SHORT COMMUNICATION

Lantana (*Lantana camara* L.) biocontrol agents in Australia with possible options for India and Sri Lanka

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Abstract

The focus of this short article is the biocontrol agents of the globally-important species - lantana (*Lantana camara* L.), which was introduced as an ornamental plant during the 18th and 19th Centuries across continents. Lantana is now naturalized in most continents and causing problems in human-modified landscapes and is also spreading fast into conservation areas and forests. Currently, where it needs to be controlled, a variety of methods are available, which include manual, mechanical and chemical control, as well as fire. However, none of these methods, even when applied in combinations (integrated) have been sufficiently effective on a landscape level or can be sustainably applied to control large and dense infestations. It appears that future lantana management must be oriented towards re-investing in biocontrol simply because it is not feasible to control lantana over the long term using conventional methods. Numerous biocontrol agents have shown considerable promise but have not been well utilized in countries that have increased risks of further spread.

Efforts to manage lantana in Australia are still continuing, with a well-developed National framework, an integrated approach and investment in additional biocontrol agents. South-Asian countries, especially India and Sri Lanka, can certainly benefit from Australian experiences in lantana management and R&D investments in biological control. This is especially so since research on host specificity and the effectiveness of agents would have already been conducted. This would require that both countries, and also, possibly some African countries, re-appraise the risks of lantana and make an increased effort at biocontrol to manage those risks, especially in natural ecosystems and conservation areas, heavily disturbed by tourism activities.

Keywords: Lantana biocontrol agents, host specificity, invasive, *Teleonemia scrupulosa*, *Uroplata girardi*

Introduction

Lantana camara L. (Verbenaceae) is a globally-important weed found in over 80 countries or island groups. Lantana has the potential to significantly affect flora and fauna biodiversity, as well as have negative impacts on agriculture and the economy (Swarbrick, 1985; Swarbrick et al., 1995; DNRM&E, 2004; Gooden et al., 2009a; b).

Lantana's dual reproductive strategy of profuse seed production and extremely robust and vigorous vegetative reproduction contribute to its fast spread, regrowth and persistence at any infested site, year after year. Frugivorous birds and small mammals consume the berries and also spread lantana seeds over medium or long distances, making lantana difficult to control and presenting a significant dilemma to land managers (Gosper and Vivian-Smith, 2003; Buckley et al., 2006; Zalucki et al., 2007; Bhagwat et al., 2012; Kannan et al., 2013a, b).

Land-clearing for timber and farming combined with the construction of roads, railways and linear infrastructure (oil, gas and water pipelines, and powerlines) across large landscapes, were the main causes of the initial spread. Roads and facilities construction for tourism inside nature reserves, nursery trade, neglected properties and urban gardens also contribute greatly to lantana becoming further established in new areas (Day et al., 2003a;b; DNRM&E, 2004; Urban et al., 2011).

Dutch explorers introduced the plant into the Netherlands in the 1600s from Brazil (Stirton, 1977; Spies and du Plessis, 1987). It was then hybridized in glasshouses in Europe before its introduction to other countries as an ornamental. Subsequent hybridization has resulted in over 600 varieties or forms, During the colonial period, many aesthetically pleasing species, such as lantana, were transferred between colonies. These were seen as 'exotic novelties' (Kannan et al., 2013a; b). As a result, many former British colonies share similar issues with potentially 'invasive' ornamental plants brought in by colonial settlers. Collecting exotic plants for newly established public or private botanical gardens was a novelty within the colonies and was a well-remunerated occupation, promoted by plant acclimatisation societies (Janick, 2007).

Over the past two decades, research in Australia has demonstrated that large and continuous lantana stands, above a threshold of about 75% cover, would significantly modify the biological environment around the stands. Such large lantana stands significantly alter native species compositions of all growth forms around them. Fewer canopy trees occur among the heavily lantana-infested sites, which cause substantial changes in vegetation from tall open forests to low, lantana-dominated shrublands and open areas (Gooden et al., 2009a;b).

The spread of lantana in tropical and sub-tropical forests, agricultural landscapes, nature reserves and conservation areas, including biodiversity hotspots, has been of great concern, not just in Australia (Day et al., 2003a, b; Zalucki et al., 2007), but also in India (Sharma et al., 2005; Kannan et al., 2013; Singh and Singh, 2015), Sri Lanka (Sampson et al., 2018) and numerous African countries (Simelane et al., 2021). Therefore, a re-appraisal of available management options is timely.

Lantana: Management efforts

The key to good management of lantana is constant vigilance to prevent its spread into new areas. Repeated control of new regrowth is also critical to its long-term management success. Control of new infestations should be a priority because lantana can expand its range during good seasons but does not necessarily die out during poor conditions (Day et al., 2003a;b; Zalucki et al., 2007).

The Australian guidelines and experiences indicate that the 'golden rules' of lantana management should be (a) control infestations early but in stages; (b) prioritize infestations, based on site characteristics (size and distribution of infestations and feasibility of control), and (c) integrate suitable methods for each site, depending on accessibility and available resources (DNRM&E, 2004).

Lantana infestations can be controlled with herbicides, manual and mechanical means or by the use of fire, followed subsequently by the planting of competitive native species (DNRM&E, 2004). However, in many infested areas, the sheer size of the infestations makes these methods impractical. Mechanical grubbing, slashing and hand pulling are really only suitable for relatively small areas, while controlled fire and burning can only be used over large areas away from plantations or where other valuable species are growing.

The most commonly applied lantana control methods in developing countries are manual methods, combined with some forms of mechanical removal using backhoes, drag chains and tractors. Herbicide use for lantana management is uncommon in developing countries mainly because they are unaffordable for control treatments over very large tracts of infested lands. Although labour costs have been increasing steadily everywhere, compared with developed countries, there is still a greater availability of labour for hire in developing countries for tedious weed control work, such as those required for lantana management, especially in conservation areas.

Despite these well-established methods, their integration into programs that can successfully deliver on-ground control of lantana has been difficult everywhere. In many situations, manual, mechanical and chemical control methods are not feasible for full implementation and long-term management. Lantana infestations, growing on steep hillsides or along creeks, are often inaccessible for herbicide treatment or mechanical removal, and fire is not an option in some native forests or in orchards or plantation forests (Day et al., 2003a; b). Therefore, in many situations where lantana is a problem, biological control options are the only viable long-term solution to its management.

Lantana: Biological control agents

Biocontrol efforts to manage lantana started in 1902 in Hawai'i, with research later conducted in Australia (Day et al., 2003a; b; Zalucki et al., 2007; Day and Zalucki, 2009; Day 2012) and South Africa (Urban et al., 2011; Simelane et al., 2021). Since then, 44 agents have been deliberately released in 33 countries, with 28 agents getting established in at least one country. However, through the natural spread, biological control agents for lantana are now found in 65 countries worldwide (Winston et al.,

2014). Despite intense efforts in many countries, biocontrol of lantana has only ever been partially successful, and the weed is presently not adequately controlled anywhere where it had been introduced in the past (Zalucki et al., 2007; Winston et al., 2014).

Lantana biocontrol agents in Australia

Since 1914, 29 insect species and one pathogen have been tested for their specificity and then introduced in Australia. Twenty of those biocontrol agents established; however, these releases have had only limited success (Day et al., 2003a; Day, 2012; Winston et al., 2014). Biocontrol agents have in many cases, at least seasonally, decreased the volume of individual plants, making other control methods considerably easier.

One of the main reasons for lantana's weediness and for the limited success of biocontrol is the capacity for hybridization between varieties of *Lantana camara* and closely related species in the genus (Spies and du Plessis, 1987; Simelane et al., 2021; Lu-Irving et al., 2022;). Lantana's origin as a hybrid ornamental plant complicates the search for its centre of origin and thus, the searches for potential agents. Agents collected from similar lantana species or varieties to those lantana varieties in the target countries, or that have a broad host range, have been more successful at establishing (Day et al., 2003a, b). Another reason for limited control is that lantana can be found in a wide range of climatic regions, often occurring where biocontrol agents are not adapted (Day et al., 2003a, b).

Field surveys for potential biocontrol agents have been conducted in Mexico, Central America, the Caribbean, and Brazil, and agents have been collected from several different lantana species. These agents have been host-tested and released in Hawaii, South Africa, Australia, several countries in east Africa, south and east Asia, and the Pacific (Winston et al., 2014). The most important and damaging agents in Australia are given in **Table 1**.

The lantana lace bug - *Teleonemia scrupulosa* (Stål.) (Figure 1), the leaf-mining beetles - *Uroplata girardi* (Pic.) (Figure 2) and *Octotoma scabripennis* (Guérin-Méneville) (Figure 3) are all widespread and damaging biocontrol agents. These agents have contributed to the partial control of lantana in many regions of Australia. They should be a high priority for release in countries initiating or enhancing biocontrol of lantana (Day et al., 2003 a; b).

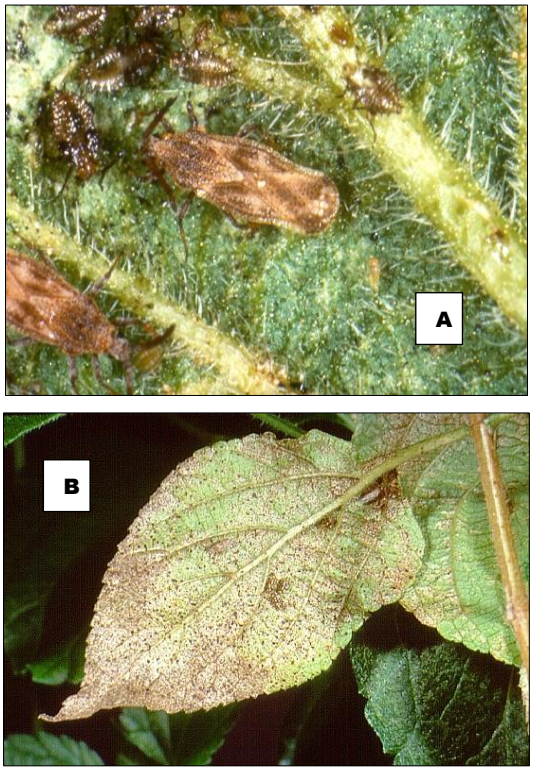

Figure 1 (A) Lantana lace bug- *Teleonemia scrupulosa* (B) Leaf damage caused by *T. scrupulosa*

Figure 2 (A) Lantana leaf-mining beetle *Uroplata girardi* (B) Leaf damage caused by *U. girardi*

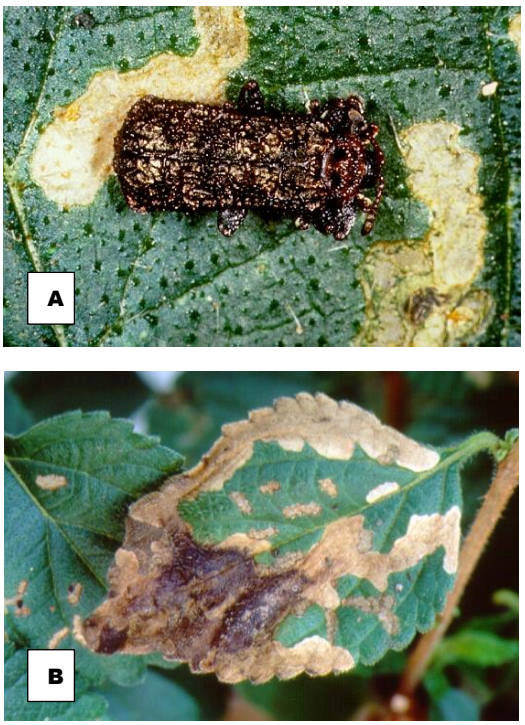

Figure 3 (A) Leaf mining beetle *Octotoma scabripennis* (B) Leaf damage caused by Octotoma scabripennis

Other damaging lantana biocontrol agents in Australia, include the gall-forming bud mite - *Aceria lantanae* (Cook) (Figure 4), the leaf-mining flies - *Calycomyza lantanae* (Frick) and *Ophiomyia camarae* Spencer, a defoliator moth - *Hypena laceratalis* (Walker) and the pathogenic rust - *Prospodium tuberculatum* (Speg.) Arthur.

Figure 4. Damage caused by the lantana flower gall mite, *Aceria lantanae*

Although these agents do not fully control lantana, they may make valuable contributions in countries and regions where few other biocontrol agents are currently present (Day et al., 2003 a; b).

Table 1 A summary of the main lantana biocontrol agents in Australia *

Agent Family	Agent Scientific Name	Agent Origin	First Released	Province/Area Released	Established?	General Impact
Agromyzidae	*Calycomyza lantanae*	Trinidad	1974	NSW, Qld	Yes	Variable
Agromyzidae	*Ophiomyia camarae*	USA	2007	Qld	Yes	Variable
Agromyzidae	*Ophiomyia lantanae*	Mexico	1914	NSW, Qld	Yes	Slight
Chrysomelidae	*Octotoma scabripennis*	Mexico	1966	NSW, Qld	Yes	Moderate-high
Chrysomelidae	*Uroplata girardi*	Brazil	1966	NSW, Qld	Yes	Moderate-high
Erebidae	*Hypena laceratalis*	Kenya	1965	NSW, Qld	Yes	Slight-moderate
Eriophyidae	*Aceria lantanae*	USA	2012	NSW, Qld	Yes	Variable
Miridae	*Falconia intermedia*	Jamaica	2000	Qld	Yes	Variable
Pucciniaceae	*Prospodium tuberculatum*	Brazil	2001	NSW, Qld	Yes	Variable
Tingidae	*Teleonemia scrupulosa*	Mexico	1936	NSW, Qld	Yes	Moderate-high
Tortricidae	*Crocidosema lantana*	Mexico	1914	NSW, Qld	Yes	Slight

* Source: Winston et al., 2014

Lantana biocontrol agents in India and Sri Lanka – An update

Biocontrol of lantana in India was first attempted in 1921 when the seed fly *Ophiomyia lantanae* was introduced. Since then, five other agents have been deliberately introduced. Four of these agents have been established. Six other agents have spread naturally into the country (Table 2). Sri Lanka has never deliberately introduced a biocontrol agent for lantana, but five agents have been reported to have spread into the country and established (Table 3).

Unfortunately, detailed studies on their distribution and impact on lantana in either country have not been undertaken (Winston et al., 2014). However, lantana remains a significant weed in both countries and additional biocontrol agents that have been reported to be damaging in other countries

could be introduced if either or both countries were amenable to biocontrol (Tables 4 & 5). These agents have been tested for specificity before release and are now causing variable to high impacts on lantana in other countries such as Australia, South Africa and Hawai'i where they have been established (Day, 2012; Winston et al., 2014; Simelane et al., 2021).

Table 2 The status of lantana biocontrol agents in India *

Agent Family	Agent Scientific Name	Agent Origin	First Released	Province Released	Established?	General Impact
Introduced						
Agromyzidae	*Ophiomyia lantanae*	Mexico	1921	KA	Yes	Unknown
Chrysomelidae	*Octotoma scabripennis*	Mexico	1972	UP, MP	Yes, UP, MP	Unknown
Chrysomelidae	*Uroplata girardi*	Brazil	1972	UP, MP	Yes, UP, MP	Unknown
Crambidae	*Salbia haemorrhoidalis*	Trinidad	1971	-	No	Not Established
Noctuidae	*Diastema tigris*	Trinidad	1971	-	No	Not Established
Ortheziidae	*Orthezia insignis*	Mexico	1921	KA	Yes	Unknown
Naturally Occurring						
Agromyzidae	*Calycomyza lantanae*	Mexico	2018	Yes	Unknown	Unknown
Agromyzidae	*Ophiomyia lantanae*	Mexico	1921	Yes	None	None
Erebidae	*Hypena laceratalis*	Kenya	2018	Yes	Unknown	Unknown
Ortheziidae	*Orthezia insignis*	Unknown	1915	Yes	None	None
Pterophoridae	*Lantanophaga pusillidactyla*	Mexico	1919	Yes	Unknown	Slight
Tingidae	*Teleonemia scrupulosa*	Mexico	1941	Yes	Countrywide	Slight
Tortricidae	*Crocidosema lantana*	Mexico	1986	Yes	KA, TN	None

Source: Winston et al., 2014; UP (Uttar Pradesh); MP (Madya Pradesh); KA (Karnataka); TN (Tamil Nadu)

Table 3 The status of lantana biocontrol agents naturally occurring in Sri Lanka

Agent Family	Agent Scientific Name	Agent Origin	Date 1st Recorded	Established	General Impact
Agromyzidae	*Calycomyza lantanae*	Mexico	2013	Yes	Unknown
Agromyzidae	*Ophiomyia lantanae*	Mexico	1933	Yes	Unknown
Ortheziidae	*Orthezia insignis*	Unknown	1893	Yes	Heavy
Pterophoridae	*Lantanophaga pusillidactyla*	Mexico	1920	Yes	Unknown
Tingidae	*Teleonemia scrupulosa*	Mexico	2013	Yes	Unknown

Table 4 Effective lantana biocontrol agents that could be introduced into India

Agent Family	Agent Scientific Name	No. of countries where the agent is present	Impacts Elsewhere	Notes (presence or absence in Asia)
Acari	*Aceria lantanae*	7	Variable to high	Not present in Asia; Shows preferences for some lantana forms over others
Agromyzidae	*Ophiomyia camarae*	14	Variable to high	Not present in Asia; Causes defoliation in the tropics
Miridae	*Falconia intermedia*	2	Medium to high	Not present in Asia; Shows preferences for some lantana forms over others
Tephritidae	*Eutreta xanthochaeta*	1	Variable to high	Not present in Asia; Prefers drier areas.

Source: Winston et al., 2014

Table 3 Effective lantana biocontrol agents that could be introduced into Sri Lanka

Agent Family	Agent Scientific Name	No. of countries where the agent is present	Impacts Elsewhere	Notes (presence or absence in Asia)
Acari	*Aceria lantanae*	7	Variable to high	Not present in Asia; Shows preferences for some lantana forms over others
Agromyzidae	*Ophiomyia camarae*	14	Variable to high	Not present in Asia; Causes defoliation in the tropics
Chrysomelidae	*Octotoma scabripennis*	7	Variable to high	Present in India; Causes widespread defoliation
Chrysomelidae	*Uroplata girardi*	24	Variable to high	Present in India and the Philippines; it causes widespread defoliation
Miridae	*Falconia intermedia*	2	Medium to high	Not present in Asia; Shows preferences for some lantana forms over others
Tephritidae	*Eutreta xanthochaeta*	1	Variable to high	Not present in Asia; Prefers the drier areas

Source: Winston et al., 2014

What Can be Done about Lantana Infestations?

The interest in lantana management in India has been steadily increasing, which indicates that infestations are spreading across many regions and provinces (Sharma et al., 2005; Kannan et al., 2013a, b; 2016; Singh and Singh, 2015). The evidence in India is that relatively small infestations may be easily controlled and removed with manual and mechanical means. However, it is almost impossible to eradicate large infestations, which are decades old and deeply entrenched in forests and mountainous areas with steep slopes. Nevertheless, the general feeling among forest managers and volunteers working on lantana control in India is that long-term planning and community involvement (Kannan et al., 2016; ATREE, 2020) are critical to ensure that further spread is reasonably contained.

Developing management strategies for a highly robust, successful and naturalized species, such as lantana, is quite challenging. In managing lantana in high-value conservation areas, biodiversity hotspots and National Parks, such as in India, Sri Lanka and Australia, the clear benefit is the reduction of further spread, which then allows native species, including grasses, to regenerate. However, these benefits must be weighed and balanced with the costs involved, including the environmental risks (i.e. creating more disturbances) and other risks of conducting control programs to humans, other animals and plants.

In Sri Lanka, lantana infests many urban and rural areas and has been listed as a weed of national significance (Marambe and Wijesundera, 2021). In the last two decades, disturbances caused by the construction of roads and infrastructure, and tourism-oriented facilities, have allowed lantana to establish in national parks and conservation areas on a scale previously not recorded (Sampson et al., 2018). Haphazard lantana control interventions in nature reserves pose a risk of harm to both humans and animals, such as wild elephants and wild buffaloes. To intervene in lantana control or not is a delicate balancing act. Unfortunately, tourism revenue is essential in many developing countries.

A long-term vision and planning are required for many sites, such as the *Udawalave National Park*, in Sri Lanka, where, as noted by Sampson et al. (2018), the Asian elephant density and grazing pressures from other animals, such as buffaloes, are high. At such sites, if the spread can be effectively monitored and mapped, even a 'wait-and-see' approach of no active management intervention might be appropriate, instead of aggressive mechanical or manual control at the risk to animals and weed control staff. In South India too, a precautionary approach may be required in some National Parks, such as tiger reserves, based on understanding the 'site-specific' characteristics of infested areas, and adequate monitoring of lantana spread.

In any such lantana management project, attempts must focus on mitigating the primary causal factors of spread (for instance, disturbances caused by road construction, tourist traffic and facilities etc.). In these ecologically sensitive areas, biological control can play an integral part in managing weeds, as biocontrol agents are specific and attack only the target species. Biological control also works over time, so there is little degradation of landscapes. A re-appraisal of the existing biological control agents and

exploring the potential of those that are likely to succeed under Indian and Sri Lankan conditions is highly desirable going forward, to reduce the risks of further spread and impacts of lantana.

Learnings from Australia and elsewhere

Managing lantana in Sri Lanka and India will always be challenging. In both countries, lantana control in specific situations, at specific sites, should only be undertaken with due consideration for the harmful effects of taking action vs no action.

Where control of small infestations or eradication are needed, some degree of herbicide use and physical removal will have to be employed with suitable safeguards. However, to manage lantana across the landscape, biological control utilizing host-specific and effective agents is the most cost-effective and sustainable method.

Mandatory property inspections, increasing the awareness of local communities and stakeholders of (invasion) pathways and taking consistent control action, where possible, with local and regional collaboration across boundaries, are key components of lantana management strategies.

Reactive management is common even in Australia, which boasts well-developed weed management approaches, policies and systems. Proactive monitoring and management over large landscapes are not very common and should be an essential part of the attempt to reduce the spread of species, such as lantana in any country.

The Australian experiences of successful lantana management have the following essential elements: (a) Collaboration across jurisdictional borders (i.e. States and Territories) via a declaration of lantana as a 'Weed of National Significance' (WONs), making the selling, moving and propagation of lantana illegal, and a Nationally-recognized *Lantana Management Plan* (DNRM&E, 2004); (b) Education and awareness training for weed managers and other land managers; (c) Keeping the public informed through effective communications (Newsletters, magazine and newspaper articles); and (d) coordination of actions via stakeholder engagement. This includes, for instance, convincing dialogues with Government Departments, corporations, industry and private landowners on the 'duty of care' (legislative requirements) and also the benefits vs. costs of managing lantana on their lands. Finally, as part of active management across landscapes, biological control forms an integral part of control programmes. This is evident in the 30 biocontrol agents deliberately introduced into Australia, since 1914.

Management of expanding lantana infestations needs to be mostly site-specific, especially within large, infested areas affecting biodiversity hotspots, national parks, wildlife corridors, infrastructure corridors (water and gas pipelines, roads and railways) or urban bushlands that are open for further infestations. Actions need to be taken even down to specific, property-level infestations. The 'containment zones' and site prioritization approaches, well developed and applied in Australia (Grice et al., 2010), should be applicable in any country that needs to take lantana management action.

Communications, policies, local government involvement, Public involvement and outreach, funding etc are all elements that would ensure success with a species, such as lantana. It goes without saying that funding available from governments, and industry is always finite and there is a limit to the time and efforts of individuals who volunteer their time for managing weeds in urban bushlands.

As a result, especially with species such as lantana, funds and effort need to be spent on weed management activities that result in the most positive outcomes for (a) biodiversity benefits; (b) management of assets and amenities that the public use, and (c) for protecting underlying ecological systems we all rely upon. Demonstrating the effectiveness of control activities and positive outcomes of well-coordinated programs ensures continuous funding from funding sources, including stakeholder agencies (such as road and railway authorities and water corporations), industry and private landholders, as well as governments.

In conclusion, it can be said that with the continual decline in resources, it is imperative that each country develops strategic approaches to weed management. This would include determining country priorities, monitoring the effectiveness of weed control action and also being flexible in approaches (i.e. adaptive management). Rather than just taking control action per se for its own sake, an outcome-orientated approach is critical for managing species, such as lantana, especially within large and infested conservation areas. The prevention of further spread with a multi-faceted approach is essential to contain lantana and to do so, biocontrol agents are critical.

In Australia, biocontrol is widely accepted as a useful tool to manage many weeds. However, biological control is not widely accepted or practised in either India or Sri Lanka. Landholders and governments do not have the means to control lantana and many other widespread weeds, leading

to many weedy species increasing their spread and distribution with increasing impacts on biodiversity and agricultural practices. Therefore, biological control could be a highly useful and cost-effective tool to manage lantana and other important and widespread weeds in India and Sri Lanka.

To ensure that lantana management delivers conservation outcomes and does not add further conflicts, data and information on other species at risk, including plants, animals and humans) also need to be incorporated into biological control and long-term management programmes. To achieve a favourable outcome, there will be a range of challenges at each infested site and trade-offs that may need to occur. The critical issue in making decisions about trade-offs is: what would be the consequences of taking control action or no control versus the associated risks.

Australian experiences show that lantana eradication is more likely to be successful if the infested area is small, perhaps less than 100 hectares. Therefore, it is important to detect any new lantana infestations early in their spread as it can make the critical difference between eradication being feasible and the need to resort to less effective control methods. Distribution and mapping have been poor in almost all countries, as a result of which lantana has become entrenched.

Apart from India and Sri Lanka, there are many other countries where lantana is a significant problem, yet there are very few or no biocontrol agents present. These countries could also benefit from introducing other host-specific and effective biocontrol agents to help manage lantana.

Furthermore, 27 countries are deemed climatically suitable to support lantana yet are reported to not contain the weed. It is recommended that these countries do not allow its importation, even of so-called horticultural varieties that are 'claimed' to be sterile (Day et al., 2003a; b; Zalucki et al., 2007).

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