DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

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____________ **day of** ____________ **2006**

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ABSTRACT

The broad aim of this study was to measure the ecosystem repair of the Sabie River (which traverses through both the grassland and savanna biomes) riparian environment in Mpumalanga, South Africa, in response to the clearing of alien plants by the Working for Water (WfW) alien plant clearing programme. This was done in order to assess the effectiveness of the WfW clearing on the Sabie River riparian plant community composition and associated environmental factors. Although "effectiveness" can be assessed in various ways, in this study it included determining whether there was a reduction in the invasion intensity (defined as the percentage aerial cover of woody alien plants) after clearing. This broad aim was achieved by studying the impacts of the WfW alien plant clearing programme, as well as the invasion of alien plants, on the plant species composition, diversity and vegetation structure of riparian ecosystems on the Sabie River. Hence, in 2005 40 modified Whittaker nested plots were sampled. The impacts on the Sabie River riparian environment were also assessed by measuring various environmental variables that are likely to change as a result of clearing, such as the ground cover (percentages of exposed soil, rock, litter, herbaceous vegetation and grass), as well as various soil chemical and physical properties. Twenty plots were surveyed along the Sabie River in the Hazeyview region (savanna biome), ten in the Sabie region (grassland biome) and ten in the Graskop region (grassland biome). The response of the Sabie River riparian community to invasive alien plant clearing by WfW (and the alien plant invasion itself) was also assessed over time, by comparing the 2005 study with one done in 1996, which used the same plots.

In 2005, a cumulative total of 282 species were found, 222 (79%) of which were indigenous and 60 (21%) alien. The grassland sites had a higher cumulative total of 222 species compared with the 171 species in the savanna sites. A total of 112 (39%) species were common between the biomes, 86 (30%) of which were indigenous and 26 (9%) alien. At the 1000 m^2 scale, the indigenous species richness (32.4 ± 1.4 (S.E.)) was significantly higher than the alien species richness (12.0 ± 0.5) ($P < 0.001$). Of the 60 alien species, 17 (28%) were shrubs and 15 (25%) trees. The grassland sites were more species rich at the 1000 m^2 scale (48.8 ± 1.8) and diverse at the 100 m^2 scale (Simpson's index of alpha diversity of 0.90 ± 0.01) than the savanna sites (species richness of 40.0 ± 2.1 and alpha diversity of 0.85 ± 0.02; $P = 0.003$ for species richness and $P = 0.04$ for alpha diversity). The Sabie sites were more species rich at the 1000 m^2 scale (52.6 ± 2.8) than the Graskop sites (45.0 ± 1.4) ($P = 0.12$). The higher species richness in the Sabie region contributed to the higher total species richness in the grasslands relative to the savanna sites. At the 1000 m^2 scale, the overall beta diversity (Sorenson's coefficient of community) between the biomes was 0.57, and the species complementarity (the Marczewski-Steinhaus distance) between the biomes was 0.60, indicating that the biomes were not that similar in terms of species composition. Even though the grassland was more rich and diverse in terms of species than the savanna, the overall relative abundances of plant species in each biome was very similar (species evenness (Simpson's measure of evenness), at the 100 m^2 scale, of 0.52 ± 0.03 in the grassland and 0.51 ± 0.03 in the savanna; P = 0.74). The savanna tended to have a higher degree of invasion intensity (aerial cover of woody alien plants of 34.4 ± 4.6% compared to 29.4 ± 4.5% in the grassland; P =

0.44), possibly due to its position lower in the catchment, and hence a sink for upstream alien plant propagules.

It was hypothesized that higher plant species richness and/or diversity should enhance community resistance to alien plant invasions, in both the grassland and savanna biomes. In the Sabie (grassland) region, there was a negative correlation between the indigenous and alien species richness, thus indicating that the Sabie region plant community may have been more resistant to the invasion of alien plants than the other two regions. Therefore, the hypothesis was not rejected for the Sabie region. On the other hand, in the Graskop (grassland) and Hazeyview (savanna) regions, there were positive correlations between the indigenous and alien species richness, thus indicating that these plant communities may not have been as resistant to the invasion of alien plants. Therefore, the hypothesis was rejected for both the Graskop and Hazeyview regions. When considering the biome scale, the hypothesis was not rejected as the increase in total species richness with increasing invasion intensity in the grassland (which was more diverse than the savanna) indicated that it may have been more resistant to the invasion of alien plants than the savanna, which had a total species richness that decreased with increasing invasion intensity.

In 2005, exposed soil, litter and grass covers tended to be slightly higher in the savanna (14.4 ± 1.6%; 43.5 ± 3.0%; 21.8 ± 1.7% respectively) than in the grassland (12.1 ± 2.5%; 43.2 ± 4.2%; 20.1 ± 2.3% respectively) (P = 0.43, 0.96 and 0.56 respectively). Rock and herbaceous covers were higher in the grassland (4.3 ± 1.6% and 20.3 ± 1.7% respectively) than in the savanna (0.8 ± 0.2% and 19.5 ± 2.2% respectively), but only rock cover was significantly different (P = 0.04) (P = 0.76 for herbaceous cover). These patterns in ground cover may have been a response to the slightly higher invasion intensity in the savanna. The hypothesis that the lower the degree of alien plant invasion, the higher the understorey vegetation cover, which may result in reduced cover of exposed soil and litter, in both the grassland and savanna biomes, was not rejected as the grassland tended to have a lower degree of alien invasion (although not significant), a higher cover of herbaceous vegetation, and corresponding lower covers of exposed soil and litter. The biomes (in 2005) did not differ significantly in soil pH (grassland pH: 4.6 ± 0.1; savanna pH: 4.8 ± 0.1; P = 0.34). However, the grassland soils were generally more fertile than the savanna soils, i.e. higher organic matter (4.5 ± 0.2% versus 3.3 ± 0.4%; P = 0.01) and total nitrogen (0.3 ± 0.02% versus 0.2 ± 0.02%; P = 0.03). The concentrations (mg/l) of most of the nutrients were also higher in the grassland. The lower fertility of the savanna soils may have been related to the higher litter cover of the savanna immobilizing a larger amount of available nutrients than the grassland; another possibility may have been slower rates of soil organic matter decomposition in the slightly cooler (higher altitude) grassland regions. The soils of the grassland sites tended to be more compacted (0.8 ± 0.1 kg/cm^2) (but not significantly) than those of the savanna sites (0.7 ± 0.1 kg/cm^2) (P = 0.43), and the savanna plots were on significantly steeper ground (12.8 ± 1.7º) than the grassland plots (4.8 ± 1.1º) (P < 0.001), which may have also contributed to lower fertility through greater leaching and erosion losses. From the detrended correspondence analysis (DCA) of the species by plot data, there were no distinct plant communities separating out between the biomes and regions. This is probably because the Sabie River riparian environment essentially supports a riparian forest/woodland, rather than reflecting the species typically found in the adjoining (more upland) grasslands and savannas. Hence, the species composition of the riparian environment was fairly uniform throughout the study area. The canonical correspondence analysis (CCA), which also incorporates the environmental variables, showed that altitude, exposed soil cover, soil pH, organic carbon content and slope steepness were the variables that most closely (and significantly) correlated with the species composition, and two of these variables relate directly to soil fertility, and the other three are indirectly related to soil fertility.

Of the original "treatments" of the 1996/1997 study, namely (A) biome (grassland versus savanna), (B) invasion intensity (high (> 50%) versus low (< 50%)), and (C) clearing (cleared versus uncleared), the legacy of the latter two did not persist over time, as there was little or no clear overall relationship between the 1996 and 2005 data when analysed by ANCOVA. The cumulative total species richness sampled in the 40 plots increased from 163 species in 1996, to 282 in 2005 (42% increase). Mean species richness (at the 1000 m^2 scale) was 24.1 ± 1.0 in 1996 and 44.4 ± 1.5 in 2005 ($P < 0.001$). Trees increased from 28 species in 1996 to 46 in 2005 (39% increase), shrubs from 44 to 82 (46%), herbaceous plants from 71 to 121 (41%), and grasses from 20 to 33 (39%). However, even though the species richness of each growth form increased over time, the proportion of each growth form remained approximately the same, i.e. in 1996, 17% of the species were trees, 27% shrubs, 44% herbaceous and 12% grasses; whereas in 2005, 16% were trees, 29% shrubs, 43% herbaceous and 12% grasses. The greatest increase over time was for category 1, 2 and 3 weed species, namely 25 in 1996 to 50 in 2005, a 50% increase. Although mean alpha diversity was higher in 2005 (0.9 ± 0.01 compared to only 0.3 ± 0.03 in 1996 (at the 100 m^2 scale); $P < 0.001$), overall beta diversity over time (a change from 1996 to 2005) was relatively low, indicating a small change in overall species composition, despite the increase in species richness.

The invasion intensity (percentage aerial cover of woody alien plants) was similar between the years, i.e. 30.0 ± 4.6% in 1996 and 31.9 ± 3.2% in 2005 (P = 0.73). When comparing the invasion intensity between the three original treatments over time, the invasion intensity of the 1996 grassland and savanna plots remained unchanged. The invasion intensity of the 1996 high invaded plots also remained unchanged over time, however the low invaded plots had a significantly higher invasion intensity in 2005 ($P = 0.004$). The invasion intensity of the 1996 uncleared plots remained unchanged over time, whereas the cleared plots had a significantly higher invasion intensity in 2005 ($P = 0.03$). These results clearly show that the legacy of the original invasion intensity and clearing treatments measured in the 1996/1997 study did not persist over time, whereas the inherent differences between the biomes did. The hypothesis that higher plant species richness and/or diversity should enhance community resistance to alien plant invasions was rejected, as both the 1996 and 2005 plant communities were not that resistant to the invasion of alien plants, even though there was a significantly higher species richness and diversity in 2005 than in 1996. It is concluded that because of both the similar growth form composition and invasion intensity over time, the WfW clearing efforts are not succeeding in the primary aim of controlling aliens, particularly woody alien species. However, there was a considerable decrease in the aerial cover of large alien plants, namely (a) alien plants > 5 m decreased from 15.8 ± 4.1% in 1996 to 5.8 ± 1.2% in 2005 ($P = 0.02$), and (b) those between 2 – 5 m tended to decrease from 13.3 ± 2.8% in 1996 to 11.1 ± 2.4% in 2005 ($P = 0.55$). However, these decreases were balanced by a considerable increase in the aerial cover of alien plants < 2 m in height, which increased from 3.9 ± 1.0% in 1996 to 15.0 ± 2.1% in 2005 ($P < 0.001$). This therefore showed that the WfW clearing programme is succeeding, to some extent, in removing most of the larger alien plants but not in controlling the regenerating plants, which recover through post-clearing resprouting and/or newly established seedlings.

Exposed soil, rock and litter covers were higher in 2005 (13.3 ± 1.5%; 2.5 ± 0.8%; 43.3 ± 2.5% respectively) than in 1996 (2.1 ± 0.5%; 0.9 ± 0.3%; 16.4 ± 2.7% respectively) ($P < 0.001$ for soil and litter covers, and 0.07 for rock cover). Herbaceous and grass covers were significantly higher in 1996 (47.8 ± 2.8% and 32.8 ± 2.6% respectively) than in 2005 (20.0 ± 1.4% and 20.9 ± 1.4% respectively) ($P < 0.001$ for herbaceous and grass covers). These differences in the ground covers between the years may have partially been a response to the major February 2000 flood event, which cleared a large proportion of the vegetation, resulting in much greater rates of erosion and deposition of soils. The WfW clearing operations also removed a significant proportion of the vegetation, and disturbed much that remained, thus modifying the environment. The increase in litter cover may have also been due to the slightly higher invasion intensity in 2005 than in 1996. Soil pH remained unchanged over time (both years had a pH of 4.7 ± 0.1; $P = 0.99$), indicating that pH was unaffected by the invasion and subsequent clearing of alien plants, as well as the 2000 flood event which moved a tremendous amount of sediment. The hypothesis that the lower the degree of alien plant invasion, the higher the understorey vegetation cover, in both 1996 and 2005, was not rejected as the plots in 1996 had a lower degree of alien invasion (although not significant), a higher cover of herbaceous vegetation, and corresponding lower covers of exposed soil and litter.

Along the Sabie River, the alien tree and shrub species with the greatest densities were *Rubus cuneifolius* (American bramble) (1828 plants/ha), *Lantana camara* (Lantana) (1760), *Solanum mauritianum* (Bugweed) (838), *Indigofera macrophylla* (640), *Eucalyptus grandis* (Saligna gum) (560), *Caesalpinia decapetala* (Mauritius thorn) (403), *Agrimonia odorata* (Agrimonia) (220), *Lilium formosanum* (St. Joseph's lily) (218), and *Populus x canescens* (Grey popular) (125). Focusing the clearing efforts on these species will help to reduce the frequency of re-invasions, reduce costs, and increase ease of clearing.

The primary aim of the WfW programme is to increase water supplies by controlling woody alien plants. Therefore, it is concluded that the WfW clearing along the Sabie River has been partially successful, as there has been a significant decrease in the invasion intensity of large (> 5 m) alien trees (which tend to have the highest transpiration rates) over time from 1996 to 2005. In 1996, these large alien trees were represented mainly by *Eucalyptus* spp. However, the WfW programme was not effective in terms of ecosystem repair, as the invasion intensity increased slightly from 1996 to 2005, largely as a result of the significant increase in the aerial cover of smaller alien shrubs (< 2 m). If left unchecked, these will probably in time result in even higher levels of invasion intensity when the individual plants increase in size and cover. Furthermore, the growth form composition remained relatively unchanged over time, and more than half of the alien species found in 2005 were tree and shrub species. Therefore, little or no ecosystem repair has occurred along the Sabie River. In order to improve the effectiveness of the WfW programme, various detailed recommendations are included, which largely revolve around improvements in follow-up treatments.

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