INSIGHTS

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How widespread is *Parthenium hysterophorus* and its biological control agent *Zygogramma bicolorata* in South Asia?

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Summary

Parthenium hysterophorus is a weed of global significance causing severe economic, environmental, human and animal health problems in Asia, Africa, Australia and the Pacific. In South Asia, *P. hysterophorus* occurs in India, Pakistan, Sri Lanka, Bangladesh and Nepal. A host-specific leaf-feeding beetle *Zygogramma bicolorata* from México was introduced into India in 1984, as a biological control agent for *P. hysterophorus*. In this study, a GIS-based distribution map of *P. hysterophorus* and its biological control agent *Z. bicolorata* in South Asia based on meta-analysis is presented. The map highlights the limited published information on *P. hysterophorus* incidence in many of the states and territories in India, as well as in neighbouring Bangladesh, Bhutan, Nepal and Pakistan. Incidence of *Z. bicolorata* was recorded as three distinct clusters, covering many states in India. In Pakistan, *Z. bicolorata* was recorded in the Punjab region bordering India. A CLIMEX model based on the current distribution of *Z. bicolorata* in India suggests that the geographic range of this agent in India and Pakistan can extend to other *P. hysterophorus*-infested areas in the region. The CLIMEX model also suggests that all of Bangladesh and Sri Lanka, and parts of Nepal are climatically suitable for *Z. bicolorata*.

Keywords: biological control, climate model, parthenium weed, chrysomelid beetle, distribution, CLIMEX, India, South Asia.

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Introduction

Parthenium hysterophorus L., (parthenium; Asteraceae) is a weed of global significance occurring in Asia (Bangladesh, India, Israel, Pakistan, Nepal, southern China, Sri Lanka, Taiwan and Vietnam), Africa (Ethiopia, Kenya, Madagascar, Mozambique, South Africa, Somalia, Swaziland and Zimbabwe), Australia and the Pacific (New Caledonia, Papua New Guinea, Seychelles and Vanuatu) (Dhileepan, 2009). *Parthenium hysterophorus* causes severe human and animal health issues, agricultural losses and serious environmental problems (Dhileepan, 2009; Dhileepan & Strathie, 2009). In South Asia, *P. hysterophorus* was first reported in India in 1956 (Rao, 1956) and now occurs throughout the country (Yaduraju *et al*., 2005). *Parthenium hysterophorus* has spread to neighbouring countries, including Pakistan (Javaid & Anjum, 2005; Shabbir & Bajwa, 2006), Sri Lanka (Jayasurya, 2005), Bangladesh (Rahman *et al*., 2008; Karim, 2009) and Nepal (Adhikari & Tiwari, 2004).

Biological control of *P. hysterophorus* in South Asia was initiated in India in 1984 with the introduction of a host-specific leaf-feeding beetle *Zygogramma bicolorata*

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Pallister (Coleoptera: Chrysomelidae) from México (Jayanth, 1987). The biological control agent became established that year, but its population levels attained damaging levels only after 3 years (Jayanth & Geetha, 1994). Field releases continued in 15 states in India (Viraktamath *et al*., 2004) and now the beetle occurs in a majority of areas in India and in the Punjab region of Pakistan (Dhileepan & Strathie, 2009). Attempts to establish *Z. bicolorata* under quarantine in Sri Lanka have not been successful (Dhileepan, 2009).

A considerable amount of literature is available on *P. hysterophorus* and its biological control agent *Z. bicolorata* in South Asia, most of them from India. This includes 574 publications (cited in CAB abstracts up to April 2009) and proceedings of two international conferences (Mahadevappa & Patil, 1997; Ramachandra Prasad *et al*., 2005). However, no spatial information is available on the distribution of *P. hysterophorus* and its biological control agent on a national scale. A GIS-based distribution map would be valuable to understand the current distribution of *P. hysterophorus* and its biological control agent in South Asia, and to develop spatial and climate models. This would also help to identify areas where such spatial information is lacking, to focus future survey efforts. A climate model would help to identify climatically suitable areas to introduce *Z. bicolorata*.

Materials and methods

Study organisms

Parthenium hysterophorus, native to the Gulf of México and central South America, is an annual herb with an extensive root system and an erect shoot that becomes woody with ageing. Young plants initially develop into a rosette with a short stem and numerous large leaves close to the ground. As it matures, the plant develops many branches and may eventually reach a height of more than 2 m. A fully-grown plant can produce more than 15 000 flowers in its lifetime, with each flower bearing four or five seeds. With suitable moisture and temperature, *P. hysterophorus* can germinate and grow at any time of the year.

Adults and larvae of *Z. bicolorata* feed preferentially on younger leaves of *P. hysterophorus*. Adults lay eggs on the leaves, flower heads, stems, and on terminal and axillary buds. The emerging larvae feed on leaves and the fully-grown larvae burrow into the soil to pupate. The pupal stage lasts 2 weeks. The life cycle is completed in 6–8 weeks and up to four generations per year occur, depending on rainfall and food availability. In India, adults undergo diapause in the dry season (November–April) and emerge with the commencement of monsoon rains (May–June). Adult beetles live up to 2 years and spend up to 6 months under diapause in soil.

Distribution maps

Distribution maps of *P. hysterophorus* and *Z. bicolorata* in South Asia were developed using ArcGIS 9.3 software, on the basis of a meta-analysis of published information, web-searches (including newspaper articles) and opportunistic surveys (Gujarat, Rajasthan and Tamil Nadu states in India). Only studies that contained details on the study sites were included. A total of 551 sites with *P. hysterophorus* in Bangladesh (3 sites), India (495 sites), Nepal (9 sites), Pakistan (16 sites) and Sri Lanka (28 sites) were identified (Table 1). However, GPS readings could be obtained only for 499 sites through map-locating websites (http://multiMAP.com and http://earth.google.com).

CLIMEX model

CLIMEX^{TM} (Sutherst *et al*., 2007) is a climate modelling software package widely used to predict the potential establishment and distribution of invasive plants (e.g. Dunlop *et al*., 2006; Potter *et al*., 2009) and their biological control agents (e.g. Palmer *et al*., 2007; Rafter *et al*., 2008). The climate profile of *Z. bicolorata* (Table 2), derived from its current distribution in India and earlier biological studies (e.g. Jayanth & Geetha, 1993, 1995; Sushilkumar & Bhan, 1997; Gautam *et al*., 2005), was used to identify climatically suitable areas for *Z. bicolorata* and thus its potential distribution range in South Asia. The suitability of an area was expressed in terms of its Eco-climatic Index (EI), with areas having an EI value of >30 considered favourable (Sutherst *et al*., 2007). The distribution map was produced on a 10-min grid using interpolated climate data and the ArcGIS program.

Results and discussion

Based on the analysis, a comprehensive map of the documented distribution of parthenium in South Asia (Fig. 1; Table 1) was developed. *Parthenium hysterophorus* has been reported from all states and territories in India. We believe that *P. hysterophorus* in India may be more widespread than shown here. The density of records does not reflect *P. hysterophorus* infestation levels, but rather the survey efforts. For example, although *P. hysterophorus* is currently not a major weed in Kerala, the high number of infestations documented in Kerala (Fig. 1) was because of the systematic nature of surveys made in this state (Abraham & Girija, 2005). Similar systematic surveys are required in other states and

Table 1 The number of documented sites with *P. hysterophorus* and its biological control agent *Z. bicolorata* in South Asia

Country/state or province	Number of recorded sites	
	P. hysterophorus	*Z. bicolorata*
Bangladesh (states)	**3**	**0**
Chittagong	0	0
Khulna	1	0
Dhaka	1	0
Rajshahi	1	0
India (states & territories)	**495**	**118**
Andaman & Nicobar islands	2	0
Andhra Pradesh	28	10
Arunachal Pradesh	1	0
Assam	14	0
Bihar	7	0
Chattishgarh	15	10
Delhi	6	2
Gujarat	5	0
Haryana	15	2
Himachal Pradesh	15	5
Jammu & Kashmir	9	4
Jharkhand	3	0
Karnataka	72	23
Kerala	71	0
Madhya Pradesh	47	6
Maharashtra	49	28
Manipur	1	0
Meghalaya	1	0
Mizoram	1	0
Nagaland	1	0
Orissa	10	1
Pondicherry	9	0
Punjab	9	5
Rajasthan	10	0
Sikkim	1	0
Tamil Nadu	49	15
Uttar Pradesh	22	4
Uttaranchal	8	2
West Bengal	14	1
Nepal (regions)	**9**	**0**
Far Western region	0	0
Mid Western region	1	0
Western region	3	0
Central region	4	0
Eastern region	1	0
Pakistan (provinces)	**16**	**3**
Baluchistan	0	0
Northern areas	0	0
North West Frontier province	5	0
Punjab	11	3
Sind	0	0
Sri Lanka (provinces)	**28**	**0**
Northern province	4	0
North Central province	8	0
North Western province	2	0
Eastern province	2	0
Central province	4	0
Western province	0	0
Southern province	0	0
Sabara-Gumuwa province	3	0
UVA province	5	0

territories in India, where only limited published information is available (Fig. 1, Table 1). In Pakistan, most of the reports of *P. hysterophorus* infestations have been in the north-eastern parts of Punjab province bordering India (Fig. 1). *Parthenium hysterophorus* has the potential to spread throughout Punjab and Sind provinces in Pakistan, in view of the current *P. hysterophorus* occurrence in adjoining Gujarat, Rajasthan, Jammu and Kashmir states in India. In Nepal, *P. hysterophorus* occurs widely (Fig. 1), including Kathmandu valley and Siwalik and Terai regions. In Bangladesh, *P. hysterophorus* has been reported recently in Dhaka, Jessore and Rajshahi districts (Rahman *et al.*, 2008; Karim, 2009) (Fig. 1, Table 1). However, no systematic surveys have been made so far on *P. hysterophorus* incidence in Nepal, Bhutan and Bangladesh. It is highly likely that the weed occurs more widely in these countries, as it is widespread in adjacent areas in India (Fig. 1).

In India, *Z. bicolorata* was first released in the Bangalore region in 1984 (Jayanth, 1987) and since then due to natural spread and deliberate introductions has spread widely across the country (Viraktamath *et al.*, 2004). Incidence of *Z. bicolorata* was recorded at 118 sites as three distinct clusters, covering the majority of the states in India (Table 1, Fig. 2). In India, the number of sites with *Z. bicolorata* reported in each state increased with the increase in the number of recorded sites with *P. hysterophorus* ($R^2 = 0.51$, $F = 29.8$, $P < 0.001$). This was possibly because of increased biological control efforts in states where *P. hysterophorus* is more widespread (e.g. Karnataka and Maharashtra). Widespread incidence of *Z. bicolorata* in India is in contrast to earlier predictions, which suggested that *Z. bicolorata* would not be suitable for arid regions of central India (Jayanth & Visalakshy, 1994). In Australia, unlike in India, *Z. bicolorata* has a restricted distribution range, mainly in central Queensland (Dhileepan & McFadyen, 1997). In India, *Z. bicolorata* is widespread in Karnataka and Maharashtra states, while in other states, it has a limited geographic range (Fig. 2). For example, in Tamil Nadu, *Z. bicolorata* has been recorded only in western and northern regions. Similarly, in Andhra Pradesh, recordings were mostly in the north and in west bordering Karnataka, with very limited recordings in the coastal and southern regions. Incidence of *Z. bicolorata* has not been documented in Gujarat, Rajasthan, Kerala, Jharkhand, north-eastern states including Assam and Andaman and Nicobar Islands (Fig. 2). In Pakistan, *Z. bicolorata* has been recorded from the Punjab region (Shabbir & Bajwa, 2006) bordering India (Fig. 2). It is possible that *Z. bicolorata* from the bordering regions of India has spread naturally into Pakistan, as this agent was not introduced officially in Pakistan. So far, *Z. bicolorata*

Table 2 The indices and parameters used to develop a model of the potential geographic range of *Z. bicolorata* from its current distribution in India

Index	CLIMEX parameter	Value
Temperature	Limiting low temperature	12
	Lower optimal temperature	18
	Upper optimal temperature	35
	Limiting high temperature	40
Moisture	Limiting low moisture	0.05
	Lower optimal moisture	0.15
	Upper optimal moisture	1.0
	Limiting high moisture	2.0
Cold stress	Cold stress temperature threshold	6
	Cold stress temperature rate	−0.01
	Cold stress degree-day threshold	7
	Cold stress degree-day rate	−0.01
Heat stress	Heat stress temperature threshold	40
	Heat stress temperature rate	0.005
Dry stress	Dry stress threshold	0.05
	Dry stress rate	−0.05
Wet stress	Wet stress threshold	2.00
	Wet stress rate	0.005

has not been reported from Bhutan, Bangladesh and Nepal, but is likely that the biological control agent will spread into these countries from India, as in Pakistan.

A more systematic survey is required in areas where *Z. bicolorata* has not been recorded, to understand the extent of spread of the agent in India and Pakistan. A CLIMEX model on the basis of current distribution of *Z. bicolorata* in India suggests that the geographic range of this agent can extend to other *P. hysterophorus* infested areas in central, eastern coast and the north-eastern region in mainland India, as well as in the Andaman and Nicobar Islands, where the agent is currently not known to occur (Fig. 3). The CLIMEX model also suggests that all of Sri Lanka and Bangladesh, northern parts of Pakistan and southern parts of Nepal are also climatically suitable for *Z. bicolorata* (Fig. 3). Hence, future attempts should focus on redistributing the agent in the climatically suitable areas within India (e.g. north-eastern states), Pakistan (e.g. Punjab region), Bangladesh and Sri Lanka.

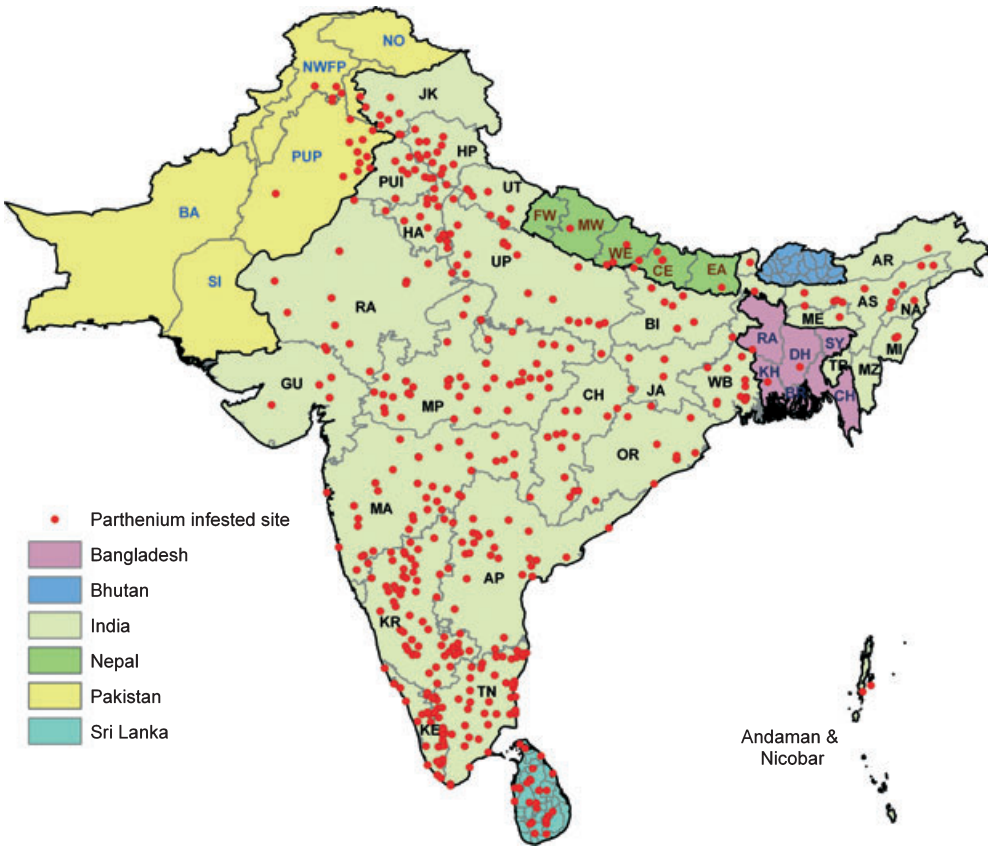

Fig. 1 Map showing sites known to be infested with parthenium in Bangladesh (BR, Barsal; DH, Dhaka; KH, Khulana; RJ, Rajshahi; SY, Sylhet), India (AP, Andhra Pradesh; AR, Arunachal Pradesh; AS, Assam; BI, Bihar; CH, Chhattishgargh; GU, Gujarat; HA, Haryana; HP, Himachal Pradesh; JA, Jharkhand; JK, Jammu & Kashmir; KR, Karnataka; KE, Kerala; MP, Madhya Pradesh; MA, Maharashtra; MI, Manipur; ME, Meghalaya; MZ, Mizoram; NA, Nagaland; OR, Orissa; PUI, Punjab; RA, Rajasthan; TN, Tamil Nadu; TR, Tripura; UT, Uttaranchal; UP, Uttar Pradesh; WB, West Bengal), Nepal (FWR, Far Western Region; MWR, Mid Western Region; WR, Western Region; CR, Central Region and ER, Eastern Region), Pakistan (BA, Baluchistan; NA, Northern Areas; NWFP, North West Frontier Province; PUP, Punjab; SI, Sind) and Sri Lanka in South Asia.

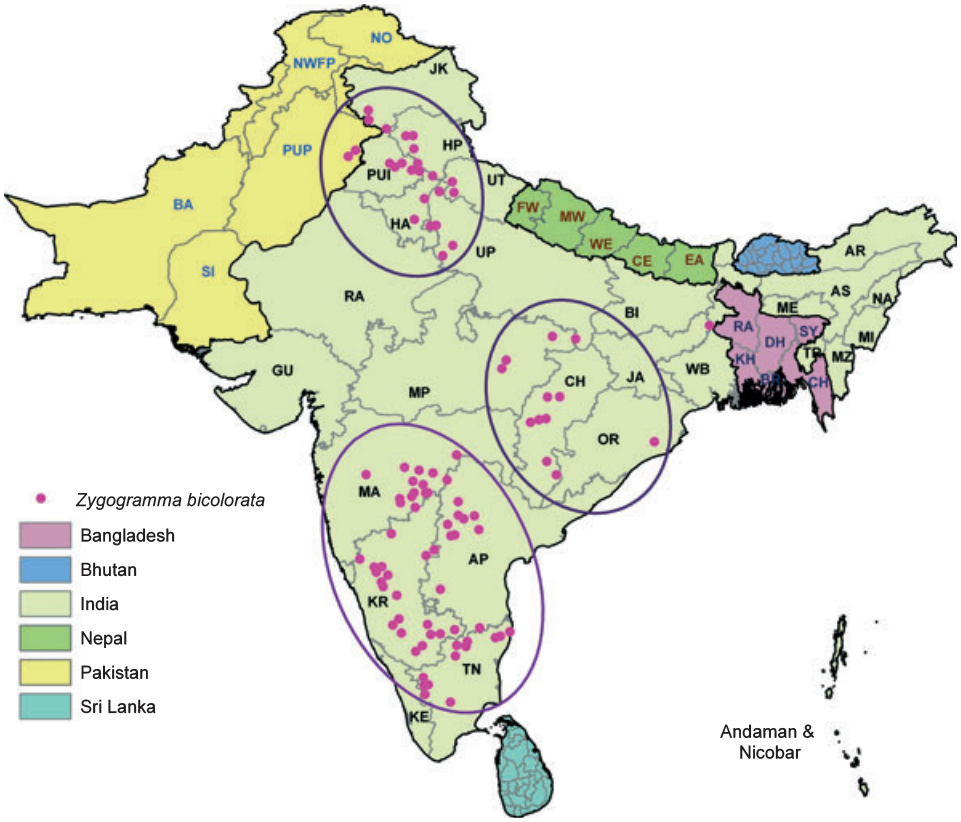

Fig. 2 Map showing sites with *Zygogramma bicolorata* in South Asia (for state and province names, see Fig. 1 legend).

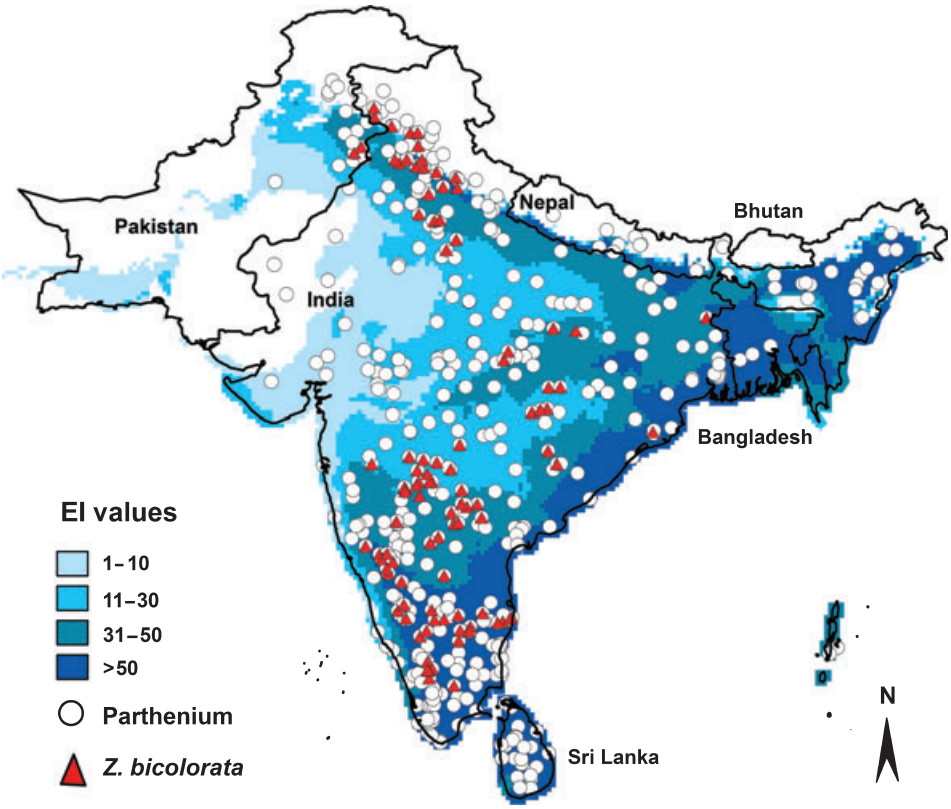

Fig. 3 Climatic suitability of South Asia for *Zygogramma bicolorata* estimated by interpolation of Eco-Climatic Index derived from a CLIMEX model (Table 2). Higher EI values indicate a more suitable climate.

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