1. INTRODUCTION

1.1 Background

Species which are able to colonize target region in distant geographical range outside their home territory with the aid of human are called alien species (Huston 1994, Williamson 1996, Richardson *et al.* 2000). Alien species may be of three types: casual, naturalized and invasive. Casual aliens are those which survive occasionally outside cultivation. Naturalized alien when they become able to maintain population without support from human and invasive alien when they start to expand over the target region. Furthermore, if introduced plants produce reproductive offspring in areas distant from the sites of introduction (approximate scales:>100m over<50 years for taxa spreading by seeds and other propagules; > 6m/3 years for taxa spreading by roots, rhizomes, stolens or creeping stems) are called naturalized plants (Richardson *et al*. 2000).

Naturalized alien species maintaining viable population at considerable distance from their original home range are identified as invaders (Richardson *et al*. 2000). In this definition stress is given for the spread of a species. While more emphasis is given on the impact of an invader on its introduced environment by Davis and Thompson (2000). In the opinion of most scientists invaders are those species that established themselves in a new environment, spread and exert a threat to the ecosystem (Mack *et al*. 2000). Generally, disturbed and semi-natural communities are prone with the invasion of the taxa that can cope with the abiotic and biotic environment. Out of the many alien species if only a small proportion become invasive it has significant negative impacts on biodiversity at local level (Williamson 1999). Invasive species can pose significant impact on native species, communities, ecosystem and biodiversity (Sakai *et al*. 2001). It is considered as an important component of global change (Vitousek *et al*. 1996).

For the success of invaders, three important factors seem to be involved, which are: propagule pressure (the rate of introduction of propagules, seeds and breeding individuals), set of factors that help species to survive and increase from low densities; and set of factors that predict local abundance (Willeamson & Fitter 1996). Traits of invasive plant can be considered as one of the most important factor which includes production of copious amounts of seeds with a high viability, fast growth, having successful dispersal mechanisms, ability to thrive on disturbance, very opportunistic, lack of predators, pathogens and diseases to keep population numbers in check. Success of invader in a particular habitat is contributed by some structural and physiological attributes like bark thickness (Richardson *et al*. 1990), symbiotic nitrogen fixation (Vitousek & Walker 1989), rapid root growth (Hulbert 1955), Shade tolerance (Jones & Mcleod 1990), and resistance to browsing or stem photosynthesis (Bossard & Rejmanek 1992).

1.2 Statement of the problem

Although biological invasion has been considered as a leading threat to biodiversity (Crawly 1987; Ruesink *et al*. 1995, Kareiva 1996, Rejmanek & Richardson 1996, Williamson 1996, Rahel 2000, Mack 2001), the characteristics playing major role in expansion of invasive species are less understood (Kolar & Lodge 2001). *Parthenium hysterophorus* L. (here after referred as parthenium) is native of the Gulf of Mexico and Central South America and is widespread in North America, South America and the Caribbean. Now it has invaded more than 20 countries around the world including five continents and numerous islands. Recent studies have shown that African countries are at high risk of invasion. The most under threat areas are South East Asia, the Pacific and Western Africa (Shabbir 2010). Parthenium is considered as a weed of global significance and has received the status of major weed in Australia, India and many parts of the world (Adkins *et al*. 1997).

Parthenium is able to colonize new areas rapidly by means of relatively high numbers of seeds, dispersed via vehicles, water, animals, farm machinery and wind. Disturbed habitats, such as roadsides and railway tracks, stockyards, around buildings and fallow agricultural lands are particularly suitable for parthenium. The successful establishment of parthenium is because of its specific allelopathic effect through which the weed can compete more effectively with other crops or pasture species. Due to invasive capacity and allelopathic effects (Mersie & Singh 1987), natural ecosystems are disrupted (Evans

1997). Allelopathy is achieved primarily via two groups of allelochemicals, phenolics and sesquiterpene lactone, mainly parthenin (Belz *et al*. 2007) which inhibit germination and growth of plants including pasture grasses, cereals, vegetables and other plant species (Navie *et al*. 1996).

Parthenium is the most noxious and aggressive weed as it forms pure stand reducing the biodiversity and affects landscape and soil quality. Parthenium invasion adversely affects the carrying capacity of the grazing land (Bhowmik *et al*. 2007), decline in agricultural productivity (Khosla & Sobti 1981, Tamado & Milberg 2000, Tamado *et al*. 2002), reduction in forage production in grasslands by upto 90% (Nath 1988). In the pastoral regions of Central Queensland parthenium weed is the dominant species excluding all beneficial forage plants resulting in monoculture of non-nutritious, vegetable matter where it is not possible to sustain cattle (Chippendale & Panetta 1994). This ultimately causes a catastrophic drop in the productivity of pasture, reducing the carrying capacity (Haseler 1976). Parthenium caused annual losses of about Aus$ 16.5 million to beef producers due to reduced stock numbers and live weight gains and additional production and control costs (Chippendale & Panetta 1994). About Aus$ 1.8 million dollars is spent annually by producers and government in Central Queensland for the chemical control of the weed (Chippendale & Panetta 1994).

In Nepal this weed might have entered early in 1960s from India. However, the rapid expansion in most of the urban areas has been noticed during 1990s. Recently, it has been invaded mostly in the urban areas, roadside land, grasslands, fallow lands and community forest of tropical and subtropical regions throughout Nepal (Joshi 2005, Tiwari *et al*. 2005, Karki 2009, Timsina *et al*. 2011). The major urban areas like Kathmandu, Hetauda, Narayangargh, Butwal, Dang etc. are already invaded by this weed. The weed is still expanding in new areas, and population has increased rapidly in the previously invaded sites. Due to the invasion and rapid expansion of this weed in Hetauda, people have faced the problem of increasing labor in agriculture, loss of pasture land and severe allergy in animals and humans (Karki 2009). The rapid expansion of parthenium weed has become a new environmental problem in urban and peri urban areas of Nepal, including Kathmandu valley.

1.3 Justification of the study

Researches have been carried out on distribution, alleopathy, negative impacts and biological control of parthenium but details on phenology, its relation with climatic factors as well as role in the successful invasion of parthenium weed is still lacking (Fatimah & Ahmad 2009). Therefore, in the present study an attempt has been made to understand life history traits of parthenium which are responsible for the successful establishment and rapid expansion. From this study we can understand the life history traits such as number of cohort produced per year and duration of flowering phase which might have contributed in its invasiveness. Likewise, understanding of phenology is necessary before adopting the management strategy. In Kathmandu valley, parthenium can be seen in almost all months of a year but the knowledge on the numbers of cohort of this weed emerged annually is still missing. During mechanical control of parthenium weed mostly cutting is implemented. As this plant is known for its enhance regeneration capacity (Kohli 1997 c.f. Dhileepan 2009), re-growth may become a problem. Therefore, present study is conducted to investigate the effects of clipping of parthenium weed in terms of seed output. This has implication on management to know the effectiveness of controlling this weed through mechanical method. Thus, present study can be helpful in formulating the control strategy of this weed.

1.4 Research questions

In this research, an attempt is made to answer why parthenium is such a successful invasive plant. The specific research questions are:

- How long flower of parthenium blooms in Kathmandu valley?
- How many cohorts of this weed develop annually in Kathandu valley?
- How does this weed respond to mechanical damage in terms of seed output?

Answer to these questions will provide site specific information for understanding the invasiveness of parthenium in Kathmandu valley.

1.5 Hypotheses and objectives

The null hypotheses of this research are as follows:

- Frequency of flowering individual is same throughout the year in parthenium population.
- Mechanical disturbance (clipping) has no effect on seed output of parthenium.

The general objective of the research is to understand the life history traits of parthenium which make the species a successful invasive plant.

The specific objectives are:

- To analyze the seasonal variation in relative abundance of reproductive individuals of parthenium.
- To estimate the number of cohort per year in a population of parthenium in Kathmandu.
- To study the variation of species richness with density of parthenium.
- To understand the impact of mechanical disturbance (clipping) on reproductive efficiency in terms of seed output.

1.6 Limitation of the study

The chance of disturbance in permanently marked research site by human beings or cattle was minimized as number of plots was taken as much as possible. Since the field data was collected from a single site in Kathmandu valley, the phenological pattern in other parts of the country may be different from the results presented here. Also the difference in the intensity of defoliation by the bio-control agent *Zygogramma bicolorata* in the site made the replicate plots slightly different from each other.

2. LITERATURE REVIEW

2.1 Mechanisms of plant invasion

The three important factors enhancing invasion by new species are propagule pressure, the characteristic of the newly introduced species and susceptibility of the environment to the invasion of new species (Lonsdale 1999). Some of the mechanisms through which plant invades the new land and becomes invasive are described as follows.

2.1.1 Habitat invasibility

Resource fluctuation and disturbance are the two important ecological factors which are responsible to make a habitat prone to invasion (Grime 2002, Davis 2003). Similarly, other factors affecting invasibility are presence or absence of herbivore and pathogens (Lonsdale 1999), mutuality (Crawley 1987), and facilitative effect of resident vegetation (Maron & Connors 1996).

For the explanation of the habitat susceptibility to plant invasion, Resource fluctuation hypothesis has been proposed by Davis and his colleagues (2000). The theory states that a plant community with high amount of unused resources becomes prone to the plant invasion. According to Grime (2002) resource availability can be increased basically either by decline of resource use by resident vegetation or by increment of resources at faster rate than it can be used by residents. Use of resources can be decline due to the various reasons. Because of the destruction of resident vegetation uptake of nutrient, water and light can be decrease. Likewise, intensive grazing, pest out break and diseases are some of the other reasons of decline in resource uptake. A particular community is more vulnerable to invasion in both cases whether resource supply goes up or resource uptake goes down where more resource is available to the invaders. An important argument of the Resource fluctuation hypothesis is that community’s susceptibility is not static or permanent characteristics but it is the condition that can fluctuate over a temporal scale.

Shea and Chesson (2002) explained biological invasion on the basis of "niche opportunity". Three environmental factors namely resources, natural enemies and physical environment are recognized as contributors of successful invasion. Response of a species to these factors with varying time and space is a key to measure the ability of invasive species to invade. After establishment of self sustaining population density, invasive plants will start to affect the recipient community in terms of resource uptake and regulating natural enemies. Therefore, community invasibility depends on both effect and response of resident species in a community.

2.1.2 Enemy Release Hypothesis (ERH) and Plant invasion

This hypothesis is considered as the most acceptable to explain the mechanism of invasion. The statement of this hypothesis is that plant species, on introduction to an exotic region, should experience a decrease in regulation by herbivores and other natural enemies, resulting in an increase in distribution and abundance. Although the main supporting evidence for this hypothesis is the success of classical biological control, only observational evidence is not enough (Keane & Crawley 2002). This hypothesis is formulated on the basis of following three arguments such as: plant population is regulated by the natural enemies; native species are more affected by natural enemies than the exotics ones; and escape from the enemies enables plant species to grow their population explosively. From the survey of 86 populations of *Silene latifolia* in the United States and Europe it was revealed that greater level of attack which was about 17 times more in native range in Europe compared with introduced range that is in North America by generalist enemies (aphids, snails, floral herbivores)(Wolfe 2002). In the native range, the plants which are short lived and dependent on current seed production for regeneration are badly influenced by the herbivores because of reduction in seed production (Maron *et al*. 2001). They have also mentioned that for those species which escape from enemy provide an adventitious role such as increase in distribution and abundance in the recipient communities in comparison to the long lived native species which are continuously regulated by their native herbivores.

2.1.3 Allelopathy and plant invasion

Allelopathy a phenomenon of suppression of the associated species through the release of chemical is considered as one of the mechanism of successful invasion (Vivanco *et al*. 2004). Allelopathy has been recognized as a mechanism for the explanation of why invasive plant species become abundant and competitively dominant in introduced region in comparison to native (Inderjit *et al*. 2008). Invaders often form virtual monocultures where diverse communities once flourished (Hierro & Callaway 2003, Inderjit *et al*. 2008). Through the release of allelopathic chemical into the surroundings neighboring plants may be adversely impacted which ultimately influence community structure and vegetation dynamics (Callaway 2002). The Novel weapons hypothesis was first suggested when Callaway & Aschehoug (2000) found that *Centaurea diffusa*, native to Eurasia but invasive in Europe, had stronger competitive effects against North American grass species than grass congeners collected from communities in the Caucasus where the invader is indigenous. This hypothesis was proposed by Callaway & Ridenour (2004) is a new theory for the success of invasive plants. Some exotic invasive species become more successful in invading new habitat due to the possession of novel weapons, bio-chemicals that native species have never possessed. An increased competitive ability evolved in an invasive plant can be attributed to the novel weapon (Callaway & Ridenour 2004). If invaders encounter allelochemical weapons that mean they have competitive advantage over the native species in the introduced habitat than in their home range, after that selection will be in the favor of those traits (Callaway & Ridenour 2004). The invasiveness and rapid expansion of parthenium is attributed to its allelopathic potential to inhibit the growth of neighbouring species (Adkins & Sowerby 1996, Batish *et al*. 2005, Bhowmik *et al*. 2007, Marwat *et al*. 2008). Poudel (2011) reported that leaf extract of parthenium showed comparatively more inhibitory effects than inflorescence extract. The crucifer species *Raphanus sativus*, *Brassica campestris* and *Brassica oleraceae* were more sensitive to the leaf aqueous extract of parthenium and the extract had strong inhibitory effect on root elongation of seedlings in cereals shoot elongation in crucifer and wild Asteraceae (Maharjan *et al*. 2007). Inderjit (2008) has applied the three approaches namely: traditional, congeneric and bio-geographic to understand mechanistic role of allelopathy in plant invasion. In traditional approach both exotic invasive and native plants are examined in the same way for their allelopathic activities where dose fate and replenishment of chemical can provide powerful evidence for allelopathic process. The congeneric or phylogenetic approach refers to the comparative studies of exotic species with natives in the same genus or that are as closely related as possible. Whereas the bio-geographical approach compares the allelopathic effects of exotic invasive on species from their native and invaded communities.

2.2 Invasiveness of plant species

The question regarding the characteristics of the species which makes them more invasive is still unanswered (Baker & Stebbins 1965, Kornberg & Williamson 1987 c.f. Rejmanek 1996)). According to Rejmanek (1996), the first theory explaining plant invasion was given by Charles Darwin in 'On the Origin of Species' (1859). Rejmanek (1996) performed a simple discriminent analysis using ten life history characteristics namely : mean height, maximum height, minimum juvenile period, mean longevity, mean seed mass, seed wing loading index, average percentage of germination, mean interval between large seed crops, degree of serotiny, and fire tolerance index of the genus Pinus. Findings revealed that three characters viz. small seed mass, short juvenile period and short mean interval between large seed crops showed significant relationship with the invasiveness of woody species in disturbed landscape. Plant invasiveness in disturbed landscape may be also associated with genome size (low nuclear DNA content) which seems to be the result of selection for short minimum generation in time limited environments (Bachmann *et al*. 1985, Bennett 1987 c.f. Rejmanek 1996). Also, invasiveness of plant is often discussed in association with polyploidy (Rejmanek 1996). Primary (native) geographic range can be the best predictor of invasiveness of herbaceous Gramineae, Compositae and Fabaceae (Rejmanek 1996).

Generally, pattern of resource allocation to sexual and asexual reproduction (Sutherland & Vickery 1988) play an important role in variation of invasiveness of a particular species with different habitats.

Goodwin (1999) used biological attributes to examine the potential invasiveness of species on the basis of available biological information. From the comparison of plant species native to the Europe and introduced in New Brunswick, Canada to congeneric species in Europe that have not invaded North America, they found no effect of life form on invasiveness that means model could not predict invasiveness of the test species pairs. Whereas the second model with only European range was able to predict invasiveness in 70% of the test species.

Soil quality determine the plasticity in parthenium plant traits forming two contrasting strategy viz. tall, fast growing competitors producing small seed which favors rapid expansion of population and another one is short plant possessing high seed mass in order to survive in less favorable habitat where it can slowly built up population by increasing the soil seed bank (Annapurna & Singh 2003).

2.3 Life history traits

Life history characteristic is one of the most potential powers to predict the invasiveness of a species (Sakai *et al*. 2001). Many investigators have focused their study to know the life history traits of which are responsible to make population of invasive species explosive.

After profuse flowering in parthenium, prolific seeds are produced (around 25,000 seed/plant Navie *et al*. 1996) which form huge soil seed bank. Small, light and easily dispersive seed by wind and water contribute to rapid colonization in new areas. Four or five achenes of the same size varying from 0.2 to 0.4 mg are produced in each flower. Parthenium weed also possess huge amount of soil seed bank which may be due to its prolific seed production capacity as well as ability of the seed to remain viable for many years in the soil (Navie *et al*. 2004). About 200000 m^{-2} seed bank of this weed was estimated in abandoned fields of India (Joshi 1991). Hence, high number of seed production is one of the strategies of parthenium for rapid invasion. The average number of seed output in Kathmandu valley was ranged from 1392-3864 seeds per plant (Joshi 2005).The germinable soil seed bank was determined at two sites (Clernont & Moolayember Creek) infested with parthenium in Central Queensland, during 2 year period the seed bank varied between 3282 and 5094 seed/m^2 at Clermont site and between 20599 and 44639 seed/m^2 at the Moolayember Creek site (Navie *et al*. 2004). KC (2012) reported the variation in average soil seed bank density of parthenium from 11084±6552 seeds/m^2 to 10716±7651 seeds/m^2 in (2009 & 2010) respectively.

The species richness and species diversity of the seed bank as well as the seed abundance of many species was lower at Moolayember Creek during spring when there was dense infestation of the weed (Navie *et al*. 2004). Seedlings of parthenium emerged very rapidly in comparison to the other species from the soil samples. KC (2009) recorded the highest value (that is about 77% of the total) germinable soil seed bank density among all the germinated species recorded from the soil sample of 10 cm in thickness in 2009 and 2010.

Therefore, various aspects of the seed ecology of this weed such as abundance and the persistence of its seed bank, high viability of buried seeds, low seed predation, innate dormancy mechanism (Haseler 1976, Joshi 1991, Dhileepan *et al*. 1996) and the rapid emergence of its seedlings are seems to the main contributing factors to its aggressiveness in semiarid rangeland communities in central Queensland (Navie *et al*. 2004).

In all types of soil parthenium has an enormous ability to grow and establish quickly. Seed germination does not depend on the temperature, photoperiod or seasonal variation if moisture content is present in the soil. Although, rainy season is the main growing season but it can germinate throughout the year forming a thick pure stands. In case of water stressed condition rosette plant body are produced and this can increase in length with the onset of the rains (Kohli *et al*. 2006).A response of plant to simple reduction of leaf area or biomass is not so complex than it is to clipping or defoliation (Ferraro & Oesterheld 2002). Different mechanism such as stimulation of photosynthetic rate (Reich *et al*. 1993) increased tillering and altered allocation patterns (McNaughton *et al*. 1983) or greater nutrient uptake helps plant to compensate for the loss of biomass or leaf area after clipping. Patterns of plants' response to clipping are species specific and depend on morphological characters of species (Li *et al*. 2004). After the mechanical damage native plants were found to be negatively affected whereas invasive plants were unaffected (Kimball 2003). Plants that were unaffected means they were able to compensate for tissue losses after the clipping. On the other hand, negatively affected means unable to compensate for tissue losses i.e. undercompensation. Higher the susceptibility of plant to clipping greater will be the chances of controlling invasive species through mechanical methods.

Rajendrudu & Rama Das (1990), reported that parthenium weed is an intermediate between C_3–C_4 type which possess leaves on the top with C_3 mesophyll (non-Kranz leaf anatomy) and leaves on the middle and base with C_4 mesophyll (Kranz leaf anatomy).But, findings from photosynthetic gas exchange and whole plant response to carbon dioxide suggested that this weed is mostly of C_3 type (Pandey *et al*. 2003).

2.4 Population biology of invasive plants

Sakai *et al*. (2001) reviewed the literature on population biology of invasive species. The reviewed literature supported that there exist statistically significant relationship between life history characteristics and the potentialities for invasiveness. They suggested that further work on the population is necessary to predict invasiveness in a new environment. Also, the study should give more emphasis to understand the ecological role of a species in its native range and the occurrence of ecological or genetic variation between the invasive species population and its congener population. Population biology and invasive species are closely related to each other in such a way that, population biology is helpful in understanding and managing invasiveness whereas invasive species act as an important material to understand the basic phenomenon of population biology. Theory of population dynamics and population genetics can be useful in detecting the level of population where effective control can be employed.

However, less attention has been given to study the population dynamics of pure stands of parthenium weed in comparison to its interference with other species (Navie *et al*. 1996).Three successive cohorts of parthenium seedlings were formed after first rainfall in the monsoon in India with decrease in seedling density and survivorship to maturity in successive cohorts (Pandey & Dubey 1989).

2.5 Phenology

Phenology play an important key factor for the success of the invasive plant species. The difference in time for the onset of various phenophases provide an opportunity for introduced plant species to take nutrients earlier than the natives (Fatimah & Ahmad 2009).

Parthenium is a noxious annual herb with erect and much branched plant body. It can germinate, grow and flower at any time of the year with the completion of life cycle because of having wide amplitude of temperature and photoperiods in Queensland (Haseler 1976). The life cycle of parthenium weed starts in April-May and grows up to November-December (Fatimah & Ahmad 2009). This weed can grow at any time of the year but preferably does best in March-May and September-November in Islamabad, Pakistan (Fatimah & Ahmad 2009). In these months, according to Everist 1977, Pandey & Dubey 1989, there may be emergence of four or more successive cohorts of seedlings on the same site (Navie *et al*. 1996). Generally, in the spring greater sized plants with longer life span (6-8 months) are formed in comparison to the summer plants which may be due to the loss of soil moisture in hot summer months. Maharjan (2006), reported four week long vegetative phase and 12 to 16 weeks long reproductive phase of parthenium in Nepal. Fruiting and maturation of seed completed within 1 to 2 weeks after the flowering and maximum seed production was found on August (Maharjan 2006). Increase in temperature increases the biomass of the plant up to the optimum temperature of 22-30 ˚C showing temperature as an important parameter to control the length of the vegetative phase prior to flowering (Williams & Grove 1980). In parthenium plant senescence was observed from late September to October with the completion of its life cycle within 16 to 18 weeks (Maharjan 2006).

2.6 Seasonal variation in the growth of parthenium

Season play an important role in the growth of all species, especially through the change in temperature and rainfall. The growth pattern of parthenium weed also changes with different seasons. Vigorous growth of this weed can be observed during summer season whereas growth is found to be retarded during winter season most probably due to the effect of low temperature and low availability of moisture. The considerable reduction in the growth and production of flowers and seed in winter as well as plant were found to be stunted with small leaves and little branching in comparison to the summer stand of parthenium (Pandey *et al*. 2003).

Seasonal temperature also play vital role during emergence and growth of seedlings showing no emergence of seedlings in the bed from January to March and death of the emerged seedling due to low temperature and night frost was also observed at the last of the December (Pandey *et al*. 2003).

The findings of seed to flower Ratio index showed lower value in winter compared to the summer stands and seed formation was totally stopped at the low temperature but it again started to form seed after the onset of the appropriate temperature (Pandey *et al*. 2003).

2.7 Impact of Parthenium invasion on species diversity and biomass production

Parthenium can replace most of the associated herbaceous species through its allelopathic effect on neighbouring flora (Yadav & Chauhan 1998, Sinha & Deo 1999, Bhowmik *et al* 2007). In Pasture land it reduces the pasture vigour and seed set resulting in the change of habitat and ecosystem (Evans 1997, O'Donnell & Adkins 2005, Shabbir & Bajwa 2006).

In Southern Hemisphere, large areas of natural grass and shrub lands has been affected by the introduction of pines through a lot of changes in dominant life forms, decline in species richness, changed vegetation patterns and nutrient cycles (Richardson *et al*. 1994). A phytosociological survey of parthenium weed showed an appreciable sociability with *Senna accidentalis* (L.) link, *Malvastrum coromandelianum* (L.) Gracke and

Lantana camera (L.) (Shabir & Bajwa 2006). A transition phase of completion or succession was found in progress between *L. camara* with parthenium. Rapid declination in the population of medicinal plants found in wasteland of Islamabad might be due to the aggressive spreading of parthenium (Shabir & Bajwa 2006). They also found that *Cannavis sativa* another exotic species is being replaced by the invasion of parthenium with the aid of its strong allelopathy and a rapid growth rate.

Kohli *et al*. (2004), carried out a study to assess the changes in the structural composition and dynamics of vegetation where they counted a total of 12, 10 and 14 plant species in the *Ageratum conyzoides* (billy goat), *Lantana camara* (lantana) and parthenium infested areas respectively in comparison to 25 species in non-infested areas of Himachal Pradesh. The density and biomass of native flora in these three weed infested areas were significantly less in comparison to native vegetation where density was decline by nearly 64.4,82.5 and 67.6% and biomass was decline by nearly 52.7,72.4 and 59.6% in areas infested with *Ageratum conyzoides*), *Lantana camara*, and parthenium respectively (Kohli *et al*. 2004). Richness index and Shannon's index showed greater species richness and plant diversity in the uninfested areas whereas these were significantly less in weed infested areas which may be attributed to the allelopathic effect of these weeds (Kohli 2004).

Timsina *et al*. (2011), studied changes in the species composition and soil properties due to parthenium invasion in three grassland communities of Central Nepal. Significant differences between invaded, transitional and non-invaded plots in terms of species composition and soil properties were obtained. Surprisingly, the lowest species diversity in the non- invaded plots suggested increase in species diversity after the invasion of parthenium.

2.9 Management of parthenium invasion

The alternatives for the management of parthenium weed are chemical, physical, legislative, fire, mycoherbicides, agronomic practices, competitive displacement and classical biological control (Dhileepan 2009). Physical control method is often carried out for the localized infestation as a short term remedies but not effective for the long term management point of view due to the over compensatory regeneration of parthenium (Kohli 1997 c.f. Dhileepan 2009). Javaid (2010) proved Bromoxynil+ 2-methyl-4-chlorophenoxyacetic acid (MCPA) as the most effective herbicide, Arrazil and Glyphosate for the control of parthenium weed.

Although chemical control method is mostly used in the eradication and containment program (Dhileepan 2009), it is not environmental friendly method and is effective for a short period with only one generation (Javaid 2007). In addition to these it is applicable only to the existing plant but not to the seed. So, the dormant seeds and newly entered seed can germinate immediately after the availability of appropriate moisture.

Biological control is the most suitable method for the long term control of parthenium weed. Natural suppression of parthenium weed by natural enemy in its native range in comparison to the rapid expansion through increased fitness or vigor in new environment due to the lack of its natural enemy lead to the concept of biological control agent. In Australia, the established biological control agent of parthenium are Stem galling moth (*Epiblema strenuana*), a leaf feeding beetle (*Zygogramma bicolorata)*, a stem boring weevil (*Listronotus setosipennis*), a seed feeding weevil (*Smicronyx lutulentus*), a leaf mining moth (*Bucculatrix parthenica*), a stem galling weevil (*Conotrachilus albocinereus*) and the winter rust (*Puccinia abrupta* var. *partheniicola*) (McFadyen 1992, Dhileepan 2001). Dhileepan (2001) evaluated the effectiveness of biocontrol insects on parthenium in Australia. The result showed 52% increase in seedling emergence and a seven fold increase in the soil seed bank with the exclusion of biocontrol insects experiment whereas with the introduction of *Epiblema strenuana* 92 % of the plants were being affected, 32 % of plants were prevented from flowering with the reduction of their height by 40 % and flower production was reduced by 49%. *E. strenuana* caused stem-galling during early growth stages in field plants experiencing competition by which 30% of plants were prevented from reaching flowering (Dhileepan & McFadyen 2001). The leaf feeding beetle *Zygogramma bicolorata* was found to cause defoliation up to 96% in the parthenium weed (Dhileepan 2001). However, *Z. bicolorata* was found to cause 92% defoliation within 90 days reducing plant height by 27%, root length by 56% and root biomass by 69%, shoot biomass by 81%, flower production by 83% and seedling to the decrease in soil seed bank by 73% (Dhileepan 2000). *Zygogramma bicolorata* was first encountered in Hetauda municipality (Makwanpur district, Central Nepal) in 2009 and massive defoliation was noticed (Shrestha *et al*. 2011).

Likewise, there is a possibility of management of parthenium weed through competitive displacement with beneficial plants. *Bothriochloa insculpta* (Bisset blue grass) showed the strongest competitive abilities with factor 3.16 which is probably due to its high assimilation rate and prostrate growth habit (O'Donnell & Adkins, 2005). They tested other plant species such as *Dicchanthium aristat*um (Floren blue grass), *Cenchrus ciliaris* (Buffel grass), *Clitoria ternatea* (butterfly pea) which also out competed parthenium weed strongly. When the biological control agent were used in combination with suppressive plants, the extent of growth suppression of parthenium weed increased to between 60% (Seca stylo) and 86% (purple pigeon grass) in southern central Queensland, Australia (Shabbir 2013).

The volatile oil from Eucalyptus spp. exerts deleterious effects on seed germination, chlorophyll content as well as on cellular respiration of parthenium (Kohli *et al*. 1998, Paudel 2007).

3. MATERIALS AND METHODS

3.1 Study area

3.1.1 Biogeographical location and vegetation

The present study was carried out in a waste land at Sundarighat, Kirtipur municipality of Kathmandu valley which lies in subtropical zone (1000-2000m asl) of Central Nepal. The study site is located at 27°40′579″ N latitude and 85°17′699″ E longitude with an average elevation of 1253 meters. This land is surrounded by the Bagmati River in the East, way to Dakshinkali in the West, Chovar hill in the South and Balkhu in the North. The Kirtipur in Kathmandu valley was selected as a research site due to problem created by high abundance of parthenium. Another reason for selecting this site was that it is near to the Campus and was convenient to visit site and collect data monthly. Besides Parthenium, this site comprises other exotic invasive species such as *Bidens pilosa, Alternanthera philoxeroides* etc. and some palatable species like *Cynodon dactylon, Eleusine indica, Paspalum distichum*. Other associated species are *Amaranthus spinosus, Solanum xanthocarpum, Chenopodium ambrosioides, Chenopodium album, Rorripa dubia* etc.

The selected waste land has been sometimes used for grazing goats and cattle. In the past the site was used for dumping municipal waste but now it is grassland with almost entire area covered by vegetation. Furthermore, this land is disturbed by local people for dumping the solid waste and playing archery game. Similarly, the waste pickers visit to collect the reusable materials such as metal and plastics.

A small population of *Zygogramma bicolorata* limited to small area (about 0.05 ha) was encountered in 2010 with mild and complete defoliation of individual plants of parthenium (Shrestha *et al*. 2011) .In present study, this beetle was observed from June to October with complete defoliation of individual plant in all plots of transect number 3, 4, 7 and 8.

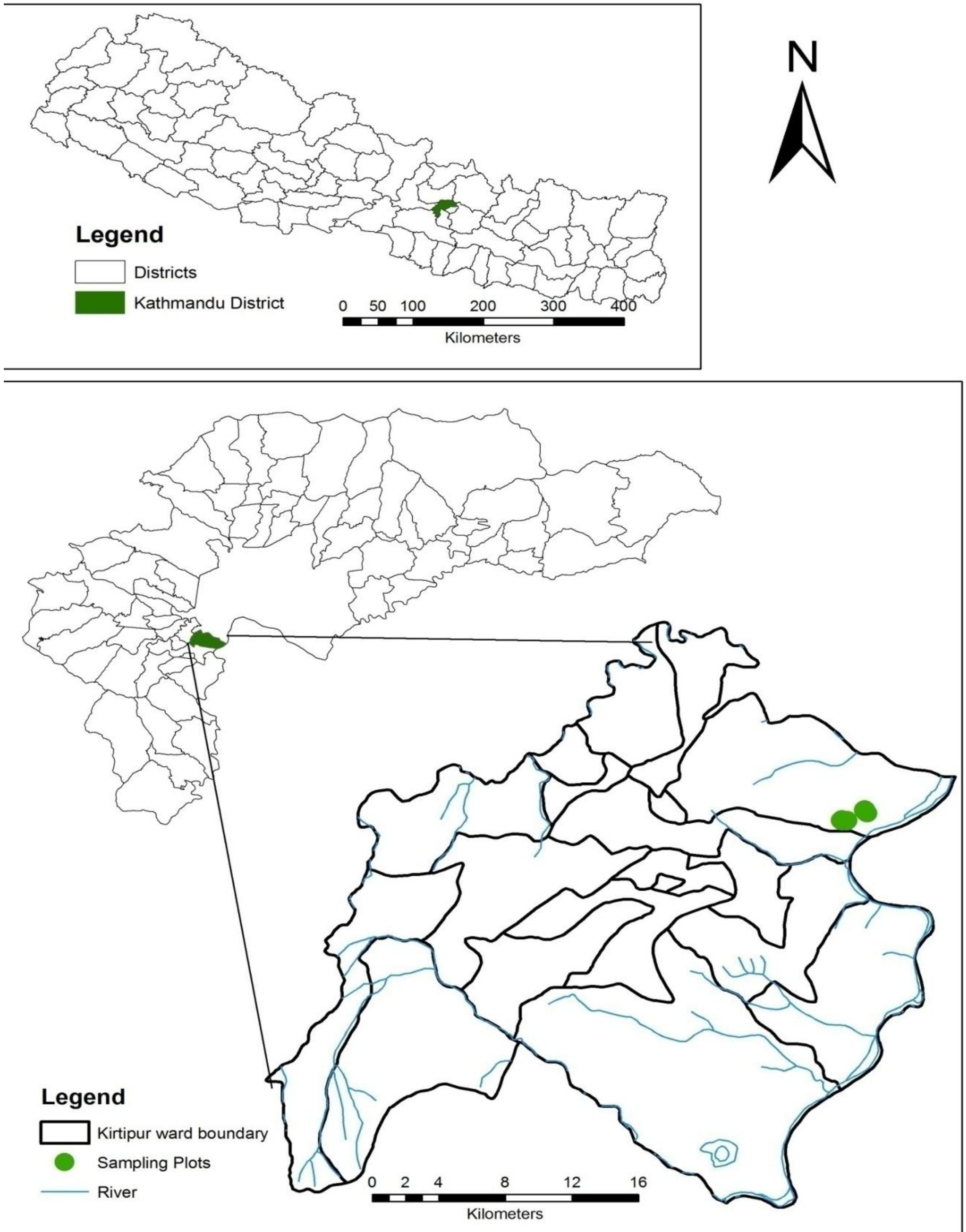

Figure 1: Map showing Study area

Figure 2: Google earth map of the study area (Sundarighat, Kirtipur)

Photo1: Parthenium flower blooming during the rainy season at the study area.

3.1.2 Climate

The data of rainfall and temperature from 2007 to 2011 was recorded at the Khumaltar station, Lalitpur. This data was taken from the Department of Hydrology and Meteorology, BabarMahal, Kathmandu. The graph shown below, the average monthly minimum temperature was 2.28˚C during the month of January whereas the average monthly maximum temperature was 28.72˚C during June. The study area received the average monthly maximum rainfall i.e. 296.38 mm during August and the average monthly minimum rainfall i.e. 0.72 mm during December. The average total annual rainfall was 1242.7 mm.

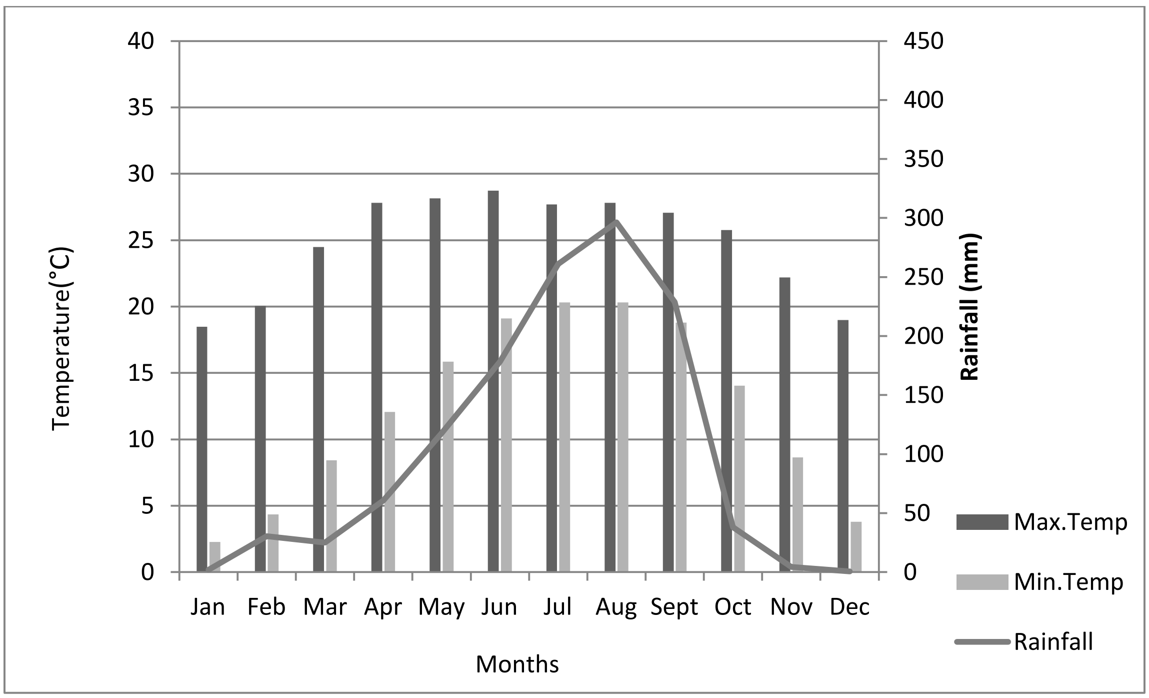

Figure 3: Average monthly minimum and maximum temperature (˚C) and rainfall (mm) from 2007 to 2011 (five years) recorded at Khumaltar Station (4 Km north east from study site), Lalitpur (Lat.27˚40′, Long.85˚20′, Ele. 1350m asl) (Source: Department of Hydrology and Meteorology/ GoN).

Seasonal variation during the study period

The one year of study period was divided into four distinct seasons: winter season (December, January and February), summer season (March, April, May), rainy season (June, July and August) and fall season (September, October and November). During the study period, the average maximum temperature ranges from 16.6- 28.5 ˚C and the minimum temperature ranges from 1.9 to 20.3˚C. The average monthly rainfall was about 135.57 mm showing maximum rainfall in the rainy season that is in June, July and August. The average monthly rainfall varies from 0 to 410 mm.

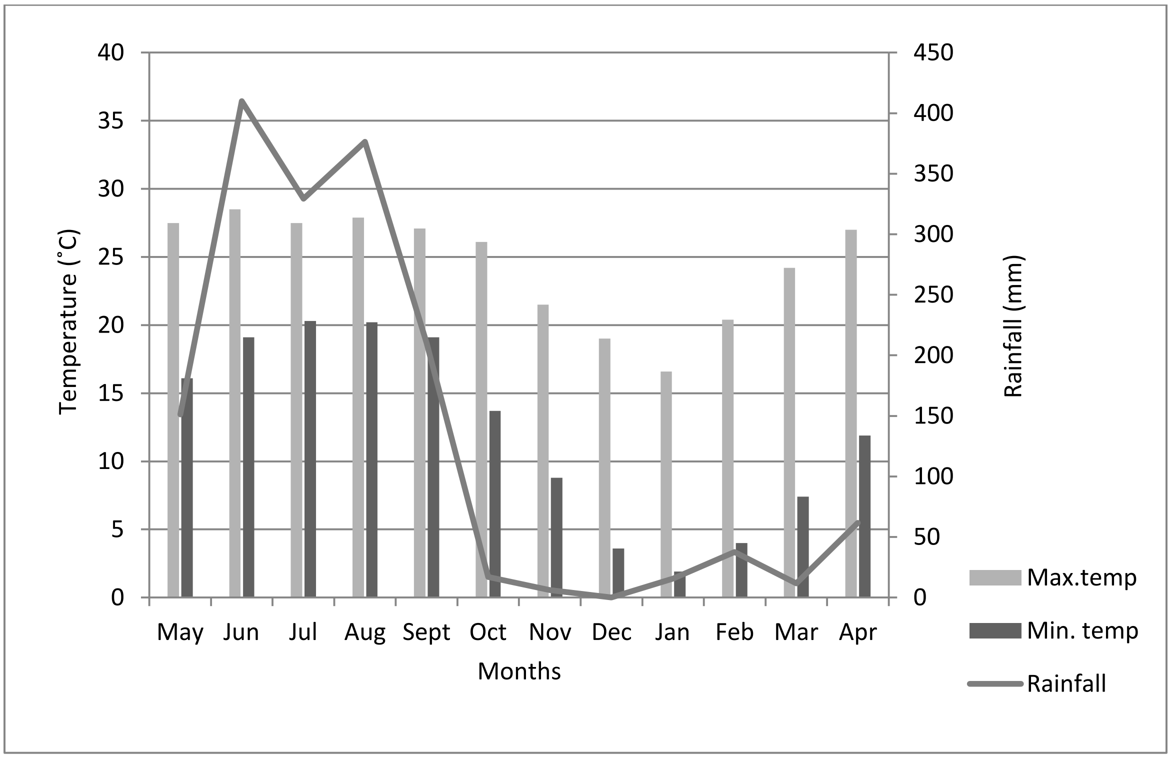

Figure 4: Average monthly minimum and maximum temperature (°C) and rainfall (mm) recorded at Khumaltar Station (4 Km north east from study site), Lalitpur (Lat.27˚40′, Long.85˚20′, Ele. 1350m asl) during the study period from May 2011 to April 2012 (Source: Department of Hydrology and Meteorology/ GoN).

3.2 Species Characteristics

Parthenium weed was identified in the field with the help of species characteristics. This weed belongs to the family Asteraceae. It is commonly called as bitter weed, Carrot grass, False ragweed, Fever few, parthenium weed, White top and Santa Maria etc while in Nepal locally known as Kanike ghans, Bethu ghans and Padke Phul etc (Tiwari et al 2005). In Nepal it grows in fallow lands, roadsides and around settlements and is still spreading to the protected area in Chitwan national Park (Shrestha 2012). Parthenium weed is an erect, much branched perennial herb which can grow up to 2m. Stem is pubescent and ribbed. Leaves are in alternate arrangement, pubescent and deeply dissected into narrow lobes. Each white flower head of parthenium consists of a conical receptacle surrounded by outer involucres of five persistent bracts, five peripheral ligulate and fertile ray florets and centrally numerous tubular disc florets which are staminate. The dry fruit called achene consists of two sterile florets adhering as wings which help in dispersal of seed. A typical mature plant possesses prolific seed production capacity. Seed production ranges from 15,000-25,000 achenes per plant (Haseler 1976, Joshi 1991and Navie et al 1996). The seed is black obovate in shape, flattened and crowned by a pappus of orbicular scales.

3.3 Vegetation sampling

Vegetation sampling was conducted from 11th May 2011 to 9th April 2012 by using belt transect method. In the study area, four pairs (eight) of belt transect with parthenium as dominant were permanently marked in May 2011. The distance between two transects were maintained 8-10 m. Plots were selected closer to each other so that climatic and edaphic condition would be similar. Each transect with the area of 10×1 m^2 was divided into 10 plots each having an area of 1×1 m^2. Out of 10 plots in each transect, 5 plots were selected randomly by lucky draw method. The plot layout of a single transect is as follows:

Transect 5

Plot1	Plot2	Plot3	Plot4	Plot5	Plot6	Plot7	Plot8	Plot9	Plot10

10 m×1 m

(Shaded plots were randomly selected plots)

Figure 5: Transect showing randomly selected plot for sampling.

In each selected plot, all the vascular plant species rooted were recorded to find the species richness. In case of parthenium total number of individual was counted according to their phenophases (seedling, juvenile and flowering) with minimum disturbance in every month. Recently emerged plant individual with cotyledonary leaf still attached was considered as seedling; plant individual whose cotyledonary leaf was shed and flowering bud did not appear were considered as juvenile plant. Plant individual possessing flowering buds, flowers or fruits were considered as flowering phase or reproductive phase. Above measurements were taken once in the third week of every month for one year from 11^{th} May 2011 to 9^{th} April 2012 in the permanently marked plots. From the field data, density of parthenium was calculated as follows:

Density (stem / m^2) = Number of plants of the species counted in all quadrats / Total number of quadrat studied × Area of quadrat

The data obtained from field observation were summarized to obtain the percentage of different phases of parthenium such as seedling, juvenile and flowering.

Example: seedling % = Number of individual in seedling phase / Total number of parthenium individual in all phases × 100

3.4 Plant collection, Herbarium preparation and Identification

In every month specimens of all species present in sampling plots were collected, tagged and pressed in the field using a newspaper and herbarium presser. In each month vegetative specimens if present were replaced by their flowering specimen by comparing with its previous specimens to make the identification easier and accurate. Field notes including color of the flower, fruit and any special features of each species were recorded. The completely dried specimens were mounted on herbarium sheet of 16.5” × 11” with the help of glue stick and labeled. The collected specimens were identified on the basis of standard literature such as Flora of Kathmandu Valley (Malla *et al*. 1986), Crop weeds of Nepal (Rajbhandari *et al*.1998). Mainly monocots were identified with the help of plant taxonomist at Tribhuvan University Central Herbarium TUCH and National Herbarium, Godavari KATH. The identified specimens were cross-matched with the herbarium placed at TUCH and KATH. The nomenclatures of all species followed Press *et al*. (2000).

3.5 Clipping experiment

3.5.1 Seed collection

For the clipping experiment, seeds of parthenium were collected from the single plant naturally growing in a fallow land of Garigaun, Kathmandu located at 27˚68'837" Latitude and 85˚34'83" Longitude.

3.5.2 Experimental Design

To understand the response of parthenium to mechanical disturbance, the clipping experiment was done by cutting twig of the plant just after the appearance of flowering bud. For this experiment, 60 earthen pots having diameter of 16 cm were filled with the mixture of soil and sand in the ratio of 2:1. Each pot was filled with 1250 g of the above mixture of soil in which 100 g of vermin-compost was added to each pot in order to promote the growth. Then, all pots were kept inside the glass house of Central Department of Botany. Seeds of parthenium from a single plant were sown on these pots on 23rd March 2012. Seeds from single plant would minimize genetic differences, if any, among individuals used in the treatments. About 200ml of water was poured in each pot in alternate days during warm months. Seed germination started within one week (from 28th March 2012). One plant which was healthy and more or less of uniform growth was selected in each pot for the treatment. First flowering was observed on 4th July (95 days after seed germination). Then, first clipping was done on 5th July just after the appearance of first flowering. During this treatment, out of 60 pots with each pot containing single plant, 15 plants were selected randomly as a control by lucky draw method. After that plants of the remaining 45 pots were subjected to the first clipping. Height of the every individual plant was recorded before clipping. During clipping, apical and a few axillary buds as well as flowers were excised by using blade. Total number of floral buds and flowers present in the clipped tip was counted and recorded in the data sheets. Then, second clipping was performed on 29th July (23 days after the 1st treatment) in 30 plants out of 45 after the appearance of flower in the new branching in about ¼ th of the 1st clipped plants in the similar way. Again, third clipping was performed on 25th August (25 days after the 2nd clipping) in 15 plants out of 30 after the appearance of flowers in newly emerged branches. At last, flowers from each plant individual were harvested after the occurrence of re-growth in triple clipping plants. To maintain the accuracy in number of flower produced in each individual harvesting was done regularly by collecting dead flowers. Then, harvested flowers were counted accurately. To calculate the seed output total number of flower head was multiplied by the 5 as each flower mostly contain five seeds.

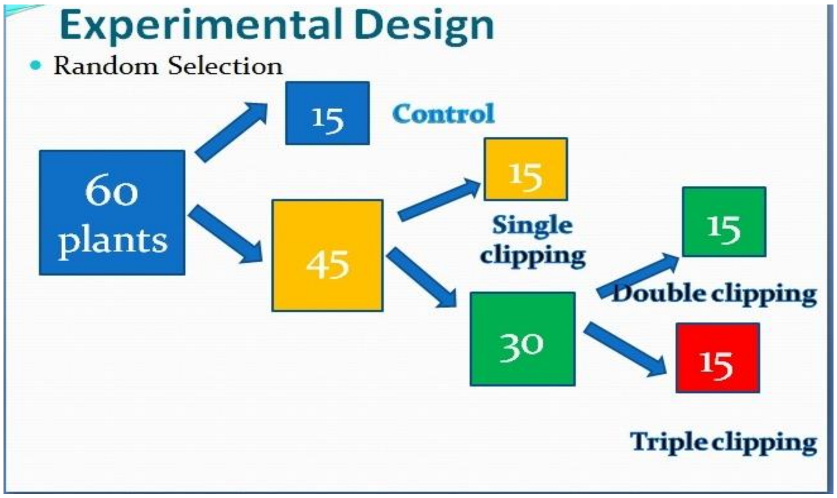

Figure 6: Experimental design for clipping experiment showing random selection.

3.6 Data Analysis

3.6.1 Monthly and seasonal variation in the different phases of parthenium

Proportion of various phenophases, average maximum height of parthenium, mean total parthenium density and mean seedling density were plotted against the different months to find out the peak of the different phenophases, the most favorable growing period and number of cohort of seedling emerged per year respectively by presenting in bar diagrams. Furthermore, for the analysis of seasonal variation in abundance of different phases of parthenium at first data were subjected for the test of homogeneity of variance where data did not meet the assumption of homoscadasticity. Therefore, data were analyzed by using non-parametric test Mann-Whitney U test where seasons (rainy, fall, winter and summer) were taken as grouping variables and the mean density of different phenophase such as seedling, juvenile, flowering and total density were taken as test variables in each test separately. From this analysis, difference among the medians of different phases and total density of Parthenium with various seasons were statistically tested.

3.6.2 Relationship between parthenium density and species richness

The average values for the parthenium density and species richness were calculated according to the plot, transect and paired transect. In case of plotwise analysis, average values of both parthenium density and species richness were calculated for each and every month for all months in a year. Similarly, in case of transectwise analysis average values of density and species richness were calculated from the five plots in each transects that were sampled for a year. Whereas, in case of paired transects average parthenium density and species richness were calculated by merging the plots of two transects which were similar to each other.

To know the relationship between parthenium density and species richness as well as with reproductive individuals the data were subjected for the normality test where data did not show the normal distribution in almost all cases even after the log and square root transformation. Only in case of transect wise density and species richness, and paired transect wise density and species richness data showed normal distribution after transformation but regression did not show significant relationship between total density and species richness. At last, data were presented in the scatter plot diagrams. However, plant species richness was regressed with the mean height of July where there was maximum mean height.

3.6.3 Impact of clipping on different parameters of parthenium

One way ANOVA test was performed to test the significance in the effect of clipping among different treatments such as no clipping (control), single clipping, double clipping and triple clipping in terms of mean seed output and maximum height of plant. But in case of number of branches emerged after clipping since the data were not normally distributed with equal variance, the Kruskal wallis test was performed. In these analyses, clipping frequencies were considered as grouping variables and mean seed output, mean maximum height of the plant and mean number of branches were considered as dependent variables.

4. RESULT

4.1 Phenological changes

Seedling of parthenium was observed in all months except in June during a year (Figure 7&8). This phase was more abundant during February. Whereas juvenile phase was more abundant during March, April, May, June but completely absent in July (Figure 7&9). On the other hand, flowering phase was observed in 8 out of 12 months showing peak in the month of July (Figure 7&10).

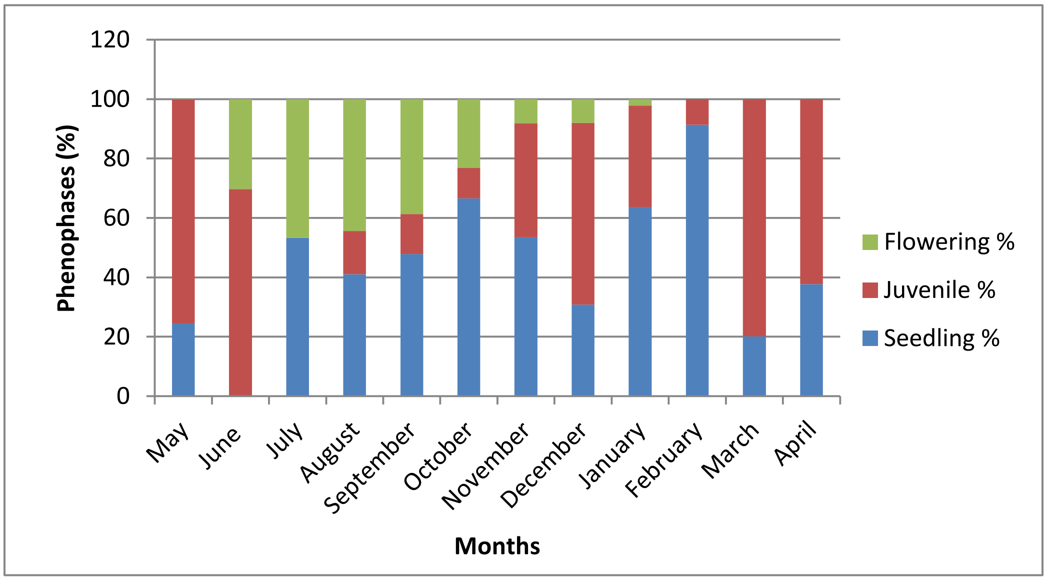

Figure 7: Percentwise various phenophases in different months of a year.

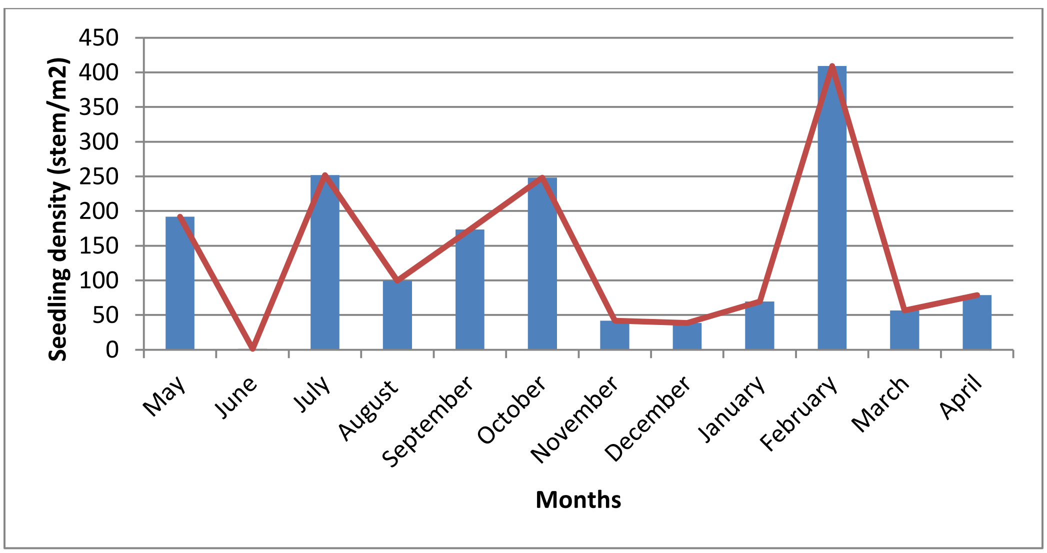

Figure 8: Seedling density in different months of a year. Each value is the mean of 40 samples.

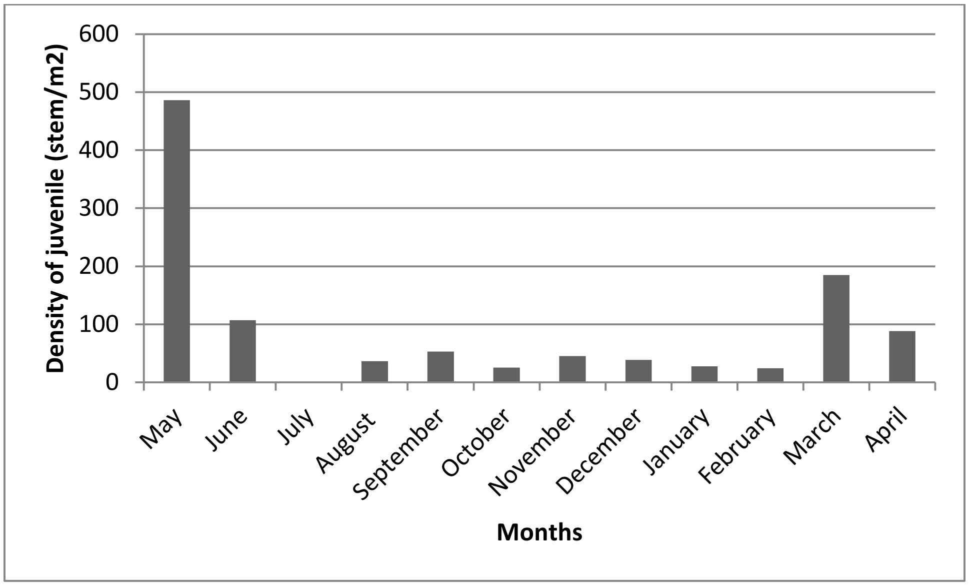

Figure 9: Density of juvenile in different months of a year. Each value is the mean of 40 samples.

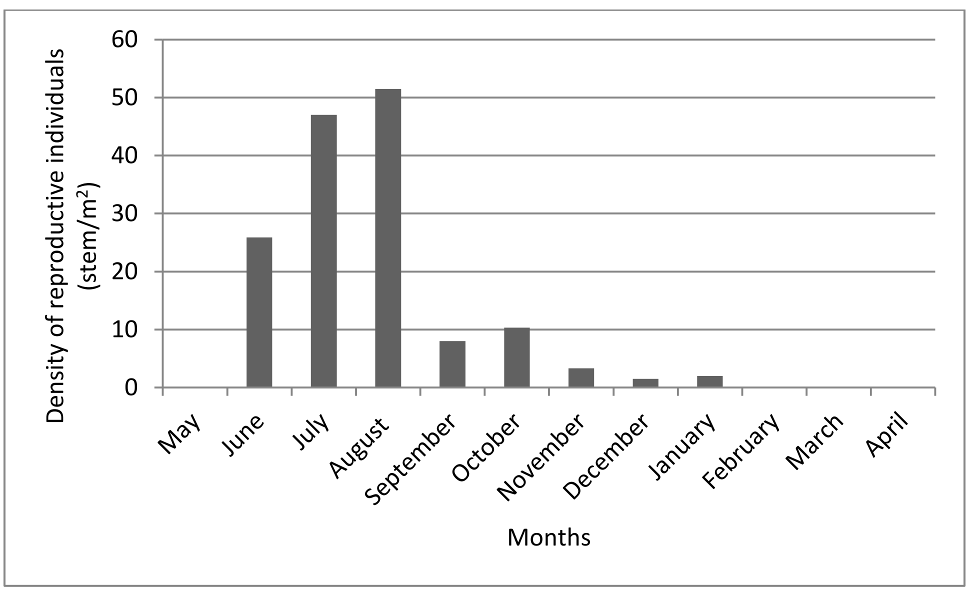

Figure 10: Density of reproductive individual in different months of a year. Each value is the mean of 40 samples.

Parthenium seedlings were found abundant in all the four seasons: rainy, fall, winter and summer. Seedling abundance was the highest in winter season and lowest in summer season. The Mann Whitney U test exhibited the significant difference between winter and other three seasons (Table 1). There was no significant difference among rainy, fall and summer seasons. Whereas, juvenile phase was more abundant in summer and less abundant in fall season. The average density of juveniles in rainy, fall, winter and summer seasons were significantly different. Furthermore, the mean reproductive individuals were more abundant in rainy season and less in fall and winter. They were completely absent in the summer season. The statistical test showed significant difference ($p<0.001$) in reproductive individuals at rainy season and fall but no significant difference was exhibited in winter and summer. Similarly, total parthenium density exhibited the significant difference ($p<0.001$) among the summer and other three seasons. But no significant difference was obtained among the rainy, fall and winter seasons.

Table 1: The median values of density of seedlings, juveniles, reproductive individuals and total density of parthenium in different seasons. The values in the bracket are inter-quartile. Different letters in the superscript denote the significant difference between the values as determined by the Mann-Whitney U test.

	Rainy	Fall	Winter	Summer	P- value
Seedling density(stem/m^2)	35.2^b (132.6)	15.2^b (255.4)	120.2^a (187.7)	60.8^b (163.9)	0.009
Juvenile density(stem/m^2)	29.2^d (36.5)	2.2^b (51.75)	108.8^a (179.1)	227.7^c (274.2)	<0.001
Flowering density(stem/m^2)	27.2^c (26)	2^b (8.8)	0.0^a	0.0^a	<0.001
Total density(stem/m^2)	111.83^a (153.2)	42.5^a (388.8)	178.0^a (239.1)	362.0^b (251.2)	<0.001

4.2 Parthenium density and height

The total average density of parthenium including the density of seedlings, juveniles and flowering individual, the highest in the May and the lowest in the December (Figure 10).The highest average maximum height of the individual of parthenium was observed in July (Figure 11). The height of the parthenium increased from May to July and then declined in successive months. During January, February, March and April the lowest values of average maximum height were observed. Also, the growth of the juvenile phase plant individual was strongly retarded. The result showed that parthenium can grow best from May to October in terms of height of the plant individual.

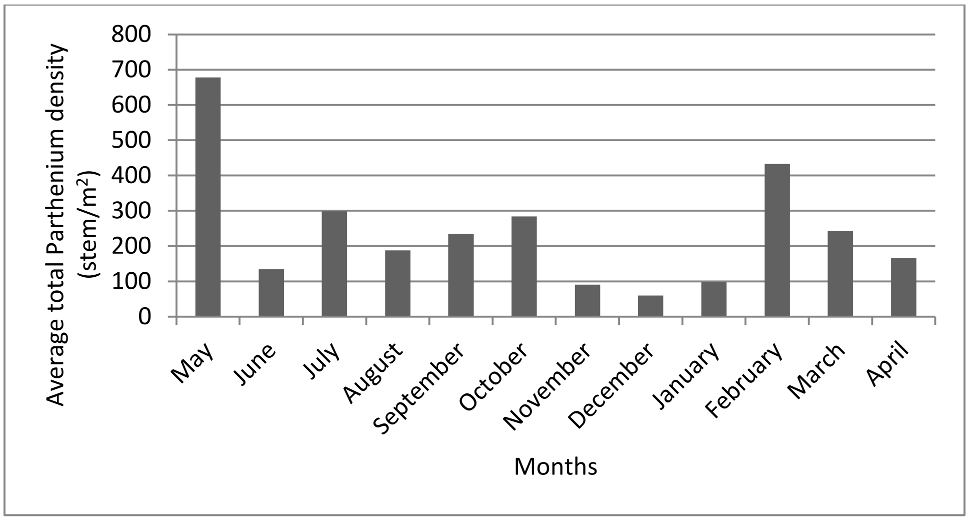

Figure 11: Total average density of parthenium in different months. Each value is the mean of 40 samples.

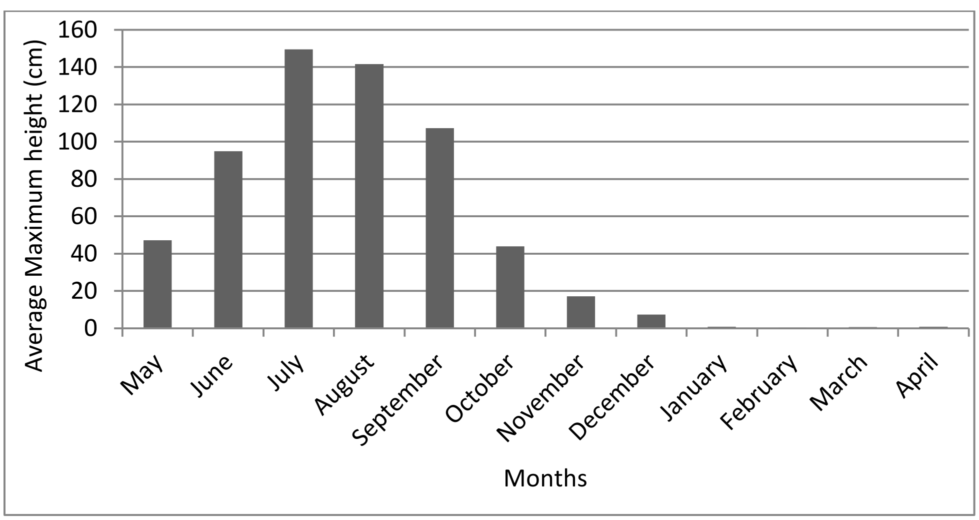

Figure 12: Average maximum height of parthenium in different months. Each value is the mean of 40 samples.

4.3 Number of cohorts

During the study period of one year, four peaks of seedling density were observed in the population of parthenium (Figure 8). It clearly showed that four cohort of seedlings emerged in a population of parthenium of Kathmandu valley within one year. The highest seedling peak was observed during the month of January and February.

4.4 Variation of seedling density with temperature and precipitation

The relationship between seedling density and temperature was not clear (Figure 13). The rise and fall in seedling density was observed from May to October when monthly mean temperature was almost constant. During the month of November as temperature decline by 4˚C (approximately), the seedling density also decreased. From November to January low seedling density was observed due to the low winter temperature. The highest seedling density was found during the month of February when mean monthly temperature was 12.2˚C. Then temperature again started to increase but the seedling density did not increase. Three cohorts of parthenium seedlings were germinated from May to October. In these periods there was abundant rainfall. During November, December and January the seedling density was decreased due to cold and dry winter months. The fourth cohort of seedling emerged in February after having light shower in the month of January and February (Figure 14).

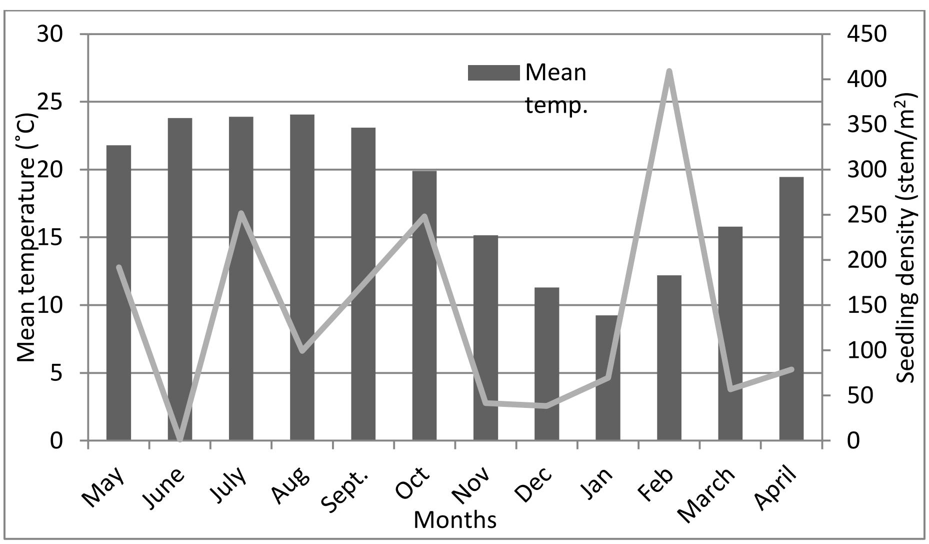

Figure13: Change in seedling density (n=40 for each month) of parthenium and mean temperature across the months.

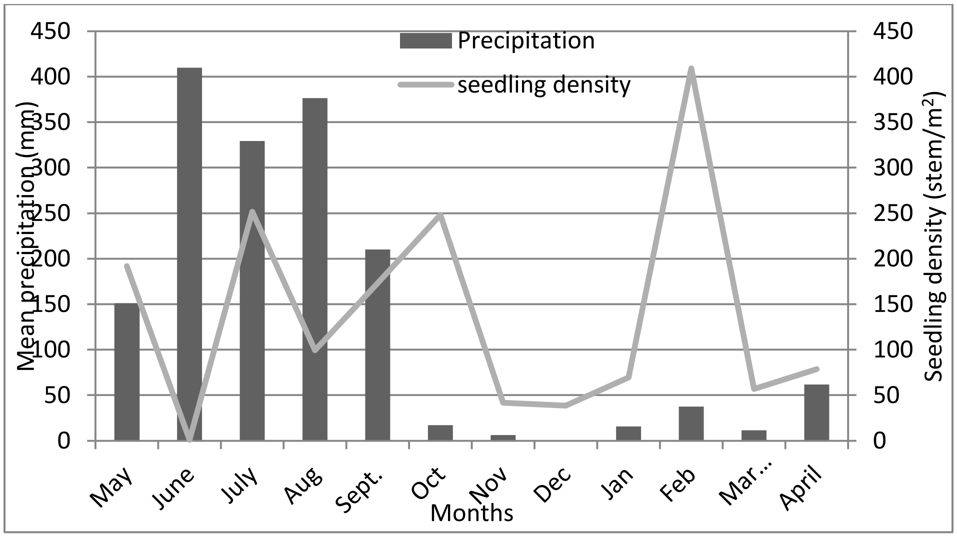

Figure 14: Change in seedling density (n=40 for each month) of parthenium and mean precipitation across the months.

4.5 Species richness and parthenium density

The mean species richness (excluding parthenium) showed no relationship with the mean total parthenium density as well as with the mean density of flowering individual in all three cases such as in transect wise, plotwise and paired transect wise means of both density and species richness . However, plant species richness showed negative relationship with the mean maximum height in July when there was highest mean maximum height of parthenium. But, it did not show relationship with the total density of May when there was highest mean total density.

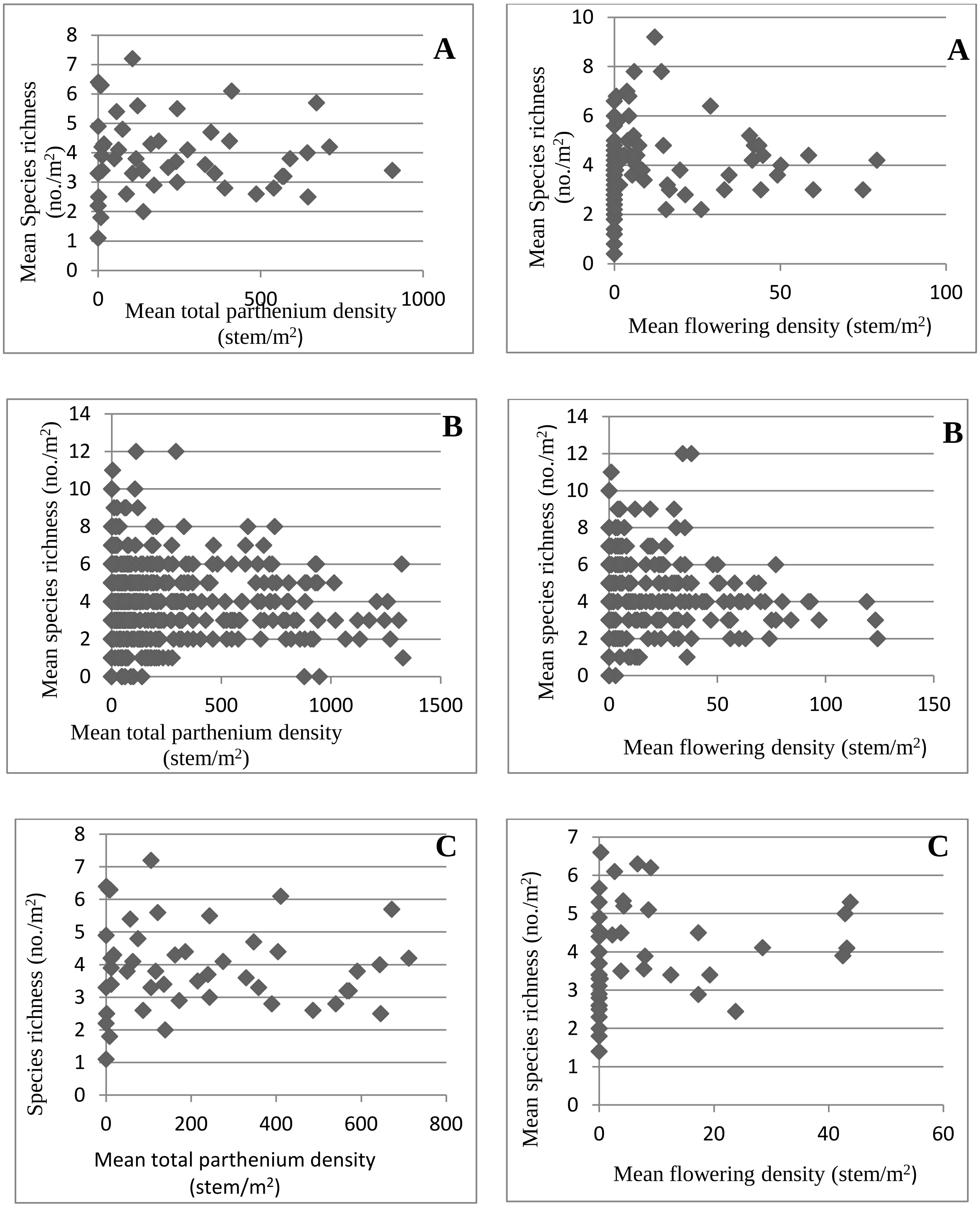

Figure15: Variation of vascular plant species richness with density of parthenium (A) transectwise-each point represents value of each sampling transect, (B) plotwise-each point represents value of each sampling plot, (C) paired transect wise-each point represent value of each paired transect.

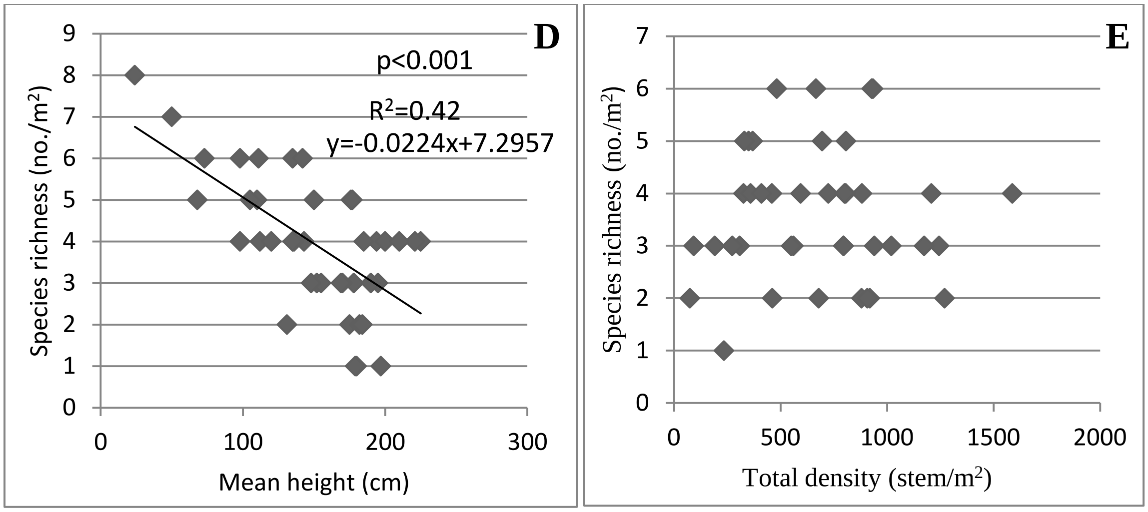

Figure 16: Relationship of vascular plant species richness with (D) mean height in July (onth having highest mean Height (E) total density in May (month having highest total density).Each point represent value of each sampling plot.

4.6 Response of parthenium to clipping

Total number of seeds per plant was the highest in control and decreased with the increasing frequency of clipping. The mean seed output of control was 2014 seed/plant. In case of single clipping seed output was found to be reduced by 11.27%, double clipping by 24.64% and triple clipping by 32.34% than that of control. The homogeneity test showed that seed output in various clipping frequency such as single clipping, double clipping and triple clipping were significantly different ($p = 0.048$) from that of control. ANOVA showed significant difference ($p=0.019$) in seed output of parthenium among various treatments i.e. clipping frequency. Although seed output of single clipping was found to be reduced by 11.27% from the control, the value was not significantly different. On the other hand seed output in double clipping and triple clipping were found to be significantly different from the control (Table 2).

At the same time the average maximum height of the plant individuals were found to be decreased with the increasing clipping frequency. The difference in the mean height among the various treatment were statistically significant ($p<0.001$). The highest mean height as 88.1 cm was found in the case of control whereas in single clipping it was lowered by 21.89%, double clipping by 33.45% and triple clipping by 43.21%. On the other hand, in terms of emerging new branches, no branches were observed in the control but they were in the clipped condition. The number of branches increased with the increasing clipping frequency. Highest average numbers of branches were observed in triple clipping. Mann Whitney U- test showed significant difference among the various treatments except zero values in case of control.

Table 2: Response of parthenium to clipping in terms of different parameters. Different letters in the superscript of the seed output value and maximum height indicate the significant difference between the values as determined by Duncan test. The percentage decline and incline values are in the bracket.

S.N	Parameters	Control	single clipping	Double clipping	Triple clipping	p- value	F value
1.	Maximum height of plant	88.1^{a}	68.81^{b} (21.89%)	58.63^{c} (33.45%)	50.03^{c} (43.21%)	0.000 (ANOVA)	28.773
2.	Number of branches	0	2^{a} (100%)	4^{b} (200%)	6^{c} (300%)	0.000 (Kruskal wallis)	50.923 (Chi-square)
3.	Seed output	2014^{b}	1787^{ab} (11.27%)	1517.67^{a} (24.64%)	1362.67^{a} (32.34%)	0.019 ANOVA	3.587

5. DISCUSSION

5.1 Phenology

Seedling of parthenium was observed in all months except in June which might be due to its well germinating ability over a wide range of fluctuating temperature between 12/2 ˚C to 35/25˚C (Tamado et al 2002). Tamado et al (2002) suggested that the long lived seeds of parthenium are available for germination at any time of the year unless soil moisture becomes the limiting in the field situation. Prolific seed production also contributes to the presence of seedling for most part of the year. Similarly, we observed juvenile phase in all months except in July indicating its ability to grow at any months of the year under favorable condition of temperature and moisture. On the other hand, reproductive individuals were observed for 8 out of 12 months. The extended period of flowering bearing maximum number of seeds could be the strategy for its invasiveness. Navie et al (1996) reported that soil moisture seems to be the major contributing factor to the duration of flowering. Therefore, our hypothesis assuming flowering frequency is same throughout the year in a population of parthenium is rejected under the field condition.

Parthenium density ranged from 24 to 486 stem /m^2 (excluding seedling density) over the period of one year. The lowest value was recorded during the month of February and the highest value during the May. It was highest in the summer which is the main season for growth and lowest during the winter might be due to unfavorable condition of temperature and moisture. Karki (2009) reported the highest value of parthenium density as 402 stem/m^2 among the data so far reported in Nepal. Thus, present record is even higher than this value reported at Hetauda by Karki (2009). Whereas K.C. (2012) reported density of 433±119 stem/m^2 in 2009 in Hetauda. Timsina (2007) reported average parthenium density as 13 stem/m^2 in most invaded plots in Kathmandu site. This record showed the rapid and aggressive expansion of this weed in the Kathmandu although there might be some difference due to different site and time period on which study was conducted. Joshi (2005) reported parthenium density ranged from 11 to 47 stem/m^2 in Kathmandu valley which was much lower than present record. Very high density of parthenium in this site might be due to nutrient fluctuation in the land because this land was previously used as a dumping site for the municipal waste. Other possible reasons might be high human disturbance, high grazing pressure, low coverage of other plant species, presence of large soil seed bank and less utilization of land for any other purpose.

The average maximum height of parthenium increased from May to July and then started to decline suddenly which might be due to the death of plant individual having higher maximum height. It was highest in July i.e. 150 cm. Joshi (2005) reported the highest average maximum height 132 cm in Tilganga, Kathmandu.During January, February, March and April the lower values of average maximum height were observed mainly due to the presence of plant individuals which were at the seedling phase and juvenile phase with the strongly retarded growth mainly due to unfavorable condition of temperature and moisture. Thus, from our study it is clearly seen that parthenium can grow best from May to October in terms of height of the plant individual.

The general trend of decrease in total density of parthenium with increasing average maximum height was observed during the growing period (Figure 10 & 11). This can be well explained by self- thinning rule which describes the relationship between individual plant size and density in even aged population (Krebs 1994). As a plant population increases in numbers and biomass either reproduction or survival will be reduced by a shortage of nutrients, water or light, or by storage of place. The self- thinning rule highlights the tradeoffs that occur in organisms with plastic growth such that the size of an individual can become smaller as density increases.

We observed four cohorts of seedlings emerged during the one year of study period. Our result is similar with the report of Everist (1976), Pandey & Dubey (1989) c.f. (Navie *et al*.1996) that four or more successive cohorts of seedlings may emerge at the same site during a favorable growing season. Seedling density did not show clear pattern with temperature and precipitation. Low seedling density was found during the winter months namely November, December and January when there was low temperature. But, during March, April and June seedling density was also low although there was favorable temperature lies in between the range 12/2 to 35/25˚C and moisture availability (Figure

13 & 14). This might either be due to the lack of space availability for germination, competition with the seedlings of *Bidens pilosa* and other species such as *Oxalis corniculata* and *Cyanodon dactylon* or growth of seedlings into the juvenile. In addition to this, disturbance due to transportation of waste by vehicle was also observed in some plots during that time. On the other hand, seedling density was found highest during the month of February which might be due to the germination of seeds which remained as dormant during the winter and started to germinate vigorously with the occurrence of rainfall.

Tamado *et al*. (2002) suggested that in the field condition seeds of parthenium are likely to emerge at irregular intervals over an extended period of time. He also concluded that temperature is not a limiting factor for germination of parthenium seeds in cropping situation of Ethiopia. In present study also seedling phase was observed in all months except in June which might be due to the unavailability of space as all space was covered by its own juvenile phase. Thus, it was not due to temperature and rainfall factor.

5.2 Species richness and parthenium density

Plant species richness did not show any significant relationship with the parthenium density. K.C. (2012) also reported no significant difference in species richness among plots having different levels of parthenium infestation. However, our result showed no relationship between species richness and parthenium density. Thus it is contrasted with the most of the previous studies which concluded that invasive species pose adverse effects on species richness. Kohli *et al*. (2004) reported decrease in plant species richness from 25 to14 species/m^2 from parthenium uninfested to infested areas in the Northwestern Himalayas of India. Similarly, Karki (2009) also reported decline in the species richness with increase in parthenium density in the invaded plots. Timsina *et al*. (2011) reported fewer number of plant species in non-invaded than transitional and invaded plots.

In present study, lack of clear relationship between species richness and parthenium density might be due to the grazing effect made by cattle over a study period and infestation made by Mexican beetle (*Zygograma bicolorata*) nearly in half of the study site. However, the decline in species richness with increase in mean height of parthenium during July (when there was heighest mean height) might be due to the competition for light, space and nutrient faced by neighbouting plants.

5.3 Response of parthenium to clipping

In the present study parthenium compensated for a single clipping in terms of seed output. At final harvest, although the number of seeds produced on single clipping was low the value was not significantly different from that of the control (Table 2). Lack of significant difference in seed output among the single to triple clipping could be due to more branches proliferate after double and triple clipping. In contrast, it was unable to compensate following double and triple clipping. On double and triple clipping, plant significantly decreased seed production than that of control. Therefore, in pot experiment parthenium plants were negatively affected by clipping. Gupta & Sharma (1977) have mentioned that mowing or slashing of parthenium plants leads to the rapid regeneration from lateral shoot close to the ground. Gao *et al*. (2009) reported that either single or repeated clipping at inflorescence stage within 1 year was more efficient for controlling *Spartina alterniflora*, another invasive plant. Esmaeili *et al*. (2009) reported strong effect of defoliation on *Carex divisa*, *Juncus articulates* and *Elytrigia repens* whereas *Eleocharis palustris* and *J. gerardii* maintained a similar performance when defoliated. The latter species were able to compensate for the biomass loss even after six repeated clippings. Kimball *et al*. (2003) reported that *Erodium circutarium*, an invasive plant, showed no significant difference in production of flowers and fruits in clipped and unclipped (control) plants. Also it was not affected by clipping in the field plots and showed positive compensatory growth when grown in pots following clipping. Therefore, for those alien invasive species which show positive compensatory growth following clipping pose difficult in management by mechanical control. From this study it can be suggested that parthenium can be controlled through repeated clipping through reducing the production of seeds under pot condition. But to know the effect in the field condition the whole experiment should be carried out in the natural condition.

Whereas in terms of number of branches the result showed significant increase in number of branches with the increasing number of clippings. However, unclipped plants did not show the branching. Li (2004) reported a decreasing pattern in all traits with increasing clipping frequency illustrating undercompensatory responses in *Cyperus esculentus* to ramet clipping. But, at high nutrient level, the number of ramets tended to increase with clipping frequency and number of ramet decrease with clipping frequency at low nutrient level.

Plant height was the highest in control and the lowest in the plant clipped for three times. However, number of branches increased with increasing clipping frequency. Therefore, the effect of biomass removal or ramet clipping on plant performance varies from negative (under-compensation) to positive (overcompensation) depending on the resource availability and competition faced by individual plants (Huhta *et al*. 2002). The negative compensatory effect on plants performance might be simply the consequence of damage to the plants or biomass removal. From present study it can be concluded that this species is sensitive to repeated clipping in terms of seed output and average maximum height of the plants. Thus, our hypothesis that the mechanical disturbance (clipping) has no effect on seed output has been rejected.

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Parthenium was found in its seedling phase in all months except in June indicating that it can germinate at any time in Kathmandu over a year. Juvenile phase of parthenium was also seen in all months except in July indicating a long favorable growth period. However, flowering phase present for 8 months over a period of one year represented that this weed require a specific time to flower when there is suitable environmental condition such as soil moisture. In one year four cohort of seedlings emerged in a population of parthenium with highest seedling density recorded during February. Therefore, it seems that temperature is not the limiting factor for emergences of seedlings in the study site until soil moisture is available. From the present study, we could not detect the significant impact of parthenium density on species richness. But the mean of maximum height of parthenium showed significant negative impact on species richness. Parthenium did not compensate for seed production and growth in terms of height following repeated clipping. However, significant increase was recorded in terms of number of branches produced after clipping. From present study, it can be concluded that there is less possibility of control of parthenium by repeated clipping method. The result of this clipping experiment is weak from the management point of view. Therefore, only mechanical control by clipping is not efficient to control parthenium unless integrated management approach has been applied.

Under the present study condition, both of our null hypotheses that assumed ‘flowering frequency of parthenium is same throughout the year’ and, ‘mechanical disturbance (clipping) has no effect on seed output’ have been rejected.

6.2 Recommendation

- Mechanical control (Clipping) is not adequate to control the growth of parthenium. Therefore an integrated approach should be followed for the control of this weed within certain time period.

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Appendix1: Percentwise various phenophases of parthenium of Sundarighat in different months.

Months	% Seedlings	% Juveniles	% Flowerings
May	24.40361	75.58953	0.006858
June	0.154454	69.50788	30.33767
July	53.37871	0	46.62129
August	40.99375	14.6258	44.38045
September	47.82943	13.44174	38.72883
October	66.59074	10.18623	23.22303
November	53.4463	38.47653	8.077171
December	30.81566	61.16202	8.022321
January	63.7028	34.09334	2.203857
February	91.39978	8.600218	0
March	20.14871	79.85129	0
April	37.72753	62.27247	0

Appendix 2: List of different plant species associated with the parthenium weed.

S.N	Name of the species	Family
1	*Ageratum houstonianum* Mill.	Compositae
2	*Alternanthera paronychioides* St.-Hil.	Amaranthaceae
3	*Alternanthera philoxeroides* (Mart.)	Amaranthaceae
4	*Amaranthus caudatus* L.	Amaranthaceae
5	*Amaranthus spinosus* L.	Amaranthaceae
6	*Amaranthus viridis* L.	Amaranthaceae
7	*Artemisia dubia* Wall.	Compositae
8	*Bidens pilosa* (Blume) Sherff.	Compositae
9	*Blumea* DC.	Compositae
10	*Cannabis sativa* subsp. *Indica* (Lam.)	Cannabaceae
11	*Chenopodium album* L.	Amaranthaceae
12	*Chenopodium ambrosioides* L.	Amaranthaceae
13	*Cirsium arvense* (L.) Scop.	Compositae
14	*Commelina bengalensis* L.	Commelinaceae
15	*Conyza* Less.	Compositae
16	*Cynodon dactylon*	Gramineae
17	*Cynoglossum zeylanicum* (Vahl exhornem)	Boraginaceae
18	*Cyperus compressus* L.	Cyperaceae
19	*Cyperus difformis* L.	Cyperaceae
20	*Cyperus iria* L.	Cyperaceae
21	*Cyperus* L.	Cyperaceae
22	*Cyperus pumilus* (L)	Cyperaceae
23	*Cyperus rotundus* L.	Cyperaceae
24	*Digitaria abludens* (Roem.& Schult)	Gramineae
25	*Digitaria* Heist.	Gramineae
26	*Echinochloa colona* (L.) Link	Gramineae

27	*Eleusine indica* (L.) Gaertn.	Gramineae
28	*Eragrostis pilosa* (L.)	Gramineae
29	*Eragrostis* Wolf.	Gramineae
30	*Fragaria daltoniana* J. Gay	Rosaceae
31	*Gnaphalium affine* D.Don	Compositae
32	*Lindernia crustacea* (L.)	Labiateae
33	*Mazus suruculosus* D.Don	Scrophulariaceae
34	*Morus* L.	Moraceae
35	*Oplismenus* P. Beauv.	Gramineae
36	*Oxalis corniculata* L.	Oxalidaceae
37	*Paspalum distichum* L.	Gramineae
38	*Plantago* L.	Plantaginaceae
39	*Polypogan monspeliensis* (L.)	Gramineae
40	*Portulaca oleraceae* L.	Portulacaceae
41	*Ranunculus sceleratus* L.	Ranunculaceae
42	*Rorripa dubia* (Pers.)	Cruciferae
43	*Solanum aculeatissimum* Jacq.	Solanaceae
44	*Solanum nigrum* L.	Solanaceae
45	*Stellaria media* (L.)	Caryophyllaceae
46	*Trifolium repens* L.	Fabaceae
47	*Xanthium strumarium* L.	Compositae

Appendix 3: List of different plant species recorded from the field sampling in different months

	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April
Alternanthera philoxeroids	1	1	1	1	1	1	1	1	1	1	1	1
Cyanodon dactylon	1	1	1	1	1	1	1	1	1	1	1	1
Chenopodium ambrosioides	1	1	1	1	1	1	1	1	1	1	1	1
Amarathus spinosus	1	1	1	1	1	1	1	1	1	1	1	1
Bidens pilosa	1	1	1	1	1	1	1	1	1	1	1	1
Chenopodium album	1	1	0	0	1	0	0	1	1	1	1	1
Eleusine indica	1	0	1	1	1	1	1	1	1	1	1	1
Solanum xanthocarpum	1	1	1	1	1	1	1	1	1	1	1	0
Rorripa dubia	1	1	0	0	0	0	1	0	0	1	1	1
Blumea sp.	1	0	0	0	1	0	0	0	0	0	0	0
Paspalam distichum	1	1	1	1	1	1	1	1	1	0	1	1
Amaranthus caudatus	1	1	1	1	1	1	1	1	1	0	0	0
Digitaria sp.	1	1	1	1	1	1	1	0	0	0	0	0
Commelina bengalensis	1	1	1	1	1	1	1	0	0	0	0	1
Solanum nigrum	1	1	1	1	1	1	1	1	1	0	0	1
Cyperus iria	1	1	0	0	1	0	0	0	1	0	0	1
Alternanthera paronychiodes	1	1	1	1	1	1	1	1	0	1	1	1
Xanthium strumarium	1	1	1	1	1	1	1	0	0	0	0	0
Trifolium repens	1	1	1	0	1	0	0	0	0	0	0	0
Portulaca oleraceae	0	1	1	1	0	0	0	0	0	0	0	0
Artimisia dubia	0	0	1	1	1	1	1	1	1	1	1	1
Eragostris sp.	0	0	1	1	1	0	0	0	0	0	0	0
Digitaria sp.	0	0	1	0	0	0	0	0	0	0	0	0
Oxalis corniculata	0	0	1	1	1	1	1	1	1	1	1	1
Cyperus sp.	0	0	1	1	1	1	1	0	0	0	0	0
Cyperus compressus	0	0	1	1	1	1	1	0	0	0	0	0

Echinochloa colona	0	0	1	1	1	1	0	0	0	0	0	0
Eragrostris pilosa	0	0	1	1	1	1	1	0	0	0	0	0
Fragaria daltoniana	0	0	1	1	1	1	1	1	1	1	1	0
Lindernia crustaceae	0	0	0	1	1	1	1	1	0	1	1	0
Stellaria sp.	0	0	0	1	1	1	1	0	0	0	0	0
Morus alba	0	0	0	1	1	1	1	0	0	0	0	0
Cyperus pilosa	0	0	0	1	1	1	0	0	0	0	0	0
Cyperus pumilus	0	0	0	1	1	1	0	0	0	0	0	0
Ageratum houstonianum	0	0	0	1	1	1	1	0	0	0	0	0
Digitaria abludens	0	0	0	1	1	1	0	0	0	0	0	0
Aster sp.	0	0	0	0	1	0	0	0	0	0	0	0
Cyperus rotundus	0	0	0	0	0	1	1	0	0	0	1	0
Plantago sp.	0	0	0	0	0	0	1	1	1	1	1	1
Lycopersicum esculentum	0	0	0	0	0	0	1	1	0	0	0	0
Conyza sp.	0	0	0	0	0	0	1	0	0	0	0	1
Unidentified	0	0	0	0	0	0	0	1	0	0	0	0
Cynoglossum zealanicum	0	0	0	0	0	0	0	1	0	0	0	0
Unidentified	0	0	0	0	0	0	0	1	0	0	0	0
Circium arvens	0	0	0	0	0	0	0	1	1	1	1	1
Ranunculus scleratus	0	0	0	0	0	0	0	0	1	1	1	1
Mazus surculosus	0	0	0	0	0	0	0	0	0	1	1	1
Poaceae	0	0	0	0	0	0	0	0	0	1	1	1
Cannabis sativa	0	0	0	0	0	0	0	0	0	1	1	1
Rumex nepalensis	0	0	0	0	0	0	0	0	0	0	1	1
Stellaria media	0	0	0	0	0	0	0	0	0	0	1	0
Cynoglossum zealanicum	0	0	0	0	0	0	0	0	0	0	1	1
Unidentified	0	0	0	0	0	0	0	0	0	0	1	0
Unidentified	0	0	0	0	0	0	0	0	0	0	1	1
Polypogan monospeliensis	0	0	0	0	0	0	0	0	0	0	1	1
Gnaphalium affine	0	0	0	0	0	0	0	0	0	0	0	1

*1 indicate presence of species, 0 indicates absence of species.

PHOTOPLATE I

Photo 1. Vegetation sampling in parthenium infested area

Photo 2. Goat grazing in the infested area

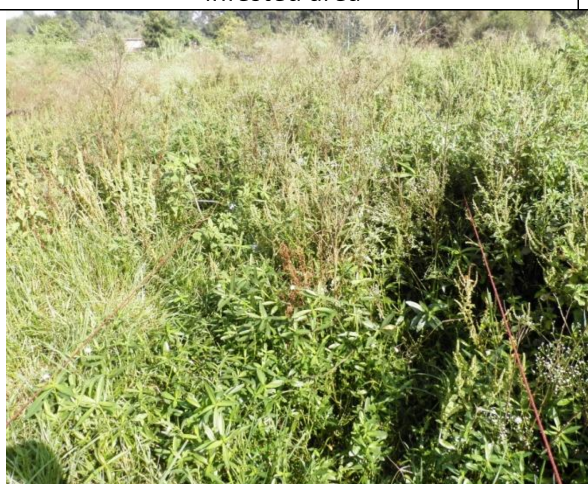

Photo 3. *Alternanthera philoxeroides* and *Amaranthus spinosus* dominating in sampling site

Photo 4. Seedlings of *Bidens pilosa* dominating juvenile of parthenium

Photo 5. Seedlings of parthenium covering the ground

Photo 6. Juveniles of parthenium in sampling plot

PHOTOPLATE II

	
Photo 7. Cattle grazing in the partheniuum infested area near the study site	*Photo 8. Zygogramma bicolorata* defoliating parthenium
	
Photo 9. Complete defoliation by *Zygogramma bicolorata*	Photo 10. Parthenium juvenile growing in pot in green house for clipping experiment
	
Photo 11. Performing clipping of parthenium	Photo 12. Plant individual immediately after the first clipping

PHOTOPLATE III

Photo 13. Occurrence of regrowth after the single clipping

Photo 14. Control plant individual at the harvest time

Photo 15. Plant exposed to single clipping

Photo 16. Plant exposed to double clipping

Photo 17. Plant exposed to triple clipping

Photo 18. Pot grown plants during their flowering stage