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First case of *Parthenium hysterophorus* L. in the southern fringes of the Okavango Delta, northern Botswana

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Parthenium weed (*Parthenium hysterophorus* L.), an Asteraceae annual plant that has successfully escaped from its native range in Central and South American and is now globally spread in many tropical and subtropical regions of the world. It is now recognized globally as a major threat to biodiversity, the environment, agro-ecosystems, and human health as is known to cause dermatitis, asthma, hay fever and bronchitis. In crop production yield loses of up to 40% have been reported. Parthenium weed possess a suite of attributes that confer its invasiveness, and include rapid growth, allelopathy, prolific seed production, persistence of seeds in soil seed bank and tolerance to drought. In the early stages of its invasion, it is mainly found in disturbed habitats such as roadsides, along railway tracks, and agricultural farms, probably due to lack of interspecies competition. In its later stages of invasion, the plant moves from these locations into the agro- and natural- ecosystems.

Latest reports indicate parthenium weed is now invasive in 49 countries, including Botswana. The first case in Botswana was reported in 2015 in Tlokweng, south eastern Botswana. The second invasion is the one currently discussed in this report and is many km from the first invasion site. It appears these two occurrences are unrelated. In Africa, it is reported widely dispersed in East Africa, and in some parts of Northern and Southern Africa. Of concern to Botswana is its reported presence in neighbouring South Africa in the provinces of Limpopo, KwaZulu Natal, Mpumalanga and North-West. South Africa shares 1,969 km long border with Botswana. Furthermore, Botswana imports 80% of its cereal grains and some horticultural crops from South Africa, putting it at risk of further accidental introduction of parthenium weed seed as a contaminant of those imported grains and horticultural produce, or by vehicle traffic over the border.

Parthenium weed has recently be recorded from the seasonal floodplains of Thamalakane River (Figures 1 and 2), on the southern fringes of the Okavango Delta, and many km from its original introduction. In this new infestation it was found to be growing in association with another invasive plant, cocklebur (*Xanthium stramonium* L.). The presence of parthenium weed close to the Okavango Delta, a Ramsar and World Heritage site is of great concern. Communities that live on the fringes of the Delta derive their livelihood through fishing and tourism-related activities. Additionally, flood recession farming, a traditional practice in which farmers growing crops on the residual moisture retained within the seasonal floodplains is also an important livelihood activity for these riparian communities. These livelihood activities are under threat due to the 'arrival' of parthenium weed.

Figure1. Parthenium weed flowers (a) and leaves (b) from an infestation growing in association with *Xanthium stramonium* along the seasonal floodplains of the Thamalakane River, Botswana.

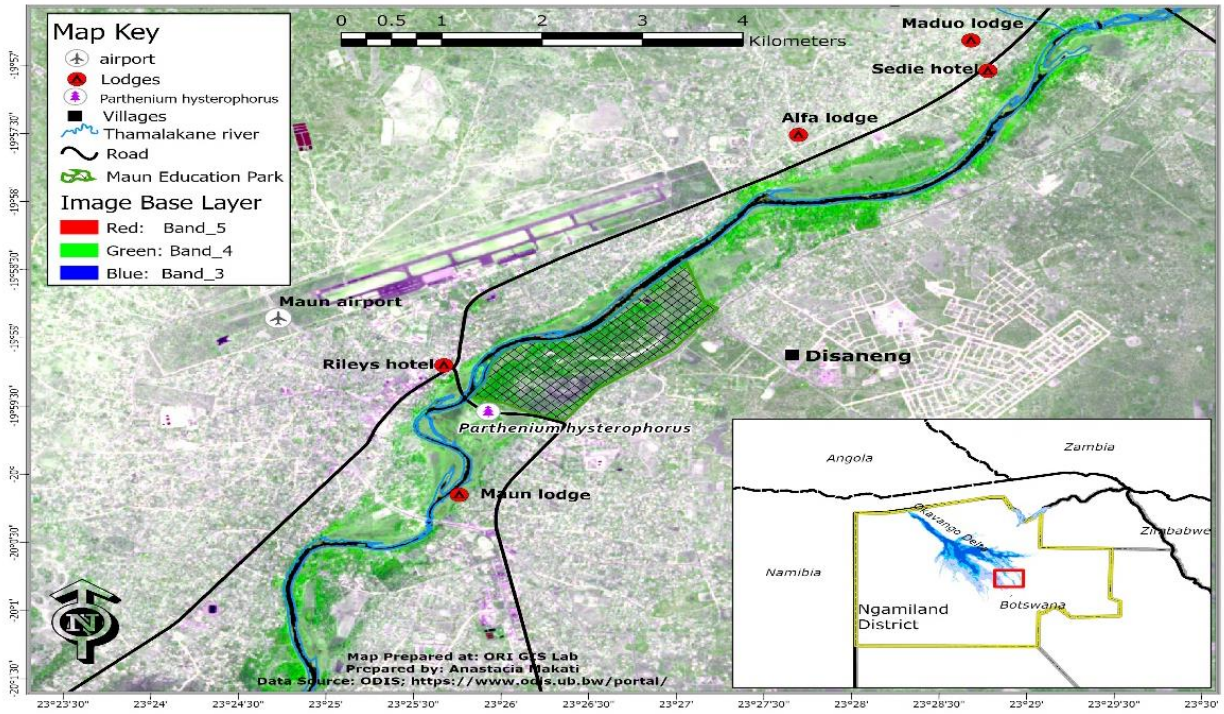

Figure 2: Map showing the location of the present parthenium weed infestation along the seasonal floodplains of Thamalakane river in Botswana.

Botswana is endowed with large areas of protected lands, with > 37% of these lands declared as either totally or partially protected. These areas include national parks, game reserves, forest reserves and nature sanctuaries. The presence of parthenium weed in Botswana is now a major threat to these protected areas, in particular the Maun Educational Park and Moremi Game which lie within the Okavango Delta reserve where the most recent case of parthenium weed infestation has been recorded. The flora and fauna in these protected areas are essential components of the natural biodiversity and ecosystem services of these regions and need to be conserved.

The invasion of Botswana by parthenium weed is still at its early stage and its negative impacts are still considered to be low. Therefore, relevant government departments and stakeholders including farmers may not be aware, let alone to be able to identify parthenium weed. The following are recommended actions that should be taken to contain parthenium weed and to limit its spread to other areas:

- Engage the relevant government departments and stakeholders, including farmers and make them aware of the arrival of parthenium weed and its impacts seen in other countries
- Provide the IPAWN identification kit or similar, to government officials and farmers to be used in the identification of parthenium weed in threatened areas.
- Provide management options to the land managers in those areas; including mechanical, and chemical control to eradicate any found new infestations.
- Conduct surveys to establish the full extent of the present parthenium weed invasion.
- At the national level, use species distribution models such as CLIMEX to determine areas that are climatically suitable for parthenium weed invasion, and then conduct surveys in those areas predicted by the model to be at risk.
- Enact laws e.g., an invasive species control act to regulate movement and importation of agricultural produce and machinery and prevent importation and spread of invasive plant species both within and from neighbouring countries.Parthenium weed's first continental introduction was probably to India, where the worst parthenium weed invasions now occur. The earliest record of the weed is in Calcutta in 1810. However, it is commonly believed that this population was subsequently lost, then replaced by a much larger incursion that occurred in 1955 into Pune. By the 1970s this new introduction was well established, having gradually expanded into most environments. By 2007, the weed was in every State of India, where the populations had naturalised into high-density monocultures. Such large populations didnotremain within India's borders. Surveys conducted reported parthenium weed to be in Nepal by 1982, in Bangladesh by 1988, Sri Lanka by 1987, and to Bhutan by 1992. Other sources suggest the introductionto Nepal could be as early as 1967. The spread into Pakistan was first recorded in the 1980s, probably from theborder crossing near Gujrat, Punjab with rapid spread alongthe road network to Islamabad, but not until the 1990s did it start spreading to other areas within Pakistan. The spread within this region was largely aided byvehicle transportation, contaminated within food or seed supplies.

Distribution of parthenium weed (*Parthenium hysterophorus* L.) in the mountainous country of Bhutan

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Bhutan is a tiny Himalayan country sandwiched between China to the north and India to the south. With a population of about 0.72 million, an area of 39,363 km2 (SYB, 2020) and with an altitude ranging from 100 to >7000 meters above sea level (masl). The country is well-known for its vast richness in biodiversity of plants and animals. One report has recorded around 11,248 species present in Bhutan, representing 0.8% of the total biodiversity of the world (NBC, 2019). However, this richness in plant and animal biodiversity is now under serious threat from invasion by alien species. There are already about 43 alien plant species (IAPS) reported in Bhutan and 16 are major IAPS (Yangzom et al., 2018), including parthenium weed (*Parthenium hysterophorus* L.). Major impacts of IAPS on crops and forests (Pallewatta et al., 2003), highland pastures (Suberi et al., 2018) and public health (Figure 1) have already been reported.

Figure 1. A skin allergic reaction to parthenium weed on a woman in Wangduephodrang, who developed this alergy while clearing the weed from her local surroundings.

The presence of parthenium weed in Bhutan was first officially reported in 1992 along the roadsides and dryland areas of Mongar, Trashigang, Trongsa and Wangduephodrang districts (Parker, 1992). Since then, the weed has spread to almost all districts of Bhutan, including the high-altitude areas of Thimphu and Paro. Recently, about a 1 km stretch of the weed was detected along the roadside near Shaba Middle Secondary School, Paro district (Figure 2A) and another stretch of about 300 m long detected near Chunzom, Thimphu district (Figure 2B). The summer rust, a biological control agent for parthenium weed was also detected in Paro (Figure 2C, 1D).

A new study undertaken by the author, to predict the future distribution of parthenium weed in Bhutan, under the present and future climate, demonstrated that parthenium weed would become a major threat in the population dense Paro and Thimphu districts by 2050 and the weed would have a significant distribution in all other districts except for the high altitudinal district of Bumthang (Figure 3). Wangduephodrang district had the highest climatic suitability with about 302 km2 (27.5%), followed by Punakha, Dagana and Samtse. Currently, about 1,100 km2 (2.8% of Bhutan's total area) has been invaded by the weed, including 17 districts (Figure 2).

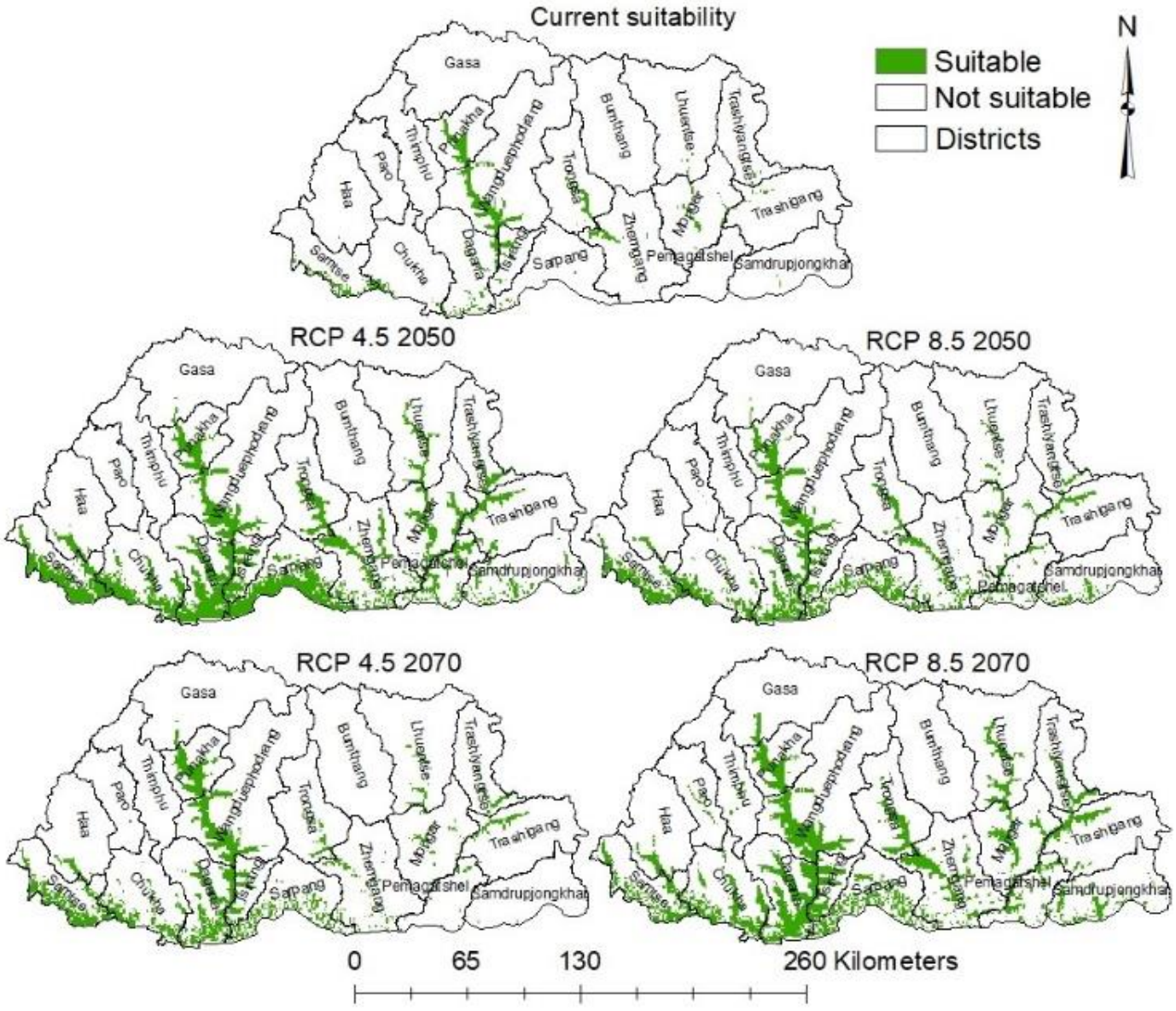

Figure 2. Predicted current and future distribution of parthenium weed in Bhutan under two climatic predictions for the years 2050 and 2070. The suitable areas are shown in green color and unsuitable areas in plain white.

For future climatic scenarios, two representative concentration pathways (RCP) – RCP 4.5 and RCP 8.5 were considered. The RCP 4.5 assumes a steady increase in radiative forcing with a projected global mean surface temperature of 1.4 – 1.8 °C, while the RCP 8.5 assumes the highest increase in radiative forcing with projected global mean surface temperature of 2.0 – 3.7 °C (Pachauri et al., 2014). The highest distribution under future climatic conditions was predicted under RCP 4.5 2050 with about 5,420 km2. District-wise, Sarpang and Dagana showed the highest suitability. Under RCP 8.5 2050, Dagana and Wangduephodrang showed the highest suitability, which remained same under RCP 4.5 2070 and RCP 8.5 2070. The highest elevation suitability was predicted to be at 2,931 masl. The presence of parthenium weed at an elevation of 2,600 masl has already been reported in Bhutan (Adkins, 2012) while in Ethiopia, it has been detected at 2,627 masl (McConnachie*et al*., 2011). The author of this article also detected a population of about five plants at 2,400 masl around his residence (27.51396°N, 89.6404°E) (Figure 4).

Figure 4. Parthenium weed in Taba (27.51396°N, 89.6404°E, 2,400 masl), Thimphu. The red circle shows a single big plant. Other plants are barely visible as they were small.

In summary, the study undertaken on the potential future distribution of parthenium weed in Bhutan showed that under two future climatic projections (RCP 4.5 and 8.5), the suitability of land for invasion in Bhutan will dramatically increase by 2050 and 2070 (Figure 2). Based on these findings, there is an urgent need to develop a country-wide management program for parthenium weed and other IAPS, such management plans need to include immediate components that raise public awareness and educate them on the adverse impacts of all IAS threatening Bhutan.

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Expanding of the parthenium weed populations from road verges to the protected areas in Nepal

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Background

Parthenium weed (*Parthenium hysterophorus* L.) has slightly more than five decades of invasion history in Nepal. Although the weed was first reported in the country during the late 1960s, the major expansion of the weed didn't occur until after the 1990s. Initially limited to urban areas and roadside vegetation, the weed is now spreading rapidly in to agricultural and natural ecosystems, including many protected areas. In the absence of effective management interventions, the current situation of parthenium weed invasion is expected to get worse. Immediate execution of species and site-specific management interventions for the weed can prevent its further expansion in to agricultural and natural ecosystems. These management interventions may range from community education and physical removal, to the promotion and use of the currently available and new biological control agents.

Parthenium beyond road verges

Until 2015, parthenium weed was mainly found in roadside vegetation, urban grasslands, and the abandoned agriculture lands in the urban areas (Figure 1). A national level survey initiated in 2013 revealed that the weed had already spread to most districts, from the southern lowlands to high mountain regions. All of which are connected via the national road network, suggesting that the weed dispersal was along the road network throughout Nepal (Shrestha *et al.*, 2019). From urban areas and road verges, parthenium weed is now expanding into agricultural and natural ecosystems. Field observations have revealed that parthenium weed has already invaded potato, soyabean, maize and rice crop fields in different parts of Nepal (Figure 2). It appears that parthenium weed invasion into the agriculture systems is still at an early stage of invasion, with low levels of impacts. However, the weed could become a major problem, particularly in the non-irrigated farming systems very soon, especially if effort is not put into stopping its further spread. It is essential to make farmers and agriculture extension staff aware of this potential problem and encourage them to control this weed at the early stage of invasions. In addition to agricultural lands, parthenium weed is also spreading rapidly into natural areas including different protected area.

Figure 1. Parthenium weed invading roadside vegetation in Kathmandu valley (A) and abandoned agriculture land in Chitwan valley (B) (Photo:BBShrestha).

Figure 2. Parthenium weed invading different cropping systems: A) a potato field in Bardia, B) a soyabean field in Makawanpur, C) a maize field in Makawanpur, and D) a rice field in Dang. (Photo: A by RB Khadka, others by BB Shrestha)

Parthenium in protected areas

Parthenium weed has invaded several protected areas including five national parks (Banke, Bardia, Chitwan, Parsa and Suklaphanta), one wildlife reserve (Koshi Tappu) and two conservation areas (Blackbuck and Api-Nampa) in Nepal (Bhatt et al. 2021). In most of these protected areas, the status of the parthenium weed invasion and its impacts on these native communities are not yet studied. However, spatial distribution of parthenium weed in Chitwan National Park has been recorded during the Asian one-horned rhinoceros census in 2015 and 2021. The census takers stopped every half hour and visually assessed the coverage of invasive plants including parthenium on a scale of 0, 1 or 2 (0 - absence; 1 - present but covered < 50%; and 2 - cover > 50% of habitat) in semicircular plot of 50 m radius (Lamichhane et al. 2014). The preliminary results have revealed that > 7% of the assessed plots in the rhinoceros habitat of Chitwan National Park has already been invaded by parthenium weed (Figure 3).

Although the percentage of the plots invaded is relatively low, distribution of parthenium weed was widespread across the grasslands and forests in the park, in the buffer zone and outside the park. Similarly, the coverage of the parthenium weed has increased as compared to previous survey in 2015 when it was <2%. Tall grasslands located on the northern part of the National Park, which are the primary habitats of the rhinoceros, are heavily colonized by parthenium weed (Figure 4). High level of invasion was observed in the grassland patches close to roads and areas where interventions (uprooting trees, cutting, and burning) had been applied for grassland management. No specific control measures for parthenium weed have been developed for the Chtiwan National Park but some effort to manage it through physical removal before flowering has been practiced on a small scale, especially in the buffer zone community forests. In addition, a biological control agent, the leaf feeding beetle *Zygogramma bicolorata* has been observed in the buffer zone of Chitwan National Park (Figure 5). Currently, the damage on the parthenium weed plants there is low,

probably due to small population size of the beetle present. Laboratory rearing of the beetle and its release to augment these natural population could increase the effectiveness of the beetle's biological control ability.

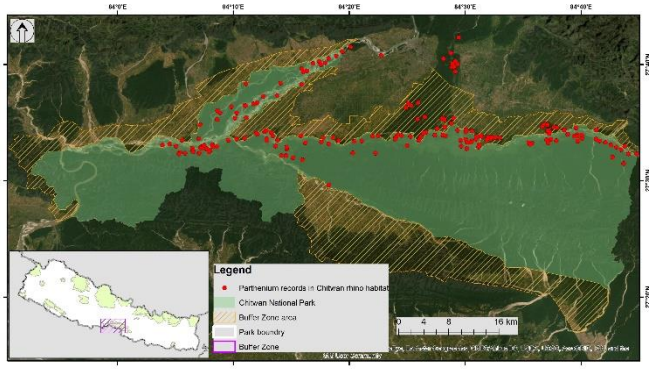

Figure 3. Occurrence of parthenium weed in the rhinoceros habitats of Chitwan National Park in 2021 (Map by BR Lamichhane)

Figure 4. Parthenium invasion in tall grasslands which are the primary habitats of the rhinoceros in Chitwan National Park (Photo: BR Lamichhane).

Figure 5. The biological control agent *Zygogramma bicolorata* recorded in buffer zone community forest of Chitwan National Park (Photo: BR Lamichhane)..

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Is parthenium weed a beneficiary of climate change? Historic rise in carbon dioxide levels have made the weed more toxic

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An international study recently published in prestigious journal; *Nature Plants* has revealed rising carbon dioxide (CO_2) levels in the atmosphere have increased the toxicity of parthenium weed (*Parthenium hysterophorus*). The scientists from the NSW Department of Primary Industries (DPI), the University of Queensland, the United States Department of Agriculture and Columbia University explored the effect of changing CO_2levels on two biotypes of parthenium weed found in Australia. The plants were grown at atmospheric CO_2 levels which were recorded in 1950 at 300 parts per million and in 2020 at 400 ppm.

The leaf tissues of the invasive biotype had concentrations of parthenin, major toxin in parthenium, 49% higher when grown in today's CO_2 levels compared with CO_2 levels 70 years ago. The plants also grew

much bigger in modern-day CO_2 levels compared with the CO_2 levels of pre-industrial era. This shows that this highly invasive plant species has already benefited from the increased atmospheric carbon levels, producing greater amounts of a *'bioweapon'* like parthenin, which suppresses the growth of crops and native plants, is dangerous to grazing animals and can cause serious allergic reactions in people. This is an example of how climate change is making weeds stronger, posing a greater threat to our environment and food security.

The journal paper can be accessed at https://www.nature.com/articles/s41477-021-00938-6,OR contact Dr. Bajwa for a digital copy:

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The Indian Society of Weed Science Webinar – 8 on the Parthenium Weed Problem and its Management at the Global Scale 16th August 2021

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This webinar (Figure 1) was jointly convened by The Indian Society of Weed Science (ISWS) and ICAR-Directorate of Weed Research (DWR), Jabalpur and was held on 16th August 2021 as an online Zoom Meeting. The webinar was organised and overseen by Drs A.K. Pandy, Chairperson and Vice Chancellor of Vikram University, Ujain; Dr Sushil Kumar, Convener and President of the Indian Society of Weed Science (ISWS); and Dr J.S. Mishra, Secretary of ISWS and Director of the Directorate of Weed Research, Jabalpur.

At the outset, Dr Sushilkumar, welcomed the participants. Dr J.S. Mishra, Director, ICAR-DWR briefed about the exhaustive work done by lead speaker Dr Steve Adkins on the parthenium weed at the global level. He shared the objectives of organising 'Parthenium Awareness Week' by the DWR at National level and the Webinar on parthenium weed at the international level.

Figure 1. The details of the Indian Society of Weed Science Webinar – 8 on the Parthenium Weed problem and its management at the global scale on 16th August 2021.

The program started with an informative presentation by the Guest of Honour Dr S. Bhaskar, Assistant Director Indian Council of Agricultural Research New Delhi, who reviewed the topics of the weed's arrival into India, its spread, and its present impacts. Creating awareness about its ill effects is very important aspect, he added. The Chief Guest Dr Suresh Chaudharl, Deputy Director General, Indian Council of Agricultural Research (ICAR) New Delhi then presented a further assessment of the status and management of parthenium weed in India. Useful information concerning the organizations working on the weed was presented, including their recent activities, important outcomes, and future work planned. Dr Choudhary appealed to all the Vice Chancellors of State Agricultural Universities (SAUs), Directors of ICAR institutes and in-charges of Krishi Vigyan Kendra [Agriculture Science Centres] (KVKs) to participate in this activity and to ensure *'Parthenium*-free' campus'

Dr S. Adkins then presented an invited paper on the topic of 'Parthenium Weed Problem and its Management at the Global Scale'. This paper drew upon his experiences of parthenium weed from Australia and around the globe. Information was presented on the topics of its spread around the globe (Figure 2), the weeds invasive traits and spread vectors and finally its management. Reference was made to the biocontrol programs underway around the globe and their successes to date. A further focus of the

presentation was on how a changing global climate will likely enhance the parthenium weed problem.

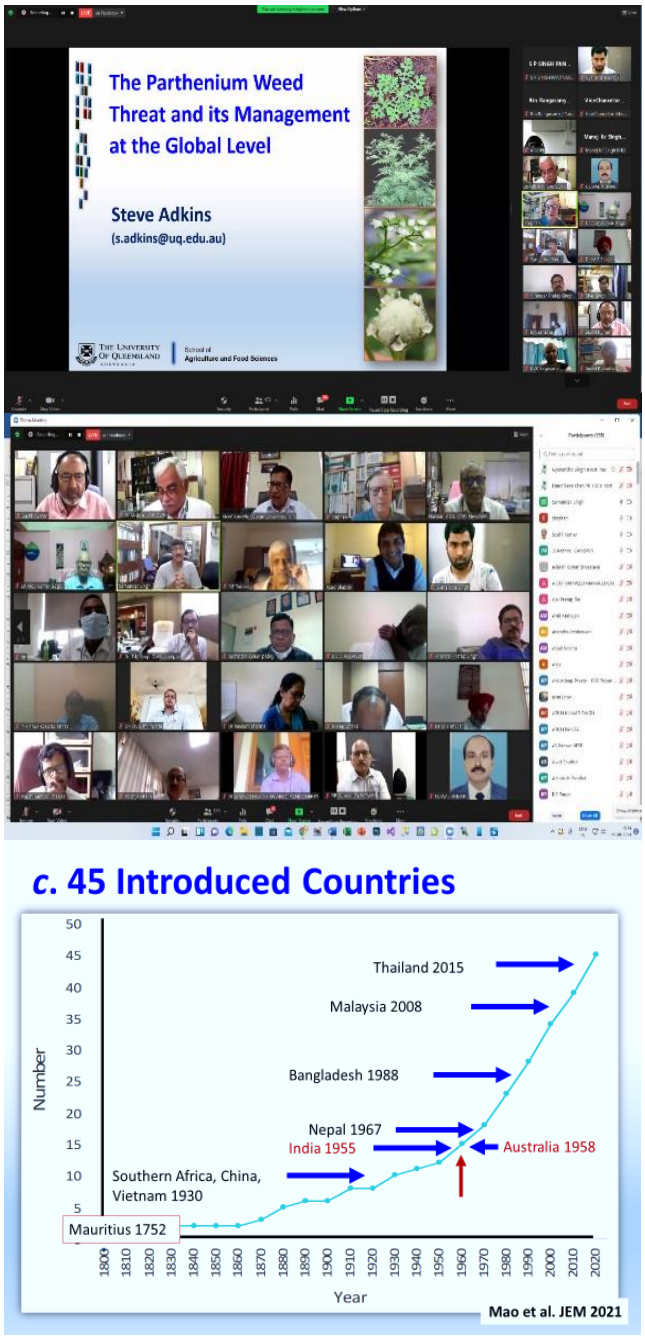

Figure 2. The dates of parthenium weed arrival in countries as it spread around the globe showing a significant increase of the rate of spread from the mid 1950's until the present (from Mao et al. Journal of Environmental Management 2021).

Following the three presentations, an active Question and Answer session took place. Over 470 participants from several countries, including India, Nepal, Bhutan, Bangladesh, Pakistan, and Australia were in attendance. Most inquired after the possibility of a practical solution for parthenium weed in India and the possibility of using biocontrol agents. More information concerning this event will be covered in another report in this IPAWN newsletter.

Biocontrol of Parthenium Webinar

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This webinar event was supported by Virginia Tech's Feed the Future Innovation Lab for Integrated Pest Management: The U.S. Government's Global Hunger and Food Security Initiative and was held on 30 March 2021 as an online Zoom Meeting. The webinar covered topics on biocontrol of parthenium weed ranging from evaluating and rearing of biocontrol agents, to initiating and developing biocontrol programs. Apart from six invited leading scientists who presented at the webinar, Dr Alec McClay who collected potential biocontrol agents in Mexico in the 1970s to 80s also joined this initiative. Nearly 200 participants, coming from at least 14 countries globally attended the online meeting.

Dr. Muniappan, the IPM Innovation Lab Director, started the proceedings by introducing the present scope of the International Organisation for Biological Control, the IOBC Global, as well as the International Association for Plant Protection Sciences. With additional support, he outlined that since 2005 the IPM lab had initiated several classical biocontrol programs against parthenium weed in East Africa and had achieved major successes in these efforts. Useful information concerning the organizations was listed in the presentation, including their recent activities, important websites, and contact information.

Dr. Dhileepan presented next on the topic of Australia's biocontrol program and gave a summary of the countries five decades parthenium weed biocontrol work, giving a perspective of the long-term outcomes of the biological control program. Four insect agents and two rust agents are widespread in central and north Queensland, Australia, and have proven to be effective against parthenium weed's growth and reproduction phases. The view was presented that two agents (*Listronotus setosipennis* and *Carmenta nr. ithacae*) had shown themselves as having great potential for being included in future biocontrol programs in other parts of the world (Figure 1). He then went on to explain that redistribution of these agents, to other infested areas of southern Queensland, had become the focus their biocontrol work in Australia.

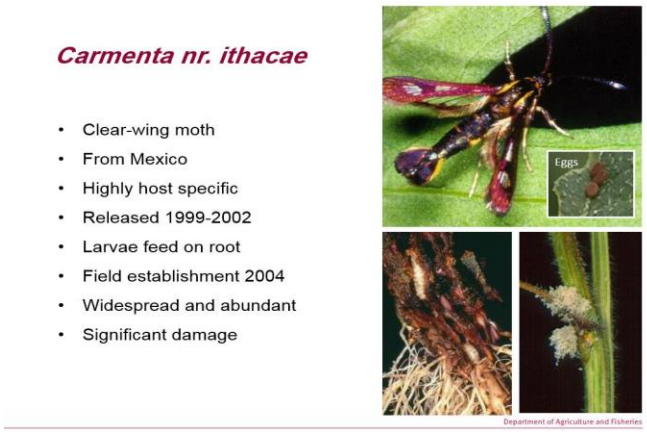

Figure 1. Details of *Carmenta*nr.*Ithacae,* a biocontrol agent having great potential for being included in many future biocontrol programs around the world.

Dr Strathie from ARC South Africa summarised the biocontrol efforts since 2003 and current research underway in South Africa, including the results of a survey to determine the establishment of three recently introduced biocontrol agents, *Smicronyx lutulentus*, *Listronotus setosipennis* and *Zygogramma bicolorata* into South Africa. The South African initiative also involved the supply of biocontrol agent starter cultures and techniques to several African and South Asian countries (Figure 2).

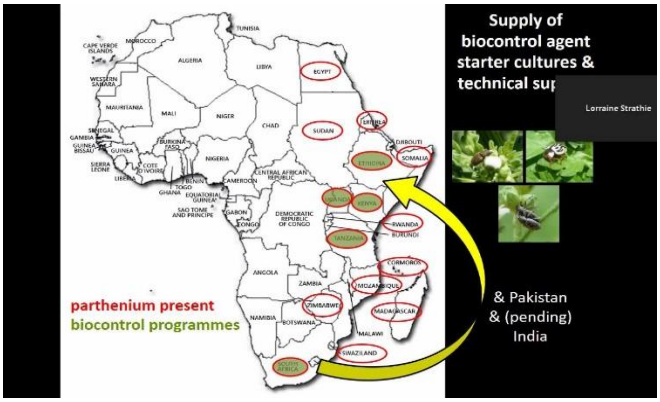

Figure 2. The South African initiative has involved the supply of biocontrol agent starter cultures and techniques to several African and South Asian countries.

Dr Mersie from Virginia Tech's Feed the Future Innovation Lab discussed the introduction and rearing of biocontrol agents in Eastern Africa, their release and the early impacts. Substantial defoliation by *Z. bicolorata* had then been detected in Ethiopia, while damage caused by *Puccinia abrupta* var.*partheniicola* had been considerable due to unusually high rainfall. Following the successful introduction into Ethiopia, permits have now obtained to release two agents, *Z. bicolorata* and *L. setosipennis* from South Africa to Kenya. In Uganda, these two agents have been released in two phases from late 2019 to early 2021.

Dr. Bakthavatsala from the Indian Council of Agricultural Research (ICAR) summarised the biocontrol program for parthenium weed in India. A list of insects, including the already introduced *Z. bicolorata,* and other local species (Figure 3) that have been found to damage the weed in the field, was presented. The local species are to be included in a plan to find new damaging agents in India. The recent failure of *S. lutulentus* in quarantine needs to be examined, while *Bucculatrix parthenica* and *C. nr. Ithacae* may also be introduced into the current biocontrol effort.

Insect species recorded in India

Species	Damage
Hypothenamus erudistus (Scolytid)	Stem borer
Oberea sp (Cerambycid)	Stem borer
Ferrisia virgate, mites *Tetranychus cucurbitae* and *Tetranychus* sp., *Aphis fabae* and *Pseudococcus* sp	Sucking pests
Nupserha sp (cerambycid)	borer
Heliothis helicoverpa, Clania cramari, Dicrasia obliqua and grass-hoppers	Foliage feeder

Figure 3. Local Indian species that have been found to damage parthenium weed in the field and are to be considered for use as agents to control the weed

Dr. Jha from Tribhuvan University Kathmandu described the invasive status of parthenium weed in Nepal and the accidental arrival of two biocontrol agents, Z. *bicolorata* and *P. abrupta* var. p*artheniicola*. Recent studied have demonstrated that parthenium weed will spread further in the country by 2050 and 2070. The distribution of the weed and *Z. bicolorata* has already been mapped, however further surveys of the two introduced biocontrol agents are planned.
Dr Ali reported that the Centre for Agriculture and Bioscience International (CABI) laboratory in Pakistan has initiated a biocontrol program from a newly established quarantine facility. He reported that Pakistan already has the biocontrol agents *Z. bicolorata* and *P. abrupta* var *partheniicola* through accidental introduction. The possible host range of *L. setosipennis* is presently being conducted to gain a better understanding of its potential use in Pakistan. If successful, a third biocontrol agent is expected to be introduced into Pakistan soon.

Following the six presentations, an active Question and Answer session took place. Participants from several countries including Pakistan, Nepal, India, Oman all inquired after the possibility of a practical solution for parthenium weed management using biocontrol agents. At the end of the session, contact information was posted and exchanged on the discussion board. With the support from organizers and all contributing authors, all presentations of the webinar have been shared on Google Doc after the event: https://drive.google.com/drive/folders/1BOSAFBic_HZ

o1k7q Ra2MkqbDoXUQxDpm. More information about this event can be found in IOBC Global Newsletter 109 (July 2021) at https://www.iobc-wprs.org/IOBC-Global_Newsletter_109_2021.pdf

Upcoming Conferences on Weed Science and Invasive Species

62nd Annual Meeting of the Weed Science Society of America

Dates: 21-24Febuary2022
Venue: Vancouver, CANADA
Website:https://wssa.net/meeting/2021-annual-meeting/

19th EWRS Symposium 2022

Dates: 20-23June2022
Venue: Athens, GREECE
Website: https://www.ewrs.org/en/info/Upcoming-events/19th-EWRS-Symposium-2022-Athens-Greece

22nd Australasian Weeds Conference (22AWC)

Dates: 22-29 September2022
Venue: Adelaide Oval, SA, AUSTRALIA
Website:https://wmssa.org.au/22awc/

8th International Weed Science Congress

Dates: 4 - 10 December 2022
Venue: Bangkok, THAILAND
Website:https://www.iwsc2020.com/

Recent Publications

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