1. INTRODUCTION

1.1 Background

Biological invasion by Invasive Alien Species (IAS) is now recognized as one of the major threats to native species and ecosystems. The IAS is the subset of alien species whose establishment and spread threatens ecosystem, habitats or species with economic or environmental significance (McNeely *et al*. 2001). Invasive species are those that occur outside their natural range, spread rapidly and cause harm to other species, communities, or entire ecosystems and to human well being. The IAS contributes enormously to global change because they harm human health, pose a threat to biological diversity, and cause enormous economic losses (Chippendale and Panetta 1994, Vitousek *et al*. 1997, McNeely 2001, Shabbir and Bajwa 2006). The threat to biodiversity due to IAS is considered second only to that of habitat destruction (Vitousek *et al.* 1997). Rapidly accelerating international trade, tourism, transport and travel over the past century have dramatically enhanced the spread of invasive species and caused adverse impacts on agriculture, forestry, fisheries and other enterprises, including health. The Convention on Biological Diversity (CBD) has recognized invasive species as a global problem (Singh *et al*. 2008).

Parthenium hysterophorus L. (Asteraceae, hereafter referred to as *Parthenium*) is an alien invasive species of global significance. It is considered as one of the most problematic weed in tropical and subtropical world (Evans 1997, Bhowmik *et al.* 2007). It has also made recent introduction to Nepal and has established as dominant weed in major urban cities (Shrestha *et al.* 2010). It has emerged as major threats to the grassland ecosystem in Hetaunda (Karki 2009). *Parthenium* is considered as a noxious weed because of its prolific seed production, fast spreading ability, allelopathic effect on other plants, strong competitiveness with native plants, health hazards to humans and animals (McFadyen 1992). The fast spread of this weed is a matter of serious concern because they are spreading at the exclusion of native plant and changing the plant species composition by reducing natural plant wealth and biodiversity (Batish *et al*. 2004). 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). Because of its efficient biological activity and adaptability to the varying soils and microenvironments, *Parthenium*

weed has a tendency to replace the dominant flora in wide range of habitats (Shabbir and Bajwa 2007). Effect of *Parthenium* on vegetation composition could be explained by its rapid growth and fast spreading ability. At early stage of growth, *Parthenium* takes rosette form which spreads rapidly very close to the ground interfering the emergence of other seedlings (Navie *et al.* 1996). In addition, due to its high growth rate, the weed becomes competitive and develops the ability to exclude the growth of other species. The strong effects of *Parthenium* on species composition could also be due to its allelopathic effect. Allelopathic chemicals produced by *Parthenium* exhibit inhibitory effects both on the germination and growth of wide variety of plants including pasture grasses, cereals, vegetables, other weeds (Srivastava *et al*. 1985, Marsie and Singh 1987, 1988, Swaminathan *et al*. 1990, Maharjan *et al.* 2007, Poudel 2011). Few studies have shown that invasive species have little effect on species diversity but significant effects on the species composition (Martin 1999, Hejda and Pysek 2006). *Parthenium* facilitates the growth of small herbaceous species at the initial stage of its invasion leading to increase in the species richness but latter most of the associated species disappear due to the allelopathic effect and competitive replacement by *Parthenium* (Yadav and Chauhan 1998, Sinha and Deo 1999). Impacts of *Parthenium* invasion on the species composition generally depends on the degree of invasion. Ayele (2007) reported a significant difference ($P<0.05$) in species composition among different levels of *Parthenium* infestation. *Parthenium* invasion can affect both, aboveground as well as belowground species composition.

Parthenium infested area possesses very large size of its soil seedbank; it is due to the weed's prolific seed production, various dormancy mechanisms (e.g. innate dormancy and conditional physiological dormancy) of seed and very high viability of its seeds to persist for many years in the soil. A typical mature plant can produce 15,000 to 25,000 seeds (Heseler 1976, Joshi 1991) forming enormous soil seedbank. Joshi (1991) reported 200,000 seeds/m^2 of this weed in soil seedbank of the abandoned fields in India with high *Parthenium* infestation. The data presented by Navie *et al.* (1998) and Butler (1984) have both demonstrated that a relatively large percentage of buried seeds of *Parthenium* can survive for several years. Due to its persistence in the soil seedbank, the weed could perpetuate and establish itself in wide expanse (Navie *et al*. 2004). Soil seedbank density is correlated with depth and shows gradual decreases with increase in depth of soil (Belaynesh 2006). Most of the weed seeds in

no till system are located in the top 5 cm of the soil profile (Shrestha 2006). 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). However, contribution of deep buried seeds is greater to the long-term persistence of soil seedbank (Navie *et al*. 1998). *Parthenium* weed showed dominancy in the soil seedbank flora and was found abundantly in all soil depths (0-3, 3-6 and 6-9 cm), indicating that among all species, *Parthenium* have the high number of seeds and the widest vertical distribution (Ayele 2007).

Leaf feeding beetle *Zygogramma bicolorata* has been emerging as a real hope for the biological control of *Parthenium* weed. Both larva and adults of *Z. bicolorata* feed voraciously on the leaves of *Parthenium* weed reducing the plant vigor and flower production (Shrestha *et al*. 2010). Feeding by *Z. bicolorata* on the stem tips damages the meristem reducing stem height and altering the branching pattern (Dhileepan *et al.* 2000b). Dhileepan *et al.* (1996) noted that *Z. bicolorata* can have significant impact on the size of the seedbank in a short period of time. Sustained defoliation for more than 90 days can cause the reduction in the flower production by 83% and soil seedbank by 73% (Dhileepan 2000). As the seeds persists in the soil where they are unaffected by the biological control agents (McEvoy *et al.* 1991), defoliation by the beetle would have to continue for several more years with very little or no further contribution to the soil seedbank until the existing soil seedbank is depleted (Dhileepan *et al.* 2000b).

1.2 Justification of the study

Parthenium is highly aggressive weed which sustain its survival in highly unfavourable condition where other delicate flora can't grow. Wherever it invades, the weed forms territory of its own by replacing the indigenous natural flora and forms a pure stand or monoculture until it is managed. The fast spread of this weed is a matter of serious concern because they are spreading at the exclusion of native plant and changing the plant species composition by reducing natural plant wealth and biodiversity. Study of species composition in the *Parthenium* infested site is needed for assessing the impact of *Parthenium* invasion on native plant diversity including palatable species. Despite a number of studies on the effects of *Parthenium* on species composition there is

paucity of data comparing the species composition at different levels of *Parthenium* infestation in Nepal. Comparing the vegetation composition at different levels of *Parthenium* infestation would help to assess the exact impacts of *Parthenium* on species composition. From this study we can evaluate which species can compete with *Parthenium* and which are susceptible to it and at what level of infestation. Invasive weeds not only affects the above ground vegetation composition but also affects the below ground vegetation composition which can be better understood by the soil seedbank study. Seedbank contributes significantly to the regeneration potential and future composition of the community especially to those that rely mostly or totally on non-vegetative means of reproduction. As this weed reproduces only by seeds, the dynamics of its seedbank will determine the extent of population change (Naylor 1993). *Parthenium* is a prolific seed producer with huge soil seedbank (Joshi 1991) and the buried seeds can remain viable for 2-6 years (Navie *et al*. 2004). Thus, study of its soil seedbank can be used as a tool for indicating its aggressiveness. From soil seedbank, we can figure out the future vegetation composition of that community and its impact on native flora. We can also assess the contribution of *Parthenium* to the total soil seedbank thereby determining its future aggressiveness. Soil seedbank study of *Parthenium* infested sites in Nepal has been lacking. One of the objectives of the study was to estimate soil seedbank in the plots having high (>90%) *Parthenium* cover by *ex situ* germination test. To increase the credibility of the research, soil seed bank and species richness in the highly infested sites have been measured for two years. To determine the vertical distribution of seeds in the soil seedbank, soil samples from different depths were kept for germination test. The first year of the sampling also represented the first year of the massive defoliation of *Parthenium* by the Mexican beetle. Therefore, this two-year study also provided preliminary information on the effectiveness of this biocontrol agent in the study area.

1.3 Hypothesis

Following were the research hypotheses of the study:

- Invasion by *Parthenium* reduces herbaceous plant species richness in grassland.
- Soil seedbank of *Parthenium* weed decline overtime after the initiation of biological control.

1.4 Objectives

The general objective of this research is to assess the impact of *Parthenium* invasion on the species composition of the herbaceous plant community. The specific objectives are:

- To analyze the change in species composition and richness of the herbaceous plant species across different levels of infestation by *Parthenium*.
- To estimate soil seed bank density of *Parthenium* and other species in highly infested sites.
- To study the impact of defoliation of *Parthenium* by *Zygogramma bicolorata* on the soil seedbank density.

1.5 Limitations

The present research had following limitations:

- Measurements in two years were not made in the same plots because frequent disturbance did not allow marking the plots permanently.
- Exact determination of soil seedbank density was affected by several factors, such as heavy rainfall which might have swept away some seeds on the surface, removal of grass or any vegetation from the sampling site due to grazing and fodder collection, and early germination of some seeds prior to the soil collection.
- Sampling site inside the industrial district was destroyed by the several sport activities carried out there; thus we were unable to take replica on the same site during 2nd field sampling.

2. LITERATURE REVIEW

2.1 Origin and Distribution of *Parthenium*

Parthenium hysterophorus L. (Asteraceae) is a prolific and aggressive herbaceous weed native to the Gulf of Mexico and Central South America and has become widespread in North America, South America, South Africa, Asia and Australia (Navie *et al.* 1996). It is an alien invasive weed of global significance and has received a major weed status in Australia, India and many other parts of the world (Adkins *et al.* 1997). It has also made recent introductions to Nepal. *Parthenium* might have entered Nepal early in 1950s from India. The weed was first reported from Nepal by Hara *et al.* in 1982 but the herbarium specimen was collected first in 1967 by Malla from Trishuli valley of Nuwakot district (Tiwari *et al.* 2005). However, rapid expansion of this weed in urban areas has been noticed during 1990s. Now it has invaded most of the urban areas and roadside vegetations including agricultural land and community forest of tropical and subtropical regions throughout Nepal (Joshi 2005, Tiwari *et al.* 2005, Timsina *et al.* 2011, Shrestha 2008, Karki 2009). In major urban areas like Kathmandu, Hetaunda, Narayangarh, Butwal, Dang etc. it is already in dominant stage. In the grassland of Hetaunda, it has been recorded as a dominant species and has been emerged as major threats to grassland ecosystem (Karki 2009). People have faced the problems of increasing labor in agriculture, bitter taste in milk, loss of pasture land and severe allergy in animals and humans (Karki 2009).

2.2 Species composition and richness in *Parthenium* infested site

Invasive plants 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. Their fast growth, short life cycle, greater reproductive potential, competitive ability and allelopathy make them successful invaders of the non- native habitat (Grice 2006). *Parthenium* 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).

Strong negative effects of *Parthenium* on vegetation composition could be explained by the fact that *Parthenium* grows fast and spread easily. Due to its high growth rate and short life cycle, *Parthenium* can quickly colonize sites leading to its strong dominance in these habitats. Navie *et al*. (1996) indicated that at the early stage of its growth, *Parthenium* takes the form of a rosette and thus require a suitable open area to establish. This rosette spreads rapidly very close to the ground and interferes with the

emergence of other seedlings. In addition, due to its high growth rate, the weed becomes competitive and develops the ability to exclude the growth of other species. *Parthenium* competes directly with pasture species, reducing pasture vigor and seed set leading to habitat and ecosystem change (Evans 1997, O'Donell and Adkins 2005, Shabbir and Bajwa 2006). In grazing land, it can dominate pasture under continued heavy grazing and has the potential to exclude forage plants. A research conducted on the Ethiopian rangeland have shown that most of the valuable species which are essential for grazing animals have already disappeared due to the continued increase of the invasive weed and livestock selection pressure (Ayele 2007). The strong negative correlation between the plant species composition and *Parthenium* coverage can also be due to its strong allelopathic effect. The allelopathic nature of water soluble phenolic and sesquiterpene lactones have been reported from root, stem, leaves, inflorescence, pollen and seeds. (Rajan 1973, Kanchan 1975, Jarvis *et al.* 1985, Pandey *et al*. 1993). These chemicals are released into the soil environment by the *Parthenium* and become growth inhibitors. These chemicals significantly decrease germination and the growth of the seedlings of the surrounding plants (Patil & Hedge 1988, Navie *et al.* 1996, Evans 1997). Its allelopathic character can also change the chemical nature of the soil which further accelerates the unfavourness for the other species (Quershi *et al* 2006).

Parthenium can influence the composition of species both in soil seedbank and aboveground vegetation. Ayele (2007) reported that cover abundance value of *Parthenium* which is greater than 30% exert suppressive effects on the other species which contribute to a change in species composition as the gradient levels of the infestation increases (Ayele 2007). Due to its efficient biological activity and adaptability to varying soil and microenvironment, *Parthenium* has a tendency to replace the dominant flora in a wide range of habitat (Shabbir and Bajwa 2005). Once dominant, *Parthenium* weed continues to persist as a pure stand or weed monoculture until it is managed (Shabbir and Bajwa 2007). Karki (2009) reported a decline in the plant species richness with increase in the *Parthenium* density. However, in grazing land the species richness may increase at the early stage of infestation (i.e. before the *Parthenium* forms pure stand by replacing other species) due to grazing exclusion and shift of dominance (Timsina *et al*. 2011). They reported lowest species diversity in the *Parthenium* non-invaded plots than in intermediately invaded plots, and found that *Trifolium repens, Imperata* sp. *Chrysopogan aciculatus, Sporobolus* sp. and *Dactylotenium aegypticum* were affected by *Parthenium* invasion. Good association between *Parthenium* and *Euphorbia hirta* was reported by Gautam *et al.* (2005).

Wegari (2008) showed that *Chrysopogan aucheri* and *Cynodon dactylon* could out compete the growth of *Parthenium*. However, *Ageratum conyzoides, Alysicarpus vaginalis, Borreria alata, B. articularis, Centella asiatica, Clerodendrum viscosum, Digitaria ciliaris, D. setigera, Elephantopus scaber, Eleusine indica, Fimbristylis dichotoma, Lindernia crustaceae, Oxalis corniculata, Phyllanthus urinaria* and *Sida acuta* were negatively affected by *Parthenium* invasion (Karki 2009). These species were either absent from the invaded sites or their frequencies were significantly low as compared to non-invaded sites. There were no significant differences on frequency of *Cassia tora, Chrysopogan aciculatus, Cyanotis vaga, Cynodon dactylon, Mimosa pudica, Paspalum scrobiculatum, Setaria glauca, Solanum surattense* and *Sida rhombifolia* on *Parthenium* invasion which meant that these species might compete with *Parthenium*.

2.3 Soil seedbank

A reserve of viable, ungerminated seeds in a habitat is called a seedbank (Baskin and Baskin 1998). It refers to natural seed repositories present in soil. It means natural storage of seeds, often dormant within the soil of most ecosystems. The presence of seedbank 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 populations (Hyatt 1999). The seed production of the standing vegetation influences the composition and size of the seedbank (Coffin and Lavenroth 1989). Hence, seedbanks 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 as in the case of *Parthenium*. *Parthenium* relies entirely on seed set for reproduction (Annapurna and Singh 2001) and have high dependence on seed recruitment for population maintenance and recovery after disturbance. *Parthenium* weed can form persistent soil seedbank. Very high production of seeds, high viability of seeds and more than one dormancy mechanism help it to form persistent soil seedbank (Navie *et al*. 1998).

2.3.1 Formation of soil seedbank

According to Grime (1979), most of the soil seedbank consists of buried seeds; however, some seeds are on the soil surface (Roberts 1981) or in the litter, duff or humus (Komarova 1985). Seeds can fall into cracks in the soil, be covered by sediment during flooding or have particles blown over them by the wind (Baskin and Baskin 1998). Seeds can get buried under the soil by the action of various animals. Many vertebrates like birds, rodents, snakes, etc. bury seeds either intentionally or

accidently (Garwood 1989, Gutterman 1993). Trampling effects of livestock at the time of grazing also help in seed burial in the grassland to some extent of soil depth. Invertebrates including ants, beetles and worms also bury seeds (Garwood 1989). The kinds of seed collected and buried depend on the food preferences of the seed carrying organism and on the seed availability (Holldobler and Wilson 1990). Besides these vectors various natural phenomenon like flooding, movement through soil profile help in burying seeds below the soil surface (Navie *et al.* 1998).

2.3.2 Size of the soil seedbank in the *Parthenium* infested area

Parthenium infested area possess very large soil seedbank because of the weed's prolific seed production, various dormancy mechanisms of seed and very high viability of its seeds to persist for many years in the soil. A typical mature plant can produce 15,000 to 25,000 seeds (Haseler 1976, Joshi 1991) forming enormous soil seedbank. In self regenerating population, *Parthenium* weed seedbank range from 3,000 to 40,000 seeds/m^2 and typically make up greater than 50% of the total soil seedbank (Joshi 1991). The germinable soil seedbank at the Moolayember Creek, Australia was in the range of 20,599 to 44,639 seeds/m^2 accounting for 65-87% of the total seedbank (Navie *et al.* 2004). Joshi (1991) reported an enormous seedbank estimated at 200,000 seeds/m^2 in the abandoned fields in India with high *Parthenium* infestation. Soil seedbank of 20,000 to 35,000 seeds/m^2 has been detected in a moderately dense stand of *Parthenium* in the same area (Adkins *et al*. 1996, Navie *et al.* 1997).

2.3.3 Seed viability and longevity

The viability of *Parthenium* weed seed is >85% (Haseler 1976, Navie *et al.* 1998). *Parthenium* seed can remain viable for several years even under buried condition. Long term burial studies have shown that after 12 months of burial, 90% of the seed still remain viable (Butler 1984). Various field observations suggest that buried seed can remain viable for at least six years and will germinate when brought to the soil surface (White 1994). Navie *et al.* (1998) stated that there was 74% seed viability after two years burial and predicted half life of the *Parthenium* seed to be about six years. The long-lived seeds of *Parthenium* are available for germination at any time of the year provided other environmental factors like soil moisture are not limiting in the field (Tamado *et al.* 2002).

As far as seed longevity is considered, surface lying seeds seem to be rather short as most of the unburied seeds germinate (Anonymous 1977) become non-viable or

harvested by ants (Butler 1984) within two years whereas buried seeds may remain viable in the soil for longer period forming persistence soil seedbank. The extended period of darkness in case of buried seed induces a light requirement for germination which is a form of induced or conditional dormancy and is a principal means by which germination is restricted to the proximity of the soil surface (Radosevich *et al.* 1997). Buried seeds may contribute to the long term persistence of the soil seedbank as compared to the surface lying seeds.

2.3.4 Persistence of the soil seedbank

Mechanism such as seed dormancy, germination, predation, pathogen attack, deep burial and physiological death affect seed persistence in the soil seedbank (Simpson *et al.* 1989). Dormancy is a necessary condition for a persistent nature of the soil seedbank (Grime 1981). Different seeds exhibit different persistence in the soil seedbank. Seeds from the annual forbs remain in the soil bank until the next growing season, forming a short-term persistent seed bank, but seeds from the perennial grass are mostly depleted from the soil bank at the beginning of the next growing forming a transient soil seedbank (Marone *et al.* 2000).

Buried seeds may contribute to the long term persistence of the soil seedbank. Soil seedbank density of *Parthenium* increase with the time of invasions as every year enormous seeds are added to the soil seed repositories and again the seed can remain viable for many years under buried condition providing persistent soil seedbank. The persistent soil seedbank help *Parthenium* weed to invade and persist in varied ecological and topographical conditions. Due to its persistence in the soil seedbank, the weed could perpetuate and establish itself in wide expanse (Navie *et al.* 2004). *Parthenium* weed seeds were found to be very persistent in the soil and there was relatively little change in their abundance over an 18 month period (McFadyen 2005). Persistence tests demonstrated that more than 70% of *Parthenium* seeds buried at 5cm below the soil surface survived for at least 2 years whereas surface-lying seeds survived for no longer than 6 months. Presence of seeds at the superficial layer of the soil reduces the seedbank rapidly. This facilitates seed predation, exposure of seeds to variation in temperature and humidity and breaking dormancy (Ayele 2007). *Parthenium* has very high seed production ability, therefore a small percentage of seed burial and survival could be sufficient to ensure the persistence of such populations (Navie *et al.* 1998).

2.3.5 Factors affecting the soil seedbank

Temporal variation in the size of the seedbank may depend on several factors including the pattern of rainfall and timing of subsequent germination events at a site, the timing of seed input (i.e. the seed rain) into the seedbank (Coffin & Lavenroth 1989) and seed and seedling losses due to predators (Hodgkinson *et al*. 1980, Rice 1989). Speed of depletion of soil seedbank depends on the seed production of the species (Yenish *et al*. 1992). Several factors may cause depletion of soil seedbank. They may be preyed upon by insects or other vertebrates, die due to physiological reason or due to allelopathic chemicals and could be attacked by pathogens or buried deep into the soil profile (Shrestha 2006). If the animals are allowed to continuously graze a pasture, it will not have a chance to set seed for a next year as a result the soil seedbank will become depleted (Synman 2004).

2.3.6 Impacts of *Parthenium* defoliation by *Zygogramma* on soil seedbank

Zygogramma bicolorata is a leaf feeding beetle. Both larva and adult feed voraciously on the leaves of *Parthenium*. Defoliation by *Zygogramma* from the early stages of the plant growth is largely responsible for the reduction in plant vigor (Dhileepan 2001). Extended defoliation pressure by *Zygogramma* on *Parthenium* results in the reallocation of resources from root to shoot regrowth with significant reduction in the root biomass and flower production (Dhileepan *et al.* 2000a). Defoliation by *Zygogramma* damage the primary meristem resulting in changed branching pattern and reduced plant height (Dhileepan *et al.* 2000 a,b). In India, a single adult *Z. bicolorata* per plant caused 85-100% defoliation within 6-8 weeks, depending upon the stage resulting in 96% reduction in *Parthenium* weed density (Jayanth and Bali 1994). Similarly, defoliation by *Zygogramma* alone on *Parthenium* in the field reduced the plant height by 18-65%, plant biomass by 55-89% and flower production by 75-100% (Dhileepan *et al.* 2000b). Such a huge reduction in flower production has diminished soil seedbank by 73% (Dhileepan *et al*. 2000). Plants grow slower and produced fewer flowers after defoliation especially when defoliated at rosette stage. Defoliation at early stages of plant growth also delayed the flowering by 3-4 weeks (Dhileepan *et al*. 2000). Dhileepan *et al.* 1996 noted that *Zygogramma* can have significant impact on the size of the soil seedbank of this weed in the field in a relatively short period of time. As *Parthenium* seeds can persist in the soil in buried condition for many years where they are unaffected by the biological control agents (McEvoy *et al.* 1991), defoliation by *Zygogramma* would have to continue for several more years with very little or no further contribution to the soil seedbank until the existing soil seedbank is depleted (Dhileepan *et al.* 2000b).

3. MATERIALS AND METHODS

3.1 Study Area

3.1.1 Biogeographical location

Field sampling was done in grasslands and in fallow land which lie in Hetaunda Municipality of Makawanpur district, south-central Nepal (Figure 1). The sampling site lies at 27° 25' N latitude and 85° 03' E longitude. It is situated in Doon valley with the Mahabharat range in the North and the Siwalik range in the South. The area is drained by three rivers; Rapti in the West, the Samari in the North and the Karra in the South. These three rivers flow southwest to meet Narayani River (http://www.hetaudamun.gov.np, 2011).

Among the three sampling sites selected during the first field visit in 2009, two were located in open grassland owned by Hetaunda Cement Factory for future mining which is about one kilometer south to the Karra Bridge and the other was a fallow land inside Hetaunda Industrial District. Both sites had high *Parthenium* infestation. The elevation of the sampling sites range between 445 to 518 m asl. The grassland had been grazed throughout the year by domestic animals, and the fodder collection practice was high during the summer. The fallow land inside the Industrial District was subjected to frequent sport activities.

3.1.2 Vegetation

The study area is essentially the grassland with patches of shrubs. The common shrub species found in the sampling sites were *Cassia tora, Sida acuta, Sida rhombifolia, Xanthium strumarium* and *Clerodendrum viscosum* (Karki 2009). Common herb species were *Ageratum conyzoides, Borreria alata*, *Borreria articularis, Chrysopogan aciculatus, Cynodon dactylon, Eleusine indica, Euphorbia hirta, Imperata cylindrica, Mimosa pudica, Oxalis corniculata* and *Trifolium repens* (Karki 2009).

3.1.3 Geology and Soil

Hetaunda is a Doon valley that is constituted by the fluvial sediments of both the Siwaliks and lesser Himalaya of Mahabharat range. The rocks comprises of inter-bedded conglomerate (mainly in the upper part) (UEIP 2007). The site has the typical characteristics of the soil of Siwalik range. The ingredients of soil in this Doon valley are: boulders, gravel, sand and fewer amounts of silt and clay. Soil colour varies from one spot to other. However, mostly the soil of our study site is reddish brown and is compact.

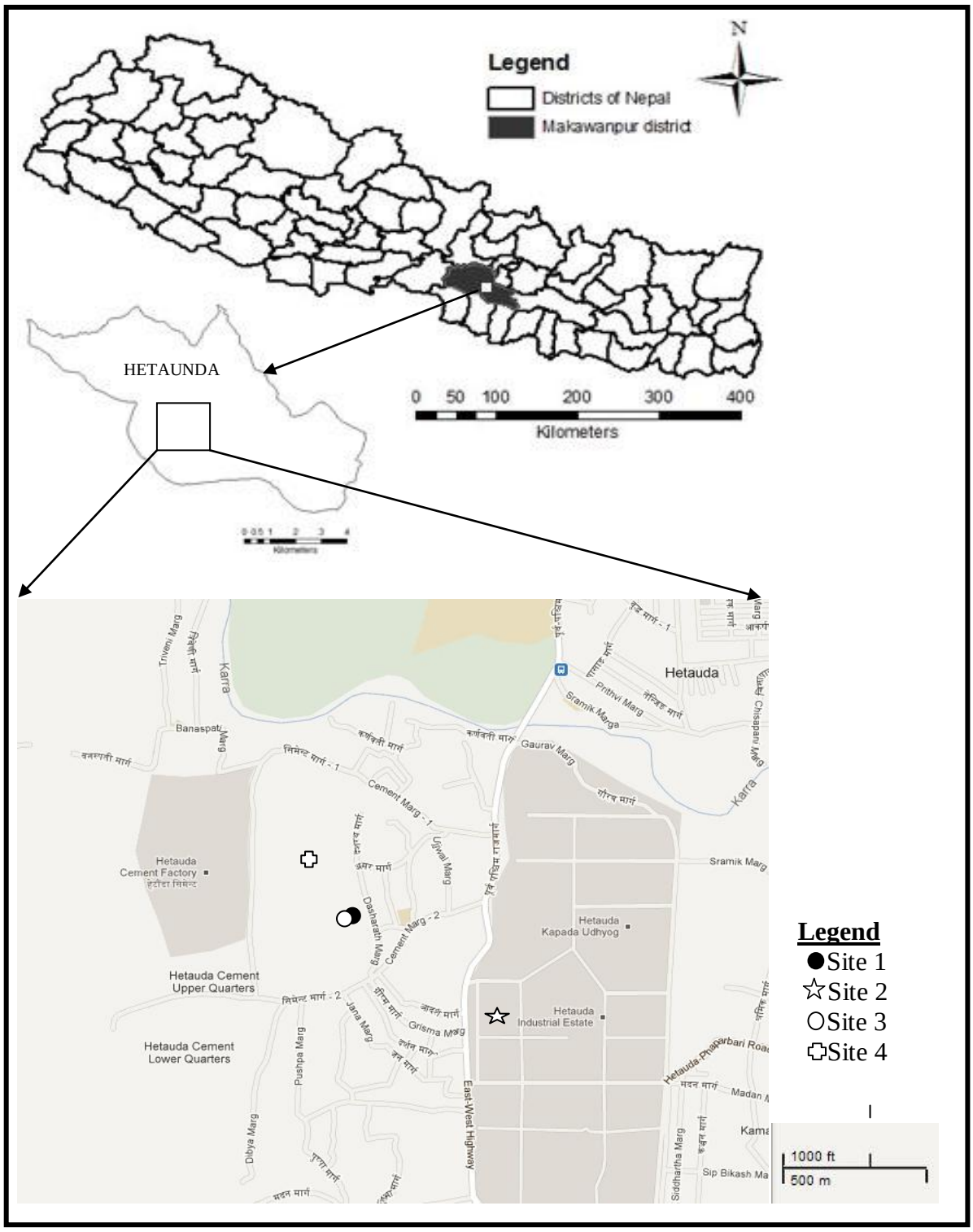

Figure 1. Location map of the study area (source: Google map)

*Sites 1, 2 and 3 indicate the sampling sites for year 1 (2009) whereas, sites 1, 3 and 4 represent the sampling sites for year 2 (2010).

3.1.4 Climate

Study area occurs in the tropical zone, thus the climate is of hot monsoon type (Shrestha 1997). It has three seasons; the summer season extends from mid-February to May which is hot and dry. Monsoon starts from June and continues up to September. Winter begins from October and extends up to the mid- February, when it is cold even though the temperature may not fall down so much. Past five years climatic data record obtained from the Department of Hydrology and Meteorology showed that the area was considerably warm. Average maximum temperature in summer rises up to 34.32°C (Figure 2). The hottest month was April. Average minimum temperature in winter falls below to 8.16°C recorded in the month of January.

The mean monthly rainfall was 189.53 mm. In monsoon season alone, the mean monthly rainfall was 465.26 mm while it was 23.40 mm during winter and 74.1 mm during summer. Peak time for rainfall was from June to September while the lowest rainfall was in November. The mean annual rainfall was 2274.32 mm for five years between 2005 and 2009. Even though this place gets a high amount of rainfall the area seems relatively dry.

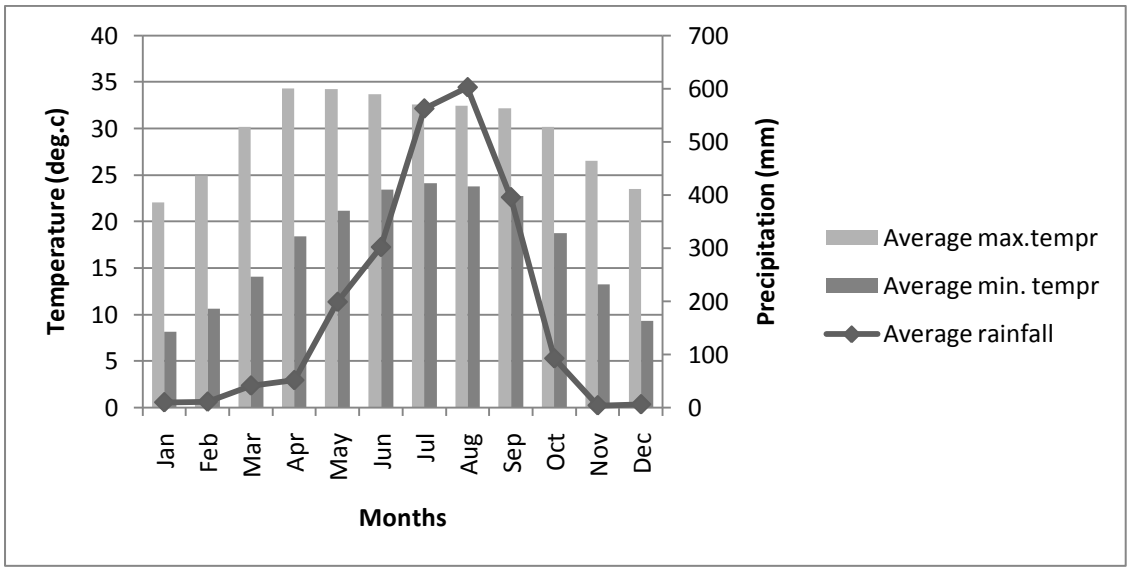

Figure 2. Five years (2005- 2009) average of maximum and minimum temperature and precipitation recorded at Hetaunda weather station (location: Institute of forestry, Hetaunda; 474 masl) which is about one kilometer north from the study site (Source: Department of Hydrology and Meteorology/GoN).

3.2 Field Sampling

During the first field visit carried out in August 2009, three sampling sites having high *Parthenium* density were selected; two sites were located in the grassland of Lamasure Danda and the other in the fallow land inside the Hetaunda Industrial District (HID). All these sites had been used for grazing. In addition the site at HID was often disturbed by sport activities. The field sampling comprised vegetation sampling to determine species richness and *Parthenium* abundance, and the soil sampling for study of germinable soil seed bank. Field sampling conducted in 2009 represented the 1^{st} year and that conducted in 2010 represented the 2^{nd} year of defoliation of *Parthenium* by the leaf feeding beetle *Zygogramma bicolorata.*

3.2.1 Vegetation Sampling

The first vegetation sampling was conducted on September 2009 (year 1) and second on September 2010 (year 2). In year 1, sampling was done along 30 transects of about 10 m long; 10 transects at each of the two sites in Lamasure and 10 at HID. Three quadrats of 1 m × 1 m were sampled along each transect in such a manner that it represented >90%, >40≤60% and <10% cover of *Parthenium*, corresponding to high, medium and low levels of *Parthenium* infestation, respectively. The levels of *Parthenium* infestation were assessed on the basis of visual estimation. Therefore, altogether 90 quadrats were sampled, 30 from each site. During the sampling, vascular plant species rooted in each quadrat were recorded to determine the plant species composition and species richness. Number of individuals of *Parthenium* was also recorded to access the *Parthenium* density. Various parameters such as latitude, longitude, altitude were recorded for each plot. Other additional data on maximum *Parthenium* height, coverage of other plant species, and grazing intensity at each sampling plot were recorded. The numerical value of 0-3 was given to measure grazing intensities; 0 for no grazing and 3 for maximum grazing. Each quadrat of high *Parthenium* infestation was marked by a wooden nail for sampling soil after one month.

In year 2 (2010), altogether 30 quadrats were sampled only on the plots having >90% *Parthenium* coverage i.e. only on the plots having high *Parthenium* infestation. All the vegetation samplings for this time were conducted only at Lamasure Danda as the

site inside the HID was damaged due to the high human interference. After finishing sampling, each plot was marked with plastic pipes.

3.2.2 Soil Sampling

Soil samples for germinable seed bank studies were collected after one month of vegetation sampling when most of the plants including *Parthenium* dispersed their seed. In both the years soil samples were collected in October. For this, soil samples were collected from the sampling plots having >90% *Parthenium* coverage i.e. high *Parthenium* infestation which were marked by wooden nails during vegetation sampling. Each plot was divided into four sub-plots and was assigned as A, B, C, and D from right hand side in clock wise direction. One of these sub-plots was selected by lottery and soil was taken out from the selected sub-plot. Prior to the soil collection, the aboveground vegetation and any plant debris (but not seeds) were removed. Soil samples were collected with the help of soil core sampler having diameter of ten centimeters. Soil was collected in two steps: i) from surface up to 5 cm, and ii) from 5 cm up to 10 cm depth. Altogether there were 60 soil samples collected from 30 plots in each year; two from each plot. Collected soil samples were packed in plastic bags. As soon as the samples were brought to lab, the bags were unpacked and were air dried by spreading on the newspaper in order to prevent anaerobic conditions and to prevent the germination of seeds before the lab analysis.

3.3 Seed Germination

The seedling emergence method was used to assess the germinable soil seedbank (Simpson 1989). Collected soil samples were kept into germination in the greenhouse for determining the soil seedbank. For this, 60 pots having 15 cm diameters were taken. In each pot 2/3rd part was filled with sand sterilized by heating in hot air oven at 120^{o}C for 24 hours to kill any possible seeds present. Circular newspaper cuttings of the size having equal diameter of pot were kept over the sand. Soil samples were spread over it uniformly such that the depth of the soil sample is $\leq$ 2 cm. Before spreading, the soil samples were sieved through the coarse mesh (of size 2.36 mm) in order to remove roots and any other remaining vegetative parts present in order to avoid any vegetative propagation which might give error in the soil seedbank estimation. The paper placed between the sand and soil sample prevent the mixing of two. All the pots were watered regularly (100 ml of water for each pot). Three control

pots with sterilized sand were also kept inside the greenhouse to monitor any seedlings that might arise due to the migration of seeds from the surrounding environment. All the pots were observed regularly for newly emerging seedlings. Number of seedlings of each species emerged in each pot were recorded weekly for first month and then in two weeks for next seven months. The experiment was followed for eight months with the assumption that there were a number of species with long seed dormancy that might germinate later. In each observation, seedlings of *Parthenium* and of other species whose identification was confirmed were removed to avoid crowding. Those species which could not be identified in vegetative stage were allowed to flower.

3.4 Plant Collection, Herbarium Preparation and Identification

Specimens of all plant species encountered during vegetation sampling as well as those grown at green house during the estimation of germinable soil seedbank, were collected, tagged and pressed using newspaper and herbarium press. When the specimens were completely dry they were mounted on the herbarium sheet. The herbarium was identified with the help of the experts of plant systematics from the Central Department of Botany, Tribhuvan University, comparing with the relevant specimens deposited at Tribhuwan University Central Herbarium (TUCH) and some of them were identified by the experts from National Herbarium and Plant Laboratories (KATH), Godawari. Plant Diversity of Eastern Nepal by Siwakoti and Varma (1999) was used for identification. Press *et al.* 2000 was followed for the nomenclature.

3.5 Numerical Analysis

For the numerical analysis, only the data recorded on Lamasure Danda during the first and second field were considered. The data recorded inside the HID during the first field were excluded as we were unable to take replica of the field sampling on the same site on the second field visit due to the disturbance.

The mean values for the species richness (number of species per sampling unit), density of *Parthenium* (stem/m^2), *Parthenium* cover (%), other species cover (%) and maximum height of the *Parthenium* (cm) recorded in each plots with different levels of *Parthenium* infestations, measured during year 1 (2009), were compared by one way analysis of variance (ANOVA). Before comparing their means, the data were

subjected to homogeneity test. Various transformations like logarithmic, square root and arcsine transformations (only for percentage values) were also done for those data which did not meet the assumptions for ANOVA (i.e. variance equal). The mean values for the *Parthenium* density, species richness were compared using one way-ANOVA followed by Duncan test as they met the assumption of equal variance after transformations. Other parameters like *Parthenium* cover, the cover of other species, and maximum height of *Parthenium* did not meet the assumption of equal variance even after transformation. They were compared using non parametric Kruskal-Wallis test followed by pair wise Mann-Whitney U test. These non parametric tests use median values for significance test of difference.

Abundance of *Parthenium* was expressed in two ways: a) product of density and cover of *Parthenium*, and b) product of density and maximum height of *Parthenium*. For assessing the impacts of *Parthenium* invasion, the plant species richness was regressed with abundance of *Parthenium*. In this analysis, the abundance of *Parthenium* was considered as independent variable and the species richness as dependent variables. Before the regression analyses, test for normality was performed.

For analysis of germinable soil seedbank of *Parthenium*, number of seedlings emerged in each pot with soil sample from different depths (0-5 and 5-10 cm) were recorded and were averaged. Also the densities and frequencies of other germinated species were determined and were averaged. Aggregated germinable soil seedbank values were also calculated for the soil depth 0-10 cm by summing up the values for 0-5 and 5-10 cm. Percentage contribution of *Parthenium* in the total germinable soil seedbank (number of total *Parthenium* seedling emerged × 100/total number of seedlings of all species emerged) were also calculated to determine the dominancy of *Parthenium* seed on the total germinable soil seedbank. Mean values for the germinable soil seedbank densities (germinating seeds/m^2) measured at two different soil depths (0-5 and 5-10 cm) were compared by one way-ANOVA. The similarity of the soil seedbank flora and the standing vegetation of the sampling sites were compared using Jaccard's (ISj) and Sorenson's Similarity Indices (ISs).

$$\text{Jaccard's Similarity Index (ISj)} = \frac{C \times 100}{A + B - C}$$

Sorenson's Similarity Index (ISs) $= \frac{2C \times 100}{A + B}$

Where, A= total number of species of the soil seedbank flora,

B= total number of species recorded in the plots with high *Parthenium* infestation, during the vegetation sampling

C= total number of species common to both soil seedbank flora and vegetation sampling.

These similarity indices were also used for comparing the standing vegetation of the plots having different levels of *Parthenium* infestations (recorded in year 1) in order to assess the impact of *Parthenium* infestation on species composition. Similarity indices were also calculated for the germinable soil seedbank flora for two different soil depths (0-5 and 5-10 cm) in order to examine if there was any variation in the vertical distribution of seeds of different species.

The study was conducted for two successive years 2009 and 2010, considering the 1st and 2nd year of *Parthenium* defoliation by *Zygogramma bicolorata*, hence, species richness as well as cover and maximum height of *Parthenium* in the plots having high *Parthenium* infestation were compared between 2009 and 2010 which helped to assess the temporal effects of defoliation on *Parthenium.* Mean values for species richness, *Parthenium* cover, and maximum height of the *Parthenium* were compared by one way-ANOVA, whereas *Parthenium* density was compared by Kruskal-Wallis test. To evaluate the impact of defoliation on the germinable soil seedbank, the soil seedbank densities measured at different depths in 2009 and 2010 were also compared by one way-AVONA.

Simple calculations, such as mean, standard deviations, summations etc. were done by using Microsoft Excel. Whereas, regressions, ANOVA, Kruskal-Wallis test, Mann-Whitney test etc. were done by using Statistical Package for Social Science (SPSS) version 16.0.

4. RESULTS

4.1 Species Composition at Different Levels of *Parthenium* Infestation

Altogether 55 species of plants including *Parthenium* were recorded during vegetation sampling of the year 1, conducted on plots of high, medium and low levels of *Parthenium* infestation; that consisted of 53 identified species (34 dicots and 19 monocots) belonging to 18 families and two unidentified dicots. Out of 55 species recorded, 52 species were present in the plots with high *Parthenium* infestation, 43 species in the medium, and 42 species in the plots with low *Parthenium* infestations (Appendix 1). Only 38 species were common among different levels of *Parthenium* infestations. Ten most frequently occurred species in plots of three levels of *Parthenium* infestation have been listed in Table 1. On doing this, 15 species were found to be most frequent.

Table 1. List of the most frequent 10 species encountered in plots of different levels of *Parthenium* infestation in year 1 (2009). The sign (-) indicated that the species was present but not as frequent as in other levels of *Parthenium* infestation.

SN	Name of the species	Levels of *Parthenium* infestation		
		High	Medium	Low
1	*Borreria alata*	75	80	65
2	*Chrysopogon aciculatus*	65	90	95*
3	*Cynodon dactylon*	75	75	-
4	*Desmodium triflorum*	85	80	80
5	*Eragrostis tenella*	-	-	80
6	*Euphorbia hirta*	90*	95*	-
7	*Fimbristylis dicotoma*	70	90	95*
8	*Hygrophila polysperma*	65	-	-
9	*Imperata cylindrica*	80	-	-
10	*Mimosa pudica*	85	95*	85
11	*Parthenium hysterophorus*	100*	100*	100*
12	*Paspalidium flavidum*	-	80	90
13	*Paspalum distichum*	-	-	65
14	*Phyllanthus urinaria*	-	-	70
15	*Polygala* sp.	-	80	-

* Sign indicates the higher frequency.

Among the 15 most frequently occurred species (Table 1), *Parthenium* had the highest frequency in the plots of all three levels of *Parthenium* infestation. *Euphorbia hirta* showed its high frequency (90%) next to *Parthenium* in the plots of high level of *Parthenium* infestation. Similarly, *Mimosa pudica*, *Euphorbia hirta*, *Chrysopogan*

aciculatus and *Fimbristylis dicotoma* occurred frequently (≥90 - <100%), next to *Parthenium,* in the plots of medium level of *Parthenium* infestation. *Fimbristylis dicotoma*, *Chrysopogon aciculatus* and *Paspalidium flavidum* were found in high frequency (≥90 - <100%), after *Parthenium,* in the plots of low *Parthenium* infestation. *Chrysopogon aciculatus* and *Fimbristylis dicotoma* showed gradual increase in the frequency with decrease in the levels of *Parthenium* infestation. *Desmodium triflorum* and *Mimosa pudica* showed high frequency (≥80- ≤85%) and (≥85- ≤95%) respectively in plots of all three levels of *Parthenium* infestations.

Species similarity indices between pairs of all levels of *Parthenium* infestation were between 70 and 90%. There was high similarity between the plots having medium and low *Parthenium* infestation (Figure 3).

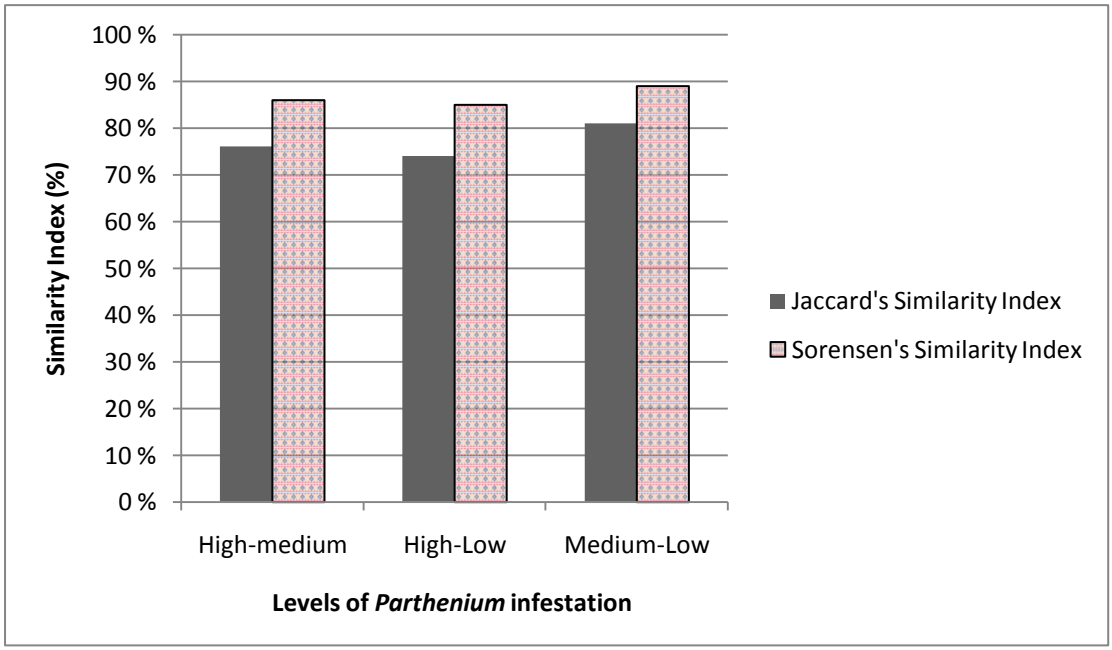

Figure 3. Comparison of similarity indices between various levels of *Parthenium* infestation, recorded during vegetation sampling in year 1 (2009).

4.2 *Parthenium* and its impact on species richness and cover

There was no significant difference in species richness among various levels of *Parthenium* infestation (Table 2). However, density, maximum height and cover of *Parthenium,* and vegetation cover of other species differed with levels of *Parthenium* infestation. High level of *Parthenium* infestation significantly reduced vegetation cover of other species.

Table 2. Plant species richness, density, maximum height and cover of *Parthenium*, and the cover of other plants in plots of different levels of *Parthenium* infestation. Numerical values within each column with different alphabets (a, b and c) in superscripts are significantly different at P<0.05. Main entries for values of species richness and density of *Parthenium* are mean with standard deviation; values for other parameters are medians with interquartile range in parentheses.

Attributes		**Species richness (number/m^2)**	**Density of *Parthenium* (stem/m^2)**	**Maximum height of *Parthenium* (cm)**	***Parthenium* cover (%)**	**Other plant cover (%)**
Levels of Infestation	High	17^{a}±4	433^{c}±119	108^{c}(25)	95^{c}(10)	80^{b}(29)
	Medium	17^{a}±3	211^{b}±126	59^{b}(13)	45^{b}(5)	100^{a}(5)
	Low	15^{a}±3	30^{a}±39	32^{a}(31)	5^{a}(4)	100^{a}(1)
Test Statistics*	F	2.155	107.436	-	-	-
	χ^2	-	-	50.493	53.180	36.074
	d.f	2,57	2,57	2	2	2
	P	0.125	0.000	0.000	0.000	0.000

*****Attributes which have been analysed by ANOVA have their F values and those analyzed by Kruskal-Wallis test have chi square values.

4.3 Variation between years

There was significant decrease in plant species richness, density of *Parthenium*, its maximum height, and cover from 2009 to 2010 (Table 3). These two years represented the 1st and 2nd year of defoliation of *Parthenium* by the leaf feeding beetle *Zygogramma bicolorata*, respectively.

Table 3. Species richness, and density, maximum height and cover of *Parthenium* measured during the 1st (2009) and 2nd (2010) vegetation sampling in the plots having high *Parthenium* infestation. Main entries for values of *Parthenium* density are medians with interquartile range in parentheses; values for other parameters are mean with standard deviation.

Attributes		**Species richness (number/m^2)**	**Density of *Parthenium* (stem/m^2)**	**Maximum height of *Parthenium* (cm)**	***Parthenium* cover (%)**
Years	2009	17 ±4	437(123)	106±20	96±5
	2010	14±2	241(376)	73±17	60±25
Test Statistics	F	8.856	-	34.344	60.746
	χ^2	-	9.666	-	-
	d.f	1,48	1	1,48	1,48
	P	0.005	0.002	0.000	0.000

*****Attributes which have been analysed by ANOVA have their F values and those analyzed by Kruskal-Wallis test have chi square values.

4.4 Plant species richness and *Parthenium* abundance

Plant species richness did not vary significantly with the product of cover and density of *Parthenium* in the plots with different levels of *Parthenium* cover in year 1 (2009) and in the plots of high *Parthenium* cover in year 2 (2010) (Appendix 15). When the species richness was regressed with the product of maximum height and density of the *Parthenium* on the plots with different levels of *Parthenium* infestation we did not find any significant relationship in 2009, but species richness declined significantly (P=0.028) with the product of maximum height and density of the *Parthenium* on the plots with high *Parthenium* infestation in 2010 (Figure 4).

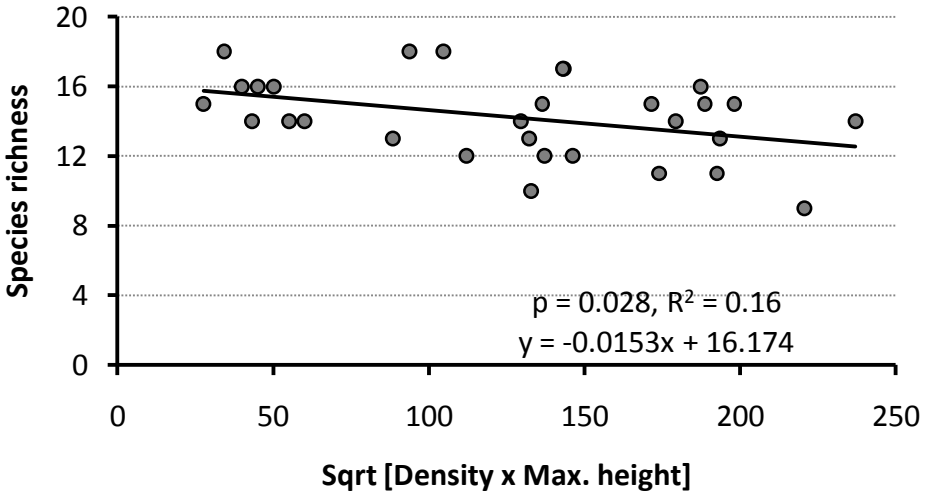

Figure 4. Relationship between the plant species richness (number/m^2) and square root transformed values of the product of density (stem/m^2) and maximum height (cm) of *Parthenium* measured at the plots with high *Parthenium* infestation in year 2 (2010). The fitted line was obtained by linear regression model. Each point represents value of each sampling plot.

4.5 Germinable soil seedbank composition and density

Altogether 51 species, belonging to 16 families were recorded from the first (2009) and second (2010) soil seedbank studies (Appendix 6). Of 51 species, 34 species were identified to species level, 15 species to genus level, and two were identified only to family level.

4.5.1 Soil seedbank: year 1 (2009).

In the **first soil** seedbank study (2009), 39 species (belonging to 15 families) were recorded; 37 from top layer (0-5 cm depth) and 20 species from deeper layer (5-10 cm

depth) (Appendix 8). On the basis of density of germinable seeds in soil, most abundant species have been presented below (Table 4a, b).

Table 4a. Most abundant species (based on density) each recorded from the different depths (0-5 and 5-10 cm) of soil in 2009 (year 1). Only 10 most abundant species have been presented for each soil depth.

SN	Name of the species	Soil seedbank density (mean±SD) and frequency*			
		0-5cm		5-10cm	
		Density (seed/m^2)	Frequency (%)	Density (seed/m^2)	Frequency (%)
1	*Ageratum conyzoides*	-	-	45±85	25
2	*Ageratum* sp.	57±105	30	×	×
3	*Bidens pilosa*	-	-	25±89	10
4	*Carex* sp.	139±280	30	25±52	20
5	*Cyperus* sp.	102±400	10	95±314	20
6	*Chromolaena odorata*	134±191	55	121±313	35
7	*Euphorbia hirta*	465±564	70	32±91	15
8	*Mecardonia procumbens*	560±1585	50	64±113	30
9	*Oxalis corniculata*	350±443	70	64±77	45
10	***Parthenium hysterophorus***	**10466±6534**	**100**	**618±960**	**85**
11	*Phyllanthus* sp.	325±1165	30	25±67	15
12	*Sonchus wightianus*	64±113	30	-	-

* '-' indicates that the species was present but in low abundance; '×' indicates the absence of the species.

Table 4b. Most abundant species (based on density) recorded from the soil depth of 0-10 cm in 2009 (year 1).

SN	Name of the species	Density (seed/m^2)	Frequency (%)
1	*Ageratum* sp.	57±105	30
2	*Carex* sp.	164±271	50
3	*Cyperus* sp.	197±535	25
4	*Chromolaena odorata*	255±355	70
5	*Euphorbia hirta*	497±545	80
6	*Mecardonia procumbens*	624±1583	65
7	*Oxalis corniculata*	414±454	85
8	***Parthenium hysterophorus***	**11084±6552**	**100**
9	*Phyllanthus* sp.	350±1218	40
10	*Sonchus wightianus*	89±138	35

Among the 12 most abundant species, *Parthenium* had the greatest germinable soil seedbank density in both the soil depths (Table 4a). *Mecardonia procumbens* and *Euphorbia hirta* were the most abundant species in the soil samples from top layer (0-5 cm) next to *Parthenium* with the values of germinable soil seedbank density being 560 and 465 seed/m^2, respectively. *Ageratum* sp. was recorded only in the soil

samples from top layer. Similarly, *Chromolaena odorata* and *Cyperus* sp. were the 2nd and 3rd most abundant species in the soil samples from the deeper layer (5-10 cm) the value for the soil seedbank density being 121 and 95 seed/m^2, respectively. When soil seed bank density of two layers were combined (i.e. 0-10 cm), *Mecardonia procumbens* and *Euphorbia hirta* were again the most abundant species after *Parthenium* (Table 4b).

4.5.2 Soil seedbank: year 2 (2010)

In the 2nd soil seedbank study, 27 species (belonging to 12 families) were recorded; 27 from the surface layer (0-5 cm depth) and 11 from the deeper layer (5-10 cm depth) (Appendix 11). On the basis of density of germinable seeds in soil, 10 most abundant species were selected from each soil depth which altogether gave 14 species in the top list (Table 5a, b).

Table 5a. Most abundant species (based on density) recorded from the different depths (0-5 and 5-10 cm) soil collected in 2010 (year 2). Only 10 most abundant species have been presented for each soil depth.

SN	Name of the species	Soil seedbank density (mean±SD) and frequency*			
		0-5cm		5-10 cm	
		Density (seed/m^2)	Frequency (%)	Density (seed/m^2)	Frequency (%)
1	*Borreria alata*	-	-	8±32	6.67
2	*Carex* sp.	47±196	6.67	×	×
3	*Cynodon dactylon*	170±24	46.67	5±23	6.67
4	*Emilia sonchifolia*	-	-	4±23	3.33
5	*Chromolaena odorata*	-	-	4±23	3.33
6	*Euphorbia hirta*	242±264	60	13±39	10.00
7	*Evolvulus nummularius*	-	-	4±23	3.33
8	*Mecardonia procumbens*	416±2183	13.33	8±46	3.33
9	*Mimosa pudica*	98±176	33.33	×	×
10	*Oxalis corniculata*	764±776	80	283±607	60.00
11	*Parthenium hysterophorus*	10313±7588	100	403±372	76.67
12	*Phyllanthus urinaria*	59±208	10	-	-
13	*Setaria glauca*	191±456	26.67	×	×
14	*Sida rhombifolia*	64±137	3.33	17±44	13.33

* '-' indicates that the species was present but in low abundance; '×' indicates the absence of the species.

Table 5b. Most abundant species (based on density) recorded from the soil depth of 0-10cm in 2010 (year 2).

SN	Name of the species	Density (seed/m^2)	Frequency (%)
1	*Carex* sp.	47±196	6.7
2	*Cynodon dactylon*	119±231	33.3
3	*Euphorbia hirta*	183±226	80.0
4	*Mecardonia procumbens*	424±2182	13.3
5	*Mimosa pudica*	98±176	33.3
6	*Oxalis corniculata*	1047±1012	86.7
7	*Parthenium hysterophorus*	10716±7651	100
8	*Phyllanthus urinaria*	64±208	13.3
9	*Setaria glauca*	191±456	26.7
10	*Sida rhombifolia*	81±156	30.0

Among the 14 most abundant species, *Parthenium* had the largest germinable soil seedbank density in both the soil depths (Table 5a). *Oxalis corniculata* and *Mecardonia procumbens* were 2nd and 3rd most abundant species next to *Parthenium* in the soil samples from the top layer. Similarly, *Oxalis corniculata* and *Sida rhombifolia* were the most abundant species after *Parthenium* in the soil samples from the deeper layer. *Carex* sp., *Mimosa pudica* and *Setaria glauca* were present only in the soil samples of top layer (0-5 cm). When the values of two soil depth were combined (i.e. 0-10 cm) *Oxalis corniculata* and *Mecardonia procumbens* were the most abundant species after *Parthenium* (Table 5b).

4.6 Germinable soil seedbank of *Parthenium* in 2009 and 2010

Germinable soil seedbank density of *Parthenium* measured at the top layer (0-5 cm depth) and the deeper layer of the soil (5-10 cm depth) did not show significant difference between 2009 and 2010 (Figure 5). Similarly, there was no significant difference in the germinable soil seedbank density between 2009 and 2010 when combined for entire depth of soil sampled (0-10 cm).

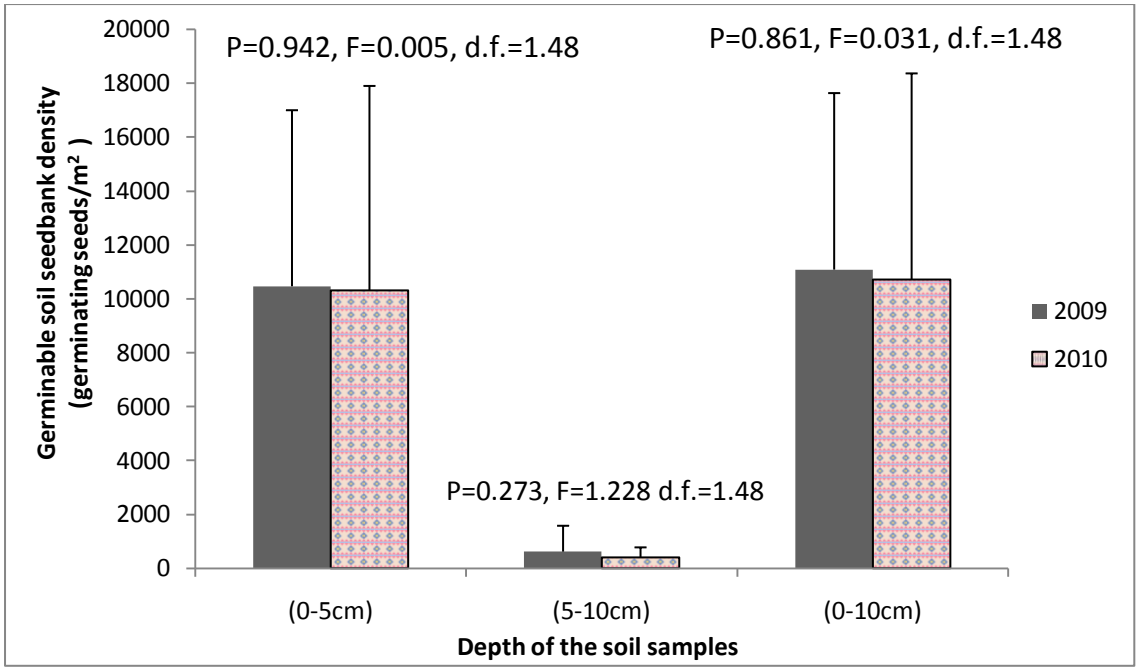

Figure 5. Mean germinable soil seedbank density of *Parthenium* in 2009 and 2010. The vertical error bars represent the standard deviation. Values of P, F and d. f. are based on one way analysis of variance (ANOVA).

4.7 Vertical distribution of germinable seeds of *Parthenium* in the soil

By analyzing the soil samples taken from different depths, we found that most of the germinable seeds of *Parthenium* were located at the top layer of the soil (0-5 cm depth). The top layer had 94.42% of the total germinable seeds of *Parthenium* in 2009 and it was 96.24% in 2010 (Figure 6).

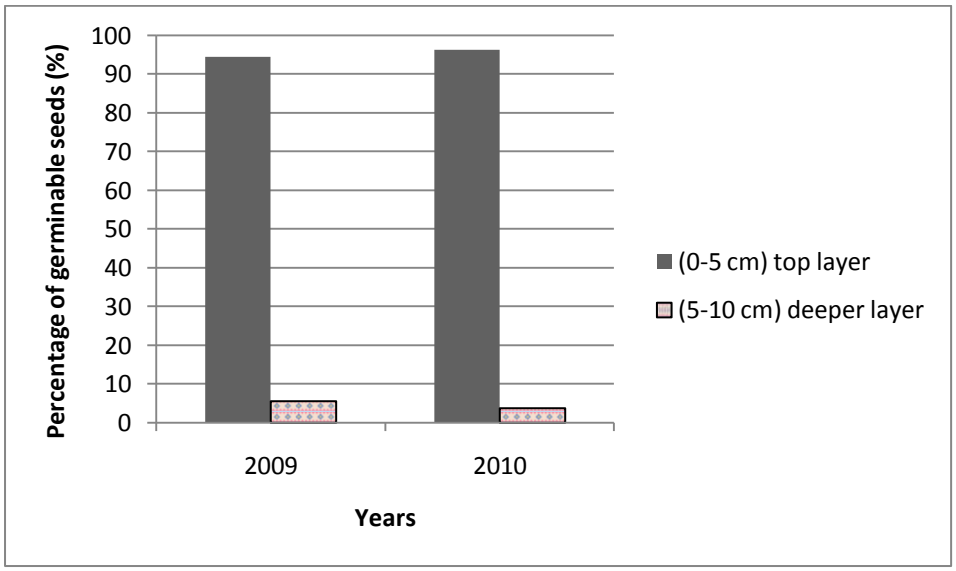

Figure 6. Vertical distribution of germinable seeds of *Parthenium*.

4.8 Contribution of *Parthenium* in the total germinable soil seedbank

Parthenium contributed nearly 4/5th of total germinable soil seedbank upto 10 cm soil depth (Figure 7). There was no significant difference in the contribution of *Parthenium* seeds in the total germinable soil seedbank between the two successive years (2009 and 2010).

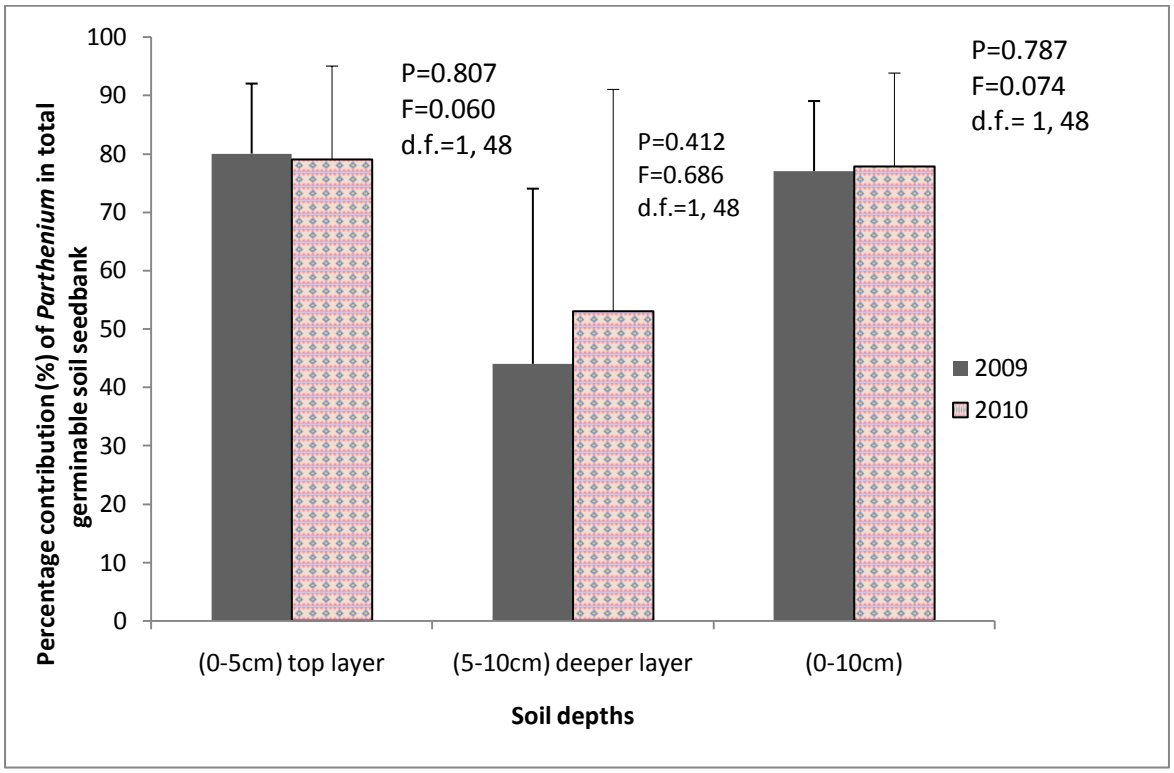

Figure 7. Percentage contribution of *Parthenium* to the total germinable soil seedbank at different soil depths in 2009 and 2010. The vertical error bars represent the standard deviation. Values for P, F and d.f. are based on one-way ANOVA.

The contribution of *Parthenium* seeds to the total germinable soil seedbank varied significantly with soil depth in both the years (Table 6). *Parthenium* contributed nearly 4/5th of the total seed bank in top layer (0-5 cm) while in deeper layer (5-10 cm) it contributed about half to the total seed bank.

Table 6. Percentage contribution of *Parthenium* to the total germinable soil seedbank at different soil depths. Main entries and the values in the parenthesis represent median and interquartile range, respectively.

Attributes		**Years**	
		2009	**2010**
Soil depths	0-5cm	83(21)	82(20)
	5-10cm	45(47)	60(72)
Test Statistics (Kruskal-Wallis test)	χ^2	14.161	5.376
	d.f	1	1
	P	0.000	0.020

4.9 Species similarity

When the standing flora of the plots having high *Parthenium* infestations, from where the soil samples were taken, were compared with the soil seedbank flora, the values for Jaccard's Similarity Index was 23% and the value for the Sorensen's Similarity Index was 37.36% for the soil samples collected in 2009 and their values were 29.09 and 45.07%, respectively for 2010. Likewise, Jaccard's indices of species similarity between 0-5 and 5-10 cm soil depth were 46 and 41% in 2009 and 2010, respectively. The corresponding values of Sorensen's index were 63 and 58%, respectively.

5. DISCUSSION

5.1 Impacts of *Parthenium* on species composition and richness

Parthenium invasion has modified the species composition of the grassland. Plots with different levels of *Parthenium* infestation showed different species composition. The species similarity index between plots with high and medium or low *Parthenium* infestation was between 70 and 85% and this was lower than the similarity index between plots with medium and low *Parthenium* infestation (80-90%) (Figure 3). Though the sample plots were close to each other (<5 m apart) the plots having high infestation had relatively low species similarity with other plots which indicated the change in species composition due to high *Parthenium* infestation. In other grasslands of central Nepal, Timsina *et al*. (2011) also reported the significant change in species composition due to *Parthenium* infestation.

Euphorbia hirta showed its high frequency next to *Parthenium* in the plots of high level of *Parthenium* infestation (Table 1). Ayele (2007) also reported a high abundance of *Euphorbia hirta* in high *Parthenium* infested sites than in other sites. These two plants have different growth behaviors; *Parthenium* grows vertically erect while *E. hirta* grows obliquely prostrate near the ground surface. Thus they belonging to different strata and competition for space and resources may be low. A good association between *Parthenium* and *E. hirta* has been also reported by Gautam *et al.* (2005). *Fimbristylis dicotoma*, *Chrysopogon aciculatus* and *Paspalidium flavidum* were found in high frequency, after *Parthenium*, in the plots of low *Parthenium* infestation (Table 1). *C. aciculatus* and *F. dicotoma* showed gradual increase in the frequency with decrease in the levels of *Parthenium* infestation. These species appeared to be more sensitive to *Parthenium* infestation than other associated species. *Desmodium triflorum* showed its highest frequency (85%) at the high level of *Parthenium* infestation but its frequency decreased and remained similar at medium and low levels of infestation. *D. triflorum* being a highly palatable species, high frequency at the plots with high *Parthenium* infestation was due to the grazing exclusion in these plots. Decrease in the frequency at the medium and lower levels of *Parthenium* infestations might be due to increasing grazing intensity.

Above examples showed a change in species composition due to infestation by *Parthenium*; this is supported by Ayele (2007), who reported significant difference in

species composition among different levels of *Parthenium* infestation. In the sites with high *Parthenium* infestation, the plant species composition could be affected by its high canopy coverage along with competition for resource utilization, grazing exclusion and allelopathic effects. Levels of grazing increased with the decreasing levels of *Parthenium* invasion. Livestock grazing could also have a profound effect on the vegetation change (Illius and O'Conner 1999). Several studies have showed that increasing grazing intensity change the herbaceous composition from high palatable to less palatable species (Illius and O'Conner 1999, Amsalu 2000). Differences in species composition among the plots of different levels of *Parthenium* infestation was not only because of the direct impact of invasion but also because of unequal grazing pressure. Low level of *Parthenium* infestation corresponds to low concentration of allelopathic chemicals leached from the plant, which might not be sufficient for the inhibition of germination of seed in soil and thereby bringing change in the species composition.

Plant species richness did not vary significantly with the abundance of *Parthenium* measured as the product of *Parthenium* cover and density. However, when species richness was regressed with the product of maximum height and density of *Parthenium* in year 2 (2010), which represented the 2nd year of defoliation (>80%) by the *Zygogramma bicolorata,* we found a gradual decrease in the species richness with increase in the *Parthenium* abundance.

We did not find any significant difference in species richness among plots of different levels of *Parthenium* infestation. This result has contrasted with the conclusions of many other studies, which suggested that invasive species have negative effects on species richness (Bimova *et al*. 2004, Dunbar and Facelli 1999, Kohli *et al*. 2004). Karki (2009) has reported decrease in the species richness on increasing the *Parthenium* density. Kohli *et al.* (2004) reported decline in species richness from 25 to 12 from *Parthenium* non-invaded site to high invaded site of lower Himalaya (India). Lack of significant difference in species richness between plots of high and low levels of *Parthenium* infestation might be the outcome of positive impact made by the defoliating beetle. During the sampling, >60% of leaves of *Parthenium* were damaged by the beetle, allowing adequate light to reach the ground surface. That environment might be less hostile than in the stands with intact leaves. Though species richness did not change significantly, there was appreciable shift in species

composition as mentioned earlier. A few studies have also shown that invasive species have little effect on species diversity but have significant effects on the species composition (Martin 1999, Hejda and Pysek 2006). Thus our hypothesis assuming the reduction in herbaceous plant species richness by *Parthenium* invasion has been rejected inder the situation when biological control is operational.

5.2 Variation between the years

Defoliation event on the *Parthenium* by the leaf feeding beetle *Zygogramma bicolorata* was reported first in August 2009 (Shrestha *et al.* 2010). Thus, the field sampling of year 1 (2009) and year 2 (2010) represented the 1st year and 2nd year of defoliation, respectively. The defoliation had significantly reduced density of *Parthenium,* its maximum height and cover from 2009 to 2010 (Table 3).

Owing to its aggressiveness the density of *Parthenium* often increases over time. In 2007 the average density of *Parthenium* in highly infested sites of the present study area was 298 stem/m^2 (max. 402 stem/m^2) (Karki 2009) while it was 433±119 stem/m^2 in 2009 (Table 2). There was 45% increase of *Parthenium* density in two years from 2007. But the density has drastically reduced from 2009 to 2010 due to defoliation. Not only the density, maximum height and cover of *Parthenium* have significantly decreased from 2009 to 2010. Feeding by *Z. bicolorata* on the stem tips damages the meristem and reduces stem height (Dhileepan *et al.* 2000). Dhileepan *et al*. (2000) reported that the defoliation at early stages of the plant growth reduced the plant height by 13-56% and flower production by 25-45%. Reduction in the flower production in 2009 could have reduced the seed bank and hence the density of *Parthenium* in 2010.

There was significant decline in the plant species richness from 2009 to 2010 in highly infested sites. This might be due to the increase in the grazing intensity. Defoliation off course had reduced the *Parthenium* density and cover but it could have increased grazing intensity, thereby reducing the species richness. Sampling in 2009 and 2010 was done in the same site but not in exactly the same plots. This might have also contributed to the significant difference in species richness between two years.

5.3 Germinable Soil Seedbank

5.3.1 Germinable soil seedbank density and composition

Parthenium had the highest value of germinable soil seedbank density among all the germinated species recorded from the soil samples of top 10 cm thick, for both years 2009 and 2010. *Parthenium* alone contributed about 77% to the total germinable soil seedbank (Figure 7). Greater contribution of *Parthenium* in the soil seedbank might be due to its prolific seed production, persistence nature of soil seedbank, high viability of buried seeds, low seed predation, innate dormancy mechanism of its seeds (Haseler 1976, Joshi 1991b, Dhileepan *et al.* 1996). *Parthenium* is a short-lived weed possessing long lived seeds often with secondary dormancy mechanism (Rice 1989). Germination inhibitors (parthenin and phenolic acids) present in the accessory structures and seed coat of *Parthenium* seeds act as autotoxins that temporarily prevent the germination of nearby *Parthenium* seeds if their density is sufficiently high (Picman and Picman 1984) thereby decreasing the seed losses because of germination. Parthenin also increase seed survival by discouraging the decay (Rice 1984, Ganeshan and Jayachandra 1993) or predation (Ahmed and Bhattacharya 1991) of seeds. The average seed density of *Parthenium* was 11084±6552 seeds/m^2 for year 1 (2009) and 10716±7651 seeds/m^2 for year 2 (2010) which was relatively lower than reported from the rangeland of Australia by Navie *et al.* (2004). The Australian report revealed that the seed density in soil seedbank ranged from 20,599 to 44,639 seeds/m^2 at high *Parthenium* infested sites. The smaller size of seedbank densities of *Parthenium* in our study site might be because of its recent invasion in Nepal which is not enough to contribute large soil seedbank as that of Australia. The differences could also be due to differences in sampling techniques behind collecting seedbank. In the Australian research, five soil samples were collected (using soil corer of size 5cm in diameter and 3.5cm height) form each quadrat (one from each of the corners and one from the center of the quadrat) and pooled to make single sample. All of these factors could affect both the size and composition of seedbank flora (Baskin and Baskin 2001). Thus, accurate comparison of seedbanks would depend on the sampling techniques and timing of data collection (Simpson *et al*. 1989). The seedbank is also attributed to the climatic factors and soil conditions which can also affect the overall size of the seedbank (Westoby *et al*. 1992).

In the soil seedbank study of year 1 (2009), *Mecardonia procumbens* and *Euphorbia hirta* were the 2nd and 3rd most abundant species after *Parthenium* recorded from the soil samples of upper 10 cm. Similarly, *Oxalis corniculata* and *Mecardonia procumbens* were 2nd and 3rd most abundant species for year 2 (2010). Their higher abundance indicated their high seed production and low seed predation. Germinable seeds of *Ageratum* sp. (from year 1), *Carex* sp., *Mimosa pudica* and *Setaria glauca* (from year 2) were detected only in the soil samples from the top layer (0-5 cm) but were absent in the soil samples from the deeper layer (5-10cm). This might be due to their loss of seed viability when buried to depth which represented the transient nature of their soil seedbank.

On comparing the species composition in the two different layers of the soil seedbank, the values for Jaccard's Similarity Index was found 46% for 2009 and 40.74% for 2010. These values represent that the species similarity was relatively low between the seeds found at the upper layer and that found at deeper layer of the soil. Different types of seeds exhibit different persistence in the soil seedbank (Marone *et al.* 1998). Mechanism such as seed dormancy, germination, predation, pathogen attack, deep burial and physiological death affect seed persistence in the soil bank (Simpson *et al.* 1989). Seed dormancy is a necessary condition to form a persistent seedbank and that non- dormant seeds usually form transient seed banks (Grime 1981). Seeds of annual forbs remain in the soil seedbank until the next growing season, forming a short-term persistent seedbank, but seeds of perennial grasses are mostly depleted from the soil bank at the beginning of the next growing season i.e. they form a transient soil seedbank (Marone *et al.* 1998). Besides the high seed dormancy, low vulnerability to the granivorous animals (Marone *et al*. 1998b, 2008) might have supported the persistent nature of the seeds from annual forbs.

5.3.2 Comparison of germinable soil seedbank of *Parthenium* between 2009 and 2010

Germinable soil seedbank density of *Parthenium* measured in two successive years 2009 and 2010 did not show any significant difference. Dhileepan *et al.* (1996) noted that *Zygogramma bicolorata* can have significant impact on the size of the seedbank in a short period of time. Sustained defoliation for more than 90 days can cause the reduction in the flower production by 83% and soil seedbank by 73% (Dhileepan 2000). In spite of such potential impact of *Zygogramma* on seedbank reduction we did

not find significant decrease in the germinable soil seedbank density from 2009 to 2010. The consistency of the germinable soil seedbank of *Parthenium* for the two successive years might be due to the persistence nature of its soil seedbank. Reduction in the flower production caused by defoliation could bring significant decrease in the germinable soil seedbank density but at the same time persistent soil seedbank helps in maintaining the soil seedbank keeping it unchanged even after the defoliation. Prolific seed production and its persistent soil seedbank help *Parthenium* to remain dominant for years. In such case just an initial state of defoliation might not have significant impact on its enormous seedbank. For the significant reduction in the soil seedbank at least the defoliation phenomenon has to be continued for few more years so that there may be the gradual depletion of its germinable soil seedbank. Thus, our second hypothesis assuming the decline in the soil seedbank of *Parthenium* after the initiation of biological control has been also rejected for the period of present study.

5.3.3 Vertical distribution of germinable seeds of *Parthenium* in the soil

Most of the germinable seeds of *Parthenium* (94.42% in year 1 and 96.24% in year 2) concentrated at the top layer (0-5 cm) of the soil (Figure 6). The concentration of the seeds at the top soil was supported by other seedbank studies (Demel and Granstrom 1995, Espinar *et al* 2005, Belaynesh 2006). *Parthenium* is a prolific seed producer and a single plant can produce 15000 to 25000 seeds. In addition to this, high viability of the buried seeds, low seed predations, persistent nature of its soil seedbank etc. have contributed their dominance in the soil seedbank. Greater percentage of seedling emergence from the soil samples of top layer (0-5 cm) showed the higher accumulation of seeds to surface soil. The deep burial of seed becomes difficult phenomenon in the area where there is less soil disturbance. The site being the grazing land, soil disturbance in this case might be just due to trampling effect of grazing animals which might lead to the shallow burial of the seeds. Deep burial of seed in such case require very long time. The lesser percentage of germinable seeds from the deeper layer could be also related with its invasion history which is not very long in the sampling site.

5.3.4 Comparison of the species composition between standing flora and soil seed bank

There was very low species similarity (Jaccard's Similarity Index being 23% for year 1 and 29.09% for year 2) between standing flora (above ground) and soil seedbank.

Our result is supported by Paul and David (1995) who obtained the value for Jaccard's Similarity Index to be 36% when the species composition of standing flora were compared with its seedbank species. Ayele (2007) compared the vegetation composition between the standing flora and soil seedbank flora in the plots with different levels of *Parthenium* infestation and found highest similarity in the *Parthenium* non invaded plots and lowest similarity in the plots with high *Parthenium* infestation, indicating the impact of *Parthenium* invasion. High degree of allelopathy might have suppressed the germination and growth of the native species (Navie *et al*. 1995). Since *Parthenium* invasion has impact on species composition, change in soil seedbank composition can be co-related with the change in species composition in the following year.

Beside the allelopathic effect of *Parthenium*, there are various other factors affecting soil seedbank species composition. Loss of seeds due to predation (Wilson *et al.* 1995), loss of seed dormancy, loss of seed viability **(**Schafer and Chilcote 1970) etc. also have impact on the plant species composition of soil seedbank. Mostly the annual forbs show high seed dormancy, low seed predation and high persistent seeds which favour the germination of most of their seeds in the coming season. Whereas, in case of perennial grasses, most of the seeds get lost before germination due the low level of seed dormancy, high vulnerability to predators etc. Buried seeds might also fail to emerge due to death as a result of physiological aging, seed decomposition etc. (Baskin and Baskin 1998). Buried seeds might undergo changes in their dormancy state which bring high germination at sometimes and sometimes little or no germination (Taylor 1970). Non-dormant seeds of some species may reenter dormancy if environmental conditions are unfavourable for germination thereby affecting the seedbank dynamics (Baskin and Baskin 1998). Thus, the soil seedbank dynamics could also be the reason for the low similarity between the soil seedbank flora and the standing flora.

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Parthenium invasion did not have significant impact on the plant species richness in presence of its biocontrol agent *Zygogramma* but it has modified the plant species composition of the grassland. Impacts of *Parthenium* on species composition cannot be merely described on the basis of its invasion but also depends upon the degree of its invasion. Different levels of *Parthenium* infestation showed different species composition. Plots having high levels of *Parthenium* infestation had relatively low species similarity with the other plots having medium and low levels of *Parthenium* invasion. Extent of canopy cover, competition for resource utilization, grazing intensity, allelopathic effects etc. directly depend upon the degree of *Parthenium* invasion which in turn affect the species composition. At the initial state of its invasion *Parthenium* facilitates the growth of small herbaceous species but latter most of the associated species disappear when *Parthenium* form pure stand. Grazing exclusion is also one of the factors affecting species composition in the *Parthenium* infested area.

Defoliation caused by the leaf feeding beetle, *Zygogramma bicolorata*, had significantly decreased the *Parthenium* density, its maximum height and cover from 2009 to 2010. Defoliation can bring remarkable decrease in flower and seed production but there was no significant decrease in the germinable soil seedbank density between the two years. Thus for the significant reduction in its soil seedbank density, at least the defoliation phenomenon has to be continued for few more years. *Parthenium* had the highest germinable soil seedbank density among all the germinated species recorded from the soil samples of top 10 cm thick, for both years 2009 and 2010, the value being 11084 and 10716 seeds/m^2 respectively and contributed nearly $4/5^{th}$ of total germinable soil seedbank. Most of the germinable seeds of *Parthenium* (94.42% in year 1 and 96.24% in year 2) were concentrated at the top layer (0-5 cm) of the soil..

Under the present study condition, both of our null hypotheses that postulated 'Invasion by *Parthenium* reduces herbaceous plant species richness in grassland' and, 'Soil seedbank of *Parthenium* weed decline overtime after the initiation of biological control' have been rejected.

6.2 Recommendations

- Long term persistent nature of its soil seedbank makes it difficult to eradicate *Parthenium* completely in a short period. In such case biological control alone seems to be inadequate. So, integrated long- term management programs must be carried out to control the weed.
- Plant species composition is affected by the *Parthenium* invasion which can displace the palatable species of grassland. Thus, grazing lands should be protected from *Parthenium* invasion to ensure sustainable fodder supply for livestock.

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APPENDICES

Appendix 1. List of different species recorded in the plots with different levels of *Parthenium* infestation during vegetation sampling of year 1 (2009).

S.N.	Name of the species	Life history	HIP	MIP	LIP
1	*Ageratum conyzoides* L.	A/F	+	+	+
2	*Alysicarpus* sp.	A/F	+	+	+
3	*Blumea* sp.	A/F	+	+	+
4	*Borreria alata* (Aubl.) DC.	A/F	+	+	+
5	*Borreria articularis* (L.f) F.N Williams	A/F	+	-	-
6	*Bothriospermum tenellum* (Hornem.) Fisch.	A/F	+	-	-
7	*Cassia tora* L.	*A/Sb*	+	+	+
8	*Centella asiatica* (L.) Urb.	*P/F*	+	+	-
9	*Chrysopogon aciculatus* (Retz.) Trin.	*P/G*	+	+	+
10	*Corchorus aestuan*s L.	A/F	-	+	-
11	*Crotolaria prostrata* Rottl.ex Willd.	*A/F*	+	-	-
12	*Crotolaria* sp.	*A/F*	+	+	+
13	*Cynodon dactylon* (L.) Pers.	*P/G*	+	+	+
14	*Dactyloctenium aegyptium* (L.) Willd.	*A/G*	+	-	-
15	*Desmodium triflorum* (L.) DC.	*P/F*	+	+	+
16	*Digitaria* sp.	*A/G*	+	+	+
17	*Echinocloa colona* L. Link	*A/G*	+	+	-
18	*Eleusine indica* (L.) Gaertn.	*A/G*	+	+	+
19	*Emilia sonchifolia* (L.) DC.	*A/F*	+	-	+
20	*Eragrostis pilosa* (L.) P. Beauv.	*A/G*	+	+	+
21	*Eragrostis tenella* (L.) P. Beauv. ex Roem.	*A/G*	+	+	+
22	*Eragrostis uniloide*s (Retz.) Nees ex Steud.	*A/G*	+	-	+
23	*Chromolaena odorata* L.	*P/Sb*	+	-	-
24	*Euphorbia hirta* L.	*A/F*	+	+	+
25	*Evolvulus nummularius* (L.) L.	*A/F*	+	+	+
26	*Fimbristylis dicotoma* (L.) Vahl	*A/G*	+	+	+
27	*Hedyotis diffusa* Willd.	A/F	-	+	+
28	*Hygrophila polysperma* (Roxb.) T. Anderson	*A/F*	+	+	+
29	*Imperata cylindrica* (L.) P. Beauv.	*P/G*	+	+	+
30	*Kyllinga brevifolia* Rottb.	*P/G*	+	+	+
31	*Mecardonia procumbens* (Mill.) Small	*A/F*	+	+	-
32	*Mimosa pudica* L.	*A/W*	+	+	+
33	*Ophioglossum* sp.	*A/F*	+	-	-
34	*Oplismenus burmannii* (Retz.) P. Beauv.	*A/G*	+	+	-
35	*Oxalis corniculata* L.	*P/F*	+	+	-
36	*Panicum* sp.	*P/G*	+	+	+
37	*Parthenium hysterophorus* L.	*A/F*	+	+	+
38	*Paspalidium flavidum* (Retz.) A. Camus	*P/G*	+	+	+
39	*Paspalum distichum* L.	*P/G*	+	+	+
40	*Phyllanthus* urinaria L.	*A/F*	+	+	+
41	*Phyllanthus virgatus* G. Forst.	*A/F*	+	+	+

42	*Physalis divaricata* D.Don	*A/F*	+	-	-
43	*Polygala* sp.	*A/F*	+	+	+
44	*Pycerus* sp.	*P/G*	+	-	+
45	*Setaria glauca* (L.) P. Beauv.	*A/G*	+	+	+
46	*Setaria* sp.	*A/G*	+	-	+
47	*Shorea robusta* Gaertn.	*P/T*	+	+	+
48	*Sida acuta* Burm.f.	*P/W*	+	+	+
49	*Sida rhombifolia* L.	*P/W*	+	+	+
50	*Sida* sp.	*P/W*	+	+	+
51	*Smithia sensitiva* Aiton	*A/F*	+	+	+
52	dicot 1	A/F	-	-	+
53	dicot 2	*A/F*	+	+	+
54	*Vernonia cinerea* L. Less	*P/F*	+	+	+
55	*Zornia gibbosa* Span.	*A/F*	+	+	+

*HIP=High Infested Plot, MIP=Medium Infested Plot and LIP=Low Infested Plot.

*Life history consists of longevity (A, Annual or biennial; P, perennial; after Stanley & Ross 1983, 1986, 1989) and life forms (F, forb; G, graminoid; Sb, sub-shrub; T, tree; W, woody forb; after Neldner 1984). + sign indicates presence of species, - sign indicates absence of species.

Appendix 2. List of the families of the identified species recorded during vegetation sampling of year 1 (2009).

S.N.	Name of the Family	Number of species
1	Acanthaceae	1
2	Boraginaceae	1
3	Compositae	6
4	Convolvulaceae	1
5	Cyperaceae	3
6	Dipterocarpaceae	1
7	Euphorbiaceae	3
8	Gramineae	16
9	Leguminosae	8
10	Malvaceae	3
11	Ophioglossaceae	1
12	Oxalidaceae	1
13	Polygalaceae	1
14	Rubiaceae	3
15	Scrophulariaceae	1
16	Solanaceae	1
17	Tiliaceae	1
18	Umbelliferae	1
Total number of identified species		53

Appendix 3. List of the total number of species (species richness) at different levels of *Parthenium* infestation. (Vegetation sampling: year 1, 2009).

S.N.	HIP	MIP	LIP
1	12	16	21
2	14	19	16
3	14	12	15
4	16	14	15
5	18	16	13
6	16	14	15
7	13	19	15
8	15	16	14
9	15	16	14
10	22	17	11
11	15	15	12
12	12	14	13
13	14	19	14
14	20	20	16
15	18	17	16
16	15	21	14
17	22	16	12
18	25	19	13
19	22	21	23
20	21	19	21
Average±SD	17±4	17±3	15±3

*HIP=High Infested Plot, MIP=Medium Infested Plot and LIP=Low Infested Plot.

Appendix 4. Frequencies of different species recorded during the vegetation sampling of year 1 (2009).

S.N.	Name of the species	Levels of *Parthenium*		
		High	Medium	Low
1	*Ageratum conyzoides* L.	10	10	5
2	*Alysicarpus* sp.	45	55	60
3	*Blumea* sp.	20	35	25
4	*Borreria alata* (Aubl.) DC.	75	80	65
5	*Borreria articularis* (L.f.) F.N. Williams	10	-	-
6	*Bothriospermum tenellum* (Hornem.) Fisch. & Mey.	5	-	-
7	*Cassia tora* L.	60	30	30
8	*Centella asiatica* (L.) Urb.	5	5	-
9	*Chrysopogon aciculatus* (Retz.) Trin.	65	90	95
10	*Corchorus aestuan*s L.	-	10	-
11	*Crotolaria prostrata* Rottl. ex Willd.	5	-	-
12	*Crotolaria* sp.	40	15	25
13	*Cynodon dactylon* (L.) Pers.	75	75	55
14	*Dactyloctenium aegyptium* (L.) Willd.	5	-	-
15	*Desmodium triflorum* (L.) DC.	85	80	80
16	*Digitaria* sp.	10	5	10
17	*Echinocloa colona* (L.) Link	45	10	-

18	*Eleusine indica* (L.) Gaertn.	15	15	5
19	*Emilia sonchifolia* (L.) DC.	5	-	5
20	*Eragrostis pilosa* (L.) P. Beauv.	10	5	5
21	*Eragrostis tenella* (L.) P. Beauv. ex Roem. &	30	65	80
22	*Eragrostis uniloide*s (Retz.) Nees ex Steud.	5	-	5
23	*Chromolaena odorata* L.	20	-	-
24	*Euphorbia hirta* L.	90	95	60
25	*Evolvulus nummularius* (L.) L.	45	30	20
26	*Fimbristylis dicotoma* (L.) Vahl	70	90	95
27	*Hedyotis diffusa* Willd.	-	5	5
28	*Hygrophila polysperma* (Roxb.) T. Anderson	65	65	55
29	*Imperata cylindrica* (L.) P. Beauv.	80	55	55
30	*Kyllinga brevifolia* Rottb.	25	15	20
31	*Mecardonia procumbens* (Mill.) Small	10	5	-
32	*Mimosa pudica* L.	85	95	85
33	*Ophioglossum* sp.	5	-	-
34	*Oplismenus burmannii* (Retz.) P. Beauv.	20	25	-
35	*Oxalis corniculata* L.	5	20	-
36	*Panicum* sp.	10	15	5
37	*Parthenium hysterophorus* L.	100	100	100
38	*Paspalidium flavidum* (Retz.) A. Camus	55	80	90
39	*Paspalum distichum* L.	40	55	65
40	*Phyllanthus urinaria* L.	50	65	70
41	*Phyllanthus virgatus* G. Forst.	5	5	5
42	*Physalis divaricata* D.Don	5	-	-
43	*Polygala* sp.	65	80	40
44	*Pycerus* sp.	5	-	5
45	*Setaria glauca* (L.) P. Beauv.	20	25	10
46	*Setaria* sp.	10	-	5
47	*Shorea robusta* Gaertn.	30	45	35
48	*Sida acuta* Burm.f.	60	35	35
49	*Sida rhombifolia* L.	25	25	40
50	*Sida* sp.	20	30	10
51	*Smithia sensitiva* Aiton	5	5	5
52	dicot 1	-	-	5
53	dicot 2	10	20	25
54	*Vernonia cinerea* (L.) Less	20	15	15
55	*Zornia gibbosa* Span.	15	5	5

*- sign indicates absent species.

Appendix 5 List of different species recorded in the plots with High level of *Parthenium* infestation during the vegetation sampling of year 2 (2010).

SN	Name of Species	Life history	Family	Frequency
1	*Ageratum conyzoides* L.	A/F	Compositae	67
2	*Bidens pilosa* L.	A/F	Compositae	3
3	*Blumea* sp.	A/F	Compositae	27
4	*Borreria articularis* (L.f.) F.N. Williams	A/F	Rubiaceae	63

5	*Bothriospermum tenellum* (Hornem.)	A/F	Boraginaceae	3
6	*Brachiaria ramosa* (L.) Stapf	A/F	Gramineae	3
7	*Cassia tora* L.	A/Sb	Leguminosae	23
8	*Chromolaena odorata* L.	P/Sb	Compositae	10
9	*Chrysopogon aciculatus* (Retz.) Trin.	P/G	Gramineae	67
10	*Clerodendrum* sp.	P/Sb	Verbenaceae	27
11	*Corchorus aestuans* L.	A/F	Tiliaceae	10
12	*Crotolaria prostrata* Rottl. ex Willd.	A/F	Leguminosae	47
13	*Cynodon dactylon* (L.) Pers.	P/G	Gramineae	77
14	*Desmodium triflorum* (L.) DC.	P/F	Leguminosae	83
15	*Digitaria* sp.	A/G	Gramineae	3
16	*Echinocloa colona* L. Link	A/G	Gramineae	10
17	*Eluesine indica* (L.) Gaertn	A/G	Gramineae	3
18	*Eragrostis tenella* (L.) P. Beauv. ex Roem. & Schult.	A/G	Gramineae	20
19	*Eragrostis uniloide*s (Retz.) Nees ex Steud.	A/G	Gramineae	7
20	*Euphorbia hirta* L.	A/F	Euphorbiace	67
21	*Evolvulus nummularius* (L.) L.	A/F	Convolvulac	27
22	*Fimbristylis* sp.	A/G	Cyperaceae	50
23	*Hackelochloa granularis* (L.) Kuntz.	A/G	Gramineae	7
24	*Hygrophila polysperma* (Roxb.) T.	A/F	Acanthaceae	60
25	*Imperata cylindrica* (L.) P. Beauv.	P/G	Gramineae	10
26	*Ixeris polycephala* Cass.	A/F	Compositae	3
27	*Lantana camara* L.	P/S	Verbenaceae	3
28	*Lindernia parviflora* (Roxb.) Haines.	A/F	Labiateae	17
29	*Mimosa pudica* L.	A/W	Leguminosae	77
30	*Oplismenus burmannii* (Retz.) P.	A/G	Gramineae	30
31	*Oxalis corniculata* L.	P/F	Oxalidaceae	13
32	*Panicum* sp. (L.)	P/G	Gramineae	7
33	*Parthenium hysterophorus* L.	A/F	Compositae	100
34	*Paspalidium flavidum* (Retz.) A.	P/G	Gramineae	63
35	*Paspalum distichum* L.	P/G	Gramineae	30
36	*Phyllanthus urinaria* L.	A/F	Euphorbiaceae	37
37	*Physalis divaricata* D. Don	A/F	Solanaceae	3
38	*Polygala* sp.	A/F	Polygalaceae	37
39	*Setaria glauca* (L.) P. Beauv.	A/G	Gramineae	30
40	*Setaria* sp.	A/G	Gramineae	40
41	*Sida acuta* Burm. f.	P/W	Malvaceae	53
42	*Sida rhombifolia* L.	P/W	Malvaceae	47
43	*Sida* sp.	P/W	Malvaceae	10
44	*Vernonia cinerea* L. Less	P/F	Compositae	40

* Life history consists of longevity (A, Annual or biennial; P, perennial; after Stanley & Ross 1983, 1986, 1989) and life forms (F, forb; G, graminoid; S, shrub; Sb, sub-shrub; W, woody forb; after Neldner 1984).

Appendix 6. List of the species recorded from the soil seedbank study of year1 (2009) and year 2 (2010).

SN	Name of the species	Life history	Family	2009	2010
1	*Ageratum conyzoides* L.	A/F	Compositae	+	+
2	*Ageratum houstonianum* Mill.	A/F	Compositae	+	-
3	*Ageratum* sp.	A/F	Compositae	+	-
4	*Bidens pilosa* L.	A/F	Compositae	+	+
5	*Boehmeria* sp.	A/F	Urticaceae	+	-
6	*Borreria alata* (Aubl.) DC.	A/F	Rubiaceae	+	+
7	*Brachiaria ramosa* (L.) Stapf	A/F	Gramineae	-	+
8	*Carex* sp.	P/G	Cyperaceae	+	+
9	*Cynodon dactylon* (L.) Pers.	P/G	Gramineae	-	+
10	*Cyperus* sp.	A/G	Cyperaceae	+	-
11	*Desmodium microphyllum* (Thunb.) DC.	P/F	Leguminosae	+	-
12	*Desmodium triflorum* (L.) DC.	P/F	Leguminosae	-	+
13	*Digitaria* sp.	A/G	Gramineae	+	-
14	*Echinocloa colona* L. Link	A/G	Gramineae	-	+
15	*Eleusine indica* (L.) Gaertn.	A/G	Gramineae	+	+
16	*Eleusine* sp.	A/G	Gramineae	+	-
17	*Emilia sonchifolia* (L.) DC.	A/F	Compositae	-	+
18	*Chromolaena odorata* L.	P/Sb	Compositae	+	+
19	*Euphorbia hirta* L.	A/F	Euphorbiaceae	+	+
20	*Evolvulus nummularius* (L.) L	A/F	Convolvulaceae	-	+
21	*Evolvulus* sp.	A/F	Convolvulaceae	+	-
22	*Fimbristylis* sp.	A/G	Cyperaceae	+	-
23	*Fimbristylis littoralis* Gaud.	A/G	Cyperaceae	+	-
24	*Galinsoga* sp.	A/F	Compositae	-	+
25	*Glinus oppositifolius* (L.) DC.	P/F	Molluginaceae	+	-
26	*Gnaphalium* sp.	A/F	Compositae	+	-
27	*Hedyotis* sp.	A/F	Rubiaceae	+	+
28	*Imperata cylindrica* (L.) P. Beauv.	P/G	Gramineae	+	-
29	*Leucas indica* (L.) R. Br.ex Vatke	A/F	Labiatae	+	+
30	*Mecardonia procumbens* (Mill.) Small	A/F	Scrophulariaceae	+	+
31	*Mimosa pudica* L.	A/W	Leguminosae	+	+
32	*Oplismenus burmannii* (Retz.) P.	A/G	Gramineae	-	+
33	*Oxalis corniculata* L.	P/F	Oxalidaceae	+	+
34	*Panicum* sp.	P/G	Gramineae	+	-
35	*Parthenium hysterophorus* L.	A/F	Compositae	+	+
36	*Paspalidium flavidum* (Retz.) A.	P/G	Gramineae	+	-
37	*Paspalum scrobiculatum* L.	P/G	Gramineae	+	-
38	*Phyllanthus* sp.	A/F	Euphorbiaceae	+	-
39	*Phyllanthus urinaria* L.	A/F	Euphorbiaceae	-	+
40	*Physalis divaricata* D. Don.	A/F	Solanaceae	-	+
41	*Polygonum plebeium* R.Br.	A/F	Polygonaceae	+	-
42	*Polypogon monospeliensis* (L.)	A/G	Gramineae	+	-
43	*Rorippa nasturtium-aquaticum* (L.)	A/F	Crucifereae	+	-

44	*Setaria glauca* (L.) P. Beauv.	A/G	Gramineae	-	+
45	*Setaria* sp.	A/G	Gramineae	+	-
46	*Sida acuta* Burm.f.	P/W	Malvaceae	+	+
47	*Sida rhombifolia* L.	P/W	Malvaceae	-	+
48	*Sonchus wightianus* DC.	P/F	Compositae	+	-
49	*Sporobolous fertilis* (Steaud.) Clayton	P/G	Gramineae	+	+
50	Unknown sp 1	A/F	Labiateae	+	-
51	Unknown sp 2	A/F	Compositae	+	-

* Life history consists of longevity (A, Annual or biennial; P, perennial; after Stanley & Ross 1983, 1986, 1989) and life forms (F, forb; G, graminoid; S, shrub; Sb, sub-shrub; T, tree; W, woody forb; after Neldner 1984). +sign indicates presence of species, - sign indicates absence of species.

Appendix 7. List of different families recorded during the soil seedbank study of year 1 (2009) and year 2 (2010).

SN	**Name of the family**	**Number of each family**	
		2009	**2010**
1	Compositae	9	6
2	Convolvulaceae	1	1
3	Crucifereae	1	0
4	Cyperaceae	4	1
5	Euphorbiaceae	2	2
6	Gramineae	**10**	**7**
7	Labiatae	2	1
8	Leguminosae	2	2
9	Malvaceae	1	2
10	Molluginaceae	1	0
11	Oxalidaceae	1	1
12	Polygonaceae	1	0
13	Rubiaceae	2	2
14	Scrophulariaceae	1	1
15	Urticaceae	1	0
16	Solanaceae	0	1

*HIP=High Infested Plot, MIP=Medium Infested Plot and LIP=Low Infested Plot

Appendix 8. List of different species at two different soil depths (0-5 cm and 5-10 cm) recorded during the soil seedbank study of year 1 (2009).

SN	Name of the species	(0-5)cm	(5-10)cm
1	*Ageratum conyzoides* L.	+	+
2	*Ageratum houstonianum* Mill.	+	+
3	*Ageratum* sp.	+	-
4	*Bidens pilosa* L.	+	+
5	*Boehmeria* sp.	+	-
6	*Borreria alata* (Aubl.) DC.	+	-
7	*Carex* sp.	+	+
8	*Cyperus* sp.	+	+
9	*Desmodium microphyllum* (Thunb.) DC.	+	+
10	*Digitaria* sp.	+	-
11	*Eleusine indica* (L.) Gaertn.	+	+
12	*Eleusine* sp.	+	-
13	*Chromolaena odorata* L.	+	+
14	*Euphorbia hirta* L.	+	+
15	*Evolvulus* sp.	+	-
16	*Fimbristylis* sp.	+	-
17	*Fimbristylis littoralis* Gaud.	+	-
18	*Glinus oppositifolius* (L.) DC.	+	+
19	*Gnaphalium* sp.	+	+
20	*Hedyotis* sp.	+	-
21	*Imperata cylindrica* (L.) P. Beauv.	+	-
22	*Leucas indica* (L.) R.Br. ex Vatke	-	+
23	*Mecardonia procumbens* (Mill.) Small	+	+
24	*Mimosa pudica* L.	+	-
25	*Oxalis corniculata* L.	+	+
26	*Panicum* sp.	+	-
27	*Parthenium hysterophorus* L.	+	+
28	*Paspalidium flavidum* (Retz.) A. Camus	+	-
29	*Paspalum scrobiculatum* L.	+	-
30	*Phyllanthus* sp.	+	+
31	*Polygonum plebeium* R.Br.	+	-
32	*Polypogon monospeliensis* (L.) Desf.	+	-
33	*Rorippa nasturtium-aquaticum* (L.) Hayek	+	-
34	*Setaria* sp.	+	-
35	*Sida acuta* Burm. f.	+	+
36	*Sonchus wightianus* DC.	+	+
37	*Sporobolus fertilis* (Steud.) Clayton	+	-
38	Unknown sp 1	+	+
39	Unknown sp. 2	-	+

*+ sign indicates presence of species, - sign indicates absence of species.

Appendix 9. Soil seedbank densities (no. of viable seeds/m^2) and frequencies of different species at different soil depths (0-5 cm and 5-10cm), recorded in the soil seedbank study of year 1 (2009).

SN	Name of the species	(0-5 cm)		(5-10 cm)	
		Density	Frequency	Density	Frequency
1	*Ageratum conyzoides* L.	13±39	10	45±85	25
2	*Ageratum houstonianum* Mill.	6±28	5	6±28	5
3	*Ageratum* sp.	57±105	30	-	-
4	*Bidens pilosa* L.	25±67	15	25±89	10
5	*Boehmeria* sp.	6±28	5	-	-
6	*Borreria alata* (Aubl.) DC.	13±57	5	-	-
7	*Carex* sp.	139±280	30	32±91	20
8	*Cyperus* sp.	102±400	10	95±314	20
9	*Desmodium microphyllum*	6±28	5	6±28	5
10	*Digitaria* sp.	6±28	5	-	-
11	*Eleusine indica* (L.) Gaertn.	6±28	5	6±28	5
12	*Eleusine* sp.	13±57	5	-	-
13	*Chromolaena odorata* L.	134±191	55	121±313	35
14	*Euphorbia hirta* L.	465±564	70	32±91	15
15	*Evolvulus* sp.	13±39	10	-	-
16	*Fimbristylis* sp.	6±28	5	-	-
17	*Fimbristylis* littoralis Gaud.	19±62	10	-	-
18	*Glinus oppositifolius* (L.) DC.	13±57	5	6±28	5
19	*Gnaphalium* sp.	13±39	10	6±28	5
20	*Hedyotis* sp.	19±47	15	-	-
21	*Imperata cylindrica* (L.) P. Beauv.	32±142	5	-	-
22	*Leucas indica* (L.) R.Br. ex Vatke	-	-	6±28	5
23	*Mecardonia procumbens* (Mill.)	560±1585	50	64±113	30
24	*Mimosa pudica* L.	51±87	30	-	-
25	*Oxalis corniculata* L.	350±443	70	64±77	45
26	*Panicum sp.*	6±28	5	-	-
27	*Parthenium hysterophorus* L.	10466±6534	100	618±960	85
28	*Paspalidium flavidum* (Retz.) A.	6±28	5	-	-
29	*Paspalum scrobiculatum* L.	6±28	5	-	-
30	*Phyllanthus* sp.	325±1165	30	25±67	15
31	*Polygonum plebeium* R.Br.	6±28	5	-	-
32	*Polypogon monospeliensis* (L.)	6±28	5	-	-
33	*Rorippa nasturtium-aquaticum*	45±126	15	-	-
34	*Setaria* sp.	6±28	5	-	-
35	*Sida acuta* Burm.f.	19±47	15	6±28	5
36	*Sonchus wightianus* DC.	64±113	30	25±78	10
37	*Sporobolus fertilis* (Steud.)	13±39	10	-	-
38	Unknown sp 1	6±28	5	6±28	5
39	Unknown sp. 2	-	-	6±28	5

*- sign indicates absence of species.

Appendix 10. Soil seedbank densities (no. of viable seeds/m^2) and frequencies of different species recorded at soil depth of 0-10 cm, recorded in the soil seedbank study of year 1 (2009).

SN	Name of the species	Density	Frequency
1	*Ageratum conyzoides* L.	57±97	30
2	*Ageratum houstonianum* Mill.	13±39	10
3	*Ageratum* sp.	57±105	30
4	*Bidens pilosa* L.	51±105	25
5	*Boehmeria* sp.	6±28	5
6	*Borreria alata* (Aubl.) DC.	13±57	5
7	*Carex* sp.	164±271	50
8	*Cyperus* sp.	197±535	25
9	*Desmodium microphyllum* (Thunb.) DC.	13±39	10
10	*Digitaria* sp.	6±28	5
11	*Eleusine indica* (L.) Gaertn.	13±39	10
12	*Eleusine* sp.	13±57	5
13	*Chromolaena odorata* L.	255±355	70
14	*Euphorbia hirta* L.	497±545	80
15	*Evolvulus* sp.	13±39	10
16	*Fimbristylis* sp.	6±28	5
17	*Fimbristylis* littoralis Gaud.	19±62	10
18	*Glinus oppositifolius* (L.) DC.	19±62	10
19	*Gnaphalium* sp.	19±47	15
20	*Hedyotis* sp.	19±47	15
21	*Imperata cylindrica* (L.) P. Beauv.	32±142	5
22	*Leucas indica* (L.) R.Br. ex Vatke	6±28	5
23	*Mecardonia procumbens* (Mill.) Small	624±1583	65
24	*Mimosa pudica* L.	51±87	30
25	*Oxalis corniculata* L.	414±454	85
26	*Panicum* sp.	6±28	5
27	*Parthenium hysterophorus* L.	11084±6552	100
28	*Paspalidium flavidum* (Retz.) A. Camus	6±28	5
29	*Paspalum scrobiculatum* L.	6±28	5
30	*Phyllanthus* sp.	350±1218	40
31	*Polygonum plebeium* R.Br.	6±28	5
32	*Polypogon monospeliensis* (L.) Desf.	6±28	5
33	*Rorippa nasturtium-aquaticum* (L.) Hayek	45±126	15
34	*Setaria* sp.	6±28	5
35	*Sida acuta* Burm.f.	25±67	15
36	*Sonchus wightianus* DC.	89±138	35
37	*Sporobolus fertilis* (Steud.) Clayton	13±39	10
38	Unknown sp. 1	13±39	10
39	Unknown sp. 2	6±28	5

Appendix 11. List of different species at two different soil depths (0-5 and 5-10 cm) recorded during the soil seedbank study of year 2, (2010).

SN	Name of the species	0-5cm	5-10cm
1	*Ageratum conyzoides* L.	+	-
2	*Bidens pilosa* L.	+	-
3	*Borreria alata (*Aubl.) DC.	+	-
4	*Brachiaria ramosa* (L.) Stapf	+	-
5	*Carex* sp	+	+
6	*Cynodon dactylon* (L.) Pers.	+	-
7	*Desmodium triflorum* (L.) DC.	+	-
8	*Echinocloa colona* (L.) Link	+	-
9	*Eluesine indica* (L.) Gaertn.	+	+
10	*Emilia sonchifolia* (L.)DC.	+	+
11	*Chromolaena odorata* L.	+	+
12	*Euphorbia hirta* L.	+	+
13	*Evolvulus nummularius* (L.) L.	+	-
14	*Galinsoga* sp.	+	-
15	*Hedyotis* sp	+	-
16	*Leucas indica* (L.) R.Br.ex Vatke	+	+
17	*Mecardonia procumbens* (Mill.) Small	+	-
18	*Mimosa pudica* L.	+	-
19	*Oplismenus burmannii* (Retz.) P. Beauv.	+	+
20	*Oxalis corniculata* L.	+	+
21	*Parthenium hysterophorus* L.	+	+
22	*Phyllanthus urinaria* L.	+	-
23	*Physalis divaricata* D. Don.	+	-
24	*Setaria glauca* (L.) P. Beauv.	+	-
25	*Sida acuta* Burm.f.	+	+
26	*Sida rhombifolia* L.	+	-
27	*Sporobolous fertilis* (Steaud.) Clayton	+	-

+sign indicates presence of the species, - Sign indicates absence of the species

Appendix 12. Soil seedbank densities (no. of viable seeds/m^2) and frequencies of different species at different soil depths (0-5 cm and 5-10cm), recorded in soil seedbank study of year 2 (2010).

SN	Name of the species	(0-5 cm)		(5-10 cm)	
		Density	Frequency	Density	Frequency
1	*Ageratum conyzoides* L.	4±23	3		
2	*Bidens pilosa* L.	8±32	7		
3	*Borreria alata* (Aubl.) DC.	8±46	3	8±32	7
4	*Brachiaria ramosa* (L.) Stapf	4±23	3		
5	*Carex* sp.	47±196	7		
6	*Cynodon dactylon* (L.) Pers.	170±246	47	5±23	7
7	*Desmodium triflorum (*L.) DC.	4±23	3		
8	*Echinocloa colona* (L.) Link	38±168	7		
9	*Eleusine indica* (L.) Gaertn.	25±70	13		
10	*Emilia sonchifolia* (L.) DC.	13±70	3	4±23	3
11	*Chromolaena odorata* L.	8±32	7	4±23	3
12	*Euphorbia hirta* L.	242±264	60	13±39	10
13	Evolvulus nummularius (L.) L.	4±23	3	4±23	3
14	*Galinsoga* sp.	8±32	7		
15	*Hedyotis* sp.	4±23	3		
16	*Leucas indica* (L.) R.Br. ex	4±23	3		
17	*Mecardonia procumbens* (Mill.) Small	416±2183	13	8±46	3
18	*Mimosa pudica* L.	98±176	33		
19	*Oplismenus burmannii* (Retz.) P. Beauv.	21±82	7		
20	*Oxalis corniculata* L.	764±776	80	283±607	60
21	*Parthenium hysterophorus* L.	10313±7588	100	403±372	77
22	*Phyllanthus urinaria* L.	59±208	10	4±23	3
23	*Physalis divaricata* D. Don.	4±23	3		
24	*Setaria glauca* (L.) P. Beauv.	191±456	27		
25	*Sida acuta* Burm.f.	4±23	3		
26	*Sida rhombifolia* L.	64±137	3	17±44	13
27	*Sporobolous fertilis* (Steaud.) Clayton	17±93	3		

Appendix 13. Soil seedbank densities (no. of viable seeds/m^2) and frequencies of different species recorded at soil depth of 0-10 cm, recorded in soil seedbank study of year 2 (2010).

SN	Name of the species	Density	Frequency
1	*Ageratum conyzoides* L.	4±23	3
2	*Bidens pilosa* L.	8±32	7
3	*Borreria alata* (Aubl.) DC.	17±55	10
4	*Brachiaria ramosa* (L.) Stapf	4±23	3
5	*Carex* sp.	47±196	7
6	*Cynodon dactylon* (L.) Pers.	174±247	33
7	*Desmodium triflorum (*L.) DC.	4±23	3
8	*Echinocloa colona* (L.) Link	38±168	7
9	*Eleusine indica* (L.) Gaertn.	25±70	13
10	*Emilia sonchifolia* (L.) DC.	17±73	7
11	*Chromolaena odorata* L.	13±39	10
12	*Euphorbia hirta* L.	255±274	80
13	*Evolvulus nummularius* (L.) L.	8±32	7
14	*Galinsoga* sp.	8±32	7
15	*Hedyotis* sp.	4±23	3
16	*Leucas indica* (L.) R.Br. ex Vatke	4±23	3
17	*Mecardonia procumbens* (Mill.) Small	424±2182	13
18	*Mimosa pudica* L.	98±176	33
19	*Oplismenus burmannii* (Retz.) P. Beauv.	21±82	7
20	*Oxalis corniculata* L.	1047±1012	87
21	*Parthenium hysterophorus* L.	10716±7651	100
22	*Phyllanthus urinaria* L.	64±208	13
23	*Physalis divaricata* D. Don.	4±23	3
24	*Setaria glauca* (L.) P. Beauv.	191±456	27
25	*Sida acuta* Burm.f.	4±23	3
26	*Sida rhombifolia* L.	81±155	30
27	*Sporobolous fertilis* (Steaud.) Clayton	17±93	3

Appendix 14. Germinable soil seedbank density (mean ± SD) of *Parthenium*

Depth of the soil samples	years		Results of ANOVA		
	2009	2010	Degrees of freedom (x, y)	F value	Significance levels (P)
(0-5cm)	10466± 6534	10313± 7588.02	1, 48	.005	.942
(5-10cm)	618± 960	403± 372.46	1, 48	1.228	.273
(0-10cm)	11084± 6552	10716± 7650.83	1,48	.031	.861

Appendix 15. Species richness at different values for cover*density of *Parthenium* measured at different levels of *Parthenium* infestations.

Years	Levels of *Parthenium* infestation	Cover * density of *Parthenium*	Species richness	Results of ANOVA		
				Degrees of freedom (x, y)	F value	Significance levels (P)
2009	High	41262.75±11196	16.95±4	1,18	0.078	0.783
	Medium	10322.25±6861	17±3	1,18	0.002	0.966
	low	197.95±346	15.15±3	1,18	2.372	0.141
2010	high	19114.8±16350.1	14.2±2.3	1,28	3.009	0.094

Appendix 16. Species richness at different values for maximum height*density of *Parthenium* measured at different levels of *Parthenium* infestations:

Years	Levels of *Parthenium* infestation	Maximum height * density of *Parthenium*	Species richness	Results of ANOVA		
				Degrees of freedom (x, y)	F value	Significance levels (p)
2009	High	43399±13436	16.95±4	1,18	2.486	0.132
	Medium	13770±8270	17±3	1,18	0.352	0.560
	low	1126±1562	15.15±3	1,18	3.495	0.078
2010	high	19669±15464	14.2±2.3	1,28	5.353	0.028

Appendix 17. Similarity Indices

SN	Parameters	Jaccard's Similarity index		Sorensen's Similarity Index	
		2009	2010	2009	2010
1	Between soil seedbank flora of soil samples of (0-5)cm depth (5-10)cm depth	46%	40.74%	63%	57.89%
2	Between the soil seedbank flora and above ground flora of HIP	23%	29.09%	37.36%	45.07%

PHOTO PLATE I

Photo 1: *Parthenium* infested area of Lamasure Danda, Hetaunda

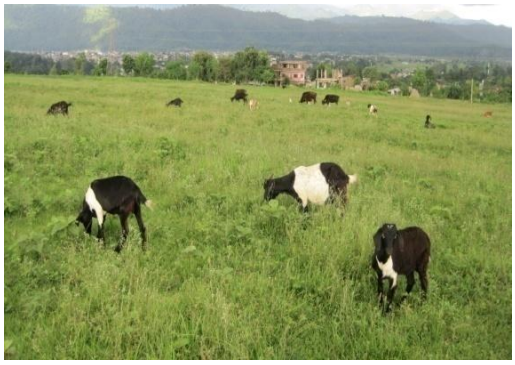

Photo 2: Grazing of domestic animals in the sampling site

Photo 3: Larva of *Zygogramma bicolorata* causing defoliation

Photo 4: Adult *Zygogramma bicolorata* causing defoliation

Photo 5: A Completely defoliated *Parthenium* plant

Photo 6: Vegetation sampling in *Parthenium* infested site

PHOTO PLATE II

Photo 7: Plot having high *Parthenium* infestation

Photo 8: Soil core sampler placed in the plot after removing the above ground vegetation

Photo 9: Soil core sampler with markings at 5cm and 10cm height

Photo 10: 10cm pit formed after evacuating the soil sample

Photo 11: Pots with 2/3 rd part filled with sterilized sand

Photo 12: Circular newspaper cuttings placed over the sand

PHOTO PLATES III

Photo 13: Soil samples spread over the newspaper cuttings

Photo 14: Depth of soil sample measuring 2cm

Photo 15: Watering of soil samples

Photo 16: 60 soil samples

Photo 17: Germinating seedlings of *Parthenium.*

Photo 18: Other plant species germinating from the soil samples