THE IMPACT OF PARTHENIUM (*PARTHENIUM HYSTEROPHORUS* L.) ON THE RANGE ECOSYSTEM DYNAMICS OF THE JIJIGA RANGELAND, ETHIOPIA

M.Sc. THESIS

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Haramaya University

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As Thesis research advisor, I hereby certify that I have read and evaluated this Thesis prepared under my guide, by SHASHIE AYELE Entitled**:** The IMPACT OF PARTHENIUM (*Parthenium hysterophorus* L.) ON THE RANGE ECOSYSTEM DYNAMICS OF THE JIJIGA RANGELAND, ETHIOPI**A.** "I recommend that it be subjected as fulfilling the *Thesis* requirement''.

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DEDICATION

The author dedicates this piece of work to her father Ayele Yemenue and her mother Aleme Sendekae for their consistent and unreserved encouragement throughout her educational carriers.

STATEMENT OF THE AUTHOR

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LIST OF ABBREVIATIONS

AIGP	Aggressivity Index of any Grass mixed with Parthenium
AIPG	Aggressivity Index of Parthenium mixed with any Grass
CSA	Central Statistics Authority
DASP	Dry Land Agriculture Strategic Plan
DMYGP	Dry Matter Yield any of Grass mixed with Parthenium
DMYPG	Dry Matter Yield of Parthenium mixed with any Grass
HIS	High Infested Site
ILRI	International Livestock Research Institute
IPM-CRSP	Integrated Pest Management Collaborative Research Support Programe
IPS	Industrial Project Service
JCS	Jaccard Coefficient of Similarity
LIS	Low Infested Site
LSD	Least Significant Difference
LSM	Least Square Mean
MIS	Moderately Infested Site
NMSA	National Metrological Service Agency
NIS	None Infested Site
PA	Peasant Association
RCCGP	Relative Crowding Coefficient of any Grass mixed with Parthenium
RCCPG	Relative Crowding Coefficient of Parthenium mixed with any Grass
Sida /SAREC	Swedish International Development Association
SERP	South East Rangeland Project
SoRPARI	Somali Regional Pastoral and Agro pastoral Research Institute
SPSS	Statistical Package for Social Sciences
SRS	Somali Regional State
SRSS	Somali Regional State Strategy
SSB	Soil Seed Bank
SV	Standing Vegetation

BIOGRAPHICAL SKETCH

The author, Shashie Ayele, was born on March 21, 1980 in Mecha Wereda, Kuesqwame Kebele, Western Gojjam, Ethiopia. She completed her high school education at Tana Haik Comprehensive School in Bahir. After passing the Ethiopian School Leaving Certificate Examination in 1996, she joined Alemaya (now Haramaya) University of Agriculture and graduated with a B.Sc degree in Animal Sciences in July 2000.

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THE IMPACT OF PARTHENIUM (*PARTHENIUM HYSTEROPHORUS* L.) ON THE RANGE ECOSYSTEM DYNAMICS OF THE RANGELANDS IN JIJIGA ZONE RANGELAND, ETHIOPIA

Major advisor: Lisanework Nigatu (PhD)

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ABSTRACT

The study was conducted in Jijiga, Kebribeyah and Harshin districts of the Jijiga Zone, Somali Regional State of Ethiopia. The objectives of the study were to assess the perception of the pastoralists on the effects of parthenium, to analyze the impact of parthenium on herbaceous plant composition and diversity, to determine spatial abundance of parthenium in soil seed bank flora compared to the other herbaceous species, to relate the flora of soil seed bank with the composition of the standing vegetation and to evaluate the ability of selected forage species to compete with parthenium. The data required to know pastoralists' perceptions of the impact of parthenium were collected through structured questionnaire, group discussion and visual observations. A total of 200 quadrats (1mx1m) in 20 sample sites were used to collect data on herbaceous vegetation and soil seed bank flora. Based on the obtained data, the rangeland was stratified into five categories, i.e. none, very low, low, moderate and high parthenium infested sites. Then, the competitive ability of the selected forage species was evaluated and aboveground biomass of all species was collected. According to the respondents, parthenium reduces the carrying capacity of the grazing land by reducing the composition as well as the diversity of palatable species. The study revealed also that the weed adversely affects the quality of milk and meat, and generally jeopardizes animal products and their markets. The weed has a harmful effect on human as well as animal health in the study area. A total of 63 herbaceous species in 20 families were identified in five infestation levels. Out of which 41, 41, 33, 23 and 22 herbaceous species were found in NIS (None Infested Site), VLIS (Very Low Infested Sites), LIS (Low Infested Sites), MIS (Moderately Infested Sites) and HIS (High Infested Sites), respectively. Out of the identified total species, the proportion of grasses were 62.72, 62, 55.93, 39.97, and 16.6% in NIS, VLIS, LIS, MIS and HIS, respectively. Similarly, the proportion of parthenium was 0, 1.5, 14.27, 30.72, and 66.98% in NIS, VLIS, LIS, MIS and HIS, respectively. The study suggested that in all infestation levels ***Asystasia schimperi, Cassia occidentalis, Cynodon dactylon, Eragrostis papposa, Chrysopogon aucheri, Ocimum basilicum and Tragus berteronianus*** *had better proportion than the other herbaceous species .On the other hand,* ***Erucastrum arabicum*** *and* ***Euphorbia hirta*** *had better proportion in HIS than the other sites. The species composition of (grasses and forbs), aboveground biomass, evenness and the diversity indices were found to be significantly different (P<0.05) among the infestation levels. The highest number of the variables was obtained in NIS and the least at HIS. What is more, the study indicated that they percentage of parthenium was negatively correlated with* *species composition, aboveground biomass and evenness and to the diversity indices. The total number of species in the soil seed bank was 59 and all of them belong to 16 families. Out of these, 81.62, 6.7 and 1.96% were herbaceous, woody herb and tree species, respectively. The most dominant species were* ***Eragrostis papposa, Digitaria abyssinica*** *and* ***Parthenium hysterophorus*** *in NIS, VLIS and LIS, MIS and HIS, respectively.* ***Parthenium hysterophorus*** *accounted for 0.58, 7.39, 54.46, 87, and 94% in NIS, VLIS, LIS, MIS and HIS, of the total species recoded, respectively. The diversity and evenness of the species among the infestation levels in soil seed bank showed significant (P<0.05) difference. The highest species diversity was obtained at VLIS whereas the least was found at HIS. The two way ANOVA made on seedling density along depths and between sites revealed a significant (P<0.05) difference. Similarly, the similarity between above ground vegetation and species in soil seed bank between infestation levels showed significant (P<0.05) differences across the infestation levels. The highest mean similarity was obtained at NIS and the lowest at HIS. The ability of grass species to compete with parthenium measured on crowding coefficient and an aggressivity index showed that* ***Bothriochloa insculpta*** *strongly out competed parthenium. This was followed by* ***Cenchrus ciliaris, Cynodon dactylon, Panicum coloratum and Chloris gayana****. Taking into account the variations between infestation levels, one can conclude that Parthenium hysterophorus exerted harmful impacts on the composition, diversity and biomass production of the grass species in the rangelands of the study area. The study suggested again that grasses are able to out compete up to a level greater or equal to the density of parthenium. It revealed also that the condition of a species' ability to compete might point out that proper use of grazing management practices would minimize rangelands' risk of infestation by parthenium.*

1. INTRODUCTION

Rangelands covers about 65% of the total area of Africa (Friedel *et al.*, 2000), and 62% of the total landmass in Ethiopia. In Ethiopia, a considerably large part of rangeland is located in the plains of the country's arid and semi-arid regions with unreliable and erratic rainfall, and high temperature (Alemayehu, 1998). The country's lowland plains are rich in open grassland, bush grassland, bush land and other highly valuable natural resources (Coppock, 1994).

Worldwide, rangeland contributes about 70% of the feed needs of domestic ruminants (Holechek *et al.*, 1998). In African and South American countries, it provides over 85% of the total feed needs of ruminants (cattle, sheep and goats). In Ethiopia, it represents a valuable resource to the pastoralist and to the nation (Obo, 1998). Some indicators are that about forty percent of the national cattle, 50% of the small ruminants, and almost all camels are found in the pastoral areas (Hogg, 1997). Furthermore, 12-15% of the country's total populations live in these dry areas. In the country, livestock resources are important economic sectors. Rangelands have an immense potential for sustained production of livestock and livestock products. In the rangeland areas, livestock are important possessions as they provide all the consumable outputs and insurance against disasters (Alemayehu, 2004).

The Somali Regional State (SRS), which is the second largest regional state found in the south eastern part of Ethiopia, covers about 281,900 km^2. The rangelands in the Jijiga Zone extend over 36, 629 km^2 (World Bank, 2000). Most of the region lies below 900 meters above the sea level although the altitude ranges between 500-2300 m.a.s.l. (IPS, 2002). Arid and semi-arid rangeland vegetation types like grasslands, open savannas (bush grass land) and closed savannas (bush land) are abundantly found in SRS (SoRPARI, 2005). Although they are rich in botanical resources, the range lands are at present are under stiff human and natural pressures (Ahmed, 2003; Belaynesh, 2006). The land use pattern of the SRS indicates that more than 80% of the total land provides the natural feed base for the livestock population (SRSS, 1997). The available pastoral and agro-pastoral production systems in the region are based exclusively on the use of natural and semi-natural vegetations of the rangelands as a feed for the livestock.

Poor rangeland management in Ethiopia has resulted in serious land degradation, reduced biodiversity, and decline in their nutritive values and the indigenous grasses' gradual replacement by poorly palatable species (Alemayehu, 2004). The Somali Regional State is a predominantly pastoral area and, like most pastoral areas elsewhere, it is affected by environmental changes and rangeland degradation that were caused mainly by increasing population pressure, over-stocking, overgrazing and deforestation (EARO, 2003). These factors have facilitated the disturbance of the rangeland ecosystem and enhanced the effect of weed invasion.

Encroachments by weeds and undesirable woody plants have been threatening the pastoral production system in the Horn of Africa, particularly in Eastern Ethiopia (Amaha, 2003; Gemado *et al*., 2006). Herbaceous weedy species like *Xanthium* and *Parthenium*, woody species like *Prosopis juliflora*, *Acacia mellifera*, *A. nubica* and succulents like *Opuntia spp.* are increasing in the areas. They are responsible for a significant reduction in production of the potential of the rangelands (SERP, 1990). The biodiversity of the Somali Regional State has recently been threatened by encroaching weeds and woody plants (EARO, 2003). Increasing deforestation, recurrent droughts and over-grazing might have caused the deterioration of the rangeland vegetation, thereby weakening the grazing and browsing capacities of the rangelands (Ahmed, 2003; SoRPARI, 2005; Amaha, 2006; Belaynesh, 2006). At present, most of the rangelands in the area are invaded by noxious weeds, one of which that aggressively invaded the rangeland is *Parthenium hysterophorus* L (SERP, 1995; Frew *et al.,* 1996; Tamado and Milberg, 2000).

As elsewhere in the world (Holm *et al.*, 1977; Singla, 1992; Evans, 1997), Parthenium, an alien invasive weed has been threatening the natural and agricultural ecosystems in Ethiopia. The weed has been spreading throughout the country after it was first noticed around Dire-Dawa in 1980's (Medehin, 1992; Frew *et al.,* 1996; Tamado, 2001). The weed that has been widely spreading to other parts of the country at an alarming rate must have now exerted a substantial amount impact on the biodiversity of rangelands and arable lands. The invasive ability of the weed can be attributed to its high reproductive and dissemination ability, its allelopathic effect on other plants, its higher phenotypic plasticity, and its ability to withstand a wide range of environmental conditions. Parthenium is so aggressive and devastating that very little and sometimes no other plant species are seen in areas where it has gained dominance (Adkin, 1996; Kohli, 2004; Prasanta *et al.*, 2005; Shabbir and Swhsana, 2005). It seems also that the uncontrolled expansion and fast growth of the weed on rangelands allow it to colonize large area easily. Wherever it invades the weed forms predominant exotic vegetation by replacing the indigenous grasses and other herbaceous plants that have for years been used for grazing (Evans, 1997). In areas where the weed occurs the productivity of forage is reduced by 90%. In addition, the weed makes land infertile and weakens the quality of grazing land, animal health, meat and milk products (Baars and Moassa, 1999; Prasanta *et al.*, 2005; Rezene *et al.*, 2005).

Parthenium is widely spread in the rangelands and in the cultivable fields of the Jijiga Zone (SERP, 1995; Frew *et al.*, 1996; Tamado, 2001) and its occurrence has been negatively affecting the composition and diversity of the rangeland vegetation through depleting wealth and biodiversity of the natural plant species in the invested areas. There is a general fear that the rapid and uncontrolled expansion of the weed may considerably weaken the carrying capacity of the grazing land

Parthenium has been menacing the rangeland ecology of the country in general and that the Jijiga Zone in particular for over two decades now. However, little or no data of scientific studies have been documented regarding the diversity and abundance of rangeland species and the size of these species in the soil seed bank flora. It is imperative to identify rangeland species that may have the ability to resist or overcome the challenges of the weed, which is increasingly reducing the quality and quantity of the composition and biomass of the herbaceous species. Such a study may come up with information that may help develop management options capable of controlling the aggressive invasion of parthenium in the rangelands.

Therefore, the objectives of the study were:

- to assess the pastoralists’ perception about parthenium weed,
- to investigate the effects of parthenium weed on the composition and diversity of rangeland herbaceous species ,
- to determine the spatial abundance of parthenium weed in soil seed bank flora compared to other herbaceous species,
- to relate the soil seed bank flora with the composition of the standing vegetation,
- to evaluate the competitive ability of selected forage species with parthenium weed.

2. LITERATURE REVIEW

2.1. Rangeland and Rangeland Degradation in Ethiopia

Rangelands are areas of the world characterized by physical limitation, low and erratic precipitation, rough topography, poor drainage, or cold temperatures. Due to this, rangelands are unsuitable for cultivation. However, they provide forage for free ranging native and domestic animals and wood products, water and wild life (Alemayehu, 2004). Worldwide, more than 200 million people depend on rangelands as sources of pastoral production. In developing countries alone about 30-40 million nomads are wholly dependent on livestock.

Rangelands are important renewable resources. In addition, they perform a number of ecological functions. They provide humans with consumable products like meat, fiber and water and non-consumptive services like recreation and wild life viewing. In Ethiopia, more than 90 % of the livestock is kept on natural pasture (Alemu, 1982). However, many of the rangelands in the country, like it is in the rest of the developing countries, are presently under extensive degradation (Tamene, 1990). Extensive degradation in turn causes loss of soil fertility and decline in land productivity.

Degradation is defined as long term decline in secondary productivity (animal out-puts) reflecting in primary productivity as species composition of the vegetation shift towards less productive and less palatable species (Scoones, 1995). Rangelands in Ethiopia are under the threat of herbaceous and woody plants invasion. For instance, the Borena rangeland is presently encroached by bushes. According to Coppock (1994), roughly 15 species of woody plants are thought to be encroachers in the Borena plateau. The most dominant of these are Acacia *drepanolobium* and *A. brevispica*. The lack of prescribed burning, accompanied by severe over-grazing and the expansion of farming in the dry land are some of the main problems that are directly or indirectly associated with encroachment. According to Oba (1998), 40% of the Borena rangelands were estimated to be encroached by bush. Beruk and Tesfaye's (2000) study in the Afar Regional State indicated that *Acacia seyal; A. mellifera, A. Senegal,* and *Prosopis juliflora* are serious ecological concerns. On the other hand, in Eastern Ethiopia in general and the Jijiga Zone in particular, the rangelands have been invaded by species such as *Xanthium* and *parthenium* (SERP, 1995). One report of the World Bank indicated that conditions of the rangelands in the SRS are under heavy stress. In Jijiga plateau, 90 % of the grasses appeared to have been overgrazed; the browse is also disappearing at an alarming rate in the region. Overgrazing has become the most formidable cause of rangeland degradation. The other major causes of degradation across Jijiga rangelands are recurrent droughts, erratic rain fall, and tree clearing (Ahmed, 2003; Belaynesh, 2006). The existence in the area of refuge camps for the last 20 years has also contributed considerably to rangeland deterioration.

2.2. Botanical Description and Germination of Parthenium

Parthenium is an annual herbaceous member of the Asteraceae, with a deep tap root and an erect stem that gradually changes into semi-woody with age. It branches itself out usually up to about 1-2 meter. It has bi-pinnatfied and pale green leaves covered with soft fine hairs (Prasanta *et al.,* 2005). Parthenium can grow and reproduce itself any time of the year. During a favorable growing season, four or five successive generations of seedlings can emerge at the same site. Pandey *et al*. (2003) reported that the photosynthetic characteristics of parthenium leaf is mostly related to C_3 type pathway and exhibits a photosynthesis rate of 25-35 ^{0}C and a high CO_2 level. Low temperature considerably reduces plant growth, mainly flowering and seed production by reducing leaf area index, relative growth rate, net assimilation rate, and leaf area duration (Navie *et al*., 1996; Pandey *et al.,* 2003). The weed grows fast and comfortably on alkaline to neutral clay soils (Dale, 1981). However, its growth is slow and less prolific on a wide range of other soil types (Adkins *et al.,* 2005; Rezene *et al*., 2005). Parthenium is a prolific seed producer. For example, in a highly infested field in India, a single plant produced 200, 000 seeds/m^2 (Joshi, 1991).

The germination process of the weed involves several steps required to change the quiescent embryo to metabolically active embryo (Buhler and Hoffman, 2000). For a seed to germinate adequate water, suitable temperature and composition of gases (O_2/CO_2 ratio) in the atmosphere, and light should be available.

Several internal and external factors prevent seed germination. Among the internal factors some the presence of biochemical inhibitor in the seed and immature embryo. The commonest external factors are soil water content and temperature (Fernandez-Qviatanilla *et al.,* 1991). The longevity of a seed represents a major mechanism of survival for weed species. It leads to a continuous source of emergency (Carvalho and Favoretto, 1995). However, the longevity of seed in soil varies according to the characteristics, burial depth, and climatic conditions of seeds (Carmona, 1992).

Studies conducted on the longevity of *P. hysterophorus* have produced inconsistent results. Butler (1984) came up with a finding that the viability of seed was 66% after one week of burial to 29% after two years. However, Navie *et al. (*1998) and Tamado *et al*. (2002) reported that the viability of seed was greater than 74% after 2 years and showed 50% viability after 26 months of burial in the soil, respectively. This suggests that a potential buildup of a substantial persistence in soil seed bank makes it difficult to eradicate a population of *P. hysterophorus* in a short period of time. The seedlings of *P. hysterophorus* emerged from shallow buried (< 0.5 cm) seeds and none from more than 5 cm depth possibly due to exhaustion of seedling reserves before emergence or an induced dormancy (Tamado *et al*., 2002).

Parthenium seeds do not posses dormancy mechanism (McFadyen, 1994). However, Picman and Picman (1984) demonstrated the presence of water soluble germination inhibitors (*i.e.* parthenin and phenolic acid) in the accessory structure and the seed coat of parthenium seeds. Parthenium has viability greater than 85% (Pandey and Dubey, 1988). Williams and Groves (1980) on their part reported maximum germination (88%) of the seed in dark, under a day/ night temperature regime of $21/16^{0}$C. They also noted that the percentage of the germination decreased as the day/night temperature differential was increased. During their work on Indian parthenium achenes in continuous light or dark, Pandey and Dubey (1988) suggested that the weed does not have a strict light requirement for germination. However, they observed that germination was enhanced under the influence of alternating day night temperatures. On the basis of their study, Pandey and Dubey (1988) concluded that $25/20^{0}$C day/night temperature regimes were optimum for germination of parthenium. In Ethiopia, Tamado *et al*. (2002) reported that germination of parthenium seed occurred at the mean minimum (10^0C) and maximum (25^0C) temperatures as well as over a widely range of fluctuating ($12/2^0$C- $35/25^0$C) temperatures.

2.3. Seed Dispersal

The spread of seeds plus their ability to remain viable in the soil for many years pose one of the most complex problems for control. This fact makes eradication difficult for many seed producing weeds (Monaco *et al.,* 2001). Weed seeds are dispersed by crop seed (hay and straw) wind, water, animals including humans and machinery. Where straw is used for mulching, it is important that the straw be free of viable weed seeds as well as grain seeds. Parthenium achenes are usually transported with crop and pasture seeds or in fodder (Gupta and Sharma, 1977).

Weed seeds have special adaptation that helps them spread. Parthenium weed seeds are very small and with short wing like structures (Navie et *al*., 1996). This helps them to float in wind. Wind transport is usually for a few meters, but whirl winds can carry a large number of light achenes to considerable distance. Weed seeds may move also with surface water, runoff, in natural streams and rivers, in the irrigation and drainage channels, and in irrigating water from ponds (Monaco *et al.,* 2001). The dispersal of parthenium achenes by water is possible as indicated by large populations of the weed spreading along water ways in central Queensland (Auld *et al.,* 1983). However, scientists have found great variation in length of time the seeds remain viable in fresh water. For example, some seeds can be stored in fresh water for three to five years and still germinate (Monaco *et al.*, 2001).

Animals, including humans, are responsible for scattering parthenium seeds. They may carry the seeds on their feet, cling to their fur or clothes, or internally (ingested seed). In addition, parthenium seed achenes are capable of being transported to long distance in mud and debris (Auld *et al.,* 1983). In most cases, the long distance dispersal of achenes occurs when they are transported on motor vehicles or machinery (Gupta and Sharma, 1977). In general, parthenium, like any other weeds, can be dispersed easily by water, farm machinery, vehicles, movement of livestock, animal dung and grain seeds. Proper cleaning of farm equipment, sowing of uncontaminated seed and a short-term quarantine of livestock in parthenium infested area will reduce the risk of spreading the weed (Tamado, 2001).

2.4. Status and Distribution of Parthenium in Ethiopia

In Ethiopia, parthenium has become a notorious weed since its discovery in the 1980's. It has been spreading from the eastern route of Ethiopia along the Dire Dawa, Addis Ababa railway presumably between 1974 and 1980. Some believe that the weed might have been transported into the country with imported or donated grain (Seifu, 1990; Fasil, 1994; Frew, 1996; Tamado, 2000). Others hold the belief that the weed entered the country the Ethio-Somali war in 1976/77 through military vehicles (Frew *et al.*, 1996). The presence of parthenium in Kenya and Somalia (Njorage, 1986) and the capacity of the seed to travel long distance through wind, water, and other means also suggested the possible entry into Ethiopia from these neighboring countries.

In the Amhara region, it is estimated that about 37,105 hectares of land is infested with parthenium (Berhe, 2002). It is abundantly found in Gojjam, in south and north Gonder with the potential to spread to agricultural districts of Metama and Setit Humera (Fessehaie, 2004). Furthermore, the weed is well established in many districts of South, north, and central Tigray. In one district alone, Alamata, about 10,000 hectares of the land has been infested with parthenium (Bezabieh and Araya, 2002). In much of the low lands of Wello, parthenium has become the most dominant weed. In these areas, the weed has been reported in 42 Woredas. The weed is also a serious problem in the Regional State of Oromia although there is no actual survey data on the total area of land infested in the region. Currently, parthenium is spreading at an alarming rate in Eastern Ethiopia; the central rift valley, and neighboring localities of Afar Region, East Shewa, Arsi, Bale and in Southern Ethiopia.

2.5. The Status and Distribution of Parthenium in Eastern Ethiopia

The most part of Eastern Ethiopia is arid and semi-arid characterized by low and erratic rain fall. In this part of the country, parthenium is spreading fast and affecting the life of both plants and animals (SERP, 1995; Frew *et al.,* 1996). The weed is abundant in Dire Dawa, Fedis, Babile, Errer, Jijiga, Durwale, Haroreys, Fafen, Dhiba, Gabogabo, Fik, Haramaya and in some of the coffee growing areas of the region. In these areas it has causing a serious damage to grazing and crop areas. Due to its impacts, the palatable species are disappearing (SERP, 1995; Frew *et al.*, 1996).

In Eastern Ethiopia, particularly around Jijiga both the rangeland and crop fields have been infested. This phenomenon has been disturbing pastoralists and farmers (SERP, 1995, frew *et al.*, 1996). Currently, the weed is expanding fast, and is prevalent down to the Ogaden lowlands in the south east and up until to Nazareth following along the rail way. In eastern Ethiopia, the weed is commonly called ‘Kildnole’ (living alone) (SERP, 1995; Tamado, 2001; Belaynesh, 2006). It is said so because the weed lives alone by excluding or expelling other species found in its vicinity.

Tamado (2001) found out that 90% of the interviewed farmers rank parthenium weed as the most serious problem both in rangeland and crop lands. Furthermore, a soil seed bank study in Jijiga rangeland indicated that 28% of the entire seed bank is dominated by parthenium (Belaynesh, 2006). It seems that its fast and robust growth helps the weed to colonize both productive to marginal lands. Today, the weed is found in range lands, along road ways, rail ways, around home yards, footpaths, and at periphery of the crop fields (SERP, 1995; Frew *et al.*, 1996).

2.6. The Impact of Invasive Weeds

2.6.1. Rangeland productivity and animal production

Weeds are increasingly affecting the utilization of both natural and sown pastures. In Ethiopia, natural pastures constitute the highest portion of the available grazing resources supporting up to 33.08 million heads of cattle (53.7%), 10.41 million goats (13.81%) and 13.46 million sheep (21.86%) (DASP, 2005). The major problem facing the pastoral production in Ethiopia is the wide scale degradation of native pasture encroachment by undesirable shrubs like Acacia sp., *Prosopis juliflora* and weeds like *Xanthium* and *Parthenium* (Amaha, 2003; Gemado *et al.,* 2006).

Range and pasture weeds are plants that reduce livestock production through poisoning, reducing stock growth (directly or by competition with preferred plants) or by inflicting mechanical damage. Pasture weed is defined as ‘a species whose presence results in a reduced economic out put in a specific system (Auld *et al.,* 1979). Plants may be weeds of pastoral land for a number of reasons. They may be poisonous or unpalatable to livestock or they may be edible, but provide less or poor quality forage when compared to other forage species. Various woody species are widely perceived to reduce the herbage supply through competition. They may inhibit the movements of livestock, reduce their access to water or forage, and make it more difficult to master livestock. Shrubs can also harbour feral animals such as pigs. This may in turn be a problem for livestock enterprise (Auld *et al.,* 1979).

The presence of weeds in rangelands leads to large scale economic losses in the form of reduced level of animal productivity, increased herd mobility rates, more difficult stock handling and management and a considerably reduced property capital values. Weeds in pasture can endanger livestock and lower their products. For instance, they reduce the quality and quantity forage and make them unpalatable or even poisonous to livestock (Kilngman and Ashton, 1995). For example, plants such as *P. hysterophorus* affect livestock through poisoning. In buffalo calves and crossbred calves fed on parthenium, the toxic signs were popular erythematous eruptions on body, alopecia and depigmentation of neck and shoulders, and oedema around eyelids and facial muscles (Ahmed *et al*., 1988).

Adult female Osmanabadi goats that fed on adlibitum aerial parts of parthenium for 12 weeks showed anorexia and dermatitis on either side of thorax, abdomen and neck (Qureshi *et al*., 1980). A study in India that was conducted on toxicity of the weed to cattle and buffalo have shown that a significant amount (10-50%) of the weed in the diet can kill animals within 30 days (Narasimhan *et al.,* 1977). The taints of meat have been detected in a group of sheep given the diet of 30% parthenium (Tudor *et al.,* 1982). In similar ay, tainting of milk has been reported from cows (Towers *et al.,* 1992). Evans (1997) indicated that the impact of parthenium on livestock production is direct as well as indirect. The author revealed that the weed affects grazing land, animal health, milk, meat quality, the marketing of pasture seeds, and grain. In Australia, parthenium could completely dominate grazing land. As a result, up to 80% reduction in stocking rate occurred with a net annual loss of $ 16.5million (Chippendale and Panneta, 1994). In addition, the presence of parthenium caused the need for establishment of new improved pasture and production of extra cultivated forage, both of which added to the cost of beef production (Chippendale and Panneta, 1994).

2.6.2. Biodiversity

Biodiversity is a term given to the variety of life on the earth and the natural patterns it forms (Alemayehu, 2005). On the other hand, McNeely (1998) has defined biodiversity as an umbrella term for the degree of nature's variety, including both the number and frequency of ecosystem, species, and genes in a given assemblage.

Invasive plants are known to exert significant impact on the natural communities as they cause their displacement and hence exert imbalance in the natural and agricultural ecosystem (Sakai *et al.,* 2001). This imbalance causes the formation of large monoculture of invasive plants in the alien environment. The weed affects not only the species diversity of the native areas, but also their ecological integrity (Kohli *et al*., 2004). In India, a number of invasive weeds have been reported. However, *Parthenium hysterophorus*, *Lantana camara,* and

Ageratum conyzoides, are tropical origin. These weeds have similar growth strategies. They grow fast, have short life cycle and except *Lantana camara,* they have greater reproductive potential, competitive ability, and allelopathy that make them successful invaders of non native habitat (Grice, 2006).

Parthenium is an aggressive weed and therefore poses a serious threat to the environment and biodiversity owing to its high invasion and allelopathic effect which has the capacity to rapidly replace the native vegetation (Pandey *et al.,* 1993). Parthenium exerts strong allelopathic effect and reduces the growth and reproductively of associated crops. It does these by releasing phytotoxins from its decomposing biomass and root exudates in soil. Bioassay, pot culture and field studies have revealed that all plant parts (shoot, root, inflorescence and seed) are toxic to plants (Yaduraju *et al*., 2005). Parthenium roots of decayed plant release soluble sesquiterpene lactones, mainly partenin (Jarvis *et al*., 1985; Pandey *et al*., 1993). These chemicals inhibit the germination and growth of plants including pasture grasses, cereals, vegetables, and other plant species (Evans, 1997; Navie *et al.,* 1996). Parthenium has been causing a total habitat change in native Australian grasslands, open wood lands, and river banks (McFadyen, 1992; Chippendale and Panetta, 1994). Kohli *et al*. (2004) reported that three exotic weeds including parthenium adversely affect the structural composition and dynamics of the diversity of the native flora in India.

The Eastern and Southern African region is one of the richest centers of biodiversity. Its rich fauna and flora is attributed to varied climatic condition and geography. The mountains and rift valleys possess many of the countries as a store house of plant diversity. However, parthenium is a declared an invader in South Africa and has spread in the north eastern part of the country (Strathie *et al*., 2005), where it is threatening the agriculture and the entire biodiversity.

Ethiopia is also one of the primary centers of the origin of many of the world’s cultivated crops such as wheat, barley, teff, coffee, okra, sorghum, millets, chickpea, lentils and other plants now widely growing in the other parts of world. However, parthenium is now listed as one of the fittest invasive species in the country (Medehin, 1992).

2.6.3. Soil seed bank flora

Soil seed bank is defined as the reservoir of viable seeds or vegetative propagules that are present in the soil and able to recompose natural vegetation (Sagar and Mortimer, 1976). The presence of seed bank in the soil allows a plant species to withstand harsh conditions over many years to maximize its chance for survival and created benefits for the population (Hyatt, 1999). The seed production of the standing vegetation influences the composition and size of the seed bank (Coffin and Lavenroth, 1989). Hence, seed banks are fundamental to the ecology of communities and to the recruitment of species, especially those that mostly or totally have non-vegetative means of reproduction. In rangelands, high grazing pressure usually leads to a decline in the density of perennial grasses and increases the density of weeds and annual species in the vegetation (O'Connor and Pickett, 1992).

The richness and diversity of the seed bank of grassland community was low when the dense infestation of parthenium was present (Navie *et a*l., 2004). Hence, the prolonged presence of parthenium may have substantially reduced the diversity of the species in seed bank thereby reducing the ability of some of the native species to regenerate in the future. The domination of parthenium in the seed bank suggests that the weed is having a substantial negative impact on the ecology of the plant community (Navie *et al.*, 2004).

2.6.4. Human health

Parthenium weed is also known to have caused human health problem like asthma, bronchitis, dermatitis, and hay fever (Srirama *et al.,* 1991; Kololgi et *al*., 1997). Studies have shown also that those who came into contact with parthenium weed can develop allergic eczematous contact dermatitis. It also causes mental depression (Oudhia and Tripathi, 1988). The clinical progression of parthenium dermatitis indicated that the severity of a reaction might worsen over time and thus may lead to chronic actinic dermatitis (Sharma *et al.,* 2005). The mild dermatitis can be treated with topical corticosteroids. However, moderate to sever dermatitis particularly airborne contact dermatitis require systematic corticosteroids and other immuno-suppressive drugs (Verma *et al*., 2001). Another widespread allergic reaction of parthenium is allergic rhinitis, or hay fever. This is caused by the presence of its pollen grains in the air (Rao *et al.*, 1985). For instance, Mangla *et al.* (1981) have reported that in areas that were infested with the weed, almost 44 % of the pollen load in the atmosphere during the months of June to September was derived from parthenium. The inhalation of the pollen of the weed can cause allergic trinities and speeds up the development of bronchitis or asthma if the pollen enters the respiratory tracts during mouth breathing (Evans, 1997). The weed of parthenium is the causative agent of many other reactive toxic classes of compounds known as sequiterpene lactones (Towers, 1981).

There has been an epidemic cause of parthenium weed dermatitis in India and several USA (Subba *et al.,* 1976; Towers, 1981). In Australia, many individuals were affected by dermatitis though human population density in the parthenium affected area (McFadyen, 1992). Other reports revealed that respiratory problems usually start with high fever and then gradually progress to asthma and allergic bronchitis after 3-5 years are increasing. McFadyen (1992) indicates that about 15% of individuals regularly exposed to parthenium plant would develop the dermatitis and another 7-15% develop respiratory problem. Affected individuals have no alternative except leaving the area. In Ethiopia, it was reported that individuals who remove parthenium with hands in infested crops suffer from dermal allergy, fever, and asthma (Taye, 2002).

The survey undertaken in Central Queensland demonstrated that individuals sensitized to parthenium were found to have a greater economic outlay to treat the effects of allergy symptoms than none sensitized residents in the same area. Seventy seven percent of individuals sensitive to parthenium weed spent up to $40 per month for medication to help treat their allergy symptoms considerably more than those who are non-sensitized in the study (Goldsworthy, 2005).

2.7. Methods of Control of Parthenium Weed

2.7.1. Use of competitive plants

Competition is one of the several types of interference among species or population. Interference refers to any type of positive and negative interactions between species. Interference may involve physical factors like space, light, moisture, nutrients, and atmosphere. It may also be a type of chemical interaction (Monaco *et al*., 2001). Competition between weeds and crops are generally associated with negative interference. Such a competition involves physical factors that decrease growth in both type of plant due to the absence of an insufficient supply of a necessary growth factor. Competition can be either within the same species (intra), that is when two or more plants of the same species co-exist in time and space or between different species (inter), that is when two or more different species co-exist. For example, allelopathy is a negative type of interference between plants that occurs in the form of chemical influence (Monaco *et al*., 2001).

Under the biological methods, use of plants with allelopathic effect is an important component of biological control of parthenium. Generally, two approaches are followed to control parthenium through bio agents. One is through maintaining naturally occurring biodiversity and the other is through planting selected plant species in target areas (Wahab, 2005). A recent botanical survey across India has shown that species such as *Cassia sericea, Cassia tora, Cassia auriculata, Croton bonplandianum, Amaranthus spinosus, Tephrosia purpurea, Hyptis suaveolens, Sida spinosa, and Mirabilis jalapa* are capable of effectively suppressing parthenium in natural habitats (Wahab, 2005). Another study in India revealed that *Cassia sericea* reduces the accumulation of parthenium by 70% and parthenium population by 52. 5% (Kandasamy and Sankaran 1997). And yet another studies showed that aqueous extracts from *Imperata cylindrical*, *Desmastachya bipinnata*, *Otcantium annulatum*, *and Sorghum halepense* markedly suppressed seedling growth and germination of parthenium (Anjum and Bajwa, 2005).

In USA, there are a large number of plants that compete with parthenuim for resource and space. Studies confirmed that parthenium could be a weak competitor in the face of other native and non native plants such as Johnson grass (*Sorghu*m *halepense*), Congongrass

(*Imperata cylindrica*), barnyardgrass (*Echinochloa crus*galli), *Senna obtusifolia, etc (*Bryson, 2003).

The occurrence of allelopathy has been widely reported in grasses like *Desmostachy*a *bipinnata, Imperata cylindrica, Eragrostis poaioides, Cenchrus ciliaris, Panicum antidotale* (Bajwa *et al*., 1998; Hussain and Abidi, 1991). Many other grasses have also been reported to exhibit allelopathy to preclude the associated species through reducing their regeneration, growth and yield. A survey in Pakistan revealed that in parthenium infested areas there was a marked reduction in the density of parthenium, particularly at *Imperata cylindrical* and Desmostachya *bipinnata* dominated localities, when compared to the infested nearby grasses. The conclusion drawn from the study was that this low density of parthenium could be due to allelopathic nature of these grasses (Anjum and Bajwa, 2005). In similar manner, a greenhouse study in Australia indicated that grasses like Bothriochloa *insculpta*, *Dichanthium aristatum* and *Cenchrus ciliaris* out compete parthenium and that among the legumes that were tested butterfly pea (*Clitoria ternatea*) competed strongly with parthenium(O'Donnel and Adkins, 2005).

2.7.2. Pasture and grazing management

2.7.2.1. Understanding grazing pressure

According to Harper (1977), herbivore animals can decrease growth and fecundity, stimulate compensatory re-growth or in severe cases cause mortality of plants. In similar way, Crawley (1987) and Louda (1989) believed that the herbivore influence the competitive interactions among plants as they reduce the ability of grazed individuals to acquire resources or as they prevent individuals from becoming competitors altogether.

Grazing pressure indicates how heavily a pasture is grazed. Grazing pressure is measured by how much the pasture animals have grazed compared with how much pasture was produced in that season. In set-stocked paddocks, grazing pressure must obviously vary with season. Therefore, when grazing pressure is high and prolonged, the competitiveness of desirable, perennial and productive grass declines. This occurs mainly because grass root systems contract. Normally, grasses with diminishing roots cannot properly use rainfall. When pasture competition decreases, parthenium weed gain the room to colonize and begin seed production, rapidly increasing its soil seed bank. When a grass species fails to set seed, its grass soil seed bank can become very low. Usually, a sensible grazing pressure takes into account the ‘amount of feed’ available rather than the traditional ‘acres per animal’ stocking rate and ensures that animals do not overgraze, desirable grasses are setting seed each season, and pasture use matches seasonal grass production (Mountmorgan, 2006).

2.7.2.2. Monitoring pasture condition

Pasture condition is a statement about grasses that make up a pasture. It is an assessment of the health, yield and ground cover of grasses. The desirable, perennial and productive grasses must dominate and produce seed to maintain good condition. Monitoring assesses the current health of pastures, picks up trends in pasture condition and indicates whether pasture condition is improving or declining. It also allows fine-tuning of grazing management before the competitive edge is lost and before animal production declines. Animal performance slips long after pasture condition starts declining (Mountmorgan, 2006).

The worst infestation of parthenium occurs in areas that have lost native vegetation or where there has been continued disturbance particularly from heavy grazing (McFadyen, 1992). There is a marked inverse relationship between existing plant cover and weed density.

2.7.2.3. Spelling paddocks

Proper grazing in pasture and in rangelands maximizes the growth environment for desirable species by minimizing the growth of yield-reducing weeds (Monaco *et al*., 2001). The rest periods are planned to suit the needs of pasture plants (not just the animals). Spelling encourages to improve the condition of pastures and to re-establish competition. Again, grasses will redevelop root systems, set seed and finally replenish depleted soil seed banks. Grass tussocks can also build up plant reserves, which are essential for vigorous growth. The first six to eight weeks of the growing season provide the most effective spelling opportunity. Grasses draw on stored reserves for new growth, which also needs time to replenish those plant reserves. After this, the grass roots start reactivating and seedlings establishing. However, native grasses establish poorly where there is parthenium. Using herbicide to control parthenium will encourage pasture re-establishment during a rest period (Mountmorgan, 2006).

2.7.2.4. Managing watering points

The distance from watering point has a significant impact on soil nutrients and, consequently on the spatial distribution of herbaceous species and rangeland conditions. As the proximity to the watering point increases, the score of range condition decreases. This implies that watering point contributes to the range deterioration (Gemedo, 2004).

In similar way, heavy grazing can change the composition of plant communities (Landsberg *et al.,* 2002). Lange (1969) argued that the interaction between animals and watering points leads to the development of distinct ecological units called biospheres. As they are usually found at the immediate vicinities of livestock watering points, biospheres are areas of high use. Thus, biospheres are defined as patterns that reflect the concentricity of stocking pressure around water points (Andrew and Longe, 1986). Stock waters are points of constant and high grazing pressure generally characterized by low ground cover, numbers of grass tussocks, and poor pasture competition. One major feature of water points are that they are highly susceptible to parthenium and often become seed dispersal areas. Therefore, to overcome high grazing pressure one needs to establish several stock waters per paddock and rotate stock by alternating the water points in use (Mountmorgan, 2006). Some studies have shown that overgrazing by domestic livestock is major degrading factor as it changes the structure and composition of vegetation. As a result, some species increase in abundance while others decrease (Yates *et al*., 2000).

2.7.2.5. Fencing different land types

Fencing different land type can achieve better grazing management. Pasture composition is determined by land type. Palatability differences within paddocks lead to uneven grazing pressures. Livestock are able to selectively graze a small proportion of the available palatable herbage and ignore the undesirable ones. Studies have suggested that the most palatable species are selected first and closely defoliated. Decline in the quality and productivity of the rangeland occurs, when the grazing pressure is high (Coupland, 1979; Cossins and Upton, 1985). This in turn creates potential weed-susceptible patches.

The vulnerability of areas can be affected by the physical situation of the areas. For example, flooded areas are highly prone to parthenium as grass is often killed by floodwaters which may contain parthenium seed. Therefore, the flooded pastures need adequate rest from grazing to regain their competitive edge. It is also advisable if the cattle are not allowed to graze in the affected areas as doing that would prevent the spread of parthenium seed (Mountmorgan, 2006).

2.7.3. Manual and mechanical control

Hand weeding of parthenium is not advisable as the weed causes contact dermatitis, asthma and fever to human beings. In addition, hand weeding is laborious as it requires frequent work following the emergence pattern of the weed. Hoeing can also be used to get rid of parthenium, but repeated operation is needed as long as there is the seed of the weed in the soil. Manually removing parthenium is the most ideal method. However, it is effective as a method only in limited areas such as residential colonies and agricultural fields. It is not a suitable or economical method to deal with the weed that has infested pasture and wastelands of wider areas. According to Gupta and Sharma (1977), cutting parthenium from base using metal blades or swards is seldom effective because it usually facilitates rapid regeneration of plants from crown buds. The authors suggested that the weed should be uprooted to prevent its regeneration from the remaining lateral shoots and that the uprooting should be done before its flowering period and when the soil is moist enough to facilitate easy removal. Who should do the removal of the weed should also need careful decision. For example, Mahadevappa (1997) and Bahn *et al*. (1997) recommended that only a person insensitive to parthenium allergy should be engaged.

2.7.4. Using herbicides

Using herbicides to control parthenium weed is not environmentally sound and economical feasible for small holder farmers and pastoralists in Ethiopia. However, under special situations spraying pasture with herbicides can be a useful way of eliminating the weed. However, parthenium should be sprayed early before it has set seed. Again, small and isolated infestation should be treated immediately. Usually, herbicide control will involve a knockdown herbicide to kill plants that are present. Residual herbicide, on the other hand, is applied to control future germination. Repeated spraying may be required even within one growing season to prevent future seed productions. However, to overcome excessive infestation one should carry out herbicide treatment in conjunction with pasture management (Mountmorgan, 2006).

A field trial undertaken in Assam, India, indicated that metribuzin 0.2% solution effectively controlled parthenium. The experiment revealed also that the native grass species were not affected and re-growth of parthenium was not observed up to three months (Rajkhawa *et al.*, 2005). One should not, however, that when the amount of metribuzin exceeds 0.2%, it destroys all plants (Sharma, 2003). Glyphosate 1.5kg/ha, paraquat 0.5kg/ha and 2, 4-D 1.0kg/ha were also able to control parthenium. Their side effect was that they killed the other vegetation. This suggested that they are effective and less harmful only when they are sprayed on road side, rail way tracts, industrial sites and dwelling habitats. However, re-growth of parthenium was noticed after 30 days of spray of these herbicides (Singh *et al.*, 2003; Rajkhowa *et al*., 2005). In none crop areas (i.e. along rail ways, road sides and waste land); spraying common salt solution at 15-20% during the active growth stage of the weed will effectively control it (De and Mukhopadhay, 1983; Ramamoorthy *et al.*, 2003). High concentration of common salt brings about plasmolysis which in turn leads to desiccation of the treated parthenium plants. After this, the weed is burned to prevent its regeneration.

An experiment carried out in New Delhi on a fallow land that was heavily and uniformly infested with natural population of parthenium revealed that metribuzin at 1 and 1.5kg/ha resulted in 100% control of flowered as well as non-flowered parthenium plants, followed by 50-60% of glyphosate at 1.0 and 1.5 kg/ha. The experiment suggested again that are the vegetativly active growing plants were comparatively more sensitive to these herbicides than the flowered plants. Fore example, 2, 4-D Ethyl Eatier at 1.0kg/ha resulted in 40% more mortality of non flowered parthenium plant than 2, 4 D Na salts. It also suggested that chlorimuron ethyl was inferior to other herbicide treatments in reducing the growth of parthenium (Sharma, 2003).

On its part, an experiment conducted in Werer Agricultural Research Center in Ethiopia on sorghum fields that were infested naturally by parthenium revealed that both Gesaprium Combi (5.5 L/ha and Primextra TZ 500 FW (5.5 L/ha) were found to be most effective in controlling parthenium for a prolonged period of time after application (Kassahun *et al.*, 1999).

2.8. Impact Assessment of Parthenium Weed on Rangeland

2.8.1. Biodiversity study

2.8.1.1. Species diversity and composition

Plant biodiversity is an important parameter in any rangeland study since high diversity is an indicator of good rangeland condition that is capable of sustaining high forage production. It is also capable of improving the nutritional conditions of land mixed diets and giving greater niche differentiation. What is more, it has the ability to give more mutualistic or sympatric inter-species benefits and increase the ecological stability of vegetation and soil (Heady and Child, 1994).

Species diversity refers to the variety of living organism on the earth and is measured by the total number of species in a given study area, habit or ecosystem (Herlocker, 1999). A study undertaken in Northern Himalayas, India, on a rangeland invaded with three exotic weeds, *Ageratum conyzoides*, *Lantana camara* and *Parthenium hysterophorus***,** revealed that the richness of species was significantly less in the weed infested than in the uninfested areas. The experiment made clear that the richness was nearly 2.2 and 2.6 times more in uninfested areas compared with areas infested by *Ageratum conyzoides* and *Lantana camara*, respectively. Likewise, the evenness index was comparatively more in uninfested areas. This situation indicates that species were evenly distributed. Lesser value in the infested areas, on the other hand, indicated the existence of patchiness in distribution. The Shannon index also indicated great plant diversity in uninfested areas. However, the index was reduced by 36 to 51% in the weed infested areas (Kohli *et al.,* 2004). High values in the index of diversity suggested variability in the type of species and heterogeneity in the community whereas lesser values suggested homogeneity in the community.

Studies carried out on selected weeds on highly infested areas of lower Himalaya to determine the impact of the weed on the structural composition of the vegetation revealed that in the presence of *Ageratum conyzoides*, a total of 12 plant species were encountered. On the other hand, in *Lantana camara* and *Parthenium hysterophorus* infested areas 10 and 14 species were counted in comparison with 25 species in uninfested areas respectively (Kohli *et al.*, 2004). The authors suggested that change in the structure of vegetation in the infested areas might be due to the allelopathic influence of these weeds.

2.8.1.2. Above ground biomass

Above ground biomass indicates plant litter in the estimation of dry matter production in an area (Clarke, 1986). Significant intra and inter-seasonal variations in plant biomass can be expected for most eastern African range production systems, where rainfall is seasonally distributed and often highly variable (Sandford, 1982). Even under similar rainfall conditions, soil type will have an effect on plant biomass production (Abel *et al.*, 1987). Since plant biomass is affected by species composition and diversity, composition should relate to productivity.

A study conducted in Himalayas, India, revealed that the density and biomass of native vegetation were significantly less in weed infested areas. According to the study, the density was reduced by nearly 64.4, 82.25, and 67.6% in areas that were infested with Ageratum, Lantana and Parthenium, respectively. It revealed also that biomass was reduced by nearly 52.7, 72.4, and 59.6% in areas that were infested with Ageratum, Lantana and Parthenium respectively (Kohli *et al.*, 2004).

2.8.2. Soil seed bank

2.8.2.1. The effect of soil depth on seedling the density of soil seed bank flora

Seeds are dispersed both horizontally and vertically in soil profile. Most weed or sorb seeds in no till system are located in the top 5 cm of the soil profile (Shrestha, 2006). Nearly the entire seed bank in no till system is in the upper 10 cm (Jdekker, 1998). The vertical distribution of seed banks depend on factors like as seed movement mechanism is associated with soil disturbance (O’ Connor and Pickett, 1992). The vertical seed movement may result from animal activities. Animal vectors include earth worm and mole. Burying the weed by caching the activities of birds, rodents, and ants etc. by physical actions such as seed burial by falling down in cracks caused by drying-wetting cycle in the soil, by surface soil erosion covering seeds. The other vertical seed movement is a situation when small seeds move down the soil profile of loose texture soils with percolating water.

According to a study conducted in central high lands of Victoria, the average seed density was 430 germinable seeds to a depth of 2 cm. The study revealed a polynomial regression relationship between the density and species richness of seeds in the soil and forest age (0.6-54 years). It suggested also that the richness of species was not significantly different among soil depths (0-2, 2-5, 5-10 and 10-20cm) in the forest stands of 54 years old. However, the study indicated that more seeds germinated from the 5-10 cm depth than from other depths. According to the study, forbs accounted for 73% of the total germinable soil seed banks (Wang, 1997). In similar way, a study conducted in Sevilla in Spain revealed that the density of soil seed banks grew considerably high on the soil surface, but declined monotonically with depth. In seasonally dry habitats that develop deep soil cracks during the dry season, it is possible that some seeds fall down the cracks and rapidly become deeply buried (Espinar *et al.,* 2005).

The vertical distribution of seeds studied in dry Afromontane forests of Ethiopia revealed that higher density of the seed bank was obtained in the first 0-3 cm depth while the density gradually decreased as the depth increased (Demel and Granstrom, 1995). The study suggested again that there was more variation between species than between sites in relation to vertical distribution. The study implied, therefore, that there are differences in seed longevity. In similar manner, a study carried out on Jijiga rangeland indicated that the vertical distribution of seeds in the soil seed bank followed a similar trend for the investigated sample sites. In this study, the highest density was recorded in the upper 0-3 cms of the soil depth and gradually decreased with increase in the depth of the soil (Belaynesh, 2006). Belaynesh (2006) added that there was more variation between species than between sites in relation to vertical distribution and that the seedlings of some species were almost entirely concentrated to the upper 0-3 cm. He pointed out, for example, that parthenium, *Dactyloctenium aegyptium*, and *Eragrostis spp.* were abundant in the upper layer than in the deeper layers. On the other hand, some species had seedlings, which were distributed in all soil layers. Some of these are parthenium *hysterophorus*, *Euphorbia hirta* and *Ocimum basilicum*. Parthenium was found abundantly in all of the three soil depth and in all study sites. This indicates that among all species, it had the highest number of seeds and the widest distribution both vertically and horizontally. This in turn shows that the specie has effective dispersal mechanism into the soil seed bank under the prevailing environmental conditions of the rangeland in the study site.

2.8.2.2. Similarity between soil seed bank flora and aboveground vegetation

A three year study of soil seed bank conducted in Raudhat al-Khafts, Saudi Arabia, which was an area infested with *Rhazya stricta* revealed that low similarity was observed between above ground vegetation and soil seed bank components. A significant seasonal variation was observed among group of species. Generally, seed bank size and species richness were high under the low level of *R.* s*tricta* infestation (Assaeed and Al-Doss, 2002). The authors concluded that most of the desirable species that have the potential to grow in the area have been disappearing. Moreover, the study conducted in coastal barrier island Florida, USA indicated that there was significant difference between vegetation type in terms of similarity between seed bank and above ground flora (Paul and David, 1995).

The species composition of degraded slopes in Southern Wallo, Ethiopia revealed poor correspondence between species composition of the seed bank and those in the standing vegetation (Kebrom and Tesfaye, 2001). Moreover, the study conducted in Jijiga rangeland showed 42 species common to the soil seed banks and the standing vegetation cover of the sample sites. These represented 87.5% species in the soil seed bank and 23.9% of the standing vegetation (Belaynesh, 2006). The author also found Jaccards similarity index in the range of (0.08-0.22), and overall mean of 17% similarity between species in the soil seed bank and standing vegetation. In contrast to the above findings, the study conducted to compare plant species in the soil seed bank and aboveground vegetation in Shinile Zone in eastern Ethiopia in three vegetation types (Grassland, bush grassland and bush land) showed that from the 27 regenerated species of grasses, about 59% were observed in the fields of the rangelands while 41% did not occur on the fields but only in soil seed banks (Amaha, 2006).

2.8.2.3. Spatial and temporal variation in soil seed bank density and species composition

Several studies in desert ecosystem have shown that seed densities were highly variable between years as well as within years. For instance, Kemp (1989) reported that differences between years up to 20 fold in soil seed densities for the Sonoran desert. Nelson and Chew (1977) reported a 10 fold annual change in seed bank under shrubs and 23 fold change in open area at a Majaue desert site. The changes were closely associated with plant cover pattern, rainfall regime (Julio *et al.*, 2002), with the variability of primary production of annual species (Nelson and Chew, 1977), and seed and seedling loss due to predators (Hodgkinson *et al*., 1980; Rice, 1989).

Seasonal variability in the abundance of soil stored seeds of some of the species (*e.g. Conyza bonariensis*) indicated the transit nature of the seeds in the soil. It seems that the majority of the seeds produced by these species in summer do not survive until the following spring due to the fact that it is either short lived in the soil and/ or selectively removed by predators (Coffin and Lauenrath, 1989).

Germinable soil seed bank study was conducted in Central Queensland, Australia at two sites (Clermont and Moolayember creek) with different infestation level of parthenium (moderate and high) on four separate occasions during two years period *i.e.* March (early autumn) and October (early spring). The result revealed that at Clermont site (having moderate infestation) the soil seed bank varied between 3,284 and 5,094 seeds/m^2. It was dominated by parthenium (47-73%) and poaceae (15-35%) propagules while few annual forbs were occasionally common (Navie *et al*., 2004). The size of the grass seed bank was relatively stable over time (780-1,181 seeds/m^2), the only significant change being an increase between the march (autumn) and October (spring) 1996 samples.

The germinable seed bank at the Moolayember creek (high infested site) was several times larger (20,599-44,639 seeds/m^2) than the seed bank at Clermont site (Navie *et al*., 2004). Once again parthenium was the most abundant species present and accounted for high proportion (65-87%) of the seed bank at the Moolayember creek site, the seed bank of parthenium at the Moolayember creek site decreased between March 1996 and October 1996. However, the accumulation of seeds prior to this time was small. The grasses were common (641-2,345 seeds/m^2), but represented a much lower proportion (1.8-5.4%) of the total seed bank than at the Clermont site (Navie *et al*., 2004).

Soil seed bank was collected at the same two sites in April 2000 and February 2001 to investigate any change that may have occurred in the intervening period. The germinable soil seed bank at the Clermont site was found to be 5,508 seeds/m^2 in April 2000 and 3,102 seeds/m^2 in February 2001. As in previous sampling at this site (Navie *et al.*, 1997; Navie *et al*., 2004), the seed bank was mostly dominated by parthenium (35-51%) and grasses propagules 26-56%. These two contributed 80-91% of the entire seed bank, but the proportion of grass propagules in the seed bank seemed to be higher than during the previous study period (Navie and Tamado, 2002).

The germinable soil seed bank at Moolayember creek site were 24,728 seeds/m^2 in April 2000 and only 13,140 seeds/m^2 during the February 2001 (Navie and Tamado, 2002). This latest value is much lower than any of those recorded on previous sampling occasions, especially in the slightly deep soil sampling in the latter occasions. Once again, parthenium weed was the most abundant species present and accounted for 26-41% of the total seed bank. The seed bank of parthenium weed was determined to be only 6,332 seeds/m^2 in April 2000 and 5,433 seeds/m^2 in February 2001 this equates to less than a third of the lowest value recorded during the original study, when it should be slightly high due to differences in sampling techniques. In addition, the authors suggested the reason why reduction occurred in the parthenium weed seed bank at the Moolayember creek site most probably due to an increase in the activity of biological control agents at the site over the last 5 years.

2.8.2.4. Depletion of soil seed bank

Some weed species may present in high intensity of emergence in the no till planting than in the conventional till. Carmona (1992) stated that no till and superficial tillage tends to reduce the amount of seeds at the soil surface shed by plants since there is induction in the germination or loss of viability. The presence of seeds at the superficial layer of the soil and frequent cultivation are factors that reduce the seed bank rapidly. This situation can facilitate seed predation, exposure of seeds to variation in temperature and humidity and breaking dormancy. However, the speed of the depletion of soil seed bank depends on the seed production of the species (Yenish *et al.,* 1992).

Several factors may cause depletion of soil seed bank. These may be preyed upon insects or other vertebrates, die due to physiological reason or due to allelopathic chemicals and could be attacked by pathogens, or get buried deep into the soil profile and cause them to go into dormancy and physical damage by agricultural implements (Shrestha, 2006). Drought and soil compaction influence the seed bank since they determine the turnover of the seed bank in arid and semiarid rangeland condition (Laura and Bronda, 2000; Snyman, 2004).

Seed predation is believed to influence primarily the dynamics of plant population that are expanding (Harper, 1977). Louda (1989) suggested that there are two group of species defined in the literature with predictable periods of expansion and significant predator impacts. The first seed predation appears to change the density and relative abundance of dominant species that have annual life history (example, grasses of annual grassland, and some agricultural crops) or that have high dependence on seed recruitment for population maintenance and recovery after disturbance. Second, seed predation influences recruitment and the occurrence and distribution of moderately large seeded species with fugitive plants that can ‘escape’ through dispersal or other means and establish elsewhere life histories (Louda 1989). Generally, the risk of predator’s impact increases as the canopy mature because a longer canopy provides greater cover.

Microorganism affects seed fate by causing decay. The annual weed species, giant ragweed (*Ambrosia trifida* L.) decayed, damaged, and germinated seed depletion is 48%, 42%, and 10%, respectively. In summer, decayed and damaged seed are 51% and 32% (Williams and

Chee-Sanford, 2006). Moreover, if animals are allowed to continuously graze a pasture, it will not have a chance to set seed for a next year as the soil seed bank will become depleted (Synman, 2004).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The Somali Regional State (SRS) has been divided into nine sub regional administrative zones. These are Jijiga, Shinille, Fique, Degahbour, Warder, Quo-raghie, Gode, Afder and Liben administrative zone. The Jijiga Zone is located in the northern part of the SRS. It is bordered in the east with the Republic of Somalia, in the west with the Oromia Regional State and Fique Zone of the SRS, and in the South with Degahbour. Generally, the zone is found at about 750 kms south east of Addis Ababa. It covers 40,861km^2, of which the rangeland extends over 36,629 km^2 (World Bank, 2001).

The Jijiga Zone is divided into six administrative districts. These are Jijiga, Kebribeyah, Harishin, Babile, Awebare, and Gursum (Fig 1).

3.1.2. Topography and soil

The landscape of the SRS represents a complex of geological structure (Mohr, 1971). The Jijiga Zone has a landscape whose physical property ranges from flat to gentle slope and hilly and mountainous topography. About 52.6% of the landscape is flat to gentle slope, 31% is hilly and about 7% of it is steep slope (IPS, 2002).

According to the Somali Regional State Strategy (SRSS, 1997), the soil of the region is dominated by weakly developed soil horizon full of stony peterocalcic and peterogypsic phases. The dominant soil types in the region are Yermosols, Xerosols, Regosols, and Solonchaks. Because of the arid climatic, most of the soils in this region have high saline content. As a result, the soils have low agricultural value (SRSS, 1997).

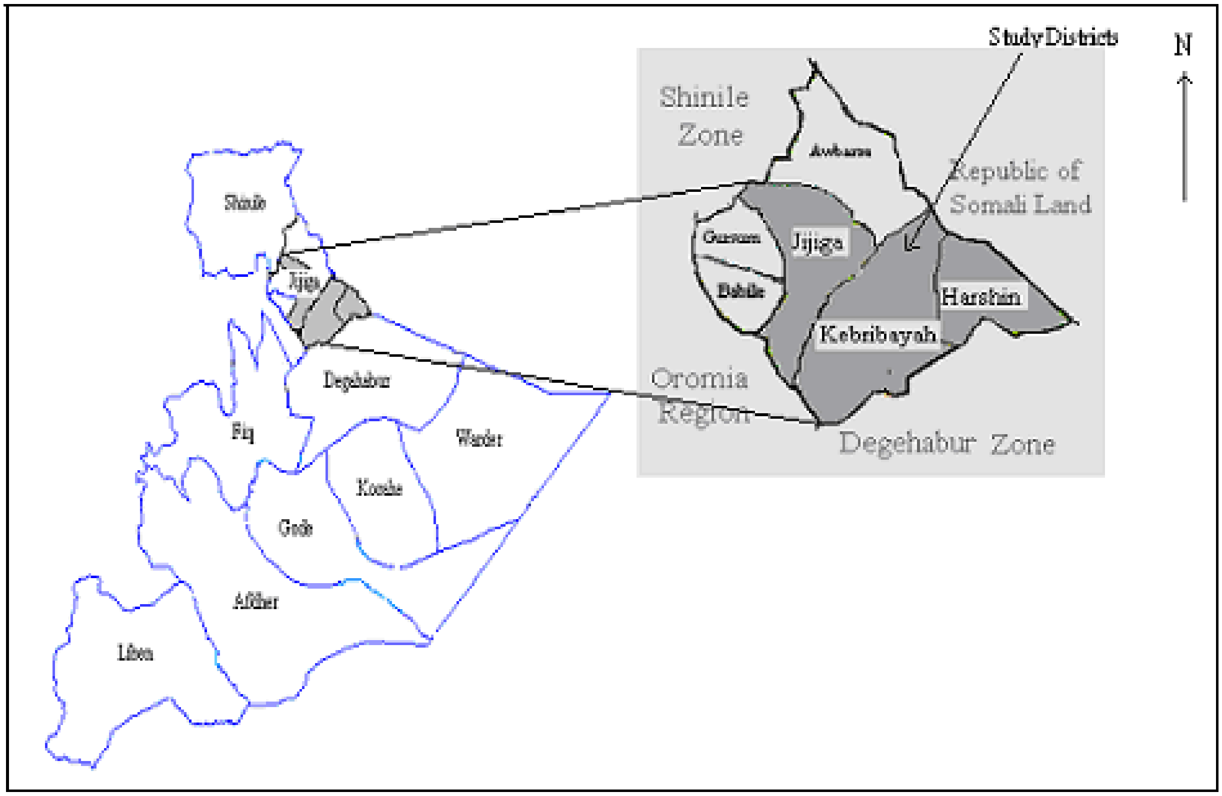

Figure 1. Map of the study area

3.1.3. Climate

The Somali Regional State has a bimodal pattern of rainfall regime. Hence, there are two cropping seasons *Gu* and *Deyr*. The relatively long rainy season *Gu* (March to April) and short rainy season *Deyr* (October to November) characterize the lowland parts of the Ogaden basin while the highland parts of the region, mainly Jijiga and its surrounding have *Gu* and *Kiremt* (July to September) as their cropping seasons (IPS, 2002).

According to the National Meteorological Service Agency (NMSA, 2000), the mean annual rainfall which is 660mm is bimodal. In the zone, there is generally low, unreliable and uneven distribution of rainfall. The temperature in the cattle rearing areas of the Jijiga Zone is relatively high through out the year. The mean minimum and the mean maximum temperature in this area are 20^0C and 350C, respectively.

3.1.4. Vegetation

The vegetation of the rangelands in the study area is characterized by the acacia wooded grassland (Friis, 1992). The open wooded land is confined to Jijiga, Kebribeyah and Harishin. The tree and shrub species that are found in the Jijiga Zone include *Acacia etbaica, A. nilotica, A. seyal. A. senegal, A. Bussei, Balanites glabra,* and *Commiphora Africana.* The grassland is dominated by *Chrysopogon aucheri, Eragrostis spp* and *Panicum coloratum* (SSRS, 1997; Ahmed, 2003; Belaynesh, 2006).

3.1.5. Water resource

In the Somali Regional State, the main sources of water for livestock and the people are ephemeral ponds, perennial and seasonal rivers, seasonal streams, shallow wells and cistern. Ponds and seasonal streams are mostly used during rainy seasons while wells and cistern are used during the dry period. Most of the sources are empty at the time of the extended dry periods or during recurrent droughts. As a result, the pastoralists are often forced to migrate along with their animals around perennial rivers or sometimes to cross boarders to find solutions in the neighboring countries (IPS, 2002). *Birka, which is* the main source of water for livestock and human in the study districts, accounts for (52%), ponds (39%), natural gorges (3.2%) and finally wells (5.8%) (Ahmed, 2003; Belaynesh, 2006). However, since the availability of water has been gradually declining, the people as well as their livestock have to depend on rain water.

3.1.6. Human and livestock population and farming system

The Jijiga Zone has a total population of about 213, 200 (CSA, 2003). Here, livestock is a very important resource for the well being of the Somali society. The Somalis rear cattle, sheep, goat, equines and camels. Reports have indicated that each household in the region owns on average 7.7 cattle, 21.3 goats, 16.3 sheep and 9 camel, and 3 cattle, 62 goats, 82 sheep and 16 camels, respectively (IPS, 2002).

The people of the region are engaged in traditional rural subsistence activities, mainly rearing livestock. Thos of them who are engaged in modern economic sectors constitute less than 10% of the total population. The land use system in the zone is predominantly pastoral and agro-pastoral. The livestock in the region entirely depend on natural vegetation. The people are generally nomadic and use much of their land for natural fodder for livestock production. Those of them who are agro-pastoralists hold small farms for subsistence (IPS, 2002).

3.2. Survey of the pastoralist' perception of the impact of Parthenium

The study was conducted in the rangeland located between the Jijiga, Kebribeyah and Harshin districts of the Jijiga zone. The districts were selected based on the aggressive invasiveness of the parthenium weed and the rangeland potential of the area. A single visit informal survey was conducted before the commencement of the actual research work. A single visit formal survey method (ILCA, 1990) was used to gather primary and secondary data on the impact of parthenium on the composition and diversity plant species and on livestock health and their products. The survey was also meant to understand the impact of the weed on human health and to trace the dispersal agents, cause of aggressiveness and the suitable seasons for the distribution of this weed in the rangeland.

Purposive sampling procedure was followed to identify and select the pastoralists. A total of 40 pastoralists two per site with an average age of 44 years (ranging 30-84) were selected based on their awareness about the aggressive colonization of the rangeland and its impact on their livestock and on themselves. A structured questionnaire was prepared to collect adequate information regarding the overall impact of the parthenium (Appendix 24). A pretest of the prepared questionnaire was practiced before the start of the actual survey to achieve effective communication of the needed information by the selected pastoralists. Furthermore, observations were made and group discussions were held with development agents, veterinary health officers, community leaders and district officials.

3.3. Sampling of the Herbaceous Vegetation Cover

The field study was undertaken between July and September, 2006 when the rangeland vegetation was to a larger extent at full flowering and vigorous growth. Road Transect survey method (Greig-Smith, 1983; Wittenberg *et al*., 2004) was employed in the rangeland located between the districts of Jijiga, Kebribeyah and Harshin. Two inverted **'M'** patterned 100 m long transects, 1 km apart from each other, and each containing five evenly spaced sample quadrats were established in order to asses the impact of parthenium on aboveground herbaceous vegetation cover and on the soil seed bank flora in the study area. A total of 200 quadrats in 20 sample sites each measuring 1m x 1m ($1m^2$) sample quadrat were laid. The samples were taken at the interval of 5 km. The quadrats were then delineated using polyethylene strings around four wooden pegs inserted in to the soil at four corners. In addition, the aspect and altitude of each sample site were measured and recorded using Silva Compass and altimeter, respectively. GPS readings (i.e. to record altitude, latitude and longitude) for each sample site was taken using GPS channel 12 reader (See Appendix Table 1) in order to locate the global position of each quadrat as well as the study site. Ten sample quadrats were taken from each sample site, which here after are coded by the numbers and the local PA names.

The majority of the plant species collected from the quadrats were identified in the field. For species that were difficult to identify in the field, Voucher specimen was collected, pressed and dried properly using plant presses and transported to the Haramaya University Herbarium for identification and proper naming. The nomenclature of the plant species followed the Flora of Ethiopia (Hedberg and Edwards, 1989, 1995) and the Flora of Tropical East Africa (Cufodontis, 1953-1972).

The cover abundance (the proportion of individual species) of the plant species encountered in each of the quadrats ($1m^2$) was recorded using the procedure documented in Wittenberg *et al*. (2004) in order to investigate the abundance and composition of the herbaceous vegetation as impacted by parthenium. This method has been found to be appropriate for areas in which an invasion is spatially patchy (Greig-Smith, 1983; Wittenberg *et al*., 2004). The method involves a total estimate based on abundance and cover of the species. The total estimate scale (abundance plus coverage) is summarized in the following ways. A plant species covers a small area given the point (+), cover small (1), less or equal to 5% area coverage (2), 6-25% area coverage (3), 26-50% area coverage (4), 51-75% area coverage (5) and 76-100% area coverage (6). A detailed description of the method has been presented in (See Appendix Table 2). Following the methods suggested by Chellamuthu *et al*.(2005), the sample sites were categorized into five parthenium infestation levels: None, very low (< 10%), low (11-25%), moderate (26-50%) and high (> 50%) of the total percent area coverage of parthenium weed.

The aboveground biomass of the herbaceous species was harvested from a total of ten sample quadrats per site, each measuring 1m x 1m ($1m^2$). Then the sample herbaceous biomass were dried for 48 hours at 70^0C and weighed for oven dry weight determination.

3.4. Soil Seed Bank (SSB) Study

3.4.1. Soil sampling

The study was undertaken to investigate the depth of the distribution of the density of seeds, and to compare with the standing herbaceous vegetation. To this effect, the soil samples were collected between August and September, 2006. The sampling period was considered to represent the end of the growing season (i.e. after seed production events) for most of the species encountered in the rangelands of the study districts. In each site, 3 quadrats measuring 1m x 1m ($1m^2$) were selected. The soil samples were taken at the center and corner of sample plot in three depth (0-3, 3-6 and 6-9cm) using a knife and a spoon. The rationale for taking the soil samples at the three layers was to examine if there was any variation in depth distribution of seeds within the same sample quadrats in the soil. The soil samples from identical layers were mixed in plastic bags to form a composite sample. The intention was to capture the spatial heterogeneity of the seed distribution in the soil. Latter on, the composite samples were transported to the Haramaya University where the germination trial was conducted in the greenhouse.

3.4.2. Incubation of Soil Samples

The seedling emergence method was used to asses the soil seed bank (Simpson, 1989). In the Haramaya University greenhouse, the soil samples were spread into the thickness of about ten centimeters on a cotton cloth placed on sterile sand on plastic pots of 24 cms diameter and 11.5 heights and kept continuously moist to field capacity. The emerging seedling that was readily identifiable were counted, recorded, and discarded every week. Species that were difficult to identify at seedling stage were counted, labeled, transplanted and were grown separately until they could be identified with certainty. Each month, the soil samples were stirred to stimulate seed germination. The experiment was followed over six months with the assumption that there were a number of species with long term dormancy that might germinate later.

3.5. Competition Experiment

3.5.1. Test species

This experiment was conducted at Haramaya University greenhouse in order to evaluate the ability of grass species that may have the potential to compete or displace parthenium. Five grass species *(Bothriochloa insculpta, Cenchrus ciliaris, Chloris gayana, Cynodon dactylon* and *Panicum coloratum)* were selected for this purpose. The seed of the test species were obtained from International Livestock Research Institute (ILRI), Woror, Holeta and Debere-Zite Agricultural Research Centers. On the other hand, the seed of parthenium was collected from high infested plots in the study area.

The test plant species were selected due to their wide range of adaptability in different soil types and their ability to tolerate prolonged drought. Furthermore, the grass species are known to grow and have wider distribution in the rangeland of Jijiga Zone (Ahmed, 2003; Belaynesh, 2006).

3.5.2. Experimental procedure

The soil samples were collected from the study area where parthenium infestation appears to be high and were sterilized using autoclave at 121^{o}C for 30 minutes for two days in order to destroy the former seed that may present in soil seed bank.

Completely randomized design (CRD) in replacement series arrangement of experimental units was used (Rejmanek *et al.*, 1989). Grass species and parthenium weed were sown in planting trays and placed in greenhouse until sufficient germination has occurred. The seedlings were then transplanted in five planting proportion of grass: parthenim (*i.e.* 100:0, 75:25, 50:50, 25:75 and 0:100) in four replication in plastic trays having 37 cm length, and 5 cm width. The plants were grown in plastic trays at a density of 16 plants/ tray or 864 plants /m^2, higher than the natural density in the field in order to shorten the period of time prior to competitive interaction occurring.

The planting trays were randomly placed in greenhouse at an average temperature of 26.5^{0}C in order to stimulate the temperature of the natural environment (Jijiga rangeland) and were kept moist for the duration of the experiment. The experiment was conducted for 60 days and then the aboveground part of plants was harvested. Then, the dry matter yield was obtained by drying the plant material for 48 hours at 70^{0}C and weighed.

3.6. Statistical Analysis

The diversity of the species in the vegetation data and the soil seed bank flora between the sample sites in the rangeland of the study area were compared using Shannon Diversity Index. This index accounts both for the abundance and the evenness of the species in natural environment as shown by the equation below (Shannon, 1963) and is used to assess the impact of parthenium on the diversity of herbaceous plant species. The higher value of index of diversity indicates the variability in the type of species and heterogeneity in the community where as the lesser values point to the homogeneity in the community.

$$\mathbf{H} = -\sum_{i=1}^{s} pi \ \ln \left(pi \right)$$

Where:

H= Shannon diversity index

pi= the importance value of the ith species

s= total number of species in the sample quadrat

The evenness of species was calculated as suggested by (Hill, 1973):

$$E = \frac{\exp(H)}{\ln s} \quad \text{Or} \quad \sum_{i=1}^{s} pi \ln pi \Big/ \ln s$$

This index explains how equally abundant each species would be in the plant community and high evenness is a sign of ecosystem health. This is because it does not have a single species dominating the ecosystem. The evenness or equitability assumes a value 0 and 1 with 1 being complete evenness and 0 a single species dominating the area.

The similarity of the soil seed bank flora and the standing vegetation (herbaceous vegetation layer) among the sample sites in the rangeland of the study area was compared using Jaccard's coefficient of similarity (JCS**)** as shown by the equation below (Krebs, 1985). Compared with other similarity indices, this coefficient has been recognized robust and un-biased even with small sample size (Goodwell, 1973; Ludwing and Reyonlds, 1988).

$$\text{JCS} = \frac{a}{a + b + c}$$

Where:

JCS= Jaccard's coefficient of similarity

a= species common to quadrat 1 and 2

b= species present in quadrant 1 but absent in quadrat 2

c= species present in quadrat 2 but absent in 1

The coefficient has a value from 0 to 1, where 1 reveals complete similarity and 0 complete dissimilarity.

The oven dry weight biomass results of the competition experiment was analyzed with model crowding coefficient (DeWit, 1960) and by aggressivity index (AI) following McGilchrist (1965) and McGichrist and Trenbath (1971).

According to DeWit, the crowding coefficient of grass-parthenium mixture of 50:50 was calculated as:

$$RCCPG = \frac{DMYPG}{DMYPP - DMYPG}$$

$$RCCGP = \frac{DMYGP}{DMYGG - DMYGP}$$

For the mixture difference from 50:50 was calculated as:

$$RCCPG = \frac{DMYPG(Zgp)}{(DMYPP - DMYPG)Zpg}$$

$$RCCGP = \frac{DMYGP(Zpg)}{(DMYGG - DMYGP)Zgp}$$

Where:

DMYPG = Dry Matter Yield of Parthenium mixed with any Grass

DMYGP = Dry Matter Yield of any Grass mixed with Parthenium

RCCPG = Relative Crowding Coefficient Parthenium mixed with any Grass

RCCGP = Relative Crowding Coefficient any Grass mixed with Parthenium

Zpg = the sowing proportion of parthenium with any grass

Zgp = the sowing proportion of any grass with parthenium

Plants with the highest coefficient are the dominant ones whereas the lesser are the dominated.

According to McGilchrist (1965) and McGichrist and Trenbath (1971), the aggressivity index (AI) of grass-parthenium mixture was calculated as:

$$\text{AIGP} = \left(\frac{DMYGP}{DMYGGxZGP}\right) - \left(\frac{DMYPG}{DMYPPxZPG}\right)$$

$$\text{AIPG} = \left(\frac{DMYPG}{DMYPPxZPG}\right) - \left(\frac{DMYGP}{DMYGGxZGP}\right)$$

Where:

AIGP = Aggressivity Index of any Grass mixed with Parthenium

AIPG = Aggressivity Index of Parthenium mixed with any Grass

DMYGP = Dry Matter Yield of any Grass mixed with Parthenium

DMYPG = Dry Matter Yield Parthenium mixed with any Grass

ZGP = the sowing proportion of any Grass with Parthenium

ZPG = the sowing proportion of parthenium mixed with any Grass

If the DM yield of species G and P is calculated on per unit area basis, species G and P have the same competitive ability if the value of aggressively index is zero. An aggressivity index that is greater than zero indicates the greater competitive ability species G over P or vise versa. The numerical value of the aggressivity index in both species is the same, but the sign of dominance is positive while the dominated species is negative; the greater the numerical value the higher the differences in competitive ability.

The survey made on the overall impact of parthenium data were summarized in SPSS (1996) for descriptive statistics *i.e.* percentage and frequency. Version 8 of SAS (2000) was used for the rangeland assessment and soil seed bank study that were obtained from the field and greenhouse experiment. Prior to statistical analysis the soil seed bank data were transformed to Log (x +1) because of large variances. A total of 20 sampling site each having 10 and 3 quadrats were used for vegetation and soil seed bank data analysis, respectively.

One way analysis of variance (ANOVA) was used for variables of vegetation (species composition aboveground biomass) in each site and in SSB seedling density (number of germinated seeds per sample) of the SSB among sample sites and between soil depths were compared using one and two way analysis of variance (ANOVA).

Least significant different (LSD) test with $p < 0.05$ was employed to investigate if a significant difference occurs for each of the vegetation and soil seed banks variables under consideration.

4. RESULTS AND DISCUSSION

4.1. Pastoralist Perception on Effects of Parthenium

4.1.1. Species composition and diversity

The majority of the respondents in the study area revealed that the proportion of grasses and legumes has decreased and is being replaced by invasive weeds whose population was observed with increase in time and space (Table 1). Eighty percent of the respondents pointed out that weed infestations has become severe in addition to the harsh and prolonged drought season in the study districts. According to the respondents, most of the valuable species in the areas which were essential for grazing animals have already disappeared due to the continued increase of the invasive weeds and livestock selection pressure.

The pastoralists mentioned some of the preferred grass species which have shown signs of serious decline in terms of biomass production and area coverage. These include: *Chrysopogon aucheri, Cynodon dactylon, Dactyloctenium aegyptium, Aristida adscensionis, Panicum coloratum, Tragus berteronianus, Cenchrus ciliaris,* and *Bothriochloa* insculpta. In some areas of the study districts these species have totally disappeared and as a consequence the pasture production has become inadequate. They have the fear that the problem might lead utilize parthenium and other weeds as feed for their livestock. Similarly, Ahmed (2003) and Belaynesh (2006) indicated that due to this new invader in the area, most of the valuable species are disappearing as a consequence there was forage scarcity. Similar problem was reported from the pastoral areas of central Queensland where parthenium was the dominant species under certain conditions by producing negative effects on the growth and performance of the associated beneficial forage plant species. The monoculture of the none-nutritious vegetation matter might make it impossible to sustain grazing animals. As a consequence, a dramatic drop in the productivity of the pasture could reach below the carrying capacity of the rangeland (Chippendale and Panetta, 1994).

The grazing areas in the study area have been highly infested with weeds. Table 1 shows that the interviewed pastoralists ranked *Parthenum hysterophorus* at the top followed by *Xanthium* *spinosum* and *Ocimum basilicum* in terms of area coverage. According to them, parthenium has covered large area resulting in reduced population of palatable plant species that would be available as feed for animals. Furthermore, pastoralists ranked the weedy species in terms of seriousness of biomass production loss that have suffered the impacts of weed. According to Table 1, 62.5% of the respondents considered parthenium and the remaining revealed Xanthium *spinosum* and *Ocimum basilicum*, respectively as factors that affect the herbaceous biomass production in the study sites. However, 35% of the respondents stated that *X. spinosum to be* more serious problem during dry season in fodder scarcity. The pastoralists revealed that due to its spiny morphology all grazing animals including camel may not tend to use the species for consumption. Furthermore, this spiny weed makes difficult stock handling and stock movement.

Table 1. Causes of pasture inadequacy, dominant weed and very dangerous weed in grazing area of the study districts

	Frequency(N=40)	Percent
Causes		
Weeds	32	80
Drought	7	17.5
Increased livestock population	1	2.5
Dominant weed in terms of area coverage		
Parthenium hysterophorus	34	85
Xanthium spinosum	4	10
Ocimum basilicum	2	5
Very dangerous weed		
Parthenium hysterophorus	25	62.5
Xanthium spinosum	14	35
Ocimum basilicum	1	2.5

Key: N= Number of respondents

The various aspects of parthenium weed seed ecology, including the abundance and the persistence of its seed bank and the rapid emergency of its seedlings, were considered the most dominant features that contribute to its aggressiveness in semi-arid rangeland plant communities and to its allelopathic effect on the other plants on their growth and development

(Navie *et al*., 2004). Allelopathy is the direct or indirect injurious effect of one plant upon the other through the exudation of phototoxic chemicals (Swaminathan *et al*., 1990). In many studies, water soluble phenolics and sesquiterpene lactose, mainly parthenin, have been found in the roots, stems, leaves, inflorescences, achenes and pollen of parthenium (Kanchana and Jayachandra, 1979, 1980; Jarvis *et al*., 1985; Patil and Hegde, 1988; Pandey *et al.,* 1993). These chemicals have been observed to exhibit an inhibitory effect both on the germination and growth of wide variety of plants including pasture grasses, cereals, vegetables, other weeds and even tree species (Srivastava *et al*., 1985; Mersie and Singh, 1987, 1988; Swaminathan *et a*l., 1990). Research has shown that the growth and nodulation of legumes were also inhibited by the weed (Kanchan and Jayachandra, 1981; Dayama, 1986). Kanchana and Jayachandra (1980) reported that parthenuim weed pollen can have an adverse effect on the chlorophyll content of the leaves, into which it comes in contact, and can interfere with the pollination and fruit set of near by species.

In the study area, the herbaceous cover has generally declined besides disappearance of the most important palatable species. Extensive area of land in the study area have been infested and covered by parthenium. Therefore, the areas might require appropriate grazing management interventions. For instance, the weed reduced stock number since there appeared to be a definite relationship between the invasion of parthenium and the vigor of pasture. It is apparent that pasture management is fundamental to the control of weed. Pasture should not be grazed heavily as this might increase the likelihood of invasion by parthenium, and the severity of existing infestation (Parsons and Cuthbertson, 1992). Thus, parthenium infested pasture should be rehabilitated by over-sowing pasture species to encourage restoration of pasture. Once cover has been established stocking rate has to be carefully adjusted according to the season and rainfall pattern should maintain grass dominance.

4.1.2. Plant competition

The majority of the respondents in the study districts described parthenium to be poor competitor and might not establish itself in the presence of other plant species with fast growth and adequate crown cover characteristics. Among the herbaceous candidate species the respondents declared that *Chrysopogon aucheri* and *Cynodon dactylon* were observed to out-compete the growth of parthenium. In many places there were adequate ground cover of grasses, particularly in areas that are dominated by *Chrysopogon aucheri* and *Cynodon dactylon* parthenium was lacking or exhibited retarded growth.

The survey conducted in India has shown that species like *Cassia sericea*, *Cassia tora, Cassia auriculata, Croton bonplandianum, Amaranthus spinosus, Tephrosia purpurea, Hyptis suaveolens, Sida spinosa* and *Mirabilis jalapa* suppressed parthenium in natural habitats (Wahab, 2005). Also in USA, there could be a large number of plants that compete with parthenuim for resource and space. Parthenium was found to be a weak competitor compared to other native and none native plants *(*Bryson, 2003).

4.1.3. Agents of weed dispersal and suitable season for parthenium infestation

As Table 2 below shows, the analysis of the survey data on the dissemination of this obnoxious weed demonstrated that most of the respondents (63.2%) reported that flood is the main seed dispersal agent followed by animal dung, wind and animal movement. Each agent might contribute to its wide range dispersal. Parthenium weed benefits from the frequency of the extreme climate events such as flooding. Such a climate facilitates seed dispersal and provides bare ground which favors germination and seedling establishment (Navie *et al*., 2005). It was also documented that seeds of many weed species could pass through the digestive tract of cattle, sheep, horse, pigs, and goats to be deposited in viable state in the feces (Harmon and Keim, 1934 cited by Monaco *et al.*, 2001).

The pastoralists in the study districts explained that parthenium has been observed to germinate at the beginning of the rainy season *i.e. Gu* (March to April) and *Kirem*t (July to September) and to set seeds at the on set of the dry season. They further elaborated that seed the germination of this weed could happen at any time of the year as long as adequate soil moisture and rainfall might be available. It has been reported elsewhere that parthenium would grow and reproduce at any time of the year and four or five successive generations and seedlings can emerge at the same site during a good growing season (Prasanta *et al.*, 2005).

Several studies on partheinum have revealed that the weed could spread unintentionally through flooding (Auld *et al.*, 1983; Navie *et al.*, 2005; Mountmorgan, 2006), animal dung (Abraham and Girija, 2005), wind (Navie *et al*., 1996; Mountmorgan, 2006) and animal movement (Gupta and Sharma, 1977; Mountmorgan, 2006). As a result it could be suggested that land managers need to be particularly vigilant in monitoring areas close to parthenium infestation and be proactive in adoptions of best management techniques to minimize incursion of parthenium in to clean areas. It is much cheaper and more efficient to cure small infestation than to wait until parthenium has caused a huge impact on the indigenous vegetation cover.

4.1.4. Infestation level of parthenium in different land use types

Table 2 depicts that in the study districts, parthenium has infested rangelands, road sides, home yards, footpaths, crop fields and watering points. Seventy three point seven percent of the interviewed pastoralists ranked the infestation level of parthenium to be highest in the grazing areas followed by crop fields, road sides, and home yards and near watering points. According to them, the grazing lands in the study districts experience frequent disturbance by livestock. They speculated that as a result of the infestation the area has already been largely overgrazed and competitive pasture plants have already diminished due to parthenium dominance. Furthermore, animals that happened to graze the parthenium infested area and then moved to none infested sites carry the seeds in their hooves and drop the dung which contains the parthenium seed. Within few days, the parthenium weed starts to grow in clean areas when it gets moisture. In Australia, McFadyen (1992) revealed that the worst infestation of parthenium occurs in areas that have been cleared of native vegetation or where there has been continued disturbance as a result mainly of heavy grazing.

Parthenium has been observed to grow in a wide variety of habitats through out the world including the vast area of waste lands and pastures (Pandey and Dubey, 1988), cleared lands (Holman, 1981), all types of crops orchards (Pandey and Dubey, 1991), forest nurseries, public lawns, open spaces in town, the sides of the rail way tracks (Jayacchandra, 1971), road sides, new constriction sites and along streams and rivers (Maheshwri and Pandey, 1971; Holman, 1981).

Table 2. Agents of weed dispersal, infestation levels in different land use types and causes of aggressiveness of parthenium weed

	Frequency (N=40)	Percent
Agents of weed dispersal		
Flood	25	63.2
Animal dung	12	28.9
Wind	2	5.3
Animal movement	1	2.6
Infestation level of parthenium in different land use types		
Grazing areas	29	73.7
Crop fields	6	15.8
Road sides	2	5.3
Home yards	1	2.6
Near watering points	1	2.6
Causes of aggressiveness of parthenium		
Overgrazing	27	68.4
Almighty God destiny	11	26.3
Drought	2	5.3

4.1.5. Causes of aggressiveness of parthenium

According to Table 2, in the study area, 68.4% of the pastoralists revealed that overgrazing was the main cause of parthenium infestation. They also considered the cause as destiny and drought. Ahmed's (2003) study on rangeland of Jijiga also indicated that in bad years when the grasses were grazed and aboveground part exhausted, the underground part were uprooted to feed livestock which resulted in reduced regeneration of plants in the future. High grazing pressure caused by high stock number or the prevailing drought might lead to a decrease in the vigor and competitiveness of the pasture and thereby allowing the entry and spread of parthenium (Mountmorgan, 2006).

Livestock grazing could also have a profound effect on vegetation change (Illius and O'Connor, 1999). It has been known that undesirable species increase at the expense of desirable species. Several other studies also showed that the grazing intensity increased the herbaceous composition change from high palatable to less palatable species (Illius and O'Connor, 1999; Amsalu, 2000). With prolonged high grazing pressure, the desirable perennial components declined, grass root system contracted and grasses with a diminished root system could not use the maximum rainfall. As a result, the competition from palatable pasture species decreased and parthenium weed would gain advantage to colonize and produce seeds (Mountmorgan, 2006).

4.1.6. Problems of weed on meat and milk quality and marketing

In the study districts, the pastoralists expressed their views concerning the quality of animal products and their marketability. They pointed out that the milk had bitter taste or taint. They added that the meat quality is deteriorated and has bad odor from livestock that fed on parthenium. They further elaborated that when animals were allowed to graze only parthenium nobody would like to drink the milk. However, when parthenium is offered as a supplement to other forages the taste might slightly improve. All respondents also revealed that they market problem for milk from such animals. They indicated that nobody would purchase the milk if alternatives were available. Kadhane *et al. (*1992) reported that though cattle would not normally graze parthenium since it is not palatable due to its irritating odor, bad taste, and presence of trichomes. However, the pastoralists pointed out that the starved the cattle often would be forced to feed on this weed during periods of fodder scarcity. Obviously, feeding the weed impairs both the quality and the quantity of their milk.

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Table 3 indicated that with regard to the quality of meat, 73.7%, of the respondents in the study area revealed that the meat could loose its quality. Some revealed that the meat has bitter taste while the rest said the quality was normal. According to them, the soup prepared with the animal's meat that was fed with parthenium is not favored as it could impair its normal taste. The respondents suggested that it would be better to prevent animals from feeding on parthenium at least five days prior to slaughtering in order to minimize the risk of loosing the meat quality. They simultaneously indicated, however, that as live animals are being sold, there is no problem of market. Nevertheless it should be emphasized that this assertion may be short sighted since in the long run the market for live animals would gradually decline. Towers *et al.* (1992) reported that parthenium weed might also affect milk and meat quality and the marketing of their products.

4.1.7. Problems of weed on animal and human health

Table 3 shows that regarding the impacts of parthenium on human health, 45% of the respondents revealed that parthenium has caused diarrhea, lung disease (coughing) while some other revealed that the weed did not exert any health problem. The probable reason why the latter respondents held such a view is that their cattle have good genetic make up to resist the disease; it could also be due to the fact that parthenium population differences that exist in Ethiopia and elsewhere.

As one can see in Table 3, in most of the study districts, parthenium forms almost a pure stand and is the only source of feed. Most of the respondents (42.5%) revealed that their cattle were more susceptible to parthenium toxicity. The rest of them reported that sheep, goats and camels were most affected. The respondents elaborated that animals that eat green parthenium (immature) had diarrhea. They stated, however, that when they feed on the mature plant their cattle had no problem of diarrhea and the taste of their milk was also improved.

The toxicity of the weed to cattle and buffalo was shown to have a significant amount (10-50% as the weed in the diet had killed animals within 30 days (Narasimhan *et al*., 1997). In addition, the toxicity of parthenium causes animals to develop dermatitis with pronounced skin lesions. The animals eventually die due to rapture of tissue and hemorrhage in their internal organs (Ahmed *et al*., 1998).

Parthenium impairs human health. Table 3 indicates the respondents' feelings that it causes asthma, bronchitis, dermatitis, and high fever. About 40 % of the pastoralists indicated that this weed causes asthma. About 37.5 % of the respondents, on the other hand, pointed out that the weed causes itching. The rest of them indicated that the weed is not a cause to any disorder in health. A person who is susceptible to parthenium weed allergy due to genetic predisposition suffers if he/she is exposed to the allergic agent parthenin, which is present in the parthenium it causes allergy. Allergy is inherited genetically among the same family members. Among the manifestations are rhinitis and dermatitis. A person may manifest at the same time while others will not suffer this problem (Nagarajachari, 2005).

Table 3. Animal and human health problems associated with parthenium in the study districts

	Frequency (N=40)	Percent
Livestock health		
Diarrhea	18	45
Cough	17	42.5
No problem	5	12.5
Animal kind susceptible to parthenium toxicity		
Cattle	17	42.5
Sheep, goat, cattle	10	25
Sheep and camel	5	12.5
Camel	4	10
No problem	4	7.5
Problems on human health		
Asthma	16	40
Itching	15	37.5
No problem	9	12.5
Problems of weed on meat quality		
Bitter taste	29	73.7%,
Normal	11	26.3

4.1.8. Management practices of parthenium in the study area

There have been little or no traditional practices used to curb the infestation of parthenium weed in the study districts. Only few respondents (5%) practiced hand weeding to get rid off the weed when it occurs in the rangelands. The majority of them (95%) pointed out that there have been no practice of weeding has been employed. The respondents expressed that hand-weeding is not an effective method as it could not stop the spread of the weed over time and space in the area.

On the other hand, hand weeding and hoeing have been used to remove the parthenium weed from the crop fields. Even these practices require frequent operation on a single crop field in each season. In most cases, weed seeds through their efficient dispersal mechanism can disperse from road side ditches and the nearby grazed lands with high infestation into crop fields. This might complicate the effort of reducing or eliminating parthenium. The respondents also revealed that the areas covered by parthenium are expanding from year to year. It has been reported that a single parthenium can produce as large as 30,000 seeds per a growing season. In addition, because of its high longevity in the soil seed bank, the weed could perpetuate and establish itself in wide expanses (Navie *et al.*, 2004). In order to control the weed integrated efforts should be made that involve diverse mechanisms of selectively suppressing the weed. To get rid of the weed the pastoralists seek the support of non-governmental and government organizations.

4.2. Biodiversity Study

4.2.1. Species composition and diversity

In the study sites, a total of 63 species in 20 families were identified. Out of these, 22 species of grasses (graminoids), 4 species of legumes, one species of sedge, and 36 species of forbs were identified (See Appendix Table 3).

In all infestation levels, *Asystasia schimperi, Cassia occidentalis, Cynodon dactylon, Eragrostis papposa, Chrysopogon aucheri, Ocimum basilicum and Tragus berteronianus* have good proportion than the other species. On the other hand, *Erucastrum arabicum and Euphorbia hirta* have good proportion in HIS (High Infested Site) than the other sites. This occurred because of a good association between these two species and parthenium (Gutam *et al.*, 2005).

In non-infested sites (NIS) of the study area, a total of 17 (62.72%) species of grasses, 4 legumes (6.63%) and 20 (30.65%) other herbaceous species categorized in 15 families were identified (Table 4 and Appendix Table 3). The sites were dominated by *Chrysopogon aucheri, Eragrostis papposa, Ocimum basilicum and Panicum coloratum* and accounted 24.47%, 8.08% 7.59% and 6.46% of the total species recorded (See Table 5).

Table 4 reveals that in very low infested sites (VLIS) of the study districts, 16 grasses (62%), 3 legumes (4.46%) and 22 forbs in 15 families were identified (See Table 4 and Appendix Table 3). Of the recorded species, 31.98% were forbs. Parthenium constituted only 1.5% of the total species identified. According to Table 5, on the other hand, species like *Chrysopogon aucheri*, *Eragrostis papposa*, *Asystasia schimperi*, *Cynodon dactylon* and *Aristida adscensionis* were frequently encountered in the sites constituted 17.4%, 7.86%, 6.85%, 6.75% and 5.95% of the total species composition in the site.

The low infested sites (LIS) of the study districts were covered by a total of 12 grasses (55.93%), 17 forbs (24.77%,), 3 legumes (5.03%) and 1 sedge that belonged to 11 families (Table 4 and Appendix Table 3). Among the frequently occurring species in these sites were *Eragrostis papposa*, *Chrysopogon aucheri*, *Parthenium hysterophorus* and *Tragus berteronianus*. Table 5 suggests that each of them accounted for 16.97%, 14.27%, 14.27%, and 10.7% respectively.

The moderately infested sites (MIS) had 9 grasses, 10 forbs and 4 legumes species in 10 families (See Appendix Table 3). Table 4 indicates that out of the total identified species, 39.97% were grasses, 23.38% forbs, 5.93% legumes and 30.72% parthenium. The dominant species found in the sites were *parthenium hysterophorus*, Chrysopogon *aucheri*, *Eragrostis papposa* and *Asystasia schimperi*. According to Table 5, the proportion of each of the species was 30.72%, 10.67%, 9.84%, and 8% respectively. Moreover, in highly infested sites (HIS) of the study districts, a total of 7 grasses, 13 forbs and 2 legumes in 13 families were identified (See Appendix Table 3). Table 4 suggests that out of the total identified species, grasses comprised 16.6%, forbs 15.1%, legumes, 1.26% and parthenium 66.98%. The sites in this category were to a larger extent dominated by parthenium.

The current study showed that the number of desirable species declined in the highly infested sites. Such a reduction could be attributed to the increasing abundance of partheinum in the sites. It is clear in Table 4 that the percent coverage of partheinum was found to escalate from 0 in NIS to 66.98% in HIS. The table shows also that 19.5% in LIS, 43% in MIS and 46.34% HIS decline in species number compared to NIS sites. This might be attributed to the continued disturbance of the sites by grazing animals that cause degradation of the sites. As it is clear, degradation favors the invader species such as parthenium. Then, the weeds easily establish themselves in the sites and start interfering with other indigenous species by suppressing their potential growth and biomass production. Parthenium was known to suppress the associated species through the release of allelochemicals from decomposing biomass and root exudates into the soil environment (Pandey *et al.*, 1993). The present finding supports Kohli *et al.*'s (2004) study in which they reported that in high infested sites of Lower Himalaya (India) the number of species were reduced from 25 to 12 species from NIS to HIS.

Table 4. The proportion of grasses, forbs, legumes and parthenium in five infestation levels

Infestation levels	Grasses %	Forbs %	Legumes %	Parthenium %
None (NIS)	62.72	30.65	6.63	0
Very low (VLIS)	62.05	31.98	4.46	1.5
Low (LIS)	55.93	24.77	5.03	14.27
Moderate (MIS)	39.96	23.38	5.93	30.72
High (HIS)	16.66	15.10	1.25	66.98

Table 5. Proportion of each species based on the cover abundance value in five parthenium infestation levels

	% Composition					
Name of species	NIS	VLIS	LIS	MIS	HIS	Life form
Acanthospermum hispidum	0.32	0.00	0.00	0.00	0.00	A
Acantus sp.	0.00	0.50	0.74	0.00	0.00	-
Ageratum sp.	0.00	0.00	1.35	0.00	0.00	-
Amaranthace dubius	0.00	0.00	0.00	0.00	0.16	A
Andropogon abyssinicus	0.00	0.20	4.30	0.00	0.00	A
Aristida adscensionis	2.90	5.95	1.72	2.14	0.00	A
Asystasia schimperi	2.75	6.85	5.65	7.59	4.08	A
Blepharis persica	5.50	4.23	0.00	0.00	0.00	A
Bothriochloa insculpta	1.86	3.93	0.00	2.37	0.00	P
Cassia occidentalis	1.62	0.50	0.49	0.12	0.47	A
Cenchrus ciliaris	6.3	3.63	1.10	0.00	0.79	P
Chenopodium murale	0.00	0.00	0.00	0.00	0.16	A
Chenopodium opulifolium	0.00	0.00	0.74	0.00	0.00	A
Chloris gayana	0.48	0.00	0.00	0.00	0.00	P
Chloris radiata	0.00	0.00	0.00	1.42	0.00	A
Chrysopogon aucheri	24.47	17.94	14.27	10.68	2.99	P
Commelina latifolia	0.40	1.00	0.12	0.00	0.00	A
Commicarpus africanus	0.08	0.80	0.00	0.00	0.00	P
Conyza bonariensis	1.29	1.20	0.49	0.00	0.47	A
Craterostigma pumilum	0.00	0.00	0.00	0.00	0.31	A
Cucumis melo	0.08	0.70	0.00	0.00	0.00	A
Cynodon dactylon	2.82	6.75	1.23	0.12	1.88	P
Cyperus rotundus	0.00	0.00	0.123	0.00	0.00	P
Dactyloctenium aegyptium	0.97	0.20	2.95	0.00	0.00	A
Digitaria abyssinica	2.66	0.00	0.00	2.6	1.57	P
Eleusine Jaegeri	0.00	0.00	0.49	0.00	0.00	P

Table 5.*(Continued)*

	NIS	VLIS	LIS	MIS	HIS	Life form
Eragrostis papposa	8.08	7.86	16.97	9.84	2.35	A
Eragrostis sp.	0.65	2.00	0.00	2.38	0.00	-
Eriochloa nubica	0.24	0.00	0.00	0.00	0.31	A
Erucastrum arabicum	0.00	0.91	0.00	0.00	3.45	A
Euphorbia granulata	0.08	0.00	0.00	0.00	0.00	A
Euphorbia hirta	1.05	0.91	2.20	0.24	2.67	A
Glycine wightii	0.81	0.00	0.00	0.59	0.00	p
Guizotia scabra	0.00	0.10	2.20	0.00	0.00	A
Heliotropium cinarescens	1.29	0.10	0.00	0.47	1.10	A
Hibiscus aponeurus	2.58	0.10	0.49	0.00	0.94	p
Indigofera amorphoides	3.64	4.00	3.81	5.10	1.257	P
Ipomoea obscura	0.16	1.10	0.00	0.00	0.00	p
Laggera appendiculata	0.00	0.10	0.00	0.00	0.00	p
Launaea sp.	0.08	0.00	0.00	0.00	0.00	-
Leucas martinicensis	0.00	0.10	0.00	0.00	0.47	A
Lintonia nutans	0.16	0.40	0.24	0.00	0.00	p
Medicago polymorpha	0.57	0.10	0.73	0.12	0.00	A
Microchloa kunthii	0.00	0.00	0.98	0.00	0.00	p
Ocimum basilicum	7.59	6.55	2.95	0.95	0.78	A
Panicum coloratum	6.46	4.23	0.00	2.96	0.31	p
panicum sp.	0.32	0.60	0.98	0.00	0.00	-
Parthenium hysterophorus	0.00	1.50	14.27	30.72	66.98	A
pennisetum polystachion	1.29	0.20	0.00	0.00	0.00	A
Ruellia patula	2.10	2.20	0.00	4.75	0.00	A
Ruellia sp.	0.00	0.00	1.72	0.00	0.00	-
Schkuhria pinnta	0.00	0.00	2.95	0.12	0.00	A
Setaria acromelaena	0.00	0.30	0.00	0.00	0.00	A
Solanum incanum	1.37	0.00	0.00	2.00	0.00	p
Solanum nigrum	1.20	2.20	1.35	0.00	0.00	A

Table 5.*(Continued)*

Sonchus oleraceus	1.61	0.10	0.00	0.00	0.00	A
Sporobolus pyramidalis	0.48	0.91	0.00	0.00	0.00	p
Tragus berteronianus	2.58	6.96	10.7	8.06	6.45	A
Triplotaxis somalensis	0.00	0.00	0.00	0.47	0.00	A
Unidentified sp.	0.00	0.20	0.00	0.00	0.00	-
Verbascum schimperi	0.00	0.00	0.12	0.00	0.00	A
Withania somnifera	0.65	1.20	0.73	0.00	0.00	p
Xanthium spinosum	0.40	0.50	0.74	0.00	0.00	A

Key :A = Annual, P=Perennials

Table 5 reveals that the species composition of herbaceous vegetation covers of grasses and forbs were significantly different ($P < 0.05$) with different parthenium infestation levels (See Appendix Tables 5 and 6). The grass species and forbs composition in NIS was significantly different from MIS and HIS.

Table 6, on the other hand, shows the existence of a non-significant difference in VLIS and LIS. The study indicated that cover abundance value of parthenium which is greater than 30% might exert suppressive effects on other species which could contribute to a decline in species composition as the gradient levels of the infestation increases. Navie *et al*. (1996) indicated that at the early stage of its growth parthenium takes the form of a rosette and thus requires a suitable open area to establish. This rosette spreads rapidly very close to the ground and interferes with the emergence of other seedlings. The stem of the weed then elongates rapidly and starts branching at the apex. When it becomes mature as well the weed branches. In addition, due to its high growth rate, the weed becomes competitive and develops the ability to exclude the growth of other species. In similar ways, studies in Australia and India have also demonstrated that parthenium adversely affects the composition and diversity of species thereby resulting displacement and imbalance in natural and agricultural system (McFadyen, 1992; Chippendale and Panneta, 1994; Sakai *et al*., 2001; Grice, 2006).

The diversity and evenness of species were inversely related to increasing level of parthenium infestation. The one-way ANOVA in the current showed that there was a significant ($P<0.05$)

variations in the diversity and evenness of species between sites with varying levels of parthenium infestation (See Appendix Tables 7 and 8). Table 6 indicates that NIS was significantly different from LIS, MIS and HIS. The diversity of species declined by 11.7%, 22% and 47.5% in LIS, MIS and HIS respectively as compared to NIS. Similarly, the evenness index, which is a measure of species abundance, decreased much as the parthenium cover became greater than 50 %.

Table 6. Grasses and forbs species composition diversity and evenness index (LSM ± SE) in five parthenium infestation levels

Infestation levels	Grass composition	Forbs composition	Species Diversity	Evenness
NIS	0.634 ±0.04[a]	0.366±0.05 [ab]	2.48±0.08 [a]	0.838±0.03 [a]
VLIS	0.616±0.04[a]	0.367±0.04 [a]	2.49±0.08 [a]	0.828±0.03 [a]
LIS	0.56±0.04[ab]	0.294±0.04 [abc]	2.19±0.08 [b]	0.827±0.03 [a]
MIS	0.465±0.03[b]	0.277±0.05[bc]	1.9±0.08 [c]	0.799±0.03 [a]
HIS	0.180±0.03[c]	0.175±0.02 [c]	1.29±0.08 [d]	0.546±0.03 [b]
CV %	17.8	32	7.4	8.9
P in ANOVA	0.000	0.042	0.000	0.000

[abcd] Means within a column with different superscript are significantly different at $P < 0.05$
Key: NIS= None Infested Sites, VLIS= Very Low Infested Sites, LIS= Low Infested Sites, MIS= Moderately Infested Sites and HIS= Highly Infested Sites.

In general, the present study indicated that there was a sharp decline of diversity index as the density of parthenium increased. This result validates Kohli *et al.*'s (2004) findings that the Shannon index showed great plant diversity in uninfested area whereas the index was reduced by 36 to 51% in the weed infested areas. The higher value of the diversity index indicates the variation in the type of species and the heterogeneity in the community, whereas the lesser value points the homogeneity in the community. Likewise, the evenness index was found to be comparatively higher in uninfested areas. This indicates the species are evenly distributed. On the other hand, the fact that it was lesser in the weed-infested area indicated patchiness in distribution.

4.2.2. Above-ground dry matter biomass

The biomass of grasses, forbs, parthenium and total biomass showed a significant variation ($P< 0.05$) between different parthenium infestations levels (See Appendix Tables 9-12). The grass biomass production in NIS (407.8 g/m^2) was significantly higher than LIS, MIS and HIS as shown in Table 7. The dry matter biomass revealed decline with increasing levels of infestation in the sampled sites. Accordingly, the aboveground dry matter biomass of grasses was reduced by 25.2%, 39.1%, 60% and 92% in VLIS, LIS, MIS and HIS, respectively as compared to NIS. Similarly, forbs dry matter biomass in NIS (167.5 g/m^2) was significantly higher than MIS and HIS. On the other hand, non-significant difference was observed in VLIS and LIS. The reduction in forbs biomass was observed in MIS (42%) and HIS (84.7%) as compared to NIS. The findings here support a similar finding in India that showed 90% (Khosla and Sobti, 1981) and 59.6% (Kohli *et al.*, 2004) reduction in forage production with increasing gradients of parthenium weed infestation.

Table 7. Dry matter biomass production of grasses, forbs, and parthenium (g/m^2) (LSM ± SE) in different parthenium infestation levels.

Infestation level	Grasses biomass	Forbs biomass	Parthenium biomass	Total
NIS	407.8 ± 12^{a}	167.46 ± 7^{a}	0^{d}	568.53 ± 19^{b}
VLIS	304.9 ± 62^{ab}	171.32 ± 15^{a}	12.29^{d}	480.6 ± 49^{b}
LIS	248.29 ± 28^{bc}	192.39 ± 23^{a}	111.65 ± 36^{d}	500.95 ± 46^{b}
MIS	159.5 ± 45^{cd}	97.16 ± 28^{b}	293 ± 34^{b}	536.44 ± 53^{b}
HIS	30 ± 27^{d}	25.5 ± 13^{c}	714.1 ± 18^{a}	769.56 ± 34^{a}
CV %	38.5	32.26	26.9	16.04
P in ANOVA	.000	.000	<.000	.006

[abcd] Means within a column with different superscript are significantly different at $P < 0.05$.

4.2.3. Correlation and regression analysis among variables

The correlation analysis of grasses and forbs biomass, grasses and forbs composition, species diversity and evenness showed significant negative correlation at $P< 0.05$ as depicted in Table 8 with parthenium percent cover and parthenium biomass. A significant and negative linear relationship ($P<0.05$) (See Appendix Tables 20 and 21 and Fig 2) was found, using regression analysis, between parthenium percent coverage and diversity and evenness index. Evenness and species diversity were correlated with parthenium percent coverage and that there was a strong negative relationship (R^2=0.95) for diversity and (R^2= 0.71) for evenness. The appearance of such variation could be attributed to increasing percent cover of the parthenium and due to its strong allelopathic effects that might have impaired the germination and growth of the associated plant species in the rangeland.

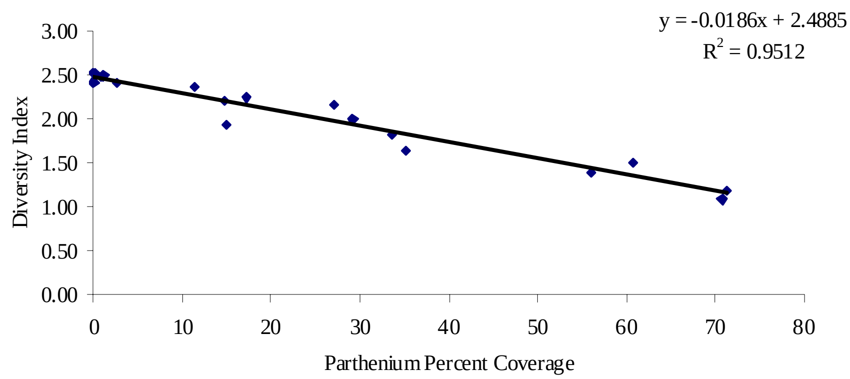
Table 8. Correlation matrix among variable.

	G.COM	F.COM	G.BIOM	F.BIOM	P.COV	P.BIOM
G.COM						
F.COM	.317					
G.BIOM	.705**	.591**				
F.BIOM	.591**	.771**	.493*			
P.COV	-.903**	-.694**	-.805**	-.745**		
P.BIOM	-.869**	-.698**	-.869**	-.781**	.976**	

** Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)
G.COM= Grasses Composition, F.COM= Forbs Composition, G.BIOM= Grasses Biomass, F.BIOM=Forbs Biomass, P.COV= Parthenium Cover and P.BIOM Parthenium Biomass.

Sridhara *et a*l.'s (2005) similar study indicated that relationship of evenness and diversity index with the percent coverage of parthenium showed negative (Y=-0.006x +1.00 and Y = -0.031+3.31) and significant correlation (R^2 =0.92, R^2 =0.95) with evenness and diversity, respectively.

The strong negative correlation among variables may be due to the allelopathic effect. The allelopathic nature of parthenium and water soluble phenolic and sesquiterpene lactones that have been reported from root, stems, leaves, inflorescences, pollen and seeds have been well documented (Rajan, 1973; Kanchaan, 1975). These chemicals are released into the soil environment by the parthenium weeds and become are growth inhibitors. Moreover, studies suggested that parthenin, caffeic acid and p-coumaric acid as primary inhibitors of growth. The compounds significantly decrease germination and the growth of the seedlings of the surrounding plants. For example, isolation and purification of parthenin from leaves of parthenium demonstrated that these compounds significantly decrease the germination of wheat seeds and adversely affect seedling growth (Patil and Hedge, 1988).



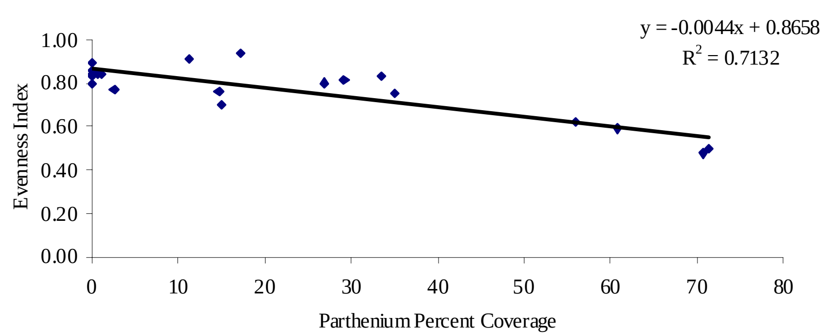


Figure 2. Regression analyses of diversity and evenness index and percent parthenium cover

4.3. Soil Seed Bank Study

4.3.1. Soil seed bank seedling density

According to Table 9, the least mean square value of viable seeds in the soil seed bank corresponds to a seed bank density dawn to 9 cm in the soil were 269 seeds/m^2 at NIS, 113.49 seeds/m^2 at VLIS, 407.65 seeds/m^2 at LIS, 1,040 seeds/m^2 at MIS and 1,699 seeds/m^2 at HIS (Table 9). Quantitatively, the seed bank was dominated by the relatively few species. The current study indicted that parthenium contributed highest seedling density 56 .46% in LIS, 87% in MIS and 94% in HIS (See Tables 10-14).

Table 9. Seedling density/m^2 (LSM ± SE) and JCS among different parthenuim infestation levels

Infestation levels	Grasses	Forbs	Parthenium	Total	JCS
NIS	214.4± 22.28^a	53.32±29.9^a	1.23^c	269±113^c	0.31±0.04^a
VLIS	47.92± 22.28^b	57.73±29.9^a	7.98^c	113.49±113^c	0.26±0.04^{ab}
LIS	41.37± 22.28^b	122.16±29.9^a	248±98^c	407.65±113^c	0.178±0.04^{ab}
MIS	31.01± 22.28^b	97.93±29.9^a	910±98^b	1040±113^b	0.20±0.04^{ab}
HIS	31.73± 22.28^b	68.67±29.9^a	1598±98^a	1699±113^a	0.137±0.04^b
CV %	34.82	24.69	37.98	13.79	0.09
Pin ANOVA	*0.013*	*0.93*	0.000	0.000	*0.091*

^{abc}Means within a column with different superscript are significantly different at $P < 0.05$
NIS=Non infested Site, VLIS= Very low Infested Site LIS= Low Infested Site, MIS= Moderately Infested Sites, HIS= High Infested Site and JCS= Jaccards coefficient of similarity.

The study suggested that the density of parthenium increased from NIS to HIS with the mean number of seedling 1,598 at HIS. On the other hand, the seedling density of grasses decreased from (214) NIS to (31) HIS as revealed in Table 9. The interaction effects of infestation levels with depths were measured through two-way analysis, ANOVA. ANOVA showed significant difference between grasses, parthenium and total seedling density along depths and sites at P< 0.05. On the other hand, the interaction effects of forbs seedling density along depths and between sites showed non-significant difference at P>0.05 (Appendix Tables 15-18). The highest total seedling density was observed at HIS. Table 9 suggests that this is due to the presence of the large amount of parthenium seedling density in the site

The study showed that the average number of seedling density of parthenium were relatively lower than those reported from the rangelands of Australia by Navie *et al.* (2004). The Australian report revealed that the seedling density is in range of 3,284 to 5,094 seeds/m^2 at moderately infested site and 20,599 and 44,639 seeds /m^2 at high infested site. The relatively lower seed bank size in the present study compared to the highly infested field of Australia for seedling densities all species along infestation levels (Table 9) might be associated with plant cover pattern. The categorization of highly infested field here might be a just a slightly infested site in Australia. The differences could also be due to differences in sampling techniques and the purpose behind collecting seed bank. All of these factors could affect both the size and composition of seed bank flora (Baskin and Baskin, 2001). Thus, accurate comparison of seed banks would depend on the sampling techniques and timing of data collection (Simpson *et al.*, 1989). Furthermore, the seed bank composition can also be attributed to climatic factors, soil conditions, and differences in the abundance of seed (Westoby *et al*., 1992). These factors reduce the overall size of the seed in the seed bank. However, the present study was relatively comparable with Navie and Tamado’s (2002) study in which the authors recorded seedling density in the range of 1,955 and 1,584 in infested rangelands of Australia.

The variation in grass seedling density among the study site might be due to differences in parthenium cover, variation in grazing pressure experienced in the sample sites and also due to variation in grass cover abundance. In this study, the relatively higher grass seedlings were obtained in NIS. This is attributed to lower parthenium cover in the site. However, due to its allelopathic property, it would suppress the growth of the surrounding plants as a result of which very little or sometimes no other vegetation could be seen in parthenium dominated area (Adkin, 1996; Kohli, 2004; Shabbir and Swhsana, 2005; Prasanta *et al.*, 2005).

The seed banks of all of the sites studied were dominated by annuals as a common phenomenon in soil seed banks (Thompson, 1978; Navie *et al.*, 1996). This domination is the result of the regeneration strategies of annual plants. The domination of the seed by a single annual species in this case parthenium is not unusual. A single species often comprises over half of the soil seed bank (Thompson, 1986; Lant, 1990; Enright *et al.*, 1997; Schott and Hamberg, 1997).

4.3.2. Soil seed bank floristic composition

The number of species from the five infestation levels ones was 59 and they belong to 16 families. However, they do not include the identified ones. Out of these species, 67.9% were annuals, 23.72% were perennial herbaceous, 6.7% were perennial woody shrub and the remaining 1% was tree (See Appendix Table 23 and Table 15). Out of the total species identified, 35, 31, 30 and 27 species were from NIS, VLIS and LIS each, MIS, and HIS sites, respectively (See Tables 10-14). The most dominant species were *Eragrostis papposa* in NIS, *Indigofera amorphoides, Eragrostis sp and Digitaria abyssinica* in VLIS and *Parthenium hysterophorus* in LIS, MIS and HIS. Furthermore, species such as, *Cynodon dactylon*, *Digitaria abyssinica*, *Eragrostis papposa*, *Euphorbia hirta*, *Medicago polymorpha* and *Parthenium hysterophorus.* They occurred throughout the five infestation levels of the study districts (See Table 15).

In NIS, the most dominant family in three soil depths, which are D1 (0-3cm), D2 (3-6) and D3 (6-9cm)   species of poaceae, accounted for 77% of the total species composition. The species composition at D1, D2 and D3 was dominated by *Eragrostis papposa*, *Panicum coloratum*, and *Chrysopogon aucheri*, respectively. *Eragrostis papposa* accounted for 34.45% of the total species composition followed by *Panicum coloratum and Chrysopogon aucheri* (Table 10).

In VLIS, the species composition in all soil layers were more or less distributed evenly across soil depths. However, *Digitaria abyssinica, Indigofera amorphoides, Parthenium hysterophorus and Withania sominfera* have good percentage contribution compared to other species (Table 11). The species composition recorded in the three soil depths of the LIS was dominated by *Parthenium hysterophorus*, *Asystasia schimperi, Eragrostis papposa* and *Solanum nigrum* in that order. The contribution of *Parthenium hysterophorus* was 56.46% of the total species composition followed by *Asystasia schimperi* (Table 12).

On the other hand, the soil seed bank seedling density in MIS and HIS were dominated by *Parthenium hysterophorus* which contribute to 87% and 94% of the total seedling density in those sites, respectively (Tables 13 and 14). Parthenium is known to have allelopathic effect in its root and shoot leachates and thus has the ability to reduce the growth and/or germination of numerous associated species (Adkins, 1996). The successful spread of the weed in part may be attributed to these allelopathic properties which enabled the seed to deposit several seeds of other species in soil seed bank of MIS and HIS. Moreover, parthenium is less preferred species by grazing animals. This condition on its part might contribute for its increased reproductive efficiency and enhance its ability to deposit seed in the soil seed bank.

The study revealed that the increasing trend of parthenium weed invasion might lead to a decline in the other species diversity and abundance in the study sites. In this regard, the study supports Navie *et al.*'s (2004) findings that in moderately and high infested sample sites the percent contribution of parthenium was recorded to be 47-73% and 65-87% and the grasses were 15-35% and 1.8-5.4%, respectively.

Table 15 reveals that parthenium accounted for 79.42% of the total seedlings compared to the other species. This species had the widest distribution in the sample sites investigated. Parthenium has been reported as a prolific seed producer, that is, a single plant capable of producing 15,000-300,000 seeds within 3-5 months of germination (Dhileepan *et al.*, 1996; Joshi, 1991). The findings of Butler (1984) and Navie *et al*. (1998) have similarly demonstrated that a relatively large percentage of buried parthenium seeds can survive for several years. Therefore, a very large size of this weed seed bank in LIS, MIS and HIS was both due the weed's prolific seed production and the ability of its seeds to persist for many years in the soil. This simply suggests that one suffers many difficulties while attempting to eradicate parthenium from the rangelands.

Table 10. Percent contribution of each species in None infested sample site along depths

Name of species	D1%	D2 %	D3%	Total
Bothriochloa insculpta	0.560	0.000	0.000	0.560
Cenchrus ciliaris	0.560	0.000	0.000	0.560
Chloris gayana	1.401	0.000	0.000	1.401
Chloris radiata	1.961	0.000	0.000	1.961
Chrysopogon aucheri	7.003	2.521	0.560	10.084
Crotalaria sp.	1.681	0.280	0.280	2.241
Cynodon dactylon	1.401	0.280	0.000	1.681
Dactyloctenium aegyptium	1.120	0.000	0.000	1.120
Digitaria abyssinica	1.401	0.000	0.000	1.401
Eragrostis papposa	27.171	4.482	2.801	34.454
Eragrostis sp	5.042	1.401	0.560	7.03
Croton macrostechys	0.000	1.120	2.801	3.922
Erucastrum arabicum	0.000	0.000	0.280	0.280
Euphorbia hirta	1.961	0.560	0.000	2.521
Galinsoga parviflora	0.280	0.000	0.000	0.280
Gutenbergia cordifolia	0.000	0.280	0.000	0.280
Glycine wightii	0.560	0.000	0.280	0.840
Heliotropium aegyptiacum	0.280	0.000	0.000	0.280
Indigofera amorphoides	1.961	2.241	0.000	4.202
Kosteletzkya adoensis	0.280	0.000	0.000	0.280
Lintonia nutans	0.280	0.000	0.000	0.280
Nicotiana tabacum	0.000	0.280	0.000	0.280
Ocimum basilicum	0.280	0.000	0.000	0.280
Panicum coloratum	6.162	5.882	0.560	12.605
Parthenium hysterophorus	0.000	0.560	0.000	0.560
Schkuhria pinnta	0.560	0.280	0.000	0.840
Solanum incanum	0.280	0.000	0.000	0.280
Solanum nigrum	0.560	0.000	0.000	0.560
Tragus berteronianus	3.361	0.560	0.000	3.922
Tribulus terrestris	0.280	0.000	0.000	0.280
unidentified spp	0.280	0.000	0.000	0.280
Withania sominfera	0.840	0.560	0.000	1.401
Xanthium spinosum	0.000	0.28	0.000	0.28
Xinnia peruviana	0.560	0.560	1.401	2.521

Table 11. Percent contribution of each species in Very low infested sample sites along depths

Name of species	D1 %	D2 %	%D3	Total
Amaranthace dubius	1.14	0.57	0.00	1.70
Aristida adscensionis	0.57	0.00	0.00	0.57
Asystasia schimperi	5.68	0.00	1.14	6.82
Chenopodium albem	0.00	0.00	1.14	1.14
Chrysopogon aucheri	3.41	0.57	0.00	3.98
Conyza bonariensis	1.14	0.00	0.00	1.14
Craterostigma pumilum	0.00	0.00	0.57	0.57
Croton macrostechys	0.57	0.57	1.70	2.84
Crotalaria sp.	1.14	1.14	0.00	2.27
Cucumis melo	0.00	0.57	0.00	0.57
Cynodon dactylon	0.57	1.14	0.00	1.70
Dactyloctenium aegyptium	0.57	0.00	0.00	0.57
Digitaria abyssinica	7.39	1.70	1.14	10.23
Eragrostis papposa	5.11	0.57	0.57	6.25
Eragrostis sp.	7.39	0.57	2.84	10.80
Erucastrum arabicum	0.57	0.00	0.00	0.57
Euphorbia hirta	3.41	1.14	0.57	5.11
Galinsoga parviflora	0.57	0.00	0.00	0.57
Heliotropium cinarescens	0.00	0.57	0.00	0.57
Indigofera amorphoides	8.52	1.70	0.57	10.80
Kosteletzkya adoensis	0.00	0.00	0.57	0.57
Medicago polymorpha	0.00	0.57	0.00	0.57
Ocimum basilicum	2.27	1.14	0.57	3.98
Parthenium hysterophorus	6.82	0.00	0.57	7.39
Poctulaca quadyifida	0.57	0.00	0.00	0.57
Solanum incanum	1.14	0.00	1.70	2.84
Solanum nigrum	1.70	1.14	0.00	2.84
Sonchus oleraceus	1.14	0.57	0.00	1.70
Tragus berteronianus	2.27	0.00	0.00	2.27
Tribulus terrestris	0.00	0.00	0.57	0.57
Withania somnifera	4.55	1.14	2.27	7.95

Key: D1, D2 and D3 are soil depths (*i.e.* 0-3, 3-6 and 6-9 cm)

Table 12. Percent contribution of each species in Low infested sample sites along depths

Name of species	%D1	%D2	%D3	Total
Ajuga sp.	0.16	0.00	0.00	0.16
Amaranthace dubius	0.16	0.00	0.00	0.16
Asystasia schimperi	13.91	0.00	0.82	14.73
Chenopodium murale	0.49	0.00	0.00	0.49
Chloris radiata	0.16	0.00	0.00	0.16
Chrysopogon aucheri	0.16	0.00	0.00	0.16
Craterostigma pumilum	0.65	0.00	0.00	0.65
Crotolaria plowdenii	0.16	0.00	0.00	0.16
Crotalaria sp.	0.49	0.00	0.00	0.49
Cynodon dactylon	0.33	0.65	0.00	0.98
Digitaria abyssinica	2.95	0.65	0.00	3.60
Eragrostis papposa	4.09	1.64	0.82	6.55
Croton macrostechys	1.96	1.31	0.16	3.44
Euphorbia granulata	0.16	0.33	0.16	0.65
Euphorbia hirta	0.33	0.65	0.00	0.98
Galinsoga parviflora	0.00	0.16	0.00	0.16
Glycine wightii	0.33	0.00	0.00	0.33
Indigofera amorphoides	0.33	0.00	0.00	0.33
Lintonia nutans	0.16	0.00	0.00	0.16
Medicago polymorpha	0.33	0.00	0.00	0.33
Parthenium hysterophorus	36.33	14.57	5.56	56.46
Schkuhria pinnta	0.16	0.00	0.00	0.16
Solanum incanum	0.33	0.00	0.00	0.33
Solanum nigrum	5.07	0.65	0.16	5.89
Solanum somalinses	0.49	0.00	0.00	0.49
Sonchus oleraceus	0.00	0.49	0.00	0.49
Tragus berteronianus	0.16	0.00	0.00	0.16
Withania somnifera	0.65	0.33	0.33	1.31

Key: D1, D2 and D3 are soil depths (*i.e*. 0-3, 3-6 and 6-9 cm), respectively

Table 13. Percent contribution of each species in Moderately infested sample sites along depths

Name of species	%D1	%D2	%D3	Total
Amaranthace dubius	0.7	0.12	0.06	0.88
Chenopodium murale	0.12	0.06	0.00	0.18
Chenopodium opulifolium	0.06	0.00	0.00	0.06
Chloris gayana	0.00	0.06	0.00	0.06
Chloris radiata	0.12	0.06	0.00	0.18
Croton macrostechys	0.12	0.06	0.18	0.35
Crotalaria sp.	0.00	0.06	0.00	0.06
Cucumis melo	0.06	0.00	0.00	0.06
Cynodon dactylon	0.06	0.00	0.00	0.06
Datura stramonium	0.06	0.00	0.00	0.06
Digitaria abyssinica	0.23	0.35	0.06	0.65
Eragrostis papposa	0.82	0.29	0.12	1.23
Eragrostis sp.	0.18	0.00	0.00	0.18
Erucastrum arabicum	0.06	0.00	0.00	0.06
Euphorbia granulata	0.06	0.00	0.00	0.06
Euphorbia hirta	0.88	0.06	0.12	1.06
Euphorbia longecornuta	0.18	0.12	0.00	0.29
Euphorbia schimperiana	0.06	0.18	0.00	0.23
Galinsoga parviflora	0.06	1.94	2.58	4.58
Glycine wightii	0.18	0.00	0.00	0.18
Indigofera amorphoides	0.06	0.12	0.00	0.18
Ipomoea obscura	0.00	0.06	0.00	0.06
Medicago polymorpha	0.06	0.00	0.00	0.06
Parthenium hysterophorus	71.34	11.34	5.23	87.91
Setaria acromelaena	0.06	0.12	0.00	0.18
Solanum incanum	0.00	0.12	0.23	0.35
Solanum somalinses	0.00	0.00	0.23	0.23
Sonchus oleraceus	0.00	0.06	0.06	0.12
Tragus berteronianus	0.18	0.06	0.06	0.29
Withania somnifera	0.12	0.06	0.00	0.18

Table 14. Percent contribution of each species in High infested sample sites along depths

Name of species	%D1	%D2	%D3	Total
Alternanthera repens	0.043	0.000	0.000	0.043
Asystasia schimperi	0.427	0.128	0.000	0.555
Bidens pilosa	0.043	0.000	0.000	0.043
Bothriochloa insculpta	0.043	0.000	0.000	0.043
Cassia occidentalis	0.128	0.000	0.000	0.128
Cenchrus ciliaris	0.128	0.000	0.000	0.128
Chenopodium murale	0.213	0.000	0.000	0.213
Chloris radiata	0.043	0.000	0.000	0.043
Conyza bonariensis	0.043	0.000	0.000	0.043
Craterostigma pumilum	0.043	0.000	0.000	0.043
Croton macrostechys	0.085	0.213	0.299	0.597
Cynodon dactylon	0.213	0.171	0.000	0.384
Digitaria abyssinica	0.085	0.000	0.000	0.085
Eragrostis papposa	0.171	0.000	0.000	0.171
Eragrostis sp.	0.299	0.085	0.085	0.469
Eriochloa nubica	0.085	0.000	0.000	0.085
Euphorbia granulata	0.043	0.213	0.000	0.256
Euphorbia hirta	0.341	0.171	0.213	0.725
Glycine wightii	0.299	0.043	0.000	0.341
Indigofera amorphoides	0.043	0.085	0.000	0.128
Medicago polymorpha	0.469	0.000	0.085	0.555
Parthenium .hysterophorus	54.735	21.971	17.363	94.070
Panicum coloratum	0.000	0.043	0.000	0.043
Solanum nigrum	0.043	0.043	0.085	0.171
Solanum somalinses	0.043	0.043	0.000	0.085
Sonchus oleraceus	0.171	0.085	0.000	0.256
Xinnia peruviana	0.000	0.043	0.000	0.043

Table 15. Percent contribution of each species in all sample site along depths

	D1%	D2%	D3%	Total
Ajuga sp.	0.017	0.000	0.000	0.017
Alternanthera repens	0.017	0.000	0.000	0.017
Amaranthace dubius	0.262	0.052	0.017	0.332
Aristida adscensionis	0.017	0.000	0.000	0.017
Asystasia schimperi	1.731	0.052	0.227	2.010
Bidens pilosa	0.017	0.000	0.000	0.017
Bothriochloa insculpta	0.052	0.000	0.000	0.052
Cassia occidentalis	0.052	0.000	0.000	0.052
Cenchrus cilaris	0.087	0.000	0.000	0.087
Chenopodium albem	0.017	0.000	0.000	0.017
Chenopodium murale	0.140	0.017	0.000	0.157
Chenopodium opulifolium	0.017	0.000	0.000	0.000
Chloris gayana	0.087	0.017	0.000	0.105
Chloris radiata	0.192	0.000	0.000	0.192
Chrysopogon aucheri	0.734	0.175	0.035	0.944
Conyza bonariensis	0.052	0.000	0.000	0.052
Craterostigma pumilum	0.087	0.017	0.000	0.105
Crotolaria plowdenii	0.017	0.000	0.000	0.017
Crotalaria sp.	0.192	0.087	0.017	0.297
Cucumis melo	0.017	0.017	0.017	0.052
Cynodon dactylon	0.245	0.122	0.000	0.367
Dactyloctenium aegyptium	0.087	0.000	0.000	0.087
Datura stramonium	0.017	0.000	0.000	0.017
Digitaria abyssinica	0.420	0.524	0.105	1.049
Eragrostis papposa	2.360	0.752	0.490	3.601
Eragrostis sp.	0.944	0.385	0.227	1.556
Croton macrostechys	0.297	0.332	0.420	1.049
Eriochloa nubica	0.035	0.000	0.000	0.035
Erucastrum arabicum	0.035	0.000	0.017	0.052

Table 15 (*Continued*)	D1%	D2%	D3%	Total
Euphorbia granulata	0.105	0.122	0.017	0.245
Euphorbia hirta	0.682	0.315	0.122	1.119
Euphorbia longecornuta	0.052	0.035	0.000	0.087
Euphorbia schimperi	0.017	0.052	0.000	0.070
Galinsoga parviflora	0.052	0.420	0.787	1.259
Glycine wightii	0.245	0.017	0.017	0.280
Gutenbergia cordifolia	0.017	0.000	0.000	0.017
Heliotropium aegyptiacum	0.017	0.000	0.000	0.017
Heliotropium cinarescens	0.000	0.017	0.000	0.017
Indigofera amorphoides	0.437	0.262	0.035	0.734
Ipomoea obscura	0.000	0.017	0.000	0.017
Kosteletzkya adoensis	0.017	0.000	0.017	0.035
Lintonia nutans	0.035	0.017	0.000	0.052
Medicago polymorpha	0.227	0.017	0.052	0.297
Nicotiana tabacum	0.000	0.017	0.000	0.017
Ocimum basilicum	0.087	0.035	0.017	0.140
Panicum coloratum	0.385	0.402	0.052	0.839
Parthenium hysterophorus	56.206	13.916	9.318	79.441
Poctulaca quadyifida	0.017	0.000	0.000	0.017
Schkuhria pinnta	0.052	0.017	0.000	0.070
Setaria acromelaena	0.017	0.017	0.000	0.035
Solanum incanum	0.087	0.035	0.017	0.140
Solanum nigrum	0.629	0.105	0.175	0.909
Solanum somalinses	0.070	0.017	0.070	0.157
Sonchus oleraceus	0.140	0.122	0.070	0.332
Tragus berteronianus	0.350	0.035	0.052	0.437
Tribulus terrestris	0.000	0.052	0.000	0.052
un identifies sp.	0.070	0.017	0.000	0.087
Withania somnifera	0.297	0.105	0.122	0.524
Xanthium spinosum	0.000	0.017	0.000	0.017
Xinnia peruviana	0.035	0.052	0.087	0.175

4.3.3. Species diversity and evenness in the soil seed bank

The diversity and evenness of species were significantly different (P< 0.05) among parthenium infestation levels (See Table 16 and Appendix Tables 13 and 14). The highest mean number (2.3) of the diversity was obtained in VLIS site while the lowest mean number (0.36) was obtained at HIS. The higher value of the diversity index indicates the varation in the type of species and heterogeneity in the communities whereas the lesser values indicate the homogeneities of the species. According to Table 16, the high mean value of (0.86) evenness was observed at VLIS and least mean value of (0.15) evenness was obtained at the HIS. The diversity and evenness of species were positively related. The higher species of diversity, the greater would be the evenness. The present study revealed that the diversity and evenness of species declined with increasing spread of parthenium. This suggests the negative influence that this species had on the status of species diversity in the studied rangeland sites.

The findings about the mean number of diversity at MIS and HIS were similar to those revealed in the study done of Navie *et al*. (2004). In their studies, the authors pointed out that the diversity values varied between 0.14 and 1. The dominance of the weed in the community may reduce the diversity of the seed bank (Hopkins and Graham, 1984). It is possible that the prolonged persistence of parthenium in the study area might have contributed to very low seed bank diversity and evenness values at MIS and HIS.

Table 16. Species diversity and evenness (LSM ± SE) in the soil seed bank along infestations **levels**

Infestation level	Diversity	Evenness
NIS	2 ± 0.097^{b}	0.713 ± 0.03^{b}
VLIS	2.3 ± 0.097^{a}	0.864 ± 0.025^{a}
LIS	1.3 ± 0.097^{c}	0.523 ± 0.058^{c}
MIS	0.6 ± 0.097^{d}	0.233 ± 0.03^{d}
HIS	0.357 ± 0.097^{d}	0.154 ± 0.021^{d}
CV %	16.16	16.14
P in ANOVA	0.000	0.000

^{abcd} Means within a column with different superscript are significantly different at P < 0.05

4.3.4. Vertical distribution of seeds

The overall vertical distributions of seedlings were similar in all sites. Table 17 below shows that the highest density occurred in the upper three cm of soil and gradually decreasing with increasing depth. For instance, the mean seedling densities were 1,427seeds/m^2, 416.48seeds/m^2 and 276.55seeds/m^2 in 0-3, 3-6 and 6-9 cm depths, respectively.

Table 17. Seedling density/m^2 (LSM ± SE) along soil depths

Depths	Grasses	Forbs	Parthenium	Total
D1(n=60)	132.43± 16.32 ^{a}	134.47±23^a	1160.28±76 ^{a}	1427.01±87 ^{a}
D2(n=60)	57.24± 16.32 ^{b}	55.53±23^b	303.72±7 ^{b}	416.48±87 ^{b}
D3(n=60)	30.56± 16.32 ^{b}	49±23^b	196.09±7 ^{b}	276.55±87 ^{b}
CV %	34.82± 16.32	24.69	37.98	13.79
P in ANOVA	0.000	0.000	0.000	0.000

^{abc} Mean within a column with different superscripts is significantly different at P < 0.05
where D1, D2 and D3 are soil depths (0-3, 3-6 and 6-9 cm), respectively.

The densities of all of the seedlings were found to be significantly different (P< 0.05) both vertically and horizontally (See Appendix Table 18). Moreover, seedling density was negatively correlated with depth (r =-0.495** (Appendix Table 22). In relation to the vertical distribution, the seedlings of species were almost entirely concentrated to the upper most soil layer (0-3 cm depth). For example, *Bothriochloa insculpta, Cenchrus ciliaris, Dactyloctenium aegyptium, Chrysopogon aucheri, Eragrostis papposa and Parthenium hysterophorus* were high in (0-3 cm) depth than the other recorded species. On the other hand, some species had seedlings which were well distributed in all soil layers. For instance, the distribution of *Parthenium hysterophorus, Panicum coloratum, Croton macrostachys* and *Amarantha dubius* in Table 15 shows this.

The concentration of the seedlings at the top soil was supported by other seed bank studies (Demel and Granstrom, 1995; Espinar *et a*l., 2005 and Belaynesh, 2006). In their studies, these authors recorded the mean number of seedling density 335.95 seeds/m^2, 101.69 seeds/m^2 and 51.83 seedlings/m^2 in (0-3, 3-6 and 6-9 cm) depths in the rangelands of Jijiga.

4.3.5. The similarity between soil seed bank flora and aboveground vegetation

From a total of 35 species germinated in NIS, 20 species were found to be common. From a total of 31 species germinated in VLIS and LIS, 20 and 13 species were found to be common, respectively. In addition, from among 30 species germinated in MIS, 13 species were found to be common. Again, from among 27 species germinated in HIS, 0 species were found to be common. Jaccard's similarity index showed a significant (P< 0.05) difference among the study sites (See Appendix Table 19). As shown in Table 9, the highest mean similarity (0.30) was observed in NIS while the lowest mean of similarity (0.14) was observed in HIS. The low similarity between species found in the soil seed bank and those in the standing vegetation could be due in part to the presence of parthenium in soil seed bank. Hence, the prolonged presence of parthenium weed in soil seed bank might have been substantially reduced the ability of some of the native species to germinate (Navie *et al*., 2004). It could also be due to the deposition of the seeds for many seasons in the seed bank (Pierce and Cowling, 1991), or due to the presence of high level of seed predation (Wilson *et al.*, 1995). As a result, all of the seeds produced by the standing vegetation do not inter into the soil seed bank. Their loss could be one of the main factors that caused lower degree of concordance between standing vegetations and the species in the soil seed bank.

The findings of the current study further strengthen the findings of Kebrom and Tesfaye (2001) in their study in southern Wallo, Ethiopia, that of Belaynesh (2006) on the soil seed bank in Jijiga and finally that of Paul and David (1995) conducted in the coastal barrier island of the North West Coast of Florida, USA. In their study, Paul and David (1995) obtained similarity in the seed bank densities to the aboveground vegetation cover of Jaccard's index 0.36. In similar way, Assaeed and Al-Doss's (2002) study in Saudi Arabia on an area infested with *Rhazya stricta* revealed the existence of low similarity between the standing vegetation and soil seed bank species in a situation where a dense infestation of the weed occurs.

4.4. Competition Study

The relative crowding coefficients based on aboveground biomass suggested that *Panicum coloratum* was more dominant than parthenium in plant mixture of 50:50 and 75:25 (Panicum: Parthenium*).* In this combination, *P. coloratum* had higher crowding coefficients. However, as shown in Table 18, 25:75, combinations parthenium was more dominant as indicated by higher crowding coefficients. The aggressivity value between these two species also showed similar trends like that of relative crowding coefficients. In 50:50 and 75:25 seed proportion, *P. coloratum* was found to be generally more dominant as indicated by positive numerical value while that of parthenium showed negative aggressivity index. However, Table 19 depicts that in seed proportion, 25:75 parthenium was more dominant as indicated by positive numerical value of an aggressivity index while that of panicum indicated negative value.

The study showed that the biomass of parthenium was strongly inhibited by the presence of *Panicum coloratum* in 50:50 and 75:25 seed proportion. However, the biomass of *panicum* was strongly inhibited by parthenium at seed proportion of 25:75. On the whole, a total biomass reduction was observed due to mutual inhibition between these two species and that *panicum* out competed parthenium at a level of combination greater or equal to 50%. However, the competitive ability of *panicum* failed when the combination is less than 50%.

Table 18 shows that the relative crowding coefficients based on aboveground biomass of *Cenchrus ciliaris and Bothriochloa insculpta* were found to be generally more dominant than parthenium in all plant mixtures (50:50, 75:25 and 25:75) (Cenchrus: parthenium) and *(Bothriochloa*: parthenium) as indicated by a higher crowding coefficient. The competitive ability of the species with parthenium in mixtures was also measured on aggressivity index based on aboveground biomass. This index revealed similar trends to that of relative crowding coefficients as made clear in Table 19. In all seed proportions, C*. ciliaris and B. insculpta* were found to be generally more dominant. This is indicated by the positive numerical value of an aggressivity index and by the negative numerical value of parthenium the index.

According to this study, the aboveground biomass of these species was strongly reduced when two species (parthenium and any grass) exist together. The reason might be due to allelopathic interaction that exists between the two species. The finding here validates the findings of O'Donnel and Adkins (2005). In their study, O'Donnel and Adkins (2005) indicated that *C. ciliaris and B. insculpta strongly out* competed *parthenium hysterophorus*.

In the current study, Chloris *gayana* out competed p. *hysterophorus* only in 75:25 (Chloris: Parthenium) proportion. However, in the rest of the combinations, 50:50 and 25:75 *P. hysterophorus* strongly out-competed *C. gayana* as the higher crowding coefficient of parthenium in these combinations indicates (See Table 18). The aggressivity index between these two species also showed similar trends like that of relative crowding coefficient. *Chloris gayana* out-competed only *Partheniun hysterophorus* in plant mixture of 75:25 combinations. On the other hand, the rest of the combinations failed to out-compete parthenium. On the other hand, *Parthenium hysterophorus* was found to be dominant in 50:50 and 25:75 plant mixture as indicated by positive aggressivity index shown in Table 19.

Table 19 reveals that *Cynodon dactylon* out competed parthenium in plant mixtures of 75:25 and 50:50 and 25:75 as indicated by a higher crowding coefficient than that of parthenium. An aggressivity index between these two species also showed *C. dactylon was* found to be dominant in plant mixtures of 75:25 and 50:50 as indicated by positive numerical value of an aggressivity index. However, in 25:75 plant mixture *C. dactylon* failed to show such dominancy.

Table 18. Relative crowding coefficients of grasses with parthenium in replacement mixture

	DMBg/m^2		75:25		50:50		25:75	
Species	100:0	0:100	kG	kP	kG	kP	kG	kP
Panicum:Parthenium	58.48	37.28	0.75	0.70	0.63	0.57	0.25	0.53
Cenchrus :Parthenium	38.74	37.28	0.47	0.26	0.53	0.34	0.7	0.32
Chloris:Parthenium	32.45	37.28	1.02	0.57	0.48	1.26	0.24	0.85
Bothriochloa:Parthenium	60.46	37.28	0.61	0.33	0.81	0.34	0.74	0.29
Cynodon:Parthenium	100.26	37.28	1.69	0.26	0.96	0.31	0.67	0.47

Key: DMB=Dry Matter Biomass, kG=relative crowding coefficients of any grass, kP relative crowding coefficients of parthenium, 100:0 =biomass of grasses, 0:100= Biomass of parthenium.

Table 19. Aggressivity index of grasses with parthenium in replacement mixture

	75:25		50:50		25:75	
Species	AG	AP	AG	AP	AG	AP
Panicum:Parthenium	+0.17	-0.17	+0.06	-0.06	-0.51	+0.51
Cenchrus :Parthenium	+0.46	-0.46	+0.54	-0.54	+0.09	-0.09
Chloris:Parthenium	+0.37	-0.37	-0.47	+0.47	-0.66	+0.66
Bothriochloa:Parthenium	+0.46	-0.46	+0.38	-0.38	+0.17	-0.17
Cynodon:Parthenium	+0.79	-0.79	+0.5	-0.5	-0.05	+0.05

Key: AG= Aggressivity index of grasses, AP= Aggressivity index of parthenium

In general, the present study indicated that the degree of competition of *Panicum coloratum* 75:25 and 50:50 combinations and *Chloris gayana* only 75:25 with *Parthenium hysterophorus* gave the higher degree of competition. Furthermore, the data revealed the superiority of *Cynodon dactylon* followed by *Chloris gayana and* Panicum coloratum over the other species sown in 75:25 combinations. However, in 50:50 combinations, *Chloris gayana* failed to show such superiority. The other important finding was that *Bothriochloa insculpta* along with *Cynodon dactylon* and *Panicum coloratum* that had great degree of competition performed better than other species in 75:25 plant mixtures. *Parthenium hysterophorus* recorded a strong competition only against *Chloris gayana* and *Panicum coloratum* when the proportion *Parthenium hysterophorus* has 75% in mixture. As shown in Table 18, the reduction in biomass of both grasses and parthenium were observed due to allelopathic interaction which caused mutual inhibition.

The investigation made to detect the competitive ability (aggressivity) of the different species against *Parthenium hysterophorus* showed that both *Cenchrus ciliaris* and *Bothriochloa insculpta* were found to be more aggressive at all of the studied combinations whereas *Panicum coloratum* and *Cynodon dactylon* were found to be more aggressive than *Parthenium hysterophorus* in 75:25 and 50:50 combinations. However, the competitive ability of Chloris *gayana* was found to be similar with the degree of competition against *parthenium hysterophorus.*

This suggests that in areas with a very high infestation level, *parthenium hysterophorus Cenchrus ciliaris* and Bothriochloa *insculpta* could be the best competitive species to replace the weed. However, in moderate to low infestation levels, Panicum coloratum and *Cynodon dactylon* can be used to rehabilitate weed infested rangelands. Furthermore, species like *Chloris gayana* can be used to renovate rangelands where parthenium has infested only slightly.

5. SUMMARY AND CONCLUSIONS

5.1. Summary

The study was conducted in three districts of the Jijiga Zone of the Somali Regional State. The purpose of the study was to assess the perception of pastoralists on the effects of parthenium, the impact of parthenium on herbaceous species composition and diversity on both aboveground and soil seed bank flora. The study's other main purpose was to evaluate the competitive ability of forage species with parthenium. The pastoralists' perception of the impacts of parthenium was assessed using structured questionnaire (40 households), group discussions and visual observations. To study the impacts of parthenium on the composition and diversity of species, the sites were categorized according to the infestation level of parthenium 0, <10, 11-25, 26-50 and > 50%. In the fields, data about the species composition, biomass, the identity of all plants and soil samples in three depth (0-3, 3-6 and 6-9 cm) were collected. The competitive ability of forage species was evaluated in Haramaya University greenhouse and the aboveground biomass of all species were collected.

5.1.1. Pastoralists' perception on effects of parthenium

The high grazing pressure caused by drought or high stock number decreased the vigor and competitiveness of pasture, and allowed the entry of parthenium. The study indicated that 68.4% of the pastoralists identified overgrazing as the main cause of parthenium infestation. About 73.7% of them revealed that infestation level was high in grazing areas. The respondents suggested that parthenium reduces the carrying capacity of the grazing land by reducing the composition and diversity of palatable species. They also argued that the weed adversely affected milk and meat quality and the marketing of their products in addition to affecting the human and animal health in the study area. The study revealed that control of the weed in the grazing area was very low. One indication is that only 5% of the respondents use hand weeding. In crop fields, they used hand weeding and hoeing to eradicate the weed. The respondents made clear their observations that the weed adversely affected palatable species and caused scarcity of forage. They pointed out also that the weed brought about tainting of meat and milk, and drastically reduced the marketing of animal products.

5.1.2. Biodiversity study

In the study sites, a total of 63 species belonging to 20 different families were identified. Out of these, 22 were grasses, 4 were legumes, 1 was sedges and 36 were forbs. Out of the total 63 identified species, 41, 41, 33, 23 and 22 species were found respectively in NIS, VLIS, LIS, MIS and HIS. This situation indicates that the infestation of parthenium decreased the richness of species. On cover abundance basis, grasses comprised respectively 62.72 %, 62%, 55.93%, 39.97% and 16.6% in NIS, VLIS, LIS, MIS and HIS. Similarly, the proportions of forbs were respectively 30.65%, 31.98%, 24.77%, 23.38% and 15.1% in NIS, VLIS, LIS, MIS and HIS. Accordingly, the proportion of parthenium was respectively 0%, 1.5%, 14.27%, 30.72%, and 66.98% in NIS, VLIS, LIS, MIS and HIS. In all infestation levels, *Asystasia schimperi, Cassia occidentalis, Cynodon dactylon, Eragrostis papposa, Chrysopogon aucheri, Ocimum basilicum and Tragus berteronianus* had good composition than other species. On the other hand, *Erucastrum arabicum and Euphorbia hirta* had good composition in HIS than in other sites. This could be because the two species had good association with parthenium.

The species composition of the herbaceous vegetation of grasses and forbs were found to be significantly different ($P<0.05$) among infestation levels. The highest species composition (0.63, 0.36), for grasses and forbs respectively, were obtained in NIS and the least (0.18, 0.175) obtained in HIS. The evenness and diversity showed significant ($P< 0.05$) difference among infestation levels. The highest variability and evenly distribution of the species was found in NIS when compared to the other infestation levels. The production of grasses and forbs biomass was found to be significantly ($P< 0.05$) different among infestation levels. The highest biomass of grasses and forbs were obtained in NIS and the least in HIS. The biomass production of grasses was reduced to 25.2, 39.1, 60 and 92% in VLIS, LIS, MIS and HIS, respectively as compared to NIS. The percentage of parthenium coverage negatively affected the composition of species, the aboveground biomass, the evenness and the diversity index.

The current study generally revealed that parthenium strongly affected the composition and the diversity of species and the aboveground biomass in the study area.

5.1.3. Soil seed bank study

A total of 59 species from five infestation levels that belong to 16 families were identified. Out of these species, 67.9 and 23.72% were annual and perennial herbaceous, 6.7% were perennial woody herb/shrub and the remaining 1% was tree (*Croton macrostechys*), which germinated in all infestation levels and depths. The proportion of grasses for the levels of infestation was 77, 36.37, 11.77, 2.65 and 1% in NIS, VLIS, LIS, MIS and HIS respectively. The most dominant species were *Eragrostis papposa*, *Digitaria abyssinica* and *Parthenium hysterophorus* in NIS, VLIS, and LIS, MIS and HIS, respectively. *Parthenium hysterophorus* accounted for 0.56% in NIS, 7.39% in VLIS, 56.46% in LIS, 87% in MIS and 94% in HIS. Generally, parthenium accounted for 79.42% of the entire seed bank in the study districts. The seed bank germination of the present study generally indicated that *Parthenium hysterophorus* was the most dominant species both horizontally and vertically. The relative higher seed bank of these species could be attributed to either their ability to persist in soil seed bank or to a relatively higher turnover of seeds.

The diversity and evenness of species in SSB among infestation levels was found to be significantly ($P<0.05$) different. The highest diversity and evenness value was obtained in VLIS and the least in HIS. This happened because a single species (*Parthenium hysterophorus*) dominated the seed bank of HIS. Grasses, parthenium and the total seedling density showed significant ($P<0.05$) difference both vertically and horizontally. However, the seedling density of forbs showed significant difference ($P<0.05$) along depths, but the interaction effects between depth and across infestation levels showed non–significant ($P>0.05$) difference. Moreover, the vertical distributions of the seedlings in the soil seed bank showed a similar trend for all of the investigated sample sites. The highest density was recorded in the upper 0-3 cm (1,427) seedlings/m^2 of the soil depths and gradually decreased with increasing depth (416seedligs/m^2 at 3-6 cm and 276.55seedlings/m^2 at 6-9 cm). Jaccard similarity index showed significant ($P<0.05$) difference between infestation levels. The highest similarity in mean was obtained in NIS and the least at HIS.

5.1.4. Competition Study

The competitive ability of grass species and parthenium showed that *Bothriochloa insculpta* strongly out competed parthenium followed by *Cenchrus ciliaris, Cynodon dactylon, Panicum coloratum* and *Chloris gayana.* Among the tested grass species tested, *Chloris gayana was* found to be of weak competence and out competed only parthenium at its higher density.

5.2. Conclusions and Recommendations

This study suggested that *Parthenium hysterophorus* has been influencing the composition and diversity of species both in SSB and aboveground vegetation. It also showed that the weed weakens the carrying capacity of the rangeland, the production system and is generally becoming a threat to the sustainability of livelihood of the Somali pastoral households. The study implicated that integrated long-term management programs must be carried out to control the weed. The study suggested that it is difficult to control the weed in short period of time due to persistent soil seed bank formation and wider area coverage. Well organized, coordinated and concerned efforts must be made to control or eliminate the weed. His requires the local people, scientists, governments and NGO's to work in unison.

On the basis of the entire study and the conclusions drawn here, the researcher makes the following recommendations:

First and foremost, conservations of pasture through proper grazing management need to be given priority since there is a definite relationship between the invasion of parthenium and the vigor of the pasture.

In addition, the pastoral communities must be advised and trained on how they should control the weed and carry out rangeland improvement measures such as proper grazing management through reducing stock numbers.

Scope for Future Research

- ❖ The effect of *Parthenium hysterophorus* on the composition and diversity species and on aboveground biomass and its abundance in the soil seed bank were studied. However, the above parameters could be affected both temporarily and spatially. Therefore, other deeper and wider studies should be made at different seasons and in different locations to observe the influence in seasons on parthenium on SSB and aboveground flora. Such a study is important to create management options for this weed.

- ❖ The impact of parthenium on animal health and their products in the present study area was undertaken with the help of structured questionnaire. Therefore, further studies must be undertaken on experimental animals by feeding them parthenium at different levels. Doing this may enable researchers to see the effect on their health as well as on their products.

- ❖ The competition experiment was examined only in greenhouse. Therefore, due consideration must be given to field trials.

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7. APPENDIX

Appendix Table 1. List of sample sites and their GPS readings

Code	Site	Altitude (m)	Latitude (N)	Longitude (E)	Slope	Infestation levels
1	Ceejiso	1402-1420	08 58 22-08 58 29	043 41 26-043 42 08	4^0	None
2	Lantaeggal	1441-1445	08 58 37-08 59 42	043 38 45-043 39 03	4^0	None
3	Farahgurae	1476-1487	09 00 12-09 01 06	043 36 20-043 36 58	5^0	Very low
4	Farahleven	1514-1583	09 02 14-09 03 10	043 33 02-043 33 26	5^0	None
5	Kurtumaley	1561-1574	09 04 02- 09 05 04	043 30 29- 043 00 47	5^0	Very low
6	Artishik Keble1	1596-1615	09 04 36-09 05 34	043 27 41-043 27 56	5^0	Moderate
7	Belyialie	1606-1613	09 06 43-09 07 48	043 25 29- 043 25 58	5^0	High
8	Artishik	1594-1604	09 08 19- 09 09 15	043 22 30-043 22 46	5^0	High
9	Ado/Cado	1649-1656	09 09 16-09 70 03	043 17 31-043 18 17	5^0	High
10	Kotroble	1655-1656	09 06 29- 09 06 36	043 14 21-043 14 25	5^0	High
11	Deneba	1715-1717	09 05 53- 09 06 15	043 11 35-043 11 45	5^0	Moderate
12	Gerebe	1746-1752	09 09 00- 09 09 11	043 08 12- 043 08 24	5^0	Very low
13	Meregacho	1677-1701	09 10 53-09 11 20	043 05 37- 043 06 00	5^0	Moderate
14	Harae 1	1637-	09 13 31- 09 13	043 02 32- 043	4^0	Low

		1648	54	02 50		
15	Amedeliae	1640-1722	09 15 23-09 15 55	042 39 45-042 59 52	5^0	Low
16	Beldaederae	1713-1790	09 17 48- 09 18 06	042 55 24- 042 55 28	5^0	Moderate
17	Allegeliae	1809-1815	09 19 32-09 20 13	42 50 21-042 52 38	5^0	Low
18	Gerebasae	1686-1739	09 20 49-09 20 52	042 49 25- 042 50 21	5^0	Low
19	Karamara	1860-1870	09 21 51-09 21 58	042 42 37-042 42 40	5^0	Very low
20	Lebeshakie	1746-1752	09 09 00-09 09 11	043 08 12-043 08 24	5^0	None

Appendix Table 2 . Total estimate scale based on abundance plus coverage (Wittenberg *et al.*, 2004)

+	Individuals of a species sparsely present in the stand; coverage very small
1	Individuals plentiful, but coverage small
2	Individuals very numerous if small; if large; covering at least 5% of the area
3	Individuals few or many; collectively covering 6-25% of the area
4	Individuals few or many; collectively covering 26-50% of the area
5	Plants cover 51-75 % of the area
6	Plants cover 76-100% of the area

Appendix Table 3. List of plant species recorded from the study sites along infestation levels

Name of species	Family name	NIS	VLIS	LIS	MIS	HIS
Acanthospermum hispidum	*ASTERACEAE*	P	A	A	A	A
Acanthus sp.	*ACANTHACEAE*	A	P	P	A	A
Ageratum sp.	*ASTERACEAE*	A	A	P	A	A
Amaranthace dubius	*AMARANTHACEAE*	A	A	A	A	P
Andropogon abyssinicus	*POACEAE*	A	P	P	A	A
Aristida adscensionis	*POACEAE*	P	P	P	P	A
Asystasia schimperi	*ACANTHACEAE*	P	P	P	P	P
Blepharis persica	*ACANTHACEAE*	P	P	A	A	A
Bothriochloa insculpta	*POACEAE*	P	P	A	P	A
Cassia occidentalis	*FABACEAE*	P	P	P	P	P
Cenchrus ciliaris	*POACEAE*	P	P	P	A	P
Chenopodium murale	*CHENOPODIACEAE*	A	A	A	A	P
Chenopodium opulifolium	*CHENOPODIACEAE*	A	A	P	A	A
Chloris gayana	*POACEAE*	P	A	A	A	A
Chloris radiata	*POACEAE*	A	A	A	P	A
Chrysopogon aucheri	*POACEAE*	P	P	P	P	P
Commelina latifolia	*COMMELINACEAE*	P	P	P	A	A

Appendix Table 3 *(Continued)*						
Commicarpus africanus	*NYCTAGINACEAE*	P	P	A	A	A
Conyza bonariensis	*ASTERACEAE*	P	P	P	A	P
Craterostigma pumilum	*SCROPHULARIACEAE*	A	A	A	A	P
Cucumis melo	*CUCURBITACEAE*	P	P	A	A	A
Cynodon dactylon	*POACEAE*	P	P	P	P	P
Cyperus rotundus	*CYPERACEAE*	A	A	P	A	A
Dactyloctenium aegyptium	*POACEAE*	P	P	P	A	A
Digitaria abyssinica	*POACEAE*	P	A	A	P	P
Eleusine Jaegeri	*POACEAE*	A	A	P	A	A
Eragrostis papposa	*POACEAE*	P	P	P	P	P
Eragrostis sp.	*POACEAE*	P	P	A	P	A
Eriochloa nubica	*POACEAE*	P	A	A	A	P
Erucastrum arabicum	*BRASSICACEAE*	A	P	A	A	P
Euphorbia granulata	*EUPHORBIACEAE*	P	A	A	A	A
Euphorbia hirta	*EUPHORBIACEAE*	P	P	P	P	P
Glycine wightii	*FABACEAE*	P	A	A	P	A
Guizotia scabra	*ASTERACEAE*	A	P	P	A	A
Heliotropium cinarescens	*BORAGINACEAE*	P	P	A	P	P
Hibiscus aponeurus	*MALVACEAE*	P	P	P	A	P
Indigofera amorphoides	*FABACEAE*	P	P	P	P	P
Ipomoea obscura	*CONVOLVULACEAE*	P	P	A	A	A
Laggera appendiculata	*ASTERACEAE*	A	P	A	A	A
Launaea sp.	*ASTERACEAE*	P	A	A	A	A
Leucas martinicensis	*LIAMIACEAE*	A	P	A	A	P
Lintonia nutans	*POACEAE*	P	P	P	A	A
Medicago polymorpha	*FABACEAE*	P	P	P	P	A
Microchloa kunthii	*POACEAE*	A	A	P	A	A
Ocimum basilicum	*LIAMIACEAE*	P	P	P	P	P
Panicum coloratum	*POACEAE*	P	P	A	P	P
panicum sp.	*POACEAE*	P	P	P	A	A

Appendix Table 3 *(Continued)*						
Parthenium hysterophorus	*ASTERACEAE*	A	P	P	P	P
pennisetum polystachion	*POACEAE*	P	P	A	A	A
Ruellia patula	*ACANTHACEAE*	P	P	A	P	A
Ruellia sp.	*ACANTHACEAE*	A	A	P	A	A
Schkuhria pinnta	*ASTERACEAE*	A	A	P	P	A
Setaria acromelaena	*POACEAE*	A	P	A	A	A
Solanum incanum	*SOLANACEAE*	P	A	A	P	A
Solanum nigrum	*SOLANACEAE*	P	P	P	A	A
Sonchus oleraceus	*ASTERACEAE*	P	P	A	A	A
Sporobolus pyramidalis	*POACEAE*	P	P	A	A	A
Tragus berteronianus	*POACEAE*	P	P	P	P	P
Tribulus terrestris	*ZYGOPHYLLACEAE*	A	A	A	P	A
Triplotaxis somalensis	*ASTERACEAE*	A	A	A	P	A
unidentified spp		A	P	A	A	A
Verbascum schimperi	*SCROPHULARIACEAE*	A	A	P	A	A
Withania somnifera	*SOLANACEAE*	P	P	P	A	A
Xanthium spinosum	*ASTERACEAE*	P	P	P	A	A

Key: P= present, A= Absent

Appendix Table 4.Test species for competition experiment

Grasses	Somali Name
1. *Bothriochloa insculpta*	Qoeba
2.Cenchrus ciliaris	Cawsmacaan
3. Chloris gayana	Serdi
4. *Cynodon dactylon*	Serdi
5.*Panicum coloratum*	Garawgaraw

Appendix Table 5. ANOVA for grasses composition of the sample sites along infestation levels

Source	DF	Sum of Squares	Mean Square	F	Sig.
Trt	4	0.559811	0.139953	18.3113	<.000
Rep	3	0.024109	0.008036	1.0514	0.406
Error	12	0.091716	0.007643		
Total	19	0.675635			

Appendix Table 6. ANOVA for forbs composition of the sample sites along infestation levels

Source	DF	Sum of Squares	Mean Square	F Ratio	Sig.
Trt	4	0.116532	0.029133	3.4669	0.042
Rep	3	0.020892	0.006964	0.8288	0.503
Error	12	0.100838	0.008403		
Total	19	0.238262			

Appendix Table 7. ANOVA for diversity index of the sample sites along infestation levels

Source	DF	Sum of Squares	Mean Square	F	Sig.
Trt	4	3.908192	0.977048	41.5048	<0.000
Rep	3	0.096421	0.03214	1.3653	0.300
Error	12	0.282488	0.023541		
Total	19	4.2871			

Appendix Table 8. ANOVA for evenness index of the sample sites along infestation levels

Source	DF	Sum of Squares	Mean Square	F	Sig.
Trt	4	0.248806	0.062201	13.6571	0.000
Rep	3	0.01306	0.004353	0.9558	0.445
Error	12	0.054654	0.004555		
Total	19	0.31652			

Appendix Table 9. ANOVA for grass biomass of the sample sites along infestation levels

Source	DF	Sum of Squares	Mean Square	F	Sig.
Trt	4	330153.8	82538.5	10.49	0.000
Rep.	3	55898.18	18632.7	2.3681	0.122
Error	12	94419.98	7868.3		
Total	19	480472			

Appendix Table 10. ANOVA for forbs biomass of the sample sites along infestation levels

Source	DF	Sum of Squares	Mean Square	F	Sig.
Trt	4	75993.93	18998.5	10.5038	0.0007
Rep.	3	23372.92	7791	4.3075	0.028
Error	12	21704.61	1808.7		
Total	19	121071.5			

Appendix Table 11. ANOVA for parthenium biomass of the sample sites along infestation levels

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Trt	4	1409996	352499	104.4299	<.0001
Rep	3	16651.8	5551	1.6444	0.2314
Error	12	40505.5	3375		
Total	19	1467154			

Appendix Table 12. ANOVA for total biomass of the sample sites along infestation levels

Source	DF	Sum of Squares	Mean Square	F	Sig.
Trt	4	214763.6	53690.9	6.034	0.0067
Rep.	3	48703.22	16234.4	1.8245	0.1964
Error	12	106776.4	8898		
Total	19	370243.3			

Appendix Table 13. ANOVA for diversity index of soil seed bank along infestation levels

Source	DF	Sum of Squares	Mean Square	F	Sig.
Trt	4	11.47204	2.86801	75.7754	<.0001
Rep	3	0.227831	0.07594	2.0065	0.1669
Error	12	0.454186	0.03785		
Total	19	12.15406			

Appendix Table 14. ANOVA for evenness index of soil seed bank along infestation levels

Source	DF	Sum of Squares	Mean Square	F	Sig.
Trt	4	1.478578	0.369644	57	<.0001
Rep	3	0.049358	0.016453	2.537	0.1058
Error	12	0.07782	0.006485		
Total	19	1.605755			

Appendix Table 15. ANOVA for interaction effect of site and depth on grasses seedling density

Source	DF	Sum of Squares	F	Sig.
FA	4	246316.44	11.5510	<.0001
FB	2	106266.61	9.9667	0.0003
FA*FB	8	165046.91	3.8699	0.0015

Key: FA= Infestation levels, FB= Depths

Appendix Table 16. ANOVA for interaction effect site and depth on forbs seedling density

Source	DF	Sum of Squares	F	Sig.
FA	4	41222.91	0.9561	0.4408
FB	2	89453.41	4.1493	0.0222
FA*FB	8	111466.76	1.2926	0.2716

Key: FA= Infestation levels, FB= Depths

Appendix Table 17. ANOVA for interaction effect of site and depth on parthenium seedling density

Source	DF	Sum of Squares	F	Sig.
FA	4	22991712	49.6461	<.0001
FB	2	11166399	48.2233	<.0001
FA*FB	8	12551034	13.5508	<.0001

Key: FA= Infestation levels, FB= Depths

Appendix Table 18. ANOVA for interaction effect of site and depth on total seedling density.

Source	DF	Sum of Squares	F	Sig.
FA	4	20708368	34.8946	<.0001
FB	2	15834219	53.3629	<.0001
FA*FB	8	10466020	8.8179	<.0001

Key: FA= Infestation levels, FB= Depths

Appendix Table 19. ANOVA for Jaccard's similarity between soil seed bank and standing vegetation

Source	DF	Sum of Squares	Mean Square	F	Sig.
Trt	4	0.070747	0.017687	2.5728	0.0918
Rep	3	0.00554	0.001847	0.2686	0.8468
Error	12	0.082496	0.006875		
Total	19	0.158783			

Appendix Table 20. ANOVA for diversity index and percent parthenium cover

Source of variation	Sum of Squares	Degree of freedom	Mean Square	F	Sig.
Regression	4.078	1	4.078	350.840	.000(a)
Residual	.209	18	.012		
Total	4.287	19			

Appendix Table 21. ANOVA for evenness index and percent parthenium cover

Source of variation	Sum of Squares	Degree of freedom	Mean Square	F	Sig.
Regression	.226	1	.226	44.769	.000(a)
Residual	.091	18	.005		
Total	.317	19			

Appendix Table 22. Correlations between seedling density and depths

		Depth	Total seedling density
Depth	Pearson Correlation	1	-.495**
	Sig. (2-tailed)	.	.000
Total seedling density	Pearson Correlation	-.495**	1
	Sig. (2-tailed)	.000	.

** Correlation is significant at the 0.01 level (2-tailed).

Appendix Table 23. Name of species germinated in the soil seed bank all sample sites investigated

Name of species	Family	Life form
Ajuga sp.	*LIAMIACEAE*	A/H
Alternanthera repens	AMARANTHACEAE	A/H
Amaranthace dubius	AMARANTHACEAE	A/H
Aristida adscensionis	*POACEAE*	A/H
Asystasia schimperi	*ACANTHACEAE*	A/H
Bidens pilosa	*ASTERACEAE*	A/H
Bothriochloa insculpta	*POACEAE*	P/H
Cassia occidentalis	*FABACEAE*	A/H
Cenchrus ciliaris	*POACEAE*	P/H
Chenopodium albem	CHENOPODIACEAE	A/H
Chenopodium murale	CHENOPODIACEAE	A/H
Chenopodium opulifolium	CHENOPODIACEAE	A/H
Chloris gayana	*POACEAE*	P/H
Chloris radiata	*POACEAE*	A/H
Chrysopogon aucheri	*POACEAE*	P/H
Conyza bonariensis	*ASTERACEAE*	A/H
Craterostigma pumilum	SCROPHULARIACEAE	A/H
Crotolaria plowdenii	*PAPILIONOIDEAE*	P/H
Croton macrostechys	EUPHORBIACEAE	P/T
Crotalaria sp.	PAPILIONOIDEAE	P/H
Cucumis melo	CUCURBITACEAE	A/H
Cynodon dactylon	*POACEAE*	P/H
Dactyloctenium aegyptium	*POACEAE*	A/H
Datura stramonium	*SOLANACEAE*	A/H
Digitaria abyssinica	*POACEAE*	P/H
Eragrostis papposa	*POACEAE*	A/H
Eragrostis sp.	*POACEAE*	A/H
Eriochloa nubica	*POACEAE*	A/H
Euphorbia granulata	EUPHORBIACEAE	A/H
Erucastrum arabicum	BRASSICACEAE	A/H

Appendix Table. 24 (*Continued)*

Euphorbia hirta	EUPHORBIACEAE	A/H
Euphorbia longecornuta	EUPHORBIACEAE	A/H
Euphorbia schimperiana	EUPHORBIACEAE	A/H
Galinsoga parviflora	*ASTERACEAE*	A/H
Glycine wightii	*FABACEAE*	P/H
Gutenbergia cordifolia	*ASTERACEAE*	A/H
Heliotropium aegyptiacum	*BORAGINACEAE*	A/H
Heliotropium cinarescens	*BORAGINACEAE*	A/H
Indigofera amorphoides	*FABACEAE*	P/WS
Ipomoea obscura	*CONVOLVULACEAE*	P/H
Kosteletzkya adoensis	*MALVACEAE*	P/H
Lintonia nutans	*POACEAE*	P/H
Medicago polymorpha	*FABACEAE*	A/H
Nicotiana tabacum	*SOLANACEAE*	P/H
Ocimum basilicum	*LIAMIACEAE*	A/H
Parthenium hysterophorus	*ASTERACEAE*	A/H
Panicum coloratum	*POACEAE*	P/H
Poctulaca quadyifida	*ACANTHACEA*	A/H
Schkuhria pinnta	*ASTERACEAE*	A/H
Setaria acromelaena	*POACEAE*	A/H
Solanum incanum	*SOLANACEAE*	P/WS
Solanum nigrum	*SOLANACEAE*	A/H
Solanum somalinses	*SOLANACEAE*	P/WS
Sonchus oleraceus	*ASTERACEAE*	A/H
Tragus berteronianus	*POACEAE*	A/H
Tribulus terrestris	ZYGOPHYLLACEAE	A/H
Withania somnifera	*SOLANACEAE*	P/WS
Xanthium spinosum	*ASTERACEAE*	A/H
Xinnia peruviana	*ASTERACEAE*	A/H
Un identified spp		

Key. A/H= Annual Herbaceous, P/H= Perennial Herbaceous, P/T Perennial Tree, P/WH= Perennial Woody shrub

Appendix 24. Survey questionnaire developed to collect information

Description

Site number--
Woreda---

Village/camp--
Household name---
Date--

1. What type of vegetation covers the rangeland during this time?

2. Mention grass/legume which is (being) destroyed due to the presence of parthenium weed?

3. Mention grasses/legumes which out compete parthenium weed?

4. Is livestock feed adequate in your area? If the answer is ‘o’, mention why it is not adequate.

5. Mention the dominant weed in your grazing areas? Among the weeds which one is the most dangerous? Why?

6. What do you think is the real cause of the infestation of parthenium weed in your grazing areas?

7. In which land type is the degree of infestation of parthenium weed higher?

8. In which season is the infestation of parthenium?

9. Mention the impact of the weed on:-

9.1. Grazing areas

9.2. Milk and meat quality

9.3. Animal and human health

9.3.1. Which animal is more susceptible to parthenium toxicity?

9.4. The marketing of animal products like meat and milk

10. How does the weed transfer from one area to another?

11. What measures do you take to control this weed in your grazing and cultivating areas?