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Effects of *Dichrostachys cinerea* (l.) Wight & Arn (Fabaceae) on herbaceous species in a semi-arid rangeland in Zimbabwe

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Abstract

Anthropogenic alteration of an environment and other disturbance regimes may enable the expansion of some native species into new geographical areas, a phenomenon observed with *Dichrostachys cinerea.* Five *D. cinerea* invaded sites, each approximately one hectare in size were assessed for the effects of *D. cinerea* on native herbaceous species diversity, richness, basal cover, litter cover, top hamper and plant vigour. The same attributes were studied in five uninvaded sites adjacent to, and equal in size to each invaded site. Forty herbaceous species were identified in the area. There were significant differences ($P < 0.05$) noted in species richness, basal cover, litter cover, top hamper, plant vigour, and species diversities between invaded and uninvaded sites, with uninvaded sites recording higher values than invaded sites. Altitude, erosion and the edaphic variables pH, N, P and K, which were included as explanatory variables, also differed significantly ($P<0.05$) between invaded and uninvaded sites. Of the 30 *D. cinerea* invaded plots established for herbaceous species assessments, 26 were positively correlated with altitude, erosion, pH, P, N and K. It is imperative to find ways of managing *D. cinerea* in order to reduce its adverse effects on herbaceous species.

Keywords
Dichrostachys cinerea, herbaceous species, invasion

Introduction

Ecologically unsustainable anthropogenic activities such as agriculture, mining, and oil exploration, coupled with climate change and variability, facilitate plant species invasions. This is exacerbated by increases in the frequency and extent of natural disturbances such as droughts, hail storms, fire, insect outbreaks and disease in boreal forests which upset ecological and economic balances, perpetrating invasions (IPCC 2007). The Convention on Biodiversity (CBD) targeted 'to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional, and national level as a contribution to poverty alleviation, and to the benefit of all life on Earth' (SCBD 2010). This facilitated development of policies to preserve biodiversity including elimination or control of alien invasive species. Most of the studies on plant species invasion ecology focus on these alien invasives, yet the control of exotic and native species by the same ecological processes may explain the positive correlation often found between exotic and native species richness (Lonsdale 1999).

Dichrostachys cinerea is a deciduous low thorny tree or shrub that produces bicoloured fragrant flowers. It is native to Africa and Asia, where it is common in the tropics of Africa, the Sahelian and Sudanian ecozones, and the South Arabian Peninsula (TTPC 2010). Both old and young *D. cinerea* plants can produce many viable seeds annually which can survive for more than 5 years in the soil. This increases propagule pressure of the species. Its infructescence has a strong aroma, and this probably attracts animals to feed on the pods, facilitating seed dispersal. The species also forms impenetrable thickets that are difficult to eliminate due to high propagation capacity and propagule pressure of *D. cinerea.* Increased grazing and trampling pressure around boreholes was shown to cause a species-poor zone in the immediate vicinity of boreholes, followed by thickets with *Acacia* spp. and *D. cinerea*, transitional to tree savanna (Tolsma et al. 1987a).

Collection and grinding of *D. cinerea* fruits have been suggested as a management tool to control its encroachment (Mlambo et al. 2004). Chemical ways are often costly, and most herbicides are dangerous and have residual effects. Manual control is labour intensive and also less effective since new seedlings and coppicing replace the mechanically removed *D. cinerea* plants. The main aim of this study was to assess the effects of *D. cinerea* on herbaceous species diversity, richness, basal cover, litter cover, plant vigour and top hamper, determining the major herbaceous characteristics of invaded sites and the extent to which invaded and uninvaded sites differ. An analysis of the invasive capacity of *D. cinerea* on rangelands will contribute immensely to its management and control, hence achievement of the 2010 Convention on Biodiversity (CBD) target, which was also incorporated as a new target in the Millennium Development Goals (MDGs).

Materials and methods

Location

Rangelands on Gokomere Farm located 18 km north of Masvingo town, and covering approximately 5800 hectares of land were studied. The farm lies in Natural Region IV (NR IV) of the Zimbabwean ecological classification system (Vincent and Thomas 1961). It is found at an altitude of 1163 m above sea level (19°57'45"S, 30°46'34"E). The farm is characterised by a few small kopjes, semi-vlei areas, and granite outcrops. Its soils are granite derived sandy-loams that are deficient in nitrogen, sulphur and phosphorous. Rainfall is unreliable both within and between seasons. Mean maximum and minimum temperatures of 21.8° C and 13.3° C are often experienced in October and June respectively. *Hyparrhenia* spp. was the main perennial cover, while *Terminalia sericea* and *Combretum* spp. were the main woody species.

Plot demarcation, and herbaceous species and edaphic assessments

A 2009 Google Earth Satellite Imagery of Gokomere Farm, followed by ground truthing was used to identify areas invaded by *D. cinerea.* Five *D. cinerea* patches were chosen using the nearest neighbour-plus-one-method. Three transects measuring 100 m each were laid down, the first one passing through the centre of each patch, and each of the other two at equi-distances from the middle and boundary of each patch. On each transect, two 10 m × 10 m plots were systematically pegged on the ground. They were established at least 50 m from main roads and rivers to reduce road and river effects. Species presence/absence data and other herbaceous assessments were carried out in five 1 m × 1 m quadrats established at the four corners and centre of each 10 m × 10 m plot (Mueller-Dombois and Ellenberg 1974). For each quadrat, herbaceous cover, litter cover, top hamper, erosion and plant vigour were awarded numeric values ranging from 1-10 whereby the higher the attribute, the higher the value. Altitude and location of the sites were recorded using a Geographical Positioning System (GPS) unit. A soil auger was used to collect soil from the top 15 cm of the soil from each of the quadrats (Stohlgren et al. 1998). The soil samples from the same plot were thoroughly mixed and the composite sample was put in an air proof polythene bag. Analysis was done on N, P, K and pH at the Department of Soil Science, University of Zimbabwe.

Data analysis

SPSS Version 13.0 (2004) was used for one way analyses of variance (ANOVA) of the herbaceous and soil variables. PAST was used to calculate diversity indices. The herbaceous variables that were analysed were basal cover, litter cover, plant vigour and top hamper. Altitude, erosion and the edaphic variables (pH, N, P and K) were included as explanatory variables. Multiple comparisons were done to test for significant differences among the plots. The relationships between the measured variables and the measured explanatory variables were explored using CANOCO for Windows (version 4). CANOCO was used to carry out Detrended Correspondence Analysis (DCA) and Redundancy Analysis (RCA) (ter Braak and Smilauer 1998). RCA was used to detect relationships using species data and the environmental variables measured. An unrestricted Monte-Carlo permutation test in CANOCO was used to test the statistical significance of the ordination (CANOCO, version 4.5 2002).

Results

Herbaceous variables

There was a total of 40 herbaceous species in the *D. cinerea* invaded and uninvaded sites. Invaded sites had 26 species while uninvaded sites had 32. The most common species in the invaded sites were *Digitaria penzii, Cynodon dactylon* and *Eragrostis trichophora* while in the uninvaded sites they were *D. penzii*, *E. trichophora* and *Hyperthelia dissoluta* (Table 1).

There were significant differences ($F_{9,50}$=9.375, P<0.05) in basal cover among invaded and uninvaded sites. Invaded sites did not differ significantly ($F_{9,50}$=2.750, P>0.05) in basal cover among themselves. However, the uninvaded sites showed significant differences ($F_{9,50}$=16.123, P<0.05). Litter cover had significant differences among invaded and uninvaded sites ($F_{9,50}$=6.024; P<0.05). Invaded sites were significantly different from each other ($F_{9,50}$=3.442, P<0.05), as were the uninvaded sites ($F_{9,50}$=6.537, P<0.05). Invaded sites recorded lower litter cover than uninvaded sites. Plant vigour in invaded sites was significantly different from that within uninvaded sites ($F_{9,50}$=5.796, P<0.05). Both the invaded sites and uninvaded sites showed significant differences in plant vigour ($F_{9,50}$=8.037, P<0.05 and $F_{9,50}$=4.605, P<0.05 respectively) among themselves. There were significant differences in top hamper among invaded and uninvaded sites

Table 1. Herbaceous species variables among the invaded and uninvaded sites.

Parameter	Invaded Site	Uninvaded Site
Basal cover	3.7^{a}	4.5^{b}
Litter cover	1.5^{a}	2.1^{b}
Species richness	2.9^{a}	3.5^{b}
Plant vigour	2.9^{a}	3.4^{b}
Top hamper	0.8^{a}	1.1^{b}
Shannon_H index	2.58^{a}	2.85^{b}
Simpson_1-D index	0.92^{a}	0.94^{b}

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

($F_{9,50}$=3.264, P<0.05). Invaded sites did not differ significantly ($F_{9,50}$=0.666, P>0.05) in top hamper. Uninvaded sites had significant differences ($F_{9,50}$=6.959, P<0.05). Species richness differed significantly ($F_{9,50}$=5.776, P<0.05) among invaded and uninvaded sites. Invaded sites were not significantly different ($F_{9,50}$=1.052, P>0.05) from each other in species richness. However, uninvaded sites had significant differences ($F_{9,50}$=7.113, P<0.05). Herbaceous species diversities also differed significantly (P<0.05) between invaded and uninvaded sites.

Edaphic properties

The pH values across invaded and uninvaded sites were significantly different ($F_{9,50}$=2.816, P<0.05). Invaded sites had significant differences for pH among themselves ($F_{9,50}$=4.738, P<0.05) unlike uninvaded sites ($F_{9,50}$=1.719, P>0.05). There were significant differences ($F_{9,50}$=70.903, P<0.05) for K between invaded and uninvaded sites. Both, invaded and uninvaded sites were significantly different from each other ($F_{9,50}$=100.952, P<0.05; $F_{9,50}$=4.535, P<0.05). The recorded P values showed significant differences ($F_{9,50}$=66.916, P<0.05) between invaded and uninvaded values. Both invaded and uninvaded sites showed significant differences among themselves ($F_{9,50}$=51.018, P<0.05 and $F_{9,50}$=24.872, P<0.05 respectively). There were significant differences ($F_{9,50}$=3.980, P<0.05) for the recorded N values between the invaded and uninvaded sites. Uninvaded sites significantly differed from each other ($F_{9,50}$=5.039, P<0.05) while invaded sites were not significantly different ($F_{9,50}$=2.735, P>0.05). There were significant differences ($F_{9,50}$=6.193, P<0.05) in altitude between the invaded and uninvaded sites. Invaded sites were significantly different ($F_{9,50}$=5.692, P<0.05) from each other. Uninvaded sites also significantly differed ($F_{9,50}$=7.637, P<0.05) from each other. Erosion significantly differed ($F_{9,50}$=3.303, P<0.05) between invaded and uninvaded sites. Invaded sites had significant differences for erosion among themselves ($F_{9,50}$=4.420, P<0.05), and so did uninvaded sites ($F_{9,50}$=3.182, P<0.05).

Herbaceous species-environmental relationships

Of the 30 *D. cinerea* invaded plots (1–30) assessed for herbaceous species attributes, 26 were correlated with altitude, erosion, pH, P, N and K (Figure 1). Twenty five of the uninvaded plots (31–60), were negatively correlated with the measured environment variables. Invaded plots classified with these uninvaded sites were 6, 22, 23 and 25. They had low K values characteristic of the uninvaded sites studied, with the exception of sites 4 and 6. They all had lower N than the invaded plots (0.5–2.1 ppm compared to 3.3–5 ppm). There was no clear pattern for pH.

The species that were negatively correlated with these variables were *Aristida* spp., *Pogonathria squarrosa, Rhynchelytrum repens, Panicum* spp. and *Digitaria penzii*. K was positively correlated with *Urochloa mozambicensis, Heteropogon contortus, Acanthosper-*

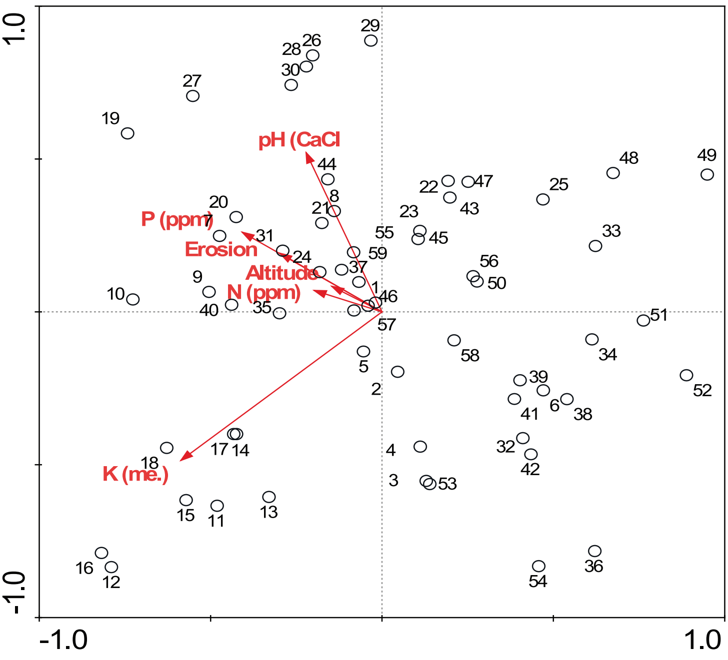

Figure 1. A redundancy analysis plot based on herbaceous species presence absence data showing relationship between the environmental variables and the plots.

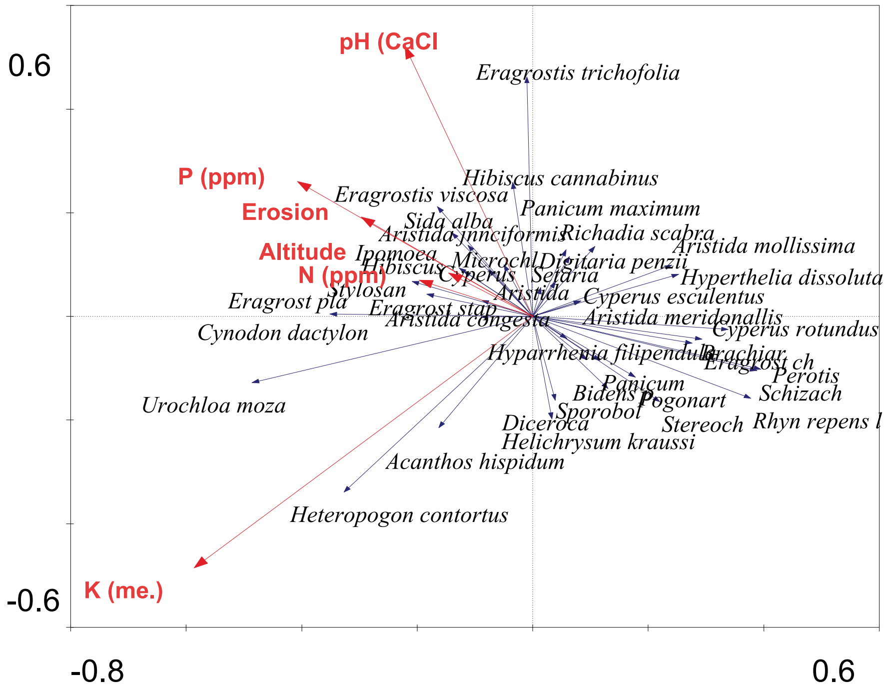

Figure 2. A redundancy analysis plot based on herbaceous species presence absence data showing relationship between the environmental variables and the species.

mum hispidum etc. It was negatively correlated with *Richadia scabra, Setaria palidifusca* and *Hyperthelia dissoluta* (Fig. 2).

We show that pH, erosion, P, altitude and N influenced the abundance of species such as *Hibiscus* spp, *Sida alba* and *Cynodon dactylon*.

Discussion

Herbaceous variables

D. cinerea invasion has caused declines in herbaceous species richness. Competitive interactions are critical between woody plants and grass dominated layers in arid to semi-arid areas (Jacoby et al. 1982). *D. cinerea* may be competing with the native herbaceous species for resources such as light, nutrient and moisture. *C. dactylon* was one of the most abundant herbaceous species. It is very competitive, particularly in fertile soils, and only aggressive legumes are capable of forming an association with it (Harlan and de Wet 1969). This explains its occurrence in invaded sites. High litter deposition by a dominant plant species can also modify competition; suppress competing plants, and lower plant species richness (Xiong and Nilsson 1999). *D. cinerea* may have reduced herbaceous species richness through litter deposition or due to its vigorous growth characteristic, extensive and dense root system that is important in propagation and recruitment as compared to native species. Uninvaded sites also recorded higher species diversity indices (Shannon Weiner and Simpson`s indices) than the invaded sites. Due to occurrence of certain species only unique to uninvaded sites in the absence of the suppressive nature of *D. cinerea* on other species, uninvaded sites had higher species richness than the invaded sites, hence higher Shannon-Weiner index.

In a study by Tolsma et al. (1987b), there was less than 10 % ground cover by herbs and grasses in *D. cinerea* thickets, with the most frequent species being annual herbs like *Boerhavia diffusa* and weedy species such as *A. hispidum*, the latter of which was only found in invaded sites in the present study. Dense thickets such as those that are formed by *D. cinerea* can result in a decrease in carrying capacity through loss of grass cover caused by replacement and by competition for limited resources. In studying an invasive species of the genus *Prosopis*, although there were certain grasses that were adapted to shade conditions, there were others which were shade intolerant and were thus inhibited by competition with species of genus *Prosopis* (Jacoby et al. 1982). *P. maximum* grows better at 30 % shade although yields are reduced by half at 50% shade (Harty et al. 1983). In the present study *P. maximum* was found in uninvaded sites which had lower canopy cover than the *D. cinerea* invaded sites, hence less shading. The reduced abundance of herbaceous species in this study could also be due to the negative impacts of increased *D. cinerea* canopy cover which may affect shade-intolerant species. Light deprivation may have affected basal cover, plant vigour and richness of herbaceous species noted in invaded sites as compared to uninvaded sites. The occurrence of *H. contortus* under the dense *D. cinerea* thickets is also in consistency with findings that *H. contortus* tolerate light shading, often dominating the understorey of *Eucalyptus* woodlands in tropical and subtropical Australia (Bhatt et al. 2006). While standing litter may protect seedlings from desiccation and high temperatures, it may also reduce light availability (Käller 2003) hence affect growth and production of other herbaceous species resulting in the observed lower herbaceous basal cover of invaded sites than that of uninvaded sites. Rapid root suckering of *D. cinerea* in propagation as well as high seed germination also make the specie a more successful invader with better plant vigour than the native herbaceous species.

In the present study there were significant differences in environmental variables between invaded and uninvaded sites. Invaded sites had higher soil N, K and P than uninvaded sites. Biological invaders change ecosystems as they differ from native species in resource acquisition and/or resource use efficiency. They may also alter the trophic structure of the area invaded, or the disturbance frequency and/or intensity (Vitousek 1990). The fluctuating resource availability theory states that plant species invasions are associated with increases in resources (Davis et al. 2000). *D. cinerea* is a nitrogen fixing shrub. The effect it has on soil could have been translated into herbaceous species composition. The decline in species richness means that native species are displaced by *D. cinerea*, resulting in a decrease in nutrient sequestration, hence increases in N, P and K observed in the invaded sites. Altitude also varied significantly among invaded sites. *D. cinerea* can occur on a wide range of altitude.

Eragrostis spp., *Hibiscus* spp., *S. alba and U. mozambicensis* were found in the *D. cinerea* invaded sites. These grasses are associated with disturbed land (Wild 1972). Disturbance is one of the major factors affecting species invasions (Davis et al. 2000). The *Eragrostis* spp. were positively correlated with erosion and negatively correlated with K. *E. viscosa* is an indicator of poor soil conditions such as is characteristic of eroded land (Wild 1972). *E. chapelieri* is also common on sandveld and it has poor forage value. Eroded soils are low in soil nutrients such as N, P and K. Erosion mostly affects the topsoil which provides the main nutrients needed by plants. *U. mozambicensis* is usually found in wooded grassland and deciduous bushland, or on disturbed sites where the soil is fertile (Burt et al. 1980). This explains the positive correlation of the species with potassium in *D. cinerea* invaded sites. *Stylosanthes guianensis* can extract P very efficiently from low P soils, but still responds to applications of P, as well as K, sulphur and calcium in soils with low levels of these nutrients (Chakraborty 2004). The species was positively correlated with K. *C. dactylon* was one of the most abundant herbaceous species. It grows on a wide range of soils, but best in relatively fertile, well-drained soils. It was correlated with N. It is very competitive, particularly in fertile soils.

The herbaceous species that were negatively correlated with the measured environmental variables were *Aristida* spp., *P. maximum, Pogonarthria squarrosa, D. penzii, H. filipendula, H. dissoluta* and *R. repens* among other species. *P. maximum* grows best in moist, well-drained soils just like *R. repens,* although some of its varieties are tolerant of lower fertility and poorer drainage (Harty et al. 1983, Wild 1972). The species was found in uninvaded sites which had lower canopy cover than the *D. cinerea* invaded sites, hence less shading. The correlation of *P. squarrosa* with uninvaded sites is in consistency with the findings of Wild (1972) who report that the species is a normal constituent of grassland on sandy soils. The *Aristida* spp. are drought resistant perennial grasses that grow in poor, gravely soils and also on clay soils.

Conclusion

Dichrostachys cinerea is a native invasive woody shrub or tree. Here, it adversely affected native herbaceous species plant vigour, basal cover and species richness. Reduced litter cover and top hamper were also observed in invaded sites. These observations can be attributed to the fast growth, propagation and propagule pressure that characterize *D. cinerea*, giving it a competitive advantage with respect to acquisition of light, nutrients and other resources. Therefore, these adverse effects on herbaceous species may, in the long term, reduce the carrying capacity of rangelands, making them even more susceptible to alien invaders. However, a long-term study may provide more information on the biology and invasive capacity of the species and on its impact on other vegetation and animal species. There is also need to find environmentally friendly and effective methods of controlling *D. cinerea* inorder to prevent its spread, hence adverse effects on herbaceous species.

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