrharta calycina*	√				√			54
POACEAE	graminoid	*Ehrharta longifolia*		√			√			135
POACEAE	graminoid	*Ehrharta ramosa*	√				√			8
POACEAE	graminoid	*Ehrharta thunbergii*		√			√			126
POACEAE	graminoid	*Eragrostis curvula*	√					√		50
POACEAE	graminoid	*Hemarthria altissima*		√				√		59
POACEAE	graminoid	*Merxmuellera cincta*	√						√	123
POACEAE	graminoid	*Pennisetum macrourum*		√	√	√		√		17
POACEAE	graminoid	*Pentameris thuarii*		√				√		132
POACEAE	graminoid	*Pentaschistis pallescens*		√				√		63
POACEAE	graminoid	*Pentaschistis sp.*		√				√		136
POACEAE	graminoid	*Phragmites australis*	√			√				42
POACEAE	graminoid	*Poaceae sp. 2*		√		√				30
POACEAE RESTINONACEAE	graminoid	*tiny multi spike restio*		√					√	87
PODOCARPACEAE	tree	*Podocarpus latifolius*			√				√	25
POLYGALACEAE	medium shrub	*Muraltia heisteria*			√					99
PRIONIACEAE	herb	*Prionium serratum*	√							10
PROTEACEAE	small tree	*Brabejum stellatifolium*	√					√		3
PROTEACEAE	tall shrub	*Leucadendron salicifolium*			√	√				14
PROTEACEAE	tall shrub	*Protea repens*			√	√				120
RESTIONACEAE	restioid	*Calopsis paniculata*			√					11

			REGERNARTION MODE			DISPERSAL				
FAMILY	GROWTH FORM	SPECIES NAME	SPROUTER	SL SEED	LL SEED	WIND	ANT	PASSIVE	ANIMAL	RANK
RESTIONACEAE	restioid	*Cannomois virgata*			√		√			7
RESTIONACEAE	restioid	*Elegia capensis*	√					√		9
RESTIONACEAE	restioid	*Elegia sp. 1*		√						115
RESTIONACEAE	restioid	*Elegia sp. 2*		√				√		140
RESTIONACEAE	restioid	*Hypodiscus aristatus*		√						121
RESTIONACEAE	restioid	*Ischyrolepis sieberi*	√				√			98
RESTIONACEAE	restioid	*Ischyrolepis sp.*	√				√			118
RESTIONACEAE	restioid	*Platycaulos callistachyus*			√			√		35
RESTIONACEAE	restioid	*Restio bifidus*			√			√		61
RESTIONACEAE	restioid	*Restio perplexus*			√			√		20
RESTIONACEAE	restioid	*Restio sp.*			√			√		71
RHAMNACEAE	medium shrub	*Phylica oleaefolia*	√				√			113
RHAMNACEAE	medium shrub	*Phylica spicata*	√				√			70
ROSACEAE	medium shrub	*Cliffortia atrata*			√			√		142
ROSACEAE	medium shrub	*Cliffortia polygonifolia*			√			√		85
ROSACEAE	medium shrub	*Cliffortia ruscifolia*			√			√		21
ROSACEAE	medium shrub	*Cliffortia strobilifera*			√			√		18
RUBIACEAE	medium shrub	*Anthospermum aethiopicum*		√				√		148
RUBIACEAE	short shrub	*Carpococe spermacocea*		√				√		90
RUBIACEAE	medium shrub	*Galium tomentosum*		√				√	√	83
RUTACEAE	short shrub	*Agathosma betulina*	√		√		√	0	0	143
RUTACEAE	short shrub	*Agathosma sp*	√		√		√			100
RUTACEAE	tall shrub	*Empleurum unicapsulare*		√	√		√			45
SALICACEAE	small tree	*Salix mucronata*	√		√	√				34
SAPINDACEAE	tree	*Dodonaea angustifolia*			√	√				131

			REGENERATION MODE			DISPERSAL				
FAMILY	**GROWTH FORM**	**SPECIES NAME**	**SPROUTER**	**SL SEED**	**LL SEED**	**WIND**	**ANT**	**PASSIVE**	**ANIMAL**	**RANK**
SCROPHULARIACEAE	tall shrub	*Freylinia lanceolata*			√			√		43
SCROPHULARIACEAE	medium shrub	*Halleria elliptica*			√			√		82
SCROPHULARIACEAE	tree	*Halleria lucida*			√			√	√	52
SCROPHULARIACEAE	medium shrub	*Oftia africana*	√					√		91
THYMELAEACEAE	medium shrub	*Gnidia oppositifolia*			√			√		141
THYMELAEACEAE	short shrub	*Struthiola sp.*			√					157
THYMELAEACEAE	medium shrub	*Passerina vulgaris*			√			√		27

Appendix 2: Summary of study site sampled in this study including treatment, clearing method, vegetation variables and soil attributes

Id	Latitude	Longitude	Site name	Clearing method	Sp. count	Vegetation cover	pH	Percentage sand			Soil depth (mm)
								FSAND	MSAND	CSAND	
1	-33.4217	19.26902	Mitch 1	Fell & Burn	10	95	4.5	50	31	17	436
2	-33.4208	19.26832	Mitch 2	Fell & Burn	9	75	4.7	22	21	55	631.2
3	-33.4201	19.27262	Mitch 3	Fell & Burn	17	70	4.6	40	43	15	564
4	-33.4196	19.27452	Mitch 4	Fell & Burn	13	97	4.7	20	32	46	790.2
5	-33.4198	19.27668	Mitch 5	Fell & Burn	10	90	4.4	18	38	42	870.6
6	-33.4203	19.27933	Mitch 6	Fell & Burn	9	40	4.8	13	30	55	72
7	-33.4206	19.28188	Mitch 7	Fell & Burn	10	78	3.7	23	57	18	694.4
8	-33.421	19.28383	Mitch 8	Fell & Burn	8	75	4.2	36	50	12	678.6
9	-33.4158	19.29085	Mitch 9	Fell & Burn	8	55	4.6	46	17	35	152
10	-33.4146	19.29057	Mitch 10	Fell & Burn	5	25	4.9	13	46	39	141
11	-33.5502	19.0452	Asbos 1	Reference	21	100	3.7	67	19	8	250
12	-33.5509	19.0458	Asbos 2	Fell & Burn	12	12	3.4	33	31	34	350
13	-33.5514	19.0462	Asbos 3	Fell & Burn	11	25	3.7	33	36	29	500
14	-34.2709	19.02208	Aries 3	Fell Only*	4	2	4.8	34	26	38	1001
15	-34.2714	19.022	Aries 2	Fell Only	15	35	4.2	46	32	20	1001
16	-34.2716	19.02192	Aries 1	Fell Only	20	75	4.1	37	25	36	1001
17	-34.2071	19.15918	Jakkals 1	Fell & Burn	8	50	3.9	72	18	8	1001
18	-34.2084	19.16087	Jakkals 2	Fell & Burn	6	98	4.1	46	21	31	429.6
19	-34.2087	19.16185	Jakkals 3	Fell & Burn	10	55	3.9	33	31	34	974.6
20	-34.2092	19.16288	Jakkals 4	Fell & Burn	16	75	3.9	38	21	39	768.4
21	-34.2095	19.16531	Jakkals 5	Fell & Burn	7	20	3.6	66	27	5	1001
22	-34.2096	19.16721	Jakkals 6	Fell & Burn	6	3	3.8	73	17	8	1001
23	-34.2104	19.16869	Jakkals 7	Fell & Burn	10	58	3.9	70	24	4	616.2
24	-34.2111	19.17009	Jakkals 8	Fell & Burn	8	12	4	61	32	5	1001
25	-34.2098	19.17771	Jakkals 9	Fell & Burn	17	40	4.4	34	31	33	384.8
26	-34.2094	19.17419	Jakkals 10	Fell & Burn	7	60	4	69	21	8	1001
27	-34.208	19.17699	Jakkals 11	Fell & Burn	5	50	4.8	23	23	52	1001

Id	Latitude	Longitude	Site name	Clearing method	Sp. count	Vegetation cover	pH	Percentage sand FSAND	MSAND	CSAND	Soil depth (mm)
28	-34.2087	19.17314	Jakkals 12	Fell & Burn	9	45	4.7	53	12	33	784.4
29	-34.2081	19.17461	Jakkals 13	Fell & Burn	9	65	4.4	44	37	17	376.6
30	-33.5563	19.1512	Wit 2	Fell & Remove	16	65	3.5	19	41	38	326
31	-33.556	19.152	Wit 3	Fell & Remove	17	75	3.5	34	42	22	1001
32	-33.5547	19.1533	Wit 4	Fell & Remove	12	80	3.9	4	40	52	764.4
33	-33.5535	19.15584	Wit 5	Fell & Remove	11	75	3.5	34	41	23	934.4
34	-33.3603	19.10246	Waterval 1	Fell & Remove	23	100	3.6	16	27	55	636.2
35	-33.356	19.10198	Waterval 2	Fell & Remove	25	98	3.6	17	38	43	555
36	-33.3581	19.10199	Waterval 3	Fell & Remove	19	85	3.6	18	28	52	970.8
37	-33.355	19.10261	Waterval 4	Fell & Remove	18	70	3.6	33	29	36	766.2
38	-33.3549	19.1032	Waterval 5	Fell & Remove	13	60	3.5	53	18	27	911.8
39	-33.3635	19.10168	Waterval 6	Fell & Remove	10	50	3.6	23	38	37	906.6
40	-33.3628	19.1029	Waterval 7	Fell & Remove	25	65	3.7	14	29	55	584
41	-33.3618	19.10301	Waterval 8	Fell & Remove	27	40	3.6	19	23	56	890.6
42	-33.3728	19.09764	Rwat 1	Reference	12	95	3.8	16	19	63	460
43	-33.3726	19.09783	Rwat 2	Reference	26	35	3.7	24	31	43	548
44	-34.1005	18.9342	Lowry 1	Fell & Burn	18	35	3.8	40	27	31	93
45	-34.0988	18.93688	Lowry 2	Fell & Burn	21	50	4.6	36	22	38	213
46	-34.0962	18.94041	Lowry 3	Fell & Burn	22	30	4.3	59	24	15	601
47	-34.0944	18.94602	Lowry 4	Reference	23	60	3.9	50	18	30	170
48	-34.0954	18.94252	Lowry 5	Fell & Burn	15	25	3.7	65	19	14	916.8
49	-33.7116	19.19656	Molenaars 1	Fell & Remove	18	15	4.2	7	28	63	160
50	-33.7092	19.19768	Molenaars 2	Fell & Remove	16	55	4.2	37	56	5	239
51	-33.6997	19.22495	Molenaars 3	Fell & Remove	10	85	6.2	45	35	18	328
52	-33.6995	19.22614	Molenaars 4	Fell & Remove	10	75	4	7	20	71	200
53	-33.9587	19.80832	Hout 1	Fell & Burn	12	100	4.5	47	25	26	150
54	-33.9577	19.80846	Hout 2	Fell & Burn	11	90	4.6	56	28	14	1001
55	-33.9554	19.80861	Hout 3	Fell & Burn	14	50	5.1	20	50	28	620.6
56	-33.9761	19.81792	Rhout 1	Reference	9	80	4.1	3	40	55	1001

Id	Latitude	Longitude	Site name	Clearing method	Sp. count	Vegetation cover	pH	Percentage sand			Soil depth (mm)
								FSAND	MSAND	CSAND	
57	-33.9773	19.81838	Rhout 2	Reference	10	95	3.9	30	29	39	431.2
58	-33.9802	19.81948	Rhout 3	Reference	11	68	4.7	19	36	43	823.2
59	-33.9977	19.83792	Hoek 1	Fell & Burn	14	50	5.7	20	38	40	978.6
60	-33.9745	19.83761	Hoek 2	Fell & Burn	10	75	5.7	59	28	11	899.6
61	-33.9739	19.83708	Hoek 3*	Fell & Burn	4	2	5.7	40	38	20	62
62	-33.9834	19.83746	Rhoek 1	Reference	8	95	4.6	21	50	27	276
63	-33.9777	19.83796	Hoek X	Fell & Burn	17	85	5	21	28	49	748
64	-33.9834	19.83781	Hoek 0	Fell & Burn	12	80	4.6	24	51	23	750.4
65	-33.3152	19.07566	Klein Berg 1	Fell Only	7	20	5.1	31	46	21	733
66	-33.3164	19.07719	Klein Berg 2	Fell Only	9	80	4.4	10	27	61	562.2
67	-33.3174	19.07854	Klein Berg 3	Fell Only	18	40	5.5	49	31	16	562.2
68	-33.3186	19.08907	Klein Berg 4	Fell Only	7	50	4.9	79	14	5	980.8
69	-33.3186	19.08907	Klein Berg 5	Fell Only	7	75	4.3	65	22	11	390
70	-33.318	19.08783	Klein Berg 6	Fell Only	10	40	4.6	18	18	62	344
71	-33.687	19.42836	Breede 1	Fell Only	6	7	4.9	94	2	2	1001
72	-33.6848	19.42274	Breede 2	Fell Only	7	10	4.7	66	17	9	1001
73	-33.6944	19.45148	Breede 3	Fell Only	10	20	5	29	39	30	1001
74	-33.6957	19.45292	Breede 4	Fell Only	4	35	4.3	42	39	17	836.6
75	-33.6965	19.45379	Breede 5	Fell Only	4	15	4.3	53	23	22	876.6
76	-33.6975	19.45476	Breede 6	Fell Only	9	17	5.2	51	41	6	548.2
77	-34.111	19.01856	Up5	Fell Only	6	35	3.2	47	34	17	888.8
78	-34.1104	19.01883	Up4	Fell Only	7	45	3.2	54	35	9	582.4
79	-34.1095	19.01776	Up3	Fell Only	8	20	3	84	12	2	814.4
80	-34.1095	19.01653	Up2	Fell Only	9	80	3.1	13	23	62	409.2
81	-34.1094	19.01545	Up1	Fell Only	10	85	2.8	91	2	3	722.6
82	-33.7201	19.09409	Du Toit -2	Fell & Remove	6	25	3.3	72	11	13	536
83	-33.7184	19.09317	Du Toit -1	Fell & Remove	14	50	3.7	40	36	22	290
84	-33.7181	19.09248	Du Toit 0	Fell & Remove	13	75	3.9	42	34	22	486.2

Id	Latitude	Longitude	Site name	Clearing method	Sp. count	Vegetation cover	pH	Percentage sand			Soil depth (mm)
								FSAND	MSAND	CSAND	
85	-33.7181	19.09211	Du Toit 1	Fell & Remove	21	65	3.9	34	28	36	314
86	-33.7167	19.0979	Du Toit 2	Fell & Remove	10	75	3.6	36	27	35	320
87	-33.7159	19.08998	Du Toit 3	Fell & Remove	6	78	3.9	54	17	25	496.2
88	-33.9311	19.17401	Viljoens 1	Fell & Burn	16	65	3.6	54	14	30	328

Note: * indicates plots sampled but excluded from the data analysis process.

Appendix 3: An experimental design for the aborted clearing experiment meant to coincide with the field survey.

An experiment was planned to corroborate the field work of sampling in cleared areas. A split plot experiment was designed to compare the differences between clearing methods and their impacts on initial establishment. The treatments tested would be Fell & Burn and Fell Only (slash removed or stacked). Within each split plot 3 different follow-up treatments would be tested namely: i) manual clearing, ii) foliar spray (seedlings and resprouts), iii) slash and stump treat (when seedlings are bigger). Replication would include a minimum of 5 plots per treatment (5x5m) with a minimum of 30 plots in total. The experimental site chosen was in the Wolvekloof valley in the Assegaaibos Reserve within the Berg River catchment area. A recently cleared riparian area was required approximately 82-100m long included 0.5m buffer between plots (Figure A3.1). Site preparation was planned for June 2005 with monitoring at the end of spring 2005, end summer 2006 and end spring 2007. Unfortunately the site could not be prepared in time for the experiment and was thus cancelled.

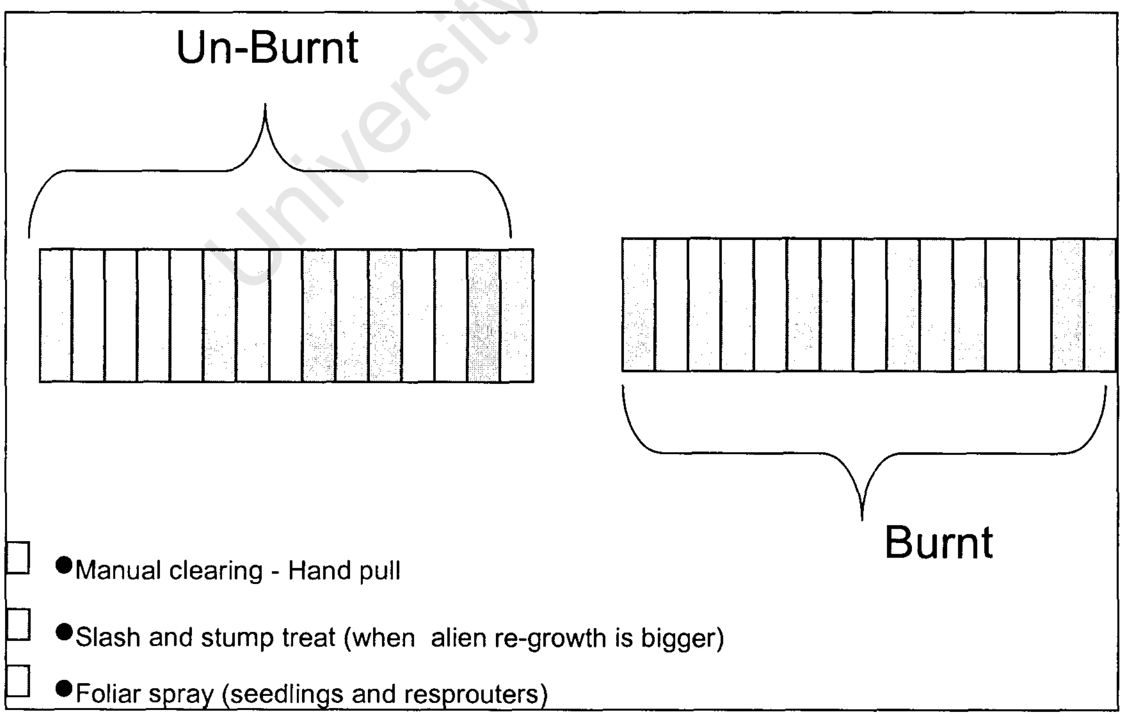

Figure A3. 1. Experimental layout of split design to be carried out in the Assegaaibos reserve.

Appendix 4: Preliminary findings of transplant and truncheon experiment

Introduction

Woody riparian plants have been known to establish via vegetative means following disturbance in many parts of the world, including in the fynbos biome of South Africa. Common riparian scrub species were chosen to test whether their establishment ability could be utilized to provide a method that would be easy to implement, with low costs, to increase indigenous cover and improve vegetation structure in recently cleared riparian areas. The rationale for this experiment follows previous work in heavily alien-invaded riparian zones requesting active restoration in recently cleared areas, as the recovery of key riparian species can be protracted. The experiment set out to explore several methods of establishing indigenous riparian scrub species in cleared areas. These methods included:

1) Transplanting seedling recruits of riparian scrub species from the wet bank (where they would be inundated and scoured by winter peak flows) (*Metrosideros angustifolia)*
2) Using truncheons (stem cuttings) from surviving riparian scrub plants
3) Planting seeds collected locally from surviving species.

Methods

The experiment was set up in July 2005 prior to the peak winter rains. Eight experimental plots were established on a recently cleared and burnt dry bank zone along the Berg River within the Assegaaibos Nature Reserve. *Metrosideros* seedlings were noted to be growing within the active water channel. These were removed and transplanted to the establishment site. Three prominent riparian scrub species namely, *Metrosideros angustifolia*, *Brabejum stellatifolium* and *Brachylaena neriifolia* were chosen for the stem cutting experiment and were taken from existing plants within the same catchment. Stems were cut 30 cm long and, where present, lateral branches were removed. A few leaves were left at the top of the stem. Immediately prior to planting stems were cut at 45 degree angle and dipped into a softwood rooting hormone. Stems were planted approximately 15 –20 cm deep. The diameter of each stake was measured at the onset of the study. At the time of setting up the experiment only *Brabejum* and *Brachylaena* seeds were readily available. Seeds were sown directly within the experimental area in line with the cuttings. Stems and seeds were planted in rows 1 m apart (n = 10 stems/species). For seeds, one Brabejum seed was placed every meter whereas Brachylaena seeds were placed in cluster of approximately 10 seeds per meter. Plots were set up and planted within one week according to Figure A4.1.

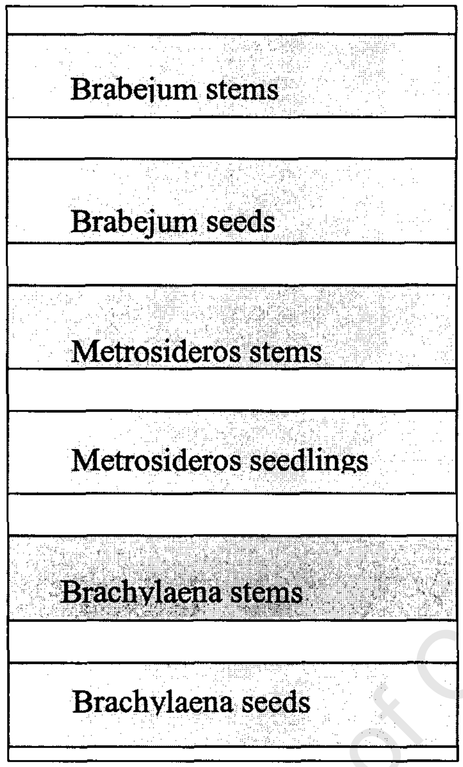

Figure A4. 1. Experiment layout of stems, seedlings and seeds in one of the 8 experimental plots.

Stake establishment was defined as both sprouting and rooting (Zahawi, 2005). A simple tug test was used to determine whether stakes had rooted. Seed germination was recorded as successful if the Brabejum seeds (inserted partially in the ground) showed signs of germinating. Brachylaena seeds were buried thus sprouts were expected to protrude from the soil. Monitoring of experimental took place in August and September 2005 before the experiment was cancelled. The analysis used to determine the survival of stakes and seed planted was a Chi Square test. This was used to calculate whether survivorship of stakes and seeds exceeded that of the expected value calculated.

Results

The *Metrosideros* seedlings died within 1-2 months of transplanting. Although some survived to the first monitoring stage they were all dead by the second. *Brabejum* seed had 50% germination within the period sampled. Some seeds were eaten by baboons as ascertained by removed seeds and chewed seed jackets left within the experimental plot and these were removed from the experiment design. No *Brachylaena* seedlings were noted to have germinated from the seeds planted after 2 months.

Table A1.1 Results of truncheon establishment. Missing = stems that have been removed, dead = stems with dead leaves, Buds =stems with new buds growing, No Change = (stems with no visible change)

Species Stems	Missing	Dead/No change	Buds	Rooted
Brabejum (n=80)	30	41	3	6
Metrosideros (n=80)	27	35	1	17
Brachylaena (n=80)	25	21	18	16

The survey results of cuttings for the three species are presented in Table 1. Chi square analysis of survival (buds + rooting) revealed the following: observed *Brachylaena neriifolia* was significantly higher than the calculated expected value χ^2=5.4, D.F = 1, P<0.05, observed *Metrosideros angustifolia* was not significant compared to the calculated expected (χ^2= 0.29, D.F = 1, P>0.05) and observed *Brabejum stellatifolium* was significantly lower than the calculated expected χ^2=7.6, D.F = 1, P<0.05).

Discussion and conclusion

The experiment showed some promising results whereby the species used had the ability to either sprout new buds or root within the soil where they were planted. However, *Metrosideros* and *Brabejum* truncheons did not perform well in the experiment: *Brachylaena* showed the best results and buds were noted to be growing on the stem cuttings. The winter peak flood mid July 2005 washed two plots away while the rest of the plots were damaged by flood waters. The rooted plants were not washed away. The damaged caused by the flood and baboon troops caused the experiment to be halted. Separate trials within smaller containers on campus revealed the *Brachylaena* stems to produce leaves before the stems died. Whereas *Brabejum* fruits planted in pots of soil grew readily without much requirements. *Brabejum* stems were also noted to have reprouted in field where mature plants had been accidentally felled.

All the species selected are usually grown from seed in indigenous nurseries, as they recognize the difficulty in using stem cuttings. Although, stems were planted within the riparian zone, distance to the active water channel could have affected the moisture content of the soil. This could have prevented budding stems and transplanted seedling from continuing to grow. Stem cuttings that were noted to do well were situated close to tufted grasses that probably provided shade or reduced the soil from drying out too much.

Transplanting *Metrosideros* seedlings that were able to germinate within the active water channel to the dry bank provided some important clues into the biogeography of riparian plants. Firstly, seeds are capable of germination provided they have suitable habitat. In this case riparian seeds germinated in moss patches on boulders and cobble within the active stream channel. Secondly, the conditions of the dry bank are not always suitable for germination of riparian species. Either the correct flooding regime and/or a suitable ground cover is required before riparian scrub species will establish.

These results are only reflective of one site and a short sampling period. The results are interesting in that at least one stem (out of 240) of each species was able to show signs of new growth. This needs to be investigated further and a longer experiment will fully determine the outcomes of using stem cuttings to propagate recently cleared riparian zones. However, based on these preliminary results, it appears that for the three species investigated, propagation from seed is likely to be more successful than from truncheons. *Brabejum stellatifolium* has been shown in another experiment to readily establish from fruits placed at the soil surface in the dry bank zone (Prins 2003). For the other smaller-seeded species some initial herbaceous cover may benefit establishment and this should be investigated further.

Reference:

Zahawi, R.A., 2005. Establishment and growth of living fence species: An overlooked tool for the restoration of degraded areas in the tropics. Restoration Ecology 13(1), 92-102.