NeoBiota 30: 167–192 (2016)
doi: 10.3897/neobiota.30.7113
http://neobiota.pensoft.net

REVIEW ARTICLE

A peer-reviewed open-access journal
NeoBiota
Advancing research on alien species and biological invasions

Biological control of weeds in the 22 Pacific island countries and territories: current status and future prospects

Michael D. Day[1], Rachel L. Winston[2]

1 *Department of Agriculture and Fisheries, Ecosciences Precinct, GPO Box 267, Brisbane, Qld 4001 Australia*
2 *MIA Consulting, 316 N. Hansen Ave., Shelley, ID 83274 USA*

Corresponding author: *Michael D. Day* (michael.day@daf.qld.gov.au)

Academic editor: *C. Daehler* | Received 6 November 2015 | Accepted 28 March 2016 | Published 23 June 2016

Citation: Day MD, Winston RL (2016) Biological control of weeds in the 22 Pacific island countries and territories: current status and future prospects. In: Daehler CC, van Kleunen M, Pyšek P, Richardson DM (Eds) Proceedings of 13th International EMAPi conference, Waikoloa, Hawaii. NeoBiota 30: 167–192. doi: 10.3897/neobiota.30.7113

Abstract

Biological control of introduced weeds in the 22 Pacific island countries and territories (PICTs) began in 1911, with the lantana seed-feeding fly introduced into Fiji and New Caledonia from Hawaii. To date, a total of 62 agents have been deliberately introduced into the PICTs to control 21 weed species in 17 countries. A further two agents have spread naturally into the region. The general impact of the 36 biocontrol agents now established in the PICTs ranges from none to complete control of their target weed(s). Fiji has been most active in weed biocontrol, releasing 30 agents against 11 weed species. Papua New Guinea, Guam, and the Federated States of Micronesia have also been very active in weed biocontrol. For some weeds such as *Lantana camara*, agents have been released widely, and can now be found in 15 of the 21 PICTs in which the weed occurs. However, agents for other commonly found weeds, such as *Sida acuta*, have been released in only a few countries in which the weed is present. There are many safe and effective biocontrol agents already in the Pacific that could be utilised more widely, and highly effective agents that have been released elsewhere in the world that could be introduced following some additional host specificity testing. This paper discusses the current status of biological control efforts against introduced weeds in the 22 PICTs and reviews options that could be considered by countries wishing to initiate weed biological control programmes.

Keywords

Host specificity, establishment, biocontrol agents

Introduction

Introduced invasive weeds are of increasing concern and importance in the Pacific region, which is reflected by the growing number of publications and websites documenting their distribution and impacts (e.g. Swarbrick 1997, Waterhouse 1997, Meyer 2000, Shine et al. 2003, PIER 2013). Weeds decrease food security and income by smothering crops, infesting plantations, and overgrowing grazing lands (Waterhouse and Norris 1987, Orapa 2001, Day et al. 2012). Weeds also affect ecosystem processes through impacts such as degrading soil and reducing water quality and quantity, and are second only to land clearing as a major threat to biodiversity (Meyer 2000, Sherley and Lowe 2000, Dovey et al. 2004). Since 1985, at least six workshops have been held in the Pacific region to prioritise weeds for improved management (e.g. Waterhouse and Norris 1987, Sherley 2000, Shine et al. 2003, Dodd and Hayes 2009, Day 2013).

Biological control is a long-term, self-sustaining and feasible option for managing many weeds (Dovey et al. 2004, Julien et al. 2007). Biocontrol of weeds is particularly beneficial and applicable to many Pacific island countries and territories (PICTs) where the capacity to tackle major weed problems is often restricted due to limited infrastructure, resources, and skills (Dovey et al. 2004). The earliest case of the deliberate introduction of biocontrol agents from their native range to control a weed was in 1902 when 23 insect species were imported into Hawaii from Mexico to control *Lantana camara* (Swezey 1923). One agent, the seed-feeding fly *Ophiomyia lantanae*, which successfully established in Hawaii, was subsequently introduced into Fiji and New Caledonia in 1911 (Guiterrez and Forno 1989), becoming the first weed biocontrol agent released in the PICTs.

Over 60 weed biocontrol agents have since been introduced deliberately into 17 of the 22 PICTs, not including Australia, New Zealand, or Hawaii (Winston et al. 2014). However, for most biocontrol agents, the number of PICTs in which they have been introduced or naturally spread is only a fraction of the number of PICTs where the target weeds occur. Consequently, there is great potential for further introductions within the PICTs. In addition, there are many more weeds present for which biocontrol has not been attempted in the PICTs. Effective biocontrol agents for some of these are available elsewhere and could be introduced.

One of the limiting factors for weed biocontrol in many PICTs is the knowledge of what agents are available and effective. Numerous workshops involving the PICTs have been conducted, with the last being held in Auckland in 2009 (Dodd and Hayes 2009) where potential biocontrol agents were discussed. These workshops have often resulted in new biocontrol programs being implemented, with new or existing agents being introduced into one or more countries (Winston et al. 2014).

This paper reviews the current status of biocontrol efforts against introduced weeds in the PICTs and identifies existing biocontrol agents that could be moved around the Pacific as well as additional effective biocontrol agents that could be introduced into the region. This information provides a platform for PICTs to identify the best and most appropriate weed biocontrol opportunities to pursue, and should be considered

against other factors such as weed importance and available resources in each country. Australia, Norfolk Island (a territory of Australia), New Zealand, and Hawaii are not included in this paper as they already have well-established biocontrol programmes, and extensive reviews on their programmes have already been conducted (Conant et al. 2013, Fowler et al. 2000, 2010, Funasaki 1988, Julien et al. 2012, Smith 2002, Trujillo 2005).

Materials and methods

The number of weed biocontrol agents introduced into the 22 PICTs, their establishment status, and their current impact were extracted from Winston et al. (2014) and supplemented by recent publications and personal communications with local researchers to provide an updated account through to 2015. The assessment did not include Australia, Norfolk Island (a territory of Australia), New Zealand, Hawaii, and Easter Island (a territory of Chile).

From the compiled dataset, we determined the weed biocontrol effort of each country, including the number of weeds targeted and the number of agents deliberately introduced. We also analysed the dataset by target weed to determine how many biocontrol agents have been introduced into the region, how many have established, and their overall level of impact against their target weeds. The level of impact was obtained from Winston et al. (2014) or from the perception of local researchers and took into consideration varying habitats and climates, with the understanding that a weed may not be under the same level of control in all areas where it exists. The two analyses allowed us to ascertain which weeds were most amenable to biocontrol, and which biocontrol agents were the most widespread, damaging, and effective against their target weed.

Numerous sources were utilized to determine the distribution of weeds in the Pacific, including workshop reports, websites, and personal communications with local land managers (Swarbrick 1997, Waterhouse 1997, Meyer 2000, Shine et al. 2003, Dodd and Hayes 2009, PIER 2013, Endemia 2015). Some of the weed biocontrol prioritisation workshops utilized herein asked participants to list the top 10 weeds in their country. In these circumstances, not all weeds present in a country were captured. The weed lists were then collated into a comprehensive compilation of weeds occurring in each country and cross-checked against weed species that have already been targeted for biocontrol worldwide (Winston et al. 2014), as well as against weed species being evaluated as potential new candidates now or in the near future (Q. Paynter, Landcare Research pers. comm. 2015, T. Johnson, US Department of Agriculture, pers. comm. 2015). Weed species not targeted for weed biocontrol were deleted from the dataset.

After combining the two datasets, we determined which biocontrol agents could be introduced into particular countries where the target weed occurs but no biocontrol agents have established to date. In doing so, we only considered those biocontrol agents that had been deliberately released into at least one country. This excluded spe-

cies that had found their way into countries naturally but had never been deliberately introduced into any country. The rationale behind excluding these species is that they are not bona fide biocontrol agents, nor have they been subjected to detailed host specificity testing; consequently, there is a risk of non-target impacts if introduced into a new region. There are no native species in the Pacific region that have been used as weed biocontrol agents.

Results were separated into three lists based on whether 1) the agent is already established in at least one of the PICTs and is having at least a medium impact (weed is partially or fully controlled in most areas) on the target weed, 2) the agent is not yet in any PICTs but has at least a medium impact on the target weed elsewhere, and 3) the agent has only a slight impact (may cause damage but does not reduce weed populations) on the target weed either in any of the PICTs or elsewhere. A fourth list documents the agents that have been recently released and are still being evaluated, and any new target weeds for which agent exploration or host specificity testing of new agents are currently being conducted. As much of the data on weed presence or importance by country is not well defined, no attempt was made to suggest specific actions.

Our analysis excluded agents that did not establish in any country in which they were introduced, agents that had established in at least one country but were considered to have no impact against the target weed, and agents that have caused significant impacts to non-target species. We determined that these agents were unlikely to succeed in terms of achieving establishment and causing a significant impact to the target weed and/or had great potential to damage non-target species in a new country (Julien et al. 2007, Paynter et al. 2015).

Results

Seventeen of the 22 PICTs have deliberately introduced at least one biocontrol agent (Table 1). Fiji (30 biocontrol agents introduced against 11 weed species) and Papua New Guinea (19 agents released against 12 weed species) have been the most active. Guam (16 agents against 4 weed species), Federated States of Micronesia (13 agents against 3 weed species), and Palau (11 agents against 4 weed species) have also been actively involved in weed biocontrol. Five countries, namely Kiribati, Pitcairn Islands, Tokelau, Tuvalu, and Wallis and Futuna, have not deliberately introduced any weed biocontrol agents to date. These countries mainly consist of small, low-lying atolls, and weeds may not be at sufficient densities to warrant biocontrol.

Since 1911, there has been a steady stream of biocontrol agents introduced into the PICTs (Fig. 1). A total of 62 biocontrol agents targeting 21 weed species have been deliberately released into at least one country in the PICTs (Table 2). Of these, 32 agents have established on 17 weed species. Two biocontrol agents, *Neogalea sunia* and *Epiblema strenuana*, did not establish when deliberately introduced into the region, but were later found to have spread into some PICTs of their own accord (Table 2). In addition, *Acalitus adoratus* and *Maravalia cryptostegiae* also self-introduced into

Table 1. The number of weed species targeted for biocontrol and the number of biocontrol agents that have been deliberately introduced (intentional) and agents that were not deliberately introduced but have been found (unintentional) in the PICTs.

	Intentional introductions			Unintentional introductions		Combined introductions	
Country	No. of weed species	No. of agents released	No. of agents establ.	No. of weed species	No. of agents establ.	No. of weed species	No. of agents establ.
American Samoa	2	2	2	0	0	2	2
Cook Islands	4	11	2	0	0	4	2
Federated States of Micronesia	3	13	10	2	2	3	12
Fiji	11	30	17	0	0	11	17
French Polynesia	2	3	3	0	0	2	3
Guam	4	16	9	2	4	4	13
Marshall Islands	1	1	1	0	0	1	1
Nauru	1	1	0	0	0	1	0
New Caledonia	4	7	6	3	4	5	10
Niue	2	4	3	1	1	3	4
Northern Mariana Islands	4	8	7	2	5	4	12
Palau	4	11	6	2	4	4	10
Papua New Guinea	12	19	12	3	6	13	18
Samoa	4	5	3	1	1	4	4
Solomon Islands	5	7	4	2	2	5	6
Tonga	3	6	5	2	2	4	7
Vanuatu	8	9	8	3	6	9	14

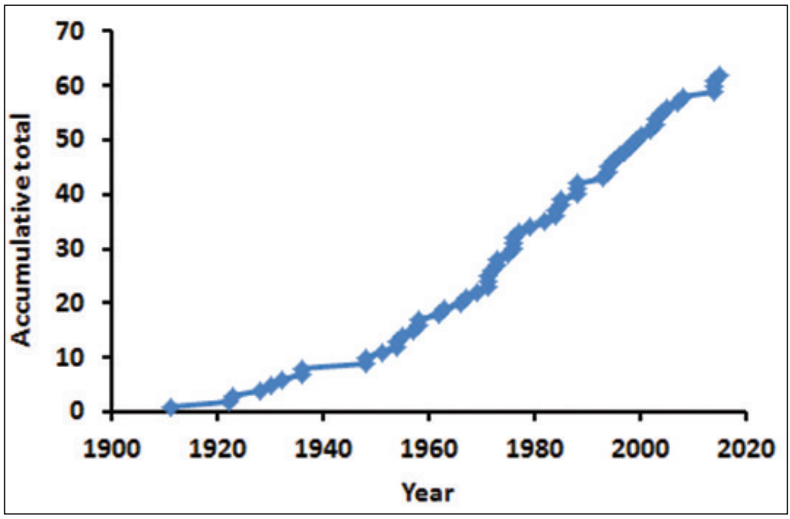

Figure 1. Cumulative number of deliberate biocontrol agent introductions in the PICTs since 1911. The values include those introductions where the agent failed to establish in any country.

Table 2. Status of weed biocontrol agents deliberately released (intentional) and/or spread of their own accord (unintentional) into the 22 PICTs and the potential countries in which they could be introduced. Countries: AS=American Samoa, CI=Cook Islands, FSM=Federated States of Micronesia, Fi=Fiji, FP=French Polynesia, Gu=Guam, Ki=Kiribati, MI=Marshall Islands, Na=Nauru, NC=New Caledonia, Ni=Niue, NMI=Northern Mariana Islands, Pa=Palau, PNG=Papua New Guinea, PI=Pitcairn Islands, Sa=Samoa, SI=Solomon Islands, Tk=Tokelau, To=Tonga, Tu=Tuvalu, Va=Vanuatu, WF=Wallis & Futuna. Status: I=intentionally introduced, U=unintentionally introduced, E=established, F=failed to establish. Impact: H=high, M=moderate, N=none, S=slight, V=variable, ?=unknown. * Potential countries where agents could be introduced (based on weed occurrence in each country, not weed density).

Weed family	Weed species	Biocontrol agent family	Biocontrol agent species	AS	CI	FSM	Fi	FP	Gu	Ki	MI	Na	NC	Ni	NMI	Pa	PNG	PI	Sa	SI	Tk	To	Tu	Va	WF
Apocynaceae	***Cryptostegia grandiflora* R. Br.**	Chaconiaceae	*Maravalia cryptostegiae* (Cummins) Ono														UE?								
Araceae	***Pistia stratiotes* L.**	Curculionidae	*Neohydronomus affinis* Hustache		*	*	*	*	*				*			*	IEV			*				IEV	
Asteraceae	***Chromolaena odorata* (L.) R. M. King & H. Rob.**	Eriophyidae	*Acalitus adoratus* Keifer			UES			UES						UES	UES	UES								
		Brentidae	*Apion brunneonigrum* Béguin-Billecocq						IF																
		Agromyzidae	*Calycomyza eupatorivora* Spencer														IF								
		Tephritidae	*Cecidochares connexa* Macquart			IEH			IEM		*		*		IEH	IES	IEV								
		Erebidae	*Pareuchaetes pseudoinsulata* Rego Barros			IEV			IEM						IEV	IF	IEV								
		Pyralidae	*Phestinia costella* Hampson						IF																
	***Elephantopus mollis* Kunth**	Tephritidae	*Tetraeuaresta obscuriventris* (Loew)		*	*	IEM	*	*				*	UE?	*	*	*			*		UEN		UEN	*
	***Mikania micrantha* Kunth**	Phlaeothripidae	*Liothrips mikaniae* (Priesner)																	IF					
		Pucciniaceae	*Puccinia spegazzinii* De Toni	*	*		IE?	*	*	*	*		*	*	*	*	IE?	*	*	UE?	*	*	*	IE?	*
	***Parthenium hysterophorus* L.**	Tortricidae	*Epiblema strenuana* (Walker)					*					*											UE?	
		Chrysomelidae	*Zygogramma bicolorata* Pallister																					I?	
	***Xanthium strumarium* L.**	Tortricidae	*Epiblema strenuana* (Walker)		*		*	*	*				*				IF*					*			
		Tephritidae	*Euaresta aequalis* Loew				IF																		

Weed family	Weed species	Biocontrol agent family	Biocontrol agent species	AS	CI	FSM	Fi	FP	Gu	Ki	MI	Na	NC	Ni	NMI	Pa	PNG	PI	Sa	SI	Tk	To	Tu	Va	WF
		Cerambycidae	*Nupserha vexator* (Pascoe)				IF																		
		Pucciniaceae	*Puccinia xanthii* Schweinitz		I?																				
Cactaceae	***Acanthocereus tetragonus* (L.) Hummelinck**	Pseudococcidae	*Hypogeococcus festerianus* (Lizer y Trelles)										IF												
	***Opuntia* spp.**	Dactylopiidae	*Dactylopius* sp. nr *confusus* (Cockerell)										IEH												
	***Opuntia ficus-indica* (L.) Mill.**	Pyralidae	*Cactoblastis cactorum* (Berg)					*					*												
	***Opuntia monacantha* (Willd.) Haw.**	Pyralidae	*Cactoblastis cactorum* (Berg)	*	*	*	*		*			*	*	*	*	*			*	*		*			
	***Opuntia stricta* (Haw.) Haw.**	Pyralidae	*Cactoblastis cactorum* (Berg)										IEH						*	*					
Cucurbitaceae	***Coccinia grandis* (L.) Voigt**	Curculionidae	*Acythopeus burkhartorum* O'Brien & Pakaluk						IF						IF										
		Curculionidae	*Acythopeus cocciniae* O'Brien & Pakaluk			*	*		IEH		*				IEM		*		*	*		*	*	*	
		Sesiidae	*Melittia oedipus* Oberthür			*	*		IEH		*				IE?		*		*	*		*	*	*	
Cyperaceae	***Cyperus rotundus* L.**	Curculionidae	*Athesapeuta cyperi* Marshall		IF		IF															IEN			
		Tortricidae	*Bactra minima* Meyrick		IF		IF															IEN			
		Tortricidae	*Bactra venosana* (Zeller)		IF		IEN						UE?												
Fabaceae	***Mimosa diplotricha* C. Wright**	Psyllidae	*Heteropsylla spinulosa* Muddiman, Hodkinson & Hollis	IEH	IEH	IEH	IEH	*	IE?				*	IEH	IE?	IEH	IEV		IEH	IEH		IEH		IES	*
		Saturniidae	*Psigida walkeri* (Grote)		IF																				
		Coreidae	*Scamurius* sp.																IF						
	***Mimosa pigra* L.**	Chrysomelidae	*Acanthoscelides puniceus* Johnson														I?								
		Chrysomelidae	*Acanthoscelides quadridentatus* (Schaeffer)														I?								
Malvaceae	***Sida acuta* Burm. f.**	Chrysomelidae	*Calligrapha pantherina* Stål	*	*	*	IEH	*	*	*	*	*	UE?	*	*	*	IEH		I?	*		*		IEH	
	***Sida rhombifolia* L.**	Chrysomelidae	*Calligrapha pantherina* Stål	*	*	*	IEH	*	*	*	*	*		*	*	*	IEH	*	I?	*	*	*	*	IEH	*

Weed family	Weed species	Biocontrol agent family	Biocontrol agent species	AS	CI	FSM	Fi	FP	Gu	Ki	MI	Na	NC	Ni	NMI	Pa	PNG	PI	Sa	SI	Tk	To	Tu	Va	WF
Melastomataceae	***Clidemia hirta* (L.) D. Don**	Crambidae	*Ategumia matutinalis* (Guenée)													IF									
		Phlaeothripidae	*Liothrips urichi* Karny	IEM		*	IEH									IEV	*		*	IF*					*
	***Miconia calvescens* DC.**	Glomerellaceae	*Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. f. sp. *miconiae* Killgore & L. Sugiyama					IEV					*				*								
Pontederiaceae	***Eichhornia crassipes* (Mart.) Solms**	Erirhinidae	*Neochetina bruchi* Hustache	*	*	*	*	*	*		*	*	*		*	*	IEH		*	*				IE?	
		Erirhinidae	*Neochetina eichhorniae* Warner	*	*	*	IEH	*	*		*	I?	*		*	*	IEH		*	IES				IEH	
		Crambidae	*Niphograpta albiguttalis* (Warren)														IF								
		Crambidae	*Xubida infusella* (Walker)														I?								
Salviniaceae	***Salvinia molesta* D.S. Mitch.**	Erirhinidae	*Cyrtobagous salviniae* Calder & Sands		*		IEH	*	*				*		*		IEH								
		Erirhinidae	*Cyrtobagous singularis* Hustache				IEN																		
		Pauliniidae	*Paulinia acuminata* (De Geer)				IEN																		
		Crambidae	*Samea multiplicalis* (Guenée)				IEN																		
Verbenaceae	***Lantana camara* L. sens. lat.**	Agromyzidae	*Calycomyza lantanae* (Frick)			UEM	IE?		UE?							UE?	UES			UES				UES	
		Chrysomelidae	*Charidotis pygmaea* Klug				IF																		
		Tortricidae	*Crocidosema lantana* Busck			IEM			UEM		IE?				UEM	UEM								UES	
		Noctuidae	*Diastema tigris* Guenée			IF	IF																		
		Erebidae	*Hypena laceratalis* Walker			IEN	IES		IEN				UES		UEN		UES							UES	
		Pterophoridae	*Lantanophaga pusillidactyla* (Walker)			IEM			UEM						UEM	IES	UES								
		Tingidae	*Leptobyrsa decora* Drake		I?		IF		IF							IF						I?			
		Noctuidae	*Neogalea sunia* (Guenée)			IF							UES												
		Chrysomelidae	*Octotoma championi* Baly				IF																		
		Chrysomelidae	*Octotoma scabripennis* Guérin-Méneville	*	IF*	*	IF*	*	IF*	*	*	*	IES	IF*	*	*	*	*	*	I?		*	*	*	*	*

Weed family	Weed species	Biocontrol agent family	Biocontrol agent species	AS	CI	FSM	Fi	FP	Gu	Ki	MI	Na	NC	Ni	NMI	Pa	PNG	PI	Sa	SI	Tk	To	Tu	Va	WF
		Agromyzidae	*Ophiomyia lantanae* (Froggatt)		I?	IE?	IES	IE?	IEM				IEM		UEM	UEM	UE?		UE?			UE?		UE?	
		Cerambycidae	*Plagiohammus spinipennis* (Thomson)						IF							IF									
		Crambidae	*Pseudopynausta santatalis* (Barnes & McDunnough)			IF	IF																		
		Crambidae	*Salbia haemorrhoidalis* Guenée			IES	IES		IF							IF									
		Lycaenidae	*Strymon bazochii* (Godart)				I?																		
		Tingidae	*Teleonemia elata* Drake		IF																				
		Tingidae	*Teleonemia scrupulosa* Stål	*	*	IEV	IEV	IE?	IEV	*	*	*	IEV	IEH	IEV	IEV	IEH	*	IEH	IEH		IES	*	IES	*
		Lycaenidae	*Tmolus echion* (L.)				IF																		
		Chrysomelidae	*Uroplata fulvopustulata* Baly				IF																		
		Chrysomelidae	*Uroplata girardi* Pic	*	IEH	IEM	IEV	*	IEM	*	*	*	IEM	IEM	IEV	IEM	IES	*	IEM	IEH		IEM	*	IES	*
Zygophyllaceae	***Tribulus cistoides* L.**	Curculionidae	*Microlarinus lareynii* (Jacquelin du Val)														IF								
			Microlarinus lypriformis (Wollaston)		*		*	*	*	*	*		*				IEH								
	***Tribulus terrestris* L.**	Curculionidae	*Microlarinus lypriformis* (Wollaston)				*										*								

some PICTs. In total, 36 weed biocontrol agents are now confirmed as present in the PICTs, attacking 19 weed species. The overall impact of these biocontrol agents ranges from no damage to high impact on the target weed, depending on country and region (Tables 2, 3).

Of the weed species on which at least one biocontrol agent has established, seven are deemed to be under complete control overall, due to the high impact of the agent(s) (Table 3). A further six weed species are deemed to be under partial to full control. The impacts of biocontrol agents on two weed species have been variable. For four weed species where biocontrol agents have only recently established, the establishment and impacts of biocontrol agents are still being evaluated. There are three weed species for which agents have either not established, or there is little, no, or unknown impact of biocontrol agents.

The most widespread and damaging biocontrol agent in the PICTs is the psyllid *Heteropsylla spinulosa*, which was introduced and has established in 13 of the 16 countries where its target weed *Mimosa diplotricha* occurs. In most areas within most countries, *M. diplotricha* is under control (Tables 2, 3). However, in high rainfall areas, control is not always achieved because heavy rain can wash the psyllids from plants.

Sida acuta and *S. rhombifolia* are deemed under control in three of the four countries where the leaf-feeding beetle *Calligrapha pantherina* was intentionally introduced and established. The establishment of *C. pantherina* in the fourth country, Samoa, is not known. *Calligrapha pantherina* has recently been reported in New Caledonia, although its mode of entry and impact on the *Sida* spp. are unknown. Other weeds considered under control by biocontrol agents in the PICTs include *Salvinia molesta*, *Tribulus cistoides*, *Opuntia stricta*, and unspecified *Opuntia* spp. (Tables 2, 3).

Eichhornia crassipes and *Pistia stratiotes* are generally under a high degree of control in each of the countries where their respective biocontrol agents have been released and established (Tables 2, 3). Control of *E. crassipes* is generally higher if both *Neochetina eichhorniae* and *N. bruchi* are present. Control of both aquatic weeds appears to be incomplete in shaded locations.

Cecidochares connexa has established and is aiding the control of *Chromolaena odorata* in all five countries in which it has been introduced (Tables 2, 3). However, *C. connexa* appears to be less effective at altitudes greater than 1000 m above sea level or in areas where rainfall is high, such as West New Britain, Papua New Guinea.

Of the two agents introduced to control *Clidemia hirta*, only *Liothrips urichi* established. This agent appears to be effective at controlling *C. hirta* in only sunny areas of the three countries in which it has established (Tables 2, 3); there is little impact where *C. hirta* is growing in shaded areas.

Three agents have been released against *Coccinia grandis*, but only two have established. *Melittia oedipus* has been released in Guam and the Northern Mariana Islands, and is having a high degree of impact in both countries. *Acythopeus cocciniae* is having a high degree of impact in Guam, while its establishment in the Northern Mariana Islands has not been confirmed (Tables 2, 3).

Twenty biocontrol agents have been intentionally introduced against *L. camara* in the PICTs. Of these, nine agents have established in at least one country (Table 2).

Table 3. Summary of the biocontrol effort against each target weed species, including the number of PICTs where biocontrol agents have established without being deliberately released. For weeds where multiple agents have been released, numbers have been pooled.

Weed family	Weed species	No. countries weed occurs	No. agents established in the Pacific	No. countries all agents established	Overall impact on weed**
Apocynaceae	*Cryptostegia grandiflora*	8	1	1	unknown
Araceae	*Pistia stratiotes*	9	1	2	medium to high
Asteraceae	*Chromolaena odorata*	7	3	5	medium to high
	Elephantopus mollis	14	1	4	variable
	Mikania micrantha	20	1	4	still evaluating
	Parthenium hysterophorus	3	1	1	still evaluating
	Xanthium strumarium	7	0*	0	still evaluating
Cactaceae	*Acanthocereus tetragonus*	1	0	0	none
	Opuntia spp.	1	1	1	high
	Opuntia stricta	3	1	1	high
Cucurbitaceae	*Coccinia grandis*	11	2	2	medium to high
Cyperaceae	*Cyperus rotundus*	21	3	2	none
Fabaceae	*Mimosa diplotricha*	16	1	13	high
	Mimosa pigra	1	0*	0	still evaluating
Malvaceae	*Sida acuta*	18	1	4	high
	Sida rhombifolia	22	1	3	high
Melastomataceae	*Clidemia hirta*	9	1	3	low to high
	Miconia calvescens	3	1	1	variable
Pontederiaceae	*Eichhornia crassipes*	15	2	4	medium to high
Salviniaceae	*Salvinia molesta*	7	4	2	high
Verbenaceae	*Lantana camara*	21	10	15	slight to high
Zygophyllaceae	*Tribulus cistoides*	8	1	1	high

* Biocontrol agents have recently been released, but establishment is not confirmed

** Rating is based on the overall level of control as per Winston et al. (2014)

Uroplata girardi and *Teleonemia scrupulosa* have been released and have established in 13 countries; both reportedly have a moderate to high overall impact in most countries where they have established. *Crocidosema lantana*, *Lantanophaga pusillidactyla*, and *Ophyiomyia lantanae* have a moderate impact in some countries but only a slight impact in other countries. The remaining agents have little or no impact on *L. camara*.

Of the biocontrol agents that have established in the PICTs and are having a medium to high impact on the target weed, many have not been released in all PICTs where their respective target weed has been recorded. For example, *C. pantherina* has proven very effective against *S. acuta* and *S. rhombifolia* in three countries, and could potentially be introduced into 14 and 18 additional countries, respectively. Likewise,

N. bruchi and *N. eichhorniae* could potentially be introduced against *E. crassipes* in 13 additional countries, while the biocontrol agents for *C. grandis* could be introduced into nine countries.

Cactoblastis cactorum was introduced into New Caledonia to control *O. stricta.* However, the agent also attacks *Opuntia monacantha*, and so could be released in the 13 countries in which this weed occurs. Similarly, *Microlarinus lypriformis* was released against *Tribulus cistoides*, but could also be used against *Tribulus terrestris* in Fiji and Papua New Guinea. The countries in which established and effective agents within the PICTs could potentially be redistributed are listed in Table 2. Because biocontrol agents can spread naturally between islands, it is recommended that countries conduct surveys to determine what biocontrol agents are present prior to any introductions.

There are also opportunities to introduce biocontrol agents that have proven effective outside the PICTs (Table 4), provided target weed densities are sufficiently high to warrant this. Additional agents attacking *L. camara*, *O. stricta,* and *Parthenium hysterophorus* could be introduced in the PICTs to supplement the biocontrol agents already established against these species. There are also effective agents for weeds that have not been targeted for biocontrol in the PICTs to date. These weed species include *Arundo donax* (present in 12 countries), *Dolichandra unguis-cati* (7 countries), and *Melaleuca quinquenervia* (7 countries) (Table 4).

Because biocontrol agents may do poorly in one region and have spectacular success elsewhere, agents having slight or variable impacts on their target weed(s) in at least one country within or outside the Pacific region are listed in Table 5.

Numerous weed species occurring in the PICTs are currently weed biocontrol targets elsewhere, but the agents have either been only recently released and not yet evaluated or not yet released (Table 6). In addition, there are several previously targeted weeds (e.g. *C. odorata*, *E. crassipes,* and *L. camara*) for which new agents were recently released and are currently being evaluated for establishment and/or impact (Table 6). Should any of these agents prove to be specific and effective against their target weeds, they could also be considered for introduction in the PICTs in the future.

Discussion

Biological control of weeds has been practiced in the PICTs for over 100 years, with over 20 weed species targeted. In that time, 17 countries have deliberately introduced at least one biocontrol agent (Winston et al. 2014). In addition to agents deliberately released into the PICTs, four biocontrol agents have found their way into the Pacific region either through natural means or unintentionally on imported goods. For over half the weed species targeted, biocontrol agents are having a medium to high impact. Consequently, weed biocontrol to date has been very cost-effective and has provided relief to farmers and land managers trying to control those weeds, and has resulted in increased production and income (e.g. Julien and Orapa 2001, Day et al. 2013a, Day and Bule this edition).

Table 4. Weed biocontrol agents that have medium to high impacts in at least one country outside the PICTs and could be introduced into the region. Prior to introduction, additional host specificity testing may be needed. Countries: AS=American Samoa, CI=Cook Islands, FSM=Federated States of Micronesia, Fi=Fiji, FP=French Polynesia, Gu=Guam, Ki=Kiribati, MI=Marshall Islands, Na=Nauru, NC=New Caledonia, Ni=Niue, NMI=Northern Mariana Islands, Pa=Palau, PNG=Papua New Guinea, PI=Pitcairn Islands, Sa=Samoa, SI=Solomon Islands, Tk=Tokelau, To=Tonga, Tu=Tuvalu, Va=Vanuatu, WF=Wallis & Futuna.

Weed family	Weed species	Biocontrol agent family	Biocontrol agent species	Possible countries for introduction#
Asteraceae	*Ageratina adenophora* (Spreng.) R. M. King & H. Rob.	Mycosphaerellaceae	*Passalora ageratinae* Crous & A.R. Wood	FP
	Parthenium hysterophorus	Chrysomelidae	*Zygogramma bicolorata**	FP, NC, Va
		Curculionidae	*Listronotus setosipennis* (Hustache)	FP, NC, Va
	Xanthium strumarium	Pucciniaceae	*Puccinia xanthii* Schweinitz*	CI, Fi, FP, Gu, NC, PNG, To
Azollaceae	*Azolla filiculoides* Lam.	Erirhinidae	*Stenopelmus rufinasus* Gyllenhal	CI
Basellaceae	*Anredera cordifolia* (Ten.) Steenis	Chrysomelidae	*Plectonycha correntina* Lacordaire	CI, Fi, FP, NC, Ni, PI
Bignoniaceae	*Dolichandra unguis-cati* (L.) L. G. Lohmann	Buprestidae	*Hedwigiella jureceki* (Obenberger)	CI, FSM, FP, Gu, NC, Ni, Va
		Tingidae	*Carvalhotingis visenda* Drake	CI, FSM, FP, Gu, NC, Ni, Va
Cactaceae	*Opuntia ficus-indica*	Dactylopiidae	*Dactylopius opuntiae* (Cockerell)	FP, NC
	Opuntia monacantha	Dactylopiidae	*Dactylopius ceylonicus* (Green)	AS, CI, FSM, Fi, Gu, Na, NC, Ni, NMI, Pa, Sa, SI, To
	Opuntia stricta	Dactylopiidae	*Dactylopius opuntiae* (Cockerell)	NC, Sa, SI
	Pereskia aculeata Mill.	Chrysomelidae	*Phenrica guerini* Bechyné	FP, NC, Pa
Fabaceae	*Acacia dealbata* Link	Curculionidae	*Melanterius maculatus* Lea	FP
	Acacia mearnsii De Wild.	Cecidomyiidae	*Dasineura rubiformis* Kolesik	CI
		Curculionidae	*Melanterius maculatus* Lea	CI
	Acacia melanoxylon R. Br.	Curculionidae	*Melanterius acaciae* Lea	CI
	Acacia pycnantha Benth.	Curculionidae	*Melanterius maculatus* Lea	Gu
		Pteromalidae	*Trichilogaster signiventris* (Girault)	Gu
	Mimosa pigra	Chrysomelidae	*Acanthoscelides* spp.	PNG
		Chrysomelidae	*Malacorhinus irregularis* Jacoby	PNG
		Curculionidae	*Chalcodermus serripes* Fåhraeus	PNG
		Geometridae	*Macaria pallidata* (Warren)	PNG
		Gracillariidae	*Neurostrota gunniella* (Busck)	PNG
		Sesiidae	*Carmenta mimosa* Eichlin & Passoa	PNG

Weed family	Weed species	Biocontrol agent family	Biocontrol agent species	Possible countries for introduction#
	Paraserianthes lophantha (Willd.) Nielsen	Curculionidae	*Melanterius servulus* Pascoe	CI
	Ulex europaeus L.	Tetranychidae	*Tetranychus lintearius* Dufour	PNG
	Vachellia nilotica subsp. *indica* (Benth.) Kyal. & Boatwr	Geometridae	*Chiasmia assimilis* (Warren)	FP, NC, SI, WF
Hydrocharitaceae	*Hydrilla verticillata* (L. f.) Royle	Ephydridae	*Hydrellia pakistanae* Deonier	Fi, Gu, NC, PNG
Lamiaceae	*Marrubium vulgare* L.	Pterophoridae	*Wheeleria spilodactylus* (Curtis)	NC
		Sesiidae	*Chamaesphecia mysiniformis* Rambur	NC
Myrtaceae	*Melaleuca quinquenervia* (Cav.) S. T. Blake	Cecidomyiidae	*Lophodiplosis trifida* Gagné	FSM, Fi, FP, Gu, NC, Pa, PNG
		Curculionidae	*Oxyops vitiosa* Pascoe	FSM, Fi, FP, Gu, NC, Pa, PNG
		Psyllidae	*Boreioglycaspis melaleucae* Moore	FSM, Fi, FP, Gu, NC, Pa, PNG
		Pucciniaceae	*Puccinia psidii* G. Winter	FSM, Fi, FP, Gu, NC, Pa, PNG
Passifloraceae	*Passiflora tarminiana* Coppens & V. E. Barney	Mycosphaerellaceae	*Septoria passiflorae* Pallister	Gu
Poaceae	*Arundo donax* L.	Eurytomidae	*Tetramesa romana* Walker	CI, FSM, Fi, FP, Gu, Na, NC, Pa, PNG, Sa, To, WF
Polygonaceae	*Rumex crispus* L.	Sesiidae	*Pyropteron doryliformis* (Ochsenheimer)	Fi, FP, NC, PNG
Solanaceae	*Solanum mauritianum* Scop.	Curculionidae	*Anthonomus santacruzi* Hustache	CI, Fi, FP, NC, SI, To
		Tingidae	*Gargaphia decoris* Drake	CI, Fi, FP, NC, SI, To
Verbenaceae	*Lantana camara*	Agromyzidae	*Ophiomyia camarae* Spencer	AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
		Eriophyidae	*Aceria lantanae* (Cook)	AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
		Miridae	*Falconia intermedia* (Distant)	AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
Zygophyllaceae	*Tribulus cistoides*	Curculionidae	*Microlarinus lareynii**	CI, Fi, FP, Gu, Ki, MI, NC, PNG
	Tribulus terrestris	Curculionidae	*Microlarinus lareynii*	Fi, PNG

* Introduced previously but failed to establish

Based on weed occurrence in each country, not weed density

Table 5. Weed biocontrol agents that have slight, variable, or unknown impacts in at least one country within or outside the PICTs that could be investigated further to assess their suitability for introduction/redistribution in the region. Prior to introduction, additional host specificity testing may be needed. Countries: AS=American Samoa, CI=Cook Islands, FSM=Federated States of Micronesia, Fi=Fiji, FP=French Polynesia, Gu=Guam, Ki=Kiribati, MI=Marshall Islands, Na=Nauru, NC=New Caledonia, Ni=Niue, NMI=Northern Mariana Islands, Pa=Palau, PNG=Papua New Guinea, PI=Pitcairn Islands, Sa=Samoa, SI=Solomon Islands, Tk=Tokelau, To=Tonga, Tu=Tuvalu, Va=Vanuatu, WF=Wallis & Futuna.

Weed family	Weed species	Biocontrol agent family	Biocontrol agent species	No. of countries in Pacific agent established	Possible countries for introduction#
Apocynaceae	*Cryptostegia grandiflora*	Crambidae	*Euclasta whalleyi* Popescu-Gorj & Constantinescu		Fi, FP, Gu, MI, NC, NMI, PNG, SI
		Chaconiaceae	*Maravalia cryptostegiae*	1	Fi, FP, Gu, MI, NC, NMI, SI
Asteraceae	*Ageratina adenophora*	Pterophoridae	*Oidaematophorus beneficus* Yano & Heppner		FP
		Tephritidae	*Procecidochares utilis* Stone		FP
	Chromolaena odorata	Agromyzidae	*Calycomyza eupatorivora*		FSM, Gu, MI, NC, NMI, Pa, PNG
		Erebidae	*Pareuchaetes insulata* (Walker)		FSM, Gu, MI, NC, NMI, Pa, PNG
		Erebidae	*Pareuchaetes pseudoinsulata*	5	MI, NC
	Cirsium vulgare (Savi) Ten.	Curculionidae	*Larinus carlinae* (Olivier)		NC
		Curculionidae	*Rhinocyllus conicus* (Frölich)		NC
		Curculionidae	*Trichosirocalus horridus* (Panzer)		NC
		Syrphidae	*Cheilosia grossa* (Fallén)		NC
		Tephritidae	*Urophora stylata* (Fabricius)		NC
	Parthenium hysterophorus	Bucculatricidae	*Bucculatrix parthenica* Bradley		FP, NC, Va
		Curculionidae	*Conotrachelus albocinereus* Fiedler		FP, NC, Va
		Curculionidae	*Smicronyx lutulentus* Dietz		FP, NC, Va
		Delphacidae	*Stobaera concinna* (Stål)		FP, NC, Va
		Pucciniaceae	*Puccinia abrupta* Dietel & Holw. var. *partheniicola* (H.S. Jacks.) Parmelee		FP, NC, Va
		Pucciniaceae	*Puccinia xanthii* Schwein. var. *parthenii-hysterophorae* Seier, H.C. Evans & Á. Romero		FP, NC, Va
		Sesiidae	*Carmenta* sp. nr *ithacae* (Beutenmüller)		FP, NC, Va
		Tortricideae	*Platphalonidia mystica* (Razowski & Becker)		FP, NC, Va

Weed family	Weed species	Biocontrol agent family	Biocontrol agent species	No. of countries in Pacific agent established	Possible countries for introduction#
	Pluchea carolinensis (Jacq.) G. Don	Tephritidae	*Acinia picturata* (Snow)		CI, FP, Gu, Ki, MI, Na, NC, NMI, Pa, To, Va, WF
	Xanthium strumarium	Cerambycidae	*Nupserha vexator*		CI, Fi, FP, Gu, NC, PNG, To
Bignoniaceae	*Dolichandra unguis-cati*	Chrysomelidae	*Charidotis auroguttata* Boheman		CI, FSM, FP, Gu, NC, Ni, Va
		Tingidae	*Carvalhotingis hollandi* Drake		CI, FSM, FP, Gu, NC, Ni, Va
Cactaceae	*Opuntia ficus-indica*	Cerambycidae	*Lagocheirus funestus* Thomson		FP, NC
		Dryophthoridae	*Metamasius spinolae* (Gyllenhal)		FP, NC
		Nectriaceae	*Fusarium oxysporum* Schlecktendahl		FP, NC
	Opuntia monacantha	Dactylopiidae	*Dactylopius opuntiae*		AS, CI, FSM, Fi, Gu, Na, NC, Ni, NMI, Pa, Sa, SI, To
	Opuntia stricta	Cerambycidae	*Moneilema blapsides* (Newman) subsp. *ulkei* Horn		NC, Sa, SI
Convolvulaceae	*Convolvulus arvensis* L.	Eriophyidae	*Aceria malherbae* Nuzzaci		Pa
		Noctuidae	*Tyta luctuosa* (Denis & Schiffermüller)		Pa
Fabaceae	*Acacia podalyriifolia* A. Cunn. ex G. Don	Curculionidae	*Melanterius maculatus*		NC
	Caesalpinia decapetala (Roth) Alston	Chrysomelidae	*Sulcobruchus subsuturalis* (Pic)		Fi, FP, NC
	Leucaena leucocephala (Lam.) de Wit	Chrysomelidae	*Acanthoscelides macrophthalmus* (Schaeffer)		AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
	Mimosa pigra	Brentidae	*Coelocephalapion pigrae* Kissinger		PNG
		Cerambycidae	*Rhytiphora piperitia* Hope		PNG
		Chrysomelidae	*Chlamisus mimosae* Karren		PNG
		Geometridae	*Leuciris fimbriaria* (Stoll)		PNG
	Parkinsonia aculeata	Chrysomelidae	*Penthobruchus germaini* (Pic)		FSM, FP, Gu, NC, SI
	Prosopis juliflora (Sw.) DC.	Chrysomelidae	*Algarobius prosopis* (Le Conte)		FP, PNG
	Ulex europaeus	Brentidae	*Exapion ulicis* (Forster)		PNG
		Oecophoridae	*Agonopterix umbellana* (Fabricius)		PNG

Weed family	Weed species	Biocontrol agent family	Biocontrol agent species	No. of countries in Pacific agent established	Possible countries for introduction#
		Pyralidae	*Pempelia genistella* (Duponchel)		PNG
		Tetranychidae	*Tetranychus linterarius* Dufour		PNG
		Thripidae	*Sericothrips staphylinus* Haliday		PNG
		Tortricidae	*Cydia succedana* (Denis & Schiffermüller)		PNG
	Vachellia nilotica subsp. *indica*	Chrysomelidae	*Bruchidius sahlbergi* Schilsky		FP, NC, SI, WF
Melastomataceae	*Clidemia hirta*	Buprestidae	*Lius poseidon* Napp		AS, FSM, Fi, Pa, PNG, Sa, SI, Va, WF
		Crambidae	*Ategumia matutinalis* (Guenée)		AS, FSM, Fi, Pa, PNG, Sa, SI, Va, WF
		Erebidae	*Antiblemma acclinalis* Hübner		AS, FSM, Fi, Pa, PNG, Sa, SI, Va, WF
		Glomerellaceae	*Colletotrichum clidemiae* B. Weir & P.R. Johnst.		AS, FSM, Fi, Pa, PNG, Sa, SI, Va, WF
		Momphidae	*Mompha trithalama* Meyrick		AS, FSM, Fi, Pa, PNG, Sa, SI, Va, WF
Poaceae	*Arundo donax*	Diaspididae	*Rhizaspidiotus donacis* Leonardi		CI, FSM, Fi, FP, Gu, Na, NC, Pa, PNG, Sa, To, WF
Polygonaceae	*Emex australis*	Brentidae	*Perapion antiquum* (Gyllenhal)		NC
Pontederiaceae	*Eichhornia crassipes*	Crambidae	*Niphograpta albiguttalis*		AS, CI, FSM, Fi, FP, Gu, MI, Na, NC, NMI, Pa, PNG, Sa, SI, Va
		Crambidae	*Xubida infusella*		AS, CI, FSM, Fi, FP, Gu, MI, Na, NC, NMI, Pa, PNG, Sa, SI, Va
		Galumnidae	*Orthogalumna terebrantis* Wallwork		AS, CI, FSM, Fi, FP, Gu, MI, Na, NC, NMI, Pa, PNG, Sa, SI, Va
		Miridae	*Eccritotarsus catarinensis* (Carvalho)		AS, CI, FSM, Fi, FP, Gu, MI, Na, NC, NMI, Pa, PNG, Sa, SI, Va
Salviniaceae	*Salvinia molesta*	Crambidae	*Samea multiplicalis*		CI, Fi, FP, Gu, NC, NMI, PNG
		Pauliniidae	*Paulinia acuminata*		CI, Fi, FP, Gu, NC, NMI, PNG

Weed family	Weed species	Biocontrol agent family	Biocontrol agent species	No. of countries in Pacific agent established	Possible countries for introduction#
Scrophulariaceae	*Buddleja davidii* Franch.	Curculionidae	*Cleopus japonicus* Wingelmüller		Fi, NC, PNG
Verbenaceae	*Lantana camara*	Agromyzidae	*Calycomyza lantanae*	7	AS, CI, FP, Ki, MI, Na, NC, Ni, NMI, PI, Sa, To, Tu, WF
		Agromyzidae	*Ophiomyia lantanae*	11	AS, CI, Ki, MI, Na, Ni, PI, SI, Tu, WF
		Brentidae	*Coelocephalapion camarae* Kissinger		AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
		Mycosphaerellaceae	*Passalora lantanae* (Chupp) U. Braun & Crous var. *lantanae*		AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
		Mycosphaerellaceae	*Septoria* sp.		AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
		Cerambycidae	*Plagiohammus spinipennis*		AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
		Chrysomelidae	*Octotoma championi*		AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
		Chrysomelidae	*Uroplata fulvopustulata*		AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
		Crambidae	*Salbia haemorrhoidalis*	2	AS, CI, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
		Erebidae	*Hypena laceratalis*	7	AS, CI, FP, Ki, MI, Na, Ni, Pa, PI, Sa, SI, To, Tu, WF
		Gracillariidae	*Cremastobombycia lantanella* Busck		AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF

Weed family	Weed species	Biocontrol agent family	Biocontrol agent species	No. of countries in Pacific agent established	Possible countries for introduction#
		Noctuidae	*Neogalea sunia*	1	AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
		Pterophoridae	*Lantanophaga pusillidactyla*	5	AS, CI, Fi, FP, Ki, MI, Na, NC, Ni, PI, Sa, SI, To, Tu, Va, WF
		Uropyxidaceae	*Prospodium tuberculatum* (Spegazzini) Arthur		AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
		Tephritidae	*Eutreta xanthochaeta* Aldrich		AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
		Tingidae	*Leptobyrsa decora*		AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
		Tortricideae	*Crocidosema lantana*	6	AS, CI, Fi, FP, Ki, Na, NC, Ni, PNG, PI, Sa, SI, To, Tu, WF
	Lantana montevidensis (Spreng.) Briq.	Agromyzidae	*Calycomyza lantanae*	7	FP, NC, WF
		Erebidae	*Hypena laceratalis*	7	FP, SI, WF
		Pterophoridae	*Lantanophaga pusillidactyla*	5	Fi, FP, NC, SI, WF

Based on weed occurrence in each country, not weed density

Table 6. Weed species currently under evaluation outside the PICTs. Agents have either not been released to date, or have been released and not yet evaluated. Biocontrol agents could potentially be introduced against these weeds in the PICTs in the future. Countries: AS=American Samoa, CI=Cook Islands, FSM=Federated States of Micronesia, Fi=Fiji, FP=French Polynesia, Gu=Guam, Ki=Kiribati, MI=Marshall Islands, Na=Nauru, NC=New Caledonia, Ni=Niue, NMI=Northern Mariana Islands, Pa=Palau, PNG=Papua New Guinea, PI=Pitcairn Islands, Sa=Samoa, SI=Solomon Islands, Tk=Tokelau, To=Tonga, Tu=Tuvalu, Va=Vanuatu, WF=Wallis & Futuna.

Weed family	Weed species	Biocontrol agent family	Biocontrol agent species	Possible countries for introduction#
Asteraceae	*Ageratina adenophora*	Pucciniosiraceae	*Baeodromus eupatorii* (Arthur) Arthur	FP
	Chromolaena odorata	Curculionidae	*Lixus aemulus* Petri	FSM, Gu, MI, NC, NMI, Pa, PNG
		Tortricidae	*Dichrorampha odorata* Brown & Zachariades	FSM, Gu, MI, NC, NMI, Pa, PNG
Bignoniaceae	*Spathodea campanulata* P. Beauv.*			AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Va, WF
	Tecoma stans (L.) Juss. ex Kunth var. *stans*	Coccinellidae	*Mada polluta* (Mulsant)	AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, Sa, SI, To, WF
	Dolichandra unguis-cati	Pyralidae	*Hypocosmia pyrochroma* Jones	CI, FSM, FP, Gu, NC, Ni, Va
Cactaceae	*Pereskia aculeata*	Coreidae	*Catorhintha schaffneri* Brailovsky & Garcia	FP, NC, Pa
Commelinaceae	*Tradescantia fluminensis* Vell.	Chrysomelidae	*Lema basicostata* Monros	FP, Na
		Chrysomelidae	*Neolema abbreviata* Lacordaire	FP, Na
		Chrysomelidae	*Neolema ogloblini* (Monros)	FP, Na
Dioscoreaceae	*Dioscorea bulbifera* L.	Chrysomelidae	*Lilioceris cheni* Gressitt & Kimoto	AS, FSM, Fi, FP, Gu, MI, Ni, NMI, Pa, PNG, Sa, SI, To, Va, WF
Fabaceae	*Falcataria moluccana* (Miq.) Barneby & J.W. Grimes*			AS, CI, FSM, Fi, FP, Gu, NC, Ni, Pa, PNG, Sa, SI, To, WF
	Mimosa pigra	Chrysomelidae	*Nesaecrepida infuscata* (Schaeffer)	PNG
		Raveneliaceae	*Diabole cubensis* (Arthur & J.R. Johnst.) Arthur	PNG
	Parkinsonia aculeata L.	Geometridae	*Eueupithecia cisplatensis* Prout	FSM, FP, Gu, NC, SI
Lamiaceae	*Clerodendrum chinensis* (Osbeck) Mabb.	Chrysomelidae	*Phyllocharis undulata* (L.)	AS, CI, FSM, Fi, FP, Gu, Ni, NMI, PNG, Sa, SI, To, Va

Weed family	Weed species	Biocontrol agent family	Biocontrol agent species	Possible countries for introduction#
Lygodiaceae	*Lygodium microphyllum* (Cav.) R. Br.	Crambidae	*Neomusotima conspurcatalis* (Warren)	FSM, Fi, Gu, NMI, Pa, PNG, SI
		Eriophyidae	*Floracarus perrepae* Knihinicki & Boczek	FSM, Fi, Gu, NMI, Pa, PNG, SI
Myrtaceae	*Psidium cattleianum* Sabine	Eriococcidae	*Tectococcus ovatus* Hempel	CI, FSM, Fi, FP, NC, Pa, PNG, PI, Sa, SI
Passifloraceae	*Passiflora rubra* L.*			AS, CI
Pontederiaceae	*Eichhornia crassipes*	Acrididae	*Cornops aquaticum* (Brüner)	AS, CI, FSM, Fi, FP, Gu, MI, Na, NC, NMI, Pa, PNG, Sa, SI, Va
		Delphacidae	*Megamelus scutellaris* Berg	AS, CI, FSM, Fi, FP, Gu, MI, Na, NC, NMI, Pa, PNG, Sa, SI, Va
Sapindaceae	*Cardiospermum grandiflorum* Sw.	Curculionidae	*Cissoanthonomus tuberculipennis* Hustache	CI, FP
Verbenaceae	*Lantana camara*	Chrysomelidae	*Longitarsus bethae* Savini & Escalona	AS, CI, FSM, Fi, FP, Gu, Ki, MI, Na, NC, Ni, NMI, Pa, PNG, PI, Sa, SI, To, Tu, Va, WF
Zingiberaceae	*Hedychium gardnerianum* Sheppard ex Ker Gawl.*			CI, FSM, Fi, FP, NC

Based on weed occurrence in each country, not weed density

* Field exploration and host specificity being conducted

However, many biocontrol agents that have established in the PICTS are only found in a fraction of the countries in which their respective target weed occurs. This could be because weed densities in countries where agents are not present are not high enough to warrant biocontrol, or because human population base, infrastructure, expertise, experience and funding to implement biocontrol programmes are limited (Dovey et al. 2004).

Both the Secretariat of the Pacific Community (SPC) and the South Pacific Regional Environmental Program (SPREP) have a responsibility in helping member countries in agricultural and environmental issues respectively, and could therefore assist in coordination of biocontrol programmes, while Australia, the USA and New Zealand could help in a technical capacity, especially regarding the additional testing of biocontrol agents (Dovey et al. 2004).

Another constraint to successfully implementing biocontrol in the PICTs is due to the nature of the Pacific. The Pacific region covers 30 million km^2, of which only 2% is landmass and is spread over 7,500 islands (Shine et al. 2003). Therefore, releasing biocontrol agents into all countries and on all islands where target weeds occur can be challenging and expensive (Dovey et al. 2004, Day et al. 2013a, c). This contrasts greatly with Asia or Africa where biocontrol agents have readily spread within and to other countries, as weed populations are often contiguous (Winston et al. 2014). To help overcome these logistical difficulties, many biocontrol programs in the Pacific region have been funded by donor organisations from Australia, Europe, the USA and New Zealand and/or have involved the assistance of the SPC.

Within these programs, substantial funds are frequently allocated to conducting weed and biocontrol agent distribution surveys in order to identify locations where a target weed is present but no agents have established. Such surveys have been conducted recently in Papua New Guinea and Vanuatu, with funding from the Australian Government. Program funds are also frequently spent on increasing capacity, such as improving infrastructure and training staff, as well as releasing biocontrol agents.

A cost-effective solution to weed biocontrol research in the PICTs is to redistribute effective agents already established in the region (Dovey et al. 2004, Julien et al. 2007, Paynter et al. 2015). In general, redistribution of agents within the Pacific requires little to no extra host specificity testing because plant assemblages are often similar between countries, and many agents have been established long enough to both identify the most highly effective agents and to detect any non-target impacts. Utilising tried and proven agents overcomes the considerable cost of host specificity testing of new agents, and reduces the likelihood of agents not establishing or having minimal impact on the target weeds (Julien et al. 2007, Paynter et al. 2015).

Countries wishing to introduce any biocontrol agent from within the Pacific region should conduct surveys to determine what agents are already present in their country. There are many examples of agents previously not reported, being found in countries following the conduct of dedicated or even opportunistic surveys (Winston et al. 2014). Regardless of the mode of entry into a country, once established within the region, biocontrol agents can spread naturally to new islands and/or countries. *Cal-*

ligrapha pantherina was released onto only 14 islands in Vanuatu and is now present on 21 islands (Day and Bule this edition). Within the PICTs, *Calycomyza lantanae* was deliberately released into only Fiji for the control of *L. camara*, but it is now found in seven countries in the PICTs. Incidentally, although *C. lantanae* has only ever been deliberately released into three countries (Australia, Fiji and South Africa), it is now found in 28 countries worldwide (Day et al. 2003, Winston et al. 2014).

In addition to redistributing agents already established within the PICTS, there are many more biocontrol agents released outside the PICTs that cause medium to high impacts on their target weed(s) and could be considered for introduction into the PICTs (Winston et al. 2014). However, such agents may not have the same efficacy in the PICTs, so climate-matching and other suitability studies may need to be conducted prior to their consideration. More importantly, because host specificity testing of these agents may have occurred in regions with very different plant assemblages, PICTs wishing to import particular agents from outside the region should determine if additional host specificity testing is required prior to the agents' importation.

Under an Australian Government funded programme, *Puccinia spegazzinii* was tested against an additional 17 local plant species by CABI prior to its introduction into PNG and Fiji. This was despite the agent being tested against 170 species on behalf of India and China prior to its introduction into those countries (Day et al. 2013b). Conversely, both *Neochetina* spp. and *C. pantherina* were introduced into the PICTs without any additional testing following their testing and subsequent release in Australia (Julien et al. 2007).

Biocontrol is seen as the most cost-effective, environmentally friendly, and sustainable option to manage many weeds in the Pacific and elsewhere. Utilising tried and proven agents that are both host specific and effective against the target weed species in other countries maximises the chance of success in new countries while minimising the risks of non-target impacts (Dovey et al. 2004, Julien et al. 2007, Paynter et al. 2015). With over 60 agents already deliberately released against more than 20 weed species, biocontrol of weeds in the PICTs is not a new concept. However, as many of these agents are found in only a few countries, there is great potential to manage the target weeds in other countries in the Pacific through their redistribution. In addition, highly damaging and host specific agents established outside the Pacific could be introduced to control those weed species not yet targeted.

Through coordinated responses, possibly involving the SPC and the SPREP, as well as Australia, the USA and New Zealand, the impacts of weeds in the Pacific region can be reduced through biocontrol, and food security for its inhabitants increased.

Acknowledgements

The authors wish to thank researchers within National Agricultural Research Institute and National Agricultural Quarantine and Inspection Authority, Papua New Guinea, Biosecurity Vanuatu, and the Secretariat of the Pacific Community for their input into

projects over the past few decades. The USDA Forest Service assisted with funding the production of the weed biocontrol catalogue, while Landcare Research New Zealand Ltd funded attendance at the EMAPI Conference held in Hawaii. The authors are grateful to Lynley Hayes and Drs Anthony Pople, Curt Daehler and Clifford Smith for providing helpful comments on the manuscript.

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