REVIEW

Weed Biological Control: Challenges and Opportunities

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Abstract

Biological control of weeds has been conducted since 1902, resulting in over 500 biological control agents being intentionally released against nearly 200 weed species in over 90 countries. Collectively, 15 countries in Asia and 17 of the 22 countries and territories in the Pacific region have intentionally released over 80 biological control agents to help manage over 30 of their most invasive weeds. Many of these programmes, have been highly successful. In fact, globally, over a third of all weed biological control programmes have resulted in some form of control of the target weed, resulting in huge benefit: cost ratios of up to 4,000:1. In addition, there have been very few (<1%) unpredicted, sustained non-target impacts on native or economic plants by weed biological control agents. This is because biological control agents have co-evolved with their host plants and are thoroughly tested, sometimes collectively across numerous countries, against up to 280 plant species, before being released. Moreover, many biological control agents that have proved to be successful in one country have now been released in over 30 countries, with no recorded non-target impacts.

Yet, despite these successes, many countries are still reluctant to implement weed biological control. Even countries that have had tremendous successes with weed biological control in the past have shied away from implementing biological control in recent times, stating that it is too risky or doesn't work. Unfounded and unscientific statements such as "biological control agents could evolve or mutate to attack other plant species" or "climate change may affect their host range" are often used to justify not implementing biological control. As a result, landowners continue to spend millions of dollars to purchase and apply herbicides, when an integrated approach, which includes biological control, can reduce management costs and enhance control. The challenge, therefore, is to educate all stakeholders, including communities, in the safety and cost-effectiveness of weed biological control. There are numerous opportunities to introduce highly specific and very effective biological control agents from countries where they are being utilized successfully, into other countries where the target weed is problematic to help manage these species.

Keywords: benefit: cost ratios, host specificity, low-risk, integrated control, biological weed control

Introduction

Biological control of weeds has had a rich and successful history since the first intentional movement of an insect to control a weed in India in 1836 and the first dedicated programme to control a weed in Hawaii in 1902. Since then, 200 weed species have been targeted for biological control, resulting in the intentional release of over 500 biological control agents. Over 90 countries have intentionally released at least one biological control agent (Winston et al., 2014). About 66% of the target weeds have been controlled or at least partially controlled, depending on the criteria used, in at least one country where the respective biological control agents have been released (Schwarzländer et al., 2018).

Most weed biological control research has been conducted in only five countries: Australia (202 agents released against 56 weed species), Canada (85 agents against 30 weed species), New Zealand (53 agents against 23 weed species), South Africa (103 agents against 51 weed species) and USA (199 agents against 74 weed species) (Schwarzländer et al., 2018). Elsewhere, weed biological control efforts have been minimal, with most participating countries releasing only 1-3 biological control agents (Winston et al., 2014). Intentional releases in most countries have usually been as a result of introductions from one of the five main practicing countries, based on host specificity testing deeming the biological control agent as being suitable and effective for release.

In Asia, 15 countries have intentionally released 42 biological control agents against 19 weed species, with 11 weed species (58%) deemed under some level of control in some countries or regions. India has been the most active in this field, intentionally releasing 20 biological control agents against 10 weed species, resulting in five weed species deemed under control (Winston et al., 2014). *Alternanthera philoxeroides* (Mart.) Griseb. (Amaranthaceae), *Ambrosia artemisiifolia* L. (Asteraceae), and *Salvinia molesta* D.S. Mitchell (Salviniaceae) have all been successfully controlled in Asian countries where their respective agents have been released (Winston et al., 2014).

In the Pacific region, not including Australia, New Zealand or Hawaii, 17 countries have intentionally released 64 biological control agents against 24 weed species, resulting in the successful control of 14 weed species (61%). Major weeds, such as *Chromolaena odorata* (L.) R. M. King and H. Rob. (Asteraceae), *Eichhornia crassipes* (Mart.) Solms (Pontederiaceae), *Mimosa diplotricha* C. Wright (Fabaceae), *Pistia stratiotes* L. (Araceae), *Salvinia molesta*, and *Sida acuta* Burm. f. (Malvaceae) are now considered under control in Pacific island countries where their respective biological agents have established. Fiji has been the most active, releasing 30 biological control agents against 11 weed species (Day and Winston, 2016). The biological control agents released for some of the above mentioned weeds are shown in Figures 1-6.

In Africa, not including South Africa, 29 countries have intentionally released 38 biological control agents against 17 weed species, resulting in the successful control of 12 weed species (71%), according to local expert opinion. Zambia has been the most active, intentionally releasing 16 biological control agents against four weed species, resulting in the control of two species (Winston et al., 2014). Most biological control efforts in Africa have been against the three main water weeds; *E. crassipes*, *P. stratiotes* and *S. molesta*, with control or partial control achieved in most countries where the respective agents have established (Mbati et al., 2005; Coetzee et al., 2009; Julien et al., 2009; Neuenschwander et al., 2009; Winston et al., 2014).

Figure 1 The gall fly *Cecidochares connexa* adult, a biological control agent for *Chromolaena odorata*

Figure 2 The weevil *Cyrtobagous salviniae*, a biological control agent for *Salvinia molesta*

Figure 3 The weevils *Neochetina bruchi* (left) and *Neochetina eichhorniae* (right), biological control agents for *Eichhornia crassipes*

Figure 4 The psyllid *Heteropsylla spinulosa*, a biological control agent for *Mimosa diplotricha*

Figure 5 The weevil *Neohydronomus affinis*, a biological control agent for *Pistia stratiotes*

Figure 6 The rust pathogen *Puccinia spegazzinii*, a biological control agent for *Mikania micrantha*

These biological control efforts and successes have resulted in enormous benefits to communities and the environment through reduced costs of weeding, including the reduction of herbicide use and increased food production and rangeland productivity (e.g., Thomas and Room 1986; Doeleman 1989; Day et al., 2013). Moreover, there have been no off-target impacts where intentionally released weed biological control agents have caused significant unpredicted impacts on non-target species (Suckling and Sforza 2014; Hinz et al., 2019). Any attack by a biological control agent against another plant species is usually predicted in host range testing before the agent is released. For example, the flea beetle *Agasicles hygrophila* Selman and Vogt (Coleoptera: Chrysomelidae) was known to feed on other *Alternanthera* species prior to its field release in China (Wang et al., 1988; Lu et al., 2010).

Despite these successes, only a small percent of the weeds present in Africa, Asia, and the Pacific regions for which biological control agents are available, have been targeted for biological control. In addition, only a few countries in each of the regions, have intentionally released a biological control agent in the past five years and 12 of the 32 countries in the Asian-Pacific region who have intentionally released a biological control agent previously, have not released a biological control agent for over 20 years (Winston et al., 2014).

Most countries, other than the five main practicing countries that conduct weed biological control research, have released only a few biological control agents, released agents on only waterweeds, or not undertaken biological control at all. There are still some perceptions that weed biological control is risky and that biological control agents may mutate or evolve or develop new strains and feed on other plants, such as crops. There are also perceptions that the exotic weed could be controlled by utilizing organisms that are native in the country where the weed is a problem. Other factors that appear to have impeded biological control efforts include the lack of resources and capacity, awareness on the impacts of invasive plants, regulations, processes, and infrastructure to facilitate the importation of biological control agents, all of which will affect opportunities for funding for biological control (Julien et al., 2007; Witt et al., 2014; Barratt et al., 2018).

This paper discusses the most significant factors affecting the adoption of weed biological control, the challenges to promote biological control in the Asian-Pacific region, and the opportunities, if countries wish to implement weed biological control. Examples from African countries have been included where relevant.

Knowledge and awareness of the impacts of invasive plants

There is a general global acceptance that weeds have negative impacts, among others, on biodiversity, water resources, human health, and agriculture (van Wilgen et al., 2001; Dovey et al., 2004; Early et al., 2016). In many countries, landowners may be aware of the impacts of weeds, but grossly underestimate the impacts on yield and rangeland productivity (Day et al., 2012; Shackleton et al., 2017a, b, c, d; Witt et al., 2018).

For countries such as Australia, New Zealand, and South Africa, which have active weed biological control programmes, studies on the impacts and costs of weeds are essential to help prioritize which particular weed species to target for biological control.

However, formal studies on the impacts of weeds by many governments have often not been conducted and many countries are, therefore, not aware of the real impact of weeds on communities, a country's economy and environment (Pimentel et al., 2001; Ellison et al., 2014; Early et al., 2016; Xu et al., 2006; Nghiem et al., 2013). In India, *Lantana camara* L. (Verbenaceae) costs the economy in terms of impact and control costs, close to US$1 billion per annum (Rao and Chauhan 2015). For China, the cost of invasive alien species, which includes pest animals, is about US$14 billion p.a. (Xu et al., 2006).

Without knowing the cost of weeds and their impacts, it is difficult for countries to prioritize how funds for research and/or infrastructure should be allocated. Even if countries were aware of the actual impacts and costs of weeds, weed management is often given a lower priority due to many other issues, such as ensuring the availability of clean water, health, and education (Labrada 1996), despite weeds also impacting on these issues.

Knowledge and awareness of weed biological control

Across Africa, Asia, and the Pacific, there are often few policies or co-ordinated efforts in managing invasive plants, leaving the management of weeds up to individuals or communities. There are also widespread views that if weeds are a problem, they can easily be controlled by manual removal or utilization. This is partly supported by the view that labour is often not considered a cost, as family members conduct weeding or labour is paid for by means of accommodation or food (Day et al., 2012; Ellison et al., 2014; Day et al., 2016). Consequently, without knowing the actual cost of controlling weeds, there is a lack of incentive by governments to explore more sustainable means of managing them.

Herbicides are also widely used to manage weeds in some countries, especially in intensive cropping in Asia. However, while the negative impacts of herbicide use on human health and the environment have been well-documented, herbicides are still used indiscriminately in many regions (see Igbedioh, 1991). While widely used, both manual and herbicide control practices are costly and not sustainable, particularly in perennial ecosystems, such as plantations and grazing lands.

Although 91 countries have undertaken weed biological control, there is still some scepticism about the discipline, even in those countries that have undertaken weed biological control previously, and/or have undertaken insect biological control (Cock et al., 2016). There seems to be less concern over insect parasitoids or predators attacking native insect species than herbivores attacking other plants. This is understandable because the consequences of non-target impacts in weed biological control could affect crops and other valuable plant species, despite research that shows that possible non-target impacts are predictable and unlikely (Suckling and Sforza 2014; Hinz et al., 2019).

Common concerns are that weed biological control agents may attack other plant species once the weed is controlled, biological control agents could mutate and start attacking other plant species, or that they may evolve to attack other plant species. Such views are often based on the perception that after biological control "eradicates" the weed, the agent may then attack other plant species. These views reflect a lack of knowledge in the principles of weed biological control, which involves the use of co-evolved organisms collected from the target weed in its native range. Furthermore, there appears to be a lack of understanding of plant-insect interactions or that the host range of a specialist herbivore, i.e., a biological control agent, is a conservative phylogenetic trait (Lonsdale et al., 2001). Quite often, there are the inappropriate comparisons with the introduction of the cane toad [*Rhinella marina* L.; Anura: Bufonidae], mongoose [*Herpestes javanicus* É. Geoffroy Saint-Hilaire; Carnivora: Herpestidae] or Indian myna bird [*Acridotheres tristis* L.; Passeriformes: Sturnidae], all of which are generalist predators, which were expected to control some pests in some countries and which subsequently became pests in their own right.

Even in countries that have implemented weed biological control in the past, there can still be negative views. There are several possible reasons for these. First, the plant may still be around, albeit in lower numbers, while the previous premise was that the weed would be eradicated. The second is that there was no baseline data on the weed, so the impacts of the weed before and after the biological control agent was released cannot be determined. Part of the problem also stems from the long time (up to 20 years) since biological control agents have been introduced into some countries in the past. Previous researchers may have retired, resulting in the loss of institutional memory on the distribution and impacts of the weed, as well as the theory, procedures, and practices of biological control.

Also, the current researchers may have little knowledge of biological control, as it is seldom taught in schools or universities or, if so, only sparingly. At numerous workshops, when asked by the authors, if any of the participants were aware that weed biological control had been implemented in their country, most have replied in the negative. This lack of knowledge could also be as a result of some weeds no longer being a problem due to earlier biological control efforts. Another reason for not implementing biological control is the perception that the biological control agent may not work in all areas where the target weed is present. This is a possibility for many countries, such as Australia, New Zealand, and South Africa, where the weed may have a wide geographical range. However, some countries believe investing in biological control efforts is not worth the risk if the weed is not going to be controlled in all areas.

Infrastructure and capacity to implement biological control

Most countries are signatories to the Convention on Biological Diversity (CBD) (McGeoch et al., 2010) and as such, are obligated to manage invasive alien species. However, having invasive species embedded in the CBD means that governments in many developing countries think that invasive species are only a biodiversity issue. As such, invasive species are not always prioritized for action, despite their significant impacts on people and livelihoods. Besides, most countries either do not have policies or are unable to manage invasive species effectively due to a lack of capacity and resources (Dovey et al., 2004; Boy and Witt 2013; Early et al., 2016).

The infrastructure and capacity in the regions vary considerably. In many parts of Asia, infrastructure is generally better than in the Pacific or Africa, especially in the main centres, where populations tend to be higher. Asia also has many institutions that are involved in agricultural research, such as the Chinese Academy of Agricultural Science, the Kerala Forest Research Institute in India, or BIOTROP in Indonesia. However, some research centres do not have adequate post-entry quarantine facilities to import biological control agents safely.

In the Pacific region, there is considerable variation among the Pacific countries. This region consists of 22 Pacific Island Countries and Territories (PICTs), consisting of 7,500 volcanic islands and coral atolls, spread over 30 million km^2, of which only about 2% is land. The population of these countries varies from less than 100 in the Pitcairn Islands to over seven million in Papua New Guinea, with over 75% of the people being involved in agriculture (Shine et al., 2003).The capacity to manage weeds in the region is limited in terms of infrastructure and skills (Dovey et al., 2004). There are only a few specialized research institutions, e.g., National Agricultural Research Institute in Papua New Guinea and the Ministry of Primary Industries in Fiji, with most countries having officers who hold multiple positions. Many countries do not have adequately-equipped laboratories, glasshouses, or a post-entry quarantine suitable for the introduction and testing of biological control agents (Ellison et al., 2014). Thus, most biological control agents released into the Pacific are those that have been tested elsewhere, such as Australia, New Zealand, or Hawaii, prior to their introduction into one of the PICTs.

In Africa, many countries are some of the poorest on earth, with the majority of people involved in agriculture. General infrastructure in many of these countries is extremely limited, especially once out of the major centres. There are a few international research centres, such as the International Institute of Tropical Agriculture, the International Centre for Insect Physiology and Ecology, the Centre for Agriculture and Biosciences International (CABI), and others, that undertake biological control research, with very few to no national research institutions taking the lead. However, these international agencies often focus on the management of crop pests, and biological control of weeds is often not a priority. Therefore, it is not surprising that facilities for conducting biological control research on invasive weeds such as post-entry quarantines, glasshouses, and laboratories, are either poorly equipped or non-existent in many countries. This is because facilities are often built through donor funds but not maintained once the projects are finished. As in the Pacific, there is a heavy reliance on donor funding (Dovey et al., 2004; Boy and Witt 2013).

Apart from infrastructure and capacity, many countries who have not undertaken weed biological control, do not have the required regulations or understanding to import, test, mass rear and release host-specific biological control agents. For some countries, rather than trying to develop procedures to implement biological control, it is less risk-averse to deny the importation of biological control agents (Barratt et al., 2018). Regulators often do not want to shoulder the responsibility of approving the release of a biological control agent. So, the norm is not to act.

For some countries that have approved the release of biological control agents, there is a lack of understanding in weed biological control. Regulators assessing applications can include conditions to release permits that are impossible to meet (Sankaran and Day 2018). One government agency wanted a process in place to destroy the biological control agent if non-targets impacts occurred in the field. Given that biological control is usually irreversible once an agent has established, it will be hard to eradicate, and the condition was unrealistic. Another government agency wanted the biological control agent to be removed or eradicated once the host plant was brought under control. This shows a lack of understanding of weed biological control because the agent does not eradicate the target species but reduces its populations to levels where the weed is no longer considered to be a problem. Removing the agent would result in populations of the weed increasing again. The approval process in some countries can be confusing or require permissions from various Government Ministries, a process that can be cumbersome, time-consuming, and costly (Barratt et al., 2018; Sankaran and Day, 2018).

On the other hand, numerous countries such as the Cook Islands, Vanuatu, Ethiopia, Namibia, and Uganda, have regulations that support the importation of biological control agents and all have intentionally released biological control agents in the past few years (Winston et al., 2014; Day and Winston, 2016). In fact, in one country, the regulators wanted to help facilitate the release process while still being accountable. Together, with the various participating agencies, a robust process to assess biological control agents was developed, and biological control agents have been released recently. It is not clear in some cases, what is the limiting factor in gaining approval to release biological control agents. First, many countries do not implement biological control because introducing anything exotic is considered unfavourably. Also, they do not have adequate processes, regulations, and facilities to do so, or such processes and facilities are not present because of the reluctance to implement biological control.

Conflict species

Another concern limiting weed biological control is that some weeds are also considered to be beneficial. Several introduced Australian *Acacia* species in Africa have social and commercial benefits (Impson et al., 2011), while the biological control of *Chromolaena. odorata* in West Africa was hampered by the perception that the plant had medicinal properties and was an excellent fallow crop and shortened the fallow period (Aigbedion-Atalor et al., 2019). One of the reasons that biological control of *Mikania micrantha* Kunth (Asteraceae) was not implemented in some countries in the Pacific was that the plant is used to treat cuts (Day et al., 2012; 2016). Some farmers also use *M. micrantha* as a cover crop. Thus, biological control was not implemented by some countries, despite *M. micrantha* also smothering crops such as bananas, papaya, and cocoa, significantly reducing yields (Day et al., 2012; 2016).

These examples are based on the perception by some people that biological control will eradicate a particular weed, and that the plant will not be available for other uses. There is a lack of understanding that biological control does not eradicate but reduces weed populations to a low level, hopefully to where it no longer causes significant impacts. This means that there will still be plants available for use in traditional medicine or other purposes. In fact, in the case of introduced Australian *Acacia* spp., biological control can actually resolve possible conflicts. In South Africa, some *Acacia* spp. are valued for their biomass but are also significant weeds. To resolve these conflicts, biological control agents that attack the flower-buds and seeds were introduced to reduce the propagule production, leaving the biomass undamaged. Therefore, the plants could still be grown commercially, but seed production is significantly reduced, which reduces the rate of spread, particularly in riparian zones (Impson et al., 2011).

Funding

Adequate funding for research into weed biological control is a problem for all countries despite the high benefit: cost ratios achieved (e.g., Page and Lacey, 2006; de Lange and van Wilgen, 2010). Julien et al.,

(2007) stated that there was more funding in Australia for salinity than for weed biological control, despite the impacts and costs of weeds being an order magnitude higher than for salinity. In many countries, within-their country priorities, lack of awareness of the negative impacts of invasive plants across sectors, such as human and animal health, water availability and crop and pasture production, has limited funding to undertake on-ground weed management, let alone weed biological control.

One of the limiting factors is the lack of funding to build expensive infrastructure and fund lengthy research projects: biological control projects often run for 10+ years. Hence, many of the biological control programmes in most countries have focused on using biological control agents that have already been tested and released elsewhere (Dovey et al., 2004; Winston et al., 2014). These transfer projects are highly cost-effective, as most of the research, such as foreign exploration, host specificity testing, field release protocols, and evaluation has already been conducted in other countries (Julien et al., 2007). Therefore, countries can take advantage of introducing only those agents with a proven record, not only of specificity, but also effectiveness against the target weed. There is little advantage and a waste of resources to import biological control agents that are not effective at reducing weed populations. For example, many of the biological control agents for *L. camara* provide little or no impact on the target weed (Day et al., 2003). As such, many of these species are not recommended for release elsewhere.

Another limiting factor is that biological control programmes, even for those using previously tested agents and known to be specific and damaging, are long-term, and many donors want to see results in shorter timeframes and are reluctant to fund such lengthy programmes (Cock et al., 2000). In fact, some donors, even those that have previously funded weed biological control projects, have been reluctant to fund biological control programmes in recent times. Similar arguments around risk and effectiveness have been used despite their organizations commissioning reports showing that not only is biological control low-risk and effective, but the return on investment is huge (e.g., Lubulwa and McMeniman, 1997).

Discussion and Opportunities

Given the high cost of physical and chemical control, coupled with the negative impacts of herbicides, and that importing tried and proven biological control agents is relatively cheap and low-risk, more countries should be availing themselves to the vast number of proven biological control agents currently utilized elsewhere (Greathead, 1995; Labrada, 1996; Julien et al., 2007). It is for these reasons that biological control is so appealing. Once the agents have established, the target weeds are controlled to varying degrees, providing significant benefits to the economy and the environment. Day and Winston (2016) documented numerous opportunities to move host specific and effective biological agents around the Pacific. Likewise, Day et al. (2018) listed numerous agents that could be moved around the Greater Mekong Subregion in Southeast Asia, and Winston et al. (2014) catalogues all weed biological control efforts globally.

Some of the more effective biological control agents target major weeds, such as *C. odorata*, *E. crassipes*, *M. micrantha*, *M. diplotricha*, *P. stratiotes*, and *S. acuta*. These successful agents are already in some countries in Asia and the Pacific region and could be introduced into other countries where the respective target weeds are present.

Prior to the release of any biological control agent, governments need to be aware of the cost and impacts of invasive plants, not just on biodiversity, but on agriculture, food security, and livelihoods. For countries that have never introduced a biological control agent, or at least not for a long time, awareness campaigns may be required to educate governments in the low-risk and benefits of weed biological control as part of an integrated weed management strategy (Labrada 1996). Highlighting benefits also assist in attracting funding from donors. The challenge is not so much the science of weed biological control, although some may disagree, but communicating and trying to allay the fears of weed biological control (Lonsdale et al., 2001).

The first step could be to highlight the theory and science behind weed biological control, i.e., the use of co-evolved host-specific organisms and that monophagy and oligophagy in insects and pathogens are common and that even the most serious insect pests often have a limited host range. In fact, of the 500+ weed biological control agents released, only a few have caused non-target impacts at a population level, and these were known before their release (Schwarzländer et al., 2018; Hinz et al., 2019). This is quite different from that of the mongoose and cane toad, which were known generalist predators before their introduction into various countries.

Weed biological control researchers and managers need to promote the successes, in that twothirds of the weeds targeted for biological control are at least under partial control (Winston et al., 2014; Schwarzländer et al., 2018). In doing so, the critics of biological control, who claim biological control doesn't work, could be silenced. They claim that there is no supporting data, despite Winston et al. (2014), providing numerous examples. However, the critics themselves have no supporting data to state biological control doesn't work. Humans seem to have an appetite for bad news and are suspicious of good news, and so the negative comments gain traction. If biological control is going to be challenged, then those who oppose biological control also need to be challenged and held accountable.

It is worth mentioning again that weed biological control doesn't eradicate the target species, and conflicts between whether a weed is also considered beneficial can often be resolved using cost: benefit analyses. Finally, it is worth mentioning the consequences if biological control is not implemented, the impacts of those weeds will most likely continue to increase, along with the costs of managing them (Julien et al., 2007). Also, land clearing of new areas for agriculture and herbicide use will most likely continue to rise in the future (Ghosheh, 2005) Thus, there is also a significant risk of not implementing weed biological control. There is also scope for weed biological control to be introduced into the curriculum of schools and universities to build capacity and raise awareness. Such moves are already being considered in some countries such as Pakistan and the Philippines. Other opportunities to promote weed biological control include the conduct of workshops and training courses for both researchers and regulators.

From 1993-2005, initially under the Cooperative Research Centre (CRC) for Tropical Pest Management, a two-week international course on biological control of weeds was run in Brisbane, Australia, every two years (Julien and White, 1997). The course attracted participants from Africa, Asia, and the Pacific. It had strong field components, with presenters from the Queensland Government, CSIRO and the University of Queensland. The workshops included demonstrations in host specificity testing and field monitoring, to highlight the safety and impacts of weed biological control. Similar courses have since been run in South Africa and New Zealand, as well as by CABI to increase awareness. As well as formal courses, there have been numerous international exchanges of scientists, particularly between Australia and New Zealand, and China, Cook Islands, Myanmar, Solomon Islands, Thailand, and Vanuatu. However, there is scope to expand the exchanges further and involve more countries. Additionally, organizations, such as the Association of Southeast Asian Nations (ASEAN) and the Southeast Asian Regional Centre for Tropical Biology (SEMEAO-BIOTROP) in Asia, and the Secretariat of the Pacific Community (SPC) and Secretariat of the Pacific Community Regional Environmental Programme (SPREP) in the Pacific, could play key roles in increasing the awareness of the low risk and effectiveness of weed biological control.

While there is already an International Symposium on the Biological Control of Weeds, which is held every four years, there is scope to expand the biological control component in other international conferences and symposia. Weed biological control accounted for only a small percentage of talks at the most recent Asian-Pacific Weed Science Society Conference in Kuching. It accounted for a tiny fraction of the presentations at the last few Ecology and Management of Alien Plant invasions conferences. Both these conferences had strong herbicide and/or herbicide resistance components but little in the way of sustainable management strategies. Expanding the biological control components creates awareness and initiates discussions among researchers, academics, and policy people who may have had little exposure to weed biological control. To highlight the effectiveness of such meetings, following recent conferences and workshops in the Philippines and Malaysia, discussions have since been held with one of the authors (MD) on how to expand weed biological control in various countries of the region. Academics are now considering how to promote biological control and encourage students to undertake small projects.

While weed biological control is not the panacea for all weeds or even all situations, the fact that over 270 weed species are resistant to herbicides, suggests that biological control has a vital role in future integrated weed management programmes. Weed biological control has a proven track record over 100 years and has helped control some of the world's most important weeds. However, effective biological control agents have been introduced into only a fraction of the countries where the respective target weeds are present. This creates numerous opportunities to expand the use of these agents to help manage the weeds in countries where the agents are not present. There is scope for greater engagement between biological control practitioners and recipient countries to take advantage of the tremendous benefits of weed biological, and safely manage some of their worst weeds.

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