CHAPTER ONE

1. INTRODUCTION

1.1 Background

The invasion of ecosystem by non-native species is a global problem with serious consequences for ecological, economic and social systems (Pimental et al. 2000). The study of alien floras or non-native species along with native floras in many places of the world is essential for understanding plant invasions (Pickard 1984, Kloot 1987). Any species including its seeds, eggs, spores or other living entities through which it is capable of multiplying and propagating in a foreign ecosystem is said to be an alien species. Invasive plants produces reproductive offspring, often in very large numbers, at considerable distances from parent plants and thus has potential to spread over a considerable area. Introduction of plants from one place to another may be natural (accidental) or planned (intentional). Although an introduction may meet a desired objective in one area, at one time, or for some sectors, unwanted and unplanned effects may also occur. Many introduced plants have been naturalized in a new environment and form a part of existing landscapes and ecosystems. Such introduced plants may out-compete the native species and turns to invasive.

There are about 8000 species of plants that are believed to be agricultural weeds in the world and about 2500 species are considered to be potentially dangerous (Yaduraju et al. 2000). There is an enormous change in ecology, environment, biodiversity and even changes in atmospheric composition and climate due to biological alien invasions.

Introduction of exotic species following habitat change and soil degradation has equal contribution to the threats of Nepal's biodiversity as other factors such as the human activities, habitat destruction and over-exploitation of natural resources (Chaudhary 1998). The wide range of habitat and environmental conditions makes Nepal vulnerable to the establishment of invasive species of foreign origin (Tiwari et al. 2005). Potential invasive alien species from most areas of the world find suitable habitat somewhere in Nepal and accidental or intentional introduction by gardeners, traders and foresters have contributed to the large number of exotic plant species in Nepal (Kunwar 2003). It has been estimated that there are >200 introduced plant species in Nepal (Tiwari et al. 2005). Among the alien invasive plant species, *Parthenium hysterophorus* L. has emerged as a major threat to grassland ecosystems in the urban areas of Nepal. *P. hysterophorus* (commonly known as Parthenium weed, hereafter referred to as *Parthenium*) invaded Southeast Asian countries such as India, Pakistan and Sri Lanka through cereal and grass seed shipments from USA during 1950s (Kathiresan et al. 2005). It is considered that after a few years of invasion of *Parthenium* in India this plant invaded southern Nepal and progressively to other parts of Nepal through road transportation. In Nepal, a research survey carried out by Tiwari et al. (2005) showed that *Parthenium* is found through out tropical region from east to west of Nepal and finds its way towards subtropical regions.

Although it is acknowledged that invasions by exotic plant species represent a major threat to biodiversity and ecosystem stability, relatively little attention has been paid to potential impacts of these invasions on nutrient cycling processes in the soil. Introductions of alien plant species have potential to change many components of the carbon (C), nitrogen (N), water and other cycles of an ecosystem (Ehrenfeld 2003). Studies have shown that invasive plant species frequently increase biomass and net primary productivity, increase N availability, alter N fixation rates, and produce litter with higher decomposition rates than co-occurring natives (Ehrenfeld 2003).

The right kind of soil and climatic conditions in the place where weeds are introduced will only aid in its faster establishment and subsequent spread. This might lead to a situation where the exotic weed would dominate local weed flora (Yaduraju et al. 2000). The presence of weed population in an arable field is the result of ecological reaction of previous management practices, soil characteristics and the regional climate (Tamado and Milberg 2000). Successful invasion by the plant species depends on presence of safe sites for their establishment, and availability of resources for growth and reproduction in these sites (Yatsu et al. 2003). Competition may occur between invasive and native species. The spread of invasive plants may result in degradation or local extinction of populations of native species and thus the alien invasion has been considered as one of the major threats to native biological diversity (Yatsu et al. 2003, Shabir and Bajwa 2006).

1.2 Justification of the study

Parthenium is an annual weed with wide amplitude of ecological adaptability in terms of photoperiodicity as well as thermoperiodicity (Oudhia 2001). With good rainfall and warm temperature *Parthenium* can germinate, grow and flower at any time of the year (Dhileepan et al. 2000, Maharjan 2006). It is considered as a noxious weed because of its prolific seed production and fast spreading ability, allelopathic effects on other plants, strong competitiveness with crops and health hazard to human as well as animals (Raghubanshi et al. 2005). Although herbarium specimen from Nepal was first collected in 1967 (Tiwari et al. 2005), *Parthenium* became more common after 1990s. Now it has emerged as one of the major threats to biodiversity of roadside and urban grasslands. Except an inventory of IUCN Nepal (Tiwari et al. 2005) and a few works in Kathmandu valley (e.g. Joshi 2005, Maharjan 2006) there is no comprehensive information on the distribution and ecological impact of *Parthenium* invasion to natural ecosystems of Nepal. Since most of the urban areas of Nepal in tropical to subtropical regions has already been invaded by *Parthenium* it is high time to assess the impact of its invasion to soil properties and biodiversity. Present work, though in a small scale, is the first step to this direction. It mainly focused on the changes in soil physico-chemical properties and plant community structure (eg. plant species richness, density, importance percentage, etc) of three grasslands in tropical to sub tropical urban areas of central Nepal. If we can generate such data for the whole range of *Parthenium* invasion, mitigation and control measure of its invasion would be more easier and successful.

1.3 Objectives

An attempt has been made to evaluate the impact of *Parthenium* invasion on soil physico-chemical properties and species composition of grasslands in three valleys of central Nepal. The specific objectives of the research are given below:

i. To analyze the community structure of *Parthenium* invaded grasslands with frequent grazing by domestic animals.

ii. To examine the extent of change in physico-chemical properties of soil due to *Parthenium* invasion.

iii. To understand the change in species composition due to *Parthenium* invasion.

iv. To know the population response of native species to *Parthenium* invasion.

1.4 Limitation of the study

Although *Parthenium* has invaded a wide range of land uses, grasslands of three urban valleys of central Nepal were examined in the present study due to limited time and resources.

CHAPTER TWO

2. LITERATURE REVIEW

Biological invasion by alien invasive species is now recognized as one of the major threats to native species and ecosystems (Kathiresan 2004, Kathiresan et al. 2005). *Parthenium* is an alien invasive species of tropical to subtropical world which has been designated as one of the most troublesome species. The adverse effects of *Parthenium* on human health, livestock, agriculture productivity and biodiversity have been well documented. There has been only a few references on the impact of *Pathenium* invasion on physico-chemical properties of soil.

Parthenium is globally distributed in pantropical regions of north and south America, Australia, Ethiopia, India, Israel, Nepal, Taiwan, West Indies (Picman and Picman 1984, Peng et al. 1988, Mishra 1991, McFadyen 1992, Medhin 1992, Evans 1997, Shabbir and Bajwa 2006). *Parthenium* is distributed throughout Nepal from tropical to sub-tropical regions (75-1350 m asl) (Tiwari et al. 2005). It has achieved major weed status in India and Australia within the last few decades (Navie et al. 1996, Mahadevappa 1997, Evans 1997) and in Nepal it is among the ten most important invasive plant species (Tiwari et al. 2005).

Parthenium has caused a number of environmental and agricultural problems, such as the loss of crop productivity, fodder scarcity to livestock, biodiversity depletion and health problems for human beings and livestock (Evans 1997). Because of its invasive capacity and allelopathic properties *Parthenium* has potential to disrupt natural ecosystems. *Parthenium* can form its huge monoculture strands with no other plant in the vicinity (Singh et al. 2005a). In Islamabad (Pakistan) many common medicinal plants have been threatened because of the aggressive colonization by *Parthenium* in cultivated lands, wasteland, degraded areas, rocky crevices, along water channels, roadsides, and railway tracks (Shabbir and Bajwa 2006). This noxious weed can affect crop production, animal husbandry, human health (e.g. allergic dermatitis, allergic rhinitis, bronchitis, hay fever and asthma) and biodiversity (Chippendale and Panetta 1994, Kohli and Rani 1994, McFadyen 1995, Navie et al. 1996, Evans 1997, Shabbir 2002). Other problems are contamination of seed products and total habitat change in the invaded area (Chippendale and Panetta 1994).

Tamado and Milberg (2000) carried out an exploratory weed survey on 240 crop fields in eastern Ethiopia to assess the influence of environmental and crop improvement factors on weed species composition and distribution and to investigate the association of recently introduced *Parthenium* with other components of weed flora. They concluded that *Parthenium* was second most abundant species on cropland. Despite being rare at high altitudes and perceived as one of the most troublesome weeds within only 20 plant generations from its introduction, *Parthenium* is now recognized as serious problem of crop and rangelands in Ethiopia. In Australia, *Parthenium* has been regarded as one of the worst weeds because of its invasiveness, potential for spread, and economic and environmental impacts (Anonymous 2003). *Parthenium* has posed a major problem in rangelands and summer cropping areas, threatened biodiversity in the Einasleigh uplands bioregion and native grasslands in the central highlands of Queensland. In addition, *Parthenium* has affected primary production both in livestock and grain enterprises as well as caused health problems for human and animals in Queensland, Australia (Anonymous 2004, O'Donnell and Adkins 2005). *Parthenium* can dominate pastures under continued heavy grazing and has the potential to exclude useful forage plants, thus decreasing pasture productivity, carrying capacity and land values. *Parthenium* competes directly with preferred pasture species, reducing pasture vigour and seed set, leading to habitat and ecosystem changes.

Parthenium has strong allelopathic effects on germination and growth of cultivated as well as wild plant species. Negative allelopathic effect of *Parthenium* on cultivated plants (e.g. *Abutilon theophrasti*, *Brassica* spp (*B. campestris*, *B. oleracea* and *B. rapa*), *Glycine max*, *Lolium multiflorum*, *Oryza sativa*, *Phaseolus vulgaris*, *Raphanus sativus*, *Triticum aestivum*, *Vigna radiate* and *Zea mays*) has been well documented (e.g. Wondimagegnehu and Singh 1987, Yadav and Chauhan 1998, Sinha and Deo 1999, Oudhia 2000a, Oudhia 2000b, Chetry 2003, Singh et al. 2003, Singh et al. 2005b, Rajendiran 2005, Maharjan et al. 2007). *Parthenium* also showed negative allelopathic effect to its associated wild species such as *Artemisia dubia* and *Ageratina adenophora* (Maharjan et al. 2007), *Age-*

ratum conyzoides (Singh et al. 2002). Seed germination of *Parthenium* was inhibited by leaf leachates of *Azadirachta indica* and latex of *Calotropis procera* (Goyal and Singh 2003).

Parthenium colonizes a wide range of vegetation and soil types but the most common are in the alkaline, clay loam soils (Anonymous 2006). It is an efficient colonizer and a highly competitive plant. *Parthenium* colonizes overgrazed pastures with low ground cover, cultivated lands, disturbed and bare areas such as roadsides and tracks, and heavily stocked areas such as stockyards and watering points (McFadyen 1992). This plant shows aggressive growth in most of the growing sites. Fundamental reproductive traits, such as seed mass and seed set, of *Parthenium* varies with soil type (Annapurna and Singh 2003) and this variation would enable *Parthenium* to adjust to a variety of habitat conditions. Annapurna and Singh (2003) found that seed mass of *Parthenium* declined in relatively coarser soils whereas seed production increased. In soils rich with clay, the plant produced a smaller number of larger seeds. Parthenium invaded sites at Kathmandu had sandy loam soil pH from 5.4 to 7.4, water holding capacity 16.8 to 63%, organic matter 1.134 to 4.24%, total nitrogen 0.055 to 0.206%, available phosphorus 31.86 to 69.93 kg/ha and available potassium 74.72 to 746.5 kg/ha (Joshi 2005).

Plant invasion also alters the soil properties. Bidwell et al. (2006) found that organic matter and nitrogen content of soil increased with the increase of invasive weed abundance in Australia. Differences in soil ecology are valuable indications of the effect of species richness on invasion dynamics (Collins 2005). For example, Duda et al. (2003) tested nutrient levels (NO_3, P, K, Na) among the native, ecotone and exotic derived soils of the exotic annual chenopod, *Halogeton glomeratus* at the Desert Experimental Range in western Utah, U.S.A. and found that *H. glomeratus* invasion altered soil chemistry and soil ecology, possibly creating conditions that favor exotics over native species.

O'Donnell and Adkins (2005) performed the glasshouse study on four grass species and four legume species and reported that the grass species *Bothriochloa insculpta*, *Dicanthium aristatum* and *Cenchrus ciliaris* all had strongest competitive abilities than *Parthenium* by factors of 3.16, 1.49 and 1.11 respectively. *Digitaria milanjiana* was only competitively equivalent to 0.84 *Parthenium*. Lugumes such as *Clitorea terneata* competed strongly, with single plant being competitively equal 2.89 *Parthenium*. *Glycine latifolia*, *Macroptilium brachteatum* and *Stylosanthes seabrana* had strengths relative to *Parthenium* of 0.43, 0.38 and 0.38 respectively. Although these legumes not being superior in competitive ability to *Parthenium*, would still add nitrogen to thye soil and in pasture situation, could have some benefit through a promotive effect on desirable pasture grasses' competitive ability against *Parthenium*. They concluded that prostrate grass and legume species could be considered in any future studies designated to test competitive ability against *Parthenium*.

Joshi (2005) studied reproductive efficiency and biomass allocation of *Parthenium* growing in different habitats of Kathmandu valley. Average density ranged from 11 to 47 pl/m^2. In individual plants, vegetative allocation (93%) was found comparatively higher than reproductive allocation (7%). Seed germination ranged from 38 to 85%.

CHAPTER THREE

3. STUDY AREA

3.1 Location and Physiography

The selected sites were grasslands on the process of increasing *Parthenium* invasion. Three grasslands, lying at river valleys, were sampled in Gorkha, Nuwakot and Kathmandu districts (Figures 1-3). In each district single grassland was sampled. In Gorkha, sampling was done within the premises of Gorakhkali Rubber Udhyog Limited at Deurali Village Development Committee area (here after referred as Gorkha site). In Nuwakot, the selected grassland lies at Majhitar of Bidur Municipality-5 (here after referred as Nuwakot site). In Kathmandu, the selected grassland lies within the premises of Tribhuvan University Central offices at Kirtipur (here after referred as Kathmandu site) which is the proposed site for construction of Natural History Museum of Tribhuvan University. The area of each grassland sites were more than 1000 square meters. Gorkha and Nuwakot sites lie in tropical climatic zone (<1000 m asl) and site in Kathmandu site lies in subtropical zone (1000-2000 m asl).

The three selected sites were open grazing grasslands without any plantation. The grasslands lie along a side of main road ways leading to different places. They were mainly disturbed by cattle grazing. Moreover, study sites are disturbed by solid wastes thrown by people living nearby and vehicles that temporarily are parked. The extent of *Parthenium* invasion was increasing in all sites. The invasion in the selected grasslands has started 5-6 years back.

3.2 Climate

Average meteorological data of last five years (2002-2006) have been presented for all three sites (Figures 1-3). At Gorkha site, the average minimum temperature was 7.1°C in January and average maximum temperature was 33.6°C in June (Figure 1). The average maximum rainfall was 546 mm in July and average minimum rainfall was 4.4 mm in December. The total annual rainfall was 2310 mm.

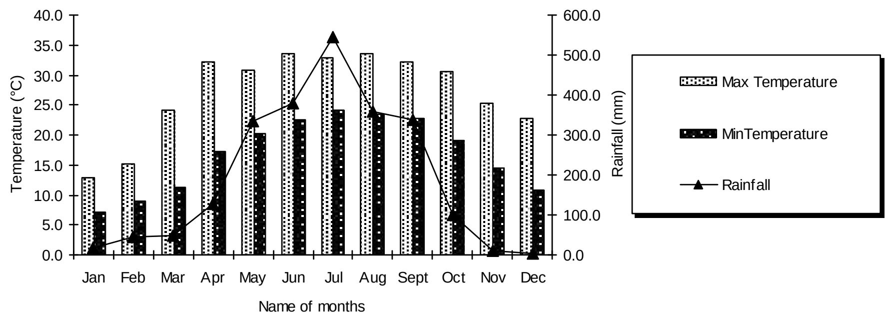


Figure 1. Average monthly minimum and maximum temperature (°C) and rainfall recorded at Khaireni weather station, Tanahun, for five years (2002-006). (Source: Department of Hydrology and Meteorology/GoN). The study site (Gorkha site) is located at a distance of about 2 km from the weather station.

At Nuwakot site, the average minimum temperature was 7.5°C in January and average maximum temperature was 31°C in June (Figure 2). The average maximum rainfall was 517 mm in July and average minimum rainfall was 5.4 mm in December. The total annual rainfall was 1812 mm.

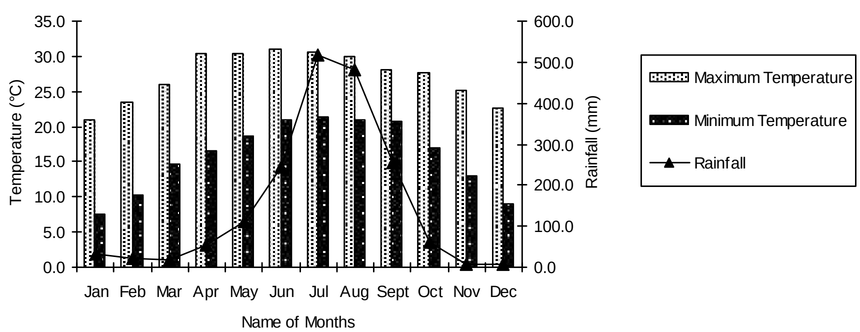


Figure 2. Average monthly minimum and maximum temperature (°C) and rainfall recorded at Kakani weather station, Nuwakot for five years (2002-2006) (Source: Department of Hydrology and Meteorology/GoN). The study site (Nuwakot site) is located at a distance of about 25 km from the weather station.

At Kathmandu site, the average minimum temperature was 3°C in January and average maximum temperature was 29.4°C in June (Figure 3). The average maximum rainfall was 437 mm in July and average minimum rainfall was 7.2 mm in December. The total annual rainfall was 1472 mm.

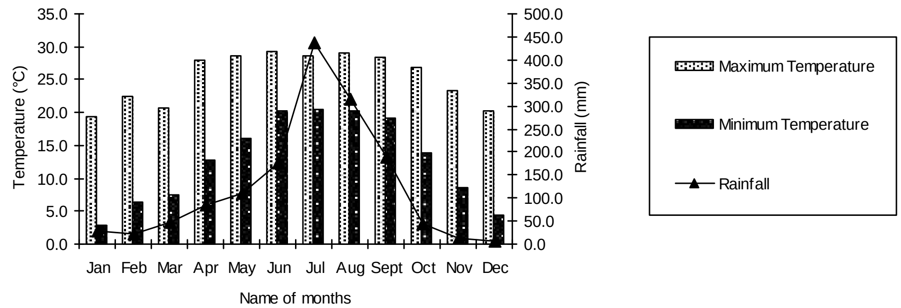


Figure 3. Average monthly minimum and maximum temperature (°C) and rainfall recorded at Tribhuvan International Airport weather station, Kathmandu for five years (2002-2006) (Source: Department of Hydrology and Meteorology/GoN). The study site (Kathmandu site) is located at a distance of about 10 km from the weather station.

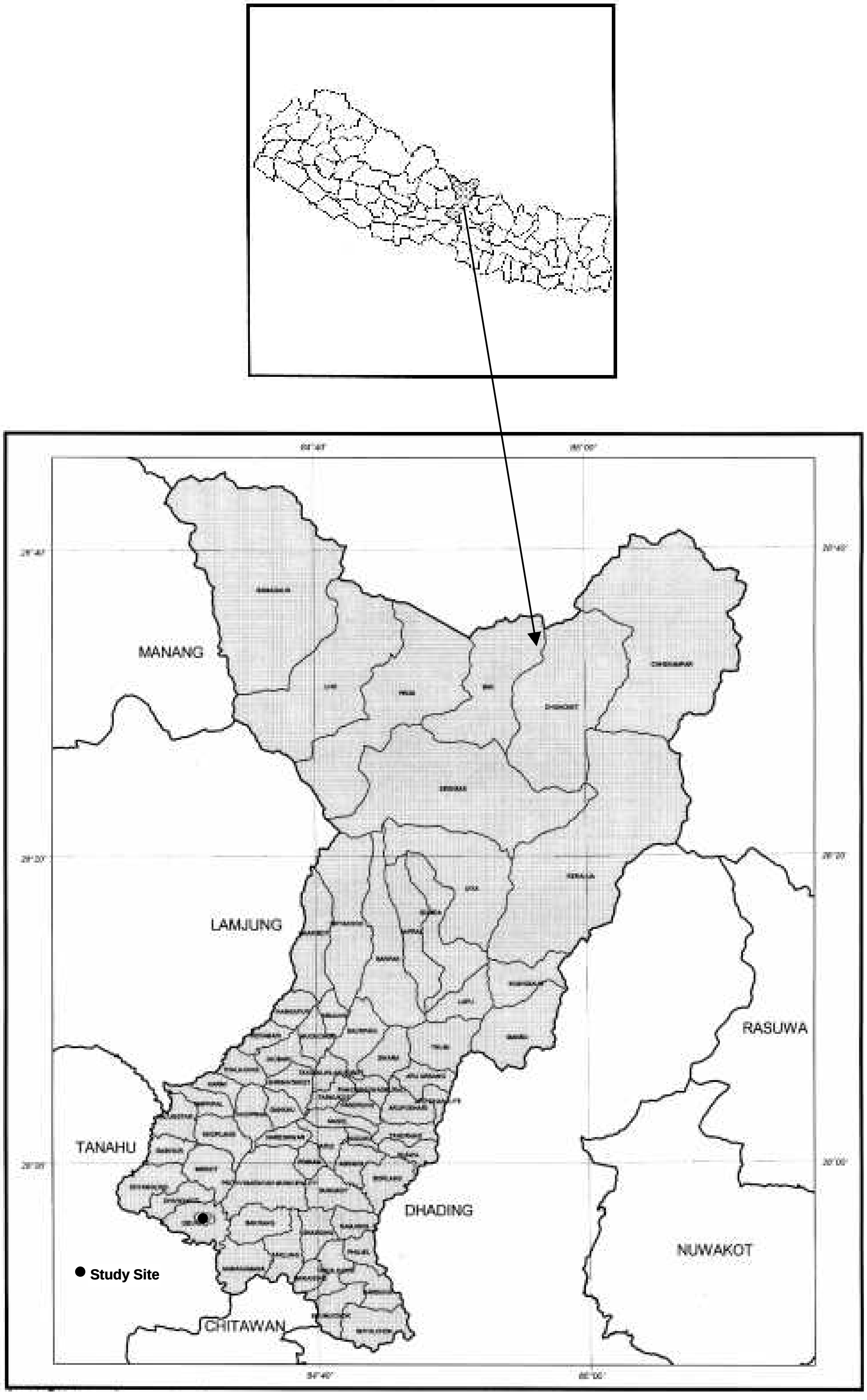


Figure 4. Map of Gorkha study site

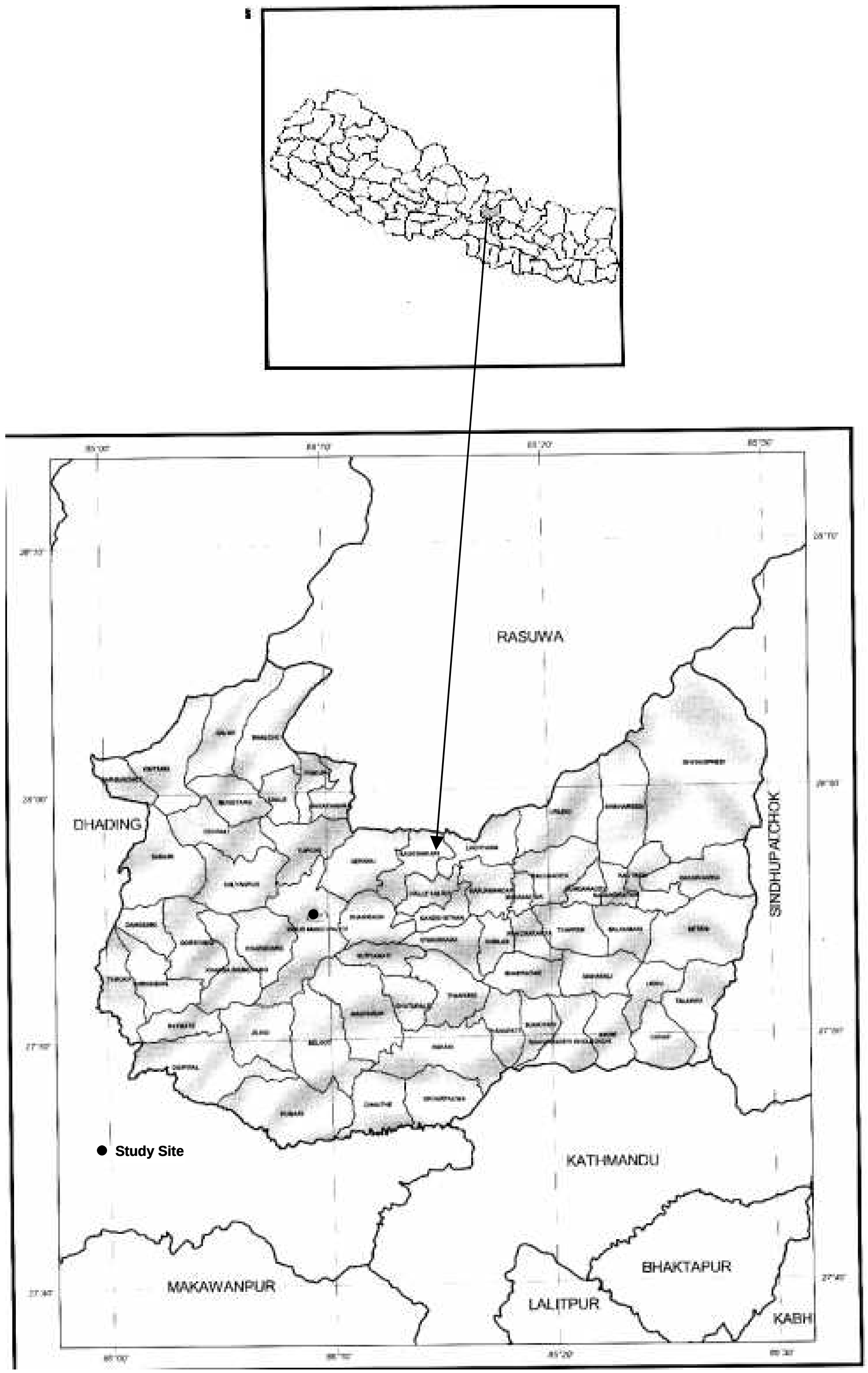


Figure 5. Map of Nuwakot study site

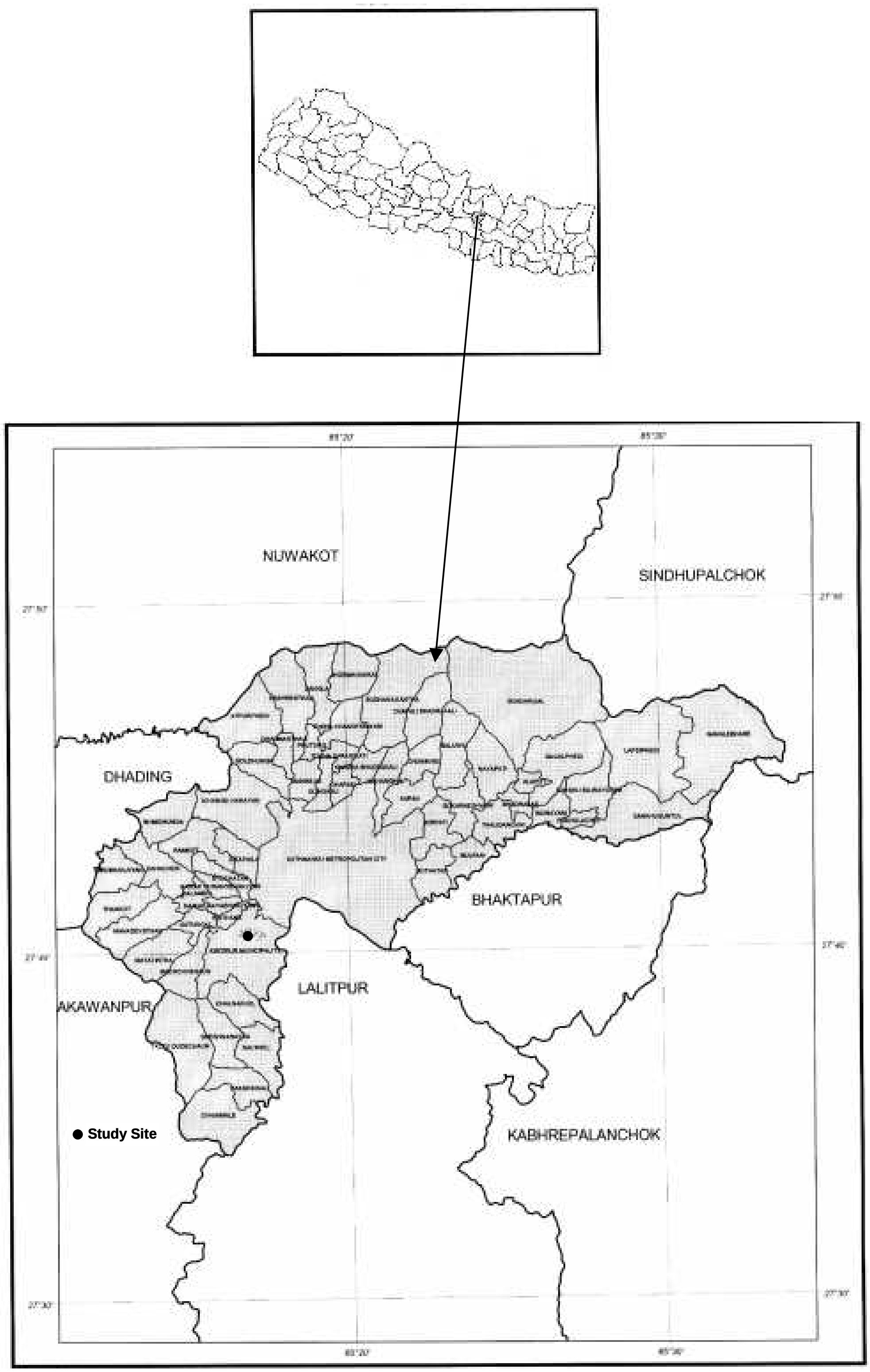


Figure 6. Map of Kathmandu study site

CHAPTER FOUR

4. MATERIALS AND METHODS

4.1 Species characters

Parthenium (family Asteraceae) is an annual herb native to north and south America and the West Indies (Picman and Picman 1984). It is variously called as Bitter weed, Carrot grass, False rage weed, Fever few, Parthenium weed, Ragweed, white top, Santana Maria, etc in different parts of the world and called Kanike ghans, Bethu ghans, Padke phul etc in Nepal (Adhikari and Tiwari 2004, Tiwari et al. 2005).

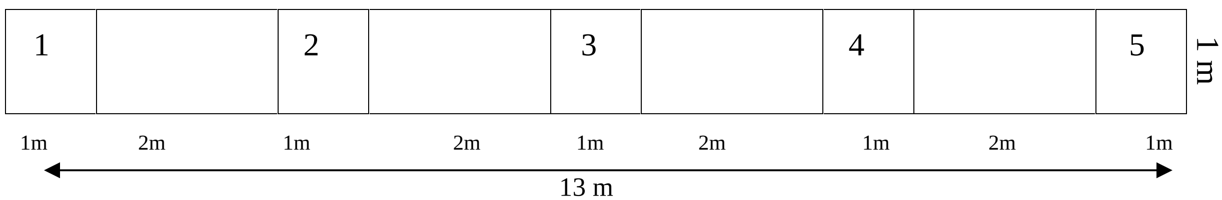
Parthenium is aggressive colonizer in poor ground cover and exposed soil such as wastelands, roadsides and overgrazed pastures (McFadyen 1992). Buried seeds can still germinate after eight to ten years. Because of all these reasons *Parthenium* weed has succeeded invasion in different parts of the world and has become widespread or cosmopolitan in nature.

Parthenium is perennial, erect or profusely branched herb up to 2 m high. Stem is unbranched in lower part and profusely. It has dull green deeply dissected leaves covered with fine white hairs and are arranged in alternate manner. Leaf blade are generally ovate. *Parthenium* has numerous white flowers borne in compact heads near the top of the stem. Five flattened fruits are formed in each floret. Each seed is 1-2 mm long and enclosed in a fine white seed coat. Dry fruits are called achenes and a typically mature plant can produce from 15000 to 25000 achenes. General look of the pland leads to misidentification as *Artemisia* species (Haseler 1976, Joshi 1991, Tiwari et al. 2005). The total seed out put varies from 1392-3864 seeds/plant and average biomass varies from 11.39-29.7 g/plant (Joshi 2005).

4.2 Field Sampling

4.2.1 Vegetation Sampling

Field sampling was done from 23rd August to 20th September, 2006. Belt transect method was used for vegetation sampling (Martin 1995, Cunningham 2001). In each grassland, ten belt transects (each with 13 m × 1 m) were defined in such a way that each transect included both invaded (by *Parthenium*) and non invaded parts of the grassland. In each transect, 5 quadrats (1 m × 1 m) were sampled at interval of 2 m, in such a way that two quadrats lied on non invaded part, one quadrat at transition position and two quadrats at invaded part. The quadrats in each transect were designated as 1, 2, 3, 4 and 5; the quadrats 1 and 2 were non invaded, quadrat 3 the transition position and quadrats 4 and 5 the invaded. The numbers of quadrats sampled in each grassland were 50; thus 150 quadrats were sampled in total for all sites.



* 1 and 2: non invaded, 3: transition, 4 and 5: invaded

Figure 7. Location of sampling plots in each transect

In each quadrat the total number of species (i.e. species richness) and total number of individuals of each species were recorded. Mid point values for coverage of each species were estimated visually following Zobel et al. (1987).

4.2.2 Soil sampling

Soil samples were collected from four corners and a middle of each quadrat at the depth of 15 cm. These sub samples were mixed thoroughly and about 200 g was collected in polythene bag. The soil samples were air dried in shade for a week and stored in air tight bags until laboratory analysis. There were 150 soil samples in total.

4.3 Laboratory Analysis of soil

Soil samples were analyzed at Soil Science Division of National Agricultural Research Council (NARC), Khumaltar, Lalitpur. Soil texture, pH, organic carbon (OC), total Nitrogen (N), available Phosphorus (P) and available Potassium (K) were estimated in the soil samples. The various methods that were used to analyze soil have been described detail in Pradhan (1996) and Bajwa et al. (1997).

4.3.1 Soil texture: Soil texture was determined by hydrometer method. Soil samples were treated with dispersing agent and allowed to settle freely. Soil hydrometer, was calibrated to read the percent of solid gives silt and clay in 40 seconds reading and gave clay at 3 hours. Organic matter, calcium carbonate and soluble salt, if present in appreciable amount, were removed by treating with hydrogen peroxide and hydrochloric acid before dispersing for analysis.

Soil sample (100 g) was taken in a 250 mL beaker and water was added to cover the soil. Sodium hexametaphosphate solution (20 mL) was added and stirred and left overnight. It was transferred in a dispersion cup and two third of the cup was filled with water. It was stirred in the mechanical stirrer, transferred in the hydrometer jar and made the volume up to mark with the hydrometer in it. The hydrometer was removed and the jar was shaken in upside down position for several times by closing the mouth either by the hand or cork. When the soil was well dispersed, it was kept in the table and the time was noted immediately. The hydrometer was immersed in the jar and it was read at 40 sec. and after 3 hours.

(Silt +Clay) % = Hydrometer reading at 40 sec. + 0.3 × (t-20) ° C

Clay (%) = Reading at 3 hrs. + 0.3 × (t-20)° C

Sand (%) = 100- % (Clay+ Silt)

Silt (%) = % (Clay + Silt) - % Clay

where t is the temparature of suspension at the time taking hydrometer reading.

4.3.2 Soil pH: Soil pH was determined using Fischer’s Digital pH meter in 1:2 ratio of soil-water mixture. Before measurement the pH meter was calibrated with the help of buffer solutions of known pH (pH 4 and 7). During the measurements, 50 mL of distilled water was poured into 25 g of soil sample. It was stirred at least four times over 30 minutes to allow the soil and water to reach equilibrium and settled for 25 minutes. The electrode was dipped in the mixture and reading of pH was noted.

4.3.3 Organic matter content: Organic matter content in the soil was calculated by Walkey and Black's rapid titration method (1934). Soil sample (2 g) passed through fine sieve (0.5 mm) was taken in a 250 mL conical flask and added 10 mL of 1N $K_2Cr_2O_7$ and 20 mL of conc. H_2SO_4 with gentle swirling. The reaction being exothermic, the flask was kept on asbestos sheet for about 30 minutes to allow cooling to room temperature. To that mixture 5 mL orthophosphoric acid, 100 mL distilled water and 10 drops diphenylamine indicator solution were added successively and shaken.

0.5N ferrous ammonium sulphate was run from burette, with constant stirring until the colour changed from violet to bright green through blue. The volume of ferrous ammonium sulphate solution used for titration was noted. A blank titration (without soil) was carried out in a similar manner.

Volume of 0.5N ferrous ammonium sulphate solution used for blank titration: X

Volume of 0.5N ferrous ammonium sulphate consumed with soil: Y

Volume of 1N $K_2Cr_2O_7$ used for oxidation of organic carbon in soil: $\frac{X-Y}{2}$

$$\text{Organic carbon in soil (\%)} = \frac{X-Y}{2} \times 0.003 \times \frac{100}{2}$$

$$\text{Organic matter in the soil (\%)} = \text{Organic carbon in soil} \times 1.724$$

4.3.4 Total Nitrogen: Micro-Kjeldahl method consisting of conversion of organic Nitrogen into ammonia by boiling with conc. H_2SO_4; the ammonia was subsequently liberated from its sulphate by distillation in presence of an alkali, which is titrated against HCl.

Ten gram soil was taken in a 300 mL Kjeldahl digestion flask and 30 mL conc. H_2SO_4 was added to the soil. As catalyst, 10 g of Habbard’s mixture (potasium dichromate, ferrous sulphate and copper sulphate in the ration of 20:10:1), 1 g salicyclic acid and 5 g of sodium thiosulphate were added. The mixture was heated at low heat till there was no frothing and then the heat was raised until the content of the flask would grey or greenish in colour for complete digestion. The digest was cooled and about 100 mL distilled water was added. It was transferred to a 250 mL volumetric flask and made up to that volume by adding distilled water and filtered.

Two drops of methyl red indicator was added to a 150 mL conical flask containing 20 mL 0.1N H_2SO_4 and placed under the delivery tube condenser in the distillation assembly. 10 mL of the filtrate was pipetted in the distillation flask and 10 mL of 45% NaOH solution was added in that flask through the funnel connected through a tube to a distillation flask and the filtrate was distilled. 30 mL of distillate was taken and the excess of the acid in the receiver was titrated against 0.1N NaOH.

Nitrogen (%) = (X-Y) ×0.0014 ×vol. of digested sample made ×100/V×M

Where,

X = Vol. of 0.1N H_2SO_4 taken in the receiver (mL)

Y = Vol. of 0.1N NaOH required to neutralize the excess of acid (mL)

V = Vol. of the filtrate used for distillation (mL)

M = Mass of the soil taken for digestion (g)

4.3.5 Available Phosphorus (P): The available P was extracted with 0.5M $NaHCO_3$ (pH 8.5) as detailed by Olsen et al. (1954).

Preparation of a standard curve: To make 100 ppm P solution, 0.4387g of KH_2PO_4 was dissolved in distilled water and made volume to one litre. 5mL of 100 ppm P solution was diluted to 100 mL with distilled water to make standard solution of 5 ppm P solution. To prepare standard curve 0, 0.5, 1, 2, 3, 4 mL of 5 ppm P solution were taken in six different volumetric flasks (25 mL). 5 mL ammonium molybdate was added to the solution with continuous shaking until evolution of carbondioxide stopped. About 10 mL distilled water was added through washing the neck of the flask. Then 1 mL dil. $SnCl_2$ solution was added and made the volume to the mark with distilled water. The colour intensity in each of the standard solution was read in colorimeter at wave length of 660 nm and the absorbance was recorded. A curve showing relationship between concentration of P and the absorbance was plotted on a simple graph paper.

Analysis of test sample: One gram of soil was transferred to a conical flask (100 mL). A pinch of Darco-G 60 and 20 mL of 0.5 N $NaHCO_3$ solution was added. It was mixed and shaked on an electric shaker for half an hour and filtered. In a similar way, a blank with all reagents and no soil was prepared. More Darco-G60 was added to the flask, if filtrate after shaking was not clear. 5 mL of filtrate was taken in a volumetric flask (25 mL) and proceed further for colour development as detailed under preparation of standard curve.

Available P in soil (ppm) = X×100

Where,

X= Concentration of P read from standard curve against absorbance of test solution

100 = Total dilution

Available P (Kg/ha) = Available P expressed in ppm ×2.24

4.3.6 Available Potassium (K): A known weight of soil was shaken with neutral normal ammonium acetate solution. Ammonium ions exchange with K ions adsorbed on soil colloids. The extract contained exchangeable and water soluble K was used for determination of available K in soils.

Preparation of a standard curve: To make standard 1000 ppm K solution, 1.91 g of KCl was dissolved in distilled water and made up the volume to one litre. That solution was diluted 100 times to get 10ppm K solution. The reading of the galvanometer was adjusted to 100 by aspirating 10 ppm K solution and then readings of solutions containing 2, 4, 6 and 8 ppm K were taken. A curve was plotted showing relationship between the K concentration on X-axis and galvanometer readings on Y-axis.

Analysis of test sample: Five gram of soil was transferred to a 150 mL conical flask and added 25 mL of neutral ammonium acetate solution. It was shaken for 5 minutes on an electric shaker and filtered. The filtrate was aspirated into the atomizer of the calibrated flame photometer and the reading was noted. This reading was located on the standard curve and the amount of K was calculated in the soil using the dilution factor.

Available K in soil (ppm) = Y× Total dilution

Where, Y = K (in ppm) as read from the standard curve

Available K (Kg/ha) = Available K expressed in ppm × 2.24

4.4 Plant Collection, Herbarium Preparation and Identification

Specimens of all plant species that were encountered during the field sampling were collected, pressed and dried in field by natural drying technique in sunlight (Forman and Bridson 1989). The voucher specimens were tagged and pressed in the field with the help of newspaper and herbarium presser. Field notes were prepared including colour of the flower, fruit, fragrance or any special feature of the plants collected. When the plant specimens were completely dry, it was mounted on herbarium sheet of 16.5” × 11” with the help of glue, and labeled properly.

The herbarium specimens were identified with the help of standard literatures (Hara et al. 1978, 1982, Hara and Williams 1979, Polunin and Stainton 1984, Stainton 1988). They were also compared with specimens at Tribhuvan University Central Herbarium (TUCH) and National Herbarium, Godawari (KATH) and some of them were identified by experts of Taxonomy. Nomenclature followed in this document is in accordance to Press et al. (2000). The herbarium specimens have been deposited at TUCH, Kirtipur, Nepal.

4.5 Numerical Analysis

To characterize vegetation of the sampling sites, the field data were used to calculate density, frequency, coverage and importance percentage. Field data of those quadrats which occupied same position in transects were pooled together (i.e. data of ten quadrats, one from each transect). Thus, there were five sets of data for each grassland sampled. Above mentioned attributes of the vegetation were calculated separately for each set of quadrats following Zobel et al. (1987) and Dallmeir (1992). The formulae were as follows:

$$\text{Frequency (F, \%)} = \frac{\text{Number of qudrats in which a species ‘A’ occurred}}{\text{Number of total quadrats sampled}} \times 100$$

$$\text{Relative Frequency (RF, \%)} = \frac{\text{Frequency of a species ‘A’}}{\text{Sum of frequencies of all species}} \times 100$$

$$\text{Density (D, pl/m}^2) = \frac{\text{Number of individuals of a species 'A' in all quadrats}}{\text{Total number of quadrats sampled} \times \text{size of a quadrat (m}^2)}$$

$$\text{Relative density (RD, \%)} = \frac{\text{Density of a species 'A'}}{\text{Sum of density of all species}} \times 100$$

$$\text{Coverage (C, \%)} = \frac{\text{Total mid point values of coverage of a species 'A'}}{\text{Total number of quadrats sampled}}$$

$$\text{Relative coverage (RC, \%)} = \frac{\text{Coverage of a species 'A'}}{\text{Total coverage of all species}} \times 100$$

$$\text{Importance percentage (IP)} = \frac{\text{RF + RD+ RC}}{3}$$

Species richness (number of species per sampling unit), density of *Parthenium* (pl/m^2) and total density of all other species (excluding *Parthenium*) were determined for each quadrat. Plot wise data of vegetation and soil attributes were used in statistical analysis. Mean values of *Parthenium* density, species richness, total density excluding *Parthenium*, soil pH, organic matter (OM) content, Nitrogen (N), Phosphorus (P) and Potassium (K) were compared among the five sets of data (corresponding to the position of the quadrats on the transect) for each grassland using Duncan homogeneity test of one way analysis of variance (ANOVA). For correlation and regression plot wise data (n = 150) of all the three grasslands were pooled together. Spearman's correlation coefficients were determined among species richness, density of *Parthenium*, total density of other species (excluding *Parthenium*) and soil attributes. In regression *Parthenium* density was considered as explanatory variable and other vegetation and soil attributes as response variable. The data were fitted to various regression models and the best fitted model (i.e. cubic in present work) was presented. All statistical analyses were done using Statistical Package for Social Sciences (SPSS) version 11.5.

CHAPTER FIVE

5. RESULTS

5.1 Soil characters

Soil texture

In Gorkha, sandy loam type of soil was observed in all the plots. In Nuwakot, sandy loam type of soil was observed in invaded plots and loam type of soil in transition and non-invaded plots. In Kathmandu, soil types in different plots were found to be of various kinds and they were sandy loam in invaded plots, sandy loam in transition plots and silt loam type in non-invaded plots (Table 1).

Table 1. Soil texture of the study sites

Study Sites	Texture	Position of quadrats in the transect*				
		1	2	3	4	5
Gorkha	Sand (%)	64.51±0.08	64.47±0.11	64.57±0.01	65.19±0.07	65.13±0.03
	Silt (%)	26.26±0.03	27.26±0.09	29.31±0.04	28.44±0.04	28.32±0.11
	Clay (%)	8.59±0.04	8.45±0.05	6.39±0.04	6.38±0.05	6.39±0.05
	Class	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Nuwakot	Sand (%)	48.47±0.03	48.44±0.03	44.72±0.01	59.27±0.02	59.28±0.02
	Silt (%)	35.32±0.01	35.36±0.01	33.23±0.01	28.5±0.01	28.4±0.02
	Clay (%)	16.15±0.01	16.24±0.01	22.14±0.01	12.34±0.03	12.29±0.02
	Class	Loam	Loam	Loam	Sandy loam	Sandy loam
Kathmandu	Sand (%)	22.6±0.01	22.57±0.01	38.44±0.03	66.75±0.01	66.73±0.01
	Silt (%)	51.24±0.01	51.25±0.01	45.17±0.01	27.2±0.01	27.21±0.01
	Clay (%)	26.18±0.01	26.16±0.01	16.16±0.01	6.21±0.01	6.18±0.01
	Class	Silt loam	Silt loam	Sandy loam	Sandy loam	Sandy loam

* 1 and 2: non invaded, 3: transition, 4 and 5: invaded

Soil pH

The analysis of variances (ANOVA) showed significant difference ($\rho < 0.001$) in soil pH among the plots with different level of *Parthenium* invasion in all sites. In Gorkha site, soil pH ranged from 5.9 to 6.3 (Table 2). Invaded plots had the lowest soil pH while the transition plots had the highest. In Nuwakot site, the pH ranged from 5.8 to 6.7. The invaded plots had higher soil pH than the non invaded and transition plots, and there was no significant difference in soil pH between non invaded and transition plots. In Kathmandu site, soil pH ranged from 5.5 to 6.3, and it was lowest in non invaded plots and highest in invaded plots (Table 2).

Organic Matter (OM)

There was significant difference in soil organic matter content among non invaded, transition and invaded plots of all study sites (Table 2). In Gorkha, the OM content ranged from 0.39 to 1.21% and it was the highest in transition plots. The invaded plots had higher OM content than the non invaded plots. In Nuwakot, the OM content ranged from 1.62 to 2.11% and it was the highest in transition plots. The non invaded plots had higher OM content than the invaded plots. In Kathmandu, the OM content ranged from 1.36 to 2.14% and it was the highest in invaded plots. The transitions plots had higher OM content than the non invaded plots.

Total Nitrogen (N)

There was significant difference in soil N content among non invaded, transition and invaded plots of Gorkha and Nuwakot sites but in Kathmandu site soil N content of transition plots was not significantly different from that of non invaded plots (Table 2). The invaded plots had higher soil N content than in non invaded plots of Gorkha and Kathmandu sites but opposite pattern was observed in Nuwakot site. In Gorkha site, soil N content ranged from 0.03 to 0.08% and it increased in following order: non invaded plots < invaded plots < transition plots. In Nuwakot, soil N content ranged from 0.11 to 0.14%, with lowest value in invaded plots. It increased in following order: invaded plots < non invaded plots < transition plots. In Kathmandu, soil N content ranged from 0.10 to 0.15% and it was highest in invaded plots.

Table 2. Mean values (± SD, standard deviation) of soil pH, Organic matter content (OM, %), total Nitrogen (N, %), available Phosphorus (P, kg/ha) and available Potassium (K, kg/ha) in Gorkha, Nuwakot and Kathmandu sites, for each site mean values with different alphabets indicates significant difference at ~= 0.05

Study Sites	**Position of quadrats in the transect***	**Soil chemical properties**				
		pH	Organic matter (%)	Total N (%)	Available P (kg/ha)	Available K (kg/ha)
Gorkha	1	6.16±.03b	0.39±0.007a	0.033±0.003a	154±2d	283±1a
	2	6.17±.05b	0.39±0.006a	0.032±0.002a	154±1d	284±1a
	3	6.30±.06c	1.21±0.005c	0.085±0.005c	151±1c	563±4c
	4	5.92±.03a	0.83±0.003b	0.056±0.003b	87±2a	307±2b
	5	5.94±.03a	0.83±0.007b	0.057±0.002b	88±1b	305±3b
Nuwakot	1	5.84±.02a	1.96±0.002b	0.13±0.002b	-	323±3a
	2	5.84±.02a	1.96±0.001b	0.13±0.002b	-	324±3a
	3	5.85±.02a	2.11±0.002c	0.14±0.002c	-	605±2b
	4	6.73±.02b	1.62±0.002a	0.11±0.002a	-	736±2c
	5	6.73±.02b	1.62±0.002a	0.11±0.002a	-	736±3c
Kathmandu	1	5.49±.16a	1.38±0.06a	0.10±0.002a	89±1a	186±2a
	2	5.54±.02a	1.36±0.003a	0.10±0.002a	88±2a	186±2a
	3	5.94±.03b	1.41±0.003b	0.10±0.002a	164±1b	186±2a
	4	6.35±.03c	2.14±0.003c	0.15±0.002b	495±2c	805±2b
	5	6.35±.02c	2.14±0.002c	0.15±0.003b	497±2d	806±2b

* 1 and 2: non invaded, 3: transition, 4 and 5: invaded

Table 3. Mean values of soil pH, organic matter content, nitrogen, phosphorus and potassium in all study sites (Gorkha, Nuwakot and Kathmandu), values of sampling plots occupying same position in transect were pooled together

Soil attributes	Position of sampling plot	Mean±SD	Range
Soil nitrogen	1	0.08 ± 0.04a	0.03-0.13
	2	0.08 ± 0.04a	0.03-0.13
	3	0.1 ± 0.02a	0.08-0.14
	4	0.1 ± 0.04a	0.05-0.15
	5	0.1 ± 0.04a	0.06-0.15
Soil phosphorus	1	81.08 ± 64.37a	0.00-157.2
	2	80.64 ± 64.18a	0.00-156.20
	3	105.15 ± 75.81ab	0.00-165.50
	4	193.85 ± 219.36b	0.00-497.00
	5	195.01 ± 220.18b	00.00-499.00
Soil potassium	1	263.9 ± 58.68a	182.00-329.00
	2	264.33 ± 59.15a	182.00-328.00
	3	451.53 ± 191.78b	183.00-609.00
	4	616.17 ± 223.85c	302.00-808.00
	5	615.63 ± 225.07c	301.00-809.00
Soil PH	1	5.83 ± 0.29a	5.05-6.20
	2	5.85 ± 0.27a	5.51-6.30
	3	6.03 ± 0.21b	5.82-6.40
	4	6.33 ± 0.33c	5.90-6.76
	5	6.34 ± 0.33c	5.90-6.75
Soil OM	1	1.24 ± 0.65a	0.39-1.96
	2	1.23 ± 0.65a	0.38-1.95
	3	1.58 ± 0.39a	1.21-2.11
	4	1.23 ± 0.65a	0.83-2831.00
	5	1.53 ± 0.54a	0.82-2.14

* 1 and 2: non invaded, 3: transition, 4 and 5: invaded

Available Phosphorus (as P_2O_5)

There was significant difference in soil P (as P_2O_5) content among non invaded, transition and invaded plots of Gorkha and Kathmandu sites (Table 2) but in Nuwakot site soil P was not found in detectable amount. The non invaded plots had higher soil P (P_2O_5) content than in invaded plots of Gorkha site but opposite pattern was observed in Kathmandu site. Soil P (P_2O_5) content ranged from 87 to 154 kg/ha and it increased in following order: invaded plots < transition plots < non invaded plots in Gorkha. In Kathmandu, soil P content ranged from 88 to 497 kg/ha. It increased in following order: non invaded plots < transition plots < invaded plots.

Table 4. Results of analysis of variance (ANOVA) among different soil parameters of Gorkha, Nuwakot and Kathmandu study sites

Study site	Parameters	Source of variation	Degree of freedom	F value	Significance level (ρ)
Gorkha	pH	Between groups	4	175	0.000
		Within groups	45		
		Total	49		
	Organic matter	Between groups	4	43879	0.000
		Within groups	45		
		Total	49		
	Nitrogen	Between groups	4	661	0.000
		Within groups	45		
		Total	49		
	Phosphorus	Between groups	4	6967	0.000
		Within groups	45		
		Total	49		
	Potassium	Between groups	4	22969	0.000
		Within groups	45		
		Total	49		
Nuwakot	pH	Between groups	4	10660	0.000
		Within groups	45		
		Total	49		
	Organic matter	Between groups	4	258928	0.000
		Within groups	45		
		Total	49		
	Nitrogen	Between groups	4	792	0.000
		Within groups	45		
		Total	49		
	Potassium	Between groups	4	63480	0.000
		Within groups	45		
		Total	49		
Kathmandu	pH	Between groups	4	350	0.000
		Within groups	45		
		Total	49		
	Organic matter	Between groups	4	3104	0.000
		Within groups	45		
		Total	49		
	Nitrogen	Between groups	4	2313	0.000
		Within groups	45		
		Total	49		
	Phosphorus	Between groups	4	198486	0.000
		Within groups	45		
		Total	49		
	Potassium	Between groups	4	276544	0.000
		Within groups	45		
		Total	49		

Available Potassium (as K_2O)

There was significant difference in soil K (as K_2O) content in invaded plots of Nuwakot and Kathmandu sites but in Gorkha site soil K content of transition plots was not significantly different from that of non invaded plots (Table 2). The invaded plots had highest soil K content than in non invaded plots of Nuwakot and Kathmandu sites but in Gorkha site, soil K was highest in transition plot. In Gorkha site, soil K content ranged from 283 to 563 kg/ha and it increased in following order: non invaded plots < invaded plots < transition plots. In Nuwakot, soil K content ranged from 323 to 736 kg/ha, with lowest value in non invaded plots. It increased in following order: non invaded plots < transition plots < invaded plots. In Kathmandu, soil K content ranged from 186 to 806 kg/ha and it was highest in invaded plots.

Table 5. Results of analysis of variance (ANOVA) of soil attributes among three study sites (Gorkha, Nuwakot and Kathmandu), for each site, data of all sampling plots were pooled

Parameters	Source of variation	Degree of freedom	F value	Significance level (ρ)
Soil nitrogen	Between Groups	4	2.649	0.036
	Within Groups	145		
	Total	149		
Soil phosphorus	Between Groups	4	4.659	0.001
	Within Groups	145		
	Total	149		
Soil potassium	Between Groups	4	32.146	0.000
	Within Groups	145		
	Total	149		
Soil PH	Between Groups	4	22.772	0.000
	Within Groups	145		
	Total	149		
Soil OM	Between Groups	4	1.003	0.408
	Within Groups	145		
	Total	149		

5.2 Number of species

Total number of species recorded in sampling plots were 22 in Gorkha site and 23 in both Nuwakot and Kathmandu sites (Table 6). The number of species was the highest in transition plots (position 3) of Gorkha site but in Nuwakot site, the highest number of species (17) was recorded in non-invaded plots and least number of species (13) in invaded plots which was the most disturbed plots in all three sites . In Kathmandu site the highest number of species (16) was recorded both in invaded and non invaded plots.

Table 6. Total number of species recorded in plots of various positions in the study sites (Gorkha, Nuwakot and Kathmandu)

Study sites	Number of species					
	Total	Position of quadrats in the transect*				
		1	2	3	4	5
Gorkha	22	14	12	17	15	16
Nuwakot	23	17	15	16	13	13
Kathmandu	23	11	16	12	13	16

*1 and 2: non invaded quadrats, 3: transition quadrat, 4 and 5: invaded quadrats

5.3 Changes in density and species richness

The analysis of variances (ANOVA) showed significant difference ($\rho < 0.001$) in *Parthenium* density and total density (excluding *Parthenium*) among the plots with different level of *Parthenium* invasion in each site. *Parthenium* density in most invaded plots (position 5 in transects) ranged from 1.5 to 38 pl/m^2 (average 20 pl/m^2) in Gorkha site, 1 to 29 pl/m^2 (average 15 pl/m^2) in Nuwakot site and 2 to 26 pl/m^2 (average 13 pl/m^2) in Kathmandu site. Thus maximum *Parthenium* density was recorded at Gorkha site (Table 9). Total density of all plant species excluding *Parthenium* was high in non invaded plots 222 pl/m^2 in Gorkha site, 219 pl/m^2 in Nuwakot site and 225 pl/m^2 in Kathmandu site and that value was the lowest in invaded plots of all sites (Table 9)**.**

Table 7. Results of analysis of variance (ANOVA) among different parameters of Gorkha, Nuwakot and Kathmandu study sites

Study site	Parameters	Sources of variation	df	F value	Significance level (ρ)
Gorkha	*Parthenium* density	Between Groups	4	17.423	.000
		Within Groups	31		
		Total	35		
	Species richness	Between Groups	4	1.699	0.167
		Within Groups	45		
		Total	49		
	Total Density#	Between Groups	4	12.484	0.000
		Within Groups	45		
		Total	49		
Nuwakot	Parthenium density	Between Groups	4	51.753	0.00
		Within Groups	32		
		Total	36		
	Species richness	Between Groups	4	0.54	0.707
		Within Groups	45		
		Total	49		
	Total Density#	Between Groups	4	28.922	0.000
		Within Groups	45		
		Total	49		
Kakthnandu	Parthenium density	Between Groups	3	18.387	0.000
		Within Groups	30		
		Total	33		
	Species richness	Between Groups	4	3.049	0.026
		Within Groups	45		
		Total	49		
	Total Density#	Between Groups	4	15.607	0.000
		Within Groups	45		
		Total	49		

Density excluding *Parthenium*

There was significant difference in species richness among the various positions of sampling plots in Gorkha and Kathmandu sites but the difference was not significant in Nuwakot site (Table 9). In Gorkha, species richness was the lowest in non invaded plot (position 1) and it increased towards invaded plots. In Nuwakot, species richness ranged from 4 to 7 species/m^2 in invaded plots and from 4 to 8 species/m^2 in non-invaded plots. In Kathmandu, species richness ranged from 3 to 8 species/m^2 in invaded plots and from 3 to 8 species/m^2 in non-invaded plot**.** In this site both lowest and highest species richness were recorded in non invaded plots.

Table 8. Results of analysis of variance (ANOVA) of *Parthenium* density, species richness and total density of other plant species excluding *Parthenium* among three study sites (Gorkha, Nuwakot and Kathmandu), for each site, data of all sampling plots were pooled

Parameters	Source of variation	Degree of freedom	F value	Significance level (ρ)
Parthenium density	Between Groups	4	119.335	0.000
	Within Groups	145		
	Total	149		
Species richness	Between Groups	4	3.013	0.020
	Within Groups	145		
	Total	149		
Total density#	Between Groups	4	50.686	0.000
	Within Groups	145		
	Total	149		

Density excluding *Parthenium*

Table 9. Mean values of *Parthenium* density, species richness and total density of other plant species excluding *Parthenium* in *Parthenium* invaded plot of Gorkha, Nuwakot and Kathmandu

Study Sites	Community attributes	Position of quadrats in the transect*				
		1	2	3	4	5
Gorkha	*Parthenium* density	1.5±0.7a	1.3±0.5a	15.6±8.9b	32.0±13.5c	38.0±7.4c
	Species richness	5.3±0.8a	6.0±1.1ab	6.3±1.1ab	6.3±1.3ab	6.5±1.4b
	Total density#	222±82b	172±81b	95±35a	87±32a	76±29a
Nuwakot	*Parthenium* density	1	2.8±0.8	11.1±5.0	20.9±3.4	28.8±4.5
	Species richness	5.4±1.3a	5.3±1.1a	5.8±1.1a	5.2±1.0a	5.7±1.1a
	Total density#	219±57c	190±46c	108±48b	82±26ab	53±19a
Kathmandu	*Parthenium* density	0	2.0±1.2	8.8±4.2	18.3±7.1	25.7±8.4
	Species richness	3.9±0.9a	5.8±1.8b	5.3±0.7b	4.8±1.3ab	5.3±1.6b
	Total density#	225±81c	142±79b	94±49ab	50±23a	57±33a

* 1 and 2: non invaded, 3: transition, 4 and 5: invaded; # Density excluding *Parthenium*

Table 10. Mean values of *Parthenium* density, species richness, total density (excluding *Parthenium*) for all study sites (Gorkha, Nuwakot and Kathmandu), values of sampling plots occupying same position in transect were pooled together

Parameters	Position of sampling plot	Mean ± SD	Range of values
Parthenium density	1	0.13 ± 0.43a	0.00-2.00
	2	1 ± 1.29a	0.00-4.00
	3	12 ± 6.8b	3.00-33.00
	4	24 ± 11c	9.00-55.00
	5	31 ± 8.6d	13.00-50.00
Species richness	1	4.87 ± 1.2a	3.00-8.00
	2	5.7 ± 1.32ab	3.00-8.00
	3	5.8 ± 1.03b	4.00-8.00
	4	5.43 ± 1.33ab	4.00-8.00
	5	5.83 ± 1.42b	3.00-8.00
Total density#	1	222 ± 72d	94.00-390.00
	2	168 ± 71c	51.00-324.00
	3	99 ± 43b	37.00-185.00
	4	73 ± 31ab	15.00-130.00
	5	62 ± 28a	14.00-118.00

*1 and 2: non invaded, 3: transition, 4 and 5: invaded; # Density excluding *Parthenium*

In average, higher plant species richness was found in invaded plots and transition plot than in non-invaded plots (Table 10).

5.4 Change in Importance Percentage (IP)

The importance percentage (IP) of *Imperata* sp., *Trifolium repens* and *Acrachne racemosa* were lower in invaded plots than in non invaded plots in Gorkha site (Figure 8). The IP of *Mimosa pudica* was higher in transition and most invaded plots than in non invaded plots. The IP of *Chrysopogan aciculatus* increased from invaded plots to non-invaded plot (Appendix 1a-1e).

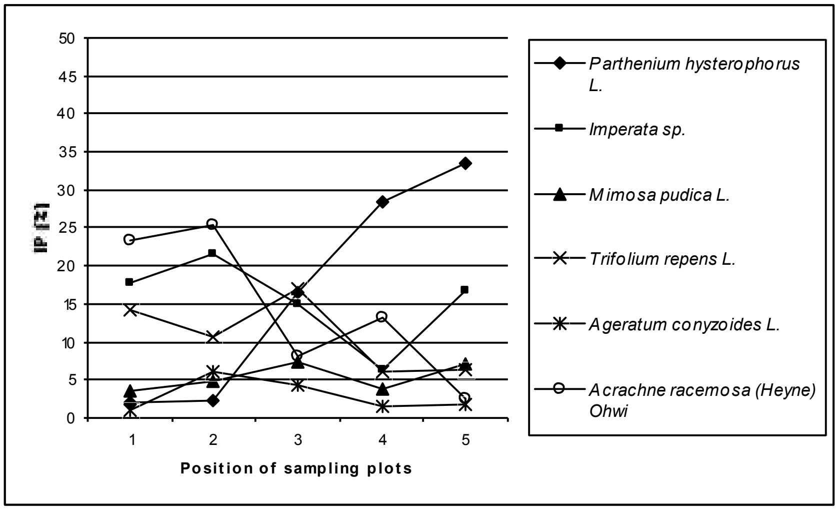


Figure 8. Importance percentage (IP, %) of some plant species in different sampling plots of *Parthenium* invaded grassland in Gorkha site * 1 and 2: non invaded, 3: transition, 4 and 5: invaded

In Nuwakot, the IP of *Mimosa pudica* increased from non-invaded plot to invaded plots (Figure 9). *Acrachne racemosa* had the highest IP in non-invaded plots (32.39%) and the lowest in most invaded plots (6.43%). The IP of *Imperata* sp. declined marginally from non-invaded to invaded plots. The IP of *Ageratum conyzoides* L. increased from non-invaded plots to invaded plots.

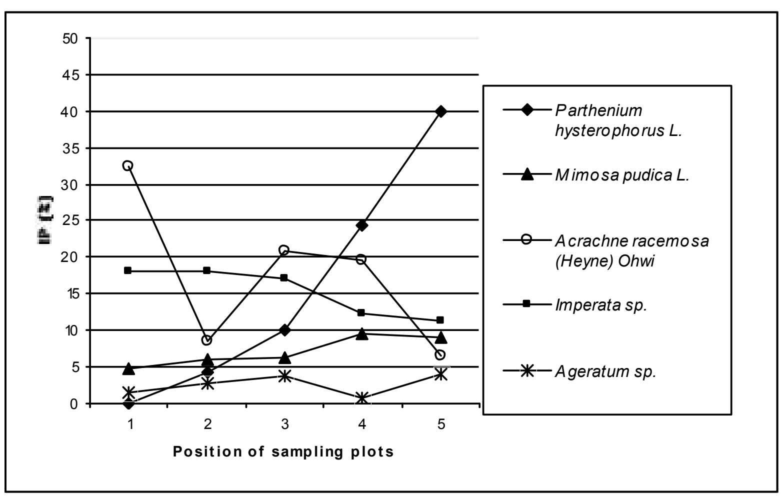


Figure 9. Importance percentage (IP %) of some plant species in different sampling plots of *Parthenium* invaded grassland in Nuwakot site * 1 and 2: non invaded, 3: transition, 4 and 5: invaded

In Kathmandu, the IP of *Acrachne racemosa* and *Sporobolous* sp. declined from non-invaded to invaded plots (Figure 10). The IP of *Trifolium repens* was lower in invaded plots than in non invaded. The IP of *Dactyloctenium aegypticum* was the lowest in transition plot and highest in non invaded plot.

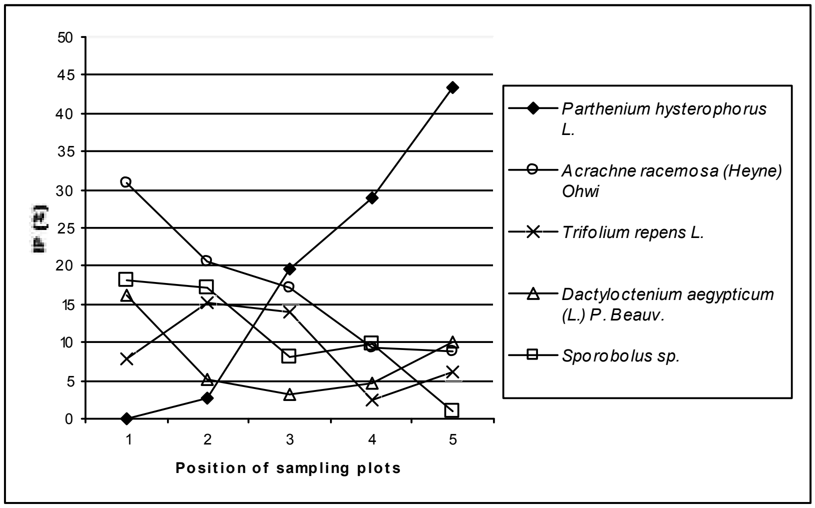


Figure 10. Importance percentage (IP %) of some plant species in different sampling plots of *Parthenium* invaded grassland in Kathmandu site * 1 and 2: non invaded, 3: transition, 4 and 5: invaded

5.5 Relation between plant community and soil attributes

Correlation analysis for the combined data from all three site showed increase in species richness and decline in total density (excluding *Parthenium*) with increasing *Parthenium* density (p = 0.01) (Table 11). *Parthenium* density was positively correlated with species richness, soil pH and K content. Species richness was negatively correlated with soil N and OM content. Total density excluding *Parthenium* was negatively correlated with all measured soil attributes (Table 11).

Table 11. Spearman's Correlation coefficients (r) among the plant community and soil characters

Parameters	*Parthenium* density	Species richness	Total density#	Soil Nitrogen	Soil Phosphorus	Soil Potassium	Soil PH
Species richness	0.230**						
Total density#	−0.679**	−0.06					
Soil Nitrogen	0.148	−0.224**	−0.271**				
Soil Phosphorus	0.018	−0.043	−0.181*	−0.138			
Soil Potassium	0.546**	−0.011	−0.474**	0.669**	−0.096		
Soil pH	0.548**	0.031	−0.538**	0.079	0.244**	0.648**	
Soil OM	0.159	−0.231**	−0.285**	0.981**	−0.123	0.671**	0.094

** Significant at $p = 0.01$, * significant at $p = 0.05$, # density excluding *Parthenium*

Total density of other species declined sharply with increasing density of *Parthenium* at the initial stage of invasion but the former slightly increased when the *Parthenium* density has medium value (20 – 40 pl/m^2, Figure 11). Towards the highest value of *Parthenium* density (> 40 pl/m^2) the total density of other species again declined sharply. Soil potassium (K) content and pH showed hump-shaped (or dome shaped) relations with *Parthenium* density (Figures 12, 13). Soil K content was low on non invaded as well as most invaded plots. At initial phase of *Parthenium* invasion, soil pH increased towards neutral. But in most invaded plots, soil pH declined and became acidic.

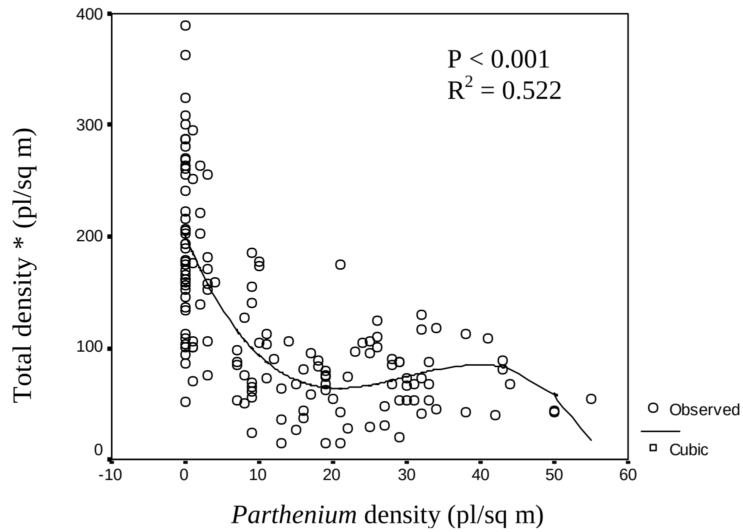


Figure 11. Relationship between total density (excluding *Parthenium*) and *Parthenium* density. The relations were obtained by regression analysis (cubical model) using combined data for all three sites. Each circle represents a sampling plot. *Total density of other plant species excluding *Parthenium*

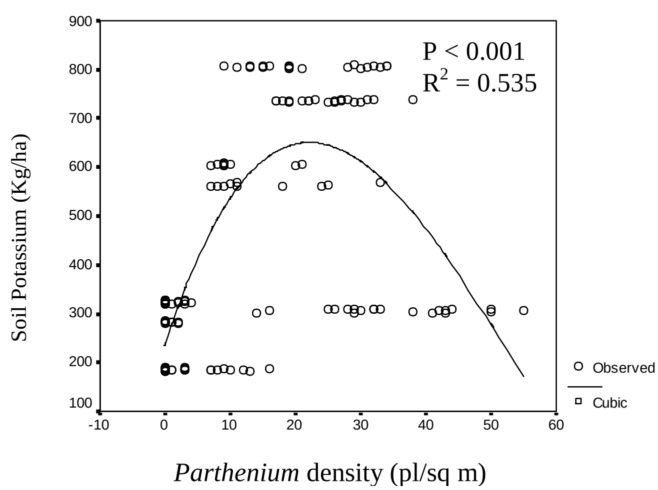


Figure 12. Relationship between potassium content of soil and *Parthenium* density. The relations were obtained by regression analysis (cubical model) using combined data for all three sites. Each circle represents a sampling plot.

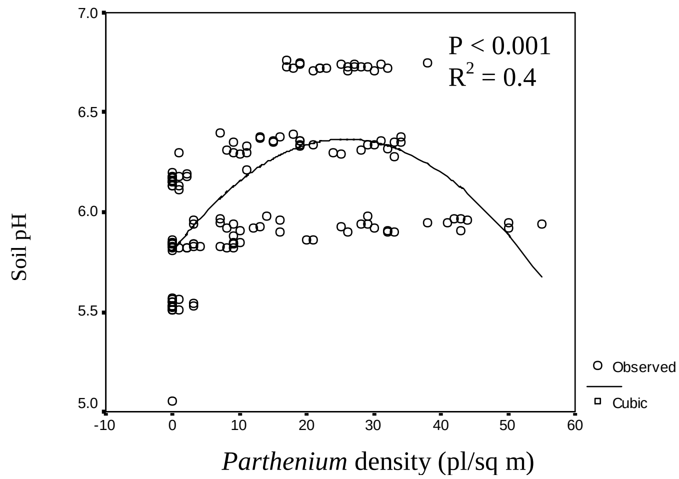


Figure 13. Relationship between soil pH and *Parthenium* density. The relations were obtained by regression analysis (cubical model) using combined data for all three sites. Each circle represents a sampling plot.

CHAPTER SIX

6. DISCUSSION

6.1 Soil characters

While moving from non-invaded plots to invaded plots, soil type was changed to sandy loam type in all three sites (Table 1). This result was similar to report of Joshi (2005). She reported that sandy loam types of soil have favoured the growth of *Parthenium* due to more aeration in soil. Annapurna and Singh (2003) have reported that the life cycle of *Parthenium* is slow in high clay soils because the amount of plant-available N would be lower in clay-rich soils and loamy sand would be expected to be the most fertile soil for *Parthenium*.

In all three sites soil pH declined from non-invaded plots to invaded plots (Table 3) and soil was slightly acidic or neutral. Soil might become slightly acidic or neutral in *Parthenium* invaded plots through root exudates (Bhowmik et al. 2007), which could include allelochemicals. High *Parthenium* density both in acidic and neutral soil has been reported in Kathmandu valley (Joshi 2005). However *Parthenium* is capable of growing in most soil types but becomes dominant in alkaline clay loam soil (Anonymous 2006).

In average, the soil OM and N did not change significantly from *Parthenium* non-invaded plots to invaded plots in all three study sites (Table 3). This result was contradictory with the findings of Bidwell et al. (2006) which showed that OM and N content of soil increased with the increase of invasive weed abundance in Australia. It has been reported that the extreme degree of *Parthenium* mortality was observed in the soils with highest clay contents because the amount of plant available N would be lower in clay-rich soils (Annapurna and Singh 2003). Changes in soil nutrient pools due to invasion might require longer periods of time to show differences to native patches (Collins 2005). There might have implications in soil extractable pools in long term.

Soil K increased from non-invaded plots to invaded plots (Table 3). Many grass species with fine, fibrous root systems are able to exploit K held in clay interlayer and near the edges of mica and feldspar of clay and silt (Brady and Weil 2002). Grass species were dominant in non invaded plots and also clay content was high in those plots. This result is contradictory to Collins (2005) which showed lower level of soil K in invaded plots than non-invaded plots while working with invasive species of *Imperata cylindrica* in America.

There were a number of trends in changes in soil properties that might be due to heterogeneous nature of habitat, instead of *Parthenium* invasion. The study sites were partially and newly invaded sites of about five years old and the period might be not sufficient to change soil properties. Plant invasions do not result in consistent changes in soil properties, even for the same invasive species (Collins 2005). Hook et al. (2004) suggested that *Centaurea maculosa*, might increase soil C and N pools in native grasslands in Montana (USA). and available data suggest a number of trends with respect to soil nutrients and plant invasions. Bhowmik et al. (2007) expected that *Parthenium* can survive in natural system either due to slow release of allelochemicals with less concentration in system or the chemicals donot persist in soil for a long time to effect the system.

6.2 Change in vegetation pattern

Parthenium density ranged from 1.5 to 38 pl/m^2 in invaded plots for all study sites (Table 10). The density ranged from 2 to 25.7 pl/m^2 in invaded plots of Kathmandu site which is similar to the range (11 to 47 pl/m^2) reported by Joshi (2005) from Kathmandu valley. Tiwari et al. (2005) has shown *Parthenium* density of 0.55 pl/m^2 in fallowlands which is very low as compared to present data. Very low density could be possible at the initial stage of invasion but it rapidly increases over time. Density of *Parthenium* was 55 pl/m^2 at eastern Ethiopia (Tamado et al. 2002) which was higher than the values reported in present study and other studies in Nepal. Density of associated plant species generally declined with increasing density of *Parthenium* (Figure 11) due to competitive replacement. Slight increase in density of associated species at intermediate level of *Parthenium* density (25 – 40 pl/m^2) might be due to transition from *Acrachne recemosa* dominated community to *Parthenium* dominated community. When density of mat forming *Acrachne recemosa* declined then space could be available for growth of small herbaceous species which latter dissappeared due to increasing population of *Parthenium*. Low grazing pressure due to presence of unpalatable *Parthenium* could also have contributed to slight increase in density of associated species in these plots.

6.3 Impact of *Parthenium* invasion on species richness

When considered three sites together the species richness was the highest in the most invaded plots (Table 10). However the individual sites did not show consistent pattern in species richness with *Parthenium* invasion (Table 9). At Gorkha the species richness was the highest at most invaded plots but at other two sites high species richness was recorded both in non invaded and invaded plots. Thus it is clear that despite the lack of consistent pattern for indiviudal sites, the species richness did not declined due to *Parthenium* invasion at this initial stage. The non invaded plots in all sites were dominated by *Acrachne recemosa* (Figures 8-10) which formed continuous mat and suppressed the growth of associated species. With the initiation of *Parthenium* invasion importance of *Acrachne recemosa* declined and dominance shifted to *Parthenium*. *Acrachne racemosa* forms mat like layer due to its extensive rhizome and root network which doesnot allow the growth of other plant species at ground level. *Parthenium* lacks such type of network but creats shaded condition which favours growth of other plant species under dense canopy at ground level. Due to different growth form, *Parthenium* allowed the growth of small herbaceious species, leading to high species richness at initial stage of invasion. But latter most of the associated species would disappear due to allelopathic effect and competitive replacement by *Parthenium* (Yadav and Chauhan 1998, Sinha and Deo 1999). Thus history of plant invasion should be considered while accounting the species richness in relation to invasion. Melbourne et al. (2007) also showed that diversity can increased as a result of biological invasions. Invasion directly doesnot replace native species at first it creats a heterogeneous environmental condition which is formed due to coexistance of different plant species at the same time. In present study sites, heterogeneous environmental conditions might have created due to presence of *Parthenium* in patches at initial stage and increase the species richness.

6.4 Response of native species to *Parthenium* invasion

Acrachne racemosa is a palatable grass of family Poaceae. Importance percentage (IP) of *A. racemosa* declined from non invaded plots to invaded ones (Figures 8-10) in all study sites. Dominant shifts from *Acrachne racemosa* to *Parthenium* moving from non invaded plots to invaded plots and also *Acrachne racemosa* has prostrate rhizome and root network. Likewise *Trifolium repens*, *Imperata* sp., *Chrysopogan aciculatus*, *Sporobolus* sp. and *Dactyloctenium aegypticum* were also affected by *Parthenium* invasion. These plant species are palatable species and so there might be possible impact on fodder supply. Thus *Parthenium* competes directly with pasture species, reducing pasture vigour and seed set and leading to habitat and ecosystem change (Evans 1997, O'Donnell and Adkins 2005, Shabbir and Bajwa 2006). There might be reduction in pasture production after several years of *Parthenium* invasion. *Parthenium* releases chemicals that inhibit the germination and growth of pasture grasses and other plants (Bhowmik et al. 2007). IP of *Ageratum conyzoides* and *Mimosa pudica* increased from non invaded plots to invaded (Figure 8, 9). That was the evidence of competitive vigour of those plant species to *Parthenium*. The IP of *Euphorbia hirta* and *Cassia tora* did not vary significantly with different levels of *Parthenium* invasion which meant that those species might compete with *Parthenium*. *Commelina bengalesis*, *Bidens pilosa* var. *minor*, *Drymeria cordata*, *Justicia* sp. and *Alternanthera* sp. were present in invaded plots and absent in non invaded plots. *Commelina bengalesis* and *Alternanthera* sp. were delicate species; thus these two species might be suppressed due to grazing and trampling in non invaded plots. *Spilanthus sinensis* var. *amoena* and *Hydrocotyle* sp. were present in non invaded plots but absent in invaded plots (Appendix 1a-3e); thus these species could be more sensitive to invasion.

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATION

7.1 Conclusions

Soil became slightly acidic and neutral due to *Parthenium* invasion. Soil OM and soil N content remained unchanged and soil K increased due to *Parthenium* invasion at initial stage but it declined with increasing *Parthenium* density. Plant species richness was high in invaded plots probably due to increase in habitat heterogeneity at initial stage of invasion. Dominance shifted from *Acrachne racemosa* to *Parthenium* and density of associated species declined with increasing *Parthenium* density. Many palatable species (*Acrachne racemosa* (Heyne) Ohwi., *Trifolium repens* L., *Imperata* sp., *Chrysopogan aciculatus* (Retz.) Trin., *Sporobolus* sp. and *Dactyloctenium aegypticum* (L.) P. Beauv.) were negatively affected by *Parthenium* invasion.

7.2 Recommendations

Based on the results of present study the following recommendations have been made:

- Palatable species of grasslands were found to be highly sensitive to *Parthenium* invasion. Thus grazing lands should be protected from *Parthenium* invasion to ensure sustainable supply of fodder to livestocks.
- Maintainance of correct stock numbers is the most important in controlling *Parthenium* because high grazing decreases vigour and competitiveness of pastures and allows the entry and spread of *Parthenium*.
- The researches related to change of soil properties due to invasive species such as *Parthenium* are very scarce and there is an urgent need to focus on this field.

REFERENCES

Adhikari, B. and S. Tiwari. 2004. *Parthenium hysterophorus* L.: Highly invasive alien plant growing tremendously in Nepal. *Botanica Orientalis* **4**(1): 36-37.

Annapurna, C. and J. S. Singh. 2003. Variation of *Parthenium hysterophorus* in response to soil quality: implication for invasiveness. *Weed Research* **43**: 190-198.

Anonymous. 2003. *Parthenium* weed (*Parthenium hysterophorous*). Weed Management Guide. CRC Weed Management, Australia. 6p.

Anonymous. 2004. *Challenges, opportunities and strategies: Parthenium weed management*. Department of Natural Resources, Mines and Energy and Department of Primary Industries and Fisheries, The State of Queensland, Australia. vii+82p.

Anonymous. 2006. Fact of *Parthenium* weed: *Parthenium hysterophorous*. Department of Natural Resources, Mines and Water, Queensland Government, Australia. 3p. [Online: http:// www.nrm.qld.gov.au.com, Accessed on July 22nd 2006].

Bajwa, M. S., B. R. Arora, D. S. Chahal, B. D. Kansal, I. M. Chibba and C. L. Arora. 1997. *Practical Manual Soil Fertility (Soils 2001)*. Ludhiana Chapter, Indian Society of Soil Sciences, India.

Bhowmik, P. C., D. Sarkar and N. T. Yaduraju. 2007. The status of *Parthenium hysterophorous* and its management. *Ecoprint* **14**: 1-17.

Bidwell, S., P. M. Attiwill and M. A. Adams. 2006. Nitrogen availability and weed invasion in a remnant native woodland in urban Melbourne. *Australian Ecology* **31**: 262–270.

Brady, N.C. and R. R. Weil. 2002. *The Nature and Properties of Soils*. 13th addition. Pearson Education Limited, Inc., Upper Saddle River, New Jersey, U.S.A. 629p.

Chaudhary, R.P.1998. *Biodiversity in Nepal*: *Status and Conservation.* S. Devi, Saharapur, India and Craftsman Press, Bankok, Thailand. 324p.

Chetry, J. 2003. *Effects of aqueous extracts of some plants of Asteraceae on seed germination and seedling growth Vigna radiate (L.) R. Wilezek*. [M.Sc. Dissertation]. Central Department of Botany, Tribhuvan University, Kathmandu, Nepal.

Chippendale J. F. and F. D. Panetta. 1994. The cost of Parthenium weed in Australia Cattle industry. *Plant Protection Quarterly* **9**: 73-76.

Collins, A. R. 2005. *Implications of plant diversity and soil chemical properties for Congrass (Imperata cylindrica) invasion in northwest Florida* [A Graduate Thesis]. University of Florida, U.S.A. 77p.

Cunningham A. B. 2001. *Applied Ethnobotany: people, wild plant use and conservation.* A People and Plants Conservation Manual, Earthscan, London. 300p.

Dallmeir, F. (ed.). 1992. *Long term monitoring of biological diversity in tropical forest area: methods for establishment and inventory of permanent plots.* Man and biosphere Digest 11. UNESCO, Paris.

Department of Hydrology and Meteorology/GoN. 2002. *Climatological records of Nepal*. Department of Hydrology and Meterology, Government of Nepal, Kathmandu.

Department of Hydrology and Meteorology/GoN. 2003. *Climatological records of Nepal*. Department of Hydrology and Meterology (DOHM), Government of Nepal, Kathmandu.

Department of Hydrology and Meteorology/GoN. 2004. *Climatological records of Nepal*. Department of Hydrology and Meterology, Government of Nepal, Kathmandu.

Department of Hydrology and Meteorology/GoN. 2005. *Climatological records of Nepal*. Department of Hydrology and Meterology, Government of Nepal, Kathmandu.

Department of Hydrology and Meteorology/GoN. 2006. *Climatological records of Nepal*. Department of Hydrology and Meterology, Government of Nepal, Kathmandu.

Dhileepan K, S. D. Setter and R. E. McFadyen. 2000. Response the weed *Parthenium hysterophorous* (Asteraceae) to defoliation by the introduced biocontrol agent *Zygogramma bicolorata* (Coleoptera: Chrysomelidae). *Biological Control*. **19**: 9-6. [Online: http:// www.idalibrary.com, Accessed on July 10th 2006].

Duda, J. J., D. C. Freeman, J. M. Emlen, J. Belnap, K. S.G., J. C. Zak, E. Sobek, M. Tracy, and J. Montante. 2003. Differences in native soil ecology associated with invasion of the exotic annual chenopod, Halogeton glomeratus. *Biology and Fertility of Soils* **38**: 72-77.

Ehrenfeld, J. G. 2003. Effects of exotic plant invasions on soil nutrient cycling processes. *Ecosystems* **6**: 503-523.

Elton, C.S. 1958. *The Ecology of Invasions by Animals and plants*. T. Methuen and Co., London.

Evans, H. C. 1997. *Parthenium hysterophorus*: a review of its weed status and the possibilities for biological control. *Biocontrol News Information* **18** (3): 89-98.

Forman, L. and D. Bridson. 1989. *The Herbarium Handbook*. Royal Botanic Gardens, Kew.

Goyal, R. and K.P. Singh. 2003. Allelopathic effect of leaf leachates and latex of some plants on seed germination and seedling growth of *Parthenium hysterophorus* L. *Environmental Biology and Conservation* **8**: 21-33.

Hara, H. and L.H.J. Willams. 1979. *Enumeration of Flowering Plants of Nepal* **2.** British Museum (Natural History), London. 220p.

Hara, H., A.O. Chater and L.H.J. Williams. 1982. *Enumeration of Flowering Plants of Nepal* **3**. British Museum (Natural History), London. 226p.

Hara, H., W.T. Stearn and L.H.J. Williams. 1978. *Enumeration of Flowering Plants of Nepal* **1**. British Museum (Natural History), London. 152p.

Haseler, W.H. 1976. *Parthenium hysterophorus* L. in Australia. *Pest Articles and News Summaries (PANS)*. **22**: 515-517.

Hierro, J.L. and R.M. Callaway. 2003. Allelopathy and exotic plant invasion. *Plant and Soil* **256**: 29-39.

Joshi, S. 2005. *Reproductive Efficiency and Biomass Allocation of Invasive weed, Parthenium hysterophorus* L. [M.Sc. Dissertation]. Central Department of Botany, Tribhuvan University, Kathmandu, Nepal. 69p.

Joshi, S. 1991. Interference effects of *Cassia uniflora* Mill on *Parthenium hysterophorous* L. *Plant and Soil* **132**: 213-218.

Kathiresan, R.M., I. Gnanavel, R. Anbhazhagan, S.P. Padmaria, N.K. Vijayalakshmi and M.P. Arulchezhian. 2005. Ecology and control of *Parthenium* invasion in command area. In: Proceedings of Second International Conference on *Parthenium* Management, Bangalore, India. Pp 77-80.

Kathiresan R.M. 2004. Invasive weeds in agro-ecosystems of South India [Abstracts]. In: *National Workshop on Invasive Alien species and Biodiversity in India*, Banaras Hindu University, Vanarasi, India. 149p.

Kloot, P. M. 1987. The invasion of Kangaroo Island by alien plants. *Australian Journal of Ecology* **12**: 263–266.

Kohli, R. K. and D. Rani. 1994. *Parthenium hysterophorus*-a review. *Research Bulletin (Science)* (Panjab University) **44**:105-149.

Kunwar, R. M. 2003. Invasive alien plants and *Eupatorium*: Biodiversity and livelihood. *Himalayan Journal of Sciences* **1** (2): 129-133.

Mahadevappa, M. 1997. Ecology, distribution, menace and management of parthenium. In: *Proceedings of the 1st International Conference on Parthenium Management;* Karnataka, India, October 6–8, 1997. University of Agricultural Sciences, Dahrwad.

Maharjan, S. 2006. *Phenology, leaf attributes and allelopathic potential of Parthenium hysterophorus L., a highly allergic, invasive weed in Kathmandu valley* [M.Sc. Dissertation]. Central Department of Botany, Tribhuvan University, Kathmandu, Nepal. 59p.

Maharjan, S., B. B. Shrestha and P. K. Jha. 2007. Allelopathic effect of aqueous extract of leaves of *Parthenium hysterophorus* L. on seed germination and seedling growth of some cultivated and wild herbaceous species. *Scientific World* **5**(5): 33-39.

Martin, G. J. 1995. *Ethnobotany: A People and Plants Conservation Manual.* Chapman and Hall, London. xxiv+268p.

McFadyen, R.E. 1992. Biological control against *Parthenium* weed in Australia. *Crop Protection* **11**: 400-407.

Medhin, B. G. 1992. *Parthenium hysterophorus*: a new weed problem in Ethiopia. FAO *Plant Protection Bulletin* **40**: 49.

Melbourne, B. A., H. V. Cornell, K. F. Davies, C. J. Dugaw, S. Elmedorf, A. L. Freestone, R. J. Hall, S. Hrrison, A. Hastings, M. Holland, M. Holyoak, J. Lambrinos, K, Moore and H. Yokomizo. 2007. Invasion in a heterogerous world: resistance, coexistance or hostile takeover? *Ecology Letters* **10**: 77-94.

Mishra, K. K. 1991. *Parthenium hysterophorus* Linn. A new record for Nepal. *Journal of Bambay Natural History Society* **88**: 466-467.

Pradhan, S. B. 1996. *Soil and Plant Analysis Manual*. Nepal Agricultural Research Council (NARC), Khumaltar, Lalitpur, Nepal.

Navie, S. C., R. E. McFadyen, F. D. Panetta and S. W. Adkins. 1996. The biology of Australian weeds 27. *Parthenium hyterophorous* L. *Plant Protection Quaterly* **11**: 76-88.

O' Donnell, C. and S.W. Adkins. 2005. Management of Parthenium weed through competitive displacement with beneficial plants. *Weed Biology and Management* **5**: 77-79.

Olsen, S.R., C.V. Cole, F.S. Watanabe and L.A. Dean. 1954. Estimation of available phosphorus by extraction with sodium carbonate. U.S. Department Agriculture Circulation.

Oudhia, P. 2000a. Allelopathic effect of some obnoxious weeds on germination of soybean. *Indian Journal of Plant Physiology* **5**(3): 295-296.

Oudhia, P. 2000b. Allelopathic effects *Parthenium hysterophorus* and *Ageratum conyzoides* on wheat var. sujata. *Crop Research* (Hisar) **20**(3): 563-566.

Oudhia, P. 2001. Phyto-sociological studies of rainy season wasteland weeds with special reference to *Parthenium hysterophorus* L. in Raipur (Inida) district. *Asian Journal of Microbiology, Biotechnology and Environmental Sciences* **3**(1-2): 89-92.

Peng, C. I., L. A. Hu and M. T. Kao. 1988. Unwelcome naturalisation of *Parthenium hysterophorous* (Asteraceae) in Tiwan. *Journal of Tiwan Museum* **41**: 95-101.

Pickard, J. 1984. Exotic plants on Lord Howe Island: distribution in space and time, 1853–1981. *Journal of Biogeography* **11**: 181–208.

Picman, J. and A. K. Picman. 1984. Autotoxicity in *Parthenium hysterophorus* and its possible role in control of germination. *Biochemistry, Systematics and Ecology* **12**: 287 - 297.

Pimental, D., L. Lach, R. Zuniga and D. Morrison. 2000. Environmental and economic costs of non-indigenous species in the United States. *Bioscience* 50: 53-65.

Polunin, O. and Stainton, A. 1984. *Flowers of the Himalaya.* Oxford University Press. India. 580p.

Press, J. R., K. K. Shrestha and D. A. Sutton. 2000. *Annotated checklist of flowering plants of Nepal*. The Natural History Museum, London. x+430p.

Raghubanshi. A. L., L. Rai, J. P. Gaur and J. S. Shing. 2005. Invasive allien species and biodiversity in India. *Current Sciences* **88** (4): 539-540.

Rajendiran, K. 2005. Mitodepressive effects of aqueous extracts of *Parthenium hysterophorus* L. on *Vigna radiate* (L) Wilczek. *Geobios* **32**(4): 237-240.

Shabbir, A. 2002. *Parthenium hysterophorus* L. *An exotic weed threatening agricultural lands and biodiversity of Islamabad and adjoining districts* [Masters thesis]. University of the Panjab. Lahore, India.

Shabbir, A. and R. Bajwa. 2006. Distribution of Pathenium weed (*Parthenium hysterophorus* L.), an alien invasive weed species threatening the biodiversity of Islamabad. *Weed Biology and Management* **6**: 89-95.

Singh, H.B., D.R. Batish, J.K. Pandher and R.K. Kohli. 2003. Assessment of allelopathic properties of *Parthenium hysterophorus* residues. *Agricultural Ecosystem and Environment* **95(**2-3): 537-541.

Singh, H. P., D.R. Batish, J.K. Pandher and R.K. Kohli 2005a. Phytotoxic effects of *Parthenium hysterophorus* residues on three *Brassica* species. *Weed Biology and Management* **5:** 105-109.

Singh, H.P., D.R. Batish, N. Setia and R.K. Kohli 2005b. Herbicidal activity of volatile oils from *Eucalyptus citriodora* against *Parthenium hysterophorus*. *Annals of Applied Biology* **146**: 89-94.

Singh, H.P., D.R. Batish, R.K. Kohli, D.B. Saxena and V. Arora. 2002. Effect of pathenin - A sesquiterpene lactone from *Parthenium hysterophorus* – on early growth and physiology of *Ageratum conyzoides*. *Journal of Chemical Ecology* **28**(11): 2169-2179.

Sinha, P. and P.M. Deo. 1999. Allelopathic effects of *Parthenium* root extracts on germination and early seedling growth of Kidney bean (*Phaseolus vulgaris* L.) *Geobios* **26**(2-3): 127-130.

Stainton, A., 1988. *Flowers of Himalaya*: *a supplement*. Oxford University Press, India. xi+86p.

Tamado, T. and P. Milberg 2000. Weed flora in arable fields of eastern Ethiopia with emphasis on the occurrence of *Parthenium hysterophorus*. *Weed Research* **40**: 507-521.

Tamado, T., W. Schultz and P. Milberg. 2002. Germination ecology of the weed *Parthenium hysterophorus* in eastern Ethopia. *Annals of Applied Biology* **140**: 263-270.

Tiwari, S., B. Adhikari, M. Siwakoti and K. Subedi. 2005. *An Inventory and Assessment of Invasive Alien Plant Species of Nepal*. IUCN – The world Conservation Union, Nepal. 115p.

Wondimagegnehu, M. and M. Singh. 1987. Allelopathic effects of *Parthenium* (*Parthenium hysterophorus* L.) extract and residue on some agronomic crops and weeds. *Journal of Chemical Ecology (Historical Archive)* **13**(7): 1739-1747.

Yadav, A. and S.V.S. Chauhan. 1998. Studies on allelopathic effect of some weeds. *Journal of Phytological Research* **11**(1): 15-18.

Yaduraju, N. T., P. C. Bhowmik and S. Kushwala. 2000. The potential threat of alien weeds to agriculture and environment. In: Jha, P.K., S.B. Karmacharya, S.R.Baral and P. Lacoul (eds.). *Environment and agriculture*: *At the crossroad of the New Millennium*. Ecological Society (ECOS), Nepal. Pp 229-234.

Yatsu, Y., N. Kachi and H. Kudoh. 2003. Ecological distribution and phenology of an invasive species, *Cardamine hirusta* L., and its native counterpart, *Cardamine flexuosa* With. in central Japan. *Plant Species Biology* **18**:35-42.

Zobel, D.B., P.K. Jha, M.J. Behan and U.K.R. Yadav. 1987. *A practical Manual for Ecology*. Ratna Pustak Distributors, Kathmandu, Nepal. 149p.

APPENDICES

Appendix 1a. Values of density, frequency, coverage, relative density, relative frequency, relative coverage and importance percent (IP) of all plant species in *Parthenium hysterophorus* L. non-invaded plots (position 1) of Gorkha site.

S.N.	Name of Species	Density	Frequency	Coverage	Relative Density	Relative Frequency	Relative Coverage	IP
1	Acrachne racemosa (Heyne) Ohwi	57.6	50	30.75	29.16	10	30.92	23.36
2	Imperata sp.	40.4	50	22.55	20.45	10	22.67	17.7
3	Trifolium repens L.	29	70	13.75	14.68	14	13.82	14.16
4	Chrysopogan aciculatus (Retz.) Trin.	20.7	80	10.75	10.48	16	10.8	12.42
5	Oplismenus sp.	32	10	8.5	16.2	2	8.54	8.91
6	Euphorbia hirta L.	5	60	3.6	2.53	12	3.6	6.04
7	Cassia tora L.	4.1	50	3.55	2.07	10	3.56	5.21
8	Mimosa pudica L.	3.1	30	3.25	1.56	6	3.26	3.6
9	Sida rhombifolia L.	3	30	1.8	1.51	6	1.8	3.1
10	Parthenium hysterophorus L.	0.5	30	0.15	0.25	6	0.15	2.13
11	Ageratum conyzoides L.	1	10	0.25	0.5	2	0.25	0.91
12	Cynodon dactylon (L.) Pers.	0.5	10	0.25	0.25	2	0.25	0.83
13	Aconogonum sp.	0.5	10	0.25	0.25	2	0.25	0.83
14	Cyperus sp.	0.1	10	0.05	0.05	2	0.05	0.7
Total		197.5		99.45	99.94	100	99.92	99.9

Appendix 1b. Values of density, frequency, coverage, relative density, relative frequency, relative coverage and importance percent (IP) of all plant species in *Parthenium hysterophorus* L. non-invaded plots (position 2) of Gorkha site.

S.N.	Name of Species	Density	Frequency	Coverage	Relative Density	Relative Frequency	Relative Coverage	IP
1	Acrachne racemosa (Heyne) Ohwi	63.5	60	34.75	36.34	9.52	30.03	25.29
2	Imperata sp.	46.9	80	29.25	26.84	12.69	25.28	21.6
3	Chrysopogan aciculatus (Retz.) Trin.	17.3	90	10.25	9.9	14.28	8.85	11.01
4	Trifolium repens L.	22.6	60	11.25	12.93	9.52	9.72	10.72
5	Cassia tora L.	4.3	80	6.6	2.46	12.69	5.7	6.95
6	Ageratum conyzoides L.	5.9	40	10.3	3.37	6.34	8.9	6.2
7	Euphorbia hirta L.	4.2	50	3.75	2.4	7.93	4.32	4.88
8	Mimosa pudica L.	4.2	50	4.8	2.4	7.93	4.14	4.82
9	Parthenium hysterophorus L.	0.5	40	0.2	0.28	6.34	0.17	2.26
10	Sida rhombifolia L.	1.1	20	1.55	0.62	3.17	1.33	1.7
11	Setaria glauca (L.) P. Beauv.	3	10	1.5	1.71	1.58	1.29	1.52
12	Cynodon dactylon (L.) Pers.	1.2	10	1.5	0.68	1.58	1.29	1.18
Total		174.7		115.7	99.93	93.57	101.02	98.13

Appendix 1c. Values of density, frequency, coverage, relative density, relative frequency, relative coverage and importance percent of (IP) all plant species in *Parthenium hysterophorus* L. transition plots (position 3) of Gorkha site.

S.N.	Name of Species	Density	Frequency	Coverage	Relative Density	Relative Frequency	Relative Coverage	IP
1	Trifolium repens L.	27.2	60	18.25	24.81	9.67	16.55	17.01
2	Parthenium hysterophorus L.	15.6	100	21	14.23	16.12	19	16.45
3	Imperata sp.	20.7	60	18.25	18.88	9.67	16.55	15.03
4	Acrachne racemosa (Heyne) Ohwi	7.6	30	13.75	6.93	4.83	12.47	8.07
5	Mimosa pudica L.	6.2	60	7.75	5.65	9.67	7.2	7.44
6	Chrysopogan aciculatus (Retz.) Trin.	8	50	6.25	7.29	8.06	5.66	7
7	Euphorbia hirta L.	3.7	50	3.75	3.37	8.06	3.4	4.94
8	Oplismenus sp.	4.1	30	6.75	3.74	4.83	6.12	4.89
9	Ageratum conyzoides L.	4.2	30	4.5	3.83	4.83	4.08	4.24
10	Sida rhombifolia L.	4.3	40	2.25	3.92	6.45	2.04	4.13
11	Cassia tora L.	2.4	40	2.25	2.18	6.45	2.04	3.55
12	Cynodon dactylon (L.) Pers.	2.5	20	3	2.28	3.22	2.72	2.74
13	Bidens pilosa var. minor (Blume) Sherff	0.9	10	1.5	0.82	1.61	1.36	1.26
14	Setaria glauca (L.) P. Beauv.	0.9	10	0.25	0.82	1.61	0.22	0.88
15	Hydrocotyle sp.	0.6	10	0.25	0.54	1.61	0.22	0.79
16	Oxalis corniculata L.	0.5	10	0.25	0.45	1.61	0.22	0.76
17	Dioscorea bulbifera L.	0.2	10	0.25	0.18	1.61	0.22	0.22
Total		109.6		110.25	99.92	99.91	100.07	99.4

Appendix 1d. Values of density, frequency, coverage, relative density, relative frequency, relative coverage and importance percent (IP) of all plant species in *Parthenium hysterophorus* L. invaded plots (position 4) of Gorkha site.

S.N.	Name of Species	Density	Frequency	Coverage	Relative Density	Relative Frequency	Relative Coverage	IP
1	Parthenium hysterophorus L.	32	100	47.5	29.96	15.62	40.08	28.55
2	Acrachne racemosa (Heyne) Ohwi	17.2	40	20.25	16.1	6.25	17.8	13.14
3	Oplismenus sp.	10.7	40	13	10.01	6.25	10.97	9.07
4	Chrysopogan aciculatus (Retz.) Trin.	11.2	50	5	10.48	7.81	4.21	7.5
5	Imperata sp.	1.6	60	10	1.49	9.37	8.43	6.43
6	Euphorbia hirta L.	6.4	60	3.8	5.99	9.37	3.2	6.18
7	Trifolium repens L.	7.4	40	6	6.92	6.25	5.06	6.07
8	Cynodon dactylon (L.) Pers.	4.9	40	6	4.58	6.25	5.06	5.29
9	Sida rhombifolia L.	2.5	60	0.9	2.34	9.37	0.75	4.15
10	Mimosa pudica L.	4.3	40	1	4.02	6.25	0.84	3.7
11	Cassia tora L.	2.6	40	2.05	2.43	6.25	1.72	3.46
12	Commelina bengalesis L.	1	20	1.75	0.93	3.12	1.47	1.84
13	Setaria glauca (L.) P. Beauv.	1.6	20	0.5	1.49	3.12	0.42	1.67
14	Ageratum conyzoides L.	1.4	20	0.5	1.31	3.12	0.42	1.61
15	Dioscorea bulbifera L.	0.2	10	0.25	0.18	1.56	0.21	0.65
Total		105		118.5	98.23	99.96	100.64	99.31

Appendix 1e. Values of density, frequency, coverage, relative density, relative frequency, relative coverage and importance percent (IP) of all plant species in *Parthenium hysterophorus* L. invaded plots (position 5) of Gorkha site.

S.N.	Name of Species	Density	Frequency	Coverage	Relative Density	Relative Frequency	Relative Coverage	IP
1	Parthenium hysterophorus L.	38	100	54.75	33.71	15.38	51.62	33.57
2	Imperata sp.	28.4	80	13.5	25.19	12.3	12.75	16.74
3	Mimosa pudica L.	5.5	70	5.75	4.88	10.76	5.42	7.02
4	Trifolium repens L.	8.3	40	6	7.36	6.15	5.65	6.38
5	Chrysopogan aciculatus (Retz.) Trin.	7.5	50	3.75	6.65	7.69	3.53	5.95
6	Euphorbia hirta L.	5.1	70	1.75	4.52	10.76	1.65	5.64
7	Cassia tora L.	3.6	60	4	3.19	9.23	3.77	5.39
8	Cynodon dactylon (L.) Pers.	3.9	30	4.5	3.46	4.61	4.24	4.1
9	Sida rhombifolia L.	2.1	40	1	1.86	6.15	0.94	2.98
10	Setaria glauca (L.) P. Beauv.	1.9	30	2	1.68	4.61	1.88	2.72
11	Acrachne racemosa (Heyne) Ohwi	2.8	10	3.75	2.48	1.53	3.53	2.51
12	Oplismenus sp.	3	20	1.75	2.66	3.07	1.65	2.46
13	Ageratum conyzoides L.	0.9	20	1.55	0.79	3.07	1.46	1.77
14	Bidens pilosa var. minor (Blume) Sherff	0.6	10	1.5	0.53	1.53	1.41	1.15
15	Aconogonum sp.	0.9	10	0.25	0.79	1.53	0.23	0.85
16	Commelina benghalensis L.	0.2	10	0.25	0.17	1.53	0.23	0.64
Total		112.7		106.05	99.92	99.9	99.96	99.87

Appendix 2a. Values of density, frequency, coverage, relative density, relative frequency, relative coverage and importance percent (IP) of all plant species in *Parthenium hysterophorus* L. non-invaded plots (Position 1) of Nuwakot site.

S.N.	Name of Species	Density	Frequency	Coverage	Relative Density	Relative Frequency	Relative Coverage	IP
1	Acrachne racemosa (Heyne) Ohwi	98.8	80	42.25	41.91	15.09	40.18	32.29
2	Imperata sp.	61.5	40	21.5	26.09	7.54	20.44	18.02
3	Trifolium repens L.	34.4	40	15.25	14.59	7.54	14.5	12.21
4	Oplismenus sp.	9.4	40	3.3	3.98	7.54	3.13	4.88
5	Hyptis suaveolens (L.) Poit	5.6	30	6.75	2.37	5.66	6.41	4.81
6	Mimosa pudica L.	3.8	50	3.35	1.61	9.43	3.18	4.74
7	Cyperus sp.1	3.5	50	2.3	1.48	9.43	2.18	4.36
8	Conyza sp.	3.7	40	2.25	1.56	7.54	2.13	3.74
9	Cassia tora L.	1.4	40	0.6	0.59	7.54	0.57	2.9
10	Chrysopogan aciculatus (Retz.) Trin.	2.3	20	1.75	0.97	3.77	1.66	2.13
11	Cynodon dactylon (L.) Pers.	4.8	10	1.5	2.03	1.88	1.42	1.77
12	Ageratum conyzoides L.	1.2	20	0.5	0.59	3.77	0.47	1.61
13	Ipomoea sp.	1.2	20	0.5	0.59	3.77	0.47	1.61
14	Aerva sp.	1	20	0.3	0.42	3.77	0.28	1.46
15	Spilanthus sinensis var. amoena H.Hara	1.8	10	1.5	0.76	1.88	1.42	1.35
16	Euphorbia hirta L.	1.1	10	1.5	0.46	1.88	1.42	1.25
17	Solanum surattense Burm.f.	0.2	1	0.05	0.08	1.88	0.04	0.66
Total		235.7		105.15	100.08	99.91	99.9	99.79

Appendix 2b. Values of density, frequency, coverage, relative density, relative frequency, relative coverage and importance percent (IP) of all plant species in *Parthenium hysterophorus* L. non-invaded plots (Position 2) of Nuwakot site.

S.N.	Name of Species	Density	Frequency	Coverage	Relative Density	Relative Frequency	Relative Coverage	IP
1	Oplismenus sp.	68.9	50	34.25	35.92	9.43	30.56	25.3
2	Imperata sp.	41	60	24	21.37	11.32	21.41	18.03
3	Trifolium repens L.	34.5	4	20	17.98	7.54	17.84	14.45
4	Acrachne racemosa (Heyne) Ohwi	14.1	50	9.75	7.35	9.43	8.7	8.49
5	Mimosa pudica L.	4.5	70	2.8	2.34	13.2	2.49	6.01
6	Hyptis suaveolens (L.) Poit	6.3	40	4.55	3.28	7.54	4.06	4.96
7	Parthenium hysterophorus L.	1.7	60	1.1	0.88	11.32	0.98	4.39
8	Cassia tora L.	2.2	40	2.05	1.14	7.54	1.82	3.5
9	Chrysopogan aciculatus (Retz.) Trin.	4.1	20	3	2.13	3.77	2.67	2.85
10	Setaria glauca (L.) P. Beauv.	5.8	10	3.75	3.02	1.88	3.34	2.74
11	Ageratum conyzoides L.	1.7	30	1.8	0.88	5.66	1.6	2.71
12	Euphorbia hirta L.	0.8	20	1.75	0.41	3.77	1.56	1.91
13	Cynodon dactylon (L.) Pers.	2.8	10	1.5	1.48	1.88	1.33	1.56
14	Conyza sp.	2.6	10	1.5	1.35	1.88	1.33	1.52
15	Aerva sp.	0.8	20	0.25	0.41	3.77	0.22	1.46
Total		191.8		112.05	99.94	99.93	99.91	

Appendix 2c. Values of density, frequency, coverage, relative density, relative frequency, relative coverage and importance percent (IP) of all plant species in *Parthenium hysterophorus* L. transition plots (Position 3) of Nuwakot site.

S.N.	Name of Species	Density	Frequency	Coverage	Relative Density	Relative Frequency	Relative Coverage	IP
1	Acrachne racemosa (Heyne) Ohwi	39.2	70	19.5	32.9	12.06	17.52	20.82
2	Parthenium hysterophorus L.	11.1	100	37.5	9.31	17.24	33.7	20.08
3	Imperata sp.	30.5	70	15	25.6	12.06	13.48	17.04
4	Oplismenus sp.	15.2	40	15.25	12.76	6.89	13.7	11.11
5	Mimosa pudica L.	3.2	60	6.1	2.68	10.34	5.48	6.16
6	Cassia tora L.	2.8	70	3.85	2.35	12.06	3.46	5.95
7	Ageratum conyzoides L.	3	40	2.25	2.51	6.89	2.02	3.8
8	Aerva sp.	3.7	20	3	3.1	3.44	2.69	3.07
9	Hyptis suaveolens (L.) Poit	2.5	30	2	2.09	5.17	1.79	3.01
10	Setaria glauca (L.) P. Beauv.	3.7	20	1.75	3.1	3.44	1.57	2.7
11	Trifolium repens L.	1.5	10	1.5	1.25	1.72	1.34	1.43
12	Evolvulus nummularis (L.) L.	1	10	1.5	0.83	1.72	1.34	1.29
13	Cyperus sp.1	0.6	10	1.5	0.5	1.72	1.34	1.18
14	Ipomoea sp.	0.7	10	0.25	0.58	1.72	0.22	0.84
15	Euphorbia hirta L.	0.2	10	0.25	0.16	1.72	0.22	0.7
16	Solanum surattense Burm.f.	0.1	10	0.05	0.08	1.72	0.04	0.61
Total		119		111.25	99.8	99.91	99.91	99.79

Appendix 2d. Values of density, frequency, coverage, relative density, relative frequency, relative coverage and importance percent (IP) of all plant species in *Parthenium hysterophorus* L. invaded plots (Position 4) of Nuwakot site.

S.N.	Name of Species	Density	Frequency	Coverage	Relative Density	Relative Frequency	Relative Coverage	IP
1	Parthenium hysterophorus L.	20.09	100	37.5	19.36	17.54	36.05	24.31
2	Acrachne racemosa (Heyne) Ohwi	28.8	80	18.75	26.69	14.03	18.02	19.58
3	Imperata sp.	14.9	70	11.3	13.8	12.28	10.86	12.31
4	Oplismenus sp.	15.5	50	7.5	14.36	8.77	7.21	10.11
5	Mimosa pudica L.	6.3	80	9.05	5.83	14.03	8.7	9.52
6	Cassia tora L.	5.6	70	8	5.18	12.28	7.69	8.38
7	Hyptis suaveolens (L.) Poit	6.7	40	3.5	6.2	7.01	3.36	5.52
8	Cynodon dactylon (L.) Pers.	4.2	20	3	3.89	3.5	2.88	3.42
9	Aerva sp.	3.2	30	3.25	2.96	5.26	3.12	2.78
10	Sida rhombifolia L.	0.4	30	0.15	0.37	5.26	0.14	1.92
11	Solanum surattense Burm.f.	0.1	10	1.5	0.09	1.75	1.44	1.09
12	Ageratum conyzoides L.	0.7	10	0.25	0.64	1.75	0.24	0.87
13	Euphorbia hirta L.	0.6	10	0.25	0.55	1.75	0.24	0.84
Total		107.09		104	99.92	105.21	99.95	100.65

Appendix 2e. Values of density, frequency, coverage, relative density, relative frequency, relative coverage and importance percent (IP) of all plant species in *Parthenium hysterophorus* L. invaded plots (Position 5) of Nuwakot site.

S.N.	Name of Species	Density	Frequency	Coverage	Relative Density	Relative Frequency	Relative Coverage	IP
1	Parthenium hysterophorus L.	28.8	100	71.5	35.46	17.8	66.79	40.01
2	Oplismenus sp.	15.3	70	9.25	18.84	12.5	8.64	13.32
3	Imperata sp.	10.6	80	6.8	13.05	14.28	6.35	11.22
4	Mimosa pudica L.	6.3	80	5.75	7.75	14.28	5.37	9.13
5	Cassia tora L.	5.2	60	6.5	6.4	10.71	6.07	7.72
6	Acrachne racemosa (Heyne) Ohwi	5.6	50	3.75	6.89	8.92	3.5	6.43
7	Ageratum conyzoides L.	3.2	40	1.25	3.94	7.14	1.16	4.08
8	Trifolium repens L.	4.5	10	1.5	5.54	1.78	1.4	2.9
9	Sida rhombifolia L.	0.4	30	0.15	0.49	5.35	0.14	1.99
10	Euphorbia hirta L.	0.7	10	0.25	0.86	1.78	0.23	0.95
11	Aconogonum sp.	0.3	10	0.25	0.36	1.78	0.23	0.79
12	Ipomoea sp.	0.2	10	0.05	0.24	1.78	0.04	0.68
13	Bidens pilosa var. minor (Blume) Sherff	0.1	10	0.05	0.12	1.78	0.04	0.64
Total		81.2		107.05	99.94	99.88	99.96	99.86

Appendix 3a. Values of density, frequency, coverage, relative density, relative frequency, relative coverage and importance percent (IP) of all plant species in *Parthenium hysterophorus* L. non-invaded plots (Position 1) of Kathmandu site.

S.N.	Name of Species	Density	Frequency	Coverage	Relative Density	Relative Frequency	Relative Coverage	IP
1	Acrachne racemosa (Heyne) Ohwi	77.3	50	33.25	48.64	13.15	31.11	30.96
2	Sporobolus sp.	7.1	70	33.5	4.46	18.42	31.45	18.11
3	Dactyloctenium aegypticum (L.) P. Beauv.	34.7	70	9	21.83	18.42	8.42	16.22
4	Parthenium hysterophorus L.	13.7	40	4.75	8.62	10.52	4.44	7.86
5	Xanthium strumarium L.	3.3	40	8.05	2.07	10.52	7.53	6.7
6	Eragrostis pilosa (L.) P. Beauv	6.1	30	6.25	3.83	7.89	6.31	6.01
7	Setaria glauca (L.) P. Beauv.	3.1	30	3.05	1.95	7.89	2.85	4.23
8	Cyperus sp.1	4.2	20	1.75	2.64	5.26	1.63	3.17
9	Hydrocotyle sp.	5	10	3.75	3.14	2.63	3.5	3.09
10	Cyperus sp.2	3.2	10	1.5	2.01	2.63	1.4	2.01
11	Oplismenus sp.	1.2	10	1.5	0.75	2.63	1.4	1.59
Total		158.9		106.35	99.94	99.96	100.04	99.95

Appendix 3b. Values of density, frequency, coverage, relative density, relative frequency, relative coverage and importance percent (IP) of all plant species in *Parthenium hysterophorus* L. non-invaded plots (Position 2) of Kathmandu site.

S.N.	Name of Species	Density	Frequency	Coverage	Relative Density	Relative Frequency	Relative Coverage	IP
1	Acrachne racemosa (Heyne) Ohwi	41.6	60	22.75	29.46	11.11	21.54	20.7
2	Sporobolus sp.	27	70	20.75	19.12	12.96	19.64	17.24
3	Trifolium repens L.	24	90	12.25	16.99	16.66	11.6	15.08
4	Xanthium strumarium L.	4.1	40	19	2.9	7.4	17.99	9.43
5	Setaria glauca (L.) P. Beauv.	9.1	60	4.8	6.44	11.11	4.54	7.36
6	Eragrostis pilosa (L.) P. Beauv	6.1	30	9	4.32	5.55	8.52	6.13
7	Dactyloctenium aegypticum (L.) P. Beauv.	5.8	40	4.55	4.1	7.4	4.3	5.26
8	Cyperus sp.1	4.2	30	3.25	2.97	5.55	3.07	3.86
9	Drymeria cordata (L.) Wild. Ex Roem. and Schult	9	10	1.5	6.37	1.85	1.42	3.21
10	Brachiaria sp.	5.8	10	3.75	4.1	1.85	3.55	3.16
11	Parthenium hysterophorus L.	0.8	40	0.4	0.56	7.4	0.37	2.77
12	Hydrocotyle sp.	2.7	20	1.55	1.91	3.7	1.46	2.35
13	Oplismenus sp.	0.7	20	1.75	0.49	3.7	1.65	1.94
14	Oxalis corniculata L.	0.2	10	0.25	0.14	1.85	0.23	0.74
15	Ageratum conyzoides L.	0.1	10	0.05	0.07	1.85	0.04	0.65
Total		141.2		105.6	99.94	99.94	99.92	99.88

Appendix 3c. Values of density, frequency, coverage, relative density, relative frequency, relative coverage and importance percent (IP) of all plant species in *Parthenium hysterophorus* L. transition plots (Position 3) of Kathmandu site.

S.N.	Name of Species	Density	Frequency	Coverage	Relative Density	Relative Frequency	Relative Coverage	IP
1	Parthenium hysterophorus L.	8.8	100	30.75	8.63	19.6	30.28	19.5
2	Acrachne racemosa (Heyne) Ohwi	30.8	50	12	30.22	9.8	11.81	17.27
3	Xanthium strumarium L.	7.9	100	20.05	7.75	19.6	19.74	15.69
4	Trifolium repens L.	23.2	60	7.75	22.76	11.76	7.63	14.05
5	Eragrostis pilosa (L.) P. Beauv	10.5	50	9.75	10.3	9.8	9.6	9.9
6	Sporobolus sp.	8.3	50	6.25	8.14	9.8	6.15	8.03
7	Cynodon dactylon (L.) Pers.	5	30	4.5	4.9	5.88	4.43	5.07
8	Setaria glauca (L.) P. Beauv.	2.9	20	3	2.84	3.92	2.95	3.23
9	Dactyloctenium aegypticum (L.) P. Beauv.	2.7	20	3	2.64	3.92	2.95	3.17
10	Chrysopogan aciculatus (Retz.) Trin.	1.2	10	1.5	1.17	1.96	1.47	1.53
11	Oxalis corniculata L.	0.5	10	1.5	0.49	1.96	1.47	1.3
12	Bidens pilosa var. minor (Blume) Sherff	0.1	10	1.5	0.09	1.96	1.47	1.17
Total		101.9		101.55	99.93	99.96	99.95	99.91

Appendix 3d. Values of density, frequency, coverage, relative density, relative frequency, relative coverage and importance percent (IP) of all plant species in *Parthenium hysterophorus* L. invaded plots (Position 4) of Kathmandu site.

S.N.	Name of Species	Density	Frequency	Coverage	Relative Density	Relative Frequency	Relative Coverage	IP
1	Parthenium hysterophorus L.	18.3	100	43.75	27.31	20.83	38.56	28.9
2	Xanthium strumarium L.	5	70	12.5	7.46	14.58	11.01	11.01
3	Sporobolus sp.	8.6	40	9.25	12.83	8.33	8.15	9.77
4	Acrachne racemosa (Heyne) Ohwi	6.8	40	10.5	10.14	8.33	9.25	9.24
5	Cynodon dactylon (L.) Pers.	8.8	40	6	13.13	8.33	5.28	8.91
6	Setaria glauca (L.) P. Beauv.	5	40	4.75	7.46	8.33	4.18	6.65
7	Eragrostis pilosa (L.) P. Beauv	7.1	30	3.05	10.59	6.25	2.68	6.5
8	Brachiaria sp.	0.8	10	12.5	1.19	2.08	11.01	4.76
9	Dactyloctenium aegypticum (L.) P. Beauv.	3.4	30	3.25	5.07	6.25	2.86	4.72
10	Sida rhombifolia L.	0.4	40	1.65	0.59	8.33	1.45	3.45
11	Trifolium repens L.	2	10	3	2.98	2.08	2.64	2.56
12	Bidens pilosa var. minor (Blume) Sherff	0.5	20	1.75	0.74	4.16	1.54	2.14
13	Hyptis suaveolens (L.) Poit	0.3	10	1.5	0.44	2.08	1.32	1.28
Total		65	470	110.45	96.95	97.88	97.29	97.33

Appendix 3e. Values of density, frequency, coverage, relative density, relative frequency, relative coverage and importance percent (IP) of all plant species in *Parthenium hysterophorus* L. invaded plots (Position 5) of Kathmandu site.

S.N.	Name of Species	Density	Frequency	Coverage	Relative Density	Relative Frequency	Relative Coverage	IP
1	Parthenium hysterophorus L.	25.7	100	78.25	32.53	21.27	76.19	43.33
2	Dactyloctenium aegypticum (L.) P. Beauv.	6.1	60	10	7.72	12.76	9.73	10.07
3	Cynodon dactylon (L.) Pers.	11.2	60	4	14.17	12.76	0.85	9.26
4	Acrachne racemosa (Heyne) Ohwi	13.5	30	3.25	17.08	6.38	3.16	8.87
5	Trifolium repens L.	7.4	40	1	9.36	8.51	0.21	6.02
6	Eragrostis pilosa (L.) P. Beauv.	3.9	50	2.5	4.93	10.63	2.43	5.99
7	Setaria glauca (L.) P. Beauv.	4.1	30	2	5.18	6.38	1.94	4.5
8	Oplismenus sp.	1.8	20	0.5	2.27	4.25	0.1	2.2
9	Alternanthera sp.	2	10	0.25	2.53	2.12	0.24	1.63
10	Drymeria cordata (L.) Wild. Ex Roem. and Schult	1.3	10	0.25	1.64	2.12	0.24	1.33
11	Oxalis corniculata L.	1.1	10	0.25	1.39	2.12	0.24	1.25
12	Sporobolus sp.	0.4	10	0.25	0.5	2.12	0.24	0.95
13	Bidens pilosa var. minor (Blume) Sherff	0.2	10	0.05	0.25	2.12	0.04	0.8
14	Justicia sp.	0.1	10	0.05	0.12	2.12	0.04	0.76
15	Sida rhombifolia L.	0.1	10	0.05	0.12	2.12	0.04	0.76
16	Xanthium strumarium L.	0.1	10	0.05	0.12	2.12	0.04	0.76
Total		79		102.7	99.91	99.9	95.73	98.48

Appendix 4a: pH categories of Soil.

Categories	pH
Strongly acidic	<4.5
Moderately acidic	4.6-5.5
Slightly acidic	5.6-6.5
Nearly neutral	6.6-7.5
Moderately alkaline	7.6-8.5
Strongly alkaline	>8.5

Appendix 4b: Nutrient rating of soil.

Nutrient Status	Organic matter (%)	Total nitrogen (%)	Available P_2O_5 (Kg/ha)	Available K_2O (Kg/ha)
Very low	<0.75	<0.03	<10	<55
Low	0.75-1.5	0.03-0.07	10-30	55-110
Medium	1.5-3.0	0.07-.015	30-55	110-280
High	3.0-5.0	0.15-0.25	55-110	280-500
Very high	>5	>0.25	>110	>500

Appendix 4c: Texture classes of soils.

Soil classes or Textual Names	Range in relative percentage of soil		
	Sand	Silt	Clay
Sandy soil	85-100	0-15	0-10
Loamy sand	70-90	0-30	0-15
Sandy loam	43-80	0-50	0-20
Loam	23-52	28-50	7-27
Silt loam	0-52	50-88	0-27
Silt	0-20	8-10	0-12
Sandy clay loam	45-80	0-28	20-35
Clay loam	20-45	15-53	27-40
Silty clay loam	0-20	40-73	27-40
Sandy clay	45-65	0-20	35-45
Silt clay	0-20	40-60	40-60
Clay	0-45	0-40	40-100

Appendix 5a: Climatological data on maximum-minimum Temperature and Rainfall of Khaireni weather station, Tanahun from 2002-2006.

Months	Maximum Temperature	Minimum Temperature	Rainfall
January	13.0	7.1	18.2
February	15.2	9.0	46.2
March	24.0	11.2	48.4
April	32.2	17.3	127.2
May	30.7	20.2	332.9
June	33.6	22.6	379.0
July	32.9	24.0	545.8
August	33.5	23.5	357.3
September	32.3	22.8	339.5
October	30.5	19.2	100.6
November	25.3	14.5	10.4
December	22.9	10.8	4.4

Appendix 5b: Climatological data on maximum-minimum Temperature and Rainfall of Kakani weather station, Nuwakot from 2002-2006.

Months	Maximum Temperature	Minimum Temperature	Rainfall
Months	21.0	7.5	32.9
January	23.4	10.3	22.8
February	26.0	14.8	17.8
March	30.3	16.7	53.1
April	30.3	18.7	113.1
May	31.0	20.9	244.5
June	30.6	21.3	516.8
July	30.0	21.1	481.9
August	28.1	20.7	255.6
September	27.7	17.1	61.6
October	25.2	12.9	6.3
November	22.6	9.1	5.4

Appendix 5c: Climatological data on maximum-minimum Temperature and Rainfall of Tribhuvan International Airport weather station, Kathmandu from 2002-2006.

Months	Maximum Temperature	Minimum Temperature	Rainfall
Months	19.3	3.0	27.5
January	22.4	6.3	21.4
February	20.7	7.5	48.4
March	28.0	12.8	84.7
April	28.6	16.0	109.6
May	29.4	20.2	176.5
June	28.7	20.5	437.2
July	29.1	20.3	313.1
August	28.5	19.1	190.2
September	26.8	13.9	42.8
October	23.4	8.6	13.3
November	20.2	4.3	7.2
December	19.3	3.0	27.5