

Woody Species Composition and Structure in a Semi – Arid Environment Invaded by *Dichrostachys Cinerea* (L.) Wight & Arn (Fabaceae)

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Abstract- Invasive plant species are a key factor of universal environmental change. They threaten global biodiversity and cause ecosystem degradation. The impacts of *Dichrostachys cinerea* on native woody species diversity, floristic composition and vegetation structure were determined. The study also assessed the dynamics and extent of invasion (population size, relative abundance, size class distribution and recruitment capacity) of *D. cinerea*. Forty woody species were identified in the study area. There were significant ($P < 0.05$) differences in woody species canopy cover, basal area, abundance, richness, density and height classes between invaded and uninvaded sites. Height classes showed that most woody plants were saplings followed by shrubs, trees and lastly seedlings for both invaded and uninvaded sites. Significant ($P < 0.05$) differences were also noted among invaded sites and among uninvaded sites in both density and abundance. Within uninvaded sites, richness also differed significantly ($P < 0.05$). However, there were no ($P > 0.05$) significant differences in basal area and canopy cover among the invaded sites and among uninvaded sites. Richness among invaded sites and height classes among uninvaded sites also did not ($P > 0.05$) differ significantly. There is, therefore, urgent need to manage *D. cinerea* to curb its adverse effects on native woody species.

Index Terms- *Dichrostachys cinerea*, invasion, woody vegetation

I. INTRODUCTION

Invasive plant species are a key component of global environmental change, and a major threat to global biodiversity (SCBD, 2010). They directly cause biodiversity loss (Hao *et al.*, 2010; Keller *et al.*, 2009), ecosystem degradation, and impairment of ecosystem functions (Yu *et al.*, 2010; Gosper *et al.*, 2010; Schooler *et al.*, 2006). Synanthropic invaders comprise of native taxa, and anthropophytes (aliens) are introduced for deliberate purposes such as forestry, agriculture or research. Recent findings in species invasion ecology cover arthropods (Perdereau *et al.*, 2010; Snyder and Evans, 2006), birds (Clavero *et al.*, 2009), mammals (Jaksic *et al.*, 2002), ferns (Kentaro *et al.*, 2007), cornifers (Richardson *et al.*, 2007), mosses (Peck and Moldenke, 2010) and other animals and plants.

However, most of these studies focus on aliens (Irigoyen *et al.*, 2010; Westphal *et al.*, 2008), yet the damage caused by native invasives, which are functionally indistinguishable from aliens, is equally important (Shen *et al.*, 2010; Davis *et al.*, 2000; Huston, 1994).

Dichrostachys cinerea is a semi-deciduous to deciduous shrub or low tree, characterised by bipinnate compound leaves, bicoloured flowers, yellow-brown, narrow pods, and strong, alternate thorns (SANBI, 2011). It rapidly encroaches into disturbed land, producing dense impenetrable thickets due to the density and abundance of its long, stiff and sharp thorns. Traits such as fast growth rates, rapid reproduction, high dispersal ability, and phenotypic plasticity for which an invasive displays greater ecological performance account for much of its invasiveness (Muñoz and Ackerman, 2010). Natural regeneration of *D. cinerea* is strongest by root suckers. It has lateral horizontal roots that extend extensively in all directions, supporting roots at an acute angle to the taproot, and numerous fibrous roots (PIER, 1998). In 10 years, an individual tree can produce 130 new stems in a radius of 15 m by its root suckers. A single *D. cinerea* plant produces approximately 1 million viable seeds /year. Both young and old *D. cinerea* plants produce seeds almost all year long. Germination of the seeds improves with storage. The species is highly aggressive, difficult to eliminate and has high propagule pressure. The herbivore – *D. cinerea* relationship is antagonistic through herbivory, and mutualistic through seed dispersal (Calvino-Cancela, 2010). Its seeds are capable of germination after passing through the alimentary canal of cattle or herbivorous browsers such as nyala due to increased permeability to water (van Staden *et al.*, 1994). In a study assessing shrub encroachment in Swaziland, *D. cinerea* contributed 81% of all encroachment in the lowveld savanna of Swaziland (Roques *et al.*, 2001). Its management involves frequent physical uprooting, which is heavy and expensive. Cutting down the parent plants stimulates development of fibrous roots and production of shoots (PIER, 1998).

Dichrostachys cinerea has formed impenetrable thickets that range from diameters of 50 meters to ≥ 300 meters on rangelands in the study area. Rangelands are areas of the world where wildlife and livestock graze or browse on natural vegetation, accommodating about a third of the world's people, both in cities and as producers on land (Heady and Heady, 1982). *D. cinerea* invasion has the capacity to alter woody vegetation

structure and composition of rangelands, rendering them more susceptible to shocks and disturbances, less resilient to grazing pressure, and less capable of delivering services. It also minimises visibility for wildlife and livestock when foraging. Impenetrable thickets, mainly consisting of *Acacia spp* and *D. cinerea* are one of the most serious problems in the semi-arid savanna ecosystem of Botswana (Tolsma *et al.*, 1987). They have reduced valuable fodder grasses and subsequently increased the grazing pressure on other species. They have also given rise to the browsing of trees by cattle due to reduction in grasses. By altering vegetation community structure, *D. cinerea* may affect the habitats of most animals and birds. It may also alter fire frequency and increase fire intensity by increasing the standing plant biomass. Greater flame lengths, higher temperatures and greater heat release have all been recorded or predicted for invaders of humid grassland, savannah or fire-prone shrubland ecosystems (Van Wilgen and Richardson, 1985; in Levine *et al.*, 2003). The species itself is fire – tolerant. Seedlings of *D. cinerea* survived fire through resprouting (Gambiza and Nefabas, 2007).

Dichrostachys cinerea fixes nitrogen. Woody plants with N-fixing symbionts may inhibit establishment and growth of later successional trees. Schulze *et al* (1991) found that along an aridity gradient in Namibia, while in *Acacia albida* nitrogen fixation was only 2%, it was 49% in *Acacia hereroensis* and *D. cinerea*. The species is also a source of food, animal fodder, firewood and medicine (Banso and Adeyemo, 2007; Smith *et al.*, 2005; Mlambo *et al.*, 2004). However, it is considered a threat to agricultural production, and is listed on the Global Invasive Species Database (Fournet, 2005), and on the invasive species list or noxious weed law in North America (CISEH, 2009). A risk assessment for *D. cinerea* in Hawaii and other Pacific Islands noted that the species was 'likely to cause significant ecological or economic harm in Hawaii and on other Pacific Islands' (PIER, 2008).

Identification and comprehension of the ecological factors that influence invasiveness is an important requirement for the management of invasive species (Perdereau *et al.*, 2010). Goal 6 of the Convention on Biodiversity (CBD) focuses on controlling invasive species as they are a threat to global biodiversity (SCBD, 2010). Therefore, a study that improves comprehension of the mechanisms behind *D. cinerea* invasion will help to curb the future economic and environmental impacts of invasive native plant species in general.

The objectives of this study are to determine the impact of *D. cinerea* invasion on native woody species diversity, floristic composition and vegetation structure; and to assess the dynamics and extent of this invasion (population size, relative abundance, size class distribution, recruitment capacity/fecundity) on the area.

II. MATERIALS AND METHODS

A. Site

The study was carried out in Gokomere Area located 18 km north of Masvingo town, and covering approximately 5800 hectares of land (Figure 1).

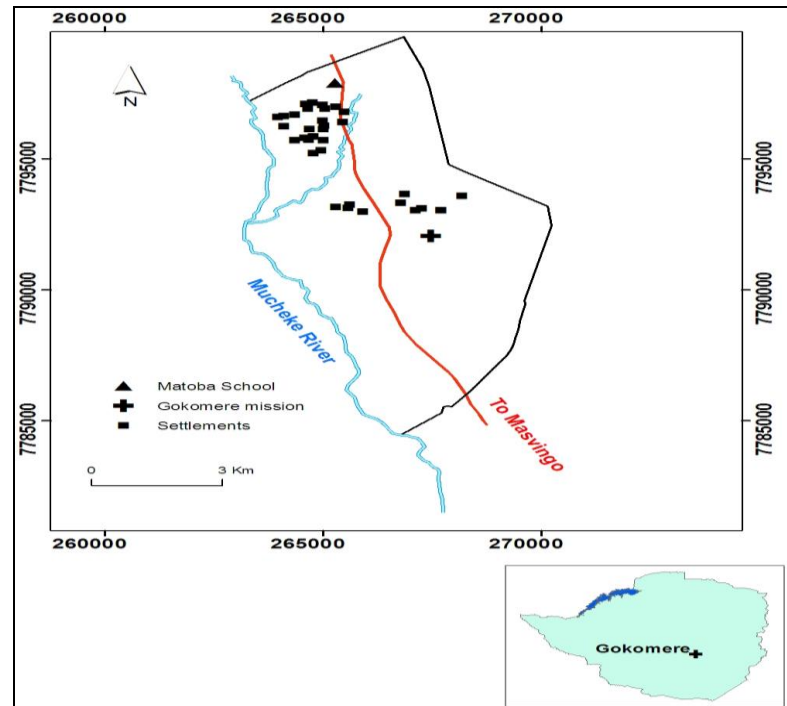


Figure 1: A GIS map and location of the study area. Map coordinates are in meters, Universal Transverse Mercator Zone 36 South

The area is located in Natural Region IV (NR IV) of the Zimbabwean ecological classification system (Vincent and Thomas, 1961). It is found at altitude 1163m above sea level, on latitude 19°57'45" S and longitude 30°46'34"E. On the west, it is bound by Mucheke River, and is characterised by a few small kopjes, semi-vlei areas and granite outcrops. The parent granite is of the dwala type, and the soils are sandy-loams deficient in nitrogen, sulphur and phosphorous. The area experiences mean maximum and minimum temperatures of 21.8⁰ C in October, and 13.3⁰ C in June respectively. Rainfall is unreliable and mainly falls between November and March. Highest monthly rainfall of 158 mm is mainly recorded in December. The main perennial cover is characterised by *Hyparrhenia spp* while *Terminalia sericea* and *Combretum spp* are most dominant woody species.

B. Selection of the *D. cinerea* invaded and uninvaded sampling sites

The five patches of *D. cinerea* invasion studied were identified using a 2009 Google Earth Satellite Imagery of the area, then verified by ground truthing. They measured ~ 1 hectare each, representing ~10 % of the total invaded area. The first patch was randomly selected and subsequent patches were selected by considering the nearest neighbour plus one method. Patches that did not meet the area criteria were omitted, and the next nearest patch was considered. Five sites not invaded by *D. cinerea*, but adjacent and equal in size to each of the five randomly selected *D. cinerea* patches were also studied.

C. Demarcation of plots, and woody vegetation sampling

Three 100 m transects were laid down, with one transect passing through the centre of each patch. Each of the other two

transects was laid at equi-distances from the centre and periphery of each patch. Two 10 m x 10 m plots were systematically established on each transect for woody species assessments. The plots were located 50 m from main roads and rivers to reduce road and river effects. Four wooden rods were pegged on the ground to mark the corners of each plot using a 50 m tape measure. A string was used to mark the perimeter of each plot for tree floristic composition and structure assessments. Plot sizes were adopted from Mueller-Dombois and Ellenberg (1974). A Geographical Positioning System (GPS) unit was used to record altitude and location of the plots. Woody vegetation, comprising trees and shrubs, was assessed during the rainy season. Field identification guides (van Wyk and van Wyk, 1997; Carruthers, 1997; Plower and Drummond, 1990) were used to identify woody species encountered in the plots. Canopy structure, growth habit, leaf, bark and other structures were used to differentiate closely related trees. All woody vegetation rooted within the plot, or along plot margins with at least half of the rooted system inside the plot was measured and recorded (Walker, 1976). Height classes for the woody species were modified from Chinuwo *et al* (2010) to define trees, shrubs, saplings and seedlings as: trees- rooted, woody, self-supporting plants with one or a few definite trunks of basal diameter ≥ 0.06 m, and a height of ≥ 3 m; shrubs- rooted, woody, self-supporting plants of height of 1m - <3 m; saplings - plants of height 0.15 m - <1 m in height; seedlings - individuals of height <0.15 m. Woody vegetation heights, stem circumferences and canopy diameters were recorded.

D. Data analysis

Basal area, canopy cover, abundance and density of species were analysed. SPSS Version 13 (SPSS, 2004) was used for one

way analyses of variance (ANOVA) of the woody variables. The data obtained from 3 of the 5 invaded sites sampled (Sites 1, 2 and 3), and their respective adjacent uninvaded site (Sites 6, 7 and 8) was tested using independent t-tests to check for significant differences in the various variables measured. The results were compared with those from one way ANOVA done on all invaded and uninvaded sites for the same variables. The two sets of results were similar. One way ANOVA was therefore used to analyse the rest of the data obtained from the field. Multiple comparisons were done to test for significant differences among the plots. Ordination techniques (Principle Component Analysis (PCA) and Cluster Analysis (CA)) were used to arrange sites along axes basing on woody species composition data (McGarigal *et al.*, 2002; ter Braak and Smilauer, 1998).

III. RESULTS

A. Woody vegetation structure

Basal Area

A total of 40 woody species was recorded for both habitat types, 22 in the invaded plots and 34 in the uninvaded plots. These are shown on the importance curve for the woody species in Figure 2. The invaded sites significantly ($P < 0.05$) differed from the uninvaded sites when compared on the basis of basal area. There were no significant ($P > 0.05$) differences in basal area among the invaded sites, neither were there significant ($P > 0.05$) differences among the uninvaded sites. Higher basal area was recorded on invaded sites.

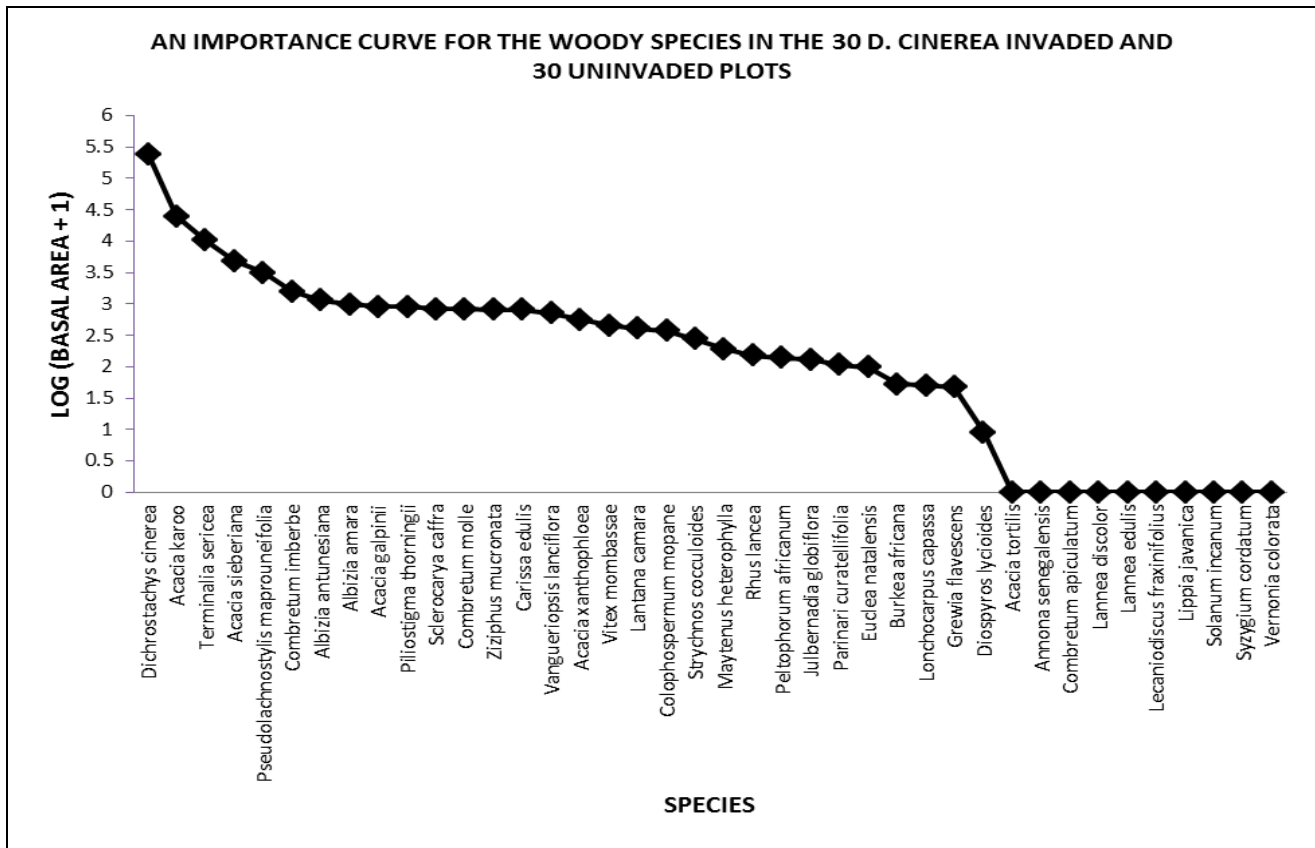


Figure 2: Species importance curve for woody species

D. cinerea, *A. karoo*, *T. sericea*, *A. sieberiana*, *P. maprouneifolia* and *C. imberbe* were the dominant species while *A. tortilis*, *A. senegalensis*, *C. apiculatum*, *L. discolor*, *L. edulis*, *L. fraxinifolius*, *L. javanica*, *S. incanum*, *S. cordatum* and *V. colorata* were rare species (Figure 2).

Tree heights

Height classes showed that most woody plants were saplings followed by shrubs, trees and lastly seedlings for both invaded and uninvaded sites (Figure 3). A two way analysis of variance showed significant ($P < 0.05$) differences in height classes between invaded and uninvaded sites, and among the invaded sites. The uninvaded sites did not differ significantly ($P > 0.05$) among themselves.

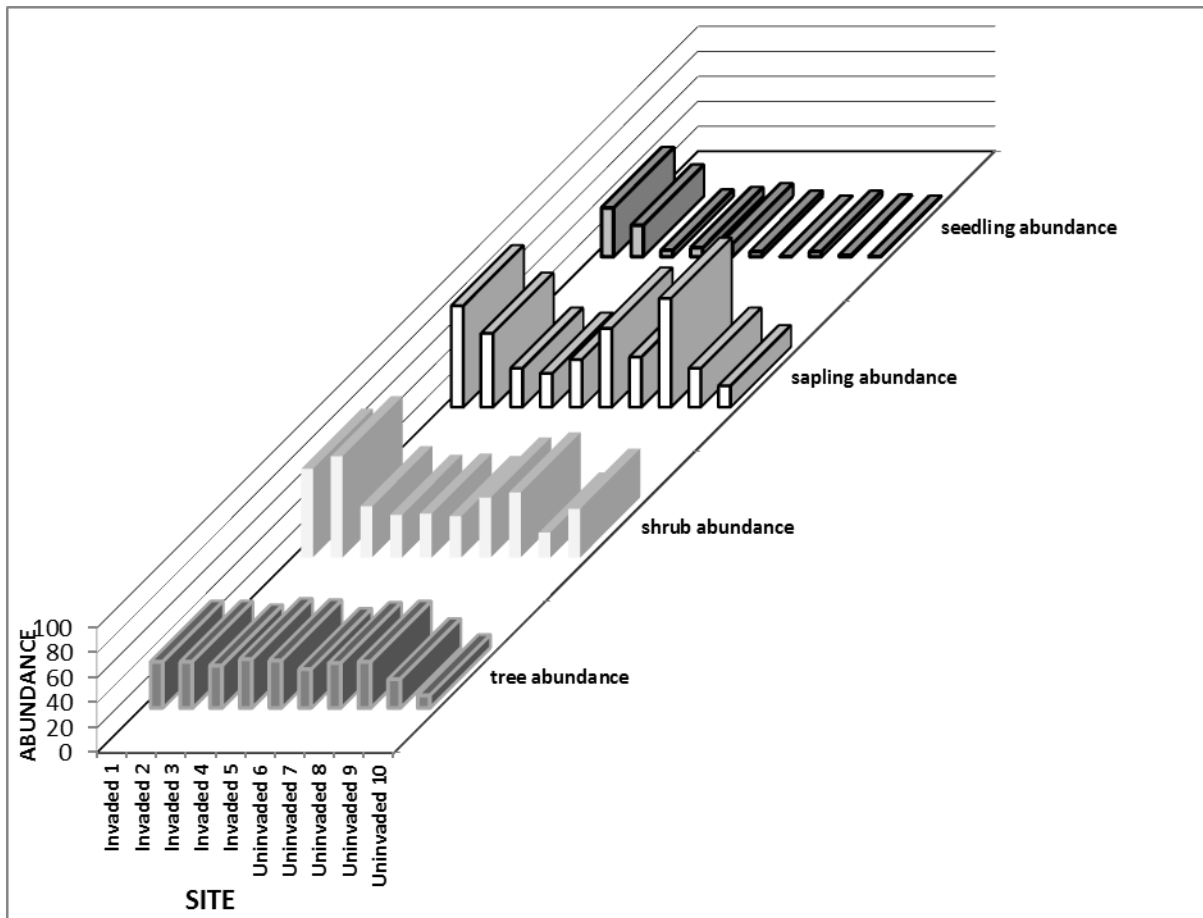


Figure 3: Size class distribution of woody species in *D. cinerea* invaded and uninvaded sites

Canopy cover

Canopy cover from invaded and uninvaded sites was significantly ($P < 0.05$) different. This parameter was not

significantly ($P > 0.05$) different among the invaded sites. It was also not significantly ($P > 0.05$) different among the uninvaded sites. A cluster diagram based on principal component analysis of canopy cover measurements separated the invaded plots from the uninvaded plots (Figure 4).

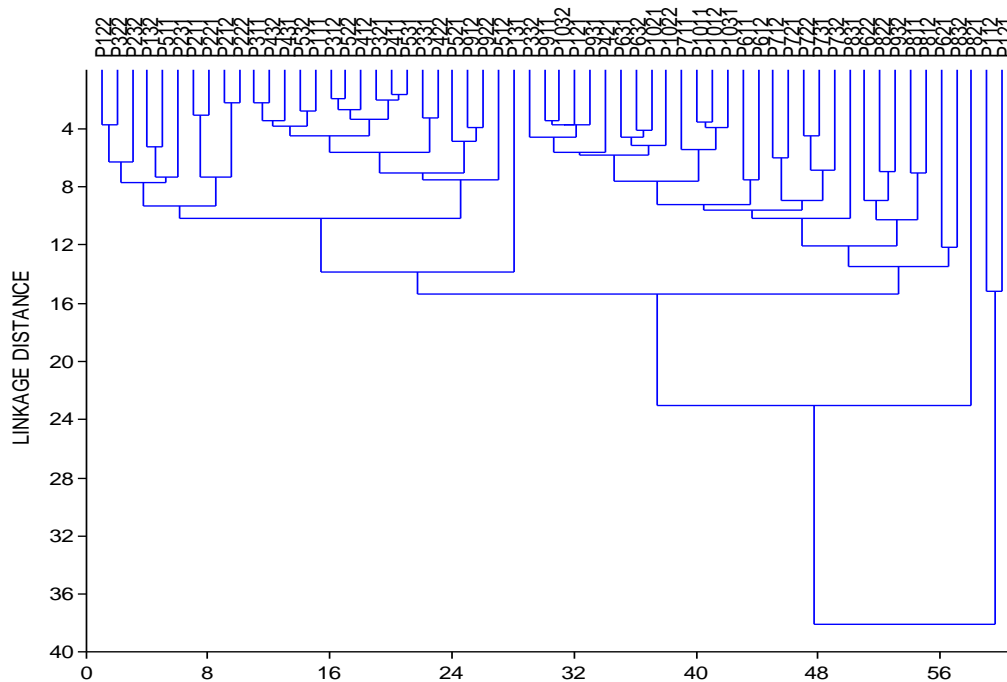


Figure 5: Dendrogram (single linkage, euclidean distances) from cluster analysis of *D. cinerea* invaded and uninvaded plots

C. Diversity indices

Table 1 shows the evenness and diversity indices for the invaded and uninvaded sites. The invaded sites had higher evenness, Shannon-Weiner indices and Simpson's indices than the uninvaded sites. There were significant ($P < 0.05$) differences in evenness, Shannon-Weiner index and Simpson's index among the invaded and uninvaded sites.

Table 1: Species diversities among the invaded and uninvaded sites

Diversity index	Invaded Site	Uninvaded Site
Evenness_e ^{H/S} _S	0.351 ^a	0.504 ^b
Shannon_H	1.127 ^a	2.104 ^b
Simpson_1-D	0.493 ^a	0.815 ^b

Means in rows with different superscripts are significantly different ($P < 0.05$)

IV. DISCUSSION

A. Woody vegetation composition and diversity

Woody species richness, abundance, density and diversity in areas of Gokomere invaded by *Dichrostachys cinerea* have declined. Likewise, Hejda *et al* (2009) report approximately 90% decreases in species numbers per plot and total number of species recorded in invaded plant communities. Invasive plant species threaten ecosystem function and community diversity, dominating natural systems through suppression of, competition with, and replacement of native species (Kelly *et al.*, 2009). They are characterized by mono-specific stands. The dominance that

D. cinerea achieves in invaded areas suppresses native woody species (Daehler, 2003) causing lower species richness as observed in the study plots. It is most likely that its vigorous growth characteristic is responsible for its impact on native species. The species also has an extensive and dense root system that is important in propagation and competitive exclusion of other species.

Uninvaded sites were characterized by spatial heterogeneity that resulted in significant differences among sites, hence supporting a variety of species resulting in high species richness. Compared to the dense *D. cinerea* stands, treefall gaps in uninvaded sites create spatial heterogeneity in understory light levels (Canham *et al.*, 1990) which is essential for the maintenance of species diversity. The uninvaded sites recorded higher species evenness and Shannon-Weiner and Simpson's indices than the invaded sites. Hejda *et al* (2009) note reductions in species richness, diversity and evenness in invaded plots compared to uninvaded sites. Similarly, Hartman and McCarthy (2008) state that invasions by Amur honeysuckle (*Lonicera maackii*) are frequently linked to poor individual performance and reduced species diversity. Higher species richness in the uninvaded sites in this study resulted in higher diversities. The invaded sites were dominated by *D. cinerea*, hence they had lower diversity. Holmes and Cowling (1997) also note that invasion by *Acacia saligna* results in declines in fynbos species richness, cover and frequency.

Canham (1985) concludes that the dynamics of canopy recruitment by *Acer saccharum* and *Fagus grandiflora* depended on light penetration through gaps into the understory beneath the northern edges of gaps. Reduced abundance of seedlings of other native species shown in this study could be due to the negative impacts of increased *D. cinerea* canopy cover which may affect

shade-intolerant native species. Germination and seedling survival are likely to be affected by light deprivation. Due to higher species richness, uninvaded sites are characterized by different types of litter whose distribution and decomposition cause patchy micro-environmental conditions. These present distinct niches that support proliferation of different woody species in a given area, hence the high diversity indices calculated for uninvaded sites in this study. Most of the woody species abundant in the uninvaded sites were deciduous in nature. They included *T. sericea*, *B. africana* and *A. amara*. These species contributed to the higher litter in the uninvaded sites compared to the invaded plots which were dominated by *D. cinerea*.

The invaded plots had higher density than the uninvaded plots. *D. cinerea* is propagated through rapid root suckering. It also has high seed germination rates. Immediately after cutting down an adult tree, shoots are formed from the numerous fibrous roots. Seed dispersal of the species is facilitated by both livestock and wildlife that feed on the pods. The species is also a nitrogen fixing tree (Bein *et al.*, 1996), and this ability might be the reason for its rapid growth rate. In a study by Vitousek and Walker (1989), measurements of litter decomposition and nitrogen release, soil nitrogen mineralization, and plant growth in bioassays all demonstrate that nitrogen fixed by the invader *Myrica faya* become available to other organisms. These various biological aspects of *D. cinerea* interact to make the species a successful invader, forming dense impenetrable thickets.

B. Vegetation structure

This study has shown that *D. cinerea* invaded plots studied were significantly different in woody structure elements from uninvaded plots. The highest canopy cover, basal area and woody species height classes in the invaded sites had greater abundance than in the uninvaded sites. The higher basal area of the invaded sites as compared to uninvaded sites was mainly due to *D. cinerea*. Although most stems of *D. cinerea* in the studied plots had a mean diameter of 7cm each, the species is multi-stemmed. Given this multi-stem characteristic and its high density, *D. cinerea* therefore had the highest cumulative basal area. The high densities of *Acacia spp* such as *A. karroo* and *A. sieberiana* found in the *D. cinerea* plots had a similar effect. Species that dominated the uninvaded plots were *T. sericea*, *P. maprouneifolia* and *C. imberbe*. Although these are single trunked mainly (SANBI, 2008), they form thick trunks. Their high abundances in the uninvaded sites also contributed to high cumulative basal area. The insignificance in difference of basal area of the invaded and uninvaded sites was due to homogeneity in the *D. cinerea* plots, and dominance of species such as *T. sericea* in the uninvaded sites, respectively. An importance curve of the species showed that *D. cinerea* was the most dominant species, followed by *A. karroo*, *T. sericea*, *A. sieberiana*, *P. maprouneifolia* and *C. imberbe*. Rare species like *C. apiculatum*, *L. discolor*, *L. edulis*, *L. javanica*, *S. incanum* and *S. cordatum* contributed the least to basal area.

There were significant differences in canopy cover between the invaded and uninvaded sites, but not within invaded plots or within uninvaded sites. *D. cinerea* forms a heavily intertwined overhead canopy which grows faster than other native species.

This characteristic and the dominance of *D. cinerea* in the invaded plots resulted in the higher canopy cover observed unlike in uninvaded sites where differences in occurrence of woody species probably caused the observed variations. *A. karroo* which has a similar canopy to *D. cinerea* also contributed to the observed canopy cover in invaded sites as shown on the principal component analysis diagram, while canopy cover in the uninvaded sites was mostly due to *T. sericea* and *A. amara*. *Albizia amara* is a deciduous tree with a more or less domed crown while *T. sericea* is also deciduous with a light irregular crown (Wild, 1972).

The height class distribution showed the dominance of the saplings followed by the shrubs, trees and lastly seedlings. In assessments of uninvaded and invaded sites, Hartman and McCarthy (2008) note significant reductions in densities in the herb, seedling, and sapling layers and also reduced species richness in the seedling, sapling and herbaceous layers due to invasion. The higher abundance of saplings in this study was probably due to higher survival rate and better competition of saplings as compared to seedlings. Shrubs were more abundant than trees due to the fact that *D. cinerea* mainly occurs as a shrub. Plant species invasion are often associated with a decrease in the abundance of native species, particularly trees, and this is typically interpreted as evidence for direct resource competition between the invader and native species (Meiners, 2007). The higher abundance of seedlings in invaded plots compared to uninvaded plots was most probably due to the high propagule pressure of *D. cinerea* through root suckers and the high germination rate characteristic of the species. This is supported by the fact that seedling richness was lower in the invaded sites with the most abundant seedlings being *D. cinerea* seedlings. According to Lonsdale (1999), seed dispersal or propagule pressure plays a vital role in plant invasions. Forest studies have shown that light is a critical resource affecting growth and mortality, and that many plant invaders are thought to suppress native recruitment by reducing light availability. Holmes and Cowling (1997) report that the long invaded dense *Acacia* canopies intercepted more light than fynbos. *D. cinerea* forms dense canopies that intercept light to the understory vegetation.

V. CONCLUSION

The current study has revealed that *D. cinerea* has adverse impacts on native woody species composition and structure. It has also provided strong evidence to show the negative impact the species has on vegetation recruitment and regeneration. These changes in vegetation structure and composition may have important implications on wildlife and livestock habitat, biotic diversity and feed availability. Due to financial constraints and a shorter period of sampling, vegetation assessments were done on only 5 patches of *D. cinerea* during one season. It is recommended that a long term study on a bigger area be done to provide more information on the impact of the species. Analyses of the results compared findings from all the invaded sites against findings from all the uninvaded sites. Future studies could compare each invaded site against its adjacent uninvaded site.

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