DEPARTMENT: WATER AFFAIRS AND FORESTRY
WORKING FOR WATER

EFFECTS OF ALIEN INVASIVES ON THE BREEDE RIVER

PROJECT REPORT

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1 INTRODUCTION

Invasive alien trees and shrubs, especially those belonging to the genera *Acacia, Pinus* and *Hakea* (Stirton 1978, Richardson *et al*. 1992, Richardson *et al*. 1997) infest large parts of the Fynbos Biome. *Acacia* species rank as some of the most severe invaders in the biome (Macdonald and Jarman 1984). The impact of alien invasives is widespread, but many authors (Henderson and Wells 1986; Macdonald and Richardson 1986; Wells *et al.* 1986; Rowntree 1991) claim that the riparian zones of rivers are most impacted areas in southern Africa. Although many studies have been conducted on the effects of aliens on fynbos diversity on flatlands, which are azonal, scant attention has been paid to riparian communities, which are structurally distinct (zonal systems) and generally consist of tree dominated communities in the natural state.

Riparian habitats form the interface between the river and the surrounding uplands, and are an important dimension of river ecosystems. The riparian vegetation found along rivers is determined by differences in the flow patterns along different river reaches, and by associated differences in the substrates (e.g. degree and type of rockiness, soil texture, pH, resistance and levels of wetness). Riparian habitats have distinct ecological functions related to their location along the river continuum (Vannote *et al*. 1980), and also function as important buffer zones, controlling the flux of materials between rivers and the terrestrial environment (Decamps, 1993).

Boucher (2002) defined the following lateral zones extending outward from the free water area in rivers to the outward end of riparian influence (Table 3.4): Aquatic Zone (consisting of a Free Water Subzone and a Rooted Aquatic Subzone); a Wetbank Zone (consisting of a Lower Wetbank Subzone, inundated during the wet period and an Upper Wetbank Subzone, inundated by wet season freshers) and a Drybank Zone (consisting of a transitional Lower Dynamic Subzone, inundated by annual wet season floods; a Tree-shrub Subzone, inundated by 2-20 year interval floods and a transitional Back Dynamic Subzone inundated by 20-50 year floods).

Riparian areas are prone to invasions by alien plants mainly due to easy access to moisture and periodic disturbances in the form of floods that modify the environment, disperse seeds, aid germination, provide seedbeds and remove competing plants (Richardson *et al*. 1997). Fire also plays a pivotal role in driving alien invasions, and is a feature of the Fynbos Biome to which many alien invasives are extremely tolerant (Richardson *et al.* 1997). Although fires are important in the establishment of a number of riparian species from seed (Rungo 1998), germination and resprouting is conditional on the temperature of the burn being fairly low. Woody invasive exotics, such as *Acacia mearnsi*i have an overlapping flowering period (October – April) with indigenous riparian species, but have hard-coated seeds which are more temperature tolerant and thrive under hotter fires. The superior fire resilience of the alien populations buffers them from local extinctions and damage under hot fires, which are more frequent in early summer. The heat of a fire breaks the dormancy of the *Acacia* seedbanks and a dense growth of *Acacia* seedlings is usually the result, with concurrently germinating fynbos species being rapidly out-competed. Thus with each successive wildfire, *Acacia* densities increase.

Concomitant with an increase in alien densities is a reduction in the light availability in the stand. Studies indicate that where an overstorey shrub forms a dense canopy, as opposed to a sparse canopy, understorey species richness is halved, suggesting that fynbos species are shade intolerant (Cowling and Gxaba, 1991). Other studies have also noted a decline in species richness with an increase in alien plant cover (Turpey 1986; Richardson *et al*. 1989) and recommend the clearing of alien stands before canopy closure is attained in order to enhance restoration potential of the indigenous flora.

The Western Cape appears to be the most heavily invaded of all the provinces, especially the wetter catchments of the coastal mountain ranges and broad coastal lowlands in the west and south. The worst effected systems are the Berg and Breede River catchments, with the Breede catchment having a condensed invaded area of 84 398 hectares (Versfeld 1998). The primary riparian invader is *Acacia mearnsii*, which tends to form monospecific stands that displace the indigenous fynbos and forest vegetation (Boucher 1978, Macdonald and Richardson 1986).

Many problems are associated with dense stands of *A. mearnsii*, such as an increase in riverbank erosion (Macdonald and Jarman 1984, Macdonald and Richardson 1986), an increase in the fuel load to such an extent that the soil may be sterilized during periodic fires and thus enhance periods of post-fire soil exposure (Macdonald and Jarman 1984, Breytenbach 1989, Cilliers *et al.* 2004) and a reduction in species richness under dense stands of alien species, particularly when the canopy cover of alien species exceeds 50 % (Richardson *et al*. 1989). Alien plants may also effect community processes such as succession, establishment, pollination, seed dispersal and herbivory of fynbos plants (Macdonald and Jarman 1984).

Fynbos vegetation normally occurs on acidic, nutrient poor soils (Kruger *et al*. 1982, Witkowski and Mitchell 1987). Nutrients are important in shaping vegetation structure and function in Mediterranean ecosystems (Kruger *et al*. 1982). Soils under Australian *Acacia* species were found to have a twofold increase in soil elemental concentrations compared to Fynbos soils (Musil and Midgley 1990). This enrichment has been ascribed (Musil and Midgley 1990) to the higher annual dry litterfall of the *Acacia* species (Milton 1981, Michell *et al*. 1986), higher foliar litter elemental concentrations (Milton 1981), and slower litter decomposition turnover times (Milton

1981, Michell *et al*. 1986). Australian heath plants adapted to poor nutrient status were negatively affected in nutrient enrichment experiments, with seedlings having a higher mortality rate and the life cycle of plants being disturbed (Specht 1963, Heddle and Specht 1975). While fynbos plants do not appear to be influenced to the same extent, Witkowski and Michell (1989) found herbaceous fynbos plants to grow better, with a more rapid nutrient uptake following nutrient additions, than their woody counterparts. Regeneration of indigenous fynbos plants, following clearing of invasive alien plants, is relatively poor (Holmes and Cowling 1997, Musil 1993), and the vegetation following clearing is normally dominated by grasses and further exotic plants (Milton 1980), compared to pure fynbos where the early successional stage is dominated by Restionaceae and coppicing shrubs (Hoffman *et al*. 1987). The impact of exotic *Acacia* species on the soil chemical status might be relatively short term (Van der Berckt 2002) due to the effect of fire (Stock and Lewis 1986) and the inability of sandy fynbos soils to store large quantities of nitrogen (Witkowski *et al*. 1990). However, some researchers are of the opinion that a changed nutrient status can negatively influence the re-establishment of indigenous species following clearing (Musil and Midgley 1990, Stock *et al*. 1995), particularly as nutrients can, in some cases, remain in the soil for prolonged periods of time (Heddle and Specht 1975).

Working for Water

Some exotic invasive plant species, including *A. mearnsii*, consume large quantities of water in comparison to the indigenous fynbos vegetation, with runoff from infested catchments being 30 – 70 % lower than from uninvaded fynbos (Richardson *et al*. 1997). Water supply is the most important constraint to development in the Western Cape Region (Versfeld 1993). This excessive use of water by alien plants, compared to indigenous fynbos vegetation, inspired the Department of Water Affairs and Forestry to start clearing invasive plants from water catchment areas and riparian zones (Anon. 1995/1996). The clearing programme, known as the “Working for Water” Programme, instigated in 1995 to tackle the escalating problem of invasive alien trees, particularly in mountain catchments and river courses. The main aim of the “Working for Water” programme are to secure the continued supply of water from natural systems, whilst providing employment opportunities for previously disadvantaged people. However, an equally important benefit may be long-term biodiversity conservation via the restoration of indigenous ecosystems (Holmes and Marais 2000).

A. mearnsii is difficult to control as it coppices easily after fire (Pieterse 1996) and after felling (Macdonald *et al.* 1985, personal observation). Large seed banks and annual seed fall have been reported for a number of *Acacia* species (Milton and Hall 1981, Dean *et al.* 1986) and *A. mearnsii* seems to be no exception (Sherry 1971, Boucher 1978). Seed are long-lived and may persist for more than 50 years in the soil (Boucher 1978). This provides an additional problem in controlling invasive *Acacia* species and may be the main reason why they are so successful in the south-western Cape (Milton 1981). *Acacia* seed often have a water impermeable seed coat, associated with longevity, keeping the seed from germinating until the seed coat is damaged (Rolston 1978). In addition, *A. mearnsii* seed germinates rapidly after fire (Boucher 1978, Pieterse 1996), and fire is a natural feature in the Fynbos Biome (Deacon *et al.* 1992).

1.1 BACKGROUND TO THE STUDY

Dr Charlie Boucher of the Botany Department, University of Stellenbosch was approached by Dr Christo Marias of Working for Water with a request that he submit a project proposal for an investigation of the potential impacts (positive and negative) of the alien removal programme in the Breede River Catchment. In response to this request, Dr Boucher approached Dr Richard Knight of Botany Department, University of the Western Cape and Dr Cate Brown of Southern Waters Ecological Research and Consulting cc (ER&C) to form a consortium for the project.

The resulting project proposal (originally submitted in 29 August 2000, reviewed and resubmitted on 31 January 2001) was thus a joint submission from Botany Department, University of Stellenbosch, Botany Department, University of the Western Cape and Southern Waters ER&C.

The full project team comprised:

Dr Charlie Boucher	University of Stellenbosch
Mr Eugene Pienaar	University of Stellenbosch
Dr Richard Knight	University of the Western Cape
Ms Joyce Loza	University of the Western Cape
Dr Cate Brown	Southern Waters ER&C
Mr Rodney February	Southern Waters ER&C
Mr Charles Pemberton	Southern Waters ER&C.

This report outlines the approach, methods, tasks, schedule and budget for the project[2].

1.2 OBJECTIVES

The proposed research programme aimed to investigate:

1. the potential impacts of alien vegetation on channel pattern and shape.

[2] A series of progress reports, minutes and other communications track the problems that arose in undertaking the project and the resultant change in the duration of and deliverables for the project (see Appendix 1). This information will not be repeated in the body of the report.

2. the potential impacts of alien vegetation on the biodiversity of riparian vegetation, and recovery rates after removal.

These aims were addressed through four main tasks. These were:

Task 1:	Analysis of historic aerial, orthophotographs and/or satellite images (Loza and Knight).
Task 2:	Assessment of the persistence and nature of the sediments in the riparian zone under different vegetation conditions, *viz.* alien-dominated, indigenous-dominated and following clearing (Pienaar, Boucher and February).
Task 3:	Assessment of the persistence of alien seed banks following the removal of the alien vegetation (Pienaar, Boucher, Brown and February).
Task 4:	Assessment of the species diversity in the riparian zone under alien-dominated versus indigenous-dominated communities (Pemberton and Boucher).

Duration of the project

The project commenced in March 2001 and was completed in June 2004.

1.3 THIS REPORT

This report provides the methods, results and conclusions for Tasks 2, 3 and 4 above. The methods, results and conclusions for Task 1 will be provided in a separate report, as Ms Loza took up employment with DWAF: WfW before the end of the study, and agreed to complete the report under the supervision of Dr Christo Marais of WfW.

The report is composed of the following sections:

Section 1 (this section):	Introduction, background and project team.
Section 2:	Description of the study area.
Section 3:	Assessment of the species diversity in the riparian zone under alien-dominated versus indigenous-dominated communities.
Section 4:	Assessment of the persistence and nature of the sediments in the riparian zone under different vegetation types, *viz*. alien-dominated, indigenous-dominated and following clearing.
Section 5:	Assessment of the persistence of alien seed banks following of the removal of the alien vegetation.
Section 6:	Relevance of this research for management of alien infested or previously infested catchments.

Section 7:	References.
Appendix A:	Key progress reports, minutes and communications.

2 DESCRIPTION OF THE STUDY AREA

The Breede River Basin drains an area of *c.* 12 600 km^2, bounded by the Skurweberge and Langeberge to the north and the Indian Ocean to the south. The Breede River Catchment is one of the most heavily invaded catchments in South Africa, having a condensed invaded area of 84 398 hectares (Versveld 1998). The primary riparian invader in the catchment is *Acacia mearnsii*, the impacts of which form the basis of this study.

Adjacent or nearby areas containing stands of natural vegetation and of *A. mearnsii* infestation were chosen along each of three rivers in the Breede River Catchment, namely the Wit, Molenaars and Holsloot Rivers. The Breede River Basin is divided up into six sub-basins, with all three of the study rivers falling into what is known as the Upper Breede River sub-basin (DWAF 1999).

2.1 THE WIT RIVER

The Wit River is a relatively short (*c*. 11.2 km), single channel, perennial river which drains the south-western slopes of the Slanghoekberge and the Obiekwaberge. In the study area the Wit River is transitional between a mountain stream and foothill-cobble bed river, and is characterised by deep bedrock/boulder-bottomed pools interspersed with longer riffle/run sections and occasionally short cascade sections.

The natural site is located *c*. 250 m upstream of the gauging weir at Drosterskloof, while the infested site is *c*. 100 m downstream of the weir, above the confluence with the Drosterskloof stream.

The riparian vegetation is well developed at the natural site, with the main impact at the site being slight infilling at the top of the left bank due to the construction of the road through the pass. The left bank at the infested site is constrained by a rocky outcrop, making transects on the left bank relatively short. Natural riparian vegetation is well established throughout the wetbank at the infested site, with the infestation being dominant from the top of the wetbank onwards.

2.2 THE MOLENAARS RIVER

The Molenaars River system constitutes a relatively large portion of the Upper Breede River. The Molenaars River originates in the Du Toit's Kloof Pass in the Klein Drakenstein Mountains and is fed by streams on the southern slopes of the Witteberge. It also drains the north-eastern slopes of the Klein Drakensteinberge, the northern Du Toitsberge (via the Tierstel River) and the south-eastern slopes of the Slanghoekberge. The Molenaars River is a perennial river, and joins the Breede River just north of Rawsonville.

Both the natural and infested sites were selected on the mainstem of the Molenaars River, with the natural site *c*. 200 m upstream of the DWAF gauging weir, and the infested site a further *c*. 2 km downstream of the weir. In this section the Molenaars is a foothill-cobble bed river, with the instream habitat being characterised by small to large cobbles and larger boulders. At the natural site backwater areas of sand occur which are inundated during the winter months. The infested site was characterised by very steep, exposed banks consisting of large cobbles and boulders. At the top of the cobble/boulder bank the gradient flattens out and the infestation is characterised by deep coarse sands.

2.3 THE HOLSLOOT RIVER

The Holsloot River is a perennial, foothill cobble-bed river, which drains the southern slopes of the Du Toitskloofberge and the northern slopes of the Stettynsberge. The Holsloot River joins the Breede River just upstream of the Papenkuils Wetland and Brandvlei Dam, *c*. 1 km outside of the town of Rawsonville. The major impact on the river is an in-channel dam, the Stettynskloof Dam, roughly 10 km upstream of the natural site.

The natural site is located *c*. 2.5 km upstream of the turn off to Dwarsberg Farm, while the infested site is located *c*. 3 km downstream of the turn off to Dwarsberg Farm, just before the pass. All transects at the infested site were located on the left bank owing to the right bank being heavily impacted by the building of the road. The river consists of a single channel at the infested site. The riparian zone is characterised by deep sands and large, old stands of *A. mearnsii*, which had been previously burnt. Clearings occur sporadically in the infested stands due to fallen trees.

The riparian vegetation at the natural site forms a closed canopy over the river. Back channels occur on both sides of the main channel which were only found to be flowing in mid-winter after heavy rains. The back channel on the right bank had been manipulated to form a pool, into which farm pumps had been installed.

Additional site descriptions are provided in Chapter 3, 4 and 5, where relevant.

3 SPECIES DIVERSITY IN THE RIPARIAN ZONE UNDER ALIEN-DOMINATED VERSUS INDIGENOUS-DOMINATED COMMUNITIES

C. Pemberton and C. Boucher

3.1 OBJECTIVE

The objective of this part of the study is to assess the effects of *Acacia mearnsii* invasion on the structure of indigenous riparian plant communities. It is hypothesised that the effects would be somewhat reduced relative to terrestrial systems as a result of the unique structuring of riparian systems.

3.2 METHODS

Sampling methods

Adjacent or nearby areas containing stands of natural vegetation and of *Acacia mearnsii* infestation were chosen along each of three rivers in the Breede River Catchment, namely the Wit, Molenaars and Holsloot Rivers. Six transects of 50 meters in length were established at each site. Density, percentage cover and height were recorded for each species found in samples of one square meter arranged along transects extending from the waters edge.

Data analysis methods

The vegetation sample data were analysed using the TURBOVEG (Hennekens 1996a) and MEGATAB (Hennekens 1996b) packages, which incorporate two-way indicator species analysis (using the TWINSPAN program). This process was followed by manual manipulation to smooth out aberrant patterns. These data emphasise the relationship between particular groups of species and environmental features. This is the classificatory approach based on Braun-Blanquet principles.

Diversity was assessed using richness (total number of species identified), species densities (mean number of species per plot), the Shannon-index, H (Shannon and Weaver, 1949), and the bias corrected form of the inverse of the Simpson's Index (I/D). The latter is expressed as a reciprocal so that as the index increases, so does diversity. Evenness of spread (equitability) was also calculated for each of the sites. The equations used for the Shannon index and inverse of the Simpson's index are as follows:

$$H = -\Sigma p_i \ln p_i;$$

$$I/D = 3 \frac{(n_i(n_i\text{-}1))}{(N(N\text{-}1))}$$

An analysis of variance was undertaken to determine whether differences existed between two or more of the population means (mean number of species per plot for each site). A further multiple comparisons test, the Fishers Least Significance Difference (LSD) method, was conducted to assess exactly which of the means differed statistically from one another.

3.3 RESULTS

Descriptions of Riparian Communities at the Study Sites

WIT NATURAL SITE

The Lower Wetbank Subzone is dominated by 1.0-1.5 m tall *Prionium serratum* Shrubland, with the sedge *Juncus lomatophyllus* occurring nearer the waters edge, and *Ehrharta ramosa*, *Elegia capensis* and *Restio pedicellatus* from the upper edge of the sedge. Scattered trees of between 4.0-5.0 m of *Metrosideros angustifolia* and *Morella serrata* also occur in the Lower Wetbank Subzone. The Upper Wetbank Subzone is dominated by trees, 5.0-6.0 m tall, of *Metrosideros angustifolia* and *Morella serrata*. Scattered elements beneath the canopies include *Erica curvirostris, Ischyrolepis sieberi*, *Ischyrolepis tenuissima* and *Stoebe plumosa*. At the top of Wetbank Zone the *Metrosideros angustifolia* and *Morella serrata* trees are interspersed with 2.0-3.0 m tall clumps of the restio *Cannomois virgata*. The Tree-shrub Subzone of the Drybank Zone is characterised by 5.0-7.0 m *Brabejum stellatifolium* trees combined with other tree and shrub elements, including *Heeria argentea*, *Podocarpus elongatus* (mainly on the cooler south-facing banks), *Cassine peragua*, *Maytenus acuminata* and *Myrsine africana*. The understorey of the Tree-shrub Subzone consists of scattered *Aristea macrocarpa, Pellaea pteroides*, *Pteridium aquilinum, Rhus angustifolia* (2.0-3.0 m) and *Zantedeschia aethiopica*. The Back Dynamic Subzone is dominated by *Pteridium aquilinum*.

WIT INFESTED SITE

The Wetbank Zone of this infested site is virtually free of infestation by *Acacia mearnsii* or of any other woody invasive species. It is dominated by *Prionium serratum* Shrubland. Other dominant elements found in this zone include *Brabejum stellatifolium*, *Metrosideros angustifolia* and *Morella serrata*. Many of the larger shrub and tree elements that are dominant in the Upper Wetbank, Tree-shrub and Back Dynamic Subzones of the natural site, are present, but at a reduced cover-abundance level in the infested site. These include *Brabejum stellatifolium, Cannomois virgata*, *Metrosideros angustifolia*, *Morella serrata*, *Myrsine africana,* *Podocarpus elongatus*, *Pteridium aquilinum* and *Rhus angustifolia*. The infestation at this site is neither as old as that sampled along the Holsloot River, nor as dense as that of the infested site along the Molenaars River. As a result, the zonal structure is more pronounced than at either of the other infested sites.

HOLSLOOT NATURAL SITE

The channel of the Holsloot River at the sampling site is incised, with steep banks, and consequently almost no Wetbank Zone is present. *Prionium serratum* is sparsely situated in the open patches along the river where the canopy is not closed over. A closed canopy, forest community, 4.0-8.0 m tall, dominated by *Metrosideros angustifolia*, in combination with *Brabejum stellatifolium, Brachylaena neriifolia, Morella serrata*, and *Salix mucronata*, forms the Tree-shrub Subzone. Other, more scattered elements include *Diospyros glabra*, *Kiggelaria africana, Maytenus acuminata*, *Rhus angustifolia* and *Pellaea pteroides*. In the open canopy patches within this forest community *Elegia capensis, Erica caffra* and *Stoebe plumosa* occur. The Back Dynamic Subzone is dominated by 2.0-3.0 m tall *Rhus angustifolia* and *Diospyros glabra*. *Cliffortia ruscifolia*, *Ehrharta ramosa*, *Hymenolepis parviflora*, *Ischyrolepis sieberi, Pentaschistis airoides* and *Salvia africana* are common within this subzone. Less common elements include *Aristida junciformis, Asparagus rubicundus*, *Briza maxima* and *Ehrharta calycina*.

HOLSLOOT INFESTED SITE

The channel is not as incised as it is at the natural site, and the bank has a lower gradient, allowing for a wider Wetbank Zone than is the case at the natural site. The Lower Wetbank Subzone at this site is not infested by *Acacia mearnsii*, and indigenous elements dominate this zone. As with the natural site, *Prionium serratum* is patchily distributed owing to shading by the larger indigenous forest elements from the Tree-shrub Subzone. The sedge *Juncus lomatophyllus* is also patchily distributed in the Lower Wetbank Subzone. A much-reduced 4.0-6.0 m tall *Morella serratum – Metrosideros angustifolia* Forest community dominates approximately the first 10 metres of the Tree-shrub Subzone. *Ehrharta ramosa, Pentaschistis airoides* and *Stoebe plumosa* are regularly present in the open patches in this forest community. The *Acacia mearnsii* infestation dominated from roughly 15 m from the waters edge. This site exhibits the oldest *Acacia mearnsii* infestation of the three sampled in this study. The trees are large (10.0-15.0 m tall) and well spaced, with clearings having formed from fallen trees and broken branches. The stand had been partially burnt and as a result seedlings of up to 0.25 m tall were prolific under the living larger trees. Within the infestation, very few remnants of the natural communities were apparent. *Diospyros glabra*, *Ehrharta ramosa*, *Ischyrolepis sieberi, Maytenus acuminata, Pentaschistis airoides*, *Stoebe plumosa* and were sparsely distributed throughout the infestation. The substrate at this site was mainly soft, deep sands.

MOLENAARS NATURAL SITE

The Wetbank Zone is dominated by both trees and shrubs, principally of *Metrosideros angustifolia, Morella serrata* and *Prionium serratum*, 1.0–3.5 m tall. *Calopsis paniculata* and *Erica caffra* are also present. The Lower Dynamic Zone is dominated by *Calopsis paniculata* and *Metrosideros angustifolia*, as well as *Brabejum stellatifolium*, *Erica caffra* and *Morella serrata*, while *Brachylaena neriifolia* and *Salix mucronata* are generally also present. The Tree/shrub Subzone is a 1.0 – 2.5 m tall shrubland comprised of *Halleria elliptica* and *Rhus angustifolia*. *Diospyros glabra* and *Maytenus oleoides* occur sparsely within this shrubland. The Back Dynamic Subzone is dominated by *Halleria elliptica, Ischyrolepis sieberi, Pennisetum macrourum* and *Pteridium aquilinum*, with *Merxmuellera cincta* being patchily distributed. The upper limit of the Back Dynamic Subzone is marked by the presence of 2.0-3.0 m tall *Protea nitida* shrubs.

MOLENAARS INFESTED SITE

Large boulders form the substrate in the Wetbank Zone of the Molenaars infested site. The river gradient and the Wetbank itself are steep and the high flow velocities occur during winter here that make it difficult for vegetation to establish. A few large *Brabejum stallatifolium* and *Metrosideros angustifolia* shrubs are the only permanent vegetation in this zone. Above the Wetbank Zone the gradient flattens and the substrate is soft sand overlaying cobbles and boulders. This is a fairly densely infested site, relative to the other two infested sites in this study. *Maytenus oleoides* shrubs, 1.0-2.0 m tall, are the most commonly occurring indigenous plants within the infested stand. *Diospyros glabra* (0.5-1.5 m tall) and *Rhus angustifolia* (1.0 – 2.0 m tall) shrubs are less abundant, while *Ischyrolepis sieberi* and *Pennisetum macrourum* are sparsely distributed in the sandy open patches. Occasional shrubs of *Cliffortia polygonifolia* and *Erica caffra* are present throughout the infested stand.

Diversity Indices

Table 3.1 provides a summary of the diversity indices calculated for all of the study sites, showing values for species richness, densities, the Shannon-Weiner Index, the inverse of the Simpson's Index and Evenness. The results for the different indices are also depicted in Figures 3.1-3.5.

Table 3.1 A summary of the diversity indices calculated for all of the study sites, showing values for species richness, densities, the Shannon-Weiner Index, the inverse of the Simpson's Index and Evenness.

Site Name	Species Richness	Mean no. of species/m^2	Shannon-Weiner Index	Inverse of the Simpson's Index	Evenness
Wit Natural	55	3.44	3.43	23.55	0.86
Wit Infested	32	2.8	2.71	9.68	0.78
Holsloot Natural	47	3.64	3.26	16.47	0.84
Holsloot Infested	25	1.88	2.38	3.04	0.74
Molenaars Natural	41	3.8	3.09	18.48	0.83
Molenaars Infested	17	1.51	1.76	5.76	0.62

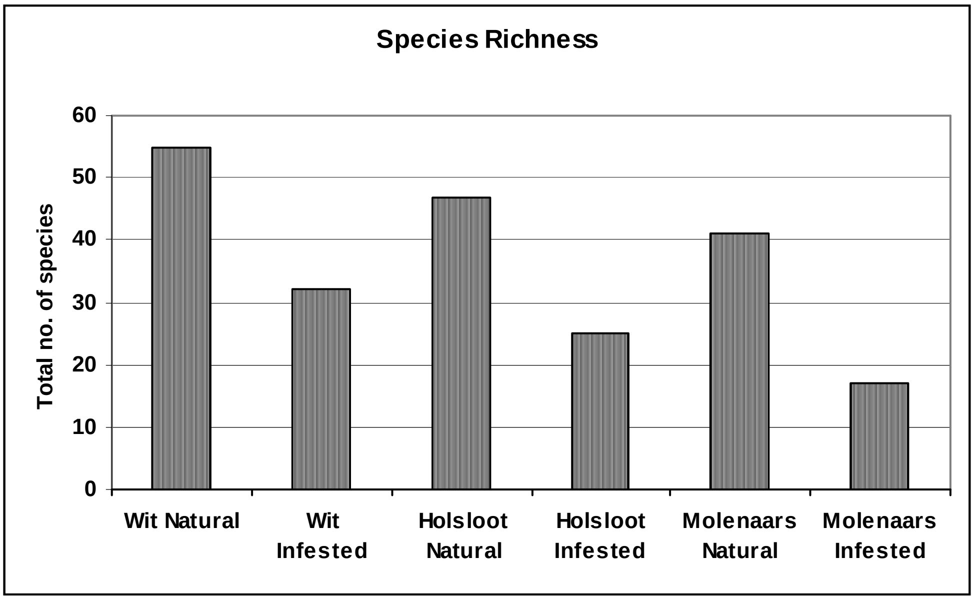

Figure 3.1 Differences in species richness between the six study sites.

All of the natural sites exhibited greater species richness than the infested sites. Species richness was greatest at the Wit Natural site, followed by the Holsloot, and then Molenaars natural sites. The species richness for the infested sites followed the same pattern as for the natural sites, with the Wit infested having the greatest number of species in total and the Molenaars site having the least.

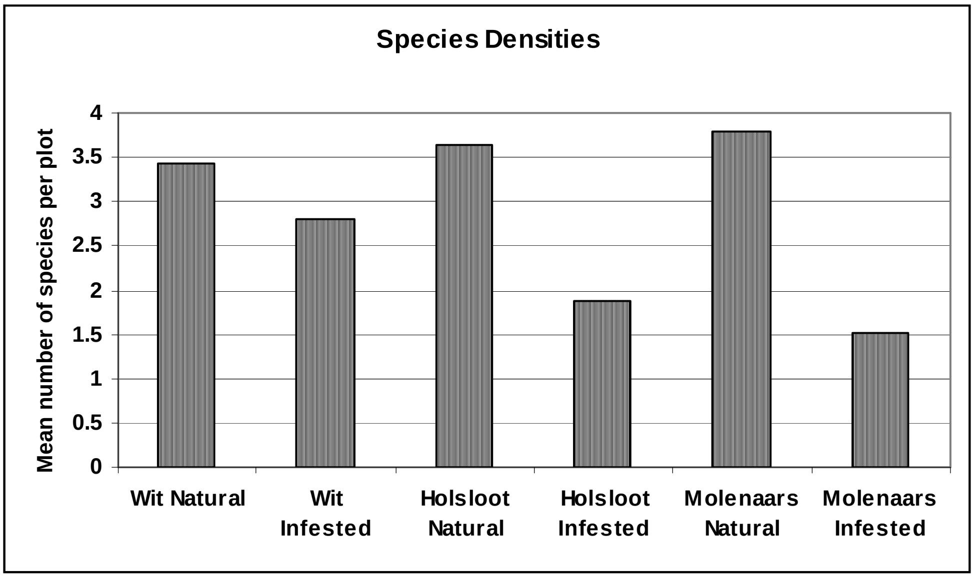

Figure 3.2 Differences in mean number of species per m^2 (species densities) for each of the study sites.

The mean number of species per m^2 sample plot was highest at the Molenaars natural site, followed by the Holsloot and then Wit natural sites. The reverse was found for the infested sites, with the Wit having the greatest number of species per m^2 and the Molenaars the least.

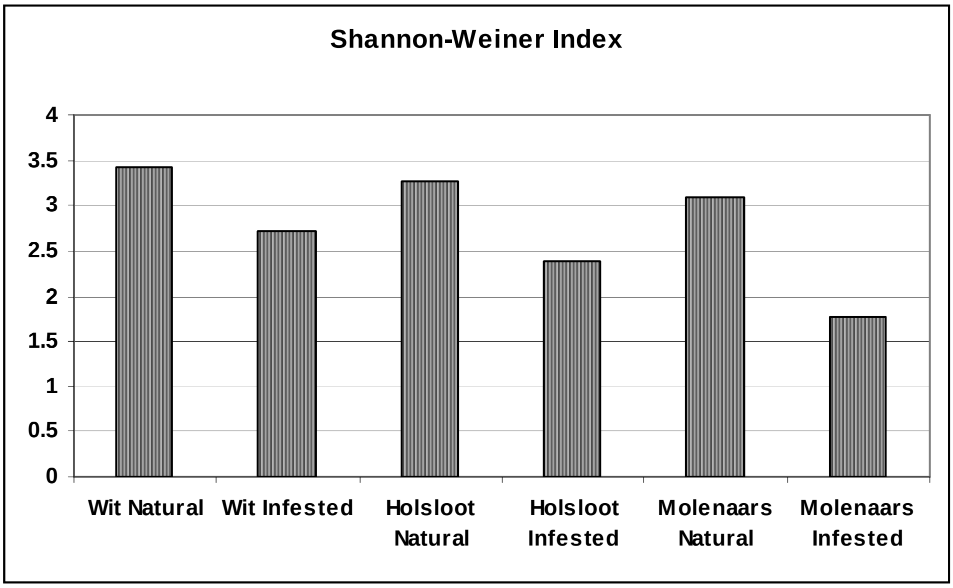

Figure 3.3 Differences in H (Shannon-Weiner Index) for the six study sites.

The Shannon-Weiner Index was highest for the Wit natural site, followed by the Holsloot and then Molenaars natural sites. The same pattern was found for the value of the index for the infested sites, with the Wit have the highest value and the

Molenaars the lowest value. The Shannon-Weiner Index for each of the natural sites was higher than that of any of the infested sites.

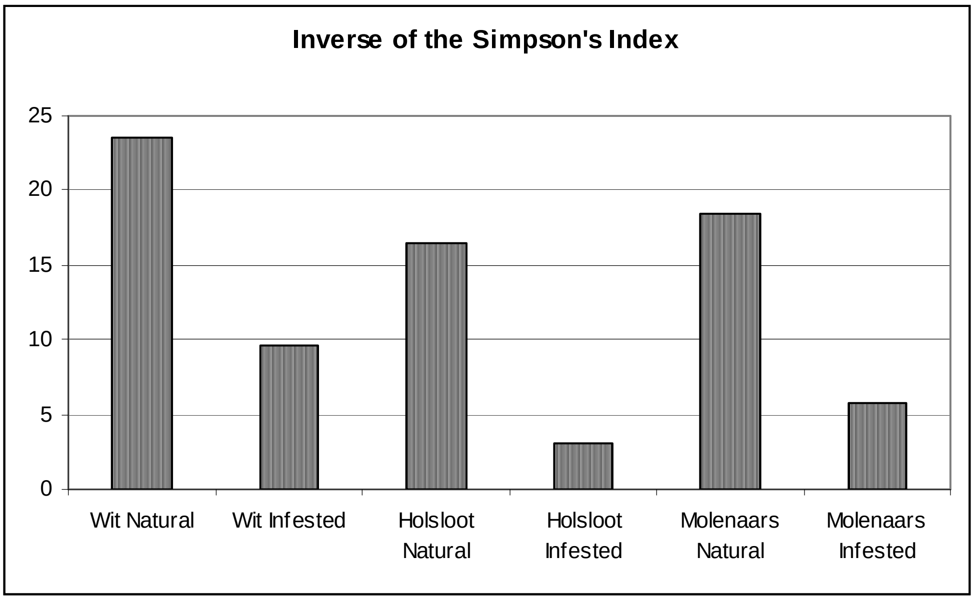

Figure 3.4 Differences between the inverse of the Simpson's Index.

The Wit natural site was found to have the highest value for the inverse of the Simpson's Index (1/D), followed by the Molenaars and then the Holsloot natural sites. The same pattern was found for the infested sites. The inverse of the Simpson's index for each of the natural sites was greater than that determined for each of the infested sites.

The evenness of spread of species for each of the natural sites is only marginally greater than that of the infested sites. The Wit natural site exhibits the greatest degree of evenness, followed by the Holsloot and then Molenaars natural sites. The same pattern was found for the infested sites.

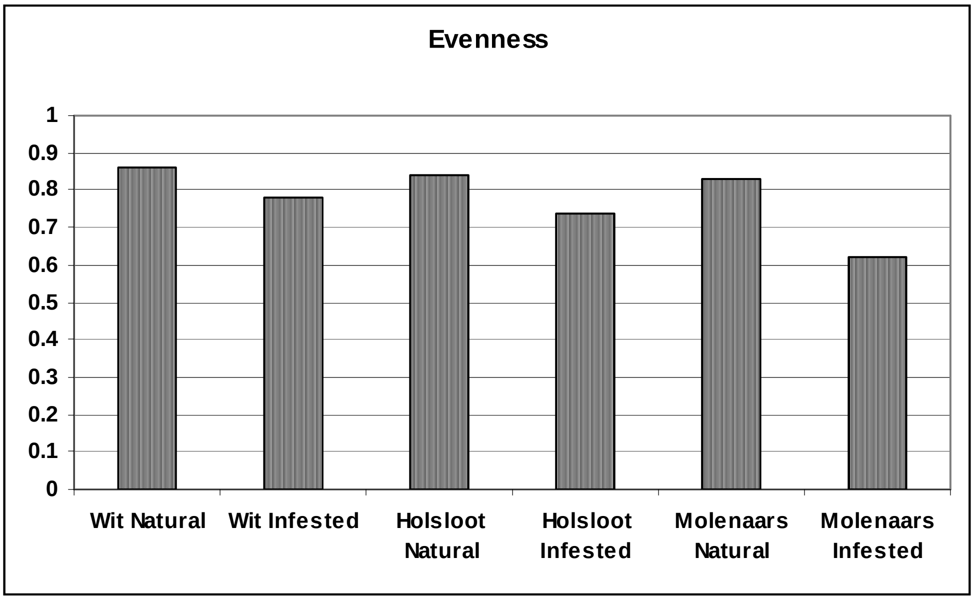

Figure 3.5 The evenness of spread of species (equitability) determined for the six study sites.

Analysis of Variance

An analysis of variance (ANOVA) was performed on the data for all of the six study sites. The ANOVA results showed that there was a significant difference at the 5% level between at least two of the sample means (P-value = 4E-86) (Table 3.2). Fishers Least Significance Difference method was used to determine which of the means differed significantly (Table 3.3). If the absolute value of the difference between the treatments is greater than the LSD value, then the two treatments are seen as significantly different. The highlighted blocks indicate the treatments that differ significantly. No difference was found between the treatments of the natural sites, whereas all of the infested sites were found to differ significantly from one another, as well as from the natural sites.

Table 3.2 Results of the analysis of variance.

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	974.9594	5	194.9919	97.20964	4E-86	2.221547
Within Groups	2411.08	1202	2.00589			
Total	3386.04	1207				

Table 3.3 Results of the Fishers Least Significance Difference method. The population means that differ significantly are shaded in grey.

Treatment	Treatment	Difference	LSD (alpha = 0.05)
Wit Nat	Wit Inf	0.64	0.29
	Hol Nat	-0.21	0.29
	Hol Inf	1.55	0.28
	Mol Nat	-0.36	0.29
	Mol Inf	1.92	0.28
Wit Inf	Hol Nat	-0.84	0.29
	Hol Inf	0.92	0.28
	Mol Nat	-0.99	0.29
	Mol Inf	1.29	0.28
Hol Nat	Hol Inf	1.76	0.27
	Mol Nat	-0.16	0.28
	Mol Inf	2.12	0.27
Hol Inf	Mol Nat	-1.91	0.27
	Mol Inf	0.36	0.26
Mol Nat	Mol Inf	2.28	0.27

Table 3.4 Model of relationships between lateral riverine vegetation zones and flow regimes (modified from Boucher and Tlale, 1999).

Zone	Subzone	Inundation interval	Abb.	Marker
				Debris Line
Dry Bank Zone	Back Dynamic Subzone (Transitional)	approx. >20 year floods	BD	
	Tree/Shrub Subzone	2- approx. 20 year floods	TS	
	Lower Dynamic Subzone (Transitional)	Within year floods	LD	
Wet Bank Zone	Shrub or Willow Subzone	Wet Season Freshers	WS	Bottom Dry Bank Top Wet Bank
	Fringing Sedge Subzone	Wet Season base flow Dry Season Freshers	WE	
Aquatic Zone	Rooted Aquatic Macrophyte Subzone	Dry Season Base Flow	AM	
	Algae	No flow	AA	Perennial Free Water

3.4 DISCUSSION

The observed species richness of the infested sites is roughly half of that determined for the natural sites (Table 3.1 and Figure 3.1). Riparian vegetation in the Fynbos Biome therefore has the same tendencies as the general surrounding fynbos shrublands where the understorey species richness is halved when overstorey shrubs form a dense canopy (Cowling and Gxaba 1991) irrespective of whether indigenous or exotic. The densest canopy was recorded at the Molenaars site, which experienced the largest reduction in species richness. However, species richness is largely uninformative, as it does not reflect the relative abundances of species that comprise the riparian communities. The Shannon-Weiner Index and Inverse of the Simpson's Index are more effective measures of species diversity as they account for both species richness and the evenness with which individuals are distributed among species (Krebs 1994).

The Simpson's Index is also referred to as a dominance index (Van der Maarel 1997), which weights towards the abundance of the most common species. The index gives the probability of any two individuals drawn at random from a community belonging to different species. The inverse of the Simpson's Index is also given because an increase in this index is comparable to an increase in diversity. Values for the infested sites are low relative to the natural sites, showing the high proportion and dominance of *Acacia mearnsii*. The high values of the inverse of the Simpson's Index for the natural sites show that species are more equally represented. Overall, the inverse of the Simpson's Index (Table 3.1; Figure 3.4) shows that diversity is considerably reduced in the infested sites relative to the natural sites.

Values for the Shannon-Weiner Index (H) for typical communities generally lie between 1.5 and 3.5 (Kreb 1994). All of the natural sites had values for H greater than 3.0, indicating a high degree of diversity. The H-values for infested sites were lower than those of the natural sites, and ranged from between 2.7 (Wit) and 1.76 (Molenaars). These values correlated with the density of the invasion, in that the denser the infestation, the lower the H-value, or species diversity.

The Lower Wetbank Subzone of the infested sites was found to be generally free of alien invasion and accounts for most of the indigenous species sampled along transects at the infested sites. This pattern is also reflected in the evenness values (Table 3.1 and Figure 3.5) for the infested sites. The evenness or equitability of species within a community impacts upon diversity by increasing diversity if species are evenly distributed, or decreasing diversity if species distribution is clumped (Van der Maarel 1997). Indigenous species are either confined to the Lower Wetbank Zone or occur in the more open patches along the infested transects. This creates clumped distributions of indigenous species and decreases diversity.

Acacia mearnsii seems to be excluded from the Lower Wetbank, probably due to the high velocities of winter flows, which wash seedlings out before they establish properly. A different suite of invasive species, including *Sesbania punicea* and *Salix babylonica*, would invade the Lower Wetbank. This research project targeted areas invaded by *Acacia mearnsii*, consequently other invaders were inadvertently avoided. Reductions in flows could cause further invasion of the Wetbank by *Acacia mearnsii*, and concomitantly in further reductions in riparian plant diversity.

Results of the ANOVA and Fishers LSD test showed that the mean densities between the infested sites, and between the infested and natural sites differed. The mean densities between the natural sites were all statistically similar. The reasons for the differences between the infested sites can be attributed to differences in the age and degree of infestation. The Molenaars is the most densely infested; the Holsloot has been infested the longest, while the Wit has the lightest infestation. This has led to physical differences in habitat, which effected the structuring of the communities.

Indigenous plant species found in the Molenaars infested stand were limited to shade tolerant species, such as *Maytenus oleoides*, *Diospyros glabra* and *Rhus angustifolia*. Indigenous species found in the Lower Dynamic and Tree/shrub Subzones of the Molenaars natural site were almost completely absent at the infested site. The Holsloot infested site consisted of very large and old *Acacia mearnsii* individuals. Broken branches and fallen trees formed open patches, and it is in these clearings that indigenous elements were found to be present. The Wit infested site has the least dense infestation of invasive plants, and species richness, H-values, and 1/D values were higher than in any of the other infested sites. *Acacia mearnsii* trees did not form a closed canopy at this site, resulting in the presence of many of the larger elements dominant at the natural site in the Upper Wetbank, Tree-shrub and Back Dynamic Subzones.

Because these riparian plant communities are formed by forest elements, one expects them to be more tolerant of shading, but an increasing level of infestation appears to reduce their diversity. All of the indices calculated showed a reduction in either species richness or in general diversity of the riparian plant communities under *Acacia mearnsii* infestations. Invasions of the woody alien *Acacia mearnsii* trees into the riparian zones in the Fynbos Biome, as with general fynbos shrubland vegetation, clearly alters its composition and structure, and reduces overall species diversity. It is therefore imperative that the efforts to control invasions in this ecosystem, through the Working for Water programme, for instance, are continued as South Africa is signatory to the Convention on Biological Diversity and the conservation of the region's biodiversity is therefore a national priority.

4 THE PERSISTENCE AND NATURE OF SEDIMENTS IN THE RIPARIAN ZONE UNDER DIFFERENT VEGETATION TYPES

E. Pienaar and C. Boucher

4.1 AIM AND KEY QUESTIONS

The aim of this part of the study is to compared the variation in soils in riparian zones under stands of indigenous vegetation to those under dense woody alien *A. mearnsii* stands along the Breede River system, Western Cape, South Africa.

Four key questions are addressed:

1) Does the soil under riparian vegetation in different Western Cape rivers display differences in terms of pH, soil fractions (silt and clay, fine sand and coarse sand), carbon and resistance?
2) Are there significant differences between the soil under alien dominated sites from sites dominated by indigenous vegetation?
3) What is the lateral and vertical distribution of selected soil properties?
4) To what extent does the soil under a previously invaded site resemble the soil under natural vegetation 10 years after clearing?

4.2 STUDY AREA

Sites were selected in the foothill reaches of the Wit, Molenaars and Holsloot Rivers. In each river, an area was chosen that was densely invaded by *A. mearnsii*, referred to here as an invaded site, compared to an ecologically similar area that is relatively natural and free of invasive plants, termed a natural site. In both the Wit and Molenaars Rivers the invaded and natural sites are situated within 1 km of each other, while in the Holsloot River they are about 3 km apart. An additional site was sampled in the Molenaars River, which was previously densely invaded but had been cleared by a Working for Water team ten years previously. This site (called the Molenaars River immature site) is situated between the invaded and natural sites, and currently supports indigenous vegetation interspersed with scattered juvenile alien plants. All three invaded sites have had dense, mature stands of *A. mearnsii* for longer than 20 years. The natural sites selected are all presently dominated by indigenous vegetation although sporadic clearing of alien vegetation has taken place through them in the past.

Soils in the Wit, Molenaars and Holsloot Rivers are derived from alluvial material from either weathered Cape Granite or sedimentary Table Mountain Group (TMG) materials, or a mixture of the two (De Villiers *et al*. 1964).

All sites in the Wit, Molenaars and Holsloot Rivers are situated in valleys with Mediterranean type climates, characterized by wet winters and dry summers. Most rain falls during April to September. Temperatures in these valleys can vary between 0–36℃ (Anon. 1988).

The Wit, Molenaars and Holsloot Rivers all form part of the greater Breede River system. All three rivers are prone to flooding their banks in winter, a feature typical of many fynbos mountain rivers, while low water levels are experienced during dry summer months.

4.3 MATERIALS AND METHODS

Soil samples were collected from riparian zones along the Wit, Molenaars and Holsloot Rivers along six transects per river perpendicular to the river bank, usually with three transects located on each bank. Soil was collected using a soil auger, at distance intervals of 1, 2, 4, 8, 16, 24, 32 and 45 m from the edge of the freewater, in 0.10 m depth intervals sampling every second depth interval, to a maximum depth of 1.10 m. All soil was air dried, after which it was analysed for pH (in KCl and H_2O), electrical resistance and carbon content (25 g of soil @ 900 ºC for 2h) using standard soil science techniques as described in Anon (1990).

Results were analysed using STATISTICA (Version 6.1.409). Data deviated from a normal distribution curve, consequently, the log values of the original data were used in the statistical analysis. Data were analysed in terms of individual rivers (Wit, Molenaars and Holsloot Rivers), condition of infestation (natural, invaded or immature) and overall trends with the variables carbon, pH, resistance and soil texture. No distinction was made between silt and clay fractions during soil analyses and silt and clay values were bulked into one textural class referred to as silt-clay.

Field codes used in the figures and text refer to river systems: Wit (W), Molenaars (M) and Holsloot (H) Rivers; and state of invasion: natural (N), invaded (I) or immature (Im). For instance, W-I and W-N would refer to the Wit natural site. I, N and Im in the figures refers to invaded, natural and immature sites respectively.

4.4 RESULTS

River fingerprinting

The soils examined from study rivers differ significantly from each other in terms of patterns of values for pH, soil texture fractions (silt-clay, fine sand and coarse sand), carbon and resistance (Figures 4.1 – 4.6), with each river having a unique soil fingerprint. pH recordings in some rivers are significantly lower in natural sites than in invaded sites (e.g. Holsloot River), but in other cases they are slightly higher although not always significantly so (Figure 4.1). The simultaneous comparison of all data for all the rivers indicates a significant negative correlation between pH and carbon (Figure 4.7), but this could not always be observed at the individual river level (Figures 4.1 and 4.5). A significant positive correlation exists between pH and resistance (Figure 4.8). This positive correlation can, in some cases, be observed at the level of individual rivers (Figures 4.1 and 4.6).

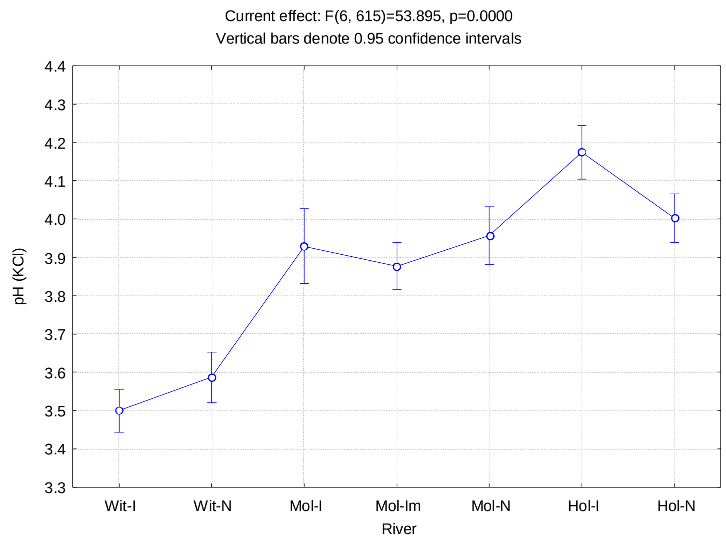

Figure 4.1 pH (KCl) values for soil from the Wit, Molenaars and Holsloot Rivers, natural and invaded sites.

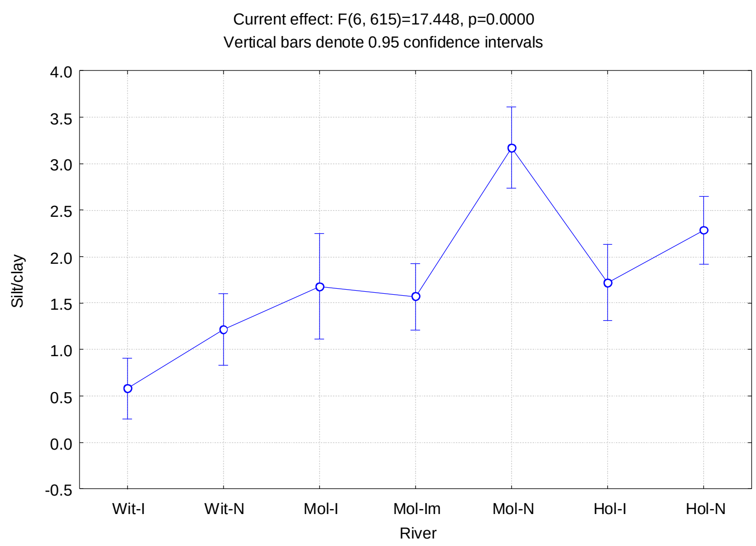

Figure 4.2 Silt-clay percentages for soil from the Wit, Molenaars and Holsloot Rivers, natural and invaded sites.

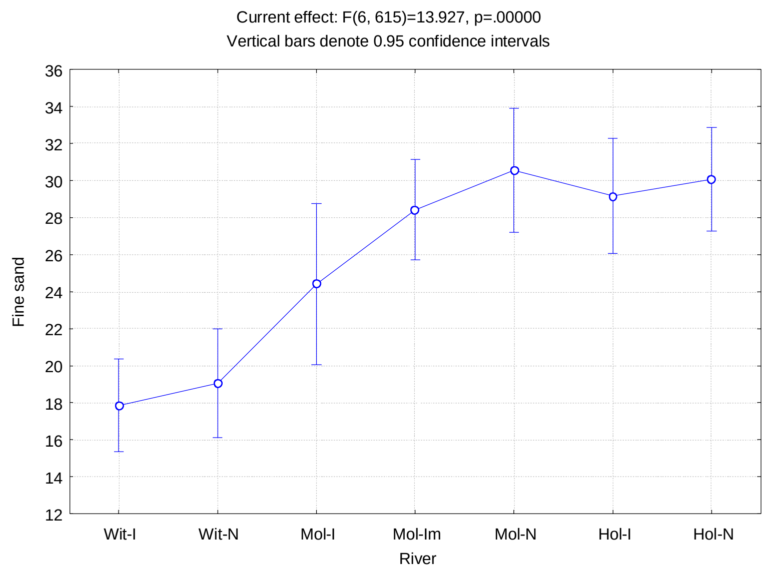

Figure 4.3 Fine sand percentages for soil from the Wit, Molenaars and Holsloot Rivers, natural and invaded sites.

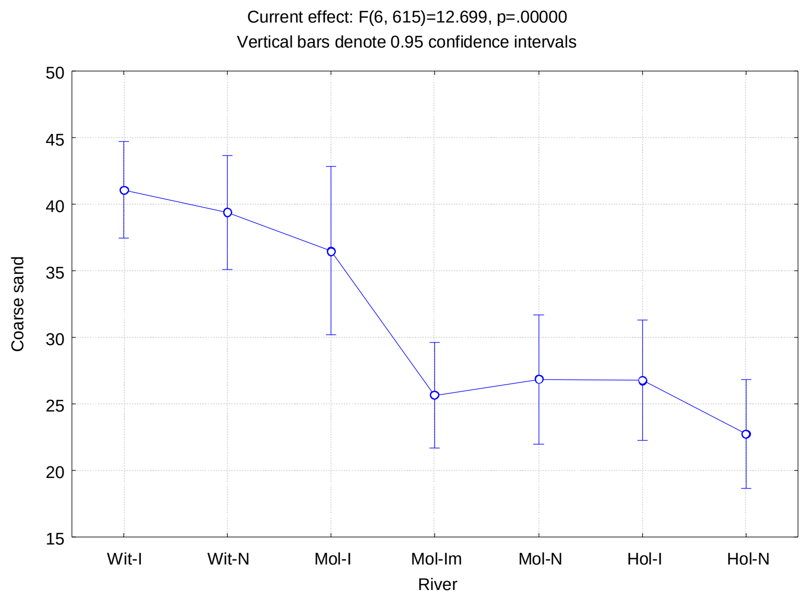

Figure 4.4 Coarse sand percentages for soil from the Wit, Molenaars and Holsloot Rivers, natural and invaded sites.

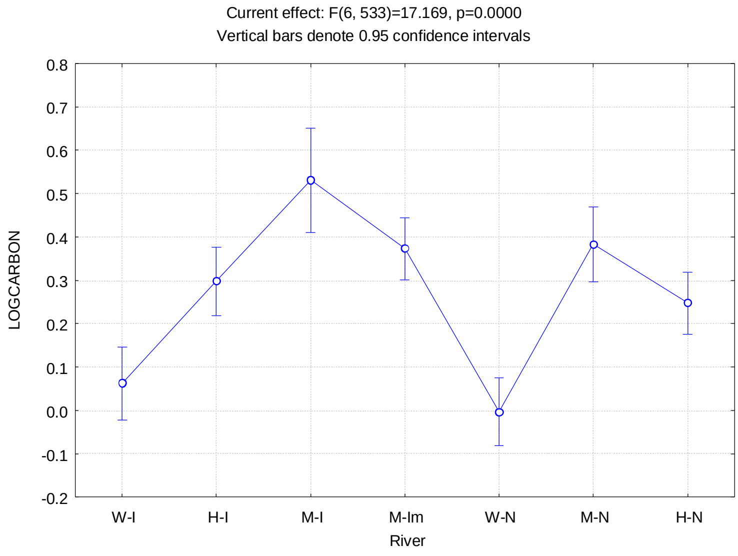

Figure 4.5 Log of carbon values for soil from the Wit, Molenaars and Holsloot Rivers, natural and invaded sites (note the change in order of the sites on the x-axis).

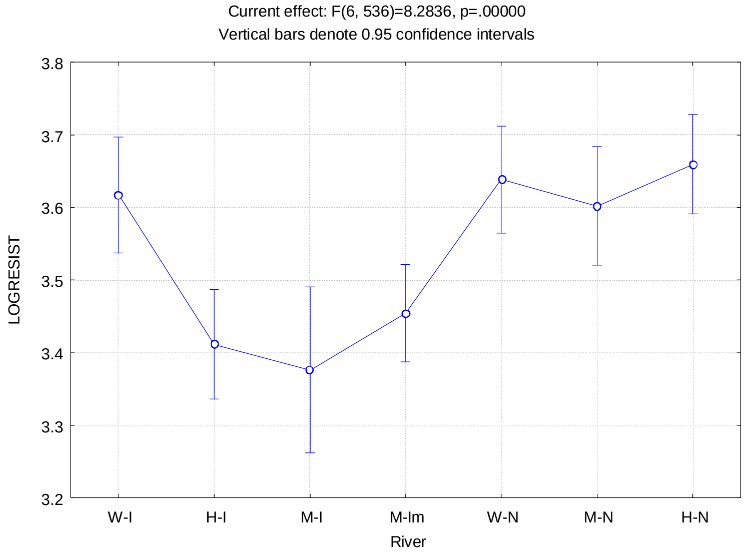

Figure 4.6 Log of resistance values for soil from the Wit, Molenaars and Holsloot Rivers, natural and invaded sites.

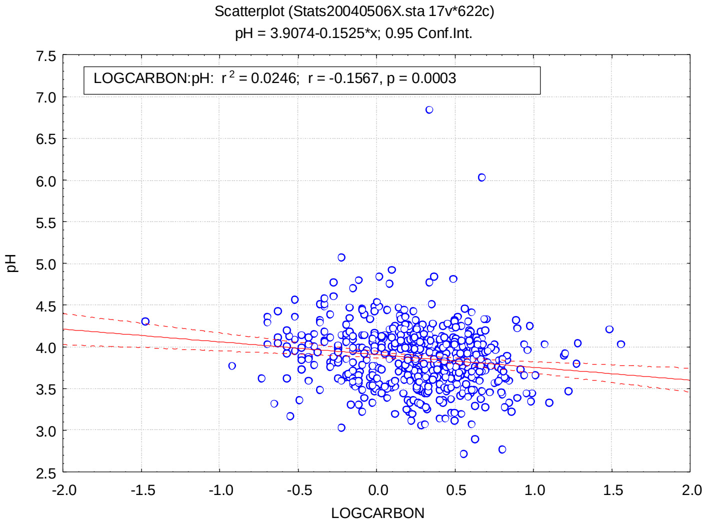

Figure 4.7 A scatterplot showing the correlation between pH (KCl) and log of carbon values, all sites.

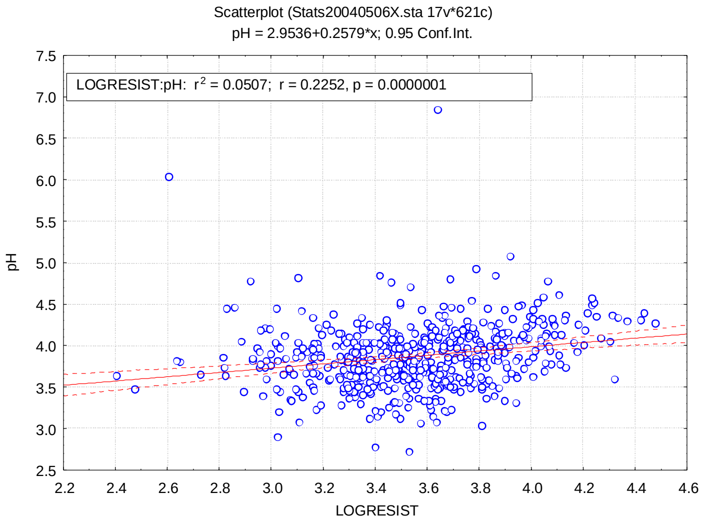

Figure 4.8 A scatterplot showing the correlation between pH (KCl) and log of resistance values, all sites.

Soil under natural vegetation compared to soil under alien dominated vegetation

Comparisons between pH and state of infestation (invaded, natural and immature) over all the samples in all the rivers together are insignificant (Figure 4.9). pH and carbon do not differ significantly between invaded and natural sites (Figures 4.9 and 4.10). A significant negative correlation exists between pH and carbon in the combined data (Figure 4.7), but once again this could not always be observed at the degree of infestation level (Figures 4.9 and 4.10). A significant positive correlation exists between pH and resistance in the combined data (Figure 4.8). This positive correlation can also, in some cases, be observed at the degree of infestation level with invaded sites having more acid conditions than natural sites (Figures 4.9 and 4.11). Soil resistance differed significantly between natural and invaded sites (Figure 4.11). A significant negative correlation exists between resistance and carbon (Figure 4.12) overall, but is not evident at different infestation levels (Figures 4.10 and 4.11). A significant negative correlation exists between resistance and silt-clay (Figure 4.13). In contrast, the correlation between resistance and silt-clay is positive at the degree of infestation level (Figures 4.11 and 4.14).

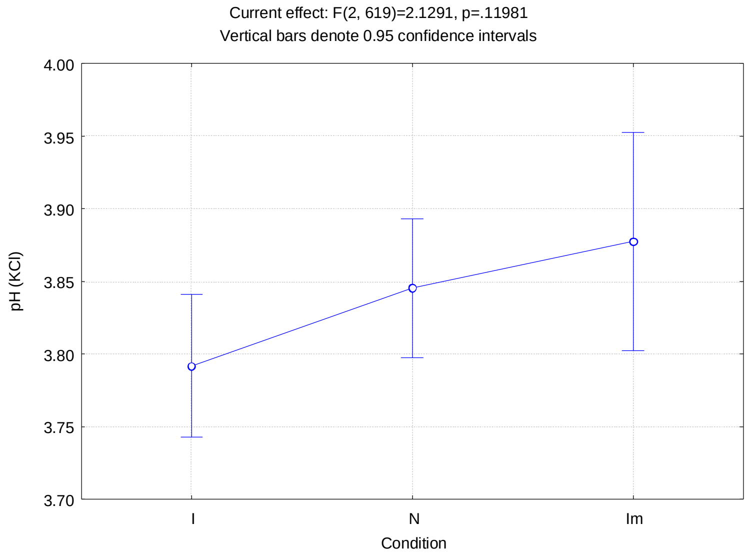

Figure 4.9 pH (KCl) values for soil from invaded sites (I), natural sites (N) and the immature site (Im).

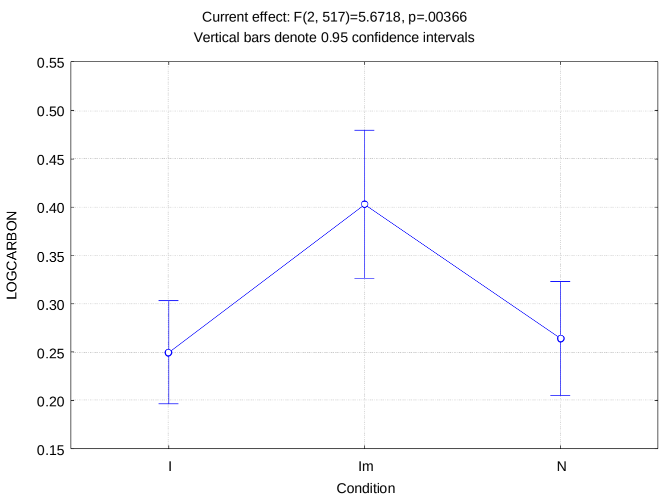

Figure 4.10 Log of carbon values for soil from invaded sites (I), natural sites (N) and the immature site (Im).

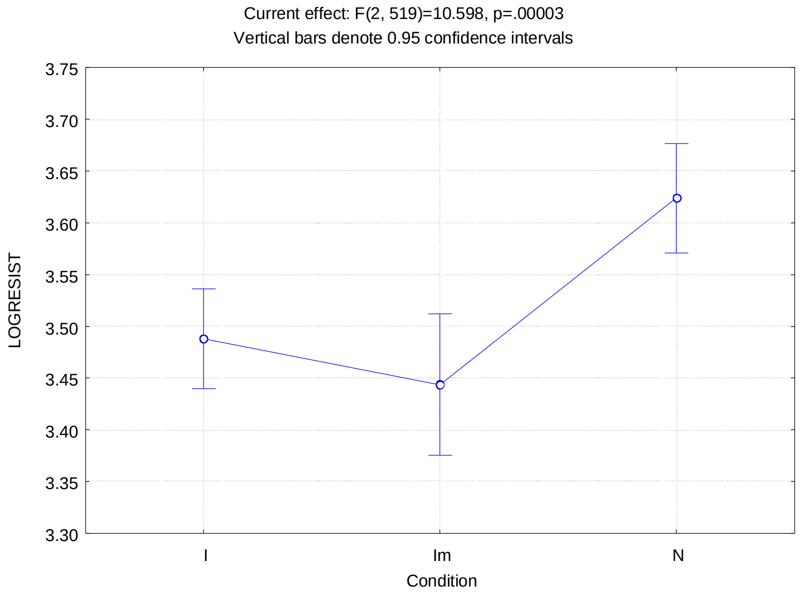

Figure 4.11 Log of resistance values for soil from invaded sites (I), natural sites (N) and the immature site (Im).

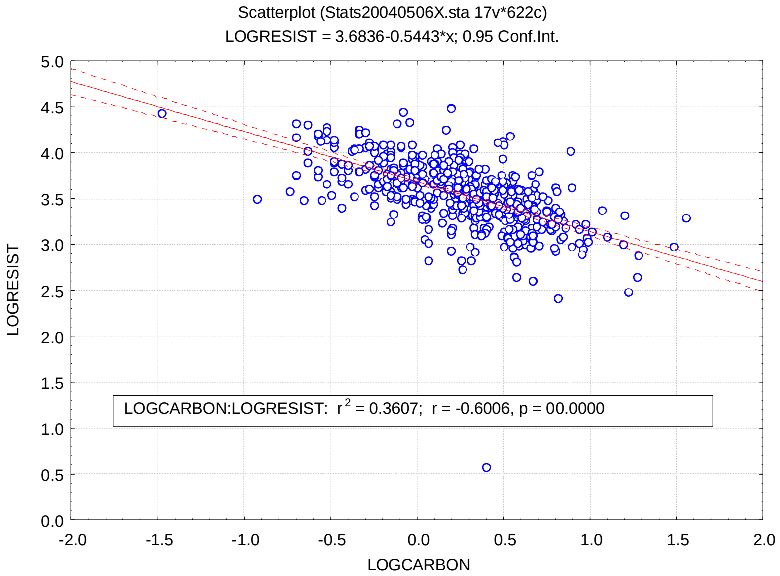

Figure 4.12 A scatterplot showing the correlation between log of resistance values and log of carbon values, all sites.

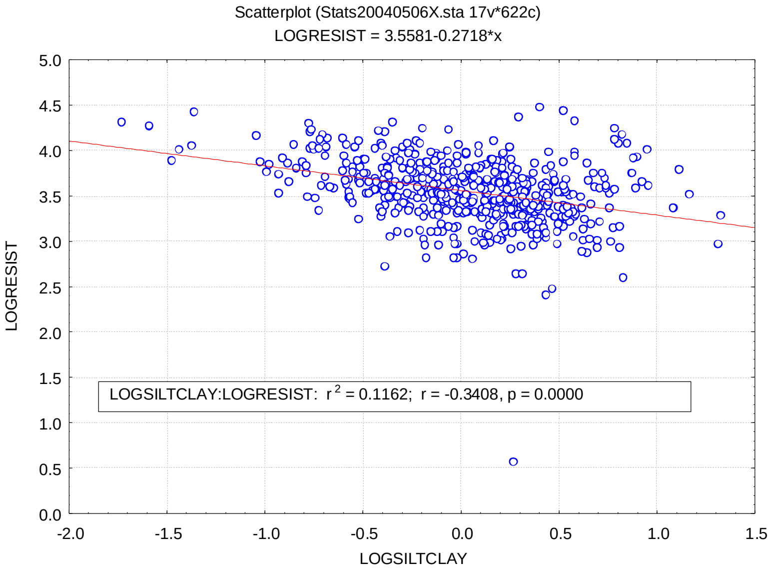

Figure 4.13 A scatterplot showing the correlation between log of resistance values and log of silt-clay values, all sites.

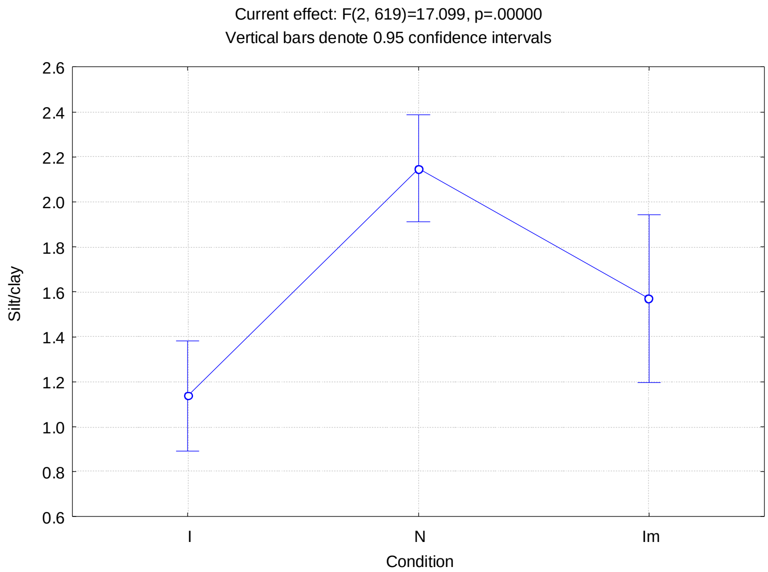

Figure 4.14 Silt-clay percentages for soil from invaded sites (I), natural sites (N) and the immature site (Im).

Natural sites contain significantly finer fractions (silt-clay) with less coarse sand than do invaded sites (Figures 4.14 and 4.15).

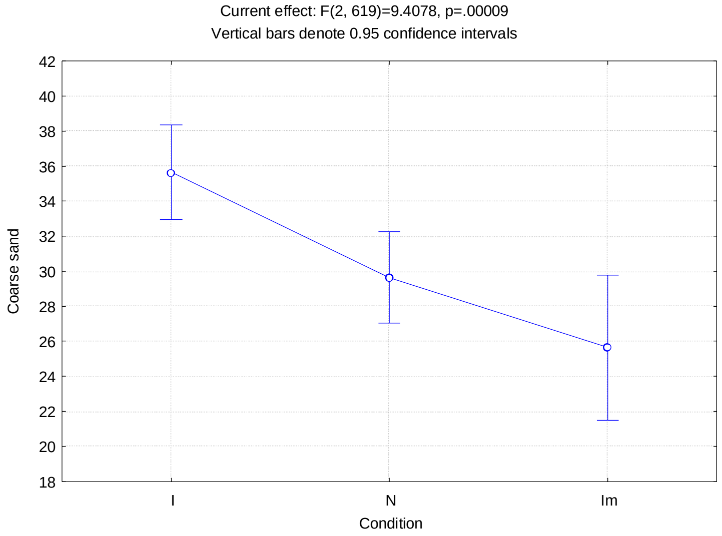

Figure 4.15 Coarse sand percentages for soil from invaded sites (I), natural sites (N) and the immature site (Im).

The lateral and vertical distribution of carbon, resistance and pH

Carbon decreases with increased distance from the water's edge (Figure 4.16) and with an increase in depth in the soil profile (Figure 4.17). However, carbon values for the natural, invaded and immature sites display a seemingly erratic pattern with an increase in distance away from the river bank (Figure 4.18).

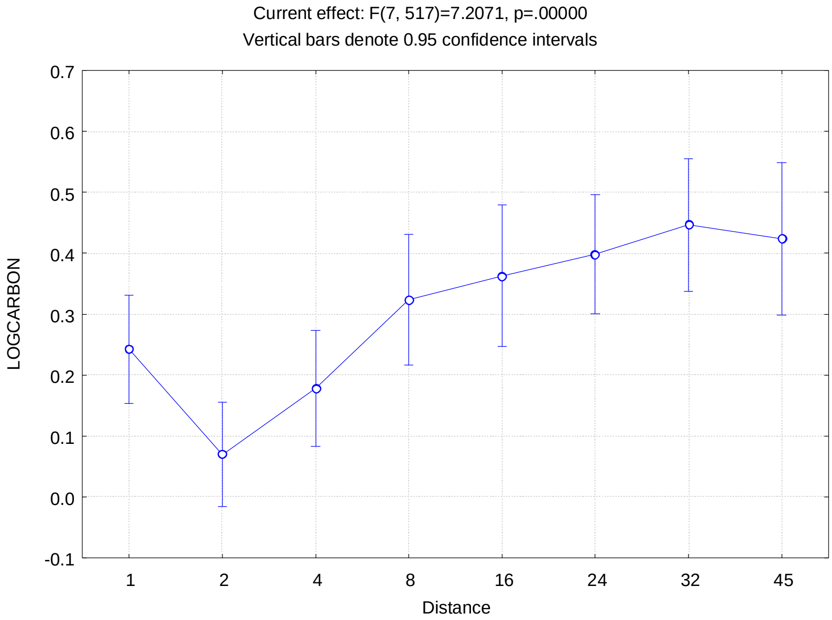

Figure 4.16 Log of carbon values with an increase in distance away from the river bank, all sites.

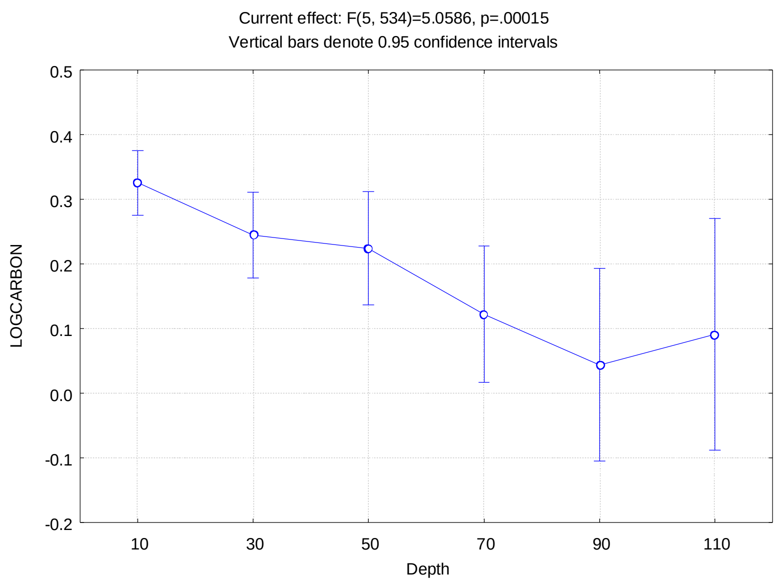

Figure 4.17 Log of carbon values with an increase in depth in the soil profile, all sites.

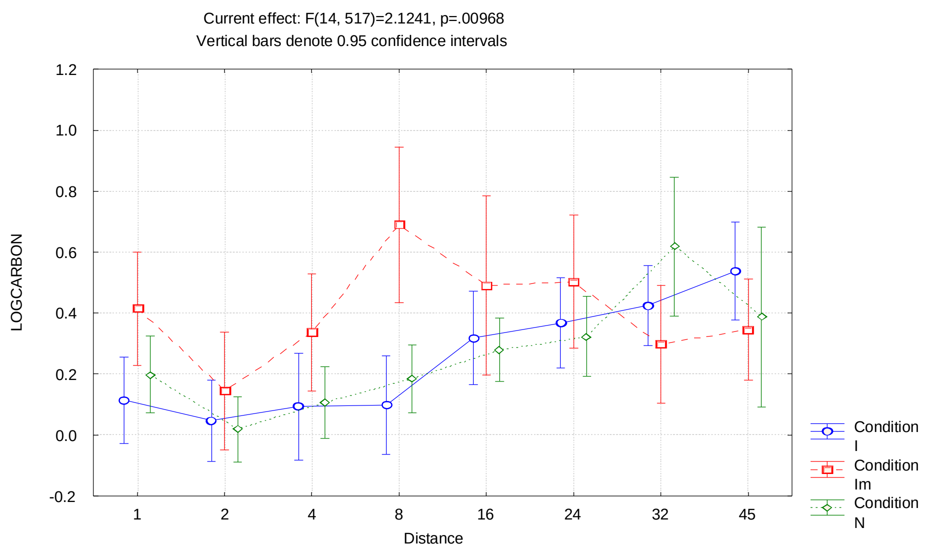

Figure 4.18 Log of carbon values with an increase in distance away from the river bank for the conditions invaded (I), natural (N) and immature (Im).

The silt-clay fraction generally increases with increased distance from the water's edge (Figure 4.19), while the coarse sand fraction decreases (Figure 4.20). pH decreases significantly with an increase in depth (Figure 4.21), while resistance increases (Figure 4.22). A significant negative correlation exists between resistance and carbon (Figure 4.12) and a positive correlation between resistance and pH (Figure 4.10).

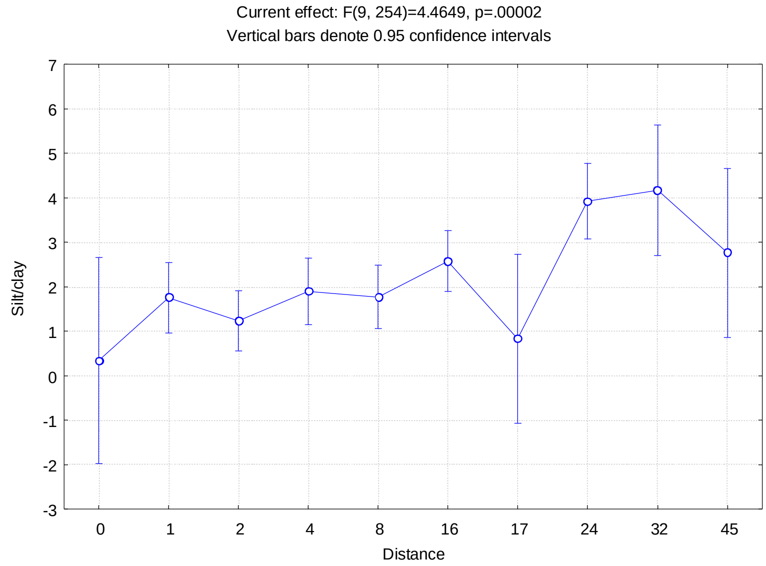

Figure 4.19 Silt-clay percentages with an increase in distance away from the river bank for natural sites.

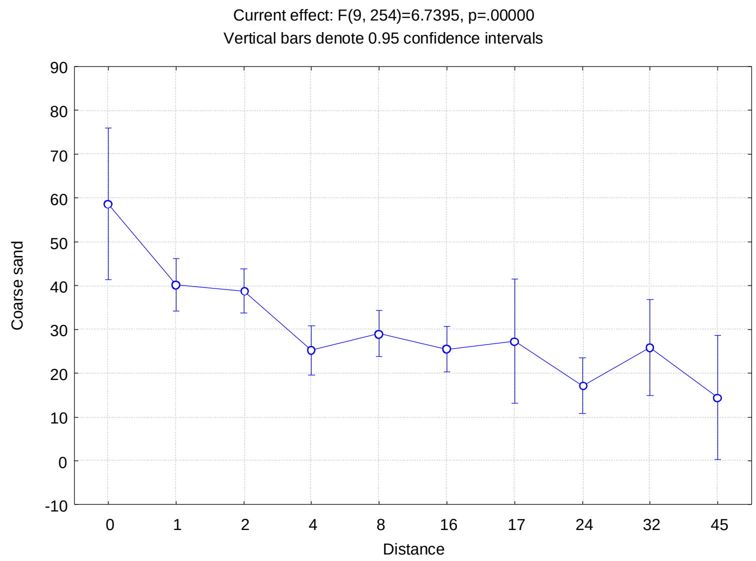

Figure 4.20 Coarse sand percentages with an increase in distance away from the river bank for natural sites.

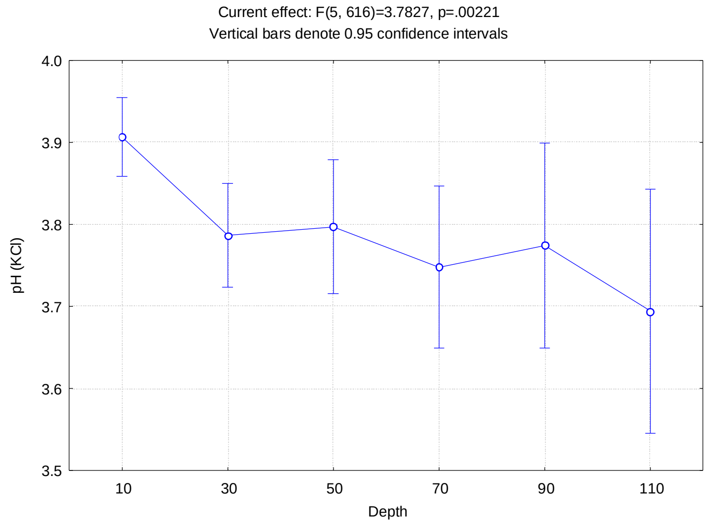

Figure 4.21 pH (KCl) values with an increase in depth in the soil profile, all sites.

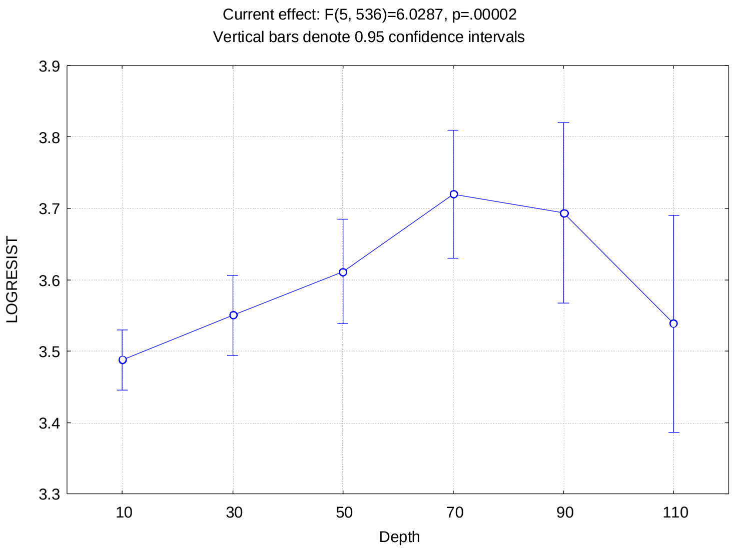

Figure 4.22 Log of resistance values with an increase in depth in the soil profile, all sites.

Recovery of a previously invaded site over the past 10 years

pH, soil texture fraction ratios, carbon and resistance values in the Molenaars River immature site are, in most cases, comparable to values from both the Molenaars invaded site and the Molenaars natural site (Figures 4.1 – 4.6). The Molenaars immature site has similar percentages of silt-clay to the Molenaars invaded site (Figure 4.2), and similar percentages of coarse sand to the Molenaars natural site (Figure 4.4). Resistance of soil under the immature site is similar to that of soil under the invaded site, and is significantly different from soil under the natural site (Figure 4.6).

4.5 DISCUSSION

River fingerprinting

Soils under both invaded and natural vegetation differ significantly between the Wit, Molenaars and Holsloot Rivers in terms of selected properties such as pH, soil texture fraction ratios (particularly of silt-clay, coarse sand and fine sand), carbon and resistance. Each river has a unique fingerprint of soil chemical properties in respect of carbon, pH and resistance. This is probably a result of differences in the substrates, rainfall and plant communities in the different catchments.

Different ratios of granite sandstone and shale parent materials contribute to differences in the soil texture signatures between rivers. Higher coarser soil fractions in some soils relative to other might be the result of more TMG sandstone parent materials in the catchments compared to more silt-clay where shales or granites are the more prevalent parent materials. A quantification of the contribution by different substrate types to catchment areas would provide more clarity about the cause and effect relationships of the different signatures observed in the different rivers.

Carbon and resistance have a significantly negative correlation to each other, with soils containing higher amounts of carbon having lower resistance values. Differences in the amounts of carbon in the soil are probably the result of each rivers fire history, density of indigenous and alien vegetation at present and in the past, flooding history, farming utilization differences, etc. Soils under natural vegetation in the Holsloot and Molenaars Rivers have significantly higher values of both pH and finer soil fractions (silt-clay and fine sand) than are found in the faster-flowing Wit River, although the correlation between pH and silt-clay, on average, is not significant. River soils are on a whole are more acid when a higher carbon percentage is present, but this could not be observed at the level of individual rivers. Parent materials, geology, rainfall etc. might override the effect of carbon on pH. The correlation between resistance and silt-clay are significant when all data points are used in the analysis, but this relationship could not be observed for the individual rivers, probably because of the low r^2 value.

Soil under natural sites compared to soil under alien dominated sites

Relatively higher percentages, despite low volumes, of the finer silt-clay fraction and lower percentages of coarse sand occur in soil under natural vegetation. This is attributed to the undergrowth in natural vegetation being far denser than that under alien vegetation. The undergrowth would slow the water’s speed down during floods allowing more silt and clay to be deposited.

Alien *Acacia* stands are known to have a higher litterfall volume than natural vegetation (Milton 1981), however, neither carbon nor pH differ significantly between natural and invaded sites.

A significant negative correlation generally exists between resistance and the silt-clay fraction. In this study high resistance values are found in soil under natural vegetation, the significantly higher percentages of silt-clay at these sites. Invaded sites produce more leaf litter contributing to a higher nutrient status than occurs under natural vegetation. However, these soils are unbuffered as they contain relatively low volumes of silt-clay, thus the nutrients are rapidly leached out of the river system. Consequently, the chemical differences between the soil under natural vegetation compared to invaded sites is realistically insignificant. Any influence on the soil chemistry, through for example increased litterfall, is likely to be nullified as a result of the unbuffered nature of the riverine soils.

The lateral and vertical distribution of carbon, resistance and pH

Leaf litter is continually added to the top layers of soil, leading to an increased amount of carbon compared to the deeper layers, while organic material is washed away closer to the river during flooding events. The influence of a back channel eroding organic material away during flooding can be seen in the profile for the Molenaars immature site in Figure 4.18.

Silt-clay increases with an increase in distance away from the river bank, while coarse sand decreases. The vegetation slows the flow speed of water further away from the river channel so that the heavier coarse sand fractions are deposited closer to the channel while the lighter silt-clay fractions are deposited progressively further away.

Resistance increases with an increase in depth in the soil profile, emphasizing the strong negative correlation between resistance and carbon. Carbon and the effect of resistance on pH are insignificant (in contrast to the significant negative correlation between carbon and pH, and the significant positive correlation between resistance and pH), with the increase in acidity as soil depth increases probably being the result of the permanently wetter nature of the deeper soils retarding decomposition.

Recovery of a previously invaded site over the past 10 years

Ten years after a Working for Water team cleared a mature *A. mearnsii* forest in the Molenaars River, silt-clay fraction levels are still comparable to those of the Molenaars invaded site, while the coarse sand values are similar to those under natural vegetation. Soil depth under natural vegetation is on average shallower than that under alien vegetation. Areas where coarse sand deposits occur are generally deeper than those with finer particles. River soils are highly erodable due to their high ratio of coarse fractions and low percentages of finer binding materials. Silt-clay percentages in soil under the Molenaars immature vegetation resemble that of soil under the Molenaars invaded site, probably because the indigenous vegetation in the Molenaars immature site has not recovered sufficiently to start acting as a trap for finer materials. Resistance values of soil under the Molenaars immature vegetation are similar to those in the Molenaars invaded site, and still differ from the soil under natural vegetation along the Molenaars River. This is possibly an indication of the longevity of the residual chemical effects of dense stands of *A. mearnsii* in respect of the soil properties examined here. However, in both the Molenaars invaded and Molenaars immature sites (± 1.6 %), and the Molenaars natural site (± 3.1 %), silt-clay percentages are so low that the differences between the two are again considered to be negligible.

4.6 CONCLUSIONS

Fynbos rivers each have their own unique fingerprint of soil chemical properties, a result of a combination of factors that differ between sites, such as parent materials, site history, rainfall, etc. Invasive alien acacias are known to increase soil nutrient status through the much higher annual litterfall compared to indigenous vegetation. Enriched soils might negatively effect the re-establishment of indigenous vegetation on areas where dense stands of alien plants has been removed. Significant differences have been found in this study between soils of previously invaded areas and soils under natural vegetation in terms of soil fraction distribution and resistance. However, soils in fynbos riverine systems contain very low percentages of silt and clay, rendering slight chemical changes to the soil under invaded sites (possibly as a result of prolonged periods of dense alien infestation), negligible due to the unbuffered nature of river soils. Less leaching, on average, takes place in soils of terrestrial fynbos ecosystems than in riverine ecosystems, and, consequently, the recovery of soils to a more natural state following the removal of the alien vegetation in terrestrial ecosystems might take much longer than in riverine ecosystems.

The soil in a previously densely invaded site has recovered significantly over the last 10 years. Coarse sand percentages resemble that of soil under natural vegetation, although the silt-clay percentage has not increased significantly over the last 10 years. We suggest that the indigenous vegetation has not been able to re-establish itself successfully on the deeper, sandy soils normally associated with invaded sites, even thought nutrient levels appear to have reached levels associated with natural vegetation. Build-up of sand in soils under invaded vegetation only erodes in floods during the first winter directly after clearing, before any regeneration has taken place. This process should be actively encouraged so that the river can return to a more natural profile sooner.

5 THE PERSISTENCE ALIEN SEED BANKS FOLLOWING THE REMOVAL OF ALIEN VEGETATION

E. Pienaar, C. Boucher and C. Brown

5.1 AIM AND KEY QUESTIONS

The aim of the tasks reported on in this Section was to investigate the distribution of *Acacia mearnsii* seed (hereafter only referred to as seed), along depth and lateral profiles, in natural and infested stands, along selected rivers in the Breede River system, Western Cape, South Africa.

We address four key questions:

1) How much seed, on average, occurs in natural vegetation and infested stands respectively, in the same or between different tributaries?
2) What is the distribution pattern of seed with an increase in depth in the soil profile on the riverbank?
3) What is the pattern of seed distribution along the bank with an increase in distance away from the water's edge?
4) Is there a distribution pattern in respect of viable seed?

5.2 STUDY AREA

Sites were selected in the upper reaches of the Wit, Molenaars and Holsloot Rivers. In each river an area was chosen that was densely invaded by *A. mearnsii*, referred to here as an invaded site, compared to an ecologically similar area that is relatively natural and free of invasive plants, termed a natural site. In both the Wit and Molenaars Rivers the invaded and natural sites are situated within 1 km of each other, while in the Holsloot River they are about 3 km apart. An additional site was sampled, in the Molenaars River that was previously densely infested, but had been cleared by a Working for Water team in approximately 1994. This site (called the Molenaars River immature site) is situated between the infested and natural sites, and currently supports indigenous vegetation interspersed with scattered juvenile alien plants. All three invaded sites have had dense, mature stands of *A. mearnsii* for longer than 20 years. The natural sites selected are all presently dominated by indigenous vegetation although sporadic clearing of alien vegetation has taken place through them in the past.

Soils in the Wit, Molenaars and Holsloot Rivers are alluvial materials from either weathered Cape Granite or Table Mountain Group sandstone, or a mixture of the two (De Villiers *et al*. 1964).

All sites in the Wit, Molenaars and Holsloot Rivers are situated in valleys with Mediterranean type climates, characterized by wet winters and dry summers. Most rain falls during the months of April to September. Temperatures in these valleys can vary between 0 – 36 °C (Anon. 1988).

The Wit, Molenaars and Holsloot Rivers all form part of the greater Breede River system. All three rivers are prone to flooding their banks in winter, a feature typical of many fynbos mountain rivers.

5.3 MATERIALS AND METHODS

Soil samples were collected from riparian zones along the Wit, Molenaars and Holsloot Rivers (see Study Area) along six transects per river perpendicular to the river bank, usually with three transects located on each bank. Soil was collected using a soil auger, at intervals of 1, 2, 4, 8, 16, 24, 32 and 45 m, in 0.10 m depth intervals, sampling every second interval, to a maximum depth of 1.10 m. Debris (mostly made up of organic material such as leaves, twigs and seeds) was scraped together off the soil surface. All soil was air dried, after which it was sieved and the seed extracted and counted manually.

Seed from different rivers and different depths were tested for viability by clipping the seed coat (Rolston 1978, Hendry and Van Staden 1982), allowing germination in the dark in a growth chamber set at 25 °C. Seeds were reg arded as having germinated once the radicle had protruded at least 2 mm.

Results were analysed using Microsoft® Excel 2000 graphs with standard error bars. Field codes used in the figures and text refer to river systems, transects and specific locations. For instance, W-I T1 P4 0.0 – 0.10 m, refers to an infested site along the Wit River on Transect 1, with the sample located 4 m away from the water's edge, at sampling depths 0.0 – 0.10 m. W-I 0.0 – 0.10 m would therefore refer to an average for baulked samples from the Wit River at a sampling depth of 0.0 – 0.10 m.

5.4 RESULTS

The average quantity of seed occurring in natural and infested stands respectively, in the same or between different tributaries.

Relatively large quantities of seed occur in soil under dense stands of *A. mearnsii* in riverine systems compared to soil under natural vegetation, which contain few, if any, seeds (Figure 5.1). Soil under natural vegetation in the Molenaars River contains more seed compared to soil under natural vegetation in the Holsloot and Wit Rivers (Figure 5.1). Soil under the Molenaars River immature stand contains an intermediate quantity of seed, significantly more than soil under natural vegetation, but less than soil under infested areas in the Molenaars River (Figure 5.1).

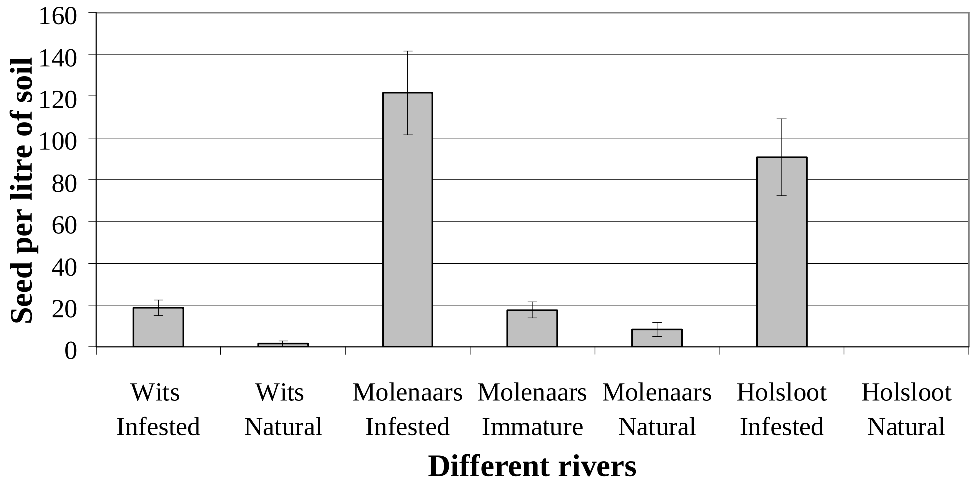

Figure 5.1 Average number of *A. mearnsii* seed per litre of soil under natural and infested areas in the Wits, Molenaars and Holsloot Rivers.

The distribution of seed, on average, with an increase in depth in the soil profile

More seed, on average, is concentrated in the top 0.30 m of soil (including the debris layer), although seed is mostly found up to the maximum sampling depth of 1.10 m (Figures 5.2, 5.3 and 5.4).

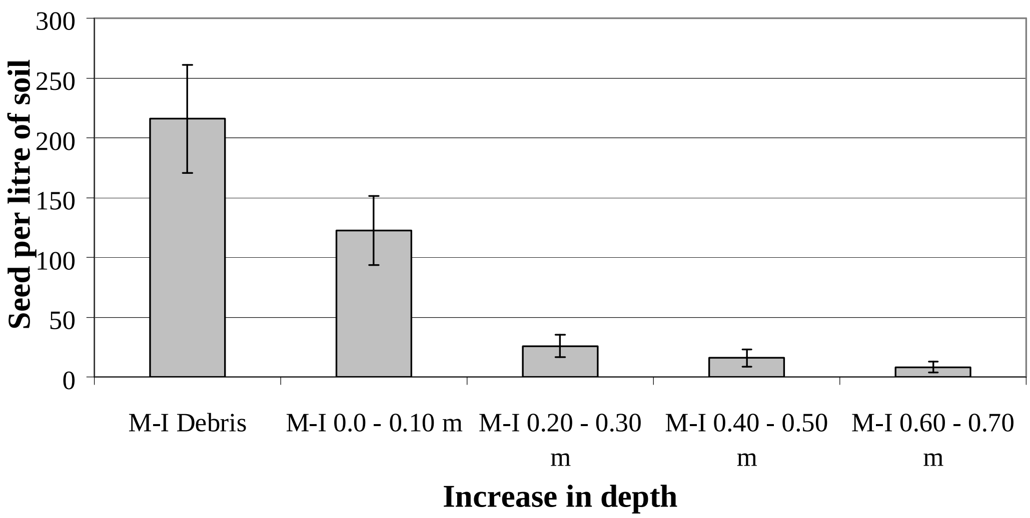

Figure 5.2 Average number of *A. mearnsii* seed per litre of soil with an increase in depth under infested areas in the Molenaars River.

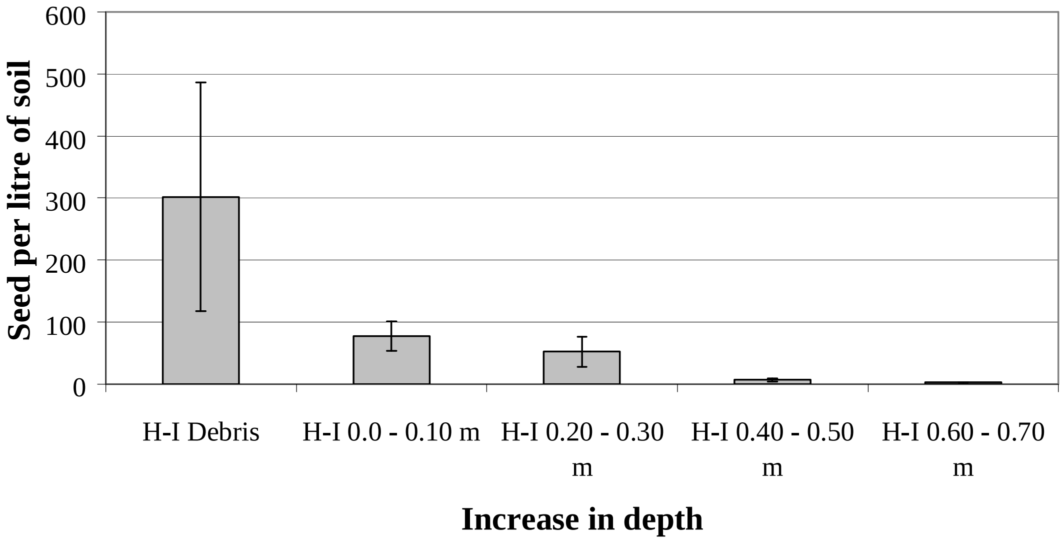

Figure 5.3 Average number of *A. mearnsii* seed per litre of soil with an increase in depth under infested areas in the Holsloot River.

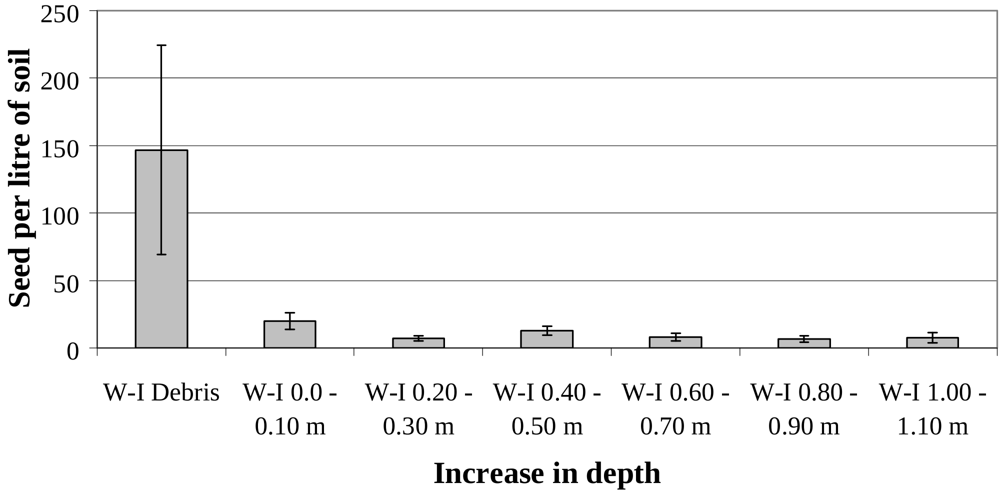

Figure 5.4 Average number of *A. mearnsii* seed per litre of soil with an increase in depth under infested areas in the Wit River.

Analysis of seed distribution patterns through individual soil cores can mostly be grouped into three distribution types: Pattern A) Regular (Figure 5.5), where the seed per litre of soil decrease with an increase in depth. Pattern B) Irregular (Figure 5.6), where the seed per litre of soil increase and decrease with an increase in depth, and Pattern C) Seed per litre of soil increase and decrease with an increase in depth, followed by a relatively steady decline in seed numbers with a further increase in depth (Figure 5.7).

The distribution of seed with an increase in distance away from the water's edge

Differences in the average number of seed per litre of soil per soil core with an increase in distance away from the river bank are apparent both at the level of sites (Figures 5.8, 5.9 and 5.10) and individual transects (Figures 5.11 and 5.12), although no set pattern exists in either.

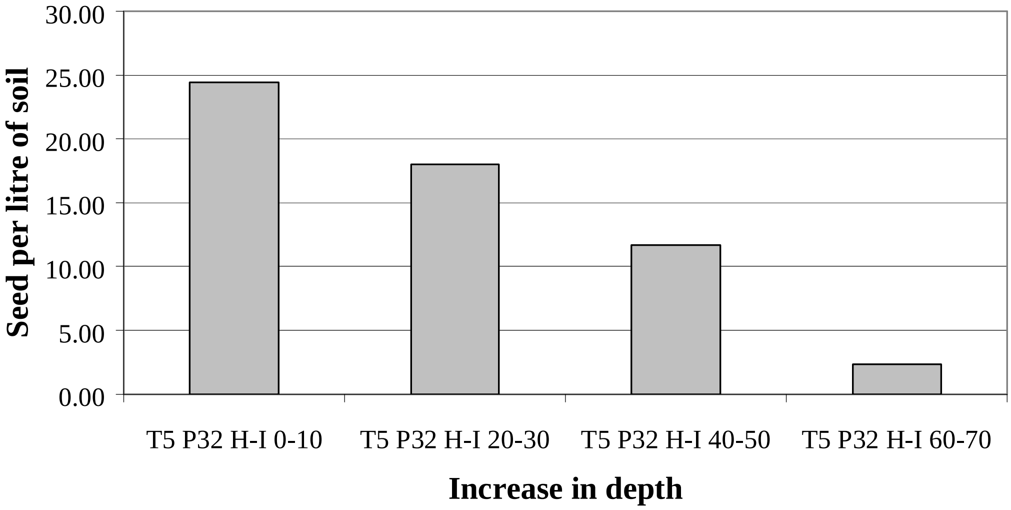

Figure 5.5 Number of *A. mearnsii* seed per litre of soil with an increase in depth under an infested area in the Holsloot River, transect 5, plot 32.

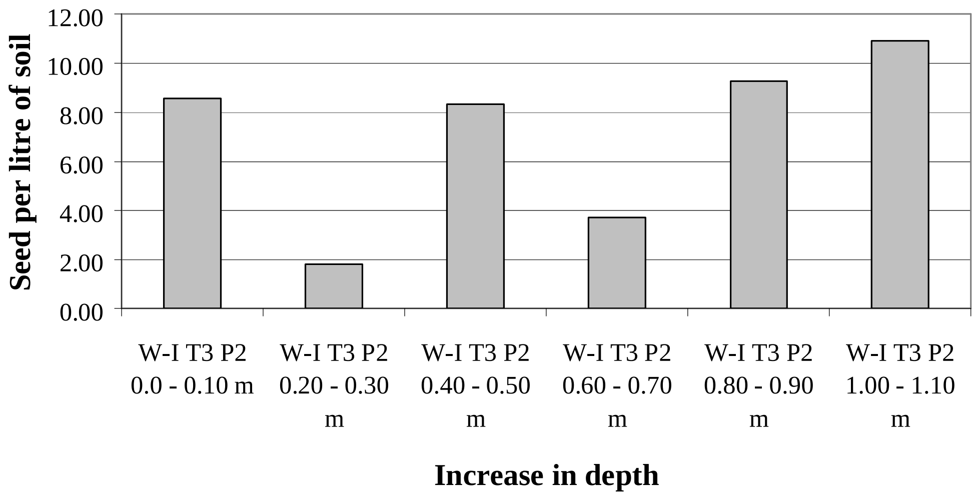

Figure 5.6 Number of *A. mearnsii* seed per litre of soil with an increase in depth under an infested area in the Wit River, transect 3, plot 2.

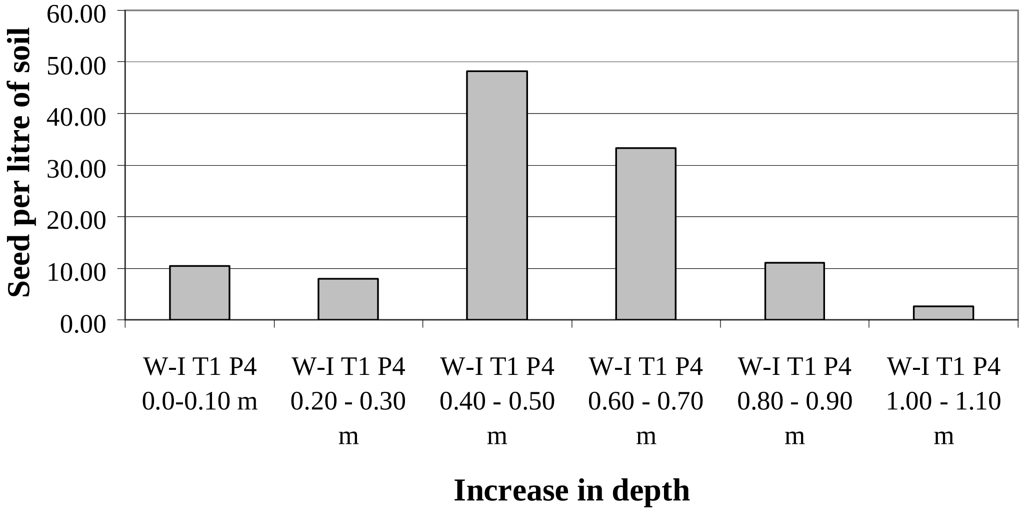

Figure 5.7 Number of *A. mearnsii* seed per litre of soil with an increase in depth under an infested area in the Wit River, transect 1, plot 4.

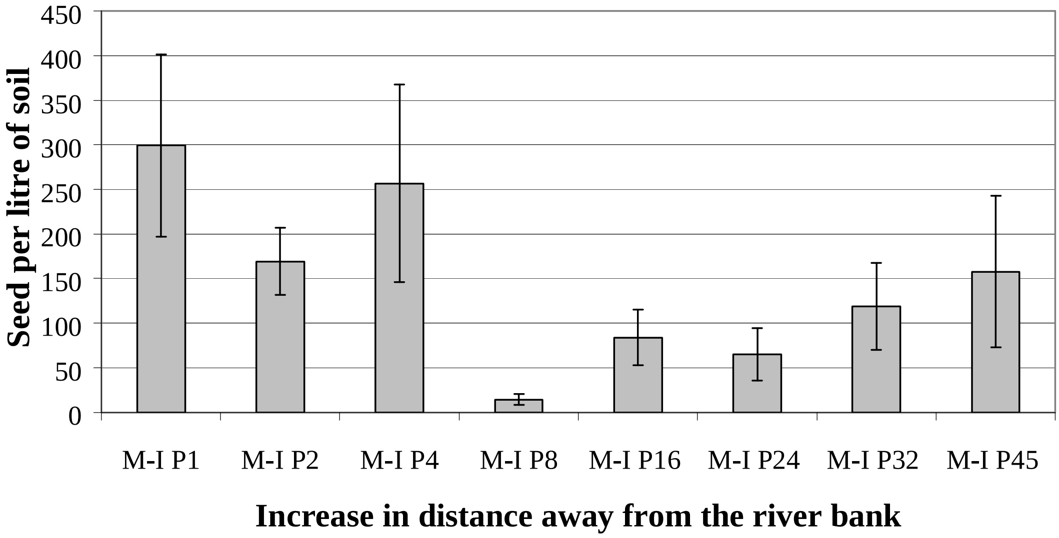

Figure 5.8 Average number of seed per soil core with an increase in distance away from the river bank in the Molenaars River.

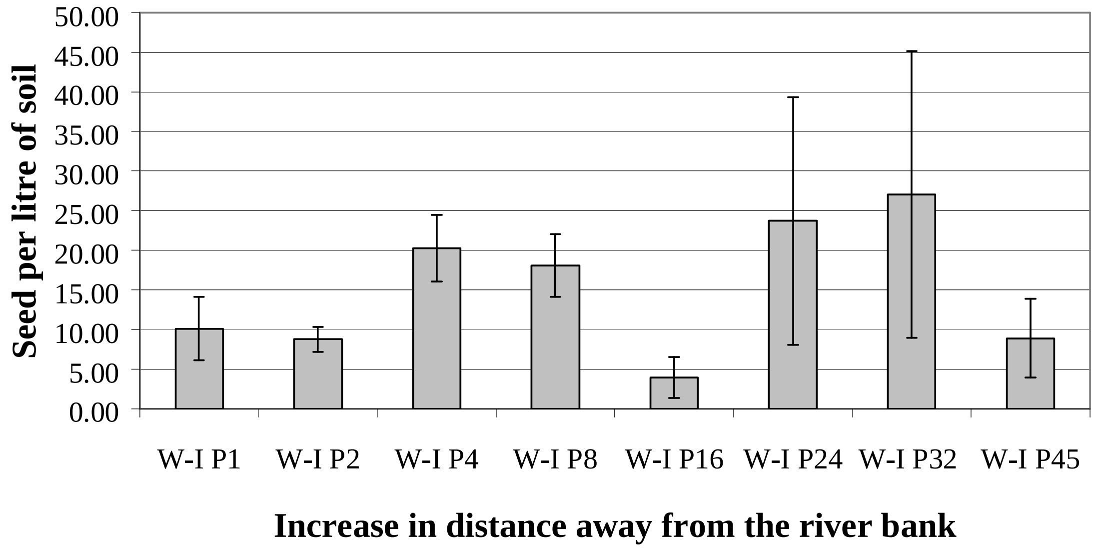

Figure 5.9 Average number of seed per soil core with an increase in distance away from the river bank in the Wit River.

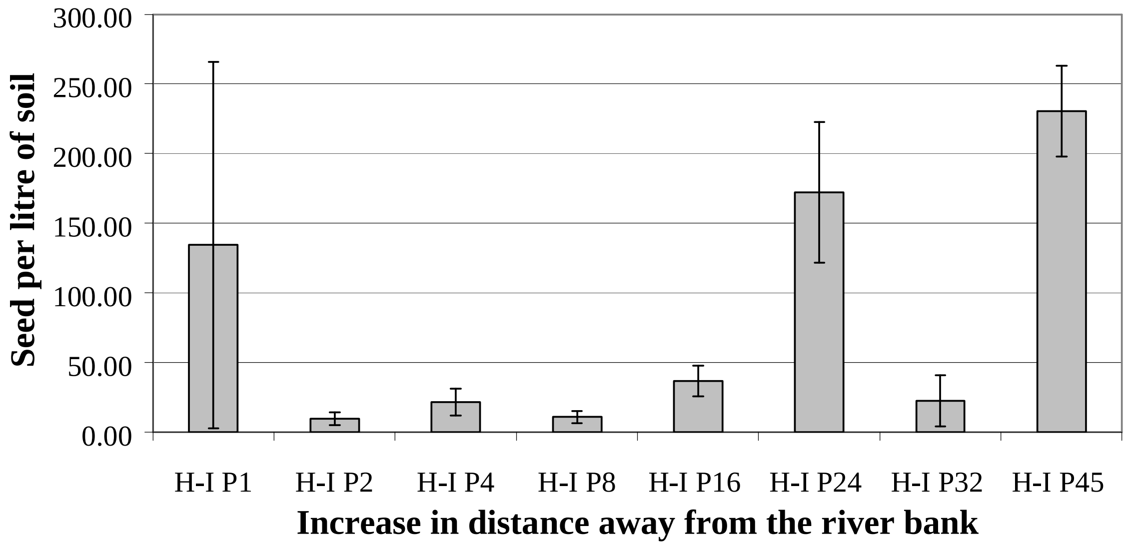

Figure 5.10 Average number of seed per soil core with an increase in distance away from the river bank in the Holsloot River.

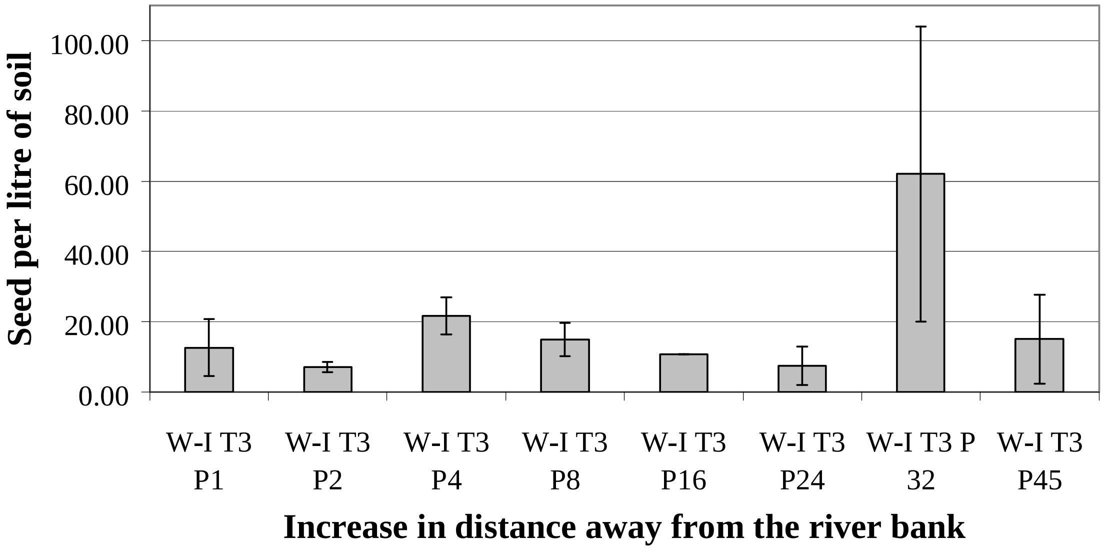

Figure 5.11 Number of seed per soil core with an increase in distance away from the river bank in the Molenaars River, transect 1, plot 4

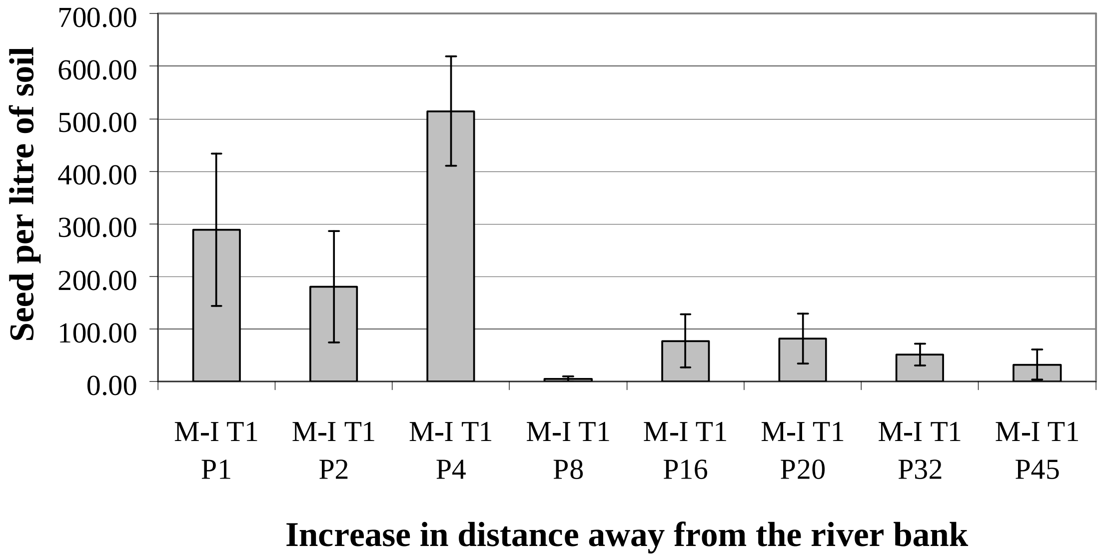

Figure 5.12 Number of seed per soil core with an increase in distance away from the river bank in the Wit River, transect 3, plot 2.

The distributional pattern in respect of viable seed

Virtually all (99.9 %) of the 3669 seeds clipped were viable. All seeds are equally viable regardless of river system, location on riverbank, degree of infestation or age of the stands.

5.5 DISCUSSION

The average quantity of seed occurring in natural and infested stands respectively, in the same or between different tributaries

Soil under dense *A. mearnsii* stands in riverine habitats in the Breede River system contains large amounts of seed, compared to soil under natural vegetation that contains few, if any, seeds. The presence of some seeds in soil under natural vegetation is probably the result of water borne seed that washed down from current or previous alien infested areas upstream of the natural areas, and / or remnants of former extensive seed banks that occurred in some of these natural areas in the past when they were invaded. At present, some *A. mearnsii* seedlings were observed in all natural areas surveyed for this study.

Invasive *Acacia* species in South Africa are known for their large seed banks (Milton and Hall 1981, Dean *et al.* 1986). *A. mearnsii* seems to be no exception. *Acacia* seeds typically have a water impermeable seed coat (Cavanagh 1980), and longevity is often associated with water impermeability (Rolston 1978). We found seed from all depths and stands (presumably all from different ages due to the dynamic nature of fynbos rivers), including present day natural stands (free of seed producing plants for more than the last 10 years at least), to be 99.9 % viable. The distribution pattern of seed through the profile can suggest that the seed has been deposited over an extended period of time, probably from at least about 60 years ago (in about 1945), when aliens were first observed to be spreading through the valley (Boucher 1988). The high seed densities per volume of soil found during this study, coupled with a 99.9 % germination rate and likely longevity of the seed, underlies the fact that these seed banks will, at present, complicate control of this plant for many years to come. Seed, once the water impermeable seed coat is damaged, germinate within 2 days under optimal conditions. Damage to seed coats, due to the abrasive action of sand coupled with the damp conditions in the soil promoting rot, will cause a continual supply of seedlings for as long as any viable seed remains in the soil.

In the pilot study by Pienaar (1997), he suggested that soil erosion took place during heavy winter flows following clearing of dense stands of *A. mearnsii* along the Molenaars River. Comparison between soil depths sampled by Pienaar during the pilot study and those in the same area during the present study (Molenaars Immature stand) indicates that the soils are deeper there now than those present after initial clearing in 1994.

This study therefore suggests that the dense regeneration of exotic seedlings that established after the initial clearing and burning (these were only cleared in a follow-up operation six years later in 1999-2000) has resulted in soil accumulating again in the Molenaars Immature stand, increasing the soil depth to similar levels to those present prior to the initial clearing.

We suggest that the deep sandy soils found under dense stands of *A. mearnsii* in riverine systems appears to be the direct result of a reduction in flow strength of water caused by the high density of alien plants, resulting in the exceptional deposition of soil.

A. mearnsii seed also tends to accumulate in soil deposited under dense stands (as high as an average of 121 seeds / litre of soil for the Molenaars Infested stand). These seeds germinate prolifically following initial clearing and burning treatments and *A. mearnsii* juveniles in the Molenaars River have been counted at densities on average of 1 047 plants / 50 m^2 (Pienaar 1997). Sand does not build up to the same extent under natural riverine vegetation in the Fynbos Biome, possibly because riparian fynbos does not retard flows to the same extent.

The above findings suggest that the follow-up clearing of dense stands of immature *A. mearnsii* plants should be treated as a high priority to stimulate erosion of abnormal soil accumulations, together with their dense loads of exotic seed from river banks.

The post-clearing erosion process should be actively encouraged so that the river will return to a more natural system sooner, thereby making future follow up work easier due to a drastically reduced seed bank. *A. mearnsii*, as an aggressive invader, mostly occurs in the upper and middle reaches of rivers in the Western Cape, despite the fact that copious amounts of seed are continually washed away downstream. We do not think flushing of the seed-laden sediments will cause an increase in invasion further downstream as heavy seed loads have been released into the system for many years from existing infestations.

The distribution of seed, on average, with an increase in depth in the soil profile

Most seed, on average, occurs in the top 0.30 m of the soil profile (including the debris layer), although some seed is mostly found up to the maximum sampling depth of 1.10 m. Riverine systems are dynamic by nature, with sand continually being eroded away and deposited during the frequent winter floods in western Cape rivers, resulting in the distribution of seed through the entire soil profile. More seed are found in the top layers of soil due to the burial action of seed through gravity, water percolation and the accumulation of sand and organic matter on top. Most alien seed in terrestrial fynbos ecosystems are concentrated within the top 0.30 m of soil (Milton and Hall 1981, Pieterse and Cairns 1986, Jasson and Esler 2003, Esler and Boucher 2004). The use of fire, as a management tool in terrestrial fynbos ecosystems, can decrease some alien *Acacia* seed banks substantially (Milton and Hall 1981, Pieterse and Cairns 1986, Holmes 1988, Holmes 1989) (although this practice has some detrimental effects on the indigenous seed banks and soil properties) (Cilliers 2002, Cilliers *et al.* 2004). However, we suggest that fire, as a management tool to reduce alien seed banks in riverine systems, will be less effective due to differences in their distribution patterns through the soil profile compared to those in terrestrial ecosystems.

Analysis of seed distribution patterns through individual soil cores can mostly be grouped into a three distribution types: Pattern A (Regular), Pattern B (Irregular) and Pattern C (a mix between regular and irregular) (see results for details). These variations are the result of factors such as the destruction of some seed by fires, possible seed predation, sand erosion and deposition on top of seed, and possible fluctuations in the productivity of alien seed production.

The distribution of seed with an increase in distance away from the water's edge

The average number of seed per soil core with an increase in distance away from the river bank, both at the level of sites and individual transects, indicates areas with increases and decreases in the number of seed present in the soil. These observed variations in the lateral distribution of seed in the soil profile are primarily the result of back channels eroding or depositing some soil, (which might or might not contain seed), therefore decreasing or increasing the soil depth in some areas, resulting in variations in the average number on seed per soil core in the affected areas. Some trees might be more productive than others, also contributing to the variations in the lateral distribution of seed, while localised fire can also destroy seeds in affected areas.

The distributional pattern in respect of viable seed

The exceptional high percentage of viable seed found in this study accentuates the problem these substantial alien seed banks cause in the Fynbos Biome.

5.6 CONCLUSIONS

Large, persistent and highly viable seed banks occur under dense *A. mearnsii* stands in the Breede River system, complicating future control in this riverine ecosystem. Alien seed, in contrast with terrestrial fynbos ecosystems, are distributed through the entire soil profile. We propose that conventional methods to decrease alien seed banks, such as burning, will be less effective in riverine ecosystems than in terrestrial ecosystems due to the difference in the distribution pattern. Deep sandy soils found under dense stands of *A. mearnsii* in riverine ecosystems are unnatural for fynbos rivers, and primarily the result of a reduction in flow strength of water due to the exceptional thick stands of *Acacia* plants, causing exceptional deposition of sand. We observed erosion of sediments, and an associated reduction in the seed bank, occurring after felling and burning of a dense stand of *A. mearnsii* trees by a Working for Water team in the Molenaars and Wit Rivers, and propose that flushing of sediments (together with their accumulated, extensive seed banks) be considered as a management tool in riverine ecosystems.

6 RELEVANCE OF THIS RESEARCH FOR MANAGEMENT OF ALIEN INFESTED OR PREVIOUSLY INFESTED CATCHMENTS

The results presented in this report offer several pointers for the management of alien infested or previously infested catchments. The first, and most obvious, of these is the dampening impact of alien invasions on biodiversity in, and supposedly resilience of, the riparian zone (e.g., Cowling and Gxaba 1991; Section 3). These sorts of species changes recorded in Section 3 go hand in hand with impacts on the riverine ecosystems such as bank instability, sedimentation, inappropriate food supply (Ractliffe *et al.* 2003). The loss of biodiversity under invaded canopies, and the (partial) restoration of such after clearing (Section 3), is also of relevance for the protection and conservation of the region's biodiversity in terms of the Convention on Biological Diversity, to which South Africa is signatory. These two results underscore the importance of the work that is being done by DWAF: WfW. Clearly, even extremely heavily infested riparian zones can be restored through clearing, thereby reinstating some of the natural species and functioning of the riparian zones of the rivers of the Western Cape.

The data presented in this report also highlight the potential importance of the flow regime of a river in assisting in its recovery post alien clearing, and suggest that flushing of seed laden soils in the riparian areas may be a more effective management tool for reducing seed banks than the burning techniques commonly employed in terrestrial ecosystems (e.g., Holmes 1988; Chapter 5). Similarly, build-up of sand in soils under invaded vegetation only erodes in floods, and specifically during the first winter directly after clearing, before any regeneration has taken place. These results underscore the importance of the providing adequate environmental flows (or 'Ecological Reserves'; DWAF 1999) to all aquatic ecosystems, including those whose riparian zones are presently invaded with alien trees, and illustrates the necessity of good communication between the different departments in DWAF, e.g., WfW and the Resource Directed Measures (RDM) Directorate, and indeed different government departments involved in catchment management, e.g., agriculture, nature conservation and roads. Floods large enough to scour the seed banks are frequently those that come under the most scrutiny when designing a modified flow regime for a river as they are difficult to manage, require considerable quantities of water and, in the case of dam construction, are expensive to design for. The protracted discussions on the outlet structures required to release channel maintenance floods for the new Berg River Dam illustrate this point (reference). However, these floods are vital for, *inter alia*, flushing alien seeds and seedlings, distributing seeds, flushing poor quality water from the system and maintaining instream habitats (e.g., Brown *et al.* 2000).

Finally, invasive alien acacias are known to increase soil nutrient status through the much higher annual litterfall compared to indigenous vegetation. Enriched soils might negatively effect the re-establishment of indigenous vegetation on areas where dense stands of alien plants has been removed. Significant differences have been found in this study between soils of previously invaded areas and soils under natural vegetation in terms of soil fraction distribution and resistance. However, soils in fynbos riverine systems contain very low percentages of silt and clay, rendering slight chemical changes to the soil under invaded sites (possibly as a result of prolonged periods of dense alien infestation), negligible due to the unbuffered nature of river soils. Less leaching, on average, takes place in soils of terrestrial fynbos ecosystems than in riverine ecosystems, and, consequently, the recovery of soils to a more natural state following the removal of the alien vegetation in terrestrial ecosystems might take much longer than in riverine ecosystems, particularly in such is accompanied by an appropriate flood regime.

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8 APPENDIX A

31 January 2001
REWORKED PROJECT PROPOSAL:
EFFECTS OF ALIEN INVASIVES ON THE BREEDE RIVER

BACKGROUND TO THE PROPOSAL
This proposal is in response to a request for proposals received from Dr Christo Marias of Working for Water for an investigation of the potential impacts (positive and negative) of the alien removal programme in the Breede River Catchment. This proposal is a joint submission from the following organisations:

- Botany Department, University of Stellenbosch
- Botany Department, University of the Western Cape
- Southern Waters ER&C.

The proposal was updated in January 2001 on the basis of a meeting between Dr C. Boucher, Dr R. Knight, Dr C. Brown and Dr C. Marias.

This proposal is valid until 16 February 2001.

TERMS OF REFERENCE
The Terms of Reference are provided in the attached letter from Working for Water.

Objectives
The work proposed here aims to address two key areas.

3. Potential impacts of alien vegetation on channel pattern and shape.
4. Potential impacts of alien vegetation on the biodiversity of riparian vegetation, and recovery rates after removal.

LAYOUT OF THIS PROPOSAL
The proposal has been divided into two sub-proposals, each of which addresses one of the objectives listed above.

PERSONNEL
Three senior project supervisors will guide the project, with the tasks shared between them in whatever ratios seem appropriate once detailed project design has been undertaken. Southern Waters will manage the project and serve as evaluators of the work produced. They will also take ultimate responsibility for producing the final reports. The main tasks of the supervisors will be project design and coordination, guidance of the students, review of the papers, writing synthesis papers and responsibility for getting the papers published in scientific journals. The three nominated supervisors are:
Dr Charlie Boucher, Botany Department, Stellenbosch University
Dr Cate Brown/Dr Bill Harding, Southern Waters ER&C, University of Cape Town
Dr Richard Knight, Botany Department, University of the Western Cape.

The proposal is designed to maximise training of young freshwater scientists. In total 5 young scientists will be employed to undertake individual components of the project. The research proposed should produce the basis for a PhD dissertation (J. Loza), and BSc (hons) project (Hons student) and first scientific papers from three junior researchers (E. Pienaar, C. Pemberton and R. February). The project leaders will also submit an additional scientific paper.

MANAGEMENT

Southern Waters will manage the project. Every effort has been made to keep these costs to a minimum, so as to maximise the training aspects inherent in the proposal. The main roles of the management team are:

- To ensure that the objectives of the project are met and the results presented clearly and completely.
- To promote team interactions through the organisation of bi-annual progress meetings;

- To facilitate an initial site selection visit to the study area, which will also be used to an orientation and team building exercise.

SUB-PROPOSAL 1 POTENTIAL IMPACTS OF ALIEN VEGETATION ON CHANNEL PATTERN AND SHAPE

Aims

- To assess changes in channel pattern following infestation of the riparian zone by alien vegetation, and the propensity for recovery following clearing.

Tasks

The following tasks are deemed necessary to address the aims of the project.

Analysis of historic aerial, orthophotos and/or satellite images

Aerial images of key areas within the Breede River catchment will be used to assess the extent and nature of alien infestation and the channel changes associated therewith. The final selection of key areas will depend on the availability of suitable aerial/satellite images, but at this stage potential key areas include:

- Breede River between Witbrug and Wolseley.
- Wit River between Tweede Tol and the confluence with the Breede River.
- Molenaars River between the confluence with Elands River and the Du Toits Kloof Hotel.
- Breede River between Brandvlei and the Villiersdorp causeway.
- Riversonderend between Greyton and Riversonderend.
- Riversonderend between Stormsvlei and the confluence with the Breede River.

The intention is to obtain a minimum of four aerial/satellite images covering the last 30 years. These will then be digitised and analysed for the following:

- Extent and pattern of alien invasion, including if possible a qualitative assessment of contributing factors.
- Changes in channel pattern (including width) or direction following invasion.
- Channel shape data will be collected at the 15 sites discussed in 2.2.
- Where possible, changes in channel pattern following removal of aliens.

Outlining potential areas of risk for invasion by aliens and resultant high impacts

The scientific literature and the results from this study (in particular Task 1.2.1a) will be analysed for trends in order to establish the characteristics of areas particularly prone to:

1. alien plant invasions;
2. negative impacts as a result of alien plant invasions.

Assessment of the persistence and nature of the sediments in the riparian zone under different vegetation types, viz. alien-dominated, indigenous-dominated and at various intervals following clearing

An assessment of the particle-size (incl. ratios) and nature of the sediments associated with riparian zones with different vegetation types will provide an indication of:

- Sediment retention characteristics of the alien vegetation relative to indigenous vegetation.
- The post-clearing flushing of sediments from previously infested areas.

Core sediment samples will be collected from each of > 5 sites with alien and indigenous vegetation and > 10 sites where the alien vegetation has been cleared. Soil depths will also be collected at key sites, to check for post-clearing flushing. The cleared sites will be chosen to represent a range of various intervals following clearing.

The samples will undergo a sediment size analysis in the laboratory. The results will be tested for statistically significant differences between the size-distribution and composition of sediments at the different sites.

Assessment of the persistence of alien seed banks following removal of the alien vegetation

The seed content of the samples collected in 1.2.2 will also be analysed and tested for differences in quantity, distribution through the soil profile, composition and viability.

Data on age and density of alien infestations will also be collected in order to inform the interpretation of the results.

Reporting

The results of the study will be written up in a scientific paper and published in an appropriate journal.

SUB-PROPOSAL 2 POTENTIAL IMPACTS OF ALIEN VEGETATION ON THE BIODIVERSITY OF RIPARIAN VEGETATION AND RECOVERY RATES AFTER REMOVAL

Aims

In areas of similar habitat and environmental conditions:

- To provide quantitative data on the species diversity of the riparian vegetation at sites that are dominated by alien vegetation relative to those where the vegetation is predominately indigenous.
- To provide quantitative data on the changes in species diversity and composition of the riparian vegetation at sites over time at sites after the alien vegetation has been removed.

2.2 Tasks

The following tasks are deemed necessary to address the aims of the project.

Assessment of the species diversity in the riparian zone under different vegetation types, viz. alien-dominated, indigenous-dominated and at various intervals following clearing

Fixed vegetation sampling plots will be established at each of > 10 sites with alien and indigenous vegetation and > 20 sites where the alien vegetation has been cleared. The cleared sites will be chosen to represent a range of various intervals following clearing.

The resultant data will be analysed for the following:

- statistical differences in species diversity between riparian zones vegetated with different types of vegetation
- trends in the re-establishment of vegetation following clearing
- the indigenous component in recently cleared areas
- to comment on effectiveness of alien control measures applied by clearing teams.

Reporting

The results of the study will be written up in a scientific paper and published in an appropriate journal.

SUB-PROPOSAL 3 REVIEW OF EFFECTS OF ALIEN PLANTS INVASIONS ON RIVERINE ECOSYSTEMS

Aims

- To review the available scientific literature to determine the effects of alien plant invasions on the structure and functioning of rivers in the Western Cape.

Tasks

The following tasks are deemed necessary to address the aims of the project.

Literature review

A review of the available scientific literature. Discussion of the results of studies from elsewhere in the light of the data obtained from the other components of this study.

Reporting

The results of the study will be written up in a scientific paper and published in an appropriate journal.

FURTHER COMMENT

We are aware that the Working for Water programme is particularly interested in quantifying the economic benefits of the alien-clearing programme. To this end, we intend to guide the research to, where appropriate provide information that can be used in a later analysis of the resource economics. For instance, it is envisaged that the results of sub-proposal 1 will provide valuable information on the sustainability of clearing operations, and the optimal timing of any follow-up work required.

TIMING OF APPROVAL:

In order for us to match the project requirements with the academic requirements of the student members of the team, approval to commence with the study is required no later than 16 February 2001.

CONTACT PEOPLE

Queries about this proposal should be directed to:

Dr Cate Brown	021-6854166,
Mr Rodney February	021-6854166,
Dr Charlie Boucher	021-8083064.

JUNE 2002:
Progress report (shortened) and adjustment of project proposal:
Effects of Alien Invasives on the Breede River

Botany Department University of Stellenbosch
Botany Department University of the Western Cape
Southern Waters Ecological Research and Consulting

Introduction.
The project team (see below) met with representatives of the Department of Water Affairs Working for Water Programme at Du Toit's Kloof Hotel on Wednesday 29 May 2002 in order to discuss progress on the project (Appendix 1), reasons for the delays/diversions from the original schedule and a possible way forward.

The results of the subsequent discussions can be summarised as follows (details of are contained in project progress reports):

1. Post-clearing sampling had not taken place because as the study sites were not cleared of invasive plants before the winter rains (2001).
2. Stakes placed along transects in the infested sites had been removed, allegedly by WFW teams working in the area.
3. WFW and the project team should work together to select new (infested) study sites – see Appendix 2.
4. The duration of the project should be extended to allow for re-sampling of infested sites in the summer of 2002/2003, and subsequent clearing of those site before winter in 2003.
5. Time should be allocated to a project team member to visit the selected sites regularly during 2003 to monitor clearing activities and report any inconsistencies.
6. The budget should be reworked to determine costs associated with 4 and 5 above, as well as those associated with completing other outstanding tasks (Appendix 1).
7. Where possible tasks should be re-arranged so that to whatever extent possible, the additional costs could be incorporated within the original budget.

NOTE:

1. In order to accomplish a reduction in budget, management has been shifted from Dr C. Brown to Mr R. February, thereby reducing costs.
2. If flushing of seeds and sediments is to be measured, it is essential that cut material be removed from the site, as per 'normal' WFW practice.
3. We have opted for a survey of the infested sites in preference of the metal stakes used thus far. The reasons for this is the stakes were removed (see 2 above), and a survey would give a better idea of overall movement of sediments along the cross-sections.

Project team.

Dr Charlie Boucher	Stellenbosch University
Rodney February	Southern Waters
Dr Richard Knight	University of Western Cape
Eugene Pienaar	Stellenbosch University
Joyce Loza	University of Western Cape
Charles Pemberton	Southern Waters
Dr Cate Brown	Southern Waters.

Project goals.
The main goals to the project are to:

1. Assess the potential impacts of alien vegetation on channel pattern and shape.
2. Assess the persistence and nature of the sediments in the riparian zone under different vegetation types.

3. Assess the persistence of alien seed banks following the removal of alien vegetation.
4. Evaluate the potential impacts of alien vegetation on the biodiversity of riparian vegetation, and recovery rates of indigenous vegetation after removal of the alien plants.
5. Review the effects of alien plant invasions on the structure and functioning of rivers.

Duration of project.
Original duration: February 2001 to October 2002.
Revised duration: March 2001 to December 2003.

Key objectives and progress.
See table overleaf.

Details of additional sampling.
Before and after clearing sampling at three additional sites, with three transects on each side of the river (six in total), 10 soil cores along each transect at five depth intervals. The following analyses will be performed:

- Particle analysis/seed extraction
- pH and resistance (60 samples a day)
- KCl 80 samples a day
- Germination
- Carbon determination using heat.

APRIL 2003:
Letter to Dr Marais:
Effects of Alien Invasives on the Breede River

Southern Waters ER&C cc
P.O. Box 13280
Mowbray
7925

Dr. Christo Marais
Scientific Services Manager
The Working for Water National Office
4th Floor Murray & Roberts Building
73 Hertzog Boulevard
Cape Town, 8000

Dear Dr Marais

I am writing to provide you with an update on the Research Project on the "Effects of Alien Invasives on the Breede River", and to request feedback on one or two important issues.

As indicated in my letter dated 31 January 2003, the sites that we re-selected for clearing in the Breede River Valley as part of our research project for Working for Water have not yet been cleared. If we are to collect the required post-winter data, these sites will need to be cleared, and the felled trees stacked and burned, by the May 16th, 2003 (assuming we do not have any major flooding in the study rivers before then, as we still need to collect some pre-winter (but post-clearing) survey data and we need to be able to let our staff know whether there will be work for them to do on this project.. If clearing does not take place, we will write up the project report based on the data we have collected to date.

If the sites are cleared by mid-May, could the clearing teams please take cognizance of the following:

- In order for the winter floods to have the anticipated effect on the sites, we estimate that the minimum area cleared at each site should be an area comprising the full width of the riparian zone (and length of the transects) for 500 m upstream and 500 m downstream of each of our set of transects. Working for Water have been given the GPS co-ordinates for these transects and their locations were pointed out to Mr. Jakobus Vaas, Mr. Umesh Rambali and Mr. Hilton Gane from the WFW Worcester Office, on three separate site visits.
- Metal stakes have been planted on a number of our transects. These stakes are important for data collection and it is important that contractors clearing the sites do not disturb them. There have been instances in the past where contractors have removed these stakes.

On a different note, during the course of the study a large quantity of soils has been collected, and is being stored at the University of Stellenbosch. We would like to now dispose of the soils that we have already analysed as storage is reaching critical capacity. Would WFW like to keep the soils for any reason (in which case we can transfer the samples to you WFW offices), or can we have your permission to dispose of them?

Yours Sincerely

Rodney February

AUGUST 2003:
Minutes of the meeting between Working For Water (WFW) and Southern Waters. Held at 50 Campground Road, Rondebosch on the 27th August 2003 at 09h30.

Present: Dr. Christo Marias, Mr. Ahmed Khan, Dr. Cate Brown, Mr. Rodney February.

General Update

Dr. Brown opened the meeting by providing a general overview of the progress of the project. This included:

- a explanation of the brief budget and payment schedules.
- alerting WFW to the fact that Southern Waters foresaw a problem with the delivery of a product from UWC as Joyce Loza had joined WFW and was therefore not able to complete the required tasks.
- noting that, because the project initiation was delayed Charles Pemberton had had to take on the work earmarked for a student and for this reason, the worlk had cost considerably more than had been budgetted but that Southern Waters was willing to cover the additional costs.
- the expectation that Charles Pemberton's work would be completed within the next six weeks.
- notification that the tasks allocated to Eugene Pienaar were taking longer than expected.
- The expectation that despite the difficulties experienced in the project both the projects, i.e., headed by Charles Pemberton and Eugene Pienaar, were expected to provide some interesting and defensible results, which could be written up in a scientific paper..
- the expectation that three scientific papers would be produced from the data collected by Charles Pemberton and Eugene Pienaar, *viz*.:
    1. Species diversity and structure in the riparian zone under alien-dominated versus indigenous-dominated communities;
    2. The persistence and nature of the sediments in the riparian zone under different vegetation types, *viz.* alien-dominated, indigenous-dominated and following clearing;
    3. The persistence of alien seed banks following removal of alien vegetation.

Budget allocation

Dr. Brown explained that the time used thus far by Rodney February (Project Manager) exceeded the allocated budget for his part of the work, and that it was expected that he would need to spend more time on the project to ensure its completion. The main reasons for budget overruns were:

- extra trips to the study sites had to be made by Mr. February. These trips were made in order to point out the study sites to different WFW area managers. . In terms of the budget regarding herself Dr. Brown explained that although her time claimed to date was still with in the allocated budget this would be used up during the preparation of the final report. It was agreed by the meeting that Dr. Brown could reallocate funds from elsewhere in the budget to cover the cost of the extra time needed to be spend on the project by Mr. February.
- The additional time spend trying to assist the WRC team with their tasks.

Report back by Charles Pemberton

Charles Pemberton reported back on the progress of his component of the project. Given questions posed by Dr. Marais to Charles Pemberton Dr. Brown suggested that a meeting between Dr. Marais and Charles Pemberton be arranged before the completion of the paper so that data that Dr. Marais deemed relevant could be highlighted by Charles Pemberton in his report.

Accumulated Soils
Rodney February explained that the work conducted by Eugene Pienaar has resulted in the accumulation of large quantities of soils. These were at present been stored at the University of Stellenbosh, which was not ideal. Dr. Brown indicated that it was best to keep these soils at least until the end of the project as they represented data. It was further suggested by Dr. Brown that photographs be taken of the collected soils so that the sheer amount of soil collected could be shown in future presentations/posters Dr. Marais suggested that WFW should look into storage space for the soils.

GIS component of the project
With regards to the GIS component of the project undertaken by Dr. Richard Knight and Ms. Joyce Loza, Dr. Marais suggested a separate meeting be set up to discuss the possible deliverables from this part of the project. Dr. Marais suggested that at this meeting three optioned be proposed Dr. Knight and Ms. Loza. These are that:

- Ms. Loza complete the project but that this would be on WFW time and that she will not able to claim from the remaining budget allocation. It was agreed that the project team would not claim any of the remaining fund within the budget allocation for this component. (See below)
- Dr. Knight is allocated the task of finishing the project.
- Dr. Knight appoints another student to finish the project with a clear indication of the costs and time involved for this process.

Mr. Ahmed Khan is to take responsibility for arranging the meeting with Dr. Knight and Joyce Loza. Dr. Marias requested that Southern Waters be present at this meeting. Two dates were suggested for this meeting these were the 08th and 25th September 2003 at 17h00. The venue for the meeting will be the WFW offices in Cape Town.