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Spread, menace and management of *Parthenium*

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ABSTRACT

Parthenium hysterophorus is an aggressive annual herbaceous plant, native to the tropical America. It is now widely distributed in a number of tropical and sub-tropical countries threatening natural ecosystems, agro-ecosystems and biodiversity worldwide. It has been considered a great cause of skin allergy in mankind and animals too in many countries around the globe. Parthenium has achieved major weed status in India and Australia and posing lurking threat to many African and South–Asian countries. Earlier, it was not considered a major threat to agricultural crops in India and other countires, but now, all types of crops are infested with the weed in India. The infestation of this weed causes yield losses up to 40% in several crops and reduces forage production up to 90%. The rapid spread of *Parthenium* in India would be a bigger risk to the expansion and sustainable production of many crops, orhcards and grassland ecosystems in protected forests. Various management approaches namely cultural, mechanical, chemical and biological have been used to minimize losses caused by this weed, but most of these approaches are ineffective and suffer from one or other limitations. Although management using herbicides and exotic bioagents *Zygogramma bicolorata* for biological control has been found to contribute effectively to suppress *Parthenium* in India, nevertheless, the weed remains a significant problem. Integrated Parthenium Management is advoated to fight against this invincible weed.Hence, an attempt has been made to review its current spread, impact on agriculture, human and animal health and management in context to world in general and India in particular.

Key words: Distribution, Infestation, Integrated management, Menace, *Parthenium*, Spread

The genus name *Parthenium* is derived from the Latin word *'parthenice'* a reference to the plant now known as *Tanacetum parthenium* (L.) Bernh. or 'feverfew'. the species name *'hysterophorus'* was derived from the Greek word*'hystera'* (womb) and *'phoros'* (bearing), referring to the prolific seeding habit of the plant (Parsons and Cuthbertson 1992). *Parthenium hysterophorus* L., globally known as feverfew, ragweed or *Parthenium* is a weed of world significance. It is most popularly known as 'congress grass' throughout India while in Hindi speaking belt known by the popular name of 'gajarghas'(carrot grass) besides vernacularly called as 'kadvighas' [bitter grass], or 'safed topi' [white top]. It is one of the most aggressive herbaceous weeds of the family Asteraceae. It is an annual short lived herbaceous plant that invades preferably vacant land, disturbed sites, road sides, railway tracks sides, wastelands, water courses, agricultural crops *etc*. It degrades natural ecosystems by reducing biodiversity (Holm *et al*. 1997) and can cause serious allergic reactions in man and animals (Lonkar *et al*. 1974, Chippendale and Panetta 1994). In Australia, it is a significant problem in rangelands (Haseler 1976). In India, it has invaded almost all types of crops and has become a serious threat for agricultural production. In spite of its non-tropical origin, it has now naturalized in several tropical and subtropical parts of the world under a wide range of environmental conditions. The weed causes immeasurable ecological and agricultural losses each year. It is spreading rapidly in Australia, many African, Caribbean and Asian countries and has become a serious concern of the government and public. The weed has great potential to spread into other new countries in the world.

The problem of *Parthenium* is particularly serious in rain-fed ecosystem and in non-cropped situations. Earlier, it was not considered a problem in agro, pasture and forest ecosystems but, at present many forests and national parks world over are severely infested with *Parthenium* threatening forest biodiversity and availability of palatable grasses to herbivores. The spread and infestation of *Parthenium* are severe in some of the countries like Australia, South Africa, Ethiopia, India and Pakistan, In India, the weed is a serious problem in states like, Andhra Pradesh, Bihar, Haryana,Karnataka, Madhya Pradesh. Tamil Nadu and Uttar Pradesh.

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Parthenium is regarded as one of the worst weeds because of its immense capacity of reproduction and ability to thrive in varied climatic conditions, to spread fast due to light and floatable tiny seeds, impact upon human health and environment. These attributes make this plant an invincible weed. Ever since, *Parthenium* has become a serious problem, efforts are being made globally to use different management approaches to contain this weed, but none of single method has been found effective due to its own limitations. Therefore, Integrated *Parthenium* Management (IPM) approach has been considered the only most effective solution to suppress the weeds below the economic threshold level. This review presents the available information on its distribution, spread, menace and managment in different agro-ecosystems, with various prevalent methods in context to world in general and India in particular. Such information would facilitate farmers, municipalities and forest managers, and weed scientists of *Parthenium* suffering countries to understand its biological attributes, spread, menace and to take appropriate measures to manage this most problematic weed.

Biological attributes responsible for *Parthenium* dominance

Parthenium is an annual herb with a deep tap root and an erect main stem that becomes woody with age having high cellulose content (Jaun *et al.* 2008 Kaur *et al*. 2014). A single plant produces many branches and eventually achieve an average height of 1.5 meter but in suitable conditions may achieve height up to 2.5 meter. Plant completes its one generation within 15 to 18 weeks and may complete 4 to 5 overlapping generations in a year depending on the climatic conditions of the area which may vary place to place and country to country. The plant has unique characteristics of achieving 'rosette' form in absence of water when after germination and achieving little growth, development become restricted, gradually leaves become thick and plant remain attached to ground. Such plants may grow normally on availability of water to produce seeds. This character makes this weed to sustain in high and low temperature regime and negligible water availability. Seeds maturation occur within two weeks of flowering and may continue even after the complete senescence of leaves. White (1994) concluded that *Parthenium* seeds may survive between 4 to 6 years. Navie *et al*. (1996) also found that buried seeds can survive for more than a year on upper surface and up to 6 years in the lower layers of soil.

Flowers are white to creamy-white in colour and are star-shaped, produced on top of the upper branches in clusters. Flowers have five petal-like ray florets, each bearing a single seed (Kohli *et al*. 2006), however, in its native range it may have yellow flowers in South American race (Dale 1981). Thus, single flower bear 5 seeds which are narrow, flattened and dark brown to black in color with wing like appendages. Seeds are 2 mm long and difficult to see by the naked eye. A single *Parthenium* plant may produce up to 25,000 seeds, leading huge seed bank in the soil. Seeds are so light that they are easily carried away up to long distance with the wind (Sushilkumar 2005). A large number of seeds fall directly onto water from the weed grown on the bank of water channels made for irrigation purpose and are carried directly to crop fields. It is one of the major factors contibuting infestation in crop fields directly. There may be up to 400 million seeds/ha on the surface soil (Joshi 1991). The seeds spread via vehicles, farm machinery, animals, pasture and crop seed lots, stock fodder/feed, wind, humans, mud adhering to vehicles, and moving water (Chippendale and Panetta 1994).

There is no seed dormancy in *Parthenium*. The seeds normally germinate with the availability of moisture. Maximum, optimum, and minimum temperatures for seed germination are 30-34, 22-25 and 12-15 °C, respectively. Maximum germination occurs at available soil moisture between 40 and 60% (Tamado *et al*. 2002). Naidu *et al*. (2007) kept fresh seeds of *Parthenium* in nylon net bags and subjected to running water for different durations of time *i.e*. 0 'hour (fresh seeds), 4 hours, 8, hours 24 hours, 28 hours, 32 hours and 48 hours. The germination was tested on filter paper in Petridishes and in sandy and clayey soils in pots. They found that per cent germination increased with increased duration of time under water flow and the seeds germinated within the nylon bags after 48 hours of running water treatment. The per cent germination was enhanced due to the removal of toxicants from the seed by running water. They concluded that germination of *Parthenium* seeds depends on sufficient rain to leach germination inhibitors from the seed. In India, good germination and growth of this weed occurs where the annual rainfall is greater than 600 mm, however, germination and growth is best having rainfall between 1000 to 1200 mm. The growth of *Parthenium* weed was restricted in saline and waterlogged soils in Pakistan (Marwat *et al*. 2010). Although *Parthenium* is capable of growing in most soil types of India, it is most dominant in alkaline, clay loam soils. But, Naidu *et al.* (2007) found that germination per cent of fresh seeds was higher in sandy soil (76%) than in clayey soil (5%) probably because of the leaching out of toxicant easily in the sandy soil. In Australia, Naive *et al*. (1996) found most favourable

areas for *Parthenium* seed germination having an annual summer rainfall of more than 500 mm in a wide variety of other soils, from sandy loams to clay loams.

Parthenium can grow over a wide range of moisture and temperature conditions but requires high soil moisture for seed germination (Tamado *et al.* 2002). Its low photorespiration under arid conditions, photo- and thermo-insensitivity, C3/C4 intermediate mechanism, more biomass production at elevated atmospheric CO_2 concentrations as compared to the normal CO_2 concentration in a rapidly changing climate make it more invasive (Pandey *et al.* 2003, Naidu and Paroha 2008, Tang *et al.* 2009, McConnachie *et al.* 2011, Shabbir 2012 Naidu 2013). Naidu and Murthy (2014) discussed that invasive weeds like *Lantana* and *Parthenium* may become more aggressive under climate change especially due to increases in atmospheric CO_2. Growth at elevated CO_2 would result in anatomical, morphological and physiological changes that could influence herbicidal uptake rates, besides translocation and overall effectiveness.

Origin and spread of *Parthenium*

Parthenium is native to the area surrounding the Gulf of Mexico, Central America, Southern North America, West Indies, and Central South America (Navie 2003). About 20 countries are considered in its native range from where it has introduced into other 34 countries (Adkin and Shabbir 2014) around the globe, including major continents except Europe and many islands. It has now naturalized in several tropical and subtropical parts of the world. *Parthenium* is one of the most troublesome weeds and figures among the list of invasive species (GISD 2014). It has spread between countries across the border mainly by the movement of contaminated grain for human or cattle feed or by vehicles and wind.

Australia has been considered second most *Parthenium* affected country after India. First introduction in Australia was reported in 1950 (Parsons and Cuthbertson 1992), while second and more substantial introduction occurred in 1958 near Clermont in central Queensland as a contaminant of a pasture grass seed lot imported from Texas, United States (Haseler 1976). By 1994, it had invaded about 17 million ha of prime grazing pastures in Central Queensland (Chippendale and Panetta 1994), which extended to about 60 million ha by 2012 (Commonwealth of Australia 2012). The loss of pasture was estimated abut $109 million per year (Adamson 1996). International spread of *Parthenium* in the past 2-3 decades has been rapid, which indicates that *Parthenium* weed is still capable to spread into many other countries in near future, especially those in West Africa, South-East Asia and Eastern Europe and other parts of the world with a suitable climate (Nigatu *et al.* 2010, Adkin and Shabbir 2014). Holm *et al.* (1977) did not categorized this weed among the top 10 weeds of the world which reflected that by that time it had not become a problematic weed in the world, however after twenty years of publication of this book, *Parthenium* has become one of the seven most damaging weeds of the world (Evans 1997), because it had spread fast and extensively in many countries of the world.

Another severely affected region is Eastern Africa, with Ethiopia being one of the most emerging affected countries. In Ethiopia, *Parthenium* has become a serious problem in grazing and cropping lands and is thought to have arrived into the country as a food grain contaminant in a USAID programme in about 1980 (Tamado *et al.* 2002, McConnachie *et al.* 2011). In China, *Parthenium* illustrates with evidence from nuclear and chloroplast DNA that multiple introductions were responsible for subsequent invasions in China (Tang *et al.* 2009) and about eight provinces were at an alarming rate in near future (Naive *et al.* 2010).

India has become one of the most *Parthenium* affected countries in the world as this weed is occurring in all of her states and presenting a major problem in many those states that have large areas of non-cropped and pastures rain-fed land (Sushilkumar and Varsheny 2010, Sushilkumar 2012). It was surmised that *Parthenium* possibly got entry from USA through the imported food grains (Vertak 1968) or through the cereals obtained for experimental purpose (Lonkar *et al.* 1974). In most of the publications, first occurrence of *Parthenium* in India has been believed to be in 1955, when it was first noticed by a retired horticulturist, Prof. Paranjape and later on described by Rao (1956). However, some reports traced its history of occurrence about one and half century old (Roxburghi 1914, Maiti 1983, Dam *et al.* 1993). Its presence in India before 1955 got further confirmation from a herbarium record in Forest Research Institute, collected by Dr. Brandis in 1880 (Bennet *et al.* 1978) and further confirmed by the author in 2008. This past record has been well elaborated by Sushilkumar (2005). From these records, it is clear that *P. hysterophrus* has entered in India before the start of 20th century and survived unknown till 1955. But, it is also true that after 1955, *Parthenium* has spread like a wild fire throughout India. The rapid spread of *Parthenium* after 1955 in India was possible due to large-scale import of wheat and other cereals under PL480 grants of USA during fifties of 20th century.

Parthenium spread rapidly throughout the country through Public Distribution System (PDS) and become noticeable. This is the reason that in most of publication, *Parthenium* occurrence is considered after 1955 in spite of its record much earlier.

Now, *Parthenium* occurs throughout country in about 35 million hectares of land (Sushilkumar and Varshney 2010). After being established in India, *Parthenium* has gradually spread into most of its neighboring countries like Pakistan (Shabbir and Bajwa 2006), Sri Lanka (Jayasurya 2005), Bangladesh (Rahman *et al*. 2008, Karim 2009) and Nepal (Mishra 1991, Adhikari and Tiwari 2004, Shrestha *et al*. 2014).

The spread of *Parthenium* has been reported from all states of India in varying intensity. The spread and invasion of *Parthenium* may be severe in some of the areas of a particular state and may be low to nil in other areas. In Uttarakhand and Himachal Pradesh, it is abundantly occurred in lower altitude, but density and occurrence gradually declined towards higher altitude. For example, in Uttarakhand state of India, Parthenium density is higher in lower elevations at Roorkee, Rishikesh, Haridwar *etc* but its density and occurrence gradually declines towards higher elevations like Devprayag, Srinagar, Parui and become nil at Joshimath. In Maharashtra, its occurrence is negligible in Konkan region while in other areas, it is abundantly occurred.

The overall average infestation of *Parthenium* varied in different states of India (Table 1). In general, overall spread in terms of density and infestation level was highest in Andhra Pradesh, Bihar, Chhattisgarh, Delhi, Haryana, Karnataka, Maharashtra, Madhya Pradesh, Punjab, Tamil Nadu and Uttar Pradesh; medium in Assam, Gujrat, Himachal Pradesh, Jharkhand, Jammu & Kashmir, Uttarakhand, Odisha, West Bengal and Rajasthan; low in Andaman & Nicobar, Arunachal Pradesh, Goa Kerala, Lakshadweep, Manipur, Mizoram, Mehgalaya, Nagaland, Pondicherry and Sikkim (Sushilkumar 2012). It is experienced that *P. hysterophorus* infestation is increasing rapidly in India and may be more widespread than shown here. In a survey report, Abraham and Girija (2005) has shown high density of *Parthenium* in Kerala state of India, but in general *Parthenium* is not a major weed in this state and it is restricted to only district Palakkad adjoining to border of Tamil Nadu state, where the weed is in abundance. In 2012, severe infestation of *Parthenium* was reported in the Mincoy island of Lakshadweep in India. Systematic surveys of *Parthenium* infested areas on 12 selected national highways of North-Eastern India were conducted during 2009-2011 by by Devi *et al*. (2013). Survey revealed the presence of *P. hysterophorus* in all the sites but severe infestation was recorded in NH-31 (Bongaigoan), high in NH-37 (Nagoan) and NH-39 (Imphal), medium in NH-37 (Jorhat), NH-44 (Agartala,Tripura), NH-52 (Tezpur) and NH-53 (Imphal-Jiri), mild in NH-39 Nagland), NH-40 (Shillong, Meghalaya), NH-54 (Aizawl, Mizoram) and NH-150 (Imphal) while negligible infestation was observed in NH-52A (Itanagar, Arunachal Pradesh) during the month of June to August.

In a detail study, Sushilkumar and Varshney (2010) revealed that *Parthenium* spread and infestation till 1960 was restricted to Maharashtra and border areas of adjoining states. Subsequently by 1970, *Parthenium* infestation increased inside of all the nearby states of Maharashtra. From 1970 onward, it rapidly spread throughout the country except a few states. The information collected from Krishi Vigyan

Table 1. Spread and infestation level of *Parthenium* in India

Name of state	Over all spread and infestation level of *Parthenium*	Name of state	Over all spread and infestation level of *Partheniu*
Andaman & Nicobar islands	Low	Kerala	Low
Andhra Pradesh	High	Madhya Pradesh	High
Arunachal Pradesh	Low	Maharashtra	High
Assam	Medium	Manipur	Low
Bihar	High	Meghalaya	Low
Chattishgarh	Medium	Mizoram	Low
Chandigarh	Medium	Nagaland	Low
Delhi	High	Orissa	Medium
Goa	Low	Pondicherry	Medium
Gujarat	Low	Punjab	High
Haryana	High	Rajasthan	Medium
Himachal Pradesh	Medium	Sikkim	Low
Jammu & Kashmir	Medium	Tamil Nadu	High
Jharkhand	Medium	Uttar Pradesh	High
Karnataka	High	Uttarakhand	Medium

Source: Sushilkumar (2012)

Table 2. Estimated infested area by *Parthenium* in India during different decades since 1955

Period	Infestation (in million ha) in different land like barren, fallow, wasteland, including land under non-agricultural uses	Crop land	Forest land	Total infested area (mha)
1955-1960	0.5	0	0	0.5
1961-1970	1.75	0.25	0	2.0
1971-1980	4.5	0.5	0	5.0
1981-1990	6.0	1.0	0	7.0
1991-2000	7.5	2.0	0.5	10.0
2001-2009	18.78	14.25	2.0	35.0

Source: Sushilkumar and Varshney (2010)

Kendra (KVKs) [Agricultural Science Centre] from all over the country has confirmed the increasing problem of *Parthenium* in almost all parts of the Country. The record of this weed in Kargil region of Jammu & Kashmir, Port Blair in Andaman & Nicobar islands and Minicoy island of Lakshadweep is a pointer to extraordinary ability of the weed to invade new environment. The problem of *Parthenium* in India is particularly serious in rain-fed ecosystem and in non-cropped situations.

Increase in land area infestation with *Parthenium* in India from 1955 to 2009: Sushilkumar and Varshney (2010) studied the spread and infestation of *Parthenium* problem since its first occurrence in India in 1955 in Pune. They found that in beginning, *Parthenium* was only a problem in wasteland and vacant land, but not in the crop areas. Reports stared to appear about its infestation in field crops after 1980. Likewise, reports of *Parthenium* infestation in forest area also started to appear after 1990. On the basis of published information of *Parthenium* infestation in wasteland, crop land and forest area, they estimated about 35 million hectares of land infested with *Parthenium* in India. The increase of *Parthenium* infestation in crop area in recent past was alarming (Table 2).

Menace of *Parthenium* in crop, orchards, pasture and forest ecosystems and human and animal health

The harmful effects of *Parthenium* have been reported world over in different ecosystems with different intensity. In the beginning of its infestation in India, *Parthenium* was known as a weed of wasteland as it used to seldom occur in crops but now it has spread in almost all types of cereal, pulse and vegetable crops besides pasture and forest ecosystems. In agricultural fields, where only one crop is taken in a year, it grows profusely in fallow period with the occurrence of mild rains. It has become a serious problem on grass availability in pastures land. In many forests, National Parks and Reserved forests, the weed has achieved the alarming status and has become a major concern for the survival of carnivores, which survives on herbivores that are mainly dependant on grasses. In India, this weed has been considered as one of the greatest sources of dermatitis, asthma, nasal-dermal and naso-bronchial types of diseases. In general, *Parthenium* is a poisonous, pernicious, problematic, allergic and aggressive weed posing a serious threat to human beings and their livestock.

Impact of *Parthenium* on agriculture and pastures ecosystems*:* *Parthenium* has gradually entered into field crops, causing considerable yield losses. In different states of India like Andhra Pradesh, Bihar, Haryana Karnataka, Madhya Pradesh, Tamil Nadu and Uttar Pradesh, it has been considered a serious weed of crop lands. Sushilkumar and Varshney (2010) estimated infestation of *Parthenium* in 18.78 and 14.25 million hectare land in barren, fallow, wasteland including land under non-agricultural uses and crop lands, respectively. Studies showing losses by *Parthenium* in field crops are limited. Das (2008) observed severe *Parthenium* competition between 15 and 45 days after sowing while Tamado *et al*. (2002) between 5 and 59 days after emergence in sorghum. Grain yield reductions due to infestation of *Parthenium* up to 40% in agricultural crops, like rice, wheat, maize, pigeonpea, blackgram, sorghum *etc* are known (Khosla and Sobti 1979, 1981, Shabbir and Bajwa 2006).

Parsons and Cuthbertson (1992) reported that *Parthenium* caused a substantial yield loss in sunflower and sorghum in central Queensland, Australia. Similarly, up to 90% reduction in forage production in grasslands has been reported from India (Vertak 1968, Nath 1988). According to Parades and Labrada (1986), one *Parthenium* plant per m^2 was the critical threshold density in direct-seeded tomato whereas a *Parthenium* density of 6 plants per m^2 was reported to be critical threshold in transplanted tomato (Morales-Payan 2000) as it resulted in 63% reduction in its plant biomass and yield. Angiras and Saini (1997)

reported sorghum grain and forage yield losses of 40 and 90%, respectively by *Parthenium*. Sorghum grain yield was reported to be declined by 40-95%, if *Parthenium* is left uncontrolled throughout the growing season (Tamado *et al*. 2002). Kumari *et al.* (2014) studied the impact of *Parthenium* invasion on species diversity of cultivated filed in Bilaspur (Chhattisgarh, India).

Parthenium affects crop growth through allelopathy. Initially, Jayachandra (1971) Kanchan and Jayachandra (1975) reported the presence of plant growth inhibitors in *Parthenium*. Many workers have evidently shown the effect of aqueous extracts of leaf, inflorescence, stem, and root of *Parthenium* to reduce germination of crops seeds and to reduce root/shoot length, root/shoot dry weights *etc*.(Knox *et al.* 2011). Maharjan *et al*. (2007) showed that increase in concentration of extract was invariably associated with decrease in germination and seedling characteristics of the crops. A strong inhibitory effect of aqueous extract of *Parthenium* on the root elongation of cereal seedlings was reported (Khan *et al.* 2011).

Gupta and Narayan (2010) found that species varied considerably in their sensitivity to the aqueous extracts of *Parthenium* for germination and growth and allelopathic impact of *Parthenium* depends on the quality of leaf biomass. *Parthenium* residues in soil affected the emergence and growth of plant species by releasing phenolics rather than decreasing the available nutrient status in the soil (Singh *et al*. 2005). In an aquatic environment, Pandey (1996) found gradual loosing of phyto-toxicity effect of *Parthenium* in control of aquatic weeds in about 30 days. Ambiye and Golatkar (2010) reported tannins, saponins, cardiac glycosides, and steroids in leaves and shoots of *Parthenium*. The inhibitory role of allelochemicals, particularly parthenin, was dependable on the amount of plant material accumulated on the soil surface and the concentration of parthenin in residues (Belz 2008).

Impact of *Parthenium* on orchards and forests ecosystem: Earlier, it was not considered a weed of orchards and forests but now it has spread rapidly in these areas too. *Parthenium* grows luxuriantly in orchards due to less frequent weeding in such ecosystems. In Himachal Pradesh, *Parthenium* has invaded majority of apple orchards in lower elevations (Bisht 2004).The invasion of *Parthenium* was reported in forest and wastelands with little or no growth of any other species and local bio-diversity was found to be threatened (Kumar and Rohatgi 1999). In many forests, National Parks and Reserved forests, the occurrence of this weed has been noticed world over. Pandey and Saini (2002) observed *Parthenium* invasion near the people habitation, crop lands, grazing lands in between the forest ecosystem in remote areas of natural forest in Madhya Pradesh. *Parthenium* has been observed in many forest nurseries in Madhya Pradesh. It had became a nuisance during 2000 in RajaJi National Parks in Uttarakhand (Goyal and Brahma 2001). The weed was observed in India at alarming rates by the author during 2010 and 2011 in Pench National Park. Author observed the weed in plenty in buffer zone of Kanha National Park and in low profile in core area too. The *Parthenium* has become a problem in Van Vihar National Park in Bhopal (Madhya Pradesh, India), where large area of grasses was replaced by the weed. This situation compelled the authorities of National Park to uproot the weed by deputing large number of labours to restore the grasses. *Parthenium* has been found responsible to reduce grass availability to herbivores in Corbett National Park in Uttarakhand (India). Sushilkumar and Varshney (2010) estimated the invasion of *Parthenium* in about 2 million hectare land of forest in India. Kumar *et al.* (2013) studied the distribution and effect of plant species density including *Parthenium* in sub-watershed of Rajouri Forest Range of Jammu & Kashmir (India). Among the eight species recorded in the area, *Parthenium* showed maximum density and importance value index which posed a significant threat to economic development and ecological integrity. *Parthenium* rapidly invaded new surroundings and replaced the indigenous species and posed a serious threat to biodiversity, reducing pasture productivity and hence fodder supply. Sushilkumar (2013) has reviewed the menace of *Parthenium* in different protected areas of India and suggested the National Parks' authorities to allow systematic rlease of bioagent *Z. bicolorata* in the protected aeas which is banned as per the rules and regulations of National Parks. In India, deliberate introduction of any exotic species in National Parks is banned in spite of the fact that good control of *Parthenium* by the *Z. bicolorta* was reported in Rajajee National Park (Goyal and Brahma 2001) and Pench National Park (personal observations). The weed has invaded the buffer zone of Chitwan National Park in Nepal, a World Natural Heritage site (Shrestha 2012). The weed has become a major threat in Kruger National Park in South Africa (Strathie *et al*. 2011) and the Masai Mara/Serengeti ecosystem in Kenya and Tanzania, which is home to an estimated 2 million wildebeest which depend upon this ecosystem for their survival (IUCN 2011). In Australia, the weed is present in Carnarvon National Park (Adkins and Shabbir 2014).

***Parthenium* menace on human and animal health:** In India and Australia, this weed has been considered as one of the greatest source of dermatitis, asthma,

nasal-dermal and naso-bronchial types of diseases. In general, *Parthenium* is a serious threat to human beings and their livestock. A major population does not feel any sensitization when they come in contact with *Parthenium* first time or for some time. But, chances of getting sensitized to the weed are high, when a person comes in contact for a period ranging from 4-15 months. *Parthenium* was detected to be the main cause of dermatitis in hundreds of cases in India in Pune (Maharashtra), Patna (Bihar) and Coimbatore (Tamil Nadu) by Ranade (1976), Chandra (1973) and Rajulu and Gowri 1976), respectively. Fisher (1996) described the incidence and severity of contact dermatitis in humans caused by *Parthenium* in India. It was argued to be the first reported instance of an imported sensitizer causing allergic dermatitis in thousands of people. Kologi *et al.* (1997) also reported the dermatological hazards in human beings. *Parthenium* was found to be predominant in the city's atmosphere (Agashe and Alfadil 1989) after its invasion in 1965 in Bangalore (Jayachandra 1971) and an increase in the incidence of naso-bronchial allergies was reported coincided with the steady and widespread growth of the weed. Random clinical surveys showed that 7.1 per cent of the study population in this area was suffering from allergic rhinitis resulting from exposure to *Parthenium* pollen (Sriramarao *et al.* 1991). Rs 800 crores were estimated to be spent for the treatment of *Parthenium* related diseses in human beings in india (Sushilkumar and Varshney 2010).

McFadyen (1995) has reviewed the information on health aspects in Australia caused by pollens and *Parthenium* dust in Central Queensland. The cost of treating symptoms can be more than $40 per month for severely affected people i Australia (Commonwealth of Australia 2012). Allergic responses can be significant with negative impacts on home, work and social aspects of living. There is a paucity of diagnostic and health care provision for individuals with allergic responses to the weed. Farmers, particularly those involved in manual fodder harvesting, developed eye inflammation and skin dermatitis on the exposed parts of their hands in Nepal (Karki 2009). Kumar (2014) has reviewed and discussed the impact of *Parthenium* on living world.

Parthenium is not palatable to livestock due to its irritating odour, taste and presence of trichomes, but, sometimes-hungry cattle may eat *Parthenium* during summer season when other green vegetations are scanty. In such cases, the weed was found to cause clinical signs such as salivation, onset of diarrhea, anorexia, pruritus, alopecia and dermatitis. In cattle, due to *Parthenium* contact, there may be loss of hair and marked depigmentation of skin. The bitter and reduced milk yield contaminated with parthenin has been reported in buffaloes and goats, fed on grass mixed with *Parthenium*. In Queensland (Australia), losses to the cattle industry due to *Parthenium* have been estimated to be $ 16.5 million per year in term of control costs and loss of pasture (Chippendale and Panetta 1994). The weed is poisonous to livestock and may cause death after 30 days if significant quantities are ingested (Ahamed *et al.* 1988). Chemicals within the plant are thought to alter the microbial composition of the rumen of dairy cattle, buffalo and sheep and can impart a bitter taste to their milk and the meat of cattle and sheep can develop an undesirable flavor (Tudor *et al.* 1982, Sushilkumar 2005, 2012).

Parthenium management

Ever since the weed became a menace, efforts are being made to manage the weed by different methods world over. So far, no single method has been proved satisfactorily as each method suffers from one or more limitations such as impracticability, temporary relief, environmental safety, high cost *etc*. A brief of different methods in practice is being given below in context to their applicability and practicability in different type of situations and ecosystems.

Mechanical and manual management: This method is applicable in all type of ecosystems in limited area in spite of high cost involved. The relief from this method is temporary and needs to be repeated on reappearing of the weed. Mechanical removal with the help of tractor, plough, *etc*. is possible up to certain extent and that too only in open fields without crop or if crops are sown in lines. Cuttings of *Parthenium* with the sword enhance its regeneration. After cuttings, large numbers of shoots are sprouted from the cut stems and flowers are produced on such shoots early than the normal plant. Therefore, cutting should be avoided under physical management. If mechanical or manual methods are to be adopted, *Parthenium* should be uprooted and such operations should be completed before flowering. Uprooting is practicable only during rainy season when soil becomes wet and plants are easily uprooted with tap roots, which is not possible during summer or winter season. Uprooting should be done by using hand globs of leather, cloths or plastic to avoid direct close contact with the skin. Uprooting of *Parthenium* by farmers is practicable only in high valued crop or in small area due to high labour cost.

It was estimated that, Rs. 182000 million or 18200 crores were required in the year 2009 to manage the weed by manual methods in 35 million hectare

of land in India (Sushilkumar and Varshney 2010). However, if uprooting is done on community basis, large area may be cleaned. In India, large number of students, farmers and general public were motivated to participate in uprooting of *Parthenium* from their colony, schools, campus and public places during '*Parthenium* Awareness Week' organized by Directorate of Weed Research (DWR), Jabalpur every year during 2005 to 2013. These events were documented in the form of reports by Gogoi *et al.* (2005), Varshney and Sushilkumar (2006, 2007, 2008, 2009, 2010), Sushilkumar and Ranganatha (2011) and Sushilkumar and Sharma (2012). Use of fire was tried in Australia to manage the weeds, but it did not prove practicable due to fast germination of *Parthenium* from the available seed bank in the soil in the niche vacated by the fire in the absence of vegetation (Vogler *et al*. 2000).

Cultural management: This method may be applicable in crop ecosystem. It has been observed that in some crop fields, *Parthenium* grows profusely. To reduce the seed bank in such crops, some fast growing species of fodders like barseem and sorghum can be taken to suppress *Parthenium* and its seed bank in the field (Sushilkumar 205, 2012). Reductions in the stock in rate and more appropriate rotational timings between grazing events are other useful methods for managing *Parthenium* weed in pastures (Adkins and Shabbir 2014).

Preventive management through legislative measures: The proverb 'prevention is better than cure' is applicable in all the countries affected with *Parthenium*. It may be implemented by enforcing suitable legislative tools and following up action by the government. In Australia, machinery and vehicles coming from infested areas and entering into non-infested area must be cleaned thoroughly to remove *Parthenium* seeds. This is done by washing with a high-pressure hose or by using roadside washdown facilities (Parsons and Cuthbertson 1992). In other countries including India, such strict measures are seldom followed. In Australia, *Parthenium* is a declared weed in all states and territories, and, landowners are directed to control it and/or report it to the concerned state authorities immediately after spotting it (Adkins and Shabbir 2014).

So far, very few legislative measures have been enforced for *Parthenium* in other countries. The management of *Parthenium* was also tried in India through the legal act, first in Karnataka State in 1975 , declaring *Parthenium* a noxious weed under 'The Karnataka Agricultural Pests And Diseases Act, 1969. Under this act, notices were issued to public in Bengaluru during the eighties by Municipal Corporation to remove *Parthenium*, but there did not appear any follow up action. Thus, in spite of this comprehensive act, it was total failure to get the weed removed from Bengaluru. Similarly, in Sri Lanka, *Parthenium* was also declared a noxious weed and under this legislation, the movement of adult plants to areas that are not presently infested is strictly forbidden (Dhileepan 2009)

Chemical management: The management of *Parthenium* by herbicides was considered only a viable option by Balyan *et al.* (1997) but the effect of herbicide was considered of temporary nature and repeated operations were required. Chemical treatment can only kill existing population at the given sites but can not prevent the entry of the seeds coming on treated side from neighboring places. (Sushilkumar 2005, Sushilkumar 2012). Nevertheless, in limited situations, chemical use is financially feasible like in high-value crops and in the situations like along roadsides, in public parks *etc*. Chemical control of *Parthenium* over a vast area like wastelands, rangelands, community land or within forests where the weed commonly found is not cost effective. Sushilkumar and Varshney (2010) estimated the requirement of Rs. 126000 million or Rs. 12600 crores to control 35 million hectares of *Parthenium* infested land in India for one time spray of chemical.

The chemical approach may be applied in wasteland, crop land, and orchards type of ecosystems depending on the situations and area infested. It is easy to use herbicides in wasteland situation where there is no danger of crop damage but in crop ecosystem, expert knowledge is required to apply suitable herbicide depending on the crop in the field (Sushilkumar 2012). A large number of herbicides have been tested against *Parthenium* in cropped and non-cropped situations (Mishra and Bhan, 1996, Brar and Walia, 1991, Sushilkumar 2012). In wasteland situation, if grasses are to be saved and *Parthenium* is to be killed, metribuzin (0.3 to 0.5%) should be used. 2,4-D (1 to 1.5 kg/ha) and metribuzin (0.3 to 0.5%) can safely be used in crops of grass family like sorghum, sugarcane, wheat, rice, oat *etc* (Brar and Walia 1991). For complete vegetation management including *Parthenium*, glyphosate (1 to 1.5 kg/ha) is recommended. Diquat 0.5 kg/ha in 500 litre spray effectively controlled *Parthenium* at all growth stages (Dhanraj and Mitra 1976). Mishra and Bhan (1994) tested six herbicides against *Parthenium* and associated weeds in soybean. Bentazon 1.5 kg/ha applied at 25 days after sowing effectively controlled *Parthenium*, *Commelina benghalensis* and yellow nut sedge (*Cyperus iria*) in soybean. Metribuzin (0.50 to 0.75 kg/ha) may be used as pre-emergence herbicide

for control *Parthenium* in potato, tomato and soybean just after sowing. Atrazin (1-1.5 kg/ha) may be used in maize as pre-emergence herbicides. Diauron yr (1-1.5 kg/ha) may be used in maize as pre-emergence herbicides. Chloromuron-methyl (10-12 g/ha) may be used to kill *Parthenium* in soybean after 25-3- days of sowing.

Biological management: Biological control has been considered most effective method against *Parthenium* in waste land, pasture, orchards and forest ecosystems by introduction of bioagent from the native place of the weeds under classical biological approache. During last two decades, much emphasis has been given to control *Parthenium* through various biological agents like pathogens, insects and plants.

(i) Biological management of Parthenium through pathogens: In India, there are many records of various pathogenic and non-pathogenic microorganisms on *Parthenium*. In spite of the presence of many pathogens, not all have been evaluated as biological control agents against the weed (Aneja *et al.* 1994, Kauraw *et al.* 1997, Pandey *et al.* 2005). Sushilkumar (2009) reviewed the status of biological control of *Parthenium* by insects and pathogens in India. In Australia, two rust species, *Puccinia abrupt* var. *partheniicola* (Jackson) Parmelee (winter rust) and *Puccinia xanthii* var. *Parthenium hysterophorae* (summer rust) have established in the field, but their prevalence and impact is highly variable and sporadic, depending upon the local climatic conditions (Dhileepan *et al.* 1996). Efforts to establish these fungi in India were advocated (Evans 1997) but so far no success have been achieved.

(ii) Biological management of Parthenium through insects: (a) By indigenous insects- In India, many insects have been reported on *Parthenium* but none of indigenous insect was found host specific yet (Sushilkumar 2009). Nevertheless, some time, indigenous insects may also play important role. A cerembycid *Nupserha* sp. was found to cause widespread damage (5-95%) to *Parthenium* (Sushilkumar 2012).

(b) By exotic insects: Classical biological control is one of the most important methods used for the management of invasive weeds. In this method, insect herbivores or plant pathogens from the native range of the weed are introduced, to suppress the growth of the weed, in the introduced range. So far, only four countries (Australia, South Africa, India, Tanzania and Sri Lanka) have released biological control agents against *Parthenium*. A further two countries (Ethiopia and Vanuatu) are in the process of releasing biological control agents, and others (Kenya, Pakistan, Nepal, China, Ethiopia) have agents that have accidentally arrived there (Adkins and Shabbir 2014).

In India in 1983 at Bengaluru, three insects namely defoliating beetle *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae), the flower feeding weevil *Smicronyx lutulentus* Dietz (Coleoptera: Curculionidiae) and the stem boring moth *Epiblema strenuana* (Walker) (Lepidoptera:Tortricidae) were imported in India (Singh 1989,1993). *S. lutulentus* could not be multiplied in the laboratory while *E. strenuana* was found to complete its life cycle on a oil seed crop niger (*Guizotia abyssinica*L.(Asteraceae) hence, its culture was destroyed (Jayanth 1987) in spite of the fact that this insect was considered to be a potential biocontrol agent in Australia (McFadyen 1985, Dhileepan 2009). After host specificity test *Z. bicolorata* was released which spread over 200 000 sq km area by 1994 (Jayanth and Visalakshy 1994). Soon after release, *Z. bicolorata* involved in controversy about its host specificity due to its occasional feeding on sunflower (Sridhar 1991, Sushilkumar and Bhan 1996), but after indepth studies under the supervision of Fact Finding Committee constituted by Government of India, the insect was declared safe and ban was lifted for its release (Sushilkumar 2009).

After first release of *Z. bicolorata* in Bengaluru in 1984 in India (Jayanth 1987) and due to deliberate introductions to different regions of the country by Directorate of Weed Research (DWR), Jabalpur after lifting of ban on release of the bioagent, it has widely spread across the country (Sushilkumar 2005, 2009 and 20012; Sushilkumar and Varsheny 2007). Incidence of *Z. bicolorata* has been recorded mild to heavy in most of the states wherever it was introduced. An economic benefit of 12150% was recorded by 6th years of its initial release comparing single application of herbicides (Sushilkumar 2006).

In India, establishment of *Z. bicolorata* has been reported corresponding to the level of infestation. This could be possible because of increased biological control efforts by DWR since 2001 by sending the beetles by post to almost all the Krishi Vigyan Kendras (KVKs) and All India Coordinated Research Project on Weed control. Sushilkumar (2005) after observing the widespread establishment of *Z. bicolorata* in Ludhiana up to Bagha border (Punjab) forecasted the bioagent entry from this route to Pakistan. Later on, Javaid and Shabbir (2006) spotted this bioagent first time from Lahor and Changa Manga Forest area of Pakistan. In Nepal too, the bioagent was entered from the nearby released places of Uttar Pradesh. This widespread occurrence of *Z. bicolorata* in India is in contrast to

earlier predictions (Jayanth and Bali 1993), who suggested that *Z. bicolorata* would not be suitable for hot regions of Central and West India and cold regions of Himachal Pradesh, Uttarakhand, Punjab and Western Uttar Pradesh. Dhileepan and Senaratne (2009) have also found the occurrence of *Z. bicolorata* in very hot and cold regions of India. Diapause in *Z. bicolorata* has been considered a negative attribute which hampers its activity (Jayanth and Bali 1993a). The diapause was broken by regulation of temperature to enhance the activity of *Z. bicolorta.* After breaking of diapause, femail laid eggs normally (Sushilkumar and Ray 2010). In crop situations, *Z. bicolorata* was found to have limited scope due to disturbance of soil during agricultural activities. However, biological control approach may be viable through augmentation of the bioagent as was demonstrated by (Sushilkumar and Ray 2011). The augmentation of bioagent may be achieved through large scale multiplication in net houses (Sushilkumar 2005).

In India, *Z. bicolorata* has well established in Andhra Pradesh, Bihar, Delhi, Haryana, Karnataka, Maharashtra, Madhya Pradesh, Punjab, Uttar Pradesh and lower hills of Himachal Pradesh and Uttarakhand, while it has medium spread and established in Odisha, Rajasthan, Tamil Nadu, upper hills of Uttarakhand and Himachal Pradesh and low established and spread in Assam, Jharkhand, Gujrat, Kerala and West Bengal. It has nil to negligible spread in Andman & Nicobar, Arunachal Pradesh, Goa, Meghalaya, Mizoram, Manipur, Sikkim, *etc* .In Tamil Nadu and Andhra Pradesh, *Z. bicolorata* has been well spread only in Western and Northern and North and West regions, respectively. In general, the incidence and spread of *Z. bicolorata* was recorded negligible in all the coastal regions besides cold and hot deserts of India (Sushilkumar 2005, 2012).

Classical biological control work in Australia is the most widely used methods and so far, 11 biological control agents (nine insect species and two rust fungi) have been released into the field. Several of these released agents have established in the field, but only three bioagents namely *Epiblema strenuana* (a stem-galling moth), *Zygogramma bicolorata* r (a leaf-feeding beetle) and *Listronotus setosipennis* (a stem boring weevil) appeared to be have a significant impact upon weed in the field Dhileepan (2009), Dhileepan and McFadyen (2012)

(iii) *Biological management of Parthenium by competitive replacement through plants:* This approach has also gained momentum after reports from India that *Cassia sericea* (=*C. uniflora*) can be used to control *Parthenium* in India (Singh 1983). *Cassia sericea*, a non-nitrogen fixing leguminous plant was suggested to be used by adopting two approaches *viz.* maintaining of naturally occurring bio-diversity and planting of species in target area (Mahadevappa 2009). In a nation wide survey under coordinated project sponsored by Department of Biotechnology (DBT), India, plant species namely *Xanthium strumarium, Tephrosia purpurea, Achyranthes aspera,Vitex negundo, Cassia sericea, Cassia tora, Cassia* spp. and *Cannabis sativa* were found to be competitive against the weed. *X. strumarium, T. purpurea, Cassia sericea* and *Cassia tora* were found most abundant species in wasteland, community land and along the road and railway track sides. After indepth deliberation of different attributes of these botanicals, *Cassia tora* was recommended to replace *Parthenium* (Yaduraju *et al.* 2005, Sushilkumar 2012).

In Jabalpur (Madhya Pradesh, India), replacement of *Parthenium* by marigold showed encouraging results and this practice was also advocated for *Parthenium* suppression (Sushilkumar 2011) in protected premises to suppress the weed apart of enhancing aesthetic value. In and around Jabalpur and many other districts of Madhya Pradesh *Cassia tora* was found to replace *Parthenium* naturally (Sushilkumar and Bhan 1997). In Jabalpur, replacement of *Parthenium* by *Cassia tora* has been well demonstrated along the road side by Sushilkumar (2011).

In Australia, Bowen *et al.* (2007) tested a number of grass and legume species against the *Parthenium* plants. Khan *et al.* (2013) tested a number of native and introduced pasture species and found that several of them suppressed *Parthenium* growth in both glasshouse and field conditions. The study of Navie *et al.* (1998) showed that the combined action of the stem-galling moth (*Epiblema strenuana*) and buffel grass (*Cenchrus cilla*ris) could significantly compromise the vegetative and reproductive growth of the weed. More recently, Shabbir *et al.* (2013) showed in a field study that biological control agents and suppressive plants can act together significantly to reduce the biomass and seed production of *Parthenium*.

Parthenium* management through its utilization*: The large scale utilization of *Parthenium* may also be one of the effective methods to manage the weed. Keeping in view the huge green and dry biomass of *Parthenium*, available in India and other countries, there is need to change this curse to boon by harnessing its various uses. The potential use of *Parthenium* was reviewed by Ramaswami (1997) and Varsheny and Sushilkumar 2010).

(i) Parthenium use as biopesticde: *Parthenium* has been well documented for its insecticidal, nematicidal and herbicidal properties (Gajendra and Gopalan 1982) besides oxalic acid (Mane *et al.* 1986) and biogas production (Gunasheelan 1987). Datta and Saxena (1996) have shown antifeedant efficacy of parthenin and it's dehydrated product to a polyphagous insect *Spodoptera litura*. Singh and Sushilkumar (2004) have found its antifeedant activity against forest pests. It was very interesting finding that *Parthenium* does not act only as an antifeedant or inhibitor but for silkworm, it also act as a phagostimulant (Patil *et al.* 1997). Pandey (1996) found sesquiterpene lactone parthenin, one of the major toxins in *Parthenium* toxic at 50 PPM to the floating aquatic weeds pistia (*Pistia stratiotes*) and lemna (*Lemna pausicostata*), and at 100 PPM to water hyacinth (*Eichhornia crassipes*), salvinia (*Salvinia molesta*), azolla (*Azolla nilotica*) and spirodella *Spirodela polyrhiza*. The lethal dose for the submerged weeds najas (*Najas graminea*), ceratophyllum (*Ceratophyllum demersum*) and hydrilla (*Hydrilla verticillata*) was 25 ppm.

(ii) Parthenium use as compost and vermi-compost: Compost and vermi-compost making from *Parthenium* may be one of the most economical and practical methods for farmers, colony residents, village Panchayat [authority] and municipalities. To ensure the killing of *Parthenium* seeds during compost making, a pit method was standardized and developed at Directorate of Weed Research (DWR) at Jabalpur (Madhya Pradesh). Study showed that compost prepared by mixing *Parthenium* with dung slurry, soil and urea in layers in at least 90 cm deep pit in anaerobic conditions could kill the *Parthenium* seeds also and compost quality was superior than the FYM (Sushilkumar *et al.* 2005). Likewise, *Parthenium* green biomass can also be converted into vermi-compost which has more nutrients than the compost prepared from pit method. *Parthenium* can also be used as green manure.

***Parthenium* management through stakeholders' participation:** Stakeholders participation recommonded by Sushilkumar and Saraswat (2001), Batish *et al.* (2004) and Sushilkumar (2005) were implimented through nation wide awareness programme and involvment for the management of *Parthenium*. It may be cited as an example to motivate people of other countries suffering from the menace of *Parthenium*. Directorate of Weed Research, Jabalpur initiated and organized people awareness raising activities throughout India involving different stakeholders like 24 centres of All India Co-ordinating Programme on Weed Control (AICRP-WC) representing almost every state of India , about 550 KVKs located in various disticts of each state, about 100 institutes under Indian Council of Agricultural Research (ICAR), many NGOs, environmental agencies, students and farmers. For effective participation of stakeholders, posters, books, extension folders and video films on *Parthenium* management were developed and distributed to them with the request to organize awareness activities by different ways as deem fit to them. DWR has also organized many training courses on *Parthenium* management for KVKs personnel, NGOs and progressive farmers besides organizing many farmer meetings at village and student meetings at school and college level. Responses received from different stakeholders from all over India proved that large number of people participated in the awareness programme through rallies, practical demonstrations, photo exhibition, film showing and broadcasting programme on radio (Gogoi *et al.* 2005,Varshney and Sushilkumar 2006-2010, Sushilkumar and Ranganatha 2011, Sushilkumar and Sharma 2012).

Integrated *Parthenium* management: From the review of literature and discussion thereon, it is clear that *Parthenium* can not be controlled by adopting any single method. Sushilkumar and Saraswat (1997) strongly advocated that *Parthenium* can be managed effectively only by adopting integrated approaches involving people participation. They suggested Integrated *Parthenium* Management (IMP) scheme involving the integration of all the available methods at different time of the year keeping in view the biology and germination of *Parthenium*. For example, manual removal involving public participation during rainy season when soil is wet and uprooting is easy, use of chemicals during winter and summer as spot treatment, use of botanical like *Cassia tora* and exotic insect *Z. bicolorata* during rainy season and involving *Parthenium* Active Group (PAG).

For effective implementation of *Parthenium* management programme, it was advocated to continue the efforts for at least 5-6 years to exhaust the avail able seed bank in the soil. Further adequate quarantine measures should be adopted to check the immigration and emigration of the weed. Therefore, combined efforts by researchers, social workers, department of horticulture, agriculture and forestry are required (Sushilkumar 2005, Sushilkumar and Varshney 2007). Effective linkage of different regional groups of different countries with international *Parthenium* weed network of Australia was advocated by Adkins and Shabbir (2014) for exchange of information amidst the different countries as in this group 300 members across the 30 countries are involved.

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