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On the Path of Invasion: Disturbance Promotes the Growth Vigor among Siam Weeds in a Mine Land Ecosystem

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ABSTRACT

Siam weed (*Chromolaena odorata*) is reputed to be among the world`s most invasive plant species with highly significant economic impact. The distribution, density and growth characteristics (shoot height, leaf area, leaf density, canopy diameter, main stem diameter and mortality) were assessed in a mining ecosystem. The study covered three undisturbed tropical forest sites and three neighboring mine wasteland sites that were 2-15 years post-mining. The growth vigor of *C. odorata* was compared to that of a dominant native plant species *Panicum maximum*. The mean leaf density per plant was significantly higher ($p<0.0001$) among *C. odorata* in mine lands than in undisturbed forest sites. *C. odorata* showed significantly ($p<0.0001$) higher plant density in the mine lands, indicating the conduciveness of disturbed mined lands as habitats that promote invasiveness among the species. Approximately 65% mortality rate of *C. odorata* occurred under the dense canopy of the undisturbed forest sites and of only 4% mortality rate was recorded for the mined land sites. The native species *P. maximum* generally depicted lesser growth vigor in the mined lands as compared to the undisturbed forest sites. The mean mortality rate was 55 and 5% within the mined lands and the undisturbed forest sites, respectively. This study identifies the absence of dense canopy and shade as the potential factors promoting the invasiveness of *C. odorata* and the capacity for spread within the mine land sites.

Key words: *Chromolaena odorata*, mortality, native species, *Panicum maximum*, pioneer vegetation, shade

INTRODUCTION

C. odorata and *P. maximum* persist prominently on farmlands adjoining tropical forests (Fening *et al*., 2010; Timbilla, 1998). *C. odorata* was introduced to the Ivory Coast in the early 1950s (Adebayo and Uyi, 2010) from where it is believed to have spread to the western corridor mining enclave of Ghana`s tropical forest. *C. odorata* could be used positively, such as for medicinal, nutritional and soil fertilization (due to high organic matter turn-over) purposes (Fasuyi *et al*., 2005; Ngozi *et al*., 2009; Fening *et al*., 2010; Ilori *et al*., 2011), but it persists in the field usually as a highly noxious invasive weed (Akobundu and Agyakwa, 1987; Hoevers and M'Boob, 1996; McFadyen and Skarratt, 1996; Parsons and Cuthbertson, 2001; Jeffery, 2010; Brooks, 2009). Researchers have identified wind dispersal, mechanical transportation through biotic agents and shifting soil seed banks as the major factors facilitating the spread of *C. odorata* (Young and Swiacki, 2006; Panetta *et al.*, 2011). *C. odorata* has been reported to spread easily to disturbed habitats. However, the impact of gold mining disturbance on the growth vigor and the capacity for invasion on *C. odorata* among the early pioneer community of species in post-mining ecosystems have rarely, if at all empirically been investigated. Mined lands are marked by complete removal or displacement of native forest vegetation which considerably disrupts the dynamics and ecological balance of the previous natural ecosystem (Merlin and Juvik, 1992; Mack *et al.*, 2000). Wide areas of mine wasteland exist in many mining areas of Ghana (Liao *et al.*, 2005). There are ecological as well as economic reasons to regenerate forests to near-original natural diversity levels (Patten, 1998; Pimentel *et al.*, 2000, 2001). It is reported that the dominant native plant *P. maximum* is better adapted to the pioneer vegetation on mined lands and could have a significant impact on the dynamics of biodiversity balance (Purvis and Hector, 2000; Wen and Pimentel, 1992). However, it is imperative to understand that in the mined land sites, *P. maximum* has been outcompeted and crowded out by the invasive species *C. odorata* (Norgrove, 2007; Booth *et al.*, 2010). *C. odorata* has been the target of vigorous eradication campaigns in many tropical forest ecosystems due to its ability to outcompete many native plant species (McFadyen and Skarratt, 1996; Goodall and Nausde, 1998; Werren, 2003; Brooks, 2009; Jeffery, 2010; Djietror *et al.*, 2011). The aim of this study was to assess the distribution, population dynamics and physiological characteristics of *C. odorata* in an undisturbed tropical forest and among the early pioneer vegetation on mined sites and to compare the growth characteristics to that of *P. maximum*. This comparison is essential to follow the trail of invasion and to forecast the potential combination of environmental and physiological factors that promote the spread of *C. odorata* on post-mining forest regeneration sites (Chambers *et al.*, 1992; Aronson *et al.*, 1995).

MATERIALS AND METHODS

Study species and area: The field study was conducted in the three major gold producing areas of Ghana, where there are wide areas of mine wastelands and infestations of *C. odorata* are present. These are in the Ashanti (6°41``15.24``N 1°37`09.19``W) and Brong-Ahafo (7°19`58.45``N 2°19`57.84``W) regions. The post-mining growth characteristics of the dominant invasive species *C. odorata* and the native species *P. maximum*, were assessed in mined lands to evaluate their growth vigor in a natural undisturbed forest and mined lands that were between 2 to 10 years post-mining. A total of 480 stands each of the two species were sampled at the three mine sites located within the premises of AngloGold Ashanti, Obuasi (6°12`13.60``N 1°39`30.88``W) and Newmont Ghana Gold, Kenyasi, (7°2`6.51``N 2°22`57.45``W) between June, 2010 and July, 2011.

Data collection and analysis: Computer-generated data and mapping was utilized to determine the vegetation pattern distribution within and around the mine sites. Information on the history of the sites was based on the available company inventory and mined site rehabilitation project records. Between June 2010 and 2011, field surveys were made in the mined sites and land rehabilitation sites of two of the major Gold mining companies, AngloGold Ashanti and Newmont Ghana Gold companies. Two main distinctive habitats were surveyed; 1) an undisturbed forest 50-100 m away from lands that have undergone gold mining (mined lands) and 2) post-mining pioneer vegetation on reclaimed mine lands 50-100 m away from the undisturbed natural forest. There were 3 natural undisturbed forests and 3 pioneer vegetation sites, with 4 plots within each site. The sites were 2-15 years post-mining. Population density was measured as the mean number of seedlings and mature plants that occurred within a 5×5 m quadrat. Field measurements were taken to determine the mean growth characteristics (shoot height, leaf density, canopy diameter and main stem diameter) of *C. odorata and P. maximum* plants randomly sampled from within 10×10 m plots arranged in a Randomized Complete Block Design. The overhead tree canopy density of each site was estimated based on computer generated emergent species (highest strata) canopy coverage. The mortality rate was measured by counting the shed leaf density (leaf litter fall) along 3 m transects during the flowering season and again when the seed heads were ripe. The data was analyzed by Statistical Package for the Social Sciences (SPSS) software program and regression analysis and was undertaken with the JMP 4 statistical software package.

RESULTS AND DISCUSSION

Growth Vigor of *Chromolaena odorata*: The growth characteristics of the dominant invasive plant species *C. odorata*, were compared between undisturbed forest sites 50-100 m from the mine sites and the pioneer vegetation on mined sites. *C. odorata* plants in the pioneer vegetation site produced significantly higher ($p<0.0014$) mean leaf density (210 leaves) when compared to that of the undisturbed forest habitat (160 leaves). Though the plants surveyed within the pioneer vegetation sites showed a higher mean stem diameter in comparison with the plants in the undisturbed sites. There was no significant difference in the main stem diameter ($p>0.0001$) between the two main sites. There was also no significant difference of mean canopy diameter of *C. odorata* between the two main sites. The mean shoot height (cm) of matured plants sampled in the undisturbed forest site (252.3 cm) was significantly higher ($p<0.0001$) compared to the mean shoot height (199.8 cm) of plants sampled at the mine site (Fig. 1). The mean plant density per plot of the dominant invasive plant species *C. odorata* in the pioneer vegetation site (30 plants) was significantly different ($p<0.0001$) from the plant density of the undisturbed forest habitat (8 plants). The mean mortahty rates of *C. odorata* were 4 and 64% within the mined land sites and undisturbed forest sites respectively (Fig. 1).

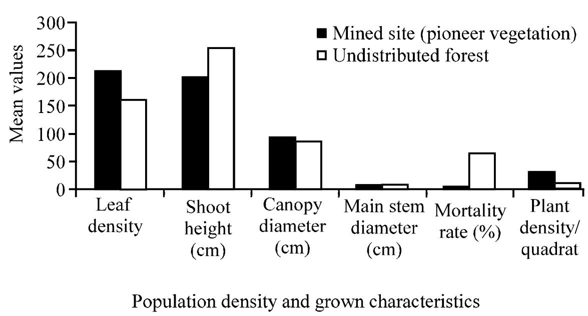

Fig. 1: The mean population density and the mean growth characteristics per mature plant of the invasive plant species *Chromolaena odorata* that was surveyed within the pioneer vegetation on the mined land site and the undisturbed forest habitat. Significant differences (means compared; Tukey HSD) in leaf density, shoot height, mortality rate and plant density per quadrat

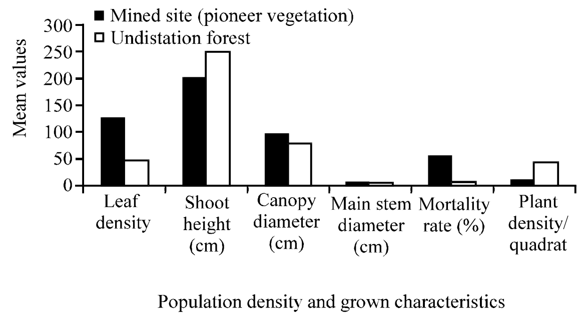

Fig. 2: The mean population density and the mean growth characteristics per mature plant of the native plant species *Panicum maximum* that was surveyed within the pioneer vegetation on the mined land site and the undisturbed forest habitat. Significant differences (means compared; Tukey Test HSD) in leaf density, shoot height, mortality rate and plant density per quadrat

Table 1: The distribution by percentage cover of angiosperm tree species that were located in the three study sites situated in both the mined land pioneer vegetation habitat and undisturbed forest habitat

	Mined land sites			Undisturbed forest sites		
Plant form	NMT	BSR	HUA	NMT	BSR	HUA
Trees						
Maranthes chrysophylla	○	Δ	○	▲	○	▲
Sterculia tragachanta	○	○	Δ	▲	▲	▲
Albizia zygia	○	Δ	○	Δ	●	●
Albizia ferruginea	Δ	Δ	Δ	▲	▲	▲
Albizia adianthifolia	○	○	Δ	▲	▲	▲
Elaeis guneensis	○	Δ	○	●	●	●
Antiaris toxicaria	○	○	○	○	▲	▲
Morinda lucida	○	○	○	▲	○	▲
Ficus exasperata	Δ	○	○	Δ	●	●
Voacanga africana	○	○	Δ	▲	▲	●
Alchornea cordifolia	○	○	Δ	●	●	●
Rhaptopetalum coriaceum	○	Δ	○	●	▲	▲
Ficus sur	○	Δ	○	▲	▲	▲
Tetrapleura tetraptera	○	▲	▲	●	●	●
Kyaya senegalensis	○	▲	○	●	●	●
Tectona grandis	▲	○	▲	○	○	○

(NMT: Newmont; BSR: Binsere and HUA: Humasi Adubirem) Percentages are represented as 20-50%: Bullet point (●); 10-20%: Black triangle (▲); 2- 10%: Empty triangle (Δ) and 0%: Empty circle (○)

Growth Vigor of *Panicum maximum*: On the contrary, the results obtained for the dominant native plant species *P. maximum* (Fig. 2), showed that plants sampled from the undisturbed forest has significantly higher ($p<0.0001$) mean shoot height (251.4 cm) than within the pioneer vegetation of the mine sites (200.2 cm). There were no significant differences between the two habitats in terms of canopy and stem diameter. The mean plant density per quadrat (5×5 m) of the native plant *P. maximum* (Fig. 2) in the undisturbed forest (42 plants) was significantly higher (p<0.001) in comparison with the mean plant density of the species within the pioneer vegetation of the mine site (9 plants). The mean mortality rate among matured *P. maximum* plants (Fig. 2) in mined land sites were significantly higher (45%), than for the undisturbed forest (5%).

Spatial distribution of *C. odorata and P. maximum* within habitats: The two plant species *P. maximum* and *C. odorata* were present in the same plots within both disturbed mine sites and undisturbed forest habitats. There was no significance difference (p>0.5167) between the plots surveyed. However, there was variation in the density and spatial distribution of the two species. While *P. maximum* was evenly distributed throughout the study plots in both habitats, *C. odorata* was evenly distributed only within the mine site plots. In the pioneer vegetation site plots, *C. odorata* was restricted to closer to the edges and only around open canopy areas within the undisturbed forest.

Percentage cover of the angiosperm species: The result of the survey of the angiosperm plant species present within the 10 m^{-2} plots was classified as 20-50% (high density); 10-20%; (moderately dense); 2-10% (low density) and 0% (non-populated). A total of number of 83 different angiosperm species was counted within the study sites and the percentage cover of 35 species comprising, creeping plants, grasses, shrubs and herbs and trees was sampled in both the undisturbed

Table 2: The distribution by percentage cover of angiosperm creeping species, grasses, herb/shrub species that were located in the three study sites situated in both the mined land pioneer vegetation habitat and undisturbed forest habitat

	Mined land sites			Undisturbed forest sites		
Plant form	NMT	BSR	HUA	NMT	BSR	HUA
Creepers/lianes						
Centrocema pubescens	▲	●	▲	●	○	○
Mimosa	●	Δ	▲	▲	Δ	▲
Zebrina pendula	●	Δ	Δ	Δ	Δ	Δ
Grasses						
Panicum maximum	Δ	Δ	Δ	●	●	●
Pennisetum purpureum	▲	▲	▲	○	○	
Cynodon plectostachus	▲	▲	▲	Δ	○	Δ
Digitaris horizontalis	●	●	▲	○	○	Δ
Herbs/shrubs						
Chromolaena odorata	●	●	●	▲	Δ	▲
Solanum torvum	▲	●	▲	▲	Δ	Δ
Sida acuta	▲	●	▲	○	○	○
Commelina engalensis	▲	●	Δ	Δ	Δ	Δ
Nephrolepis hirstula	●	▲	Δ	○	○	Δ
Synedrella nodiflora	●	▲	▲	▲	▲	▲
Lantana camara	●	●	●	Δ	Δ	Δ
Calopgonium mucunoides	▲	●	▲	▲	○	▲
Phyllanthus amarus	▲	●	○	Δ	Δ	Δ
Dioscorea rotundata	●	▲	▲	Δ	Δ	Δ
Musa sapientum	▲	○	▲	○	?	○
Solanum sabdariffa	Δ	○	○	Δ	○	Δ

(NMT: Newmont; BSR: Binsere and HUA: Humasi Adubirem) Percentages are represented as 20-50%: Bullet point (●); 10-20%: Black triangle (▲); 2- 10%: Empty triangle (Δ) and 0%: Empty circle (○)

forest sites and mined land sites (Table 1 and 2). Tree species dominated the undisturbed forest sites (Table 1) while the pioneer vegetation was dominated by the grasses herbs and the shrubs (Table 2).

DISCUSSION

Besides the differences in the growth traits of *C. odorata* between the undisturbed forests and the pioneer vegetation, it appeared that differences in overhead tree canopy density and shade conditions tended to favor the survival and rapid morphological changes that facilitated growth vigor in the species *C. odorata*. This condition was not conducive for *P. maximum* to spread and depict rapid growth in the mined land sites. In this study, leaf fall was used as an indicator of potential plant mortality and non- survival after an initial primary succession and colonization on the mined land sites. Similar indications were reported by Nigel *et al.* (2000), McDowell *et al.* (2008) and Withers (2011). Drought-induced vegetation mortality has as implications for ecosystem function, biodiversification and the long-term persistence of a species (Dale *et al.*, 2000). The growth vigor between *C. odorata* and *P. maximum* was similar in terms of mean leaf density, shoot height, canopy diameter and stem diameter. The native species *P. maximum* showed higher potential for mortality in the pioneer vegetation on the mine site as opposed to the native undisturbed forest habitat. This underscored the fact that post-mining wastelands may not be conducive for a quick succession of native species, but invasive species (Evans *et al.*, 2006). It is evident that even mined lands which have been reclaimed through revegetation practices may pose serious biodiversity risks in terms of the survival and spread of the dominant invasive species *C. odorata* and the death of native species *P. maximum* (Williamson, 1996). Significant matured plant mortality rate was observed in undisturbed forests. This is an agreement with studies by (Swain and Hall, 1983). In addition, the mean plant density of the dominant native plant species *P. maximum* was significantly lower in pioneer vegetation, while the dominant invasive *C. odorata*, showed significantly high plant density indicating the suitability of disturbed mine habitats for invasive species to spread quickly and broadly. In a related study, Idris and Sajap (2002) wrote that the relative abundance of a species could provide evidence of the extent of habitat disturbance. Quansah *et al.* (2001) and Tefera *et al.* (2008) reported high biomass production of *C. odorata* in relation to *P. maximum*. The superior growth vigor depicted by the *C. odorata* in the pioneer vegetation was and the relatively lesser vigor of *P. maximum* could have been, among other factors, the direct consequence of the biomass accumulation process. It is expected that the revegetation practices on the mine lands would create favorable conditions (Bradley and Mustard, 2006) for invasive plant species to overtake mine lands which were likely to establish on such pioneer vegetation sites (Kriticos *et al.*, 2005). The high leaf density of the *C. odorata* in the pioneer vegetation on the mine lands was an indication of its dominance of the functionality within the general biodiversity within the disturbed pioneer vegetation habitats. The dominant native plant species *P. maximum* depicted higher shoot height and leaf density in the undisturbed forests but not in the pioneer vegetation sites. The results from the survey of the angiosperm species showed that trees were dominant in the undisturbed forest. *Khaya senegalensis*, *Tetrapleura tetraptera* and *Alchornea cordifolia* were surveyed within the high density category. These species exhibited high and dense canopy which could create considerable shading and inhibit groundcover species (Davis and Thompson, 2000). *C. odorata* is shade intolerant and that might have accounted for the higher shoot height (Ganry *et al.*, 2001; Ward *et al.*, 2001; Horner, 2002) and increased mortality rate within the undisturbed forest habitat. However, since pioneer vegetation mortality rate was significantly higher among *P. maximum* plants (Nowak, 1993) when compared to the undisturbed natural forests, it is expected that in the mined land sites, native plant species might become out competed by the rapidly growing and spreading *C. odorata*. This may occur especially, during the initial primary succession stage (Webb and Conroy, 1995; Sluis, 2002; Witt, 2010).

Implications for practice:

- Siam weed control is a problem in many tropical countries. This study shows that dense canopy and shade conditions may inhibit the growth vigor and spread of the weed. Control strategies could incorporate "shade therapy" regimes using broad-leaf or wide canopy forest species that might create enough shade truncate the laxuriant growth and potential spread of *C. odorata*
- Weed scientists studying invasive plants should consider the potential of mine sites as altered habitats and condusive ecological areas that could enhance the spread of the invasive species *C. odorata*
- Mining companies should focus on the control of invasive species among the early pioneer community of species. The knowledge about growth vigor could be essential to the management of Siam weed in post-mining tropical forest ecosystems

CONCLUSION

Mining predisposed forest lands to the luxuriant growth and potential spread of the invasive plant species *C. odorata*, while inhibiting the growth vigor of the dominant native plant species like *P. maximum*. Mined land sites alter environmental conditions and biodiversity within pioneer vegetation and promote the establishment and spread of *C. odorata*. This study concludes that the establishment of broad canopy tree species could help create shade zones that inhibit the spread of *C. odorata*. The full implications for invasive-native species interaction among pioneer vegetation species in mine waste lands could be further investigated. The genetic basis for these interactions in relation with other native and invasive species might be useful to interprete and predict the trajectory of invasion of *C. odorata* in a wider range of tropical ecosystem.

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