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RESEARCH PAPER

Impact of *Parthenium hysterophorus* on grazing land communities in north-eastern Ethiopia

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An investigation into the impact of *Parthenium hysterophorus* infestation was conducted in 2007 in the north-eastern grazing lands of Ethiopia. Data on the above-ground and seedbank species diversity were collected from five areas, each having sites with low, medium, or high levels of weed infestation. A total of 72 species was found in all areas. They were categorized into grass species (23), other species (48), or *P. hysterophorus* for ease of interpretation. A regression analysis showed a highly significant, but negative, relationship between the above-ground species diversity and evenness with *P. hysterophorus* abundance. The mean cover abundance for the three infestation levels was 33.4% for *P. hysterophorus*, 41.0% for the grass species, and 26.5% for the other species. The most dominant grass species under all infestation levels were *Cynodon dactylon, Urochloa panicoides*, and *Chloris gayana*, while *Andropogon abyssinicus* and *Eragrostis* spp. were dominant under the low and medium infestation levels, respectively, and *Hyparrhenia hirta* was dominant under the low infestation level. Among the other species, *Solanum nigrum* was the most dominant under the low infestation level and *Datura stramonium* and *Xanthium* spp. were the most dominant under the medium and high infestation levels, respectively. The above-ground dry biomass of *P. hysterophorus* increased between the low and high infestation levels, while that of the grass or other species reduced in the high, as compared to the low, infestation level. Although the grass species density decreased significantly with successive increases in the *P. hysterophorus* infestation level, no such trend could be seen for the other species. Within the soil seed bank, the viable seed density for the grass species, other species, and *P. hysterophorus* were 25.7, 5.8, and 68.5%, respectively. Similarly, the soil seed bank under the low-, medium-, and high-infestation sites was dominated by *P. hysterophorus*, which contributed 25.1, 65.4, and 87.4% of the viable seed bank, respectively. Although the overall similarity between the above-ground vegetation composition and the soil seed bank was low, it was similar at the low-infested site. Thus, the invasion by *P. hysterophorus* was found to critically endanger the biodiversity of the grazing lands, particularly for the different grass and forbs species in the area. These changes might adversely affect not only future agriculture, but also food security, unless appropriate practises are developed and implemented for *P. hysterophorus* management.

Keywords: biodiversity, cover abundance, dry weight, grazing lands, *Parthenium hysterophorus*, species evenness.

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From its natural occurrence in the tropical Americas, *Parthenium hysterophorus* L. has spread and become invasive in many other parts of the world (Navie *et al*. 1996). The spread of the weed often has resulted from its seed being transported in food grain or attached to vehicles that have been moved over long distances. This weed is now present in many regions of Asia, Australia, and Africa

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(Navie *et al.* 1996). In Asia, it is a significant weed in India, Vietnam, Pakistan, Bangladesh, and Sri Lanka. In India, it interferes with the production of sugar cane (*Saccharum officinarum* L.), rice (*Oryza sativa* L.), irrigated sorghum (*Sorghum bicolor* [L.] Moench), green gram (*Vigna radiata* [L.] Wilczek), sesame (*Sesamum indicum* L.), fodder, and vegetable crops, as well as reducing cattle and buffalo production. Significant amounts (10–50%) of the weed in the diet of buffalos has been reported to kill them within 30 days (Narasimhan *et al.* 1977) as the plant contains toxic parthenin-sesquiterpene lactones that cause tissue damage and hemorrhaging in the internal organs (Ahmed *et al.* 1988). In Australia, the weed has become a dominant species in the pastoral regions of central Queensland, reducing livestock production and the quality of livestock products (Chippendale & Panetta 1994; Evans 1997). In Africa, it has become a significant weed in South Africa, Ethiopia, Kenya, Swaziland, Mozambique, Zimbabwe, Madagascar (Navie *et al.* 1996), and most recently, in Uganda (Adkins 2009, personal communication).

In Ethiopia, it was first reported from Dire Dawa in eastern Ethiopia in 1968. However, a second major center of infestation was subsequently identified in the grazing lands of north-eastern Ethiopia. As livestock farming contributes 33% to the agricultural gross domestic product of Ethiopia (Ayele *et al.* 2003), *P. hysterophorus* is now causing serious production problems in many areas of the country (Asresie *et al.* 2008). It has a C_3/C_4 photosynthesis mechanism (Moore *et al.* 1987) and is aggressively colonizing grazing lands, crops, areas along the sides of roads, riparian vegetation, and areas around homes. With a rapidly changing climate, the direct physiological effects of elevated atmospheric CO_2 will probably be most beneficial to C_3 plants and the biomass production is expected to be greater in C_3 than in C_4 species. Navie *et al.* (2005) observed the stimulated growth and increased competitiveness of *P. hysterophorus* at an elevated CO_2 concentration. These observations were taken to indicate that the weed would be even more invasive in the future and might result in an accelerated range expansion under a changing climate (Patterson 1993) that might then result in reduced grazing land productivity and stock rate carrying capacity. Therefore, the management of grazing lands that comprise mainly C_4 species might become increasingly more difficult in the future.

The rate of spread of this weed in Ethiopia has been alarming. This has been especially true in the Kobo district (2570 km^2), situated in the north-eastern lowlands of the Amhara region, where most households (95%) derive their livelihood from agriculture. The invasion of these grazing lands by *P. hysterophorus* is now threatening the native herbaceous vegetation that is used for livestock production in this region.

Little is known of the effect of *P. hysterophorus* invasion on natural community structure and function. In Australia, the weed has been reported to cause a total habitat change (Evans 1997), especially in native grasslands, open woodlands, flood plains, and along river banks. In India, the weed has been reported to replace the native vegetation in a number of ecosystems (Yaduraju *et al.* 2005). Other studies have shown that its prolonged presence might have greatly reduced the diversity of seed banks, thereby reducing the ability of native species to regenerate (Navie *et al.* 2004).

Therefore, an investigation was undertaken to determine the impact of *P. hysterophorus* on the above-ground native herbaceous species diversity and community evenness, as well as the soil seedbank structure, in Kobo district, north-eastern Ethiopia.

MATERIALS AND METHODS

Study location

The investigation was conducted in the Kobo district (11°50′36″–12°11′20″N, 39°37′26″–39°45′15″E) of the North Wello Administrative Zone of the lowland Amahra region of north-eastern Ethiopia. The altitude of the study location ranged from 1433 to 1530 m a.s.l., with a total annual rainfall of 635 mm (80% received in the months of July and August) and 26.2°C and 14.8°C maximum and minimum annual temperatures, respectively. Five areas within the study location were selected and, within each area, sites were identified that had low (0–25% land cover), medium (26–50%), or high (>50%) infestation levels of *P. hysterophorus*. These sites of low, medium, and high infestation were selected by visual estimation from randomly thrown sample quadrats (1 m × 1 m), as described by Wittenberg *et al.* (2004). The study was undertaken in September 2007, after the flower heads became hard and brown at the end of the main growing season and most of the plants would have shed their seed.

Determination of the above-ground species abundance

The herbaceous vegetation cover at the five study areas within the main Kobo region was sampled by using 120 quadrats (1 m × 1 m; 40 each for the low, medium, and high *P. hysterophorus* infestation levels). The cover abundance of the plant species that were present in each quadrat was recorded by using the cover class method (Daubenmire 1959). This involved visually designating 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 above-ground dry biomass, 10 randomly placed quadrats (1 m × 1 m) from each of the five study areas and three sites were taken and the species within them were categorized as grass species, other species (broad-leaved species and sedges), or as *P. hysterophorus* in order to plan an appropriate weed management strategy.

Soil seedbank assessment

For the soil seedbank study, soil samples were simultaneously collected from the 10 randomly placed quadrats in each of the five study areas and within the three sites. From each quadrat, five cylindrical soil cores (10 cm in diameter and 10 cm deep; one from each corner and one from the center) were removed with a soil auger and the samples were mixed together (Bigwood & Inouye 1988) and transferred back to a glasshouse. Here, the samples were spread thinly over sterilized soil (2 cm thickness) that was contained within shallow plastic trays (one quadrat sample per tray), which were distributed randomly on a series of benches in the glasshouse. Two control trays, just filled with sterilized soil, were placed among the experimental trays to monitor any seedlings that might come from the sterilized soil or from the environment of the glasshouse. Water was applied to each tray whenever it was needed to maintain the soil moisture at approximately field capacity. The readily identifiable emerging seedlings were counted, recorded, and discarded every week. Those species that were difficult to identify at the seedling stage were counted, labelled, and allowed to grow until identification was possible. At monthly intervals, the soil samples were stirred to stimulate further germination. The experiment was run over a 6 month period to enable all the species within the soil sample to be identified, including those with long-term seed dormancy. The emergence values that were found were converted into those possible from 1 m^2. For statistical interpretation, the values were then transformed into $\sqrt{x} + 0.5$.

Data analysis

The species diversity within the soil seedbank flora and the vegetation data between the sample quadrats were computed by using Shannon's diversity index (Krebs 1999; Magurran 2004; Wittenberg *et al*. 2004) and were compared to the abundance of *P. hysterophorus*. This was used to assess the impact of *P. hysterophorus* on the herbaceous weed species diversity:

$$H = -\sum_{i=1}^{s} pi \ln(pi), \tag{1}$$

where H = Shannon's diversity index, pi = the relative importance value of the ith species, and s = the total number of species in the sample quadrat.

The evenness of the species was computed from Shannon's diversity index as:

$$E = \frac{\exp(H)}{\ln s}. \tag{2}$$

A regression analysis was used, with the abundance of *P. hysterophorus* as the independent variable and species diversity and evenness as the dependent variables.

RESULTS

Effect of *Parthenium hysterophorus* coverage on the species diversity and evenness

The regression analysis showed a strong negative relationship between the level of *P. hysterophorus* coverage and species diversity (r^2 = 73%) and evenness (r^2 = 69.5%). The decline in species diversity and evenness with successive increases in the *P. hysterophorus* infestation level indicated that community heterogeneity and distribution are significantly and negatively affected by this species (Figs 1 and 2).

Effect of *Parthenium hysterophorus* coverage on the cover abundance

From the five study sites, a total of 72 species was recorded. Of these, 23 species were *Poaceae*, 12 were

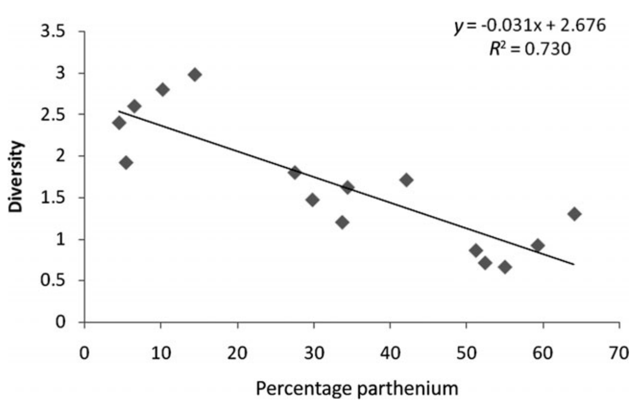

Fig. 1. Effects of different infestation levels of *Parthenium hysterophorus* on species diversity in grazing lands.

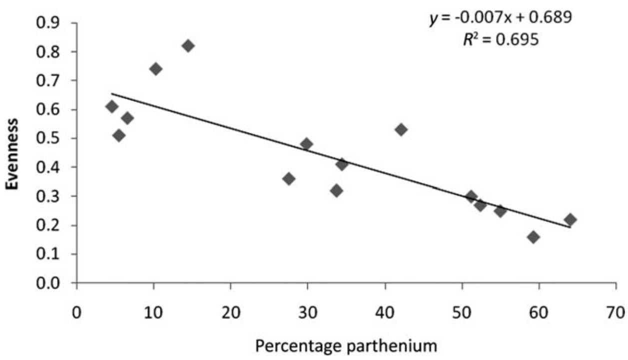

Fig. 2. Effects of different infestation levels of *Parthenium hysterophorus* on community evenness in grazing lands.

Asteraceae, and the remaining 32 species were from 22 other families. A total of 22 species (13 grass and nine others) was found at all five areas and at all three sites (Table 1). The mean cover abundance for the three sites (infestation levels) was 33.4% for *P. hysterophorus,* 41.0% for the grass species, and 25.6% for the other species (Table 1).

At the low *P. hysterophorus*-infested sites, a total of 48 species was found. Of these, 19 were grasses and 29 were other species, including *P. hysterophorus*. At these sites, the grass species gave the greatest area cover (59.7%), with the other species providing 32.1% area cover and *P. hysterophorus* providing 8.2% area cover (Table 1). Among the grasses, the most common species that were found were *Hyparrhenia hirta* (L.) Stapf, *Cynodon dactylon* (L.) Pers., *Chloris gayana* Kunth, *Andropogon abyssinicus* (Fresen.) R. Br., *Eragrostis superba* Warwa & Peyritsch. and other *Eragrostis* sp., and *Urochloa panicoides* Beauv., accounting for 9.7, 9.4, 6.5, 6.1, 4.9, 5.7, and 4.4% area cover, respectively (Table 1). As to the other species, all of the species showed <2% area cover, except for *Solanum nigrum* L., *Cyperus rotundus* L., and *Heliotropium aegyptiacum* Lehm., which had 4.2, 3.8, and 2.7% area cover, respectively (Table 1).

At the medium *P. hysterophorus*-infested sites, a total of 46 species was found. Of these, 18 were grass species and 27 were other species. As with the low-infested sites, the grass species here gave the greatest area cover (40.2%), with the other species providing 24.3% and *P. hysterophorus* providing 35.6% area cover (Table 1). Among the grasses, the most common species were *C. dactylon*, *C. gayana*, *U. panicoides*, and *A. abyssinicus*, which accounted for 8.9, 7.3, 4.7, and 3.6% of the total grass area cover, respectively (Table 1). As to the other species, all of the species showed <3% area cover, except for *Xanthium spinosum* L. and *Datura stramonium* L., which had 3.8 and 4.7% area cover, respectively (Table 1).

At the high *P. hysterophorus*-infested sites, a total of 37 species was found. Of these, 15 were grass species and 21 were other species. At these sites, *P. hysterophorus* gave the greatest area cover (56.4%), with the grass species and other species providing 23.1% and 20.6% area cover, respectively (Table 1). Among the grasses, the most common species were *C. dactylon*, *U. panicoides*, and *E. superba*. These species accounted for 13.1% of the total area cover (6.1, 3.9, and 3.1% for the three species, respectively). All the other species showed <3% area cover, except for *Xanthium abyssinica* Wallroth., *D. stramonium*, and *X. spinosum*, with 4.7, 4.1, and 3.3% area cover, respectively (Table 1).

Among the grass species, *C. dactylon*, *C. gayana*, *U. panicoides*, *Eriochloa nubica* (Steud.) Heck. & Stepf. ex., *E. superba*, *Eragrostis cilianensis* (All.) Lut., *Eragrostis papposa* (Roem. & Sch.) Steudel., *Eragrostis* sp., *Cenchrus ciliaris* L., *Aristida adscensionis* L., *Digitaria abyssinica* (A. Rich.) Stapf., *Panicum atrosanguineum* Hochst. ex. Rich, and *Panicum maximum* Jacq. (Table 1) were found at all three *P. hysterophorus* infestation levels, whereas *A. abyssinicus*, *Digitaria ternata* (A. Rich.) Stapf., and *H. hirta* were only found under the low and medium infestation levels. Among the grass species, the *Eragrostis* spp. had 19.9% area cover. Among the other species, *D. stramonium*, *X. spinosum*, *C. rotundus*, *Amaranthus hybridus* L., *H. aegyptiacum*, *Senna didymobotrya* Fresen., *Achyranthes aspera* L., *Euphorbia hirta* L., and *Argemone mexicana* L. were found at all three *P. hysterophorus* infestation levels (Table 1).

Effect of *Parthenium hysterophorus* on the above-ground dry biomass

The above-ground dry biomass that was produced by the grass species, other species, and *P. hysterophorus* was significantly different at the three *P. hysterophorus* infestation levels. The dry biomass that was produced by the grass species decreased significantly as the *P. hysterophorus* infestation level increased. The same trend was also seen for the other species (Table 2). The percentage above-ground dry biomass that was produced by the grass species was 71.1% in the low, 40.6% in the medium, and 9.6% in the high *P. hysterophorus* infestation level, while the percentage above-ground biomass that was produced by the other species was 21.8, 16.9, and 12.0% in the respective infestation levels.

Effect of *Parthenium hysterophorus* on the soil seedbank size and composition

The total number of species that was identified from the three infestation levels was 43 (18 grass and 25 other species), with 35, 26, and 17 species found under the

Table 1. Percentage of grass and other species area cover under three *Parthenium hysterophorus* infestation levels

	Infestation level			
Species	Low	Medium	High	Mean
Grass species				
Andropogon abyssinicus	6.09	3.55	–	3.21
Aristida adscensionis	1.21	1.60	0.04	0.95
Bothriochloa insculpta	0.58	–	–	0.19
Cenchrus ciliaris	1.39	1.70	1.74	1.61
Chloris gayana	6.53	7.29	2.26	5.36
Cynodon dactylon	9.44	8.88	6.05	8.12
Dactyloctenium aegyptium	–	–	0.10	0.03
Digitaria abyssinica	1.52	0.65	1.46	1.21
Digitaria ternate	1.03	0.68	–	0.57
Eragrostis cilianensis	1.78	1.16	0.70	1.21
Eragrostis papposa	0.81	0.60	0.37	0.59
Eragrostis sp.	5.73	2.15	0.79	2.89
Eragrostis superba	4.88	2.35	3.11	3.45
Eriochloa nubica	1.07	1.00	0.55	0.87
Hyparrhenia hirta	9.67	1.35	–	3.67
Lintonia nutans	–	0.05	0.00	0.02
Panicum atrosanguineum	0.90	0.65	0.61	0.72
Panicum maximum	1.48	1.75	0.79	1.34
Pennisetum polystachion	1.02	–	–	0.34
Setaria acromelaena	–	0.05	–	0.02
Setaria verticillata	–	–	0.65	0.22
Tragus berteronianus	0.18	–	–	0.06
Urochloa panicoides	4.43	4.69	3.85	4.32
Total (%)	59.74	40.15	23.07	40.99
Other species				
Acanthospermum hispidu	–	0.25	–	0.08
Achyranthes aspera	0.61	0.95	0.38	0.65
Actuca sp.	–	0.30	0.25	0.18
Ageratum conyzoides	0.46	–	–	0.15
Alternanthera pugens	–	0.10	–	0.03
Amaranthus hybridus	1.60	2.69	0.94	1.74
Argemone mexicana	1.37	0.10	0.35	0.61
Asystasia schimperi	0.46	–	–	0.15
Bidens pilosa	0.15	–	–	0.05
Commelina benghalensis	–	–	0.14	0.05
Commicarpus africanus	–	–	0.20	0.07
Commicarpus verticillatus	0.61	–	–	0.20
Conyza bonariensis	–	0.45	–	0.15
Crotalaria comosa	0.08	0.05	–	0.04
Cynoglossum lanceolatum	0.15	–	–	0.05
Cyperus rotundus	3.80	2.30	0.67	2.26
Datura stramonium	1.37	4.73	4.08	3.39
Echinopes sp.	–	0.35	–	0.12
Euphorbia hirta	1.29	0.50	0.09	0.63
Euphorbia sp.	0.46	–	–	0.15
Glycine wightii	1.37	0.35	–	0.57

Table 1. (cont.)

	Infestation level			
Species	Low	Medium	High	Mean
Heliotropium aegyptiacum	2.73	0.40	0.43	1.19
Hibiscus trionum	0.53	0.40	–	0.31
Hypoestes sp.	–	1.10	–	0.37
Indigofera brevicalyx	0.40	–	–	0.13
Indigofera hochstetteri	0.99	–	–	0.33
Ipomoea sp.	0.46	0.05	–	0.17
Leucas globrata	–	–	0.06	0.02
Leucas martinicensis	0.61	0.05	–	0.22
Malva verticillata	–	–	0.11	0.04
Nicandra physalodes	0.46	–	–	0.15
Ocimum basilicum	1.14	0.60	–	0.58
Ocimum lamiifolium	–	–	0.46	0.15
Otostegia integrifolia	–	–	0.03	0.01
Oxalis corniculata	1.43	–	–	0.48
Oxygonum sinuatum	1.98	0.15	–	0.71
Parthenium hysterophorus	8.22	35.58	56.38	33.39
Portulaca oleracea	–	–	0.20	0.07
Rubia cordifolia	–	0.05	–	0.02
Senna didymobotrya	1.44	0.10	1.04	0.86
Solanum incanum	–	–	0.17	0.06
Solanum nigrum	4.18	–	–	1.39
Sonchus oleraceus	–	0.35	–	0.12
Tagetes minuta	0.46	–	–	0.15
Trianthema pentandra	–	–	0.35	0.12
Tribulus terrestris	–	0.05	–	0.02
Xanthium abyssinica	–	2.75	4.67	2.47
Xanthium spinosum	1.51	3.83	3.28	2.87
Xanthium strumarium	–	1.30	2.67	1.32
Total	40.32	59.88	76.95	59.05

Table 2. Above-ground dry biomass production of grass, other species, and *Parthenium hysterophorus* under three *P. hysterophorus* infestation levels

Infestation level	Above-ground dry biomass production (g m^{-2})			
	Grass species	Other species	*Parthenium hysterophorus*	Total
Low	347.2	106.3	34.6	488.1
Medium	188.9	78.6	197.2	464.7
High	50.3	62.8	409.6	522.7
LSD (0.05)	32.7	33.9	27.7	44.5
CV%	11.5	28.2	8.9	6.2

CV, coefficient of variation; LSD, Least Significant Difference.

Table 3. Percentage viable seed density of grass species in the soil seed bank under three *Parthenium hysterophorus* infestation levels

Species	Infestation level			
	Low	Medium	High	Mean
Andropogon abyssinicus	2.92	1.04	–	1.32
Bothriochloa insculpta	0.14	–	–	0.05
Cenchrus ciliaris	1.53	1.80	–	1.11
Chloris gayana	5.28	1.71	1.29	2.76
Cynodon dactylon	3.33	1.71	1.54	2.19
Digitaria abyssinica	3.61	2.84	0.73	2.39
Eragrostis cilianensis	3.89	2.94	1.61	2.81
Eragrostis papposa	5.14	2.08	–	2.41
Eragrostis sp.	6.94	2.94	1.14	3.67
Eragrostis superba	11.42	4.45	1.87	5.91
Hyparrhenia hirta	4.03	–	–	1.34
Lintonia nutans	–	0.19	–	0.06
Panicum atrosanguineum	4.31	–	0.49	1.60
Panicum maximum	3.47	1.04	0.89	1.80
Setaria verticillata	1.81	–	–	0.60
Sporobolus pyramidalis	0.97	–	–	0.32
Tragus berteronianus	1.53	1.14	–	0.89
Urochloa panicoides	4.44	2.27	0.40	2.37
Total (%)	64.76	26.15	9.96	33.62

low-, medium-, and high-infestation levels, respectively (Tables 3 and 4). Thus, this study revealed a decline in species number in the soil seed bank as the *P. hysterophorus* infestation level increased. Out of the 43 species that were identified, only eight grass and five other species (including *P. hysterophorus*) were present at all infestation levels. The mean viable seed density over the three infestation levels was 59% for *P. hysterophorus* and only 33.6 and 7.1% for the grass and other species, respectively (Tables 3 and 4).

Taken over all five study areas and three infestation levels, the seed bank was dominated by *P. hysterophorus*, which contributed 25.1, 65.4, and 87.4% of all the viable seed that was found in the low-, medium-, and high-infested sites, respectively (Table 4). In the low-infested sites, grass species were more dominant than the other species (64.8 and 10.2% viable seed density, respectively; Tables 3 and 4). Among the grass species, *Eragrostis* sp., *E. papposa*, *E. cilianensis*, *E. superba*, *D. abyssinica*, *A. abyssinicus*, *U. panicoides*, *P. maximum*, *P. atrosanguineum*, *C. dactylon*, *C. gayana*, and *H. hirta* were found and accounted for 58.8% of the total viable seed density at the low-infestation sites (Table 2). All the other species contributed >1%, except for *A. hybridus, C. rotundus*, and *Crotalaria comosa* Bak., which contributed 1.1, 2.1, and 1.3% of the viable seed, respectively (Table 4). The grass species were less dominant in the medium- and high-infested sites (26.2% and 10%, respectively).

There were significant differences in all the species within the three infestation sites (Table 5). The viable seed number of *P. hysterophorus* significantly increased, while the grass density significantly decreased, as the above-ground *P. hysterophorus* infestation level increased (Table 5). Furthermore, it was observed that, out of the 23 grass and 49 other species that were present in the above-ground vegetation (Table 1), only 17 grass and 18 other species were represented by viable seed in the seed bank (Tables 3 and 4). The species composition of the soil seed bank declined as the above-ground infestation level of *P. hysterophorus* increased.

DISCUSSION

Species diversity and evenness

The decline in species diversity and evenness with an increasing *P. hysterophorus* infestation level (Figs 1 and 2) indicated that this weed is already displacing certain native species from their community. This response to invasion is to be predicted from earlier work in India (De & Mukhopadhyay 1983; Yaduraju *et al.* 2005) and is most likely related to this weed's highly competitive and allelopathic habit (Pandey & Saini 2002). The displacement of native species also might be related to this weed's highly adaptive nature and because it is poorly grazed by cattle. The dispersal of *P. hysterophorus* takes place by water currents, animals, vehicles, machinery, transport systems, stock feed, and to a lesser extent, by wind. Here, it seems that the displacement of native species also might be related to the rapid dispersal of seeds by grazing animals. Furthermore, the presence of achenes and seeds, crowned by a pappus of orbicular scales, aids in the dispersal of this weed by wind.

Effect of *Parthenium hysterophorus* on the species diversity and evenness

There are a couple of possible reasons for the significant reduction in grass species that were present at the high infestation level (Table 1). First, parthenin (one of the allelopathic substances known to be released by *P. hysterophorus*) is known to have a greater inhibitory effect on grasses than on other species (Khosla & Sobti 1979). Second, *P. hysterophorus* (a C_3/C_4 intermediate photosynthetic system plant) is capable of being more competitive than the native C_4 grasses that were found at this study site. Of the grasses present, certain ones (*C. dactylon*, *C.*

Table 4. Percentage viable seed density of other species and *Parthenium hysterophorus* under three *P. hysterophorus* infestation levels

Species	Infestation level			
	Low	Medium	High	Mean
Acalypha crenata	–	0.30	–	0.10
Amaranthus hybridus	1.11	0.60	0.39	0.70
Argemone mexicana	0.14	2.27	–	0.80
Bidens pilosa	–	–	0.19	0.06
Brassica sp.	0.42	–	–	0.14
Commelina benghalensis	0.83	–	–	0.28
Crotalaria comosa	1.25	–	–	0.42
Cynoglossum lanceolatum	0.42	–	–	0.14
Cyperus rotundus	2.08	0.68	0.19	0.98
Datura stramonium	0.69	0.61	0.52	0.61
Erucastrum abbyssinicum	–	0.15	–	0.05
Euphorbia hirta	0.14	–	–	0.05
Euphorbia sp.	0.42	0.15	–	0.19
Heliotropium aegyptiacum	–	0.15	–	0.05
Indigofera brevicalyx	0.42	–	–	0.14
Indigofera coerulea	–	0.15	0.41	0.19
Nicandra physalodes	0.14	–	–	0.05
Ocimum lamiifolium	0.14	–	–	0.05
Parthenium hysterophorus	25.10	65.44	87.36	59.30
Portulaca oleracea	0.14	–	–	0.05
Senna bicapsularis	–	0.61	–	0.20
Senna didymobotrya	0.42	–	–	0.14
Solanum psiolostchya	–	0.45	0.06	0.17
Urtica simensis	0.56	–	–	0.19
Xanthium spinosum	0.83	2.27	0.90	1.33
Total	35.25	73.83	90.02	66.37

Table 5. Viable seed density of herbaceous species under three levels of *Parthenium hysterophorus* infestation

Infestation level	Viable seed density (m^{-2})			
	Grass species	Other species	*Parthenium hysterophorus*	Total
Low	28.2	11.1	17.5	34.9
Medium	21.7	12.3	34.3	42.7
High	17.6	9.1	52.0	56.3
LSD (0.05)	3.5	2.4	4.9	5.5
CV%	11.2	13.8	9.5	8.4

CV, coefficient of variation; LSD, Least Significant Difference.

gayana, *U. panicoides*, *E. superba*, and *C. cilianensis*) were able to cope better with high infestations of *P. hysterophorus* than others. This might have been related to their stronger competitive ability, although this needs to be verified through experimentation. Although *A. abyssinicus* and *H. hirta* were dominant under low *P. hysterophorus* infestations, they could not withstand the competition under medium or high infestation levels.

The dominance of *P. hysterophorus* (Tables 1 and 4) at the study site may be attributed to features such as its fast growth rate, its high seed production, its adaptive nature, as well as its ability to interfere with neighboring plants' growth by resource competition and allelopathy (Haseler 1976; Kohli & Rani 1994; Adkins & Sowerby 1996). Also, in grazing lands, *P. hysterophorus* has the potential to exclude the most useful forage plants, thereby decreasing pasture productivity and, hence, the carrying capacity of the land (Navie *et al.* 1996). Furthermore, the roots of decaying *P. hysterophorus* plants can release certain soluble sesquiterpene lactones that inhibit the germination and growth of other plants (Navie *et al.* 1996; Evans 1997).

Effect of *Parthenium hysterophorus* on the above-ground dry biomass

Parthenin, a natural compound that is released by *P. hysterophorus* plants, is known to reduce the growth and dry matter accumulation of other plants that are growing nearby (Batish *et al.* 2002). The most dramatic reductions in dry biomass production usually occurred with the grass species, as compared to the other species; however, such a phenomenon was not observed by Asresie *et al.* (2008) when they studied sorghum fields that were infested with *P. hysterophorus*. The better competitive ability of the non-grass species component also might be related to the presence of several fast-growing, large canopy-producing, poorly palatable species, such as *D. stramonium, A. hybridus*, and *Xanthium* spp., which together had area cover values of 15.3 and 13.6%, respectively, under the medium and high *P. hysterophorus* infestation levels (Table 1). This might suggest that their good competitiveness under medium-to-high *P. hysterophorus* infestation levels might be another reason for the reduction in species diversity at these infestation levels. Similar results to those reported here in relation to a reduction in species diversity following *P. hysterophorus* invasion have been seen in India, where the weed was reported to reduce the carrying capacity of grazing lands by $\leq$90% (Jayachandra 1971).

Effect of *Parthenium hysterophorus* on the soil seedbank size and composition

The reduction in the number of species that were present and the seed number of each species in the seed bank, found under the medium and high *P. hysterophorus* infestation levels (Tables 3 and 4), are probably a result of the weed's effect on the above-ground community structure. As expected, the largest *P. hysterophorus* soil seed bank was observed under its own high infestation level. Previously, Navie *et al.* (1996) reported several aspects of the ecology of this weed (namely, its high seed production, long-term viability of the buried seed, an innate dormancy mechanism, and rapid germination and seedling establishment) that allow it to create large monospecific seed banks (Butler 1984). Over time, such dominant seed banks would lead to a decline in the diversity and abundance of other species. In this study, the seed bank that was observed in the medium- and high-infested sites had 65 and 87% *P. hysterophorus* densities, as compared to just 25% at the low-infested site (Table 5). This observation is similar to that made by Navie *et al.* (2004). The presence of *P. hysterophorus* reduced the diversity of the soil seed bank and, therefore, the ability of many native species to regenerate.

CONCLUSIONS

The study demonstrated that the populations of *P. hysterophorus* that now exist in the grazing lands of north-eastern Ethiopia are a serious threat to long-term plant community biodiversity. Under the climate change scenarios that have been predicted for eastern Africa, weeds that are C_3 or C_3/C_4 intermediates (e.g. *P. hysterophorus*) are likely to become more of a threat to the predominantly C_4 grazing lands due to their ability to increase atmospheric CO_2 levels. This will intensify the changes in the composition of the grazing lands and lead to a predominance of exotic C_3 species. This potential increase in the competitiveness of C_3 species in the future might lead to further changes in the composition of the grazing lands, which will threaten the food availability and security of the farming communities in north-eastern Ethiopia.

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