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Full Length Research Paper

Impact of parthenium weed (*Parthenium hysterophorus* L.) on the above-ground and soil seed bank communities of rangelands in Southeast Ethiopia

Shashie Ayele[1], Lisanework Nigatu[1], Tamado Tana[1*] and Steve W. Adkins[2]

[1]College of Agriculture and Environmental Sciences, Haramaya University, Dire Dawa, Ethiopia [2]School of Agriculture and Food Sciences, the University of Queensland, Brisbane, Queensland, Australia

ABSTRACT

An invasive weed (*Parthenium hysterophorus*) is widely spread in the rangelands of Jijiga zone, Southeast Ethiopia. However, its impact on the diversity and composition of the standing vegetation and the soil seed bank of rangelands has not been determined. Thus, this study was undertaken to assess the impact of parthenium weed infestation on the above-ground and on the soil seed bank of herbaceous communities. On assessment of the above-ground vegetation, a total of 56 taxa belonging to 17 plant families were recorded with the most frequent families being Poaceae (20) and Asteraceae (9). The cover percentage of grasses was decreased from 62.7% at the no parthenium weed infested sites to 16.6% at the highest infested sites. Similarly, the dry biomass of Poaceae was significantly decreased from 428.1 g m^{-2} to 30.0 g m^{-2} from no to high parthenium weed infestation. In the soil seed bank, a total of 51 species belonging to 16 plant families were recorded with the most frequent families being Poaceae (16) and Asteraceae (7). Out of the 56 taxa recorded on the above-ground vegetation, 38 taxa were present in the seed bank with the lowest coefficient of similarity of 0.14 at the high parthenium weed infested sites. The germinable soil seed bank varied from 300.8 m^{-2} at very low to 1878.6 m^{-2} at high parthenium weed infestation. Parthenium weed in the seed bank accounted for 0.1% under no to 84.2% under its high infestation while that of grasses was decreased from 81.7% to 6.1%. Species richness and evenness indices of both the above ground vegetation and of the soil seed bank were significantly decreased at the high parthenium weed infestation. Hence, it can be concluded that the infestation of parthenium weed has significantly reduced the amount and composition of both the above ground and the seed bank of herbaceous vegetation especially the palatable grass species in the rangelands of south-eastern Ethiopia.

Keywords: Grasses, herbaceous communities, invasive weed.

INTRODUCTION

The available pastoral and agro-pastoral production systems in the south-east Ethiopian rangelands are based exclusively on the use of natural and semi-natural vegetations of the rangelands as a feed for the livestock.

However, poor rangeland management has resulted in serious land degradation, reduced biodiversity, and decline in their nutritive values and replacement of the indigenous grasses by unpalatable species (Alemayehu, 2004). Encroachments by weeds and undesirable woody plants have been threatening the pastoral production system in the Horn of Africa, particularly in eastern Ethiopia (Amaha, 2006).

Herbaceous weedy species like *Parthenium hysterophorus*, woody species like *Prosopis juliflora*, *Acacia mellifera*, *A. nubica* and succulents like *Opuntia*

*Corresponding Author E-mail: tamado6@yahoo.com; Tel: +251915756411, Fax: +252255530325

spp. are increasing in the area and cause significant reduction in production potential of the rangelands (Amaha, 2006). Among the invasive species, *Parthenium hysterophorus* has become a serious threat in the rangelands of south eastern Ethiopia. Parthenium weed (*Parthenium hysterophorus* L.; Asteraceae), of central and/or south American origin, it is considered to be one of the most dangerous invasive plants in Australia, Asia and Africa (Navie et al., 1996). It is believed that parthenium weed was first introduced into Ethiopia in 1968 with a food grain shipment, but a second mass introduction to eastern Ethiopia was believed to be in 1976 during Ethio-Somali war with its seeds attached to army-vehicles (Tamado and Milberg, 2000). Currently, the weed has spread to almost all areas of the country (Mcconnachie et al., 2010).

Parthenium weed has the ability to dramatically reduce the productivity of pastures (Haseler, 1976); affect health of livestock (Narasimhan et al., 1980); cause serious human health problems like asthma, bronchitis, dermatitis, and hay fever (McFadyen, 1995) and causes significant yield loss of crops (Hammerton, 1981; Tamado et al., 2002a). In Australia, the weed has been reported to cause a total habitat change especially in native grasslands, open woodlands, flood plains, and along river banks (Evans, 1997). In India, the weed has been reported to replace the native vegetation in a number of ecosystems (Yaduraju et al., 2005). The weed was reported to reduce both the above ground species richness as well as the diversity of the soil seed bank when rangelands are densely infested (Navie et al., 2004).

Parthenium weed is widely spread in the rangelands of the Jijiga zone of south-east Ethiopia (Tamado and Milberg, 2000; Amaha, 2006; Mcconnachie et al., 2010), and the communities there depend on livestock production as a major source of their livelihood. Thus, it is hypothesized that the spread of parthenium weed modifies the structure of the invaded rangeland communities by decreasing the abundance of native grass species and reducing species diversity. However, there have been no specific studies on the impact of parthenium weed on the diversity and composition of the standing vegetation and the soil seed bank of rangelands in this region of south-eastern Ethiopia.

Therefore, this study was undertaken to determine the impact of parthenium weed on the above-ground herbaceous species composition and on the soil seed bank structure of the rangelands of Jijiga zone, south-eastern Ethiopia.

MATERIALS AND METHODS

Study area

The study was conducted on the rangelands of Jijiga, Kebribeyah and Harshin districts in the Jijiga zone of the Somali Regional State, south-eastern Ethiopia. The three districts were selected because of high infestation of parthenium weed and the rangeland potential of the districts.

The total land cover of Jijiga zone is 40,861 km^2 of which the rangelands account for about 36,629 km^2 (World Bank, 2001). The landscape of the zone is about 52.6% flat to gentle sloping (IPS, 2002). The altitudes of the study districts range from 1402 to 1870 m above sea level (Appendix 1). The mean annual rainfall of the Jijiga zone is 660 mm with a pre-dominantly bimodal distribution (NMSA, 2000). The rainfall events in the zone are characterized by a low and erratic distribution. The temperature of the study area is relatively high throughout the year with a mean minimum and maximum of 20°C and 35°C, respectively (NMSA, 2000).

The vegetation of the rangelands in the study area is characterized by the acacia wooded grassland (Ahmed, 2003). The tree and shrub species that are found in the study area include *Acacia etbaica* Schweinf. *Acacia nilotica* (L.) Delile, *Acacia seyal* Del., *Acacia senegal* (L.) Willd., *Acacia bussei* Harms, *Balanites glabra* Mildbr. & Schltr., and *Commiphora africana* (A. Rich.) Engl. The grassland consisted of native species such as *Chrysopogon aucheri* (A. Rich.) Stapf, *Eragrostis* spp, *Chloris gayana* Kunth, *Digitaria abyssinica* (A. Rich.) Stapf and *Panicum coloratum* L (Ahmed, 2003; Belaynesh, 2006).

Sampling

The road transect survey method described by Greig-Smith (1983) was used. Two transects, each a 100 m long, 1 km apart and each containing five evenly spaced sample quadrats, were established.

Following the method described by Chellamuthu et al. (2005), the sample sites were categorized visually into five parthenium weed infestation levels: no (0%), very low (1-10%), low (11-25%), moderate (26-50%) and high (>50%) of the total percent area coverage by all plants. For each infestation level, four sites were selected. The field study was undertaken between July and September 2006 when the majority of herbaceous vegetation at the specific sites in the rangelands was at the seed setting stage. The altitude, latitude and longitude records of the 20 sites were recorded using GPS channel 12 reader (Appendix 1).

Determination of the above-ground species abundance

The cover abundance of herbaceous vegetation at the 20 study sites was determined from 200 quadrats (1 m · 1 m; 10 quadrats for each site) and using the cover class method described by Daubenmire (1959). This involved visually assigning the plant species to one of six cover classes and then visually assessing their canopy cover percentage in each quadrat. Then, the species cover abundance value was determined by multiplying the number of times a cover class was recorded in the replicated quadrats by the mid-point of that cover class, and the sum of each class was then divided by the total number of quadrats used to find the mean value.

For the determination of the total above-ground dry biomass, 10 randomly placed quadrats per site, each measuring 1 m · 1m were used. The species within each quadrat were categorized as being either Poaceae, non-Poaceae or as parthenium weed. Then, the biomasses of the three groups were oven dried for 48 hours at 70 °C and then weighed.

The majority of the plant species collected from the quadrats was identified in the field. For species that were difficult to identify, a voucher specimen was collected, pressed and identified at Haramaya University Herbarium.

Determination of soil seed bank

The soil samples were taken from all 20 sites using three quadrats (1m x 1m) placed in the center and the corners using cylindrical brass ring soil corer (5 cm in diameter and 3.5 cm deep) from five spots (one from each of the corners and one from the center of the quadrat) and pooled to make a single sample as described by Navie et al. (2004). Samples were taken from three depths (0-3, 3-6 and 6-9 cm below soil surface). The three soil samples from same layers were placed into one plastic bag to form a composite sample and transported to the Haramaya University for germination tests in the glasshouse.

Two sets of germination studies were done in the glasshouse. In the first set, the soil from the three depths of each infestation site was mixed and tested in three replications while in the second set the germination was tested for the three depths separately in three replications to determine the vertical distribution of the seeds within the soil seed bank. In the glasshouse, the soil samples were spread thinly (2 cm thickness) over a layer of sterilized soil contained in shallow trays (20 cm · 25 cm) placed on a bench. Two control trays spread only with sterilized soil were placed along with the experimental trays to monitor for possible glasshouse contamination. Water was applied to each tray to keep it moist. The emerging and easily identifiable seedlings were recorded and discarded every week. The species which were difficult to identify at the seedling stage were labeled, transplanted into clay pots and grown separately until they could be identified. Each month, the soil samples were stirred to stimulate more seed germination. The experiment continued for six months to allow species with long term dormancy to germinate. The emergence values from a tray were converted to those possible from an area of one m^2 of the seed bank.

Data summary and analysis

The diversity of the species in the above-ground vegetation and in the soil seed bank was assessed using the species richness and the evenness index. The evenness index (E) was calculated as described by Magurran (2004):

$$E = \frac{H}{\ln S}$$

where H is Shannon's Diversi (Shannon and Weaver, 1963); S is number of species.

The similarity of the soil seed bank flora and the above-ground vegetation was compa coefficient of similarity (JCS) as described by Magurran (2004).

$$JCS = \frac{A}{A+B+C}$$

where: JCS = Jaccard' similarity; a = species common to both the above-ground vegetation and the soil seed bank; b = species present in the above-ground vegetation but absent in the soil seed bank; c = species present in the soil seed bank but absent in the above-ground vegetation.

Count data were square root transformed as described by Gomez and Gomez (1984) and analysis of variance (ANOVA) was done and the means were compared using the Least Significant Difference (LSD) test at 5% level of significance using STATISTICA software (StatSoft, 1999).

RESULTS AND DISCUSSION

Effects of parthenium weed on the above-ground species cover abundance

In the study sites, a total of 56 taxa belonging to 17 plant families were recorded (Table 1). The most frequent families based on the number species were Poaceae (20) and Asteraceae (9). Tamado and Milberg (2000) also reported high frequency of these two families in eastern Ethiopia as they are very rich in species composition. Annuals were more common (40 taxa) than perennials (16 taxa).

The cover abundance averaged over the five parthenium weed infestation levels was 22.7% for *P. hysterophorus*, 48.3% for grass and 28.8% for non-grass species (Table 1). At the no parthenium weed infested sites, grasses were more dominant accounting for 62.7% of the total cover percentage while non-grass species accounted for 37.1%. Among grasses, the most dominant species were *Chrysopogon aucheri*, *Eragrostis papposa*, *Tragus berteronianus* and *Panicum coloratum* accounting for 14.1, 9.0, 7.0 and 3.2% of the total area cover, respectively, averaged over the five parthenium weed infestation levels. Among the non-grass species, *Asystasia schimperi* (Acanthaceae), *Ocimum basilicum* (Lamiaceae) and *Indigofera amorphoides* (Fabaceae) were more dominant accounting for 5.4, 4.1 and 3.6% of the total cover, respectively, averaged over the five parthenium infestation levels. In line with this study, Belaynesh (2006) also recorded the highest frequency of *Chrysopogon aucheri*, *Eragrostis* spp, *Indigofera* spp and *Ocimum* spp. in the aboveground vegetation of rangelands of Jijiga.

In general, as the parthenium weed infestation levels increased, the percentage cover of both grasses and non-grasses decreased. The high relative dominance of *P. hysterophorus* might be due to its high competitive and/or allelopathic effects on the neighboring plants (Adkins and Sowerby, 1996). Navie et al. (1996) and Tamado et al. (2002b) described several other aspects of the ecology of parthenium weed that might contribute to its competitiveness including the large size and persistence of its soil seed banks, its rapid germination and emergence rate, and the innate dormancy mechanism of its seeds.

Effect of parthenium weed on the above-ground dry biomass

The above-ground dry biomass of the Poaceae, non-Poaceae species, and parthenium weed were all significantly ($P<0.05$) affected by the parthenium weed infestation levels. The dry biomass of the Poaceae species was significantly decreased from 428.1 g m^{-2} to 30.0 g m^{-2} as the parthenium weed infestation level increased from no to high, respectively (Figure 1). A similar trend was observed for the non-Poaceae species, but the rate of reduction was small. The possible reason for higher reduction in biomass of Poaceae species than the non-Poaceae species with the increase in the infestation level of parthenium weed might be selective grazing of grasses by livestock as non-grass species and parthenium weed are less preferred as a grazing plant. Similarly, Khosla and Sobti (1979) and Kohli et al. (2004) reported 90% and 59.6% reductions, respectively, in forage production with increasing levels of parthenium weed infestation. On the other hand, the dry biomass of parthenium weed was increased remarkably from 0.0 to 706.1 g m^{-2} at its high infestation level (Figure 1).

Effect of parthenium weed on the soil seed bank composition and size

From the soil seed bank study, a total of 51 species belonging to 16 plant families were recorded in the five parthenium weed infestation levels. Out of these species, 38 (74.5%) were annuals and 13 (25.5%) were perennials (Table 2). The most frequent families based on the number of species were Poaceae (16) and Asteraceae (7) as observed within the above-ground vegetation. The germinable soil seed bank varied from 300.8 m^{-2} at the very low parthenium weed infestation sites to 1878.6 m^{-2} at high parthenium weed infestation. This seed density was lower as compared to the density

Table 1. Mean cover percentage (m^{-2}) of grasses, non-grass species and parthenium weed at five *P. hysterophorus* infestation levels in the rangelands of south-eastern Ethiopia

Species	Family	Life form[1]	Parthenium infestation levels[2] 1	2	3	4	5
Grasses							
Andropogon abyssinicus Fresen	Poaceae	A/H	0	0.2	4.3	0	0
Aristida adescensionis L.	Poaceae	A/H	2.7	5.9	1.7	2.1	0
Bothriochloa insculpta (Hochst.) A.Camus	Poaceae	P/H	1.9	3.9	0	2.4	0
Cenchrus ciliaris L.	Poaceae	P/H	6.3	3.6	1.1	0	0.8
Chloris gayana Kunth	Poaceae	P/H	0.5	0	0	0	0
Chloris radiata (L.) Sw.	Poaceae	A/H	0	0	0	1.4	0
Chrysopogon aucheri (A.Rich.) Stapf	Poaceae	A/H	24.5	17.9	14.3	10.7	3.0
Cynodon dactylon(L.) Pers.	Poaceae	P/H	2.8	6.8	1.2	1.2	1.9
Dactyloctenium aegyptium (L.) P.Beauv.	Poaceae	A/H	1.0	0.2	2.9	0	0
Digitaria abyssinica (A.Rich.) Stapf	Poaceae	P/H	2.7	0	0	2.6	1.6
Eleusine indica (L.) Gaertn	Poaceae	A/H	0	0	0.5	0	0
Eragrostis cilianesis (All.) Vig. ex Janch.	Poaceae	A/H	0.7	2	0	2.4	0
Eragrostis papposa (Roem. & Schult.) Steud.	Poaceae	A/H	8.1	7.9	17.0	9.8	2.3
Eriochloa nubica (Steud.) Hack. & Stapf ex Thell.	Poaceae	A/H	0.2	0	0	0	0.3
Lintonia nutans Stapf	Poaceae	P/H	0.2	0.4	1.2	0	0
Panicum coloratum L.	Poaceae	P/H	6.8	4.8	1.0	3.0	0.3
Pennisetum polystachion(L.) Schult.	Poaceae	A/H	1.3	0.2	0	0	0
Setaria acromelaena (Hochst.) Dur. & Schinz	Poaceae	A/H	0	0.3	0	0	0
Sporobolus ioclados(Trin.) Nees	Poaceae	A/H	0.5	0.9	0	0	0
Tragus berteronianus Schult.	Poaceae	A/H	2.6	7.0	10.7	8.5	6.4
Sub-total			62.7	62.1	55.9	44.1	16.6
Non-grasses							
Acanthospermum hispidum DC.	Asteraceae	A/H	0.3	0	0	0	0
Acanthus spinosus L.	Acanthaceae	A/H	0	0.5	0.7	0	0
Ageratum conyzoides L.	Asteraceae	A/H	0	0	1.3	0	0
Amaranthus dubius Mart. ex Thell.	Amaranthaceae	A/H	0	0	0	0	0.2
Asystasia schimperi T. Anders	Acanthaceae	A/H	2.7	6.8	5.6	7.6	4.1
Blepharis ciliari s(L.) Burtt	Acanthaceae	A/H	5.5	4.2	0	0	0
Cassia occidentalis L.	Fabaceae	A/H	1.6	0.5	0.5	0.1	0.5
Chenopodium murale L.	Chenopodiaceae	A/H	0	0	0	0	0.2
Chenopodium opulifolium Schrad. ex Koch & Ziz	Chenopodiaceae	A/H	0	0	0.7	0	0
Commelina africana L.	Commelinaceae	P/H	0.1	0.8	0	0	0
Commelina latifolia Hochst. ex A. Rich.	Commelinaceae	P/H	0.4	1.0	0.1	0	0
Conyza bonariensis (L.) Cronquist	Asteraceae	A/H	1.3	1.2	0.5	0	0.5
Craterostigma pumilum Hochst.	Scrophulariaceae	A/H	0	0	0	0	0.3

Table 1 continue

Cucumis melo L.	Cucurbitaceae	A/H	0.1	0.7	0	0	0
Cyperus rotundus L.	Cyperaceae	P/Sedge	0	0	0.1	0	0
Erucastrum arabicum Fisch. & C. Mey.	Brassicaceae	A/H	0	0.9	0	0	3.4
Euphorbia hirta L.	Euphorbiaceae	A/H	1.1	0.9	2.2	0.2	2.7
Glycine wightii (Wight & Arn.) Verdc.	Fabaceae	P/H	0.8	0	0	1.2	0
Guizotia scabra (Vis.) Chiov.	Asteraceae	A/H	0	0.1	2.2	0	0
Heliotropium aegyptiacum Lehm.	Boraginaceae	A/H	1.3	0.1	0	0.5	1.1
Hibiscus trionum L.	Malvaceae	A/H	2.6	0.1	0.5	0	0.9
Indigofera amorphoides Jaub. & Spach	Fabaceae	P/S	3.6	4	3.8	5.1	1.3
Ipomoea obscura (L.) Ker Gawl.	Convolvulaceae	P/H	0.2	1.2	0	0	0
Launaea cornuta (Oliv. & Hiern) C.Jeffrey	Asteraceae	P/H	0.1	0	0	0	0
Leucas martinicesis (Jacq.) R.Br.	Lamiaceae	A/H	0	0.1	0	0	0.5
Medicago polymorpha L.	Fabaceae	A/H	0.6	0.1	0.7	0.1	0
Ocimum basilicum L.	Lamiaceae	A/H	7.6	6.5	2.9	2.9	0.8
Ruellia patula J acq.	Acanthaceae	A/H	2.1	2.2	1.7	4.7	0
Schkuhria pinnata (Lam.) Cabrera	Asteraceae	A/H	0	0	2.9	0.1	0
Solanum incanum L.	Solanaceae	P/S	1.4	0	0	2	0
Solanum nigrum L.	Solanaceae	A/H	1.2	2.2	1.3	0	0
Sonchus oleraceus L.	Asteraceae	A/H	1.6	0.1	0	0	0
Verbascum schimperianum Boiss.	Scrophulariaceae	A/H	0	0	0.1	0	0
Withania somnifera (L.) Dunal	Solanaceae	P/S	0.6	1.2	0.7	0	0
Xanthium spinosum L.	Asteraceae	A/H	0.4	0.5	0.7	0	0
Sub-total			37.1	36.1	29.7	24.6	16.3
Parthenium hysterophorus L.	Asteraceae	A/H	0	1.50	14.27	30.7	67.0

[1] Life form: A/H= Annual Herbaceous, P/H= Perennial Herbaceous, P/T Perennial Tree, P/S= Perennial shrub. [2] Parthenium infestation levels: 1 (no), 2 (very low), 3 (low), 4 (moderate) and 5 (high).

recorded in temperate grasslands by Török et al. (2009) that ranged from 10300 to 40900 seeds m^{-2} and by Valkó et al. (2011) that ranged from 4350 to 94034 seeds m^{-2}. The low seed density in the present study might be due to the semi-arid climate and overgrazing of the rangelands in the study area. The proportion of parthenium weed in the seed bank ranged from 0.1% under the no parthenium infestation level to 84.2% under the high infestation level (Table 2). The possible explanation for the dominance of the soil seed bank by the species might be that parthenium weed is a prolific seed producer, with an average plant capable of producing between 15000-30000 seeds within 3 to 5 months after emergence and a stand capable of producing between 19000 and 350000 seeds m^{-2} (Haseler, 1976; Dhileepan et al., 1996). Moreover, studies showed that parthenium weed seeds can survive for many years in the soil seed bank (Butler, 1984; Navie et al., 1998; Tamado et al., 2002b). Therefore, the very large parthenium weed soil seed bank is probably due to both its prolific seed production and the ability of its seeds to survive for many years in the soil.

In contrast, the proportion of grasses in the soil seed bank declined from 81.7% at the no parthenium weed infestation to 6.1% under the high infestation (Table 2). Most common grass species present in the soil seed bank, in order of abundance, were *Eragrostis papposa*, *Cenchrus ciliaris* and *Digitaria abyssinica* with a mean density of 49.7, 40.7 and 31.9 seedlings m^{-2}, respectively, averaged over the five parthenium weed infestation levels. However, the most abundant native grass species, *Chrysopogon aucheri*, on the above ground vegetation, was less abundant in the soil seed bank. Similarly, the proportion of non-grass species in the seed bank declined from 57.3% at very low parthenium weed infestation level to 9.6% under the high parthenium weed

Figure 1. Above-ground dry biomass (g m^{-2}) of Poaceae, non-Poaceae species and parthenium weed at five *P. hysterophorus* infestation levels

Table 2. Mean germinable soil seed bank (seedlings m^{-2}) of grasses, non-grass species and parthenium weed at five *P. hysterophorus* infestation levels in rangelands in south-eastern Ethiopia

Species	**Family**	**Life form**[1]	**Parthenium infestation levels**[2]				
			1	**2**	**3**	**4**	**5**
Grasses							
Aristida adescensionis[ɔ]	Poaceae	A/H	0	1.2	0	0	0
Bothriochloa insculpta[ɔ]	Poaceae	P/H	10.6	0	0	0	2.4
Cenchrus ciliaris[ɔ]	Poaceae	P/H	190.0	0	0	0	13.5
Chloris gayana[ɔ]	Poaceae	P/H	24.6	0	0	1.8	0
Chloris radiata[ɔ]	Poaceae	A/H	18.8	0	8.0	8.6	3.1
Chrysopogon aucheri[ɔ]	Poaceae	P/H	39.3	11.7	1.2	0	0
Cynodon dactylon[ɔ]	Poaceae	P/H	2.4	14.7	18.4	3.1	28.3
Dactyloctenium aegyptium[ɔ]	Poaceae	A/H	16.4	5.5	0	0	0
Digitaria abyssinica[ɔ]	Poaceae	P/H	103.2	19.0	19.0	15.4	3.1
Eragrostis cilianesis[ɔ]	Poaceae	A/H	6.5	15.4	0	3.7	27.0
Eragrostis papposa[ɔ]	Poaceae	A/H	150.7	12.9	46.7	27.0	11.1
Eriochloa nubica[ɔ]	Poaceae	A/H	0	0	0	0	3.1
Lintonia nutans[ɔ]	Poaceae	P/H	35.2	0	9.2	0	0
Panicum coloratum[ɔ]	Poaceae	P/H	49.1	0	0	0	24.0
Setaria acromelaena[ɔ]	Poaceae	A/H	0	0	0	13.5	0
Tragus berteronianus[ɔ]	Poaceae	A/H	15.6	39.9	10.4	15.4	0
Sub-total			662.4	120.3	112.9	88.5	115.6
Non-grasses							
Ajuga ciliata Bunge	Lamiaceae	A/H	0	0	1.2	0	0
Alternanthera repens (L.) Link	Amaranthaceae	A/H	0	0	0	0	3.7
Amaranthus dubius[ɔ]	Amaranthaceae	A/H	0	4.3	1.8	12.9	0
Asystasia schimperi[ɔ]	Acanthaceae	A/H	0	9.2	56.5	0	12.9
Cassia occidentalis[ɔ]	Fabaceae	A/H	0	0	0	0	6.8

Table 2 continue

Chenopodium album L.	Chenopodiaceae	A/H	0	1.8	0	0	0
Chenopodium murale	Chenopodiaceae	A/H	0	0	8.0	1.2	10.4
Chenopodium opulifolium	Chenopodiaceae	A/H	0	0	0	1.2	0
Conyza bonariensis[3]	Asteraceae	A/H	0	1.8	0	0	1.2
Crotalaria incana L.	Fabaceae	A/H	17.2	12.3	5.5	1.8	0
Cucumis melo[3]	Cucurbitaceae	A/H	0	3.7	0	1.8	0
Datura stramonium L.	Solanaceae	A/H	0	0	0	1.2	0
Erica sp.	Ericaceae	A/H	14.7	7.4	19.7	16.6	16.6
Erucastrum arabicum[3]	Brassicaceae	A/H	4.1	2.5	0	0.6	0
Euphorbia granulata forsk.	Euphorbiaceae	A/H	0	0	3.7	2.4	6.8
Euphorbia hirta[3]	Euphorbiaceae	A/H	14.7	7.4	5.5	14.7	46.7
Euphorbia schimperiana Scheele	Euphorbiaceae	A/H	0	0	0	8.0	0
Galinsoga parviflora Cav.	Asteraceae	A/H	2.4	3.7	1.2	44.2	0
Glycine wightii	Fabaceae	P/H	7.4	0	2.4	3.1	6.1
Heliotropium cinerascens	Boraginaceae	A/H	0	1.8	0	0	0
Indigofera amorphoides[3]	Fabaceae	P/S	13.9	18.4	19.0	4.3	21.5
Ipomoea obscura[3]	Convolvulaceae	P/H	0	0	0	1.2	0
Kosteletzkya virginica (L.) C. Presl ex A. Gray	Malvaceae	A/H	1.6	0	0	0	0
Medicago polymorpha[3]	Fabaceae	A/H	0	3.1	6.1	1.2	10.4
Ocimum basilicum	Lamiaceae	A/H	4.1	6.1	0	0	0
Schkuhria pinnata	Asteraceae	A/H	0	0	3.1	2.4	0
Solanum incanum	Solanaceae	P/S	1.6	9.8	2.4	1.8	0
Solanum nigrum[3]	Solanaceae	A/H	1.6	6.1	41.1	0	18.4
Solanum sp.	Solanaceae	A/H	0	0	3.1	62.7	0
Sonchus oleraceus[3]	Asteraceae	A/H	3.3	3.1	3.7	1.2	10.4
Tribulus terrestris L.	Zygophyllaceae	A/H	0	12.3	0	13.5	0
Withania somnifera[3]	Solanaceae	P/S	58.2	57.7	110	27.6	0
Xanthium spinosum[3]	Asteraceae	A/H	1.6	0	0	0	0
Zinnia peruviana L.	Asteraceae	A/H	0	0	0	46.7	9.2
Sub-total			146.4	172.5	294	272.3	181.1
Parthenium hysterophorus[3]	Asteraceae	A/H	1.6	8	245.1	909.8	1581.9
Total			810.4	300.8	652	1270.6	1878.6

[1]Life form: A/H= Annual Herbaceous, P/H= Perennial Herbaceous, P/T Perennial Tree, P/S= Perennial shrub; [2]Parthenium infestation levels: 1 (no), 2 (very low), 3 (low), 4 (moderate) and 5 (high); [3]Species also recorded on the above-ground vegetation.

infestation level. The dominant non-grass species were *Withania somnifera* (Solanaceae), *Euphorbia hirta* (Euphorbiaceae), *Asystasia schimperi* (Acanthaceae) and *Indigofera amorphoides* (Fabaceae) with mean densities of 50.7, 17.8, 15.7 and 15.4 seedlings m^{-2}, respectively (Table 2).

A highly significant (P<0.01) decline in seedling density of grasses was observed in the soil seed bank as the parthenium weed infestation level increased while the effect on non-grass species was not significant (Table 3). In contrast, the seedling density of parthenium weed increased highly significantly (P<0.01) with its increasing infestation level. Over time, such dominant soil seed bank of parthenium weed would lead to a decline in the diversity and abundance of all other species. In agreement to this, Navie et al. (2004) reported that the presence of parthenium weed reduced the diversity of the soil seed bank and, therefore, the ability of many native species to regenerate.

In this study a lower density (1582.0 m^{-2}) of parthenium weed was recorded at the highly infested site as compared to that recorded in the rangelands of Australia (Navie et al., 2004) where they reported from 17579 to 33904 m^{-2} at highly infested sites. The high density recorded by Navie et al. (2004) might be due to high parthenium weed infestation in the study area and soil sampling after seed shedding. On the other hand, the density of parthenium weed recorded in this study (Table 3) was much higher than that has been recorded in north-eastern Ethiopia by Lisanework et al. (2010) where they

Table 3. Mean seedling density (m^{-2})[1] of grasses, non-grass species and parthenium weed at five *P. hysterophorus* infestation levels

Parthenium weed infestation levels	Grasses	Non-grasses	Parthenium weed
No	25.75(663.0)	12.13 (146.6)	1.46(1.6)
Very low	10.99(120.4)	13.16 (172.6)	2.91(8.0)
Low	10.65(113.0)	17.17 (294.3)	15.67(245.1)
Moderate	9.43(88.5)	16.50 (272.3)	30.17(910.0)
High	10.77(115.5)	13.48 (181.2)	39.78(1582.0)
$LSD_{5\%}$	6.57	NS	6.65

[1] Values in bracket are original density while those out of the bracket are square root transformed; NS = non-significant

recorded much lower seedling density (52.0 m^{-2}) from highly infested sites. This low density as compared to this study could be due to low parthenium weed infestation in north-eastern Ethiopia as the weed was introduced to the area later than south-east Ethiopia. Baskin and Baskin (2001) described the importance of density of above-ground vegetation, the sampling techniques used, the time of the year when the soil samples collected, climatic factors, soil conditions, and differences in the abundance of seed predators etc on the density of soil seed bank.

Effect of parthenium weed on the similarity between soil seed bank flora and above ground vegetation

Out of the 56 taxa recorded in the standing vegetation of the study sites, 38 taxa (67.8%) were present in the seed bank also while 13 taxa were recorded only in the seed bank but not in the standing vegetation (Tables 1 and 2). In general, perennial species were more common on the above-ground vegetation, while annual species were more common in the soil seed bank. Such lack of correspondence between the above-ground vegetation and soil seed banks have been reported for grassland communities by Milberg and Persson (1994) and they attributed this to factors such as absolute seed production, rate and depth of burial and rates of loss of viability (Archibold, 1981). Warr et al. (1993) described one of the possible reason for lack of correspondence to be that species represented in the soil seed bank might have been derived from above-ground vegetation present at the site in previous years.

The lowest Jaccard's coefficient between species in the soil seed bank and those in the standing vegetation was recorded at the high parthenium weed infested sites (Table 4). This could be due to the prolonged presence of parthenium weed in soil seed bank that might have substantially reduced the ability of some of the native species to germinate as reported by

Navie et al. (2004). Belaynesh (2006) also reported low similarity indices (0.08-0.22) between the seed bank densities and the above ground vegetation in the Jijiga plain.

Effect of parthenium weed on the species richness and evenness

Species richness and evenness indices of both the above ground vegetation and the soil seed bank significantly decreased at the high level of parthenium weed infestation (Table 4) indicating decrease in the community heterogeneity. In agreement to this, Poggio and Ghersa (2011) also reported decreased evenness as the dominant species in the community became increasingly productive. The reduction of species diversity could be attributed to the strong allelopathic and/or competitive effects of parthenium weed that might have reduced the germination and growth of the associated plant species in these rangelands. Several studies (*e.g.* Mersie and Singh, 1987; Swaminathan et al., 1990; Pandey and Saini, 2002; Kohli et al., 2004; Sridhara et al., 2005; Lisanework et al., 2010) reported similar negative effects of parthenium weed on species richness and evenness. Such negative effect of the weed on other herbaceous vegetation is also recognized by the community in the study area where they call parthenium weed as 'Khalignole' meaning living a

Vertical distribution of seeds

of similarity (0.14)

The seedling densities of Poaceae, non-Poaceae and Parthenium weed significantly decreased along depth of soil sampling (Figure 2). The seedling density at the first layer (0-3 cm) was 56.5% for Poaceae, 62.9% for non-Poaceae and 68.5% for Parthenium weed and the density gradually decreased as the depth increased to 6-

Table 4. Species richness[1] and evenness indices of the aboveground vegetation and the soil seed bank and their coefficient of similarity at five parthenium weed infestation levels

	Above-ground vegetation		Soil seed bank		
Parthenium weed infestation	Species Richness	Evenness index	Species Richness	Evenness index	Coefficient of similarity
No	4.32 (18.67)	0.84	4.27 (18.33)	0.71	0.31
Very low	4.41 (19.50)	0.83	3.83 (14.75)	0.86	0.26
Low	4.41 (19.50)	0.83	3.51 (12.50)	0.52	0.18
Moderate	3.76 (14.25)	0.80	3.77 (14.25)	0.23	0.20
High	3.60 (13.00)	0.55	3.14 (10.00)	0.15	0.14
LSD5%	0.44	0.10	0.60	0.12	0.12

[1]Values in bracket are original numbers while those out of the bracket are square root transformed

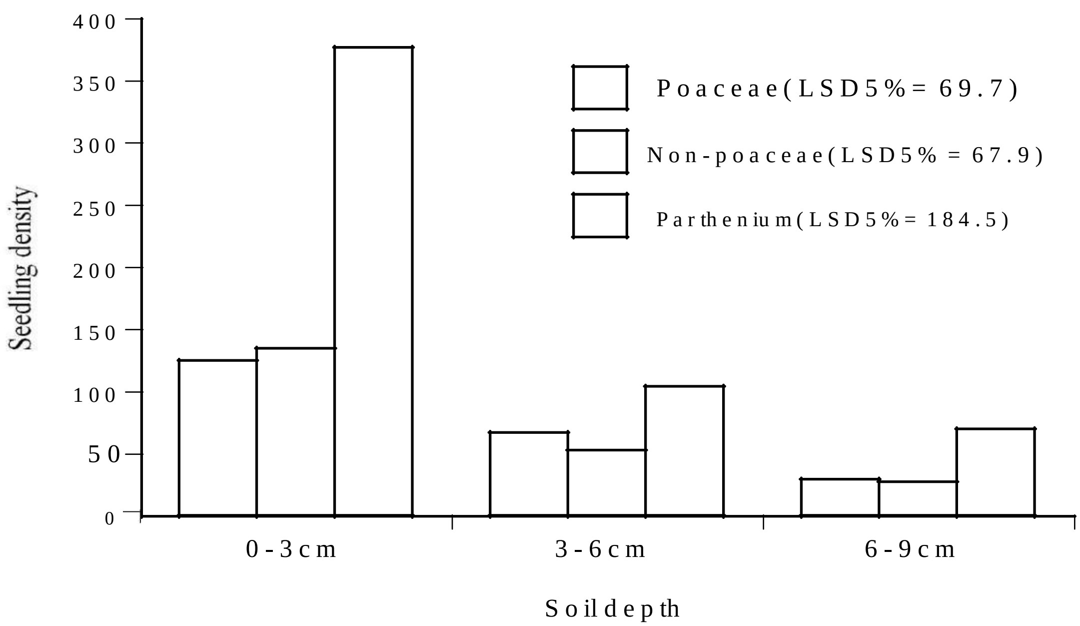

Figure 2. Seedling density of Poaceae, non-Poaceae and parthenium weed per m^{-2} at different soil depths

9 cm. Similarly, the seed density decreased by 76.6% for Poaceae, 79.9% for non-Poaceae and 81.5% for Parthenium weed as the depth increased from 0-3 cm to 6-9 cm. The relatively high concentration of seeds in the top of the soil profile is in conformity with the study by Belaynesh (2006) where mean number of 335.95 seedlings m^{-2}, 101.69 seedlings m^{-2} and 51.83 seedlings m^{-2} were recorded in 0-3, 3-6 and 6-9 cm depths, respectively, in the rangelands of Jijiga. One of the possible reasons for decreasing seedling number with increasing depth, besides low number of seeds, could be that an induction of dormancy or prevention of germination due to lack of light, could be greater with soil depth (Heap, 1997).

O'Connor and(1992)Pickettdescribedthat the vertical distribution of seed within the soil seed banks depends upon several factors that influence seed movement which is in turn associated with soil disturbance. Soil disturbance may result from animal activities or in addition, animal vectors such as earth worms and moles, and burial activities by birds, rodents, and ants can also affect the vertical distribution of seed in the soil seed bank. Moreover, the vertical distribution of the seed can be affected by physical actions such as self-imposed seed burial by falling down into cracks caused by the drying-wetting cycle in the soil, or by surface soil erosion covering seeds. The other forms of vertical seed movement may involve small seeds moving down the soil profile of loose textured soils or through the washing action of percolating water.

CONCLUSION

This study demonstrated that infestation of *Parthenium hysterophorus* has decreased the composition and diversity of both the aboveground vegetation and the soil seed bank of herbaceous species. The adverse effect is more remarkable on grass species which are the major feed sources for livestock in the rangelands. This has reduced the carrying capacity of the rangelands and has become a threat to the sustainability of livelihood of the pastoral community. Thus, there is an urgent need for a concerted management effort directed at parthenium weed in these rangelands of Southeast Ethiopia.

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Appendix

Appendix 1. List of sample sites and their GPS readings

No.	Site	Altitude (m)	Latitude (N)	Longitude (E)	Slope(°)	Parthenium infestation
1	Ceejiso	1402-1420	08 58 22-08 58 29	43 41 26-43 42 08	4	None
2	Lantaeggal	1441-1445	08 58 37-08 59 42	43 38 45-43 39 03	4	None
3	Farahgurae	1476-1487	09 00 12-09 01 06	43 36 20-43 36 58	5	Very low
4	Farahleven	1514-1583	09 02 14-09 03 10	43 33 02-43 33 26	5	None
5	Kurtumaley	1561-1574	09 04 02- 09 05 04	43 30 29- 43 30 47	5	Very low
6	Artishik Keble1	1596-1615	09 04 36-09 05 34	43 27 41-43 27 56	5	Moderate
7	Belyialie	1606-1613	09 06 43-09 07 48	43 25 29- 43 25 58	5	High
8	Artishik	1594-1604	09 08 19- 09 09 15	43 22 30-43 22 46	5	High
9	Ado/Cado	1649-1656	09 09 16-09 10 03	43 17 31-43 18 17	5	High
10	Kotroble	1655-1656	09 06 29- 09 06 36	43 14 21-43 14 25	5	High
11	Deneba	1715-1717	09 05 53- 09 06 15	43 11 35-43 11 45	5	Moderate
12	Gerebe	1746-1752	09 09 00- 09 09 11	43 08 12- 43 08 24	5	Very low
13	Meregacho	1677-1701	09 10 53-09 11 20	43 05 37- 43 06 00	5	Moderate
14	Harae 1	1637-1648	09 13 31- 09 13 54	43 02 32- 43 02 50	4	Low
15	Amedeliae	1640-1722	09 15 23-09 15 55	42 39 45-42 39 52	5	Low
16	Beldaederae	1713-1790	09 17 48- 09 18 06	42 55 24- 42 55 28	5	Moderate
17	Allegeliae	1809-1815	09 19 32-09 20 13	42 50 21-42 50 38	5	Low
18	Gerebasae	1686-1739	09 20 49-09 20 52	42 49 25- 42 50 21	5	Low
19	Karamara	1860-1870	09 21 51-09 21 58	42 42 37-42 42 40	5	Very low
20	Lebeshakie	1746-1752	09 09 00-09 09 11	43 08 12-43 08 24	5	None