Natural Rehabilitation Potential of Riparian Zones After Alien Clearing in the Fynbos Biome – Phase 1: A Reference Study of Indigenous Seed Banks

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Abstract

Riparian areas contribute significantly to the spread of many invasive species which alter the ecosystem and bring about significant water loss to the river system. These areas have therefore been targeted by many alien clearing programmes. Little attention, however, has been paid to rehabilitating these areas after clearing and the role that soil seed banks play in this process. This study aimed to assess the composition and viability of reference seed banks, to be used as a bench mark for conservation managers and landowners, when assessing post disturbance rehabilitation techniques. The focus was on soil seed bank composition of the riparian vegetation in four river systems within the fynbos biome of the south-western part of the Cape. Both mountain and foothill sections of the Eerste, Molenaars, Berg and Wit Rivers were sampled. Plots were located in relatively undisturbed fynbos/riparian areas, with less than 25% invasion. Two factors were taken into consideration when setting up the sampling plots, namely lateral (wet and dry bank) and longitudinal (mountain stream and foothill) zones.

Vegetation data were collected on site and contrasted with the seedlings that emerged from the soil samples to compare diversity and vegetation groupings. The seed bank composition was found to have little overlap with the current aboveground vegetation. The mountain stream slopes of all rivers were found to have a greater diversity within the seed bank, particularly so under the influence of past intermittent fires. On a lateral scale, the transitional zone between wet and dry banks was found to have a higher seed bank diversity with representatives of both riparian and fynbos species.

INTRODUCTION

The influence of man on his natural environment has been well documented. It is mainly through the movement of man between continents that has allowed for the spread of invasive plant species into new communities (Richardson per comm. 2005). Within southern Africa, the majority of problem plants have arrived from similar climates to ours (New Zealand and Australia) but in invaded territories the absence of their natural bio-control elements allows for their rapid colonisation (Richardson *et al.* 1992). The fynbos biome falls within a mediterranean climatic region with winter rainfall and summer drought. A combination of global warming, increased population numbers and rapid development has left this area with a serious water shortage for the majority of the year (November- March). Alien invasive plants impose greatly on the natural water table levels, removing large quantities from the water systems daily (Rowntree 1991, Galatowitsh and Richardson 2005). Additionally, these invasive species pose a major threat to the biodiversity and conservation of the Cape Floral Region, one of the countries key tourist destinations. In an attempt to curb these threats, various alien clearing initiatives have been started in recent years, from private to government, from local to national. River corridors have been significantly targeted to avoid the spread of propagules through water systems and increase the water availability (Richardson *et al.* 1997). The recruitment dynamics of the disturbed riparian areas within the fynbos biome needs to be further explored, in order to ascertain whether the main supply of new propagules for recolonisation comes from external sources, via water, wind or animal dispersal, or from *in situ* soil stored seed banks (Richardson and Galatowitsch 2004).

The seed bank is defined as 'a reserve of viable seeds, fruits, propagules and other reproductive plant structures in the soil' (Goodson *et al.* 2001). Seed banks reveal the history of lost vegetation; after destruction or disturbance of vegetation by fire, overgrazing, drought, flooding or vegetation invasion, seed banks play a role in natural regeneration (van der Valk and Pederson 1989). A study of seed bank composition assists in predicting the initial post recruitment vegetation. Seed bank data can yield information on three features of new vegetation: (1) the species composition, (2) the relative abundance of recently recruited species, and (3) the potential distribution of each species (Welling *et al.* 1988). Analyses of the compositional data of both the seed bank and aboveground vegetation can reveal which desirable species are lacking from the seed bank, and whether any undesirable species may become established. Rehabilitation is intended to return the lost functions of ecosystems following the clearing of invaded lands and a thorough understanding of the role of seed banks can be important for designing restoration projects (Richter and Stromberg 2005).

The pressures of invasive vegetation on the fynbos

The Cape Floristic Region (CFR) has approximately 9000 plant species in an area of less than 90 000km^2; 69% of these are endemic and more than 1400 are listed on the Red Data List of endangered species, making it one of the worlds richest regions in terms of botanical diversity (Goldblatt and Manning 2000). The CFR, although climatically similar other Mediterranean regions, is likened to that of tropical regions in terms of it's very high species richness; while in terms of it's high level of endemism, it is likened to floras of island habitats (Linder 2002). Several papers have distinguished the Cape Flora as completely unique in its high species diversity together with an incredibly high degree of endemism (Levyns 1964, Goldblatt and Manning 2000, Linder 2002,) Unfortunately, however, not all the statistics are favourable. To date, more than one-third of the original area occupied by fynbos has already been lost to agriculture and invasive alien species (Rouget *et al*. 2003). Invasive alien vegetation continues to plague the integrity of natural vegetation, not only in the sensitive CFR, but throughout South Africa (Richardson *et al.* 1997). The impact of invasive alien plants contributes significantly (if not entirely) to the disturbance and ultimate replacement of diverse natural ecosystems with species poor alien stands; to alterations of ecosystem functioning, more specifically, the soil chemistry, fire regimes, hydrology and geomorphological processes; and the possible extinction of localized plant and animal species as a result of the destruction of their habitats (Cronk and Fuller 1995, Richardson *et al*. 1997).

Within the fynbos biome where a unique range of geological, soil and weather conditions give rise to highly diverse, endemic and endangered plant communities and flora, these invasive stands place intensive pressure on the integrity of the community (Macdonald *et al*. 1988; Rebelo 1992; Richardson *et al*. 1992, Richardson *et al*. 1996). Several studies indicate that once invasive tree species become established, they grow at a higher rate and taller than fynbos species (Milton 1981, van Wilgen and Richardson 1985, Witkowski 1991, Holmes and Cowling 1997). Following one or two fire cycles they can form dense closed stands with reduced light penetration and altered nutrient cycling patterns, litterfall and fuel properties. These dense stands have a significantly high success rate of replacing fynbos vegetation and their impacts intensify with time since invasion and with lack of clearance action (Holmes 1998).

The deleterious effect of alien invasive species on indigenous seed banks has been widely reported. There is a significant reduction in indigenous seed-bank density and richness, as well as a change in both seed-bank composition and guild structure following the presence of invasive species (Macdonald and Richardson 1986, Holmes 2001). In older invasive stands, fynbos seed-banks are significantly smaller than the extensive seed banks of invasive species (Holmes 2001). It has been documented that soil seed banks contribute significantly to the regeneration of plant cover following a disturbance in many vegetation types (Musil and de Witt 1990, Holmes and Marais 2000) but relatively little research has focused on riparian zones. In light of these deficiencies, this research project was initiated.

The Working for Water Programme

The Working for Water (WfW) Programme has been clearing invasive alien plants from disturbed landscapes throughout South Africa, but significantly within riparian corridors. This programme was initiated in 1995 with the aim of improving and increasing both the quality and quantity of water production, and to conserve biodiversity (Van Wilgen *et al*. 1998). The aim of such clearance programmes includes the full recovery of the fynbos vegetation cover following alien removal yet a limited budget often results in unsatisfactory and inadequate results (Holmes 1998, Holmes 2001). Restoration that is found to be insufficient can result in soil erosion, loss of soil-stored propagules, poor water quality and the high risk of re-invasion by alien plant species (Holmes 2001).

Through the programme, data gathered over the years shows that the dominant guilds in the mountain catchments areas comprise of mainly *Hakea* and *Pinus* species. Occasional stands of mixed groupings occur, with resprouter species such as *Acacia mearnsii, Eucalyptus* species and *Leptospermum laevigatum* present (Holmes 1998). In such cases, it is vital to look for the best options for the specific catchment area and there are various control options available for each invasive species (Macdonald 2004, van Wilgen *et al*. 1992). Experience has revealed that control is best achieved when numerous complementary control methods (including biological, mechanical and chemical) are carefully incorporated into a fire management programme (van Wilgen *et al*. 1992).

In light infestations, the invasive species are slashed and the material is left to decay until the next fire. Any further seedling regeneration is removed prior to seed set. This approach has been found to be very successful if a systematic approach is maintained and it has little impact on fire intensities, soils and surviving fynbos vegetation (Holmes 1998). Dense infestations require a more labour intensive approach whereby stands are felled and left for 12 - 18 months to allow for seed release and germination. Soon thereafter, the site is burnt to kill off all alien seedlings and followed by regular visits at 1.5 - 2 year intervals to remove any invasive seedling recruitment. Although successful in many areas, this method increases the risk of fires as a result of the dry biomass left on site, which could have very negative effects on the indigenous recovery. Holmes (1998) recommends that felling be done outside the high risk fire period and that the dead biomass be burnt under cooler, wind-free conditions in situations where biomass levels are very high. This strategy allows for the possibility of geophytes and soil-stored seeds to remain undamaged, which are then able to initiate the vegetation recovery.

The Role of Fire in Revegetation Success

Within riparian areas fynbos elements appear, most especially within the dryer zones of the river bank where riparian vegetation meets the surrounding fynbos vegetation. Fynbos vegetation is known as predominately pyrophylic, or fire loving. These plants have adapted to the frequency of fire occurrence and have formed life strategies that are highly dependent on the fire regime (Cowling *et al.* 1997). Within this environment any slight alteration in the intensity, frequency and/ or season of the fire regime will potentially destroy many sensitive species. *Acacia saligna*, for example, threatens the natural vegetation in a variety of ways. This species has a large persistent seed bank that accumulates rapidly as a result of the prolific volumes of seeds set per flowering season. In addition, the seeds are long-lived unless stimulated to germinate by a disturbance, most especially fire (Holmes 1989). Such invasions can persist into the riparian vegetation and threaten the ecology of the area by increasing the chance and intensity of fire sweeping through the otherwise protected riparian zone. The temperature of the fire is greatly altered by the influence of alien plant species such as *Acacia saligna*. As a result of an increase in biomass, the fire is excessively fuelled causing temperatures to rise to the detriment of soil-stored seeds, micro-organisms and all fauna in and around the river system. High fire intensity may in turn affect soil surface temperatures, and fynbos seed mortality as well as germination response (Holmes 2002). The most common result following a high intensity fire is soil temperatures raised to such a degree that they damage the soil and cause seed mortality to a depth of 4cm or more (Holmes 1989). This destroys mainly the sensitive indigenous seeds that are generally concentrated in the upper 3cm of soil and promotes the robust recruitment from the alien invasive seed bank. An additional pre-adaptation of invasive species is that many are serotinous (seeds protected inside cones) and the seeds are released in large quantities after a fire (Holmes 2001). This adaptation is shared by many fynbos species, thereby stimulating severe competition in the critical germination period.

Despite negative effects associated with uncontrolled, intensely fuelled fires, the element of fire holds a very important role in the fynbos ecology and most fynbos species have germination inhibitors that require some aspect of the fire. Although not well documented, it is suspected that many riparian species react positively to fire (Holmes pers comm. 2005, Esler pers comm. 2005). Charate is the term given to the organic substances that are leached from heated or charred wood (Le Maitre and Midgley 1992). These substances stimulate the germination of many fynbos species. A combination of the breaking of allelopathic inhibitors, the increase in soil temperatures, and the chemicals released from the smoke or charate are all results of fires within the fynbos biome and stimulants have been finely tuned within each species to promote germination, and thus vegetation cover, after fire (Le Maitre and Midgley 1992).

The Ecology of Soil Seed Banks

Holmes (2004) found that seed bank composition in alien invaded stands indicates the potential for vegetation recovery, as well as the intensity of alien recolonization and it is therefore vital to incorporate the knowledge of the local succession cycle of fynbos plants when investigating the restoration potential of seed banks. The combination of seeds that accumulate in the soil allows for the succession of the variety of species within the fynbos biome and is a compounding attribute to the biodiversity of this region (Van Wilgen *et al* 1996, Musil 1991). Regeneration from soil seed banks is generally initiated by annuals and short-lived shrubs which provide soil stabilization and nutrient recycling into the soil. Within riparian areas however, large variation occurs as a result of the change in habitats between reaches (mountain stream to coastal plain) and moisture regimes (dry banks and wet banks) (see Appendix 1). It is therefore best to acknowledge that the succession cycle following a fire is unique to each habitat and is directly related to several environmental variables. A general table (Table 1) has been compiled for basic understanding of the succession time frames but should by no means be taken as static fact (Bond 1980).

Table 1: Succession Cycle of a Fynbos Community (Bond 1980)

PHASE	AGE	CHARACTERISTICS
Immediate post- fire	0-1(2) yrs	Seed germination, vegetative regeneration of almost all species. Various geophytes & most annuals reproduce only in this phase and replenish their soil-stored seeds immediately after flowering.
Transitional	3-10 yrs	All plants reach reproductive maturity and actively contribute to the seed bank, both above-and below ground. Tall shrubs emerge from the canopy and continue to grow, flower and generate seed production.
Mature	10-30yrs	Tall shrubs reach maximum height and maximum flowering activity. Seed regenerating low shrubs begin to die. Canopy becomes very dense. Virtually no seed germination. Litter accumulation & reduction in low herbaceous biomass. Veld in need of a fire to regenerate.
Senescent	30-60yrs	Mortality of seed regenerating shrubs accelerates. Foliage reduced to tufts on tips of branches, crowns become open. Litter and dead shoots continue to accumulate. Tall shrubs collapse with branches drooping downwards. Rare seed regeneration in open spaces

Seed bank formation can be divided into two main groups, those species that form transient seed stores (seeds only remain viable for one year), and those that form persistent seed banks (seeds remain viable for more than one year) (Warr *et al*. 1993). The transience or persistence of seeds in the soil is part of the regeneration strategy adopted by the species (Murdoch and Ellis 2000) and many of the fynbos species actually fall between these two groups offering both transient and persistent seed banks. These species have the potential to use both sprouter and seeder mechanisms of reproduction depending on environmental conditions (Parker and Kelly 1989, Cowling *et al* 1987). In California's chaparral vegetation (a comparative climatic area to the fynbos), Parker and Kelly (1989) found that a number of species with transient seed banks appeared to lack any form of dormancy and tend to disperse seed just prior to germination. Still other species follow the within-year dormancy patterns which are based on stratification or after-ripening requirements. Furthermore, in both chaparral and fynbos communities, the quality of the seed bank is highly dependent on the presence of seed retention in above ground serotinous cones. Many species in the *Proteaceae* family use this form of seed retention although variation may occur among and within species and between geographic locations (Cowling 1987). Fire-dependant seed release, although not essential in all serotinous fynbos species, is common. The timing and quantity of seed release is directly related to the fire temperature and cool, wet, post-fire conditions, among other environmental conditions (Parker and Kelly 1989, Bond and van Wilgen 1996). Such variations in serotiny illustrate the role of fire in the selection for dormancy and long-term seed storage (Parker and Kelly 1989). Dormancy characteristics and seed longevity are highly relevant within this study, yet relatively few studies have attempted to estimate how dormancy influences seed bank dynamics. It is found that woody species continue to produce seed and add to the seed bank between fires. In the case of short-lived plants (such as annuals, fire ephemerals and short lived perennials) time between fires and seed longevity become vital to the populations survival (Parker and Kelly 1989). Persistence in the seed bank as well as response to the next fire is dependent upon the seeds longevity and death rates (Parker and Kelly 1989). Bond (1980) found large declines in dicotyledon regeneration in older fynbos stands and a resulting shift in the seed bank composition towards moncotyledons. In his study, all Proteaceae plants were serotinous, and although prematurely opened seed cones should allow some seeds to enter the soil seed bank, results show that seeds reaching the soil before a fire will find conditions unsuitable for germination, thereby losing viability or suffering heavy predation losses. Therefore, seedling density is thought to be a function of parent population density and will decline as plants die from old age. (Bond 1980).

Van der Merwe (1966) identifies four different post-fire life-forms; fire geophytes (geophytes that regenerate from underground storage organs), fire hemicryptophytes (sprouters that regrow from rootstocks), fire chamaephytes and nanophanerophytes (plants that protect their dormant stem buds with thick bark), and fire theropytes (generally short-lived woody shrubs and soft herbs that are destroyed by fire and rely on their seed to regenerate). As illustrated in Table 1, following a fire a succession takes place, concluding with the fire therophytes dominating. Richardson and van Wilgen (1992) reiterate the close link between the optimal level of species diversity and a suitable fire regime.

Within riparian areas, little is known about the influence of fire on the seed bank germination. Additionally, seed bank composition varies according to the dominant above-ground vegetation type and is usually highly variable as a result of the disturbance by seasonally changing water levels (Leck 1989). In a study done by Harper (1977) on wetland vegetation, it was found that more often than not, the seed bank was dominated by one species, and that species was usually a monocotyledon, i.e. a graminoid (Leck 1989). This is thought to be a possible result of the variability of seed production, with one or a few species producing excessive seed counts, while other common species may only contribute very few seeds. One must also consider the fact that in wetland communities, once established, some species have the ability to expand primarily by vegetative means, which would add extensively to their local dominance (van der Valk 1981). Additionally, this phenomenon may explain regular disparities between above-ground floristic composition, and the seed bank composition (Leck *et al.*

1989). Annuals also formed a high percentage of the seed bank composition, both within wetland areas (Leck *et al.* 1989), and within the fynbos seed bank composition (Cowling and Holmes 1992) although generally herbaceous species dominate, with graminoids comprising >50% while woody species are found predominantly on the edges of the riparian/wetland bank (Leck *et al.* 1989).

Seed bank size, composition, and depth distribution are determined, in part, by longevity. Factors selecting for longevity are morphology (especially size and seed coat thickness), and dispersibility (also a factor of morphology) (Leck *et al.* 1989). Evidence shows the seed bank depth of wetlands to be fairly shallow, with 80% of the seeds occurring within the top 4-5cm (Leck *et al.* 1989), although little research has been done specifically within riparian areas. The constant turnover and displacement of soil by the passing river is a factor that will have a strong influence on the accessibility of seeds within the seed bank, as well as other factors like depth distribution and longevity, as previously mentioned. The influence of fire on seed germination within riparian areas has not been highly researched. River corridors may evade seasonal (i.e natural) fires, especially in the higher reaches, that run through the neighbouring fynbos vegetation because of their high moisture level both in the ground and within the vegetation (van Wilgen *et al*. 1990). However, as previously mentioned, the presence of invasive species with their high biomass levels could threaten the protection of riparian areas through fire damage (Manders 1990). It is therefore clear that there is a potential for a high variety of germination requirements within a relatively small area in the transition between riparian and fynbos vegetation.

Riparian Vegetation within the Fynbos Biome

Riparian vegetation within the fynbos biome is fairly distinctive from the surrounding fynbos vegetation (Boucher 1978). The composition of the riparian community varies according to the phytogeographic affinity towards either the fynbos or Afromontane forest vegetation groups; which are, in-turn, dependent on several environmental factors including stream size and position in landscape, local topography, and surrounding soils, vegetation or land use (Holmes 1998). Riparian communities with a fynbos affinity have been described as Closed-Scrub fynbos (Cowling and Holmes 1992) or Broad Sclerophyllous Closed Scrub (Kruger 1979). Such communities are usually found in the mountain stream or montane reaches of the rivers where the extent of alluvium is limited as a result of the high levels of erosion.

Dominant species in Closed Scrub Fynbos include *Metrosideros angustifolia, Brachylaena neriifolia, Salix macronata, Leucadendron salicifolium, Cunonia capensis, Rapanea melanophloeos* with dominant graminoids such as *Calopsis paniculatus, Cannomois virgata* and *Elegia capensis* (Boucher 1978, Van Wilgen and Kruger 1985, Macdonald 1988, Mcdonald 1993). In slower flowing permanent streams, the entire zone may be dominated by dense stands of swamp communities such a *Prionium serratum* with additional low-growing species (Boucher 1978).

As the gradient and velocity decrease, the ability of the river to deposit becomes greater, providing a suitable alluvium base for dense Closed Scrub communities to develop (Boucher 1978). Once again, in deep gorges or kloofs where protection from fire is available, forests may be found. Dominant species in Afromontane forest include *Rapanea melanophloeos, Halleria lucida, Maytenus acuminate, Cunonia capensis, Ilex mitis* and *Podocarpus* species (Boucher 1978, Macdonald 1988, Manders 1990). Forests usually have a fairly abrupt boundary with surrounding fynbos vegetation which is maintained by fire (Midgley *et al*. 1997).

The major components of a riparian zone can be defined as the aquatic zone (almost permanently submerged), the wet bank zone (seasonally wetted, sub-categorized into lower and upper wet bank zone), and the dry bank zone (only wetted during extreme water levels, sub-categorized into lower dynamic zone, shrub/tree zone and back dynamic zone) on a lateral scale; and mountain stream, foothill zone (sub-categorized into upper and lower foothill zones), transitional and lowland zones on a longitudinal scale (Boucher and Tlale 1999). These areas form the link between the aquatic and terrestrial ecosystems (Mackenzie *et al*. 1999). Simply put, riparian zones are recognized as corridors for movement of animals and play an important role within landscapes as corridors for dispersal of plants. Riparian ecosystems are highly important for the delivery of key services such as the provision of food, control of evapo-transpiration and water temperature, filtering of sediments, stabilisation of stream banks and support of faunal communities, as well as the conservation of biodiversity which encompasses all of the above (Naiman and Decamps 1997; Galatowitsch and Richardson 2005). However, it has been noted that riparian areas are highly prone to invasion by alien vegetation (Rowntree 1991, Planty-Tabacchi *et al.* 1996, Galatowitsch and Richardson 2005). This is thought to be a result of the exposure of riparian vegetation to periodic natural and human related disturbances, dynamic nutrient levels and hydrology, water dispersal of propagules, and the role of stream banks as a seed reservoir for both indigenous and exotic species (Rowntree 1991, Galatowitsch and Richardson 2005). The result of such invasions is the inability of the river to provide many, if not most, of the ecosystem's hydrological-related services (Galatowitsch and Richardson 2005).

Davies and Day (1998) classify the longitudinal zones of a river as the mountain stream zone, where erosion exceeds sediment accumulation; the foothill zone, where erosion and accumulation are more or less in balance; and the coastal plain river zone, where accumulation exceeds erosion (Davies & Day 1998). Many different microhabitats are found in the banks as well as in the aquatic environment of all lateral zones (Sieben 2002). These microhabitats will change as the water level fluctuates (Davies & Day 1998), particularly so in the foothill zone. Here, river size increases as the catchment size increases, the slope becomes more gentle and thus velocity decreases. This combination of an increase in suspended material and a decrease in flow velocity, raises the level of deposition. In mountain stream sections a high level of erosion is always present however, with a decrease in water capacity, small areas of deposition may form in more protected areas such as side channels of slower-moving water. Within both mountain stream and foothill zones, different moisture bands occur that are classified broadly as wet bank and dry bank zones. A cross-section through a riverbed (Figure 1) illustrates the different habitats, which are affected uniquely by different levels of flow.

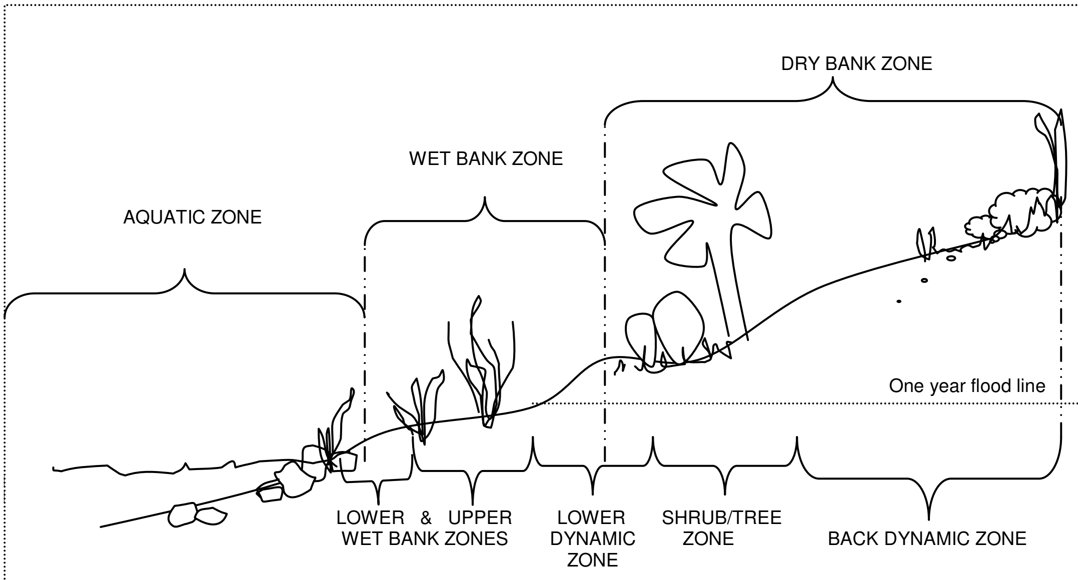

Figure 1: Zonation patterns of riparian areas within South Africa (after Boucher and Tlale 1999)

The wet bank zones consist of substrata that are moist during most of the year. Flooding is seasonal with Class 3 (wet season) flood maximum inundation level completely covering this zone. Within the wet bank, two subzones may occur; namely the moss or sedge subzone, which is wetted by 5-50% Winter baseflows and by Class 1 (dry season) floods; and the upper wetbank shrub or *Prionium* subzone, which is maintained by Class 2 and 3 (mid- and wet season) floods (Boucher 1999). Within the dry bank zone moisture is accessible only to plants with deeper roots systems as flooding is only a 1:20 year time frame. Three subzones are recognised in the dry bank zone; namely the lower dynamic subzone (the transition from wet bank to dry bank), the tree-shrub sub-zone (where vegetation is generally long-lived and is maintained by 1:2 to approximately 1:20 year maximum flood levels), and the back dynamic subzone (maintained by large floods recurring on 20-100 year intervals). The outer part of the zone is determined by the end of the riparian deposits or by a debris line where still present (Boucher 1999). It is important to note that previous studies have found that a dry bank zone may be absent in small, fast flowing mountain streams where high-speed erosion prevents efficient lateral alluvial deposits (Boucher 1999).

This study investigates these four habitats (i.e. mountain stream & foothill, wet bank & dry bank zones) in relation to the seed bank composition. Where possible, sites in this study encompassed both the wet and dry banks, however, many mountain stream sections only offered sites within the lower dynamic subzone (also referred to as transitional zone or w/d zone). Results were compared with those from similar studies on terrestrial seed bank composition in the fynbos biome. The first phase of this project investigated soil seed banks at reference, un-invaded riparian sites. A second, post-honours phase will investigate the seed banks at riparian sites that have been subject to dense alien invasion for at least one fire-cycle. The data from both phases will be compared to determine the effect of alien invasion on riparian seed bank composition. Additionally, this project is working in conjunction with a regional research project investigating various alien clearance techniques in the different vegetation biomes.

The main objectives of this study were to investigate the following questions:

1. To what extent does the seed bank have potential to regenerate riparian vegetation that is structurally and compositionally similar to undisturbed riparian vegetation?
2. What differences are there in seed bank composition among different riparian zones (longitudinal and lateral), e.g. mountain stream versus foothill and wet bank versus dry bank zones?
3. Does riparian vegetation in the fynbos biome have significant soil-stored seed banks (relative to terrestrial vegetation)?

RESEARCH DESIGN & METHODS

Study Sites

Four river systems within the South Western Cape fynbos region were chosen for their variety of reach types, history of vegetation (both alien and natural), and for their relatively close proximity to the research facilities. Plots were selected in relatively undisturbed fynbos/riparian areas, with less than 25% alien plant canopy cover. Two factors were taken into consideration when setting up the sampling plots, namely lateral (wet & dry bank) and longitudinal (mountain stream & foothill) zones. A summary of the localities of the sample sites is shown in Table 3, together with geographical details.

Table 2: Variable 1- Longitudinal Reach Type

REACH TYPE	CHARACTERISTIC GRADIENT	DIAGNOSTIC CHARACTERISTICS
Mountain stream	0.1 – 0.7	Steep gradient stream dominated by bedrock and boulders with step-pool morphology or cascades and plunge pools. Intensive erosion as a result of high velocity of water. Approximate equal distribution of 'vertical' and 'horizontal' flow components. Locally cobble or coarse gravels in pools or plane beds. Plane bed reaches at lower gradients. Vegetation invasion a moderate threat.
Upper Foothills *(cobble bed)*	0.05 – 0.1	Moderately steep, cobble-bed or mixed bedrock-cobble bed channel, with plane bed, pool-riffle or pool-rapid morphology. Narrow flood plain of sand, gravel or cobble often present. Velocity decreases and areas of deposition occur as well as erosion. Extensive vegetation cover (both natural and invasive). Accessibility leads to high potential for disturbance.
Lower Foothills *(gravel bed)*	0.01 –0.05	Lower gradient mixed bed alluvial channel with sand and gravel dominating the bed, pool- riffle morphology, or pool-rapid with sand bars. Deposition over-riding erosion. Pools of significantly greater extent than rapids or riffles. Flood plain often present. High level of disturbance and intense plant invasion.

Adapted from tables and data from the following sources :

(Chutter 1998, Rowntree and Ziervogel 1999, Boucher 1999)

Table 3: Variable 2 - Latitudinal Riparian Zone

RIPARIAN ZONE	DIAGNOSTIC CHARACTERS	SUB-ZONE CATEGORIES
Wet Bank Zone	• Substrate moist during most of the year. • Flooding is seasonal with Class 3 Flood maximum inundation level completely covering this zone. • Plants adapted to periodic waterlogging, resist erosion and bind the soil - play a very important role in the local ecology.	**1) Moss or Sedge Subzone,** • wetted by 5-50% Winter Baseflows & by Class 1 (dry season) floods **2) Upper wetbank Shrub or *Prionium* subzone,** • maintained by Class 2&3 floods
Dry Bank Zone	• Moisture accessible only to plants with a deeper roots system • Flooding is only a 1:20 year time frame.	**1) Lower Dynamic Subzone** • the transition from wet bank to dry bank **2) Tree-shrub sub-zone** • vegetation generally long-lived • maintained by 1:2 – (approx.) 1:20 year maximum flood levels **3) Back Dynamic subzone** • maintained by large floods recurring on 20-100 year intervals.

Adapted from tables and data from the following sources :

(Chutter 1998, Rowntree and Ziervogel 1999, Boucher 1999)

The Eerste River System

The source of the Eerste River is in the Dwarsberg Mountains, some 1320 m above sea level. The Mountain stream zone flows through the Hottentots Holland Nature Reserve and into Jonkershoek Nature Reserve, where the vegetation comprises predominately indigenous fynbos and riparian species. It then flows through the town of Stellenbosch as the gradient decreases and it becomes a classified foothill zone. Finally it meanders through the Cape Flats District becoming a coastal/flood plain zone river, before entering False Bay. The Jonkershoek Nature Reserve was utilised for excellent indigenous vegetation status, and all reference sites fall within this area. A map giving reference to the sites follows in Figure 3 and Table 4 gives reference to all geographical data. Three Mountain Stream sites are located at Witbrug (A), Jakkals tributary (B) and on Eerste Main (C). The three reference Upper Foothill Sites are located just above the Kleinplaas Dam (D), just below it (E) and just before the river exits the reserve (F). The Kleinplaas Dam holds water from the Riversonderend-Berg-Eerste River Government Water Scheme as well as the Stellenbosch University's experimental trout breeding station. Two of the foothill sites are located below the dam and were chosen to incorporate the investigation of potential influence of a man-made structure on vegetation distribution. Additionally, the state of the river rapidly declines as it leaves the Jonkershoek Nature Reserve, resulting in limited pristine foothill sites. All map scales are 1:50 000.

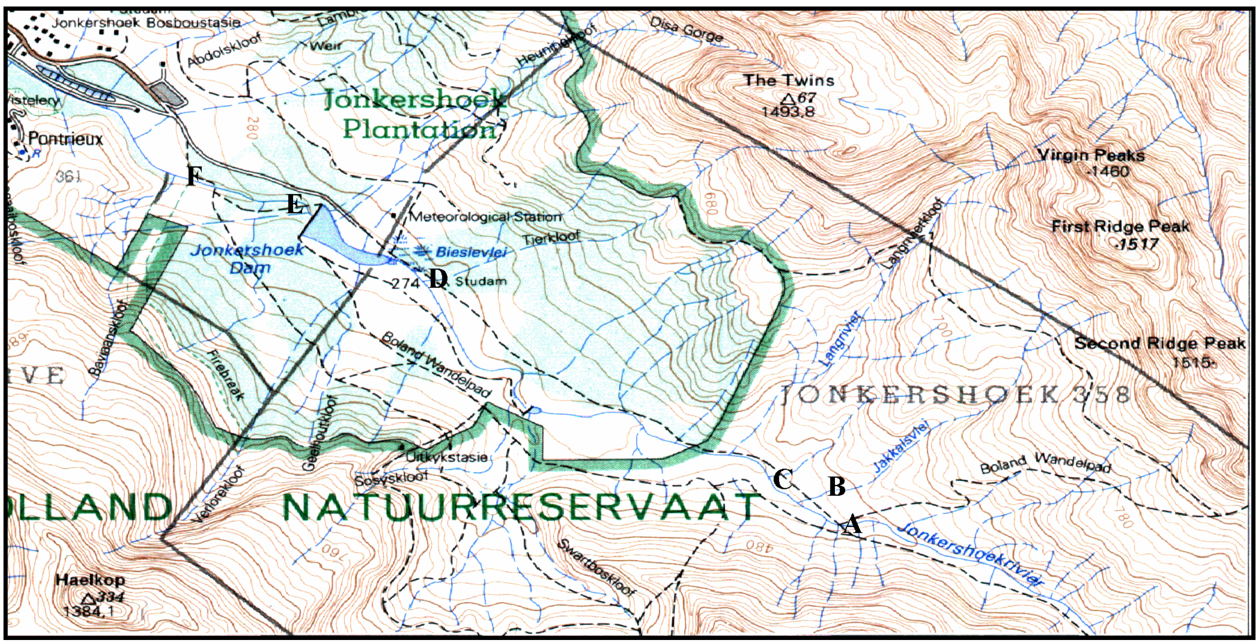

Figure 2: Study sites (A - F) of the Eerste River system

The Berg and Riversonderend River Systems

With the exception of the Franschoek Pass (which is drained by the Riversonderend River, also included in this study), nearly the whole northern section of the Hottentots Holland Nature Reserve is drained by the Berg River. The Minister of Water Affairs granted permission for the construction of a new dam in the Franschoek Valley in 1997, and construction is currently underway. Reports show that the majority of foothill and flood plain zones between Franshoek and Paarl and up to the La Motte plantation are highly disturbed by canalization and virtually all riparian vegetation has been replaced by exotic and invasive species (Burger 1992, Sieben 2002). For this reason, study sites were limited and two sites fall within the Le Motte Plantation (Assaegaaiboskloof), while the remaining sites fall within the Riversonderend Drainage Basin rather than directly into the Berg River Basin. Alien clearance within the riparian areas has been active throughout the Le Motte plantation since 2001 and fire swept through the valley in 1999 and burnt almost all of the vegetation. The Riversonderend River Basin has a similar man-made influence as the Berg River Basin, in the form of the Wemmershoek Dam, which is the one of the major sources of water to the Cape Metropolitan area and surrounding farming communities. The mountain stream sites in this area fall within the Mont Rochelle Private Nature Reserve which has relatively pristine fynbos and riparian vegetation with little evidence of disturbance. Minor infestations have been controlled by both Cape Nature Conservation and the private owner for the past four years. In 1998 a large fire swept through the area and evidence of this disturbance was found on a few sites. The remaining foothill sites are located in RusBos Nature Reserve which falls under the Theewaterskloof Nature Reserve. This area showed a high level of previous disturbance although the vegetation (both riparian and fynbos) is now well established and recovery appears positive. Alien clearance has been administered by Cape Nature Conservation on a fairly intensive level since 1995. Two fires have disturbed this area within approximately the last ten years, the most recent in 2000. Sampling sites were chosen where vegetation was relatively un-invaded (<25%) and where vegetation recovery age could be estimated at between five and six years. Sites that fall within the Berg River System at Assegaaiboskloof are (G) and (H), while sites from the Riversonderend System are detailed as (I) - (L).

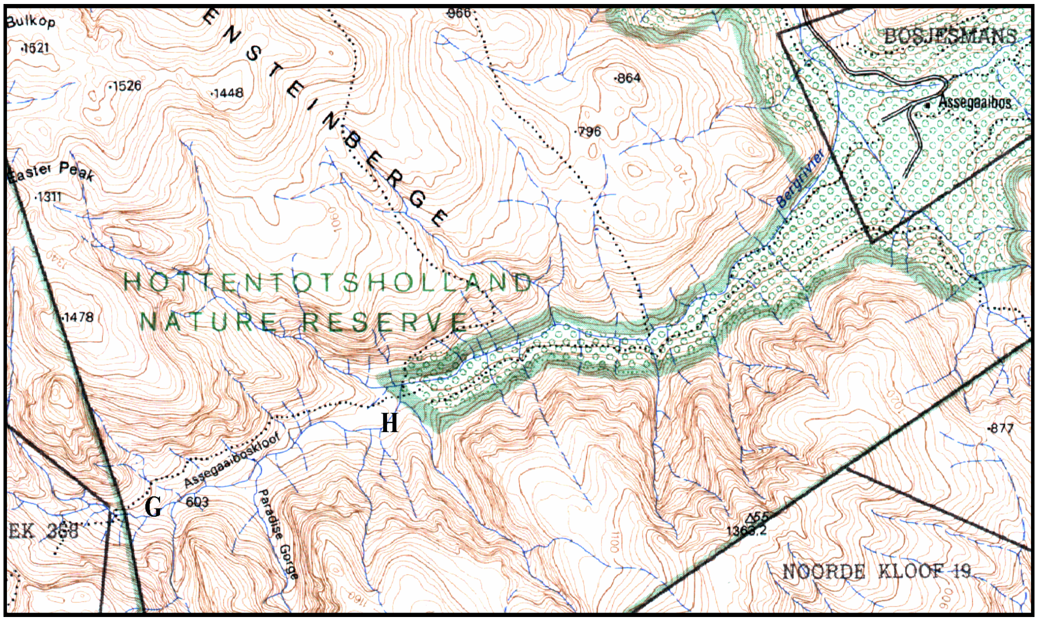

Figure 3: Study site locations (G and H) of Assegaaiboskloof along the Berg River system

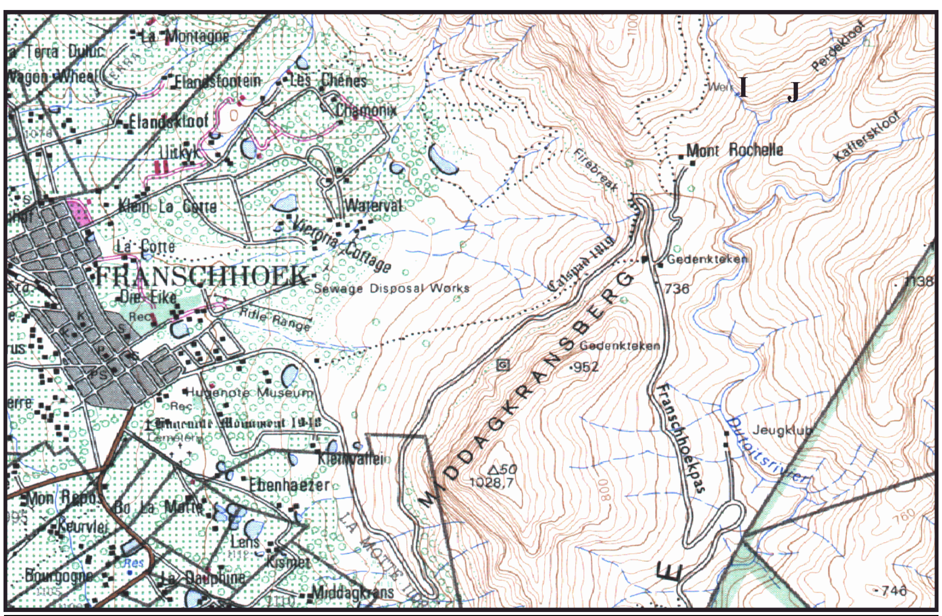

Figure 4: Study sites (I and J) of the Riversonderend river system

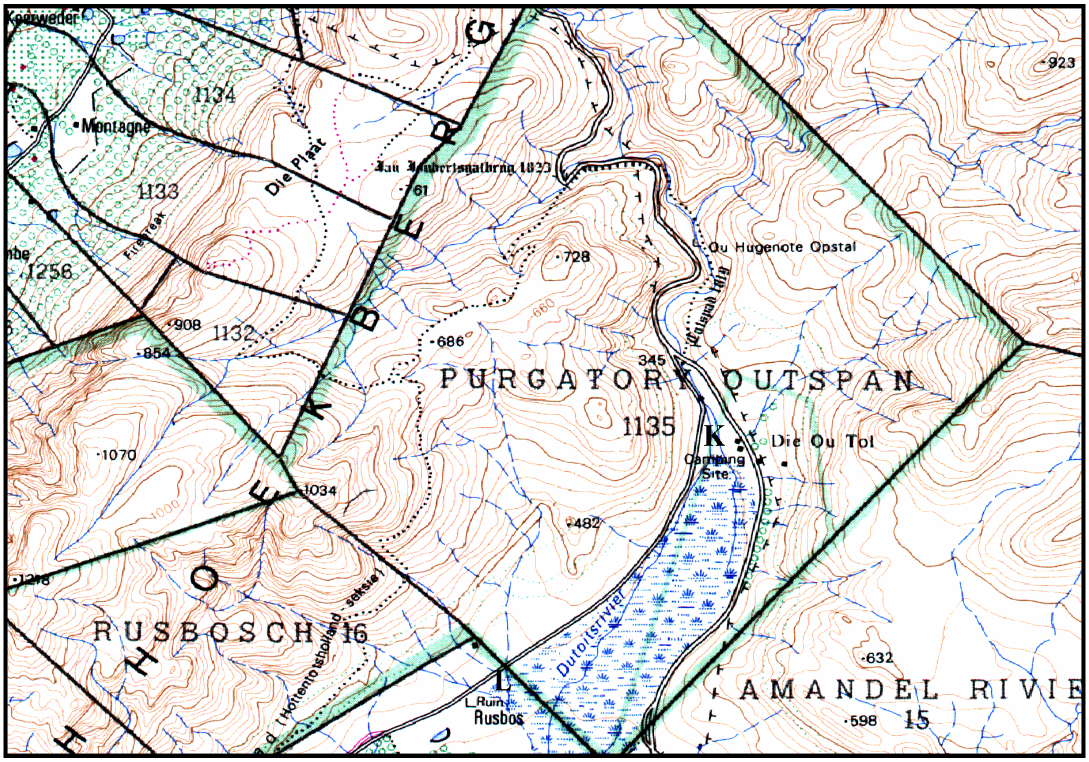

Figure 5: Study sites (K and L) of the Riversonderend river system

<u>The Wit River System</u>

The Wit River branches off from the Breede River system and runs along Bainskloof pass. Alien clearance is still ongoing throughout the river, with the densest infestations found in the lower sections of the river. The area around Tweede Tol is known to offer the most characteristic riparian and fynbos species, and all sampling sites fall within close proximity to this area. Mountain stream plots were located on the Wit main channel (M), with the second and third plots on the Tweede Tol tributary (N, O). Foothill sites were limited as a result of the dense infestations, one located on the Wit main stream just above a weir (P), and the other on the Bastiaanskloof River which is a semi-perennial tributary to the Wit (Q).

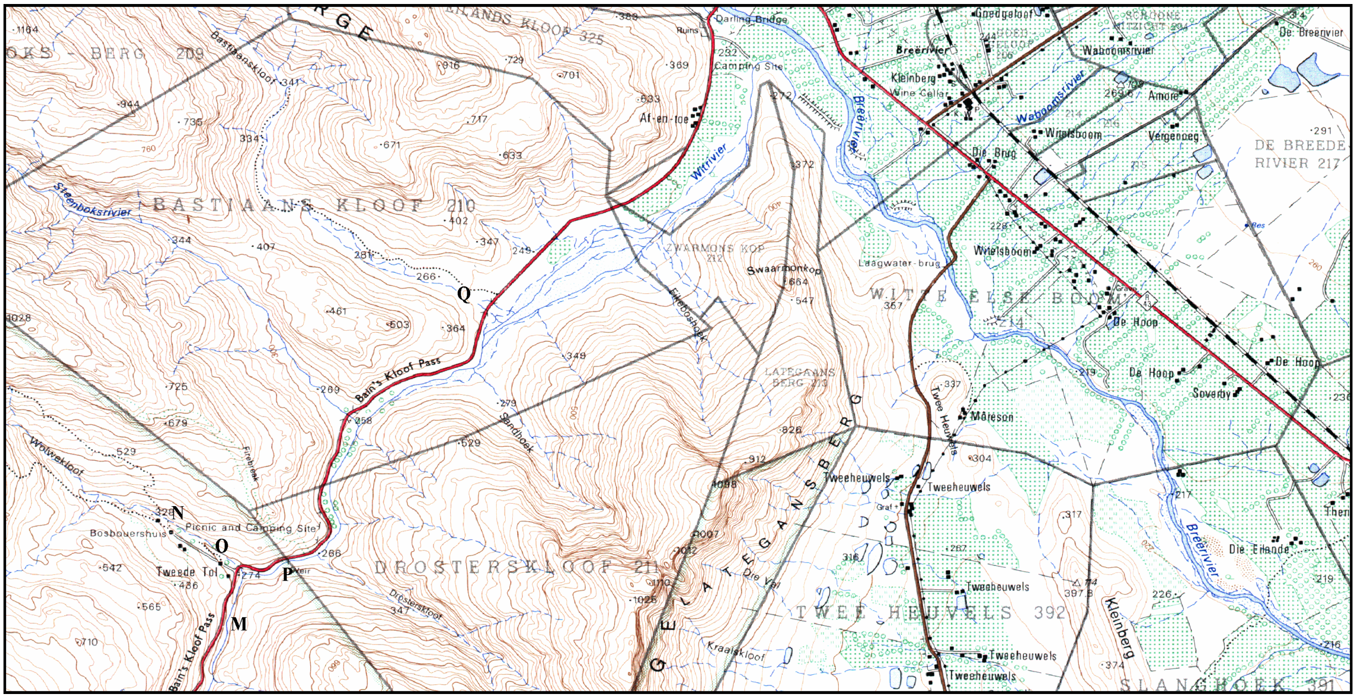

Figure 6: Study sites (N – Q) of the Wit river system

The Molenaars River System

The Molenaars has its source in the Du Toits Mountains and runs through the town of Worcester before joining the Breede River. Several tributaries start in the surrounding mountains and join the Molenaars, those included in the study are the Krom and Elands Rivers. Alien clearance is evident throughout the river and is on-going. The main channel is fairly braided in sections with islands forming along much of its length. These islands are relatively close to either side of the river and become more apparent in the summer months with the decline of water levels, becoming partially submerged for much of winter. Two of the foothill sites (S, T) are located on such “islands” as the N1 highway runs along much of the alternative river bank. The third foothill site is along the Elands River and is classified as an upper foothill zone (R). The Mountain Stream sites are on the Krom River (U), on a small tributary that joins the Krom just upstream from the Huguenot Tunnel (V), and on a small semi-perennial tributary to the Molenaars called Tygerstels River (W).

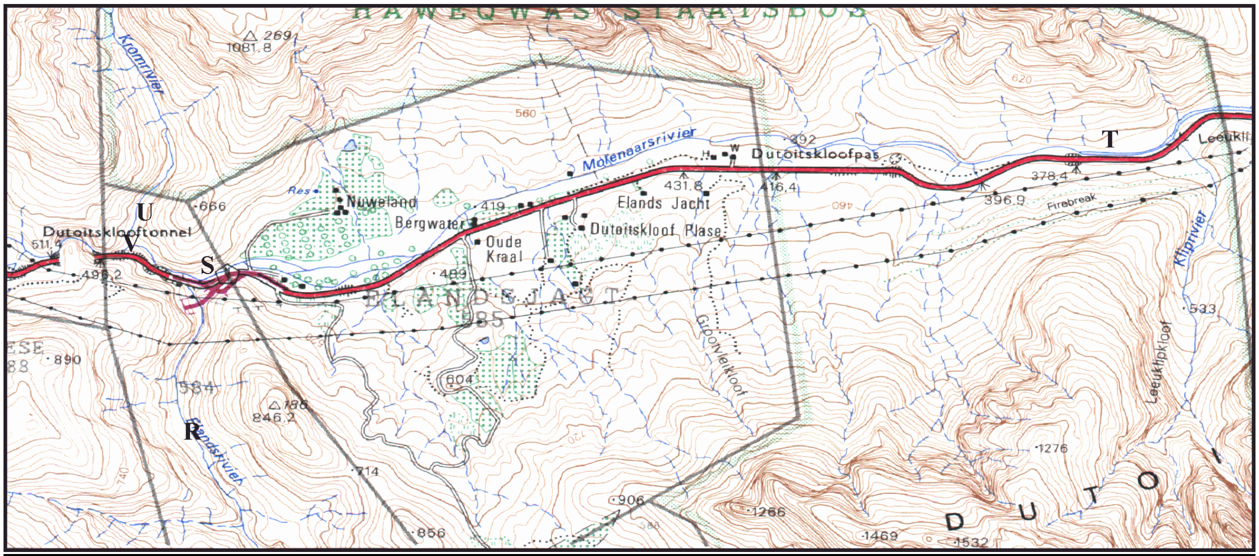

Figure 7: Study sites (R-V) of the Molenaars River system

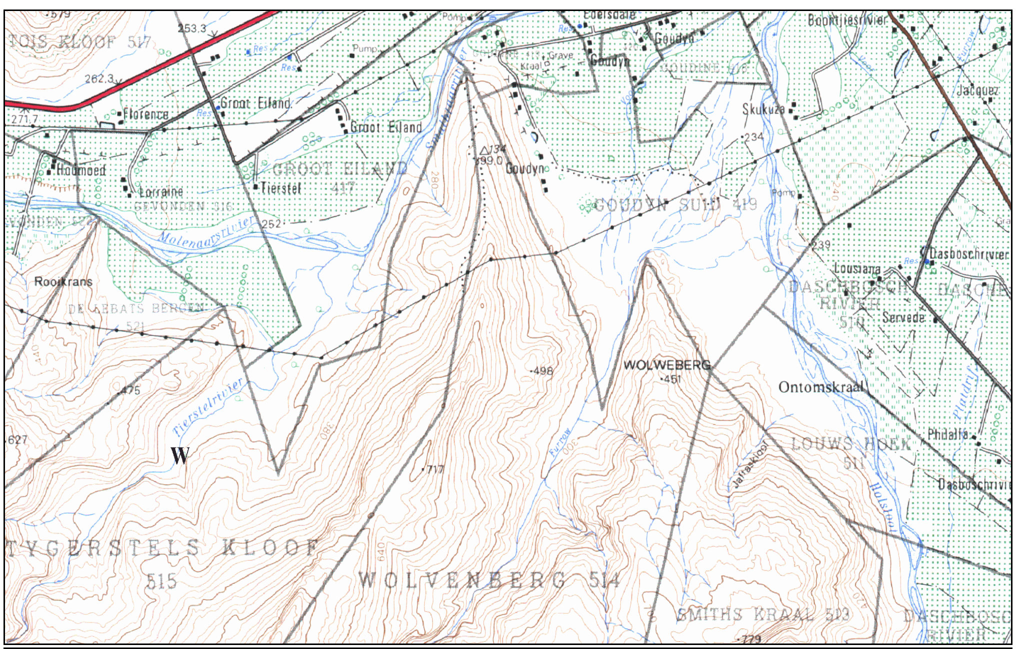

Figure 8: Study site W of the Molenaars River system

Table 4: Localities and environmental information of sites.

SITE	**Berg River** (80 samples)			**Eerste River** (90 samples)		
GRID REFERENCE	**MS** **1.Assagaibos-kloof** S 33° 59' 07" E 19° 02' 34" 353m	**2.Du Toits River** (trib to Riversonderend) S 33° 54' 190" E 19° 09' 777" 670m	**3. Perde Klip** (Trib to Du Toits) S 33° 54' 176" E 19° 09' 835" 681m	**MS** **1.Eerste-Wit brug** S 33°. 99 372° E 18°97 618 352m	**2.Eerste** Main S 33° 98' 496" E 18° 95' 520" 325m	**3.Jakkals** (trib to Eerste) S 33° 99'211" E 18° 97' 337" 364m
	FH **1.Assagaibos-kloof** S 33° 58' 02" E 19° 04' 51" 310m	**2.Du Toits River**1 S 33° 56' 921" E 19° 10' 150" 345m	**3.Du Toits River2** S 33° 58' 036" E19° 09' 365" 322m	**FH** **1.Eerste 1** (just above dam) S 33° 97' 888" E 18° 94' 997" 281m	2. **Eerste 2** (just below dam) S 33° 58' 456" E 18° 56' 346" 234m	3.**Eerste 3** S 33° 44' 434" E 19° 06 817" 251m
SITE	**Molenaars River** (70 samples)			**Wit River** (60 samples)		
GRID REFERENCE	**MS** **1.Krom River** (Trib to Mol.) S 33 °43' 788" E 19 °06' 526" 448m	**2. Krom Trib** (right fork) S 33° 43' 699" E 19° 06' 608" 452m	**3. Wolwekloof River** (Trib) S 33° 43' 226" E 19° 14' 695" 311m	**MS** **1. Witte Main** S 33° 34' 265" E 19° 08' 326" 276m	**2. Witte** 2 S 33° 34' 195" E 19° 08' 509" 279m	**3. Trib @ Tweede Tol** S 33° 34' 061" E 19° 08' 177" 300m
	FH **1.Elandspad** S 33 °44' 434" E 19 °06' 817" 468m	2.**Krom/ Elandspad Junction** S 33 °43' 905" E 19 °06' 854" 440m	**3.Molenaars Main** S 33° 43' 393" E 19° 10' 730" 359m	**FH** **1. Witte**- Weir S 33° 34' 129" E 19° 08' 696" 261m	**2. Trib @ Bastaainskloof** S 33° 32' 806" E 19° 09' 71" 259m	

Seed bank sampling

Soil samples were collected during late summer (from March-April 2005) from all sites. At each river reach a plot was established on edge of the river bank, where the influence of riparian vegetation is evident. Each plot measured twenty metres in length (parallel to the river) and five metres in width (perpendicular to the river crossing both the wet bank and dry bank zones). Where the wet bank zone was distinctive, one 20 m-long transect was placed through the wet bank vegetation and a second transect through the dry bank vegetation. Along each lateral zone transect, ten quadrats (1m x 1m) were placed using random numbers to determine their location. All geographical details were recorded for each quadrat, such as species presence and percentage canopy cover, together with an estimate of total canopy cover. A small specimen herbarium was collected of seedlings or species that were not identified on site. Various geomorphological features of the river and the sampling area were noted, including morphological unit (pool, rapid, riffle etc) geology, rock cover, altitude, aspect, slope and GPS location.

A hand-held soil corer (measuring 5cm diameter and 10cm depth) was used to extract the soil. When impossible to use the corer due to rocks and/or roots, a hand-trowel was used that maintained the uniform 5cm diameter. Each sample comprised of 5 cores collected from within the 1m^2 quadrat then lumped together. Sampling was done across the whole plot to encompass seed dispersal variation. This method was then repeated in the dry bank zone where possible. Replicate sites were then sampled along each particular river reach. However, minimal availability of reference sites along the Berg River System prompted the inclusion of the Riversonderend System to compensate for shortcomings, as previously mentioned. These two river systems were then grouped together under the Berg system when analysing the data. Where possible study sites encompassed both the wet and dry bank samples, however, many mountain stream sections only offered sites available within the lower dynamic subzone (also referred to as w/d zone). Samples were then transported in thick plastic bags to the premises on Welgevallen Experimental Farm, were they were labelled according to the details of the area of collection (e.g. – Berg1, MS, #1). Samples were then air dried and passed through a 1mm sieve to remove any fibrous roots or large stones. Seedling trays (20cm x 15cm) were lined with thin fibrous cloth to ensure that water drained without the loss of seeds. A suitable layer of washed river-sand (depending on the amount of soil collected in the sample) was placed on top of the cloth to ensure a uniform depth is maintained throughout all trays. Control trays were kept of the river sand and monitored to note any emergent seedlings deriving from the river sand or dispersal into the tunnel. The trays were labelled and placed in open-sided plastic shade tunnel. Smoke treatment was equally distributed throughout all trays on the same day (2005/11/05) by means of a diluted liquid chemical concentrate (Kirstenbosch's Seed Primer Plus Liquid Concentrate Solution at a ratio of 1part concentrate for every 9 parts water, totalling to 20litres of diluted smoke treatment used). The trays were then left for 24 hours to absorb the treatment before irrigation commenced. Trays were kept moist with a fine spray irrigation system set on an automatic cycle with regular adjustments according to outdoor variations in moisture and temperature. The temperatures were maintained as close to the natural environment as possible, with the drop in temperature during autumn and winter monitored. These temperatures are vital in the seed germinating process and a 2º C difference can signify unique germination results. The maximum and minimum temperatures recorded during the study period were 38ºC and 8 ºC respectively. Seedling emergence was monitored fortnightly for the first three months and there after continued on a monthly basis. Once basic identification was possible, duplicates in the same tray were removed after counting. Once large enough, specimens that require more space were transferred to small pots to encourage growth and flowering. To assist in future identification, a seedling herbarium is currently in progress using various stages of the specimens' development. The current level of identification is on Family level, with a few specimens on Genus level. Where possible each species will be grown until flowering stage to ensure correct identification to species level.

DATA ANALYSIS & RESULTS

A data set comprising a total of 315 soil seed bank samples and corresponding above-ground vegetation data was collected. Subsets of these data set are used to address the key questions in the study. Data of on-site aboveground vegetation was compared with the seedling germinants that represent the seed bank composition. The overall seed bank composition was grouped into growth form, dominant families and the species' origins (alien or indigenous). As many of the seedlings had not yet reached flowering stage, identification was fairly rudimentary, but is on-going with corrections and updates to be added to the data set when available. To investigate species groupings according to the habitat variables (river, slope and zone), germination data were analysed using several diversity indices and correspondence analysis. The program *Species Diversity and Richness* was utilized to calculate Simpson's Diversity Index for the different variables, and *Statistica* was used on the twenty most frequently occurring species in the correspondence analyses. Data analysis was impossible for all species as some species were so rare that their counts were not adequate to be used in the analysis. Seed bank species richness testing was done by comparing the mean species richness counts between the different rivers, slopes and zones. Results were then compared to evaluate if significant distinctions of species occurrence were found between the different variables, and to determine the seed bank composition.

Seed bank and Aboveground Vegetation Comparisons

The seed bank generally shows little reflection of the aboveground vegetation, but does represent a diverse assemblage of riparian species. Species that were found to be present in both aboveground and seed bank vegetation tended to be grasses (Poaceae) or members of Cyperaceae, as well as some longer lived Asteraceae (*Helichrysum* species), *Erica* species and some pioneer legume species (*Podalyria* species). Full details of all vegetation comparisons are given in Appendix 1.

Considering the samples were taken from reference sites with low counts of alien vegetation, a relatively high percentage (15 %) species represented in seed bank were alien. The herbaceous perennial growth form held the highest percentage of presence in the seed bank, followed closely by the shrub/shrublet form and the annuals (Figure 9). As could be expected, Asteraceae dominated the seed bank significantly against other family groups, although Cyperaceae, Poaceae, Crassulaceae and Scrophulariaceae were all well represented (Figure 10). A comparative analysis (Figure 11) of the aboveground vegetation assemblage and seed bank composition offered interesting results and is summarized in Table 5. Very little overlap in species presence was found, with the dominating groups representing very different growth forms.

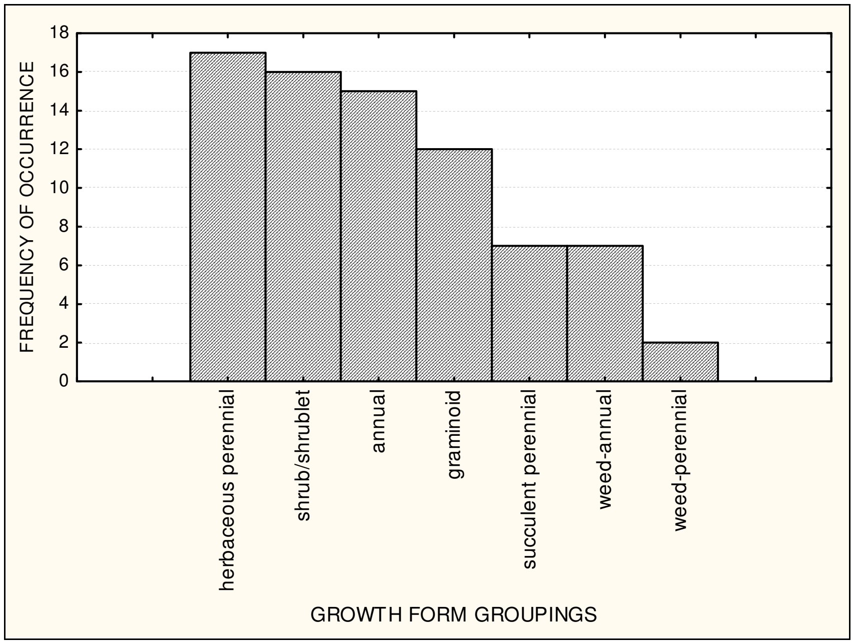

Figure 9: Histogram of seed bank growth forms

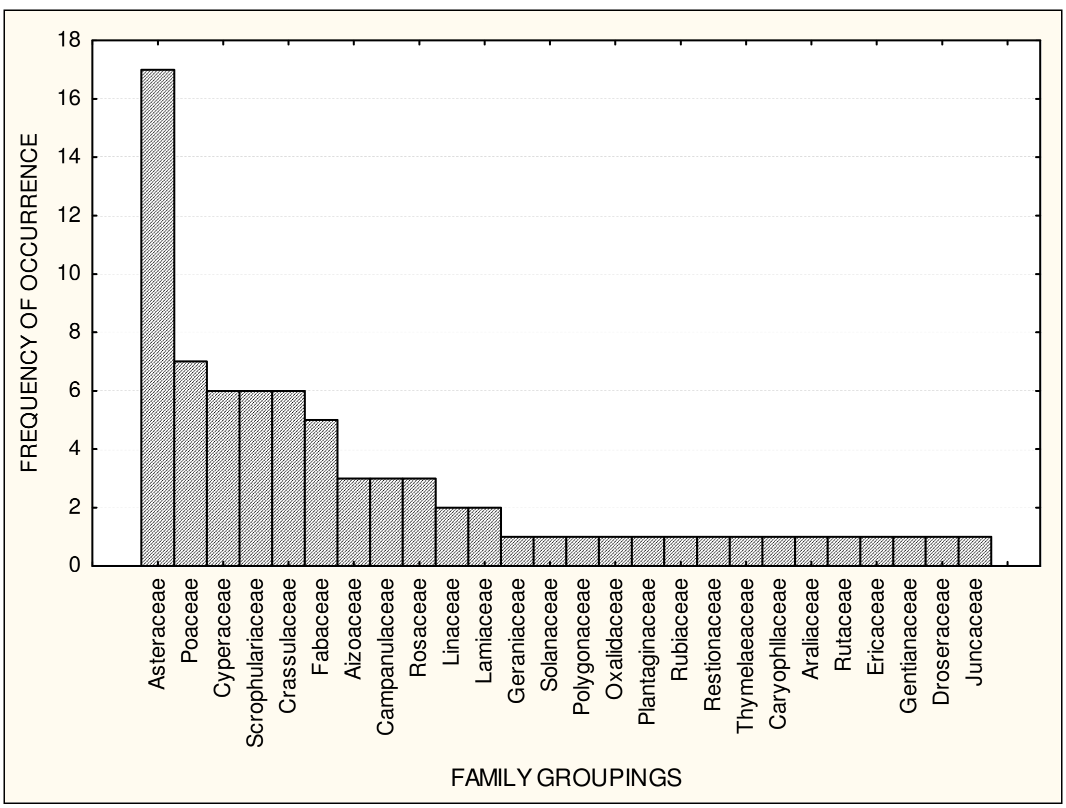

Figure 10: Histogram of seed bank family groupings

Table 5: Composition comparision between aboveground vegetation and seed bank (represented by 20 most frequently occurring species in vegetation and seedling emergents in order of decreasing frequency)

Aboveground Vegetation	Growth Form	Seedling Emergents	Growth Form	Species Code
Metrosideros angustifolia	Shrub/small tree	Poaceae	graminoid	sp 1A
Brabejum stellatifolium	Tree	Cyperaceae	graminoid	sp 1C
Brachylaena neriifolia	Shrub/small tree	Asteraceae	herbaceous perennial	sp 13
Erica caffra	Shrub/shrublet	Cyperaceae	graminoid	sp 1D
Blechnum capense	Fern	Cyperaceae	graminoid	sp 1E
Calopsis paniculata	Graminoid	Restionaceae	graminoid- *Ischyrolepis* sp. ?	sp 21
Elegia capensis	graminoid	Thymelaeaceae	herbaceous perennial-*Struthiola* sp. ?	sp 31
Prionium serraturm	graminoid	*Plecostachys* sp.	herbaceous perennial	sp 26B
Ischyrolepis sp	graminoid	*Helichrysum* sp.	herbaceous perennial	sp 26A
Morella serrata	Shrub/shrublet	Asteraceae	annual weed- *Conyza* sp. */ Hypochoeris radicata?*	sp 9
Stoebe plumose	herbaceous perennial	Campanulaceae	annual- *Microcodon* sp. ?	sp 33
Cyperus sp.	graminoid	Asteraceae	herbaceous perennial- *Euryops* sp. / *Ursinia* sp.	sp 2
Erica sp	Shrub/shrublet	Poaceae	graminoid	sp 1B
Helichrysum sp.	herbaceous perennial	*Solanum retroflexum (=nigrum)*	weed-perennial	sp 8
Rhodocoma capensis	graminoid	Cyperaceae	graminoid- *Juncus* sp. ?	sp 1J
River grass stripey,clump	graminoid	*Cliffortia cuneata*	shrub/shrublet	sp 12
Salix capensis	Tree	Ericaceae/ Campanulaceae	shrub/shrublet- *Erica sp. / Roella sp.* ?	sp 49
Acacia mearnsii	tree-alien	Scrophulariaceae	annual- *Nemesia sp. / Sutera sp.*	sp 37
Cannomois virgata	graminoid	Aizoaceae	succulent perennial- *Erepsia* sp. */ Carpobrotus* sp ?	sp 5

Seed bank variations between variables

Differences between Rivers

The Berg/Riversonderend River System has the highest species richness although the Molenaars River System had the highest density of seedlings (Table 6). Table 7 and 8 give more detailed accounts for species richness and seedling densities of each plot sampled. These results were confirmed when Simpson's Diversity Index was used. Figure 11 shows a significant difference in diversity levels between the Berg and the Wit Rivers.

(Sample codes for all analyses: Rivers: Bg- Berg, Er- Eerste, Mol- Molenaars; Slope: MS- mountain stream, FH-foothill; Zones: (w)- wet bank, (d)- dry bank, (w/d)- transitional zone. Species codes are detailed within tables of the analyses.)

Table 6: Seed bank species richness means between rivers (Totals are Mean ± SD)

BERG	Species Richness	MOLENAARS	Species Richness	EERSTE	Species Richness	WIT	Species Richness
Bg MS (w/d)	56	Mol MS (w/d)	56	Er MS (d)	40	Wit MS (d)	38
Bg FH (w/d)	39	Mol FH (d)	36	Er MS (w)	37	Wit MS (w/d)	22
Bg FH (d)	39	Mol FH (w)	30	Er FH (d)	36	Wit MS (w)	21
Bg FH (w)	37	Mol FH (w)	19	Er FH (w)	33	Wit FH (w/d)	21
				Er MS (w/d)	28		
				Er FH (w/d)	27		
Mean Species Richness	**42.75** (± 8.88)	**Mean Species Richness**	**32.25** (±15.15)	**Mean Species Richness**	**33.5** (± 5.16)	**Mean Species Richness**	**22.5** (± 8.34)

Table 7 : Seedling species richness per plot

Sample	Species Richness
Bg MS (w/d)	56
Mol MS (w/d)	56
Er MS (d)	40
Bg FH (w/d)	39
Bg FH (d)	39
Wit MS (d)	38
Bg FH (w)	37
Er MS (w)	37
Er FH (d)	36
Mol FH (d)	36
Er FH (w)	33
Mol FH (w)	30
Er MS	28
Er FH	27
Wit MS (w/d)	22
Wit MS (w)	21
Wit FH (w/d)	21
Mol FH (w/d)	19

Table 8: Total seedling counts per plot

Sample	Seedling counts
Mol MS (w/d)	1606
Bg FH (w)	1591
Bg MS (w/d)	1588
Bg FH (w/d)	1312
Bg FH (d)	595
Wit MS (d)	572
Mol FH (w)	513
Er MS (w)	464
Er MS (d)	447
Er FH (d)	441
Wit FH (w/d)	433
Er FH	383
Wit MS (w/d)	362
Mol FH (w/d)	335
Er FH (w)	326
Er MS	320
Mol FH (d)	292
Wit MS (w)	219

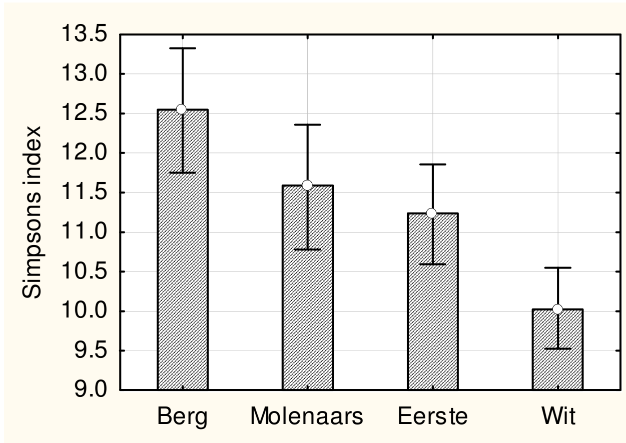

Figure 11: Histogram of Simpson’s Index for all rivers

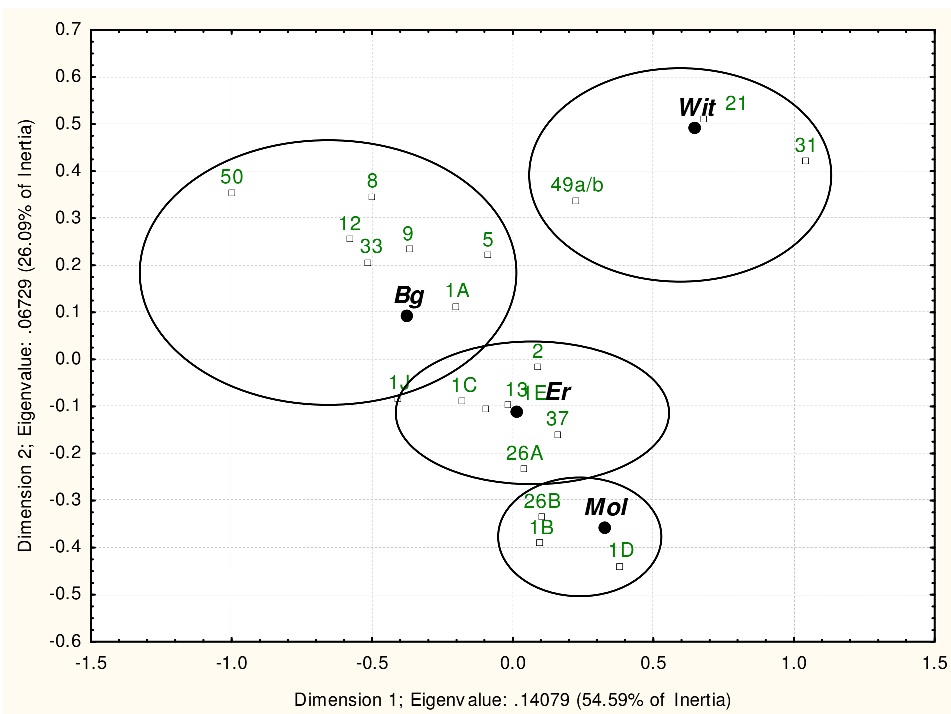

Figure 12: Correspondence analysis results of species groupings between rivers (Codes and groupings are detailed in Table 9)

Correspondence analysis of emergent seedlings from the soil seed bank show fairly well-defined species groupings (Figure 12). However, it must not be taken for fact that these species only occur in the following groupings or only within the restricted river systems. Rather that the abundance of these species was greater within the specific river systems, and the data should be analysed together with the total species abundance data for each river (Appendix 1) to gain a complete understanding. The groupings can be summarized as follows.

Table 9: Seeding groupings in relation to rivers

River	Code	Current Identification Status
BERG	50	Scrophulariaceae – *Zaluzianskya*
	8	*Solanum retroflexum (= nigrum) **
	9	*Hypochaeris radicata **
	5	*Erepsia* sp./ *Carpobrotus* sp.
	1A	Poaceae
	12	*Cliffortia cuneata*
	33	Campanulaceae – *Microcodon* sp. (?)
	1J	Cyperaceae
EERSTE	1J	Cyperaceae
	1C	Cyperaceae
	2	Asteraceae - *Euryops* sp/ *Ursinia* sp.
	13	Asteraceae (perennial)
	26A	*Helichrysum* sp.
	37	Scrophulariaceae – *Nemesia* sp./ *Sutera* sp.
MOLENAARS	1B	Poaceae
	1D	Cyperaceae
	26B	*Plecostachys* sp.
WIT	21	Restionaceae – *Ischryolepis* sp.
	31	Thymelaeaceae – *Stuthiola* sp. (?)
	49	Ericaceae/ Campanulaceae- *Erica* sp./ *Roella* sp.

* indicates alien weed species

It is suggested that the groupings are representative of the vegetation history of the site rather than any specific species grouping.

<u>Differences between Slopes</u>

Basic species counts were compiled for the slope variables throughout all rivers and the mean totals are shown in order to rank the overall species richness level between the slopes of all rivers sampled (Table 10). Figure 13 shows a much clearer distinction of the diversity levels comparisons between mountain stream and foothill slopes. Correspondence analysis (Figure 14) shows distinct species groupings between mountain stream and foothill slopes, with break-down of the groupings illustrated in Table 11 and 12. Results indicate that riparian species are better represented in the foothill slopes, with Poaceae, Cyperaceae and weed species dominating (Table 11), while the mountain stream sites represent a diverse assemblage of fynbos species, with few riparian species present (Table 12). Although not adequately illustrated here, it is suggested that a few overlaps may occur with species growing both in mountain stream and foothill habitats.

Table 10: Seedling species richness comparisons between mountain stream and foothill sections of all rivers. (Totals are Mean ± SD)

MOUNTAIN STREAM	**Species Richness**	**FOOTHILL**	**Species Richness**
Bg MS (w/d)	56	Bg FH (d)	39
Mol MS (w/d)	56	Bg FH (w/d)	39
Er MS (d)	40	Bg FH (w)	37
Wit MS (d)	38	Er FH (d)	36
Er MS (w)	37	Mol FH (d)	36
Er MS (w/d)	28	Er FH (w)	33
		Mol FH (w)	30
		Er FH (w/d)	27
		Wit FH (w/d)	21
		Mol FH (w/d)	19
Mean Mountain-stream Species Richness	**36** (± 11. 24)	**Mean Foothill Species Richness**	**31.7** (± 7.53)

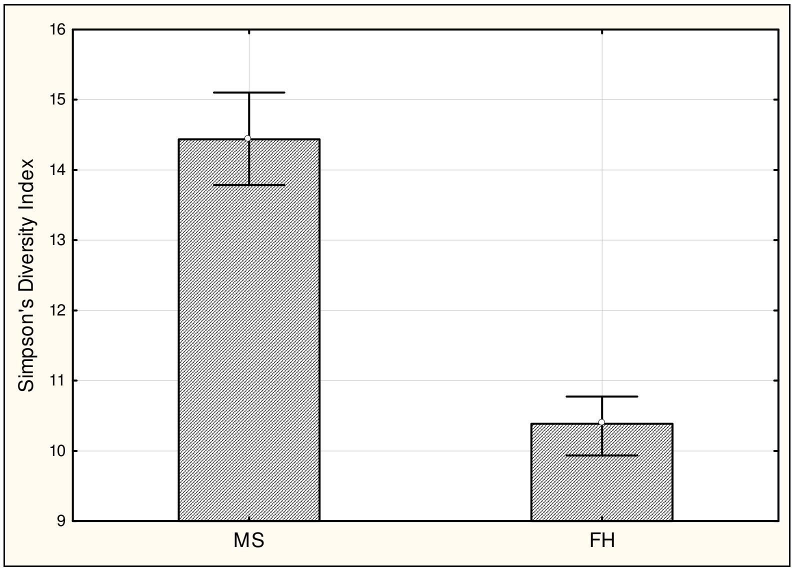

Figure 13: Simpson's Diversity Index comparison between mountain stream and foothill slopes.

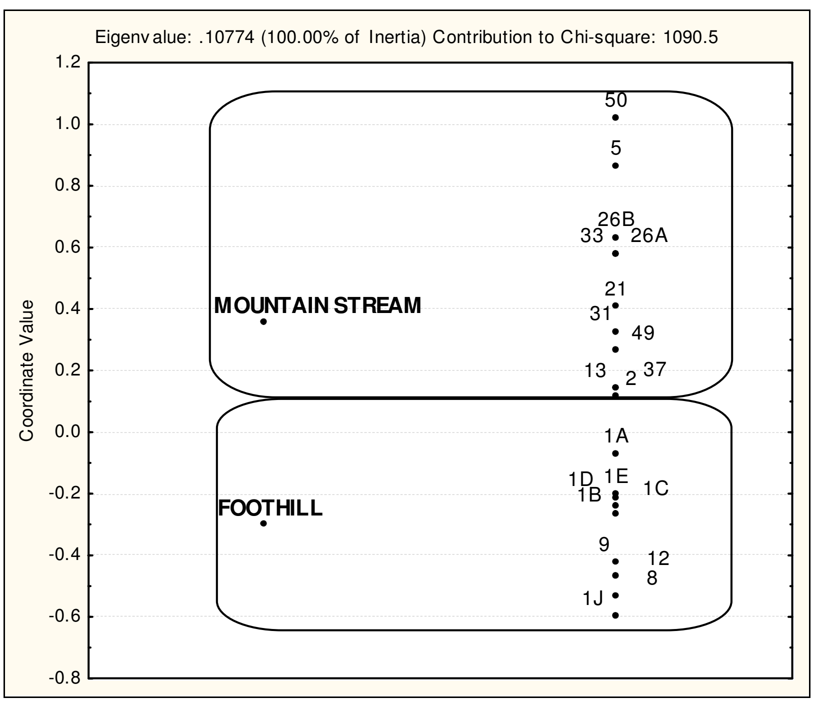

Figure 14: Correspondence analysis of species groupings between mountain stream and foothill slopes. Codes and groupings are detailed in Tables 11 and 12.

Table 11: Species groupings of seedlings within the mountain stream slope of all rivers

SPECIES CODE	DESCRIPTION
50	Scrophulariaceae, annual, herbaceous shrublet (*Zaluzianskya* sp.)
5	Aizoaceae, perennial succulent (*Erepsia* sp. / *Carpobrotus* sp.)
26A	Asteraceae, perennial, herbaceous shrublet (*Helichrysum* sp.)
26B	Asteraceae, perennial, herbaceous shrublet (*Plecostachys* sp.)
33	Campanulaceae, perennial, (*Microcodon* sp. ?)
21	Restionaceae, perennial reed (*Ischryolepis* sp.)
31	Thymelaeaceae, perennial, herbaceous shrublet (*Struthiola* sp.)
49	Ericaceae / Campanulaceae, perennial, woody shrub (*Erica* sp. / *Roella* sp.)
13	Asteraceae, perennial, herbaceous shrublet
2	Asteraceae, perennial, woody shrub (*Euryops* sp. / *Ursinia* sp.)
37	Scrophulariaceae, short-lived perennial,herbaceous shrublet (*Nemesia* sp. / *Sutera* sp.)

Table 12: Species groupings of seedlings within the foothill slope of all rivers

SPECIES CODE	DESCRIPTION
1A	Poaceae, annual/ short-live perennial grass, indigenous
1E	Cyperaceae, perennial, indigenous sedge (*Ficinia sp*. ?)
1C	Cyperaceae, perennial, indigenous sedge
1D	Cyperaceae, annual, indigenous sedge (*Ficinia* sp.)
1B	Poaceae, annual or short-lived perennial grass, indigenous
9	Annual, alien weed (*Hypochaeris radicata**)
12	Linaceae, perennial, indigenous woody shrub (*Cliffortia cuneata*)
8	Solanaceae, perennial, alien weed (*Solanum retroflexum**)
1J	Cyperaceae, perennial, indigenous sedge

* indicates alien invasive plant

Differences between Banks

Species richness is highest within the dry banks (Table 13). Simpson's Diversity Index further concluded a significantly higher diversity level within the dry bank (Figure 15). Species groupings found by using Correspondence Analysis indicated very clear groups within the different moisture regimes (Figure 16 and Table 14). As could be expected, the riparian species such as Cyperaceae and Poaceae dominate the wet banks, while most of the fynbos species are represented in the dry bank. The transitional zone (or w/d) has the greatest diversity of species representing both riparian and fynbos groups. It is important to note that the correspondence analysis results should not be compared with the species diversity figures as only the twenty most frequently occurring species were used in the correspondence analysis. Results between the two tests are opposing with the dry bank termed the least diverse bank in the correspondence analysis results. This can be explained by the fact that the dry banks are found to have the lowest species density levels (see Table 8) and this will skew the correspondence results in terms of diversity rankings.

Table 13: Seedling species richness within the different banks of all rivers. (Totals are Mean ± SD)

WET BANK	**Species Richness**	**DRY BANK**	**Species Richness**	**TRANSITIONAL ZONE (w/d)**	**Species Richness**
Bg FH (w)	37	Er MS (d)	40	Bg MS (w/d)	56
Er MS (w)	37	Bg FH (d)	39	Mol MS (w/d)	39
Er FH (w)	33	Wit MS (d)	38	Bg FH (w/d)	39
Mol FH (w)	30	Mol FH (d)	36	Wit MS (w/d)	22
				Wit FH (w/d)	21
				Mol FH (w/d)	19
Mean Species Richness = 34.25 (± 3.40)		**Mean Species Richness = 38.25** (± 1.71)		**Mean Species Richness = 32.66** (± 14.56)	

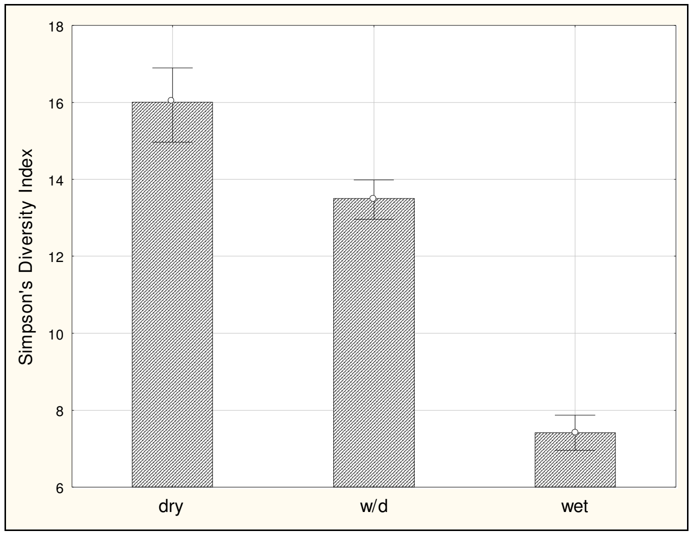

Figure 15: Simpson's Diversity Index between banks of all rivers.

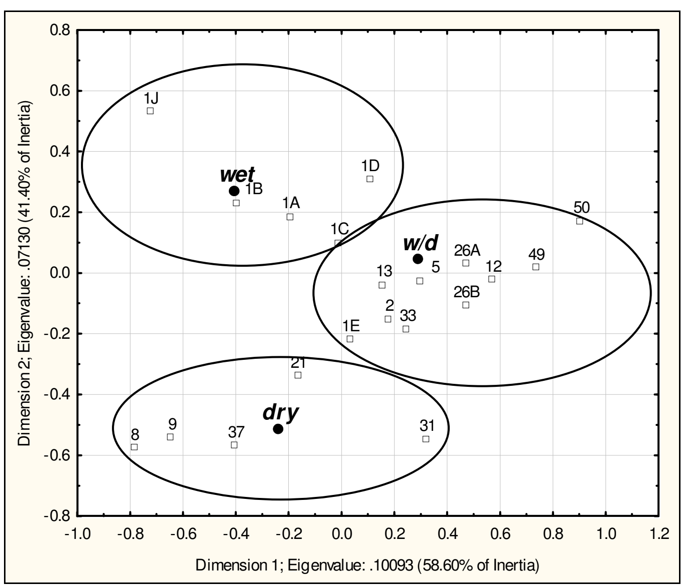

Figure 16: Correspondence analysis results comparing species groupings between banks of all rivers. Codes and groupings are detailed in table 14.

Table 14: Seed bank species groupings according to moisture regimes of banks throughout all rivers.

BANK TYPE	SPECIES CODE	DESCRIPTION (*indicates alien species)
WET BANK	1J	Cyperaceae, perennial indigenous sedge
	1B	Poaceae, annual or short-lived perennial indigenous grass
	1A	Poaceae, annual or short-live perennial indigenous grass
	1C	Cyperaceae, perennial indigenous sedge
	1D	Cyperaceae, annual indigenous sedge (*Ficinia* sp.)
TRANSITIONAL ZONE (w/d)	26A	Asteraceae, perennial herbaceous shrublet (*Helichrysum* sp.)
	5	Aizoaceae, perennial succulent (*Erepsia* sp. / *Carpobrotus* sp.)
	13	Asteraceae, perennial herbaceous shrublet
	2	Asteraceae, perennial herbaceous shrublet (*Euryops* sp. / *Ursinia* sp.)
	33	Campanulaceae, (*Microcodon* sp. ?)
	1E	Cyperaceae, perennial indigenous sedge (*Ficinia* sp.?)
	26B	Asteraceae, herbaceous shrublet (*Plecostachys* sp.)
	12	Linaceae, perennial, indigenous woody shrub (*Cliffortia cuneata*)
	49a/b	Ericaceae/ Campanulaceae , hardwood perennial shrub (*Erica* sp. / *Roella* sp.)
	50	Scrophulariaceae, annual/ short-lived perennial shrublet (*Zaluzianskya* sp.?)
DRY BANK	21	Restionaceae, perennial indigenous reed (*Ischryolepis* sp.)
	31	Thymelaeaceae, perennial herbaceous shrublet (*Struthiolia* sp. ?)
	37	Scrophulariaceae, short-lived perennial herbaceous shrublet (*Nemsia* sp. / *Sutera* sp. ?)
	9	Annual invasive weed *Hypochaeris radicata* *
	8	Solanaceae, perennial, alien weed (*Solanum retroflexum)(= nigrum*)*

DISCUSSION

A clarification between species richness and species diversity is required for complete comprehension of this study. Species richness is represented by the total species counts per unit area (also termed alpha diversity), while species diversity incorporates species richness with the relative abundance of the each specie in the homogenous community. The CFR, as previously mentioned, is world renowned for its high levels of species richness. This study found that riparian areas offer similarly high levels of species richness, particularly so within certain reaches and moisture regimes of the river. Riparian areas are complex systems, however, as they incorporate unique riparian

elements together with fynbos elements. Additionally, a large variety of disturbance regimes must be considered when investigating habitat composition indexes.
A confounding factor of influence within this study was that of disturbance, mainly in the form of water relocating the soil and erosion caused by differential seasonal water levels. The generally accepted rule is that in frequently disturbed habitats, the species composition of the seed bank and vegetation is usually similar but in undisturbed habitats there is generally less correspondence between species present in the seed bank and those in the vegetation (Warr *et al*. 1993). However, this study found that mountain stream sites, although considered to be more stable habitats, offered higher species diversity values compared to the foothill sites, where the presence of disturbance was greater. Aboveground vegetation composition confirms the habitat stability of mountain stream slopes with long-lived woody fynbos trees and shrubs and some Afromontane elements well represented and few riparian species present. Foothill slopes offer fewer woody species, and are largely dominated by graminoids and herbaceous perennials from both fynbos and riparian vegetation types. Analyses of species diversity levels between wet- and dry bank zones of both mountain stream and foothill slopes found that wet and dry zones offered significantly fewer species (both in diversity and density) than the transitional lower dynamic zone (or w/d zone). Disturbance levels are higher in both the wet bank, in the form of constant water movement; and dry banks, in the form of fire, herbivory, alien plant invasion and man-made disturbance like footpaths and motorways. This study offers the possibility that disturbance should not be considered as a confounding factor in species diversity levels along riparian corridors. Further research is needed to establish the pattern of species assemblages in relation to levels of disturbance within the fynbos biome and within riparian areas.

Comparisons of seed bank species assemblages between the lateral and longitudinal variables of the rivers offered insight into the habitat requirements of certain fynbos and riparian species. Most significant were the results from bank zone comparisons which showed distinct species groupings along the different moisture bands. As could be expected, riparian species were best represented within the wet bank zones and fynbos species similarly so within the dry bank zone, while both species were present within the transitional zone, resulting in this zone offering the highest species diversity. Diversity level comparisons between river systems were found to be impractical as results show no patterns and are suspected to be related more to site history than habitat species diversity.

It is suggested that when seed bank comparisons between fynbos/riparian communities and their neighbouring terrestrial fynbos community seek to identify diversity differences, considerations of all aspects of the different communities be taken into account to alleviate the possibility of skew in the assessment. For example, in fynbos communities, boundaries are naturally controlled by several environmental factors (substrate, moisture, and temperatures) and fire. Riparian communities, although having a strong dependency on the above mentioned environmental factors, have a far greater dependency on water levels, slope gradients and moisture regimes and far lesser fire-frequency dependency. These two factors, water and fire, are in-turn highly variable and add to the differentiation between habitats, even within the same vegetation type communities. It can be expected then that the fynbos seed bank composition should be specially adapted to use the various aspects of fire (smoke, soil temperatures, heat, ash) to their advantage in order to successfully re-establish in post-fire environments. This has been confirmed in many studies were regeneration post-fire was most prominent among annuals, short-lived forbs and shrubs (Holmes and Richardson 1999). As a result of the relatively short life span of several species within the fynbos community (the pioneers species), the utilization of long-term persistent seed banks is vital to avoid extinction as the possibility of mortality prior to the next fire is high.

Most large seeded fynbos species (approximately 30% of the flora) are limited by their short dispersal distance and deposition into the soil is added by ants which avoids a certain amount of predation. Riparian communities, on the other hand, have a greater seed dispersal distances with the aid of moving water within the river channel. However, certain adaptations must be accounted for if seeds are likely to survive in such conditions. The majority of riparian species within the study area were noted to have some sort of water adaptation for dispersal. Large seeded pods (like that of *Brabejum stellatifolium*) have a better chance of travelling to a bare patch of ground along the river's edge than other small seeded species. Many Poaceae species have seeds with small wings which allow them to float or fly for restricted distances. Many Cyperaceae form new plants at the end of their long spikes which add weight to the tips, bringing them down to the ground where it then forms roots and an entirely new plant; or alternatively, these vegetative young plants can be broken off and travel in the river channel to establish themselves in a new area. Within this study, seedling germinants of riparian species tended to belong to either Poaceae or Cyperaceae with few belonging to Restionacae or Asteraceae. Fewer annuals were present within the wet zones when compared to the fynbos germinants represented in the dry or transitional zones. Initial germination and establishment by Poaceae and Cyperaceae representatives was rapid throughout all samples, with a swift decline following the first month. Thereafter, a slower phase of germination was reflected by Ericeaeae and Restionaceae species.

Many of the species that characteristically form seed banks are early succession species (Warr *et al*. 1993). Within this study, most of the species that were identified in the first three months were noted to be pioneer species. Succession within the fynbos communities is said to be fairly constant after the initial post-fire flush or annuals and geophytes. Species are then successively eliminated according to life spans, thus differences in life histories rather than competitive abilities is thought to drive succession in fynbos communities (Bond and van Wilgen 1996). Riparian communities, however, may have higher levels competition as a result of less frequent fires enabling more stable environments which support more permanent plant life form such as trees and woody shrubs. With such unique systems present in both riparian and terrestrial fynbos communities, a true comparison in seed bank composition abilities is difficult.

In addition, seed banks are notoriously variable and complex and floristic representation is often biased as a result of the differences amongst species in seed production, dispersal and longevity in the soil. The general consensus is that seeds have irregular clustered spatial distribution, dictated by both biological and environmental factors. Within river systems, the irregular clustering can be even more skewed with the influence of pockets along the bank of high deposition rates. This was indeed true within this study where seed bank samples offered a variety of germination results regardless of the uniform environmental conditions experienced by all. One environmental factor that was found to significantly skew germination results was the presence of fire in the sampled habitat. Germination success from the Berg River system is perceived to be a direct result of the fire regime and the relatively natural state of the vegetation (i.e not heavily invaded). It is therefore suggested that a conservative use of fire be utilized in conjunction with other site specific restoration techniques to increase success.

Results from this study reiterate previous findings that seed banks offer little reference to current aboveground vegetation, but rather offer insight into past vegetation groupings as well as future vegetation assemblages (Warr *et al*. 1993). Evidence is shown that in relatively natural environments (<25% invasion), the potential for the seed bank to recruit a vegetation community similar to that of previous years is highly possible. However, the success rate of riparian seed banks as conservation tools of disturbed areas is completely dependent on the history of the site. If, for example, the area is so greatly disturbed by flooding, erosion or mining that a large percentage of the topsoil has been lost, then relying on the soil-stored seed bank would be impractical. It is vital, therefore, for conservationists to educate and implement regulations with regards to development or alteration of natural environments, in order to successfully rehabilitate these areas post-disturbance. Seed banks can hold remnants of past vegetation species that have since been lost and can greatly assist in the restoration of alien-cleared areas if properly investigated and understood. The fynbos biome is under increasing stress due to development, agriculture and global warming. It is suggested that with the right equipment such as knowledge and dedication, seed bank restoration can play a vital role in both restoring and conserving the diversity within this fragile system.

Future research aims to elaborate on the potential of seed banks and will investigate highly invaded sites (>75%) along the same river systems (Berg, Eerste, Wit and

Molenaars) and to compare germination and vegetation diversity results. Results could offer estimates of alien invasion impacts on riparian seed banks, as well as suggested restoration techniques for managers and landowners to utilise in similar post-cleared environments.

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Appendix 2 – Seed bank species codes

SPECIES CODE	FAMILY	Genus/ Species	GROWTH FORM	Indigenous/ Alien
1A	Poaceae	Currently unknown	annual	indigenous
1 B	Poaceae	Currently unknown	annual	indigenous
1 C	Cyperaceae	Currently unknown	perennial	indigenous
1Ci	Cyperaceae	Currently unknown	perennial	indigenous
1D	Cyperaceae	*Ficinia* sp. ?	perennial	indigenous
1E	Cyperaceae	*Ficinia* sp. ?	perennial	indigenous
1F	Poaceae	Currently unknown	perennial	indigenous
1G	Cyperaceae/ Restionaceae	*Ficina oligantha/Isolepis* sp. *?*	annual	indigenous
1Gi	Juncaceae/Cyperaceae	*Juncus* sp. *?*	perennial	indigenous
1H	Poaceae	*Pentameris* sp. *?*	perennial	indigenous
1i	Poaceae	*Aira cupaniana*	annual	Alien
1ix	Poaceae	*Pentaschistis* sp. *?*	annual	indigenous
1J	Cyperaceae/ Juncaceae	*Juncus* sp. *?*	perennial	indigenous
2 (a)	Asteraceae	*Euryops abrotanifolius*	perennial	indigenous
2 (b)	Asteraceae	*Ursinia paleaceae*	perennial	indigenous
3	Asteraceae	*Senecio hastifolius/cordifolius*	perennial	indigenous
5	Aizoaceae	*Erepsia* sp.	perennial	indigenous
5B	Aizoaceae	*Carpobrotus edulis*	perennial	indigenous
6	Geraniaceae	*Pelargonium* sp.	perennial	indigenous
7	Currently unknown	*Phytolypia ?*	perennial	indigenous
8	Solanaceae	*Solanum retroflexum*	perennial	Alien
9	Currently unknown	*Hyareacum olercium?*	annual	Alien
9B	Asteraceae	*Conyza* sp. */ Hypochoeris radicata?*	annual	Alien
10	Fabaceae	*Acacia mearnsii*	perennial	Alien
11	Asteraceae	*Chrysanthemoides monilifera*	perennial	indigenous
12	Linaceae	*Cliffortia cuneata*	perennial	indigenous
13	Asteraceae	Currently unknown	perennial	indigenous
14	Polygonaceae	*Polygonum lapathifolium*	annual	Alien
15	Poaceae	Currently unknown	perennial	indigenous
16	Oxalidaceae	*Oxalis corniculata*	annual	alien
16b	Linaceae	*Argyrolobium lunare?*	perennial	indigenous
16c	Fabaceae	Currently unknown	perennial	indigenous
18	Plantaginaceae	*Plantago lanceolata*	annual	alien
19	Scrophulariaceae	Currently unknown	perennial	indigenous
20	Rubiaceae	*Anthospermum* sp.	perennial	indigenous
20B	Aizoaceae	*Lampranthus* sp.	perennial	indigenous
21	Restionaceae	*Ischryrolepis* sp.	perennial	indigenous
22	Fabaceae	*Hypocalyptus coluteoides*	perennial	indigenous
24	Scrophulariacea	*Sutera* sp.*/ Diascia* sp.*?*	annual	indigenous
25A	Currently unknown	Currently unknown	perennial	indigenous

25B	Asteraceae	*Cotula* sp.	annual	alien
26A	Asteraceae	*Helichrysum* sp.	perennial	indigenous
26B	Asteraceae	*Plecostachys* sp.	annual	indigenous
26 (a)	Asteraceae	*Helichrysum pandurifolium*	perennial	indigenous
27	Asteraceae	*Othonna quinquedentata*	annual	alien
29	Fabaceae	*Podolyria calyptrata*	perennial	indigenous
30	Thymelaeaceae	*Struthiolia striata*	perennial	indigenous
31	Crassulaceae	*Crassula* sp.	annual	indigenous
32	Campanulaceae	*Microcodon* sp. ?	annual ?	indigenous
33	Crassulaceae	*Crassula* sp.	annual	indigenous
34	Caryophllaceae	*Polycarpon* sp.	annual	alien
34B	Asteraceae	*Stoebe* sp	perennial	indigenous
35	Asteraceae	*Metalasia* sp.	perennial	indigenous
35 (b)	Scrophulariaceae	*Nemesia* sp. / *Sutera* sp./ *Hemimeris* sp.	annual	indigenous
37	Araliaceae	*Centella triloba*	perennial	indigenous
38	Lamiaceae	*Salvia* sp. *?*	perennial	indigenous
39	Lamiaceae	*Stachys* sp. *?*	perennial	indigenous
39B	Currently unknown	Currently unknown	Currently unnknown	indigenous
39C	Asteraceae	*Cotula pencea*	annual	alien
41	Scrophulariaceae	*Zaluzianskya capensis*	annual	indigenous
43	Asteraceae/ Scrophulariaceae	Currently unknown	Currently unknown	indigenous
44	Rutaceae	*Agathosma crenulata*	perennial	indigenous
45	Currently unknown	*Impleurum unicapsulare ?*	Currently unknown	indigenous
45B	Rosaceae	*Cliffortia strobilifera ?*	perennial	indigenous
46	Crassulaceae	*Crassula* sp.	annual	indigenous
48	Scrophulariaceae	*Zaluzianskya* sp /*Wahlenbergia* sp.?	annual	indigenous
49a	Campanulaceae	*Roella* sp. *?*	perennial	indigenous
49b	Ericaceae	*Erica* sp.	perennial	indigenous
51	Rosaceae	*Cliffortia* sp.	perennial	indigenous
52	Scrophulariaceae / Campanulaceae ?	*Chironia* sp. *?*	perennial	indigenous
52B	Campanulaceae	*Microcodon* sp./ *Roella* sp. *?*	Currently unknown	indigenous
52C	Fabaceae/ Euphorbiaceae	*Rhynchosia* sp./ *Indigofera* sp. / *Clutia* sp. *?*	perennial	indigenous
53	Crassulaceae	*Crassula* sp.	perennial	indigenous
54	Crassulaceae	*Crassula* sp.	perennial	indigenous
54 (b)	Crassulaceae	*Crassula sp*	perennial	indigenous
55	Rosaceae	*Pelargonium* sp.	perennial	indigenous
56	Droseraceae	*Drosera hilaris*	annual	indigenous