International Journal of Botany

ISSN: 1811-9700

International Journal of Botany 8 (3): 127-135, 2012
ISSN 1811-9700 / DOI: 10.3923/ijb.2012.127.135

Spatial Analysis of the Distribution and Abundance Patterns of *Chromolaena odorata* in Ghana: An Invasion Risk Assessment

Djietror Jonathan Castel
Laboratory of Ecological Genetics and Plant Ecology, Division of Biosphere Science,
Graduate School of Environmental Science, Hokkaido University,
N 10 W 5 060-0810, Sapporo, Japan

Abstract: *Chromolaena odorata* is a dominant invasive weed with capacity for extensive spread in Ghana. An invasion risk assessment focusing on the distribution and spatial abundance of seedlings and mature plants was conducted across 26 sites covering the major ecological zones of Ghana. High plant coverage within 10 m×10 m plots occurred in the tropical rainforest (65%) and tropical deciduous forest (60%). These percentages were significantly ($p<0.001$) higher than those of the coastal savanna (18%) and Interior Guinea Savanna (IGS) (5%). There were no plants (0%) recorded for the Sudan savanna and mangrove swamp zones. A comparison was made between the density of the species (per hectare) within fragmented forest patches (49.4%), continuous forest patches (34.5%) and abandoned wastelands described as marginal lands (41.9%). The results show that *C. odorata* was abundant and widely distributed within the forest zone. The densely populated colonies in the forest zone could be the source of rapid spread to non-colonized habitats within the savanna and adjacent arid zones.

Key words: *Chromolaena odorata*, ecological zones, forest, Ghana, invasion, plant cover, savanna

INTRODUCTION

C. odorata [(L.) King and Robinson] is an invasive weed of the flowering shrub family Asteraceae. The species is native to the Americas and has been introduced to tropical Asia, West Africa and the northern parts of Australia (Tefera *et al*., 2008; Brooks, 2009; Djietror *et al*., 2011a). It is reported that the weed was firstly introduced to West Africa in the early 1960s (Goodall and Zacharias, 2002; McFadyen, 1996; Timbilla, 1996; Timbilla and Braimah, 1992; Agubretu, 2002). *C. odorata* is known to be a prominent weed that is well established across the forest ecological zone of West Africa (Abdulai *et al*., 2006; Anning and Yeboah-Gyan, 2007; Dzomeku *et al*., 2009). This weed has been described as a fast spreading invasive plant species of the tropics (McFadyen and Skarratt, 1996; Nawaz and George, 2004; Anning and Yeboah-Gyan, 2007; Brooks, 2009; Djietror *et al*., 2011b).

In many parts of West Africa, the growth is rapid through the rainy season (Weise, 1994) and flowers appear towards the end of the period. *C. odorata* easily invades disturbed habitats and smothers native plant stands. The species is entomophilous and yields a mass of light-weight seeds that are easily dispersed by wind courtesy the aviation of a buoyant pappus. The fruits have hooks and could be transported to other locations by sticking to the bodies of fauna and to farm machinery (Adebayo and Uyi, 2010).

C. odorata is common within large tracts of disturbed habitats, agricultural land and riparian zones and along major highways in West Africa (Erasmus and Van Staden, 1986; Djietror *et al*., 2011b). Then it is considered a serious threat to the balance of biodiversity in the forest zones (Tefera *et al*., 2008). In addition, significant infestations are already established in farmlands where the species smother food crops and native plants and spread rapidly in the forest ecological zones of the sub-region (Djietror *et al*., 2011a). Though there is a large volume of general information about the distribution characteristics across the larger geographical area of West Africa, invasion risk assessment of *C. odorata* in Ghana is compounded by the lack of adequate and current information on the spatial distribution and abundance of the species in confined catchments within specific ecological zones. The non-existence of specific information on the current species distribution and abundance within limited eco-geographical boundaries hinders proper research planning and complicates the planning and implementation of management strategies to limit the spread of the invasive weed within a spatially scaled range. Detailed information on the distribution and abundance should be recorded in order to facilitate the creation of models that can serve the basis in designing the control protocol. In Ghana, research has largely been focused on presumably, the region widest believed to be, the heaviest infestation locations which persist within the Brong-Ahafo and Ashanti forest enclave (Timbilla and Braimah, 1992; Anning and Yeboah-Gyan, 2007). The earliest infestation was officially reported to have existed within experimental plots in the Legon Botanical Gardens (Hall *et al*., 1972). However, there has been only one published work (Timbilla and Braimah, 1992) on the countrywide distribution and spread of *C. odorata* of Ghana, over the last two decades and the exact mode of introduction of the weed to the country is not yet clarified.

In the case of Ghana, the important questions to consider are; (1) What is the current distribution and abundance pattern of *C. odorata* within the ecological zones? (2) Currently, has the spread of *C. odorata* become adapted to some environmentally extreme eco-zones, such as the arid Sudan savanna and highly saline mangrove swamp zones? These questions are important to both understand the ecological adaptation of the species and to provide reliable information that could serve as a reference to plan control programs in limited or confined agricultural areas. It is expected that the original distribution in the native range of *C. odorata* would provide verifiable research information to resolve these critical research questions.

Information on the current distribution, extent and trajectory of spread within the different ecological zones is acutely limited, if any. In addition, very few specific attempts have been made to study the population characteristics pertaining to the specific plant density and distribution along clearly defined spatial dimensions.

Habitat fragmentation has been also shown to affect the spread of a species (Fahrig, 2003; Alofs and Fowler, 2010). To understand the impact of habitat fragmentation and disturbance on the spread of the species, the study used specific plant cover variations within continuous vegetation, fragmented forest patches and marginal lands which included abandoned mine lands, wastelands and highway peripheral lands.

These ecological variables are among the most important indicators that could help explain questions about the distribution, abundance and projectile spread of *C. odorata* in Ghana. The aim of this study was therefore, to empirically investigate and provide current and reliable information on the distribution and abundance of *C. odorata* within all the major ecological zones of the country. The findings reported are expected to provide a clear verifiable benchmark that could guide *C. odorata* control, management decisions and programs.

MATERIALS AND METHODS

Study site: Between April 2009 and November 2011 (spanning two successive major and minor rainy seasons) the plant density in terms of cover of *C. odorata* was measured at all the study sites over the period. A total of 26 study sites including 3 mined wastelands, 3 highway edge areas and 3 fragmented forest patches (Fig. 1) were surveyed across the major agro-ecological zones of Ghana (5°35' 27. 26" N, 0°11' 43. 69"W). Due to the limitation of

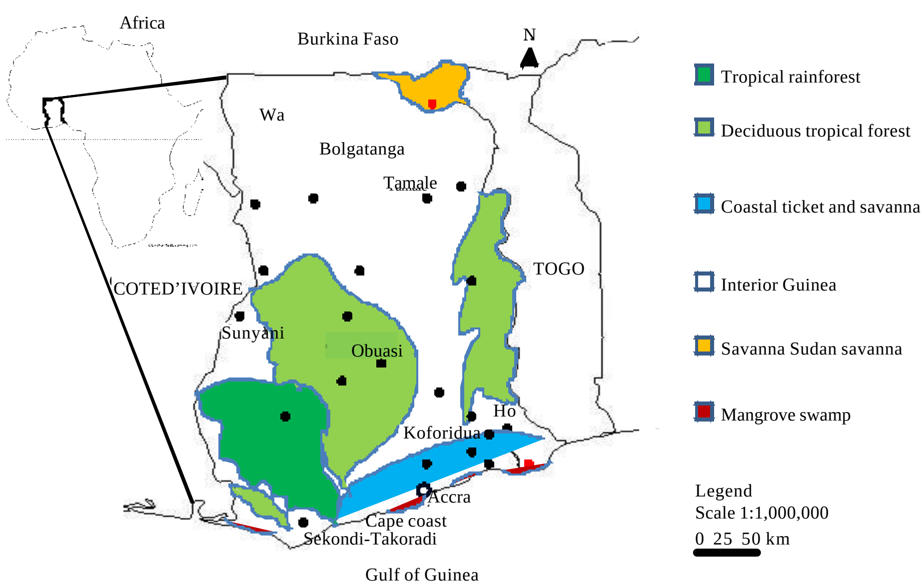

Fig. 1: Map of Ghana showing the major ecological zones, Study sites are marked by black (colonized) and red (non-colonized) dots. Due to inconsistencies between available data, observable current spatial characteristics of the vegetation, the forest-savannah transitional zone is a not distinctively presented on this map

considerable vegetation area and geographical obstacles, only one study site was surveyed in the arid Sudan savanna. However, enough information was assembled to make an accurate conclusion about the absence of the species in this zone. The average distance between study sites was 150 km. The factors considered in locating the study sites included:

- The presence or absence of considerable colonies of different plant species (*Tridax procumbens*, *Striga hermonthica*, *Axonopus compressus*, *Boerhavia diffusa*, *Lantana camara and Sida acuta*) with similar distributive traits as *C. odorata* and that normally grow within the immediate environment of *C. odorata*
- The homogeneity in the pattern of existing vegetation reflected that the characteristics of a specific ecological zone over a 200 km radius. Example, the dominance of grassland signifying the savanna or forest species strata representing a forest
- The state of habitat disturbance and fragmentation. Example, continuous forest, fragmented patch or marginal land

Survey design: Three survey plots (10 m×10 m) were established at most study sites to ensure the homogeneity of information about the abundance of *C. odorata* plants within the site. The minimum distance between the plots in a site was 50 m. The plant cover in each survey plot was measured twice, within the same plots, over 2 years. Though randomly marked within a site, the location of the survey plots was selected based on vegetation structure and composition that closely, reflected the general vegetation pattern within the larger geographical area. This included areas where *C. odorata* colonies were observed within 3-20 km radius of each of the study sites.

Data collection: Ecological zones were demarcated based vegetation records and maps available from the Ghana Forestry Commission (Gobind *et al*., 2006; GOG, 2004). The use of digital geographical maps to identify *C. odorata* colonies were similar to the GPS systems applied on the location of Siam weed colonies at the Center for Tropical Agriculture, South Johnstone, Queensland Australia (Brooks, 2009). Questionnaires were administered to gather data on existing *C. odorata* colonies from local farmers. There were interviews done for commercial vehicle drivers who ply the highways to locate *C. odorata* colonies in very remote farming areas. The feedback information and field observation data were synchronized with Global Information System (GIS) mapping to locate the study sites.

Vegetation cover measurement: The negative competitive impact of *C. odorata* on neighboring plant hinges on, in addition to the allelopathic effects, the ability to form dense thickets from profuse branching and from the luxuriant foliage formation that overshadow the other plants within its range (Abaye, 2003). Therefore, the plant density per plot was measured in terms of cover (%) per unit area, rather than in terms of the number of individual plants per stand. The structure of the vegetation in some areas included a mixture of live and dead vegetation, bare soil and stony materials which could compromise the resolution of remotely sensed data. Therefore, to prevent obstacles associated with the use of GIS-based poor models which integrate spectral characteristics recorded by remote sensors with vegetation cover. Vegetation images were obtained using an automated digital camera which was mounted on 15 m high (mature plants) and 6 m high (seedlings/juveniles) wooden platform and controlled using a portable digital remote controller. The pixel resolution of the acquired color images was 640×480×24 bit.

To incorporate contextual information into the interpretation of vegetation images, a relaxation labeling technique was used for the image processing. The cover (%) was determined using the image processing software Research System ENVI/IDL.

The plant cover (%) of *C. odorata* (%CO) within the survey plots was derived as:

$$\text{CO (\%)} = \frac{\text{COA-TOPS}}{\text{TOPA-EPA}} \times 100$$

Where:

COA	=	Area of the plot covered by *C. odorata*
TOPS	=	Total area of the plot covered by other plant species
TOPA	=	Total unit plot area-10×10 m
EPA	=	Empty patch area or non-colonized space within the total unit plot area

The same method was applied to determine the cover (%) of *C. odorata* in the continuous forest patch, fragmented forest patch and marginal land experimental plots.

The population surveyed included the percentage cover of the seedlings, juveniles and mature *C. odorata* plants. The maturity parameters were; (1) ≥100 cm tall; based on the fact that, the average mature height of the Ghana ecotype of *C. odorata*, irrespective of the prevailing edaphic conditions, was measured to be between 1-3 m in open conditions and 6-10 m when scrambled up other taller vegetation under dense forest canopies (Timbilla and Braimah, 1992; Djietror *et al*., 2011a); (2) Average leaf density is 80 leaves plant^{-1}; average leaf area is 15 cm^2 and (3) flower and fruit production.

Statistical analysis: To determine the ideal location of the *C. odorata* colonies in inaccessible areas, logistic regression was used to determine the significance of local farmers' response to the question of *C. odorata* presence (yes) or absence (no). This was important to determine the geographical range of the species within specific areas in some ecological zones where some sites were established.

The mean cover (%) of a site was determined from cover data analyzed using the set of images from all the survey plots of each site.

The mean cover percentages of the different sites within an ecological zone were averaged to determine the cumulative mean cover (%) of the sites within that ecological zone. The statistical significance ($p<0.05$; Tukey *post hoc* HSD test) of the mean cover (%) between the ecological zones was statistically evaluated using the JMP Statistical Discovery Software (Version 4), SAS Institute Inc. The mean values were statistically shown on graphs as Mean±SE bars.

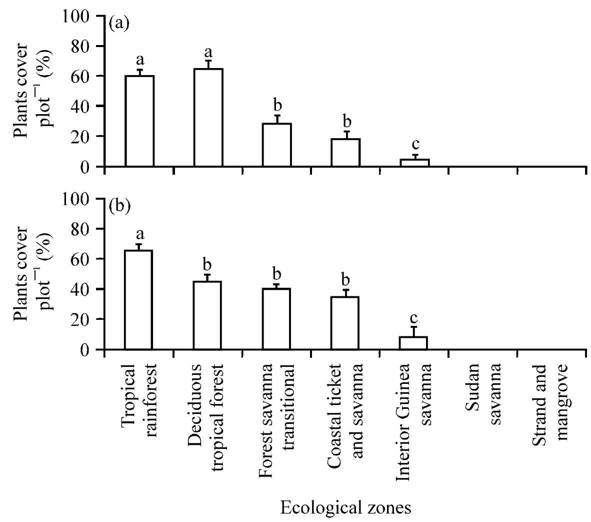

Fig. 2(a-b): The variation in mean cover of (a) Mature plants and (b) Seedlings/juveniles, surveyed in all the major ecological zones of Ghana, Standard error is shown on bars, bars with different letters show the occurrence of significant difference ($p<0.05$, Tukey test) between ecological zones

RESULTS

Mature plant distribution and abundance: Assessment of the distribution and abundance pattern shows that *C. odorata* has spread across all the major ecological zones except the Sudan Savanna (11°01'37.90" N, 0°09' 44.45" W) and Swamp and Mangrove (5°45' 09. 58" N, 0°46' 57. 90" E) ecological zones (Fig. 1). The cover (%) of seedlings and mature stands were similar within all the study sites across the ecological zones. There were no stands or colonies (0%) of *C. odorata* recorded for these two ecological zones. The highest percentage plant cover plot^{-1} was recorded within the tropical forest zone (60 %) and deciduous tropical rainforest (65 %) zones (Fig. 2a). The highest mature plant number per 10×10 m experimental plots were recorded within the deciduous tropical forest (108-140 plants plot^{-1}) and the lowest was (36-50 plants plot^{-1}) within the IGS ecological zone (plant number plot^{-1} not shown). The percentage plants cover in the savanna zones was significantly ($p<0.001$) lower than in the forest zones. The mean plants cover percentages were, 5 and 18% within the, IGS and coastal savanna zones respectively. Colonies within these zones were sparse or isolated. However, dense thickets were common within the coastal savanna zone, especially along major highways and in fallow farmlands. The percentage *C. odorata* cover for measured in the forest-savanna transitional zone (28%) was higher but not significantly different ($p<0.213$). The *C. odorata* stands in the transition zone were interspersed around the taller woody tree species and the thickets were relatively denser than in the main savanna zones.

The survey to understand the impact of habitat fragmentation and habitat disturbance on the spread of *C. odorata* within the forest patches revealed that the spatial distribution of the species was covered wide areas and plant cover was denser within the fragmented patches (Fig. 3a). There was significant ($p<0.0001$) variation in the cumulative mean plants cover (in all ecological zones) between the fragmented forest patches (49.4%) and continuous forest patches (34.5%). Similarly, the plant cover within marginal lands (41.9%) was significantly ($p<0.0001$) higher than that of the continuous patches but not different from the fragmented patches, when *C. odorata* covers, within all the ecological zones were averaged.

Dense colonies of between 60-69.7% plant cover per plot of *C. odorata* were observed to have extended from farmlands and in some cases abandoned mined lands, to the peripheral regions along the major highways. This was typically consistent within the forest ecological zones spread across the Ashanti, Brong-Ahafo, Eastern and Western administrative regional areas.

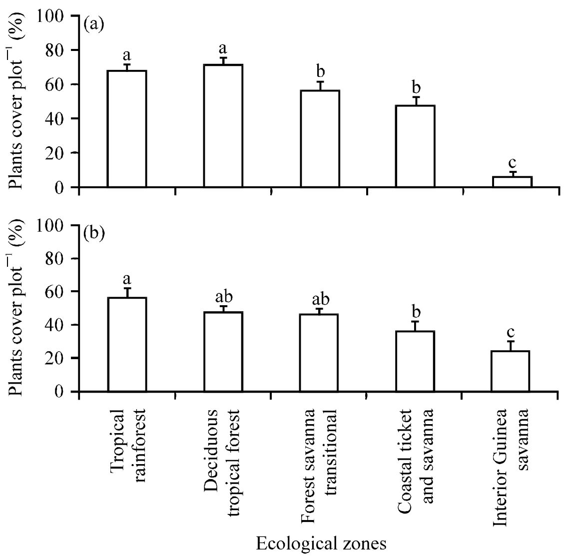

Fig. 3(a-b): The variation in mean cover of (a) Mature plants and (b) Seedlings/juveniles, randomly surveyed in the fragmented patches within the colonized ecological zones, Standard error is shown on bars, bars with different letters show the occurrence of significant difference ($p<0.05$, Tukey test) between zones

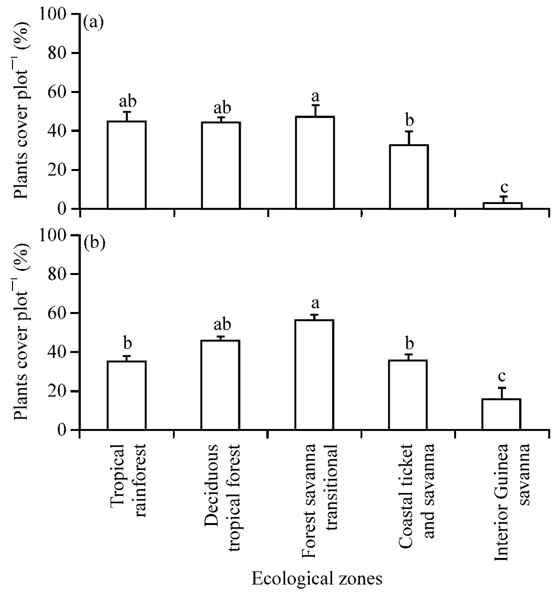

Fig. 4(a-b): The variation in mean cover of (a) Mature plants and (b) Seedlings/juveniles, surveyed in the continuous patches within the colonized ecological zones, Standard error is shown on bars, bars with different letters show the occurrence of significant difference ($p<0.05$, Tukey test) between ecological zones

As shown in Fig. 3a, the extent of spread within fragmented patches extended across the zones. The deciduous tropical forest (70.4%) tropical rainforest (67.3%) and transition zone (55.8%) were significantly ($p<0.0001$) higher than the coastal savanna (47.5%) and IGS zone (6.0%). The forest zones were again relatively higher in plant cover per plot.

The plant cover within the continuous patches across the ecological zones depicted a general reduction in total plants cover as the species spread from the forest ecological zones towards the savanna. Figure 4a shows that the cover percentages recorded both within and at the edge of the patches of the deciduous tropical forest (44.6%), tropical rainforest (45.3%) and transition (47.0%) were not substantially different. However, these mean percentage values were significantly ($p<0.0001$) higher than those of the coastal savanna (32.8%) and the IGS zone (3.0%).

The highest mean plant cover percentages surveyed within the three mined wastelands and 3 highway marginal lands was within the tropical rainforest (61.5%) and tropical forest (55.1%). This mean cover (%) was relatively higher than in plots along the highway peripherals and abandoned farmlands within the transition zone (49.4%) and significantly higher than the coastal savannah (41.3%). The lowest percentage plants cover plot^{-1} was registered within the Guinea savanna zone (2.4%), where most colonies were either established as isolated stands or sparse clusters (Fig. 5a).

Seedlings and juvenile plants distribution and abundance: Overall the range of distribution of seedlings and juveniles covered all the major ecological zones except the Sudan savanna and the Mangrove swamps zones. The abundance data showed high *C. odorata* cover percentages of 66% and 45% in the rainforest and deciduous tropical forest respectively (Fig. 2b). Across the ecological zones, there was very low (8%) seedling and juvenile *C. odorata* abundance within the IGS ecological zone (Fig. 2b).

Within the tropical rainforest, the abundance in the plots within the fragmented habitat was 56% (Fig. 3b). The 3 mine wasteland plots and 3 highway peripheral plots collectively classified as marginal lands (Fig. 5b), depicted the highest plant abundance (66%). The seedling abundance in the tropical rainforest was lowest (35%) within the continuous forest (Fig. 4b). The pattern of abundance within the tropical forest was; fragmented-47% (Fig. 3b) and continuous habitat-46% (Fig. 4b) and marginal-56% (Fig. 5b). The pattern across the other ecological zones showed that between fragmented

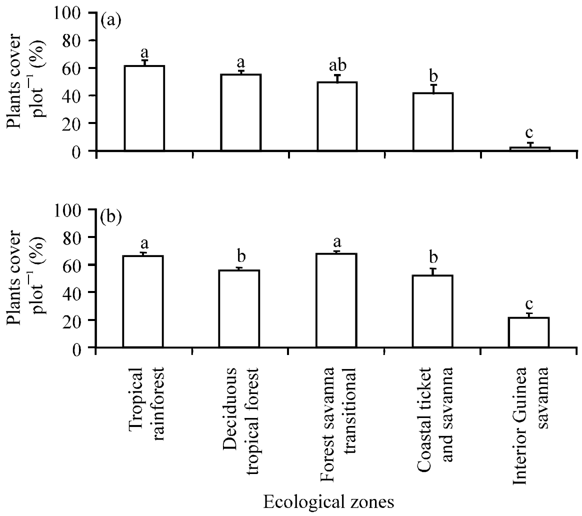

Fig. 5(a-b): The variation in mean cover of (a) Mature plants and (b) Seedlings/juveniles, randomly surveyed in 3 the mined wastelands and 3 highway peripheral plots, Standard error is shown on bars, bars with different letters show the occurrence of significant difference ($p<0.05$, Tukey test) between zones

patches, continuous habitats and marginal land areas. The marginal land areas showed the significantly ($p<0.0001$) highest seedling abundance. The distribution and abundance across ecological zones was; transitional-68%, coastal savanna-53% and IGS zone 22% (Fig. 5b).

DISCUSSION

Presently, the range of *C. odorata* infestation span the low coastal savanna in the south, the interior forest-savanna transitional zone and the tall grass dominated Guinea Savanna zone that extends to the southeast and a greater part of the northern region of Ghana. This distribution confirms earlier studies conducted by Timbilla and Braimah (1992).

Distribution characteristics in forest and patch: High matures plant cover (%) plot^{-1} was recorded in the tropical rainforest zone. A high density of *C. odorata* in the forest zones has been reported in related studies by Gautier (1996). The tropical rainforest vegetation cover contributes to high relative humidity and precipitation (mean rainfall; 2200 mm pa). The monthly temperature range is between 22.8 and 25.5°C. Kankam and Oduro (2012) reported that the temperature range from 20.5°C in July to August to 34°C in February to March. The soil type varies across the forest zone; oxisols and acid gleysols. The topsoil depth is typically 8-20 cm deep, very rich in organic matter and humus. The tropical rainforest ecological zone is characterized by high evergreen forest tree species with dense canopy cover and reduced light intensity reaching the forest floor (Djietror *et al*., 2011b). Many researchers have described *C. odorata* as shade intolerant (Muniappan and Marutani, 1988; Honu and Dang, 2000) and therefore the mature plants may not be expected to be widely distributed underneath the dense canopy vegetation of the tropical rainforest. However, the results of the mature plant cover showed that, in comparison to the savanna ecological zones, higher mean percentage cover occurred in fragmented and to a lesser degree, the continuous patches within the forest zones. This result supports the findings in related studies by Parsons and Cuthbertson (2001) and Awanyo (2007) who reported that the species can thrive under dense canopy forests but with less success in comparison to growth in the open sunlit areas.

The seedling abundance was higher in the tropical rainforest forest zone than in other zones. However, the abundance of mature plants was higher in fragmented forests where the ground level vegetation cover obviously was more exposed sunlight than in continuous forests. Though the savanna zones comparatively received higher light intensity (Hoffmann *et al*., 2009), the abundance and distribution of seedlings were relatively low. The high density of the dominantly tall savanna grass vegetation might have inhibited the abundance of *C. odorata* seedlings (Codilla and Metillo, 2011).

Though there were dense within-patch stands of mature *C. odorata* in continuous patches, high density colonies were mostly restricted to the edge of these forest patches that were surveyed. Furthermore, the plant cover (%) within and around the edge of fragmented forest patches was relatively higher compared to continuous forest patches. The fragmented patches consisted of wide open spaces and narrower shade areas and an under storey vegetation cover that was exposed to increased light intensity. The results suggested that a combination of optimum climatic (light intensity, rainfall, temperature) edaphic and ecological factors (edge effect, size of open spaces, shade cover), rather than a single climatic factor (Kriticos *et al*., 2005) that prevailed within the forest zones, could contribute to the rapid spread and wide distribution of *C. odorata*.

Similarly, the tropical forest is characterized by the dense canopy cover in continuous patches and bimodal rainfall pattern that averages 1500 mm pa. Monthly temperature of between 25.8 and 26.5°C persist from May to July during the major rainy season. The soil and climatic conditions in the tropical rainforest are not drastically different from the tropical forest conditions. This similarity is consistent with the observation that the percentage of *C. odorata* cover in the semi-deciduous tropical forest was found to have been parallel to that of the evergreen tropical rainforest.

Distribution characteristics in savanna and coastal ecosystem: The spread of both seedlings and mature *C. odorata* to the arid and perennially hot Sudan savanna and the highly saline mangrove swamp ecological zones has by far been truncated, since no stands of *C. odorata* were recorded in these zones. Prolonged high temperature conditions, low moisture soils resulting from long droughts and low single season precipitation of the Sudan savanna, might have stymied the colonization of the arid Sudan savanna ecological biomes. This is consistent with the findings of Euston-Brown *et al.* (2007) that, extreme temperature and prolonged drought could inhibit infestation and spread of the species.

It is assumed that the high salinity conditions of water and soil within the mangrove swamp could hamper the establishment and spread of the species within this zone. However, highly dense isolated colonies of *C. odorata* were identified at the Kpone site (5°41'51.65"N, 0°02' 46. 29" E, 6 km to the Atlantic coast). Djietror *et al.* (2011a) reported that *C. odorata* seeds could germinate in NaCl concentration levels of between 0.02 and 1.2 mol L^{-1}. This fact points to the potential spread of the species towards and colonize mildly-saline ecosystems in the coastal savanna ecological belt. A potential adaptation to colonize saline ecosystems was confirmed in studies by Timbilla (1996) in which a colony as close 5 m to the Atlantic seashore was identified.

The forest-savanna transitional and the IGS zones were identical in abundance, except for mature plant cover (%) in the continuous patches within these zones. The seedling abundance was relatively lower in the IGS zone. The *C. odorata* colonies in these zones were sparse and less dense, compared to the forest colonies. In the Sudan savanna, grass dominates the vegetation, lower mean annual rainfall of 1100 mm, high monthly temperature range of 27.8- 38.6°C (De Rouw, 1991b) and the soil dries up rapidly. This microclimate could potentially inhibit the spread of *C. odorata*. Both seedlings and the mature plants cover (%) within the marginal lands (mined wasteland sites and highway peripheral areas) were as high as the fragmented patch plant cover (%). In a related study, *C. odorata* has been reported as capable of displacing the secondary vegetation to become the dominant species in fallow farmlands (De Foresta and Schwartz, 1991; De Rouw, 1991a; Gautier, 1992; Roder *et al.*, 1995; Slaats, 1995).

Ecological implications of distribution for *C. odorata* management: This study focused on the distribution of *C. odorata* across the major ecological zones of Ghana. The highest density of the species was within the forest zone. The dense colonies of *C. odorata* in the forest zones remain the highest risk zones for the rapid invasion of the yet non-colonized isolated forest regions, high savanna and adjoining arid transitional zones. It is expected that, the spread of *C. odorata* will persist and spread along the non-colonized continuous and fragmented patches within the humid and shady tropical forest zones.

Marginal land areas especially, fallow agricultural fields and highway peripherals, could become source pools for new infestations and spread from already established colonies. In spite of the reported medicinal (asthma, wound treatment) nutritional (feedstuff for livestock) and agronomical (easy to clear, suppressor of other noxious weeds *Imperata cylindrica*, soil fertility recovery agent) benefits, the ecological impact of *C. odorata* in biodiversity change is crucial. The proper management of this invasive species is pertinent to the maintenance of the ecosystem balance within the wider ecological biomes. This study did not directly investigate the actual origin and specific direction of the current *C. odorata* spread on the spatial scale. It is important therefore, to explore the trajectory of *C. odorata* spread through genetic assessment such as microsatellite analytic profiling and genome sequencing analysis. Also a morphological trait comparison of different ecotypes across the ecological zones throughout the country could provide a basis for identifying variables that could be incorporated into effective management protocols.

ACKNOWLEDGMENTS

Author wish to thank the Sasakawa Research and Fellowship Foundation for supporting the data collection from field sites. He is especially grateful to Prof. Masashi Ohara of the Graduate School of Environmental Science, Hokkaido University, for his invaluable assistance in editing the manuscript and making useful suggestions. He wishes to thank Ms. Catherine Appiah, Mr. Tagoe, Mr. W. D. Akoto, Mr. E. Panford of LIPAN Hotel, Tema, C.5, Ghana for their kind hospitality and support during the fieldwork in Ghana.

REFERENCES

Abaye, K., 2003. Land use and land cover in relation to *Chromolaena odorata* Distribution, mapping and change detection in ST. Lucia wetland area, Soth Africa. M.Sc. Thesis, International institute For Geo-Information Science and Earth Observation, Enschede, The Netherlands.

Abdulai, M.S., N.N. Denwar and M. Haruna, 2006. Combating the menace of *Striga hermonthica* infestation: An integrated approach adopted in North-Eastern Ghana. J. Agron., 5: 617-620.

Adebayo, R.A. and U.O. Uyi, 2010. Biological control of invasive weed species: Nigerian experience. Int. J. Agric. Res., 5: 1100-1106.

Agubretu, C., 2002. Acheampong weed is killing Ghana. ModernGhana.com, Nigeria.

Alofs, K.M. and N.L. Fowler, 2010. Habitat fragmentation caused by woody plant encroachment inhibits the spread of an invasive grass. J. Applied Ecol., 47: 338-347.

Anning, A.K. and K. Yeboah-Gyan, 2007. Diversity and distribution of invasive weeds in Ashanti Region, Ghana. Afr. J. Ecol., 45: 355-360.

Awanyo, L., 2007. A Janus-faced biodiversity change and the partiality of ecological knowledge in a world biodiversity hotspot in Ghana: Implications for biodiversity rehabilitation. Geoforum, 38: 739-751.

Brooks, S.J., 2009. Converting field records to charts summarizing the progress of weed eradication programs. Proceedings of the 10th Queensland Weed Symposium, July 26-29, 2009, Weed Society of Queensland, Yeppoon, pp: 154-159.

Codilla, T.L. and B.E. Metillo, 2011. Distribution of the invasive plant species *Chromolaena odorata* L. in the Zamboanga Peninsula, Philippines. Int. Conf. Environ. Agric. Eng., 15: 25-30.

De Foresta, H. and D. Schwartz, 1991. *Chromolaena odorata* and disturbance of natural succession after shifting cultivation: An example from Mayombe, Congo, Central Africa. BIOTROP Spec. Publ., 44: 23-41.

De Rouw, A., 1991a. Rice, weeds and shifting cultivation in a tropical rain forest. A study of vegetation dynamics. Ph.D. Thesis, Agricultural University, Wageningen,

De Rouw, A., 1991b. The invasion of *Chromolaena odorata* (L.) King and Robinson (*ex Eupatorium odoratum*) and competition with the native flora in a rain forest zone, South-West Cote d'Ivoire. J. Biogeogr., 18: 13-23.

Djietror, J.C., M. Ohara and C. Appiah, 2011a. Predicting the establishment and spread of siam weed in Australia: A test of abiotic cues on seed dormancy and germination. Res. J. For., 5: 115-127.

Djietror, J.C., M. Ohara, S. Tsuyuzaki and C. Appiah, 2011b. On the path of invasion: Disturbance promotes the growth vigor among siam weeds in a mine land ecosystem. Res. J. For., 5: 144-153.

Dzomeku, I.K., M. Abudulai, R.L. Brandenburg and D.L. Jordan, 2009. Survey of weeds and management practices in peanut (*Arachis hypogaea* L.) in the savanna ecology of Ghana. Peanut Sci., 36: 165-173.

Erasmus, D. J. and J. Van Staden, 1986. Germination of *Chromolaena odorata* (L.) K. and R. achenes: Effect of temperature, imbibition and light. Weed Res., 26: 75-81.

Euston-Brown, D., N. Rathogwa and D.M. Richardson, 2007. Development of a clearing protocol based on ecological criteria for mesic savannas and sweet grassveld for the working for water programme. Final Report, April 2007.

Fahrig, L., 2003. Effects of habitat fragmentation on biodiversity. Ann. Rev. Ecol. Evol. Syst., 34: 487-515.

GOG, 2004. Forestry commission. Annual Report of Forestry Commission, Government of Ghana.

Gautier, L., 1992. Taxonomy and distribution of a tropical weed: *Chromolaena odorata* (L.) R. King and H. Robinson. Candollea, 47: 645-662.

Gautier, L., 1996. Establishment of *Chromolaena odorata* in a savanna protected from fire: An example from Lamto, central Cote d'Ivoire. Proceedings of the 3rd International Workshop on Biological Control and Management of *Chromolaena odorata*, October 14-18, 1996, Agricultural Experiment Station, University of Guam, Mangilao, Guam, pp: 54-67.

Gobind, N., K. Mats, J. McIntire, M. Barton-Dock, C. Jean-Christophe and M. Muthukumara, 2006. Ghana country environmental analysis: Environmentally and socially sustainable development department (AFTSD). Report No. 36985-GH, Africa Region, The World Bank Agence Francaise de Developpement.

Goodall, J.M. and P.J.K. Zacharias, 2002. Managing *Chromolaena odorata* in the subtropical grasslands of Kwazulu-Natal, South Africa. Proceedings of the 15th International Workshop on Biological Control and Management Of *Chromolaena odorata*, October 23-25, 2002, Durban, South Africa, pp: 120-127.

Hall, J.B., R. Kumar and A.A. Enti, 1972. The obnoxious weed *Eupatorium odoratum* (Compositae) in Ghana. Ghana J. Agric. Sci., 5: 75-78.

Hoffmann, W.A., R. Adasme, M. Haridasan, M.T. de Carvalho and E.L. Geiger *et al*., 2009. Tree topkill, not mortality, governs the dynamics of savanna-forest boundaries under frequent fire in central Brazil. Ecology, 90: 1326-1337.

Honu, Y.A.K. and Q.L. Dang, 2000. Responses of tree seedlings to the removal of *Chromolaena odorata* Linn. in a degraded forest in Ghana. For. Ecol. Manage., 137: 75-82.

Kankam, B.O. and W. Oduro, 2012. The effect of frugivory on postdispersal seed removal and germination in the pantropical forest tree *Antiaris toxicaria* Leschenault. Afr. J. Ecol., 50: 21-28.

Kriticos, D.J., T. Yonow and R.E. McFadyen, 2005. The potential distribution of *Chromolaena odorata* (Siam weed) in relation to climate. Weed Res., 45: 246-254.

McFadyen, R.E.C., 1996. History and distribution of *Chromolaena odorata* (L.) R.M. King and H. Robinson. Queensland Department of Lands, Alan Fletcher Research Station, Sherwood, 4075 North Queensland, Australia.

McFadyen, R.C. and B. Skarratt, 1996. Potential distribution of *Chromolaena odorata* (Siam weed) in Australia, Africa and Oceania. Agric. Ecosyst. Environ., 59: 89-96.

Muniappan, R. and M. Marutani, 1988. Ecology and distribution of *Chromolaena odorata* in Asia and the Pacific. Proceedings of 1st International Workshop on Biological Control of *Chromolaena odorata*, February 29-March 4, 1988, University of Guam, Mangilao, USA., pp: 21.

Nawaz, M. and S. George, 2004. Eupatorium (*Chromolaena odorata* (L.) King and Robinson) biomass as a source of organic manure in okra cultivation. J. Trop. Agric., 42: 33-34.

Parsons, W.T. and E.G. Cuthbertson, 2001. Noxious Weeds of Australia. CSIRO Publishing, Collingwood, Victoria Australia, pp: 3.

Roder, W., S. Phengchanh, B. Keoboualapha and S. Maniphone, 1995. *Chromolaena odorata* in slash-and-burn rice systems of Northern Laos. Agrofor. Syst., 31: 79-92.

Slaats, J.J.P., 1995. *Chromolaena odorata* in food cropping systems: An agronomic assessment in South-West Ivory Coast. Ph.D. Thesis, Wageningen Agricultural University, Wageningen, The Netherlands.

Tefera, S., B.J. Dlamini and A.M. Dlamini, 2008. Invasion of *Chromolaena odorata* in the lowveld region of Swaziland and its effect on herbaceous layer productivity. Int. J. Agric. Res., 3: 98-109.

Timbilla, J.A. and H. Braimah, 1992. Report on survey of introduction, distribution and spread of *Chromolaena odorata* in Ghana. Report Submitted to the FAO Africa Regional Office, Accra, Ghana, Crops Research Institute, Kumasi, Ghana, pp: 1-3.

Timbilla, J.A., 1996. Effect of biological control of *Chromolaena odorata* on biodiversity: A case study in the Ashanti region of Ghana. Proceedings of the 4th International Workshop on the Biological Control and Management of *Chromolaena odorata*, October 1996, Agricultural Experiment Station, University of Guam, Mangilao, Guam, pp: 97-101.

Weise, S.F., 1994. Distribution and significance of *Chromolaena odorata* (L.) R. M. King and H. Robinson across ecological zones in Cameroon. Humid Forest Station, International Institute of Tropical Agriculture, Yaounde, Cameroon.