

## **Prospects for biological control of *Merremia peltata***

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## Summary

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### 1. Objective

*Merremia peltata* is a stout subwoody twining plant (Fig. 1) that is distributed from Indian Ocean Islands and throughout Malesia and eastwards into Polynesia to the Society Islands. In the Pacific region of Polynesia and Micronesia, *M. peltata* can be a troublesome weed, capable of smothering trees up to 20 m tall (Fig. 2.).



Figure 1. *Merremia peltata* flowers. Photo: Konrad Englberger, SPC



Figure 2. *Merremia peltata* smothering vegetation. Photo: Konrad Englberger, SPC

It was recently considered one of 24 serious weed targets for which it has been identified that biological control should be explored for Pacific island countries and territories. The objectives of this study are to:

- provide information to allow decision-makers to decide if a biological control programme against *M. peltata* is feasible and should proceed, and to understand what it would involve.
- serve as a template for assessing the prospects for biocontrol of other Pacific weeds.

### 2. Methods

Information for this report was obtained by searching published literature, computer databases and Internet sites; cross-referencing; and by contacting botanists familiar with the Pacific region.

### 3. Results

- *Merremia peltata* is widely distributed throughout the Pacific region but there are contradictory reports regarding its status, presenting a very complex situation where *M. peltata* is considered native to some islands, but an invasive alien in others.
- The rationale for selecting a test-plant list for host-range testing of biological control agents is outlined, based on the phylogenetic relationships of test plants to the target weed.
- The taxonomic position of *M. peltata* was assessed from the scientific literature to determine the most closely related plant species that should be used to assess the risk of non-target attack when conducting host-range tests; the most closely related genera to *Merremia* that are present in the Pacific region are *Hewittia* and *Operculina*. The

presence of native *Merremia* species on some Pacific islands means any candidate biological control agent should have to be highly specific (probably monospecific to *M. peltata*).

- Evidence to clarify the status of *M. peltata* in the Pacific region may be gained through two approaches: first, by comparing numbers of specialist herbivores and plant pathogens associated with *M. peltata* in the Malaysian-Indonesian region (the presumed area of origin of *M. peltata*) with those in Polynesia and Micronesia; and second, by using molecular methods to determine, if possible, when and how *M. peltata* colonised the Pacific. There is a possibility that after such studies its status in the Pacific region may remain uncertain.
- There is limited published information about insects that attack *M. peltata*; however, the presence of several fungal pathogens, insects with no other recorded hosts, and the very wide geographic range of *M. peltata* indicate host-specific biological control agents may exist.
- A potential candidate for developing a mycoherbicide for *M. peltata* is *Glomerella cingulata* (anamorph = *Colletotrichum gloeosporioides*), as this fungus has already been recorded from *M. peltata* in the Pacific. Host-specialised strains of this fungus are already being used for weed control worldwide.

### Conclusions

- The prospects for biological control of *M. peltata* in the Pacific region will likely hinge on whether *M. peltata* is native to the region as the desirability of conducting classical biological control against native weed species has been the subject of disagreement and debate.
- If *M. peltata* can be shown not to be native to the Pacific region, the prospects for a classical biological control programme appear good. Unlike other control methods, classical biological control offers the advantages of safety and cost-effectiveness through continuous action and self-dispersal.
- If *M. peltata* is shown to be native to the Pacific region, or if its status remains uncertain, an inundative approach using a mycoherbicide (where a highly concentrated inoculum source of a pathogen that is already present in the region is formulated and applied to weeds in a similar manner to chemical herbicides) may be possible. Such a mycoherbicide could provide a highly selective and environmentally safe control method for islands and communities that wish to adopt a biocontrol programme without compromising islands or communities that do not.
- An assessment of the benefits of a biological control programme in the Pacific region would be enhanced by gaining a better understanding of the impact of *M. peltata*, and its removal, on the communities it invades.

### Recommendations

- Conduct surveys in the Malaysian-Indonesian region to investigate whether there are any promising natural enemies in the presumed area of origin of *M. peltata* (this would likely take 2 years and cost about US\$120–180 K).
- Conduct concurrent surveys in Polynesia and Micronesia to ensure that promising natural enemies identified in the above survey are not already present (this would likely take 3 years and cost about US\$180–240 K, being logistically more complex than the previous survey).
- Perform concurrent surveys of the genetics of *M. peltata* to determine, if possible, how and when *M. peltata* colonised the Pacific region, and to narrow search area for potential agents within its native range (this would likely take 3 years and cost about

- US\$140 K; this does not include the cost of acquiring specimens, which could be achieved through surveys for natural enemies).
- Perform ecological studies on the impact of *M. peltata*, and its removal, on the communities it invades (this would likely take 3 years and cost about US\$90 K if it could be done as a PhD study).
  - Undertake a cost-benefit analysis for various methods of controlling *M. peltata* (including no control) (this would likely take less than 1 year and cost about US\$18–36 K).
  - Once the information gathered above is available, undertake dialogue with Pacific Island Countries and Territories about whether or not a biological control programme should proceed, and if so for whom (this would likely take less than 1 year and cost about US\$30–60 K).
  - If there is overwhelming evidence that *M. peltata* is introduced into the Pacific region, and agreement that biocontrol is desirable, conduct a classical biological control programme (this would likely take 5 years or more and cost US\$300–900 K, depending on factors such as what is found in earlier surveys, how much testing is required, and how easy any potential agents are to work with).
  - If there is overwhelming evidence that *M. peltata* is native to the Pacific region and agreement that biocontrol is desirable, an inundative mycoherbicide approach is recommended (this would likely take 3–5 years and cost US\$300–600K). Note that this is after the right agent has been identified, that is, subsequent to the 2–3 year survey in Malay Indonesia and Pacific regions, to enable assessment of whether there are any organisms worthy of using as a bio- or mycoherbicide).

Note that the costings in this section are indicative only and based on the assumption that the projects could proceed without any major impediments; the costings were prepared using an exchange rate of c. 0.60 from NZD to USD.

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## 1. Introduction

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*Merremia peltata* is a coarse, climbing vine with a large underground tuber. The smooth stems, which may be up to 20 m long, twine at the tips. In the Malaysia-Indonesian region the flower colour varies from white to yellow, according to locality (van Oostroom & Hoogland 1953). In the south-west Pacific the flower colour is creamy white (Waterhouse & Norris 1987). *M. peltata* is distributed from the Indian Ocean Islands and throughout Malesia and eastwards into Polynesia to the Society Islands. In the Pacific region of Polynesia and Micronesia, *M. peltata* can be a troublesome weed, capable of smothering trees up to 20 m tall. It is common to very abundant in plantations and forest clearings and was recently considered one of 24 serious weed targets for which biological control should be explored for Pacific island countries and territories (Dovey et al. 2004). This report makes use of published literature reviews, internet web pages and correspondence with botanical experts to:

- provide information to allow decision-makers to decide if a biological control programme against *M. peltata* is feasible, should proceed and understand what it would involve.
- serve as a template for assessing the prospects for biocontrol of other Pacific weeds.

This report was prepared by biocontrol of weed scientists associated with Landcare Research, a Crown Research Institute based in New Zealand, in association with The Pacific Invasives Initiative (PII).

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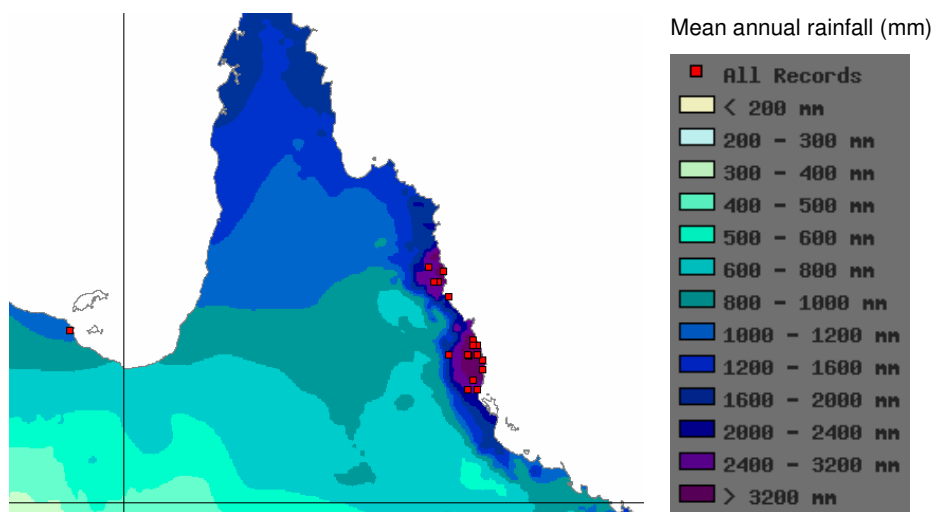
## 2. Background

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### 2.1. Global distribution of *Merremia peltata*

*Merremia peltata* is distributed from the Indian Ocean Islands of Pemba, Madagascar, Mauritius, Reunion, and the Seychelles, (see <http://www.ars-grin.gov/cgi-bin/npgs/html/taxon.pl?24108>), throughout Malesia (Malaysia, Indonesia and the Philippines), northern Australia (Fig. 3.) and eastwards into Polynesia to the Society Islands (Smith 1991). The status of *M. peltata* varies throughout its large range and information regarding its status is often contradictory. For example, it is now considered to be an exotic problem weed in the Seychelles (Kueffer et al. 2004), although many taxonomists previously assumed it to be native there (Gerlach 1994). *Merremia peltata* is restricted to warm tropical regions and in Australia it appears restricted by low rainfall.

Figure 3. Herbarium records of *M. peltata* in Australia (red) in relation to mean annual rainfall (<http://www.rbg.vic.gov.au/cgi-bin/avhpublic/avh.cgi>)



## 2.2. Distribution of *Merremia peltata* in the Pacific Region

*Merremia peltata* is widely distributed throughout the Pacific region but there are contradictory reports regarding its status there: Meyer (2000) included *M. peltata* in a list of over 30 alien invasive plants that are considered by local and academic experts to have become serious threats to the native habitats of the Pacific islands. Furthermore, Dovey et al. (2004) ranked it among the top 24 candidate weeds for classical biological control in Pacific island countries or territories, again implying that it is exotic to the region. In contrast, Smith (1991) noted that 'in the Solomon Islands, as sometimes in Fiji, this species can be a troublesome, smothering weed in forests; nevertheless, there seems no reason to doubt that it is indigenous in its Pacific range'. Kirkham (2005), citing Whistler (2002) and Space and Flynn (2002), again contended that *M. peltata* is native to the region. Indeed, Kirkham (2005) also argued that in Samoa, *M. peltata* dominance is an indicator of infrequent or recent disturbance such as hurricane damage or shifting cultivation and that, rather than a being threat to biodiversity, *M. peltata* is actually a vital part of the natural regeneration of lowland rainforest. Thus, in Samoa at least, prolonged and frequent disturbance, rather than competition with *M. peltata* may be the greatest threat to native forest biodiversity, and attempts to control *M. peltata* may even promote the invasion of exotic species, as the vine is capable of displacing other weedy non-native species (Kirkham 2005).

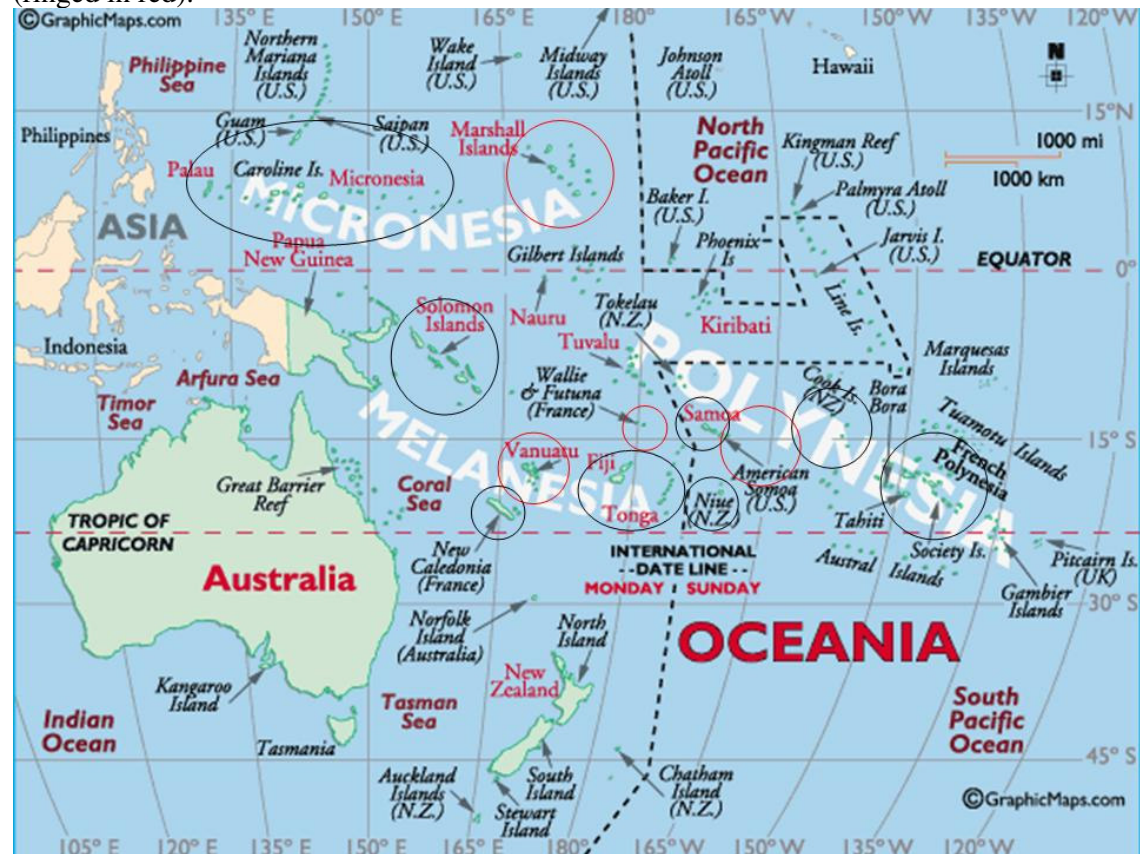
The Pacific Islands Ecosystems at Risk (PIER) website ([http://www.hear.org/pier/species/merremia\\_peltata.htm](http://www.hear.org/pier/species/merremia_peltata.htm)) presents a very complex situation, where *M. peltata* is considered native to some islands, but an invasive alien in others (summarised in Table 1 and Fig. 4). It is considered quite invasive on Tutuila, American Samoa, where local sources say it was introduced about 1970, and invasive but possibly native on Western Samoa. It is introduced and invasive on Aitutaki, Cook Islands. It is present as a native species or Polynesian introduction on Rarotonga, 'Atiu and Ma'uke. It may be a native species or an early introduction, but aggressive behaviour was observed on Kosrae, Palau and Yap (Federated States of Micronesia). It may be native, or more likely an early introduction to Tonga, as it only occurs on some islands. It is thought to have been introduced to Vanuatu about the time of World War Two, possibly by the US army for camouflage

purposes (Bakeo & Qarani 2005) and may be an old introduction (before 1769), rather than a native on Tahiti (Meyer & Florence 1996). It is naturalizing on Majuro, Republic of the Marshall Islands.

**Table 1.** Cited status of *Merremia peltata* in the Pacific (adapted from the Pacific Island Ecosystem at Risk Webpage [http://www.hear.org/pier/species/merremia\\_peltata.htm](http://www.hear.org/pier/species/merremia_peltata.htm))  
I=introduced invasive; N=native; PO=Possibly native; PR=Probably native

Country/Territory/State	Location	Cited status
American Samoa	Ta'u Island; Tutuila Island	I
Cook Islands	Aitutaki Atoll	I
	'Atiu Island, Ma'uke Island, Miti'aro Island, Rarotonga Island	N
Federated States of Micronesia	Dublon (Tonowas) Island, Fefan Island, Tol Island, Weno (Moen) Island, Yap (Waqab) Island	N
	Kosrae Island	N/I
Fiji	Kandavu Island, Mbengga Island, Taveuni Island, Vanua Levu Island, Vanua Mbalavu Island, Viti Levu Island	N
French Polynesia (Society Islands)	Huahine Island, Maupiti (Maurua) Island, Raiatea (Havai) Island, Tahiti Island	N
Guam	Guam Island	N
Marshall Islands (Ratak Chain)	Majuro Atoll	I
New Caledonia	Île Grande Terre	PO
Niue	Niue Island	N
Palau (main island group)	Babeldaob Island, Kayangel (Ngcheangel) Island, Koror Island, Malakal Island, Ngerkebesang Island	N
Western Samoa:	Savai'i Island; Upolu Island	PO
Solomon Islands	Solomon Islands	N
Tonga	'Eua Island	N/PR
	Tafahi Island	N
	Vava'u Island	N/PR
Wallis and Futuna	Alofi Island, Futuna (Horne) Island, Wallis Island	I

**Figure 4.** Islands where *Merremia peltata* is purportedly native (ringed in black) and exotic (ringed in red).



### 2.3. Current control methods

Hand control is difficult because root fragments resprout and stem fragments readily take root. Where they can be applied, chemicals can be effective: for example, trials have shown glyphosate to be an effective herbicide for use against *Merremia* sp., in forestry plantation areas of the Solomon Islands (Miller 1982). In addition, *M. peltata* is readily grazed by cattle, which can be used to control the weed, offering considerable cost savings before the establishment of permanent cover crops and tree crops. Non-grazed areas can be slashed, hand weeded or sprayed with 2,4 -D or glyphosate at recommended rates (FAO Technical Bulletin Vanuatu: <http://www.fao.org/ag/AGP/AGPC/doc/Publicat/FAOBUL2/B201.htm>).

Even well-resourced programmes for weed control can fail using conventional methods (chemical and physical control): for example, despite an extensive programme to eradicate woolly nightshade (*Solanum mauritianum*) from the Bay of Plenty region in New Zealand, the overall distribution of the plant has steadily increased there (Stanley 2003). Furthermore, inadequate storage facilities for pesticides, poor equipment and unsatisfactory safety procedures can present additional challenges for safe and effective weed control on some Pacific Islands (Konrad Englberger, Advisor Plant Protection Micronesia, and Sada Nand Lal, Entomologist. SPC, Fiji).

### 2.4. Advantages of biological control

Biological control could offer many advantages over current control methods for the management of *M. peltata*, and may be the only realistic option given the extent of the

infestations and the levels of resources and infrastructure available to manage the weed on a large scale. First, the use of host-specific biological control agents is a safe and environmentally friendly and human friendly form of weed control, compared with chemical herbicides. Second, biological control is more cost-effective than other forms of control as it offers continuous action and self-dispersal to areas that are not likely to be targeted by other control programmes.

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### 3. Objectives

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- Identify potential barriers to the use of a biological control programme against *M. peltata*, including the members of the Convolvulaceae that may be at risk of non-target attack.
- Summarise the literature and current information available from researchers worldwide on the potential for biological control of *M. peltata*.
- Assess the likelihood of success of a biological control programme for *M. peltata* in the Pacific region, and review the steps and costs associated with such a programme.

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### 4. Methods

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*Information for this report was obtained by searching published literature, computer databases and Internet sites; cross-referencing; and contact with:*

Mr Warea Orapa (Secretariat for the Pacific Community, Fiji)

Dr Andrew McDonald (University of Texas)

Dr Jean-Yves Meyer (Ministère de la Mer, la Pêche, l'Aquaculture et la Recherche, Tahiti)

Dr Jim Space (PIER)

Dr Bill Sykes (Landcare Research)

Dr Art Whistler (University of Hawai'i)

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### 5. Results

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#### 5.5. Selecting a test-plant list for host-range testing of biological control agents

##### *The history of host-range testing and associated theory*

Host-specificity testing is used to discard potential weed biological control agents that are likely to cause significant undesirable non-target damage to either native or valued exotic plants. The simplest tests are 'no-choice' starvation tests, where the potential agent is confined on a particular test plant and either feeds or starves to death. Results are extremely robust and can be used to define the fundamental host-range of a particular species – i.e. all the plant species an agent can survive (complete development) on (van Klinken & Heard 2000).

A centrifugal phylogenetic method (Wapshere 1974) has long been used to determine the host-range of a potential biological control agent by sequentially testing those plant taxa most closely related to the target weed followed by increasingly more distantly related taxa until the host-range has been circumscribed. In practice, factors such as plant morphology, biochemistry and distribution may be used to select representative plants within this circumscription (Forno & Heard 1997). However, Wapshere (1974) also defined several criteria to be used “as a safeguard against failure of the centrifugal method”, including testing cultivated plants for which there is little or no knowledge of natural enemies, which have not been exposed to the organisms under study, or which are known to be attacked by closely related organisms. As most candidate biological control agents are poorly known and are destined for possible release in a completely novel environment, these criteria have provided a rationale in most cases for the expansion of phylogenetically based test lists with a wide range of economic plant species.

However, Briese et al. (2002) argued that there is now sufficient knowledge about plant phylogeny and the evolution of host choice behaviour in insects to make the need for such safeguard species obsolete. With the recent advances in molecular techniques, there has been an enormous proliferation of publications on the phylogeny of plant taxa. Recent evidence indicates that host-shifts in lineages of specialist phytophagous insects are strongly linked to (though not necessarily co-evolved with) the evolution of host-plant lineages, and in particular plant chemistry, and that such insects show a strong phylogenetic conservatism of host associations (see Briese 1996; Briese & Walker 2002, and references). This pattern of strong phylogenetic conservatism in diet suggests non-target plants of greatest risk are those closely related to known hosts (Futuyma 2000) and this has been borne out by recent reviews of non-target attack by weed biological control agents (Pemberton 2000; Briese & Walker 2002; Louda et al. 2003). Tests based solely on the phylogenetic relationship of test plants to the target weed (e.g., Briese et al. 2002; Briese & Walker 2002; Woodburn 1993) are now commonly applied. We therefore consulted the scientific literature to determine the taxonomic position of *M. peltata* to determine the most closely related plant species that should be used to assess the risk of non-target attack when conducting host-range tests.

### **The taxonomy of *Merremia peltata***

*Merremia peltata* (L.) Merr., belongs to the family Convolvulaceae, the morning-glory family. The Convolvulaceae comprises approximately 1600–1700 species grouped in 55–60 genera (Mabberley 1987). Although nearly cosmopolitan in distribution, its members are primarily tropical plants, with many genera endemic to tropical zones of individual continents (Austin 1998). Many species of the family are widely distributed, often littoral (that is, found in coastal or shore regions), and many have been disseminated by man as ornamentals, some of these having become weeds (Smith 1991). The Convolvulaceae was recently the subject of a formal phylogenetic reclassification (Stefanović et al. 2003). The major traditional synoptic works on flowering plants place Convolvulaceae in the order Solanales along with the Polemoniaceae, Hydrophyllaceae, and Solanaceae (Stefanović et al. 2003). However, Takhtajan (1997) (cited in Stefanović et al. 2003) placed this family in its own order, Convolvulales, due to a number of characteristics, such as presence of articulated latex canals and latex cells, intraxylary phloem position, distinct seed structure and pollen morphology, not shared with other Solanales. Results of broad molecular phylogenetic studies of angiosperms in general, and Asteridae in particular, based on limited molecular data for the Convolvulaceae suggested the family is most closely related to the Solanaceae and Montiniaceae (Stefanović et al. 2003).

Stefanović et al. (2003) recognised the following tribes of the *Convolvulaceae*: *Aniseieae*, *Cardiochlamyaeae*, *Convolvuleae*, *Cresseae*, *Cuscuteae*, *Dichondreae*, *Erycibaeae*, *Humbertieae*, *Ipomoeaeae*, *Jacquemontieae*, *Maripeae* and *Merrimieae*.

#### 1. ANISEIEAE Stefanovic & Austin

This tribe is endemic to the Americas (Stefanović et al. 2003). However, *Aniseia martinicensis* (Jacquin) Choisy has been introduced throughout the Old World tropics eastward in the Pacific, at least as far as Fiji and Tonga (Smith 1991).

#### 2. CARDIOCHLAMYEAE Stefanovic & Austin

This tribe includes the genera: *Cardiochlamys* Oliver (Madagascar), *Cordisepalum* Verdc. (SE Asia), *Dinetus* Sweet (Asia), *Poranopsis* Roberty (Asia) and *Tridynamia* Gagnepain (India to SE Asia).

#### 3. CONVOLVULEAE (Choisy) Choisy.

This tribe includes the genera: *Calystegia* R. Br. (Americas, Europe, Asia), *Convolvulus* L. (worldwide, with most species in the temperate and subtropic regions), and *Polymeria* R. Br. (Australia, New Guinea).

#### 4. CRESSEAE Benth. & Hook.

This tribe includes the genera: *Bonamia* DuPetit-Thouars (pantropical), *Cladostigma* Radlk. (Africa), *Cressa* L. (Americas, Africa, Asia, Australia), *Evolvulus* L. (Americas), *Hildebrandtia* Vatke (Africa, Arabian Peninsula, Madagascar), *Sabaudiella* Chiov. (Africa), *Seddera* Hochst. (Africa, Arabian Peninsula), and *Stylisma* Raf. (E USA). Tentatively also included are: *Itzaea* Standl. & Steyerl. (Mesoamerica), *Neuropeltis* Wall. (Africa, Asia), *Neuropeltopsis* Ooststr. (Borneo), and *Wilsonia* R. Br. (Australia). A single species of *Evolvulus*, *E. alsinoides*, is present in Fiji where it appears to be adventive (Smith 1991).

#### 5. CUSCUTEAE Choisy

Cuscutae are a monogeneric tribe, comprising the genus *Cuscuta*. *Cuscuta* consists of some 160–170 species, and is nearly cosmopolitan in distribution.

#### 6. DICHONDREAE (Choisy) Choisy

This tribe includes the genera: *Dichondra* J. R. Forst. & G. Forst. (Mexico, SW USA, Africa, Australia, introduced into Asia), *Falkia* L. f. (Africa), *Metaporana* N. E. Br. (Africa, Madagascar), *Nephrophyllum* A. Rich. (Ethiopia), *Petrogenia* I. M. Johnst. (Mexico, SW USA), and *Porana* Burm. f. (SE Asia). Tentatively also included are: *Calycobolus* Willd. (tropical Americas, Africa), *Dipteropeltis* Hall. f. (Africa), and *Rapona* Baillon (Madagascar).

#### 7. ERYCIBEAE (Endl.) Hall. f.

This tribe includes the genus: *Erycibe* Roxburgh (Asia, N Australia).

#### 8. HUMBERTIEAE (Pichon) Stefanovic & Austin

The monospecific Humbertieae, endemic to Madagascar, are the sister group to the rest of Convolvulaceae. The only species, *H. madagascariensis*, retains several suspected ancestral features of Convolvulaceae.

#### 9. IPOMOEEAE Hall. f.

This tribe includes the genera: *Argyreia* Lour. (SE Asia, N Australia), *Astripomoea* A. Meeuse (Africa), *Blinkworthia* Choisy (SE Asia), *Ipomoea* L. (Americas, Africa, Asia, Australia), *Lepistemon* Blume (Africa, Asia, Australia), *Lepistemonopsis* Dammer (Africa), *Paralepistemon* Lejoly & Lisowski (Africa), *Rivea* Choisy (SE Asia, Australia), *Stictocardia* Hall. f. (Africa, SE Asia), and *Turbina* Raf. (pantropical).

*Ipomoea batatas* (L.) Lamarck, sweet potato, is the most well known member of the *Ipomoeae* and is cultivated throughout the region. *Ipomoea batatas* is of American origin, nevertheless there are numerous *Ipomoea* species that are native to the Micronesia-Polynesia region.

#### 10. JACQUEMONTIEAE Stefanovic & Austin

This tribe includes the genus: *Jacquemontia* Choisy (Americas, a few species in Asia and Australia).

#### 11. MARIPEAE Webb. & Berth.

This tribe includes the genera: *Dicranostyles* Benth. (Central & South America), *Lysiosyles* Benth. (South America), and *Maripa* Aublet (Central & South America).

#### 12. ‘MERREMIEAE’ Austin

According to Stefanović et al. (2003), the Merremieae were formally recognized only recently (Austin 1982), which reflected the lack of defining morphological characters for this group. The notion of a monophyletic Merremieae sensu Austin (1982) was rejected by cpDNA (Stefanovic et al. 2002). Even after exclusion of a subset of genera circumscribed presently in tribe Aniseieae the tribe Merremieae s.s. seems not to be monophyletic (Stefanović et al. 2003). Globose stigmas characterize the remaining taxa assigned traditionally to tribe Merremieae but this feature is also found in the members of the Ipomoeae s.l. which appear to be nested within Merremieae s.s. (Fig. 1; Stefanovic et al. 2002). Some clades within this grade are supported. For example, *Xenostegia*, *Hewittia*, and *Operculina* form a moderately supported clade, as well as most of the *Merremia* species sampled (Stefanovic et al. 2002), but the relationships between them, as well as among these two clades and several *Merremia* segregates, are largely unresolved. However, the putative monophyly of Merremieae s.s. cannot be rejected at present. Thus, Stefanović et al. (2003) retained this tribe, in its narrow sense, in their proposed classification of the Convolvulaceae. The following genera were tentatively included within the Merrimieae:

- 1 *Decalobanthus* Ooststr., contains one species *Decalobanthus sumatranus* Ooststr., which is endemic to the Indonesian Island of Sumatra.
- 2 *Hewittia* Wight & Arn. is found throughout the Old World tropics *Hewittia sublobata* (L.f.) O. Kuntze is found from tropical Africa (S. to Natal), tropical Asia (India, Ceylon, Indochina, N. to China), Polynesia, and throughout Malesia.
- 3 *Hyalocystis* Hallier f. is confined to Africa (Stefanović et al. 2003).
- 4 *Merremia* Dennst. is a pantropical genus. Apart from *Merremia peltata*, six other *Merremia* species are recorded from Fiji, two of them indigenous (one apparently endemic; Smith 1991). These are: *Merremia quinquefolia* (L.) Hall. f. (introduced weed); *Merremia tuberosa* (L.) Rendle (cultivated ornamental naturalised in Fiji); *Merremia dissecta* (Jacq.) Hall. f. (cultivated in Fiji in the past and specimens from Tonga, Samoa and the Society Islands); *Merremia umbellata* (L.) Hall. f. (introduced into Fiji, where becoming naturalised, and also in Samoa and the Society Islands); *Merremia pacifica* Ooststr (native to the Louisiade Archipelago and several islands of the Solomons, and Fiji); *Merremia calyculata* Ooststr. (endemic to Fiji, where known only from the type collection, made in Tavenui in 1860).
- 5 *Operculina* Silva Manso is a pantropical genus. One species, *Operculina turpethum* (L.) Manso, is probably native to Micronesia (Fosberg & Sachet 1977) and eastward in the Pacific to the Society and Marquesas Islands (Smith 1991).
- 6 *Xenostegia* D. F. Austin & Staples is found throughout the tropics of the old world (Africa, Asia, Australia; Stefanović et al. 2003), but is apparently not native to Micronesia-Polynesia, although Fosberg & Sachet (1977) noted that *Xenostegia* (*Merremia*) *tridentata* Ooststr. had been recorded from Palau.

Thus the current taxonomic position of *M. peltata* can be summarised as follows:

Superorder: Solananae

Order: Convolvulales  
 Family: Convolvulaceae  
 Tribe: Merremieae  
 Genus: *Merremia*  
 Species: *Merremia peltata* (L.) Merr.

The most closely related genera to *Merremia* present in the Pacific region are *Hewittia* and *Operculina*. However, the presence of native *Merremia* species, such as *Merremia pacifica*, on some Pacific islands indicates that any candidate biological control agents should have to be highly specific (probably monospecific to *M. peltata*).

## 5.6. Origins and status of *Merremia peltata* – could it be native to the Pacific region?

### *Dispersal*

*Merremia peltata* is described as a thalassochorous (sea dispersed) species (Bush et al. 1995; Ghazanfar et al. 2001). A related species, *Merremia discoidesperma* JD Smith has the distinction of holding the world record for seed dispersal distance (Gunn & Dennis 1976). This species has a limited distribution in the rain forests of southern Mexico and Central America. As an ocean drift seed it is known from Wotho Atoll in the Marshall Islands to the beaches of Norway, a total distance of more than 15,000 miles. *Merremia peltata* is considerably more widespread than *M. discoidesperma* so the precise point of origin of *M. peltata* seeds, and thus distance travelled, cannot be determined. For example, Hacker (1990) recorded viable *M. peltata* seeds in a survey of drift seeds and fruit on Raine Island on the Great Barrier Reef, but was unable to determine whether they represented relatively local dispersal from mainland Australia or longer distance dispersal, for example, from New Guinea, as *M. peltata* is present in both countries. Therefore, the distance and duration that viable *M. peltata* seeds can be transported by the sea is, to our knowledge, unknown. Nevertheless, it appears entirely conceivable that drifting seed could account for the current distribution of *M. peltata* in the Pacific region. Given that *M. peltata* thrives on disturbance (Kirkham 2005), it is also possible that while seeds may naturally disperse throughout the Pacific, colonization of Pacific islands has only occurred recently due to anthropogenic disturbance creating the conditions for *M. peltata* to colonise.

Although drifting seed could account for the current distribution of *M. peltata* in the Pacific Region, we cannot rule out the possibility that it has been dispersed either deliberately or accidentally by humans. Kirkham (2005) considered it possible that *M. peltata* seeds could have been accidentally transported in soil with deliberately transported species and also suggested that it might have been transported deliberately between islands because of its perceived beneficial properties: first, by reducing labour in dry-field taro production (by shading out other weed species that are harder to control), and also because it is perceived to improve the soil.

Furthermore, although Kirkham (2005) did not report any medicinal uses of *M. peltata* in Samoa, in Fiji a decoction of the leaves of *Colocasia* and those of wabula (*M. peltata*) is reportedly used for the treatment of cysts (Cambie & Ash 1994). Furthermore, Burkill (1966) reports numerous ethnobotanical uses including treatment for stomach ache, coughs, diarrhoea, mastitis, ophthalmia, sores, wounds and as a vermifuge, which is another potential reason for it to be transported between islands. A biological control programme would not interfere with such ethnobotanical uses of the plant, because it will not result in its eradication. Although its distribution may be reduced, *M. peltata* would remain common although much less vigorous.

***Personal communications with botanists familiar with the Pacific region.***

As well as reviewing the published literature (see section 2.2 above), we also consulted with botanists and researchers familiar with the Pacific region. Each was asked whether they thought *M. peltata* was native to the Pacific region and whether it could have been an early Polynesian introduction. Any opinions regarding whether *M. peltata* should be a target for biological control are also documented. Their responses are summarised below:

Mr Warea Orapa (Coordinator, Weed Management, Secretariat for the Pacific Community, Suva, Fiji) suspects *M. peltata* was an aboriginal introduction (by early Polynesians) either as pig feed in the hull of large sailing canoes or as binding cord to tie wooden parts of canoes or their cargoes together or for other reasons. His initial observations indicate *M. peltata* is not known from some islands but is present in others, but he also acknowledged that this may be due to land-use intensities or rainfall variations (he noted *M. peltata* grows best in high rainfall areas; see also Figure 3). He also noted that *M. peltata* is not a problem in natural undisturbed forests so, if it is native, it may be increasing due to climate change (e.g., an increasing frequency of cyclones) and increased human interference. In some places such as Samoa, areas disturbed for farming or flattened by cyclones tended to become heavily invaded. Mr Orapa believes there is potential for biological control of *M. peltata* because there is evidence that in New Guinea (where *M. peltata* is only occasionally common) and the large islands of the Bismarck Archipelago *M. peltata* is an insignificant invader as a number of organisms (albeit mostly polyphagous insects) feed on it. In the Solomon Islands he has seen severe damage to leaves.

Dr Andrew McDonald (Botanist, University of Texas) believes *M. peltata* is an Asian species that made its way naturally to a number of Asian and Micronesian islands and has been transported by humans to distant Polynesian and Micronesian islands. However, he does not know if anyone could even say what the plant's pre-human distribution was. He suggested contacting George Staples at the Bishop Museum Hawai'i, as he knows more about Asian Convolvulaceae than other contemporary botanists (we tried, but unfortunately, we received an 'out of office' autoreply stating that Dr Staples is performing research on "Biodiversity of Tropical Asian Convolvulaceae" in Thailand and Singapore until August 8).

Dr Jean-Yves Meyer (Ministère de la Mer, la Pêche, l'Aquaculture et la Recherche, Tahiti), noted that *M. peltata* is considered a Polynesian introduction in French Polynesia by some authors, including the botanist Jacques Florence, the author of *Flore de la Polynésie française*, IRD Editions, Paris (note: the Convolvulaceae family is not treated in the two published volumes of the flora: this comment is based on his unpublished database on the flora of French Polynesia). In Dr Meyer's opinion, *M. peltata* belongs typically to the "cryptogenic species" in the Polynesian region, with a doubtful biogeographical status. It could be native (seeds dispersed by the sea) or be introduced by the first Polynesian migrants (accidentally as seed contaminant, or voluntarily as a "useful" plant). According to Dr Meyer, *M. peltata* is used as a medicinal plant in Melanesia but not in Polynesia, which may be a sign it was accidentally introduced in Polynesia. The only problem Dr Meyer identified regarding biocontrol of *M. peltata* in Polynesia is the occurrence of many native Convolvulaceae (*Ipomoea* spp., *Operculina* spp.).

Dr Jim Space (Pacific Island Ecosystems at Risk; PIER) noted that in most cases, *M. peltata* is classified as native, or at least an aboriginal introduction. However, since it cannot easily be determined if a species such as *M. peltata* was an aboriginal introduction, most botanists consider a species "native" if it was there when Europeans began documenting the flora of the islands. Nevertheless, in a few cases *M. peltata* is known or suspected to be a modern introduction. In American Samoa it is said by local sources to have been introduced in the 1970s. Although it has been present on the other Cook Islands for a very long time and is either native or a Polynesian introduction, a very good case can be made for it to be a modern

introduction to Aitutaki Atoll, Cook Islands, as it was not collected before 1974 (by Sykes). According to local people it is a modern introduction to Kosrae, Federated States of Micronesia (however, it was collected by Fosberg before 1979). It is a well-documented recent (late 1990s) introduction to Majuro Atoll, Republic of the Marshall Islands (Vander Velde 2003). In Vanuatu it is rumoured to have been introduced about the time of World War II, either by the Japanese or American forces; and it is reported to be an introduced species in Wallis and Futuna. Everywhere else it is either native or an aboriginal introduction (Dr Space thinks the latter).

Dr Space noted that *M. peltata* is weedy, can reproduce from both stem fragments and seed, could easily have been moved with cultivated plants, and its occurrence throughout the Pacific is spotty, making one wonder why it is on some islands and not on others. These factors point to human distribution as the plant perhaps does not have natural vectors that would foster more widespread distribution. It is well documented that potted food plants were moved around the Pacific on the aboriginal voyages and it stands to reason that this and many other weedy species historically present on Pacific islands may have been moved with the plants and soil. More recently, it could certainly have been moved on mud/soil on vehicles or machinery, or just by people wanting a pretty flowering vine.

On the other hand, even some of the above cited cases of modern introductions may be erroneous as *M. peltata* thrives on disturbance, and widespread disturbance did not occur on many islands until after World War II. What may have been a relatively unimportant vine may have become much more noticeable with increased disturbance. For example, after Cyclone Heta severely damaged the forest in Niue, *M. peltata* increased wherever it occurred and perhaps spread to new areas. While cyclones have always caused periodic disturbance in the Pacific, anthropogenic disturbance is increasing.

Dr Space said that he has observed and understand people's frustration with this very aggressive species, but there are native species that are weedy and, because *M. peltata* is considered potentially native or an early introduction throughout most of the Pacific, he cannot recommend it as a candidate for biological control.

Dr Bill Sykes (Botanist, Landcare Research) has worked mainly in West Polynesia and the Cook Islands in East Polynesia and regards *M. peltata* as more likely to be indigenous than introduced by people to the main islands in that region. Citing Cheeseman (1903), who found it to be abundant all over Rarotonga at the end of the 19th Century and noted that 'a similar comment could be made about Niue a bit later', Dr Sykes also noted that he has never met anyone who has tried or wanted to grow it. He added that it is often seen behaving like an aggressive weed and is very noticeable because it smothers host trees up to 20 metres or so high, as well as carpeting the ground layer. However he stated that this does not necessarily preclude it from having indigenous status, because this is its natural habit. Dr Sykes hypothesized that it occurs naturally in the Cook Islands, for example, but this colonization event occurred not very long ago in historical terms and the vine, as new introductions often do, has been since expanding its range within particular islands since then. For example, in the Cook Islands there are few lianes and, as in New Zealand, introductions of such species result in them becoming dominant because this niche was not previously exploited. Therefore, whether *Merremia peltata* was brought by humans or not would make no difference to its behaviour. Dr Sykes was unwilling to comment on the advisability of conducting a biological control programme against *M. peltata*.

Dr Art Whistler (Ethnobotanist, University of Hawai'i) wrote that 'there is no question that *M. peltata* is native to Polynesia, as it was among the first collections made in Tahiti (Banks), and was in the earliest collections elsewhere in Polynesia, including Samoa (1839)'. Dr Whistler did not believe it to have been an early Polynesian introduction because 'there would

be no reason for the Polynesians to bring it'. Dr Whistler indicated he 'would see no difference between biological control of a native and alien species in this specific case, but one has to be careful when deciding this'. Nevertheless, in his view, *M. peltata* is a species that thrives on disturbance, and there has been so much human and hurricane disturbance, that it 'acts like introduced weeds that take advantage of the same situation'.

### 5.7. *Is it possible to determine whether M. peltata is native to the Pacific region?*

Two approaches could be used to provide evidence on the status of *M. peltata* in the Pacific. First, surveys of the arthropods and plant pathogens associated with *M. peltata* could be conducted in both the Malaysian-Indonesian region (the presumed area of origin of *M. peltata*; Waterhouse & Norris 1987) and in Polynesia and Micronesia. This would provide evidence on the status of *M. peltata* within the Pacific region, because the majority of plant species have reduced numbers of specialist herbivores and pathogens in their introduced range, compared to their native range (e.g., Mitchell & Power 2003). An impoverished specialist herbivore and pathogen fauna in Polynesia and Micronesia, compared with the Malaysian-Indonesian region, would therefore indicate that it might be a recent arrival there. On the other hand, the presence of specialist herbivores and pathogens confined to Polynesia and Micronesia would indicate it has long been present within the region.

The second approach is to use molecular techniques to determine, if possible, when and how *M. peltata* colonised the Pacific. Molecular techniques can be used to infer historic events by identifying geographic patterns of genetic differentiation across the range of a species ('molecular phylogeography') (Avice 1998; Comes et al. 1998). Events such as range expansion, range fragmentation, founder events and population bottlenecks can leave an imprint on contemporary levels of genetic variation. There is an array of molecular tools available for assessing genetic variation and geographical distribution of genetic markers, including allozymes, DNA fingerprinting techniques (e.g., RFLPs, AFLPs, RAPDs), microsatellites, mitochondrial DNA, chloroplast (cp) DNA, and DNA sequences (Schaal et al. 1998; Newton et al. 1999; Cox 2004), with different methods having their strengths and weaknesses.

For plants, AFLP analyses (particularly for those species for which little genetic information is available), cpDNA analyses and microsatellite analyses are among those techniques that can provide useful information about levels of genetic variation within and among populations, pathways of colonisation or invasion, numbers of introductions and to identify geographic origin. For example, AFLPs have been used to elucidate the genetic relationships and possible origins of different island populations of *Phyllis nitida* and *P. arborea* in the Atlantic and Indian Oceans (Richardson et al. 2003). Both AFLPs and cpDNA have been used to study colonisation of Northern Europe by east alpine populations of *Ranunculus glacialis* (Schönswetter et al. 2003). Gaskin et al. (2005) used the distribution and origins of cpDNA haplotypes to study the invasion of *Lepidium draba* in the western United States, and assignment tests were used to indicate most likely origins of many invasive haplotypes. Goolsby et al. (2006) used cpDNA to determine that the invasive weed fern (*Lygodium microphyllum*) in populations Florida Everglades most likely originated in northern Queensland, Australia/Papua New Guinea.

A range-wide survey of genetic variability and lineages of *M. peltata* using AFLP and cpDNA analyses could reveal patterns that indicate the manner in which the plant has spread. It may also be possible to distinguish relatively recent human-mediated dispersal from more ancient 'natural' colonisation events using DNA sequence data to date divergences of populations. This would give indirect evidence that the species is invasive rather than native.

## 5.8. Potential agents for the biological control of *M. peltata* in the Pacific region

### Classical biological control

Classical biocontrol of weeds using invertebrate herbivores or plant pathogens is internationally accepted as a practical, safe (Barton 2004), and environmentally beneficial weed management method applicable across both natural and agricultural ecosystems (Charudattan 2001). It offers the prospect of sustainable control of priority weeds at low ongoing cost and minimal environmental impact. There have been some previous successes using insects and pathogens for weed control in the Pacific region. For example, at Palikir, Pohnpei, the introduced psyllid *H. spinulosa* became abundant on the invasive weed *Mimosa invisa* and subsequently killed many plants (Waterhouse 1994). In Hawai'i, 8 weeds have been successfully controlled by introduced biological control agents (Markin et al. 1992), including mist flower (*Ageratina riparia*) in 1998 (Frohlich et al. 1999) and banana poka (*Passiflora tarminana*) (Trujillo et al. 2001). Additionally, a fungal leaf disease, *Colletotrichum gloeosporioides* f. sp. *miconiae*, was released in Hawai'i in 1997 and in Tahiti in 2000, against *Miconia calvescens* (Killgore et al. 1997). Monitoring the dynamics and evaluating the impacts of this programme has been undertaken since 2000 and results are due to be published (Jean-Yves Meyer, Ministère de la Mer, la Pêche, l'Aquaculture et la Recherche, Tahiti, pers. comm.).

There has been a long history of biocontrol in Fiji, with introductions of prospective biocontrol agents recorded as early as 1911 (Julien 1992). The introduction of a thrips (*Liothrips urichi*) in the 1930s has resulted in excellent control of Koster's curse (*Clidemia hirta*) in most areas in Fiji, with a 75% reduction in weeding costs (Julien 1992). There has also been some suppression of lantana (*Lantana camara*) through the introduction of a leaf-feeding beetle, *Uroplata girardi*, which can cause severe damage especially in shady situations (Julien 1992). Good control of salvinia (*Salvinia molesta*) and broom weed (*Sida acuta* and *Sida rhombifolia*) has also been achieved. Agents for salvinia and water hyacinth (*Eichhornia crassipes*) are washed away by floods periodically. A biocontrol programme has recently been initiated against mile-a-minute (*Mikania micrantha*) for Fiji and Papua New Guinea (W. Orapa, pers. comm.).

Adherence to the international guidelines for the selection and testing of all potential agents for weed biocontrol purposes ensures both insects and pathogens are highly host specific and will not damage valued non-target native or crop species before any release.

A survey in the native and introduced ranges for plant pathogens and invertebrates may identify potential disease agents and arthropods that could be used for biocontrol purposes. A preliminary search of host record databases <http://nzfungi.landcareresearch.co.nz>, (Farr et al. 2006; <http://nt.ars-grin.gov/fungaldatabases> (data accessed 4 May, 2006) <http://www.nhm.ac.uk/research-curation/projects/hostplants/> (data accessed 11 May, 2006) and literature (Waterhouse & Norris 1987) revealed that several plant pathogens and insects have previously been recorded on *M. peltata* or other species of *Merremia* (Tables 2 & 3). Several of the fungi are primary plant pathogens, such as fungal rusts and a powdery mildew, and could be potential agents for future assessment. Surveys would be required to collect these or other disease agents for further efficacy and host range testing. Rust pathogens have frequently been used for classical biocontrol of weed targets as some rusts are highly coevolved with their host and therefore have a narrow host range.

On occasion pathogens are so specific they are effective only on certain biotypes of the host plant. In this situation it is important that appropriate strains of pathogens are matched to the

biotypes of the target plant present where control is required (e.g., the rust *Puccinia chondrillina* on skeleton weed in Australia (Hasan 1985; Chaboudez et al. 1992), and blackberry leaf rust *Phragmidium violaceum* on European blackberry in Australia (Scott et al. 2002; Lawrence 2004) . Molecular studies can be a crucial part of this process.

Most insect surveys have been conducted in Vanuatu, where *M. peltata* is considered exotic and the insect fauna was considered sparse (Waterhouse & Norris 1987). Waterhouse and Norris (1987) recommended that a survey be conducted in the Malaysian-Indonesian region to see if there were any promising natural enemies in the presumed area of origin of *M. peltata*.

Table 2. Database records of fungi and bacteria recorded on *Merremia* hosts

Fungi and bacteria	Disease type	Location	N	H
Host: <i>Merremia peltata</i> <i>Glomerella cingulata</i> * (* = <i>Colletotrichum gloeosporioides</i> ) <i>Meliola merremiae</i> <i>Meliola quadrispina</i>	Leaf spot Rust pathogen Rust pathogen	Wallis and Futuna Islands Philippines Vanuatu	1 1 1	
Host: <i>Merremia alba</i> <i>Corynespora cassiicola</i> <i>Mycosphaerella</i> sp.	Leaf fungus Leaf fungus	Federated States of Micronesia Federated States of Micronesia	1 1	
Host: <i>Merremia gangetica</i> <i>Xanthomonas campestris</i> pv. <i>merremiae</i>	Bacterial leaf spot	India	1	
Host: <i>Merremia</i> sp. <i>Aecidium kaernbachii</i> * (* = synonymous)	Rust pathogen	Philippines Malaysia Papua New Guinea	1 2 2	2
<i>Endophyllum kaernbachii</i> *	Rust pathogen	China Thailand	1 1	
<i>Ferrarisia philippina</i> <i>Meliola quadrispina</i> <i>Oidium ipomoeae</i> <i>Pestalotiopsis</i> sp. <i>Puccinia lepestemonis</i> <i>Uredo operculinae</i> <i>Uredo operculinae</i>	Ascomycete Rust pathogen Powdery mildew Leaf fungus Rust pathogen Rust pathogen Rust pathogen	Philippines Philippines India Palau Taiwan Venezuela Thailand	1 2 1 1 1 1 1	3

N = Number of different collections recorded; H = Number of other recorded plant hosts

Table 3. Records of insects recorded feeding on *Merremia peltata*

Order and Family	Species	Country	Notes
HEMIPTERA Pseudococcidae	<i>Pseudococcus nr microadonidum</i>	Vanuatu	Few found under leaves
Cicadellidae	<i>Empoasca</i> sp.	Vanuatu	Common under leaves
Derbidae	<i>Levu</i> sp.	Vanuatu	Common under leaves
Plataspidae	<i>Brachyplataspis pacificus</i>	Vanuatu	Stem sucking, common, polyphagous
COLEOPTERA			
Chrysomelidae	<i>Arsipoda salomonensis</i>	Vanuatu	Adults and larvae feed on this species (also found on <i>M. pacifica</i> )
	<i>Aspidomorpha australasiae</i>	Vanuatu	
Curculionidae	<i>Trigonopterus nr paucisquamosa</i>	Vanuatu	
LEPIDOPTERA			
Arctiidae	<i>Euchromia oenone</i>	Solomon Islands; Vanuatu	Also recorded on <i>M. pacifica</i>
Gelechiidae	<i>Myconita lipara</i>	Fiji	Also recorded on <i>Ipomoea batatas</i>
Geometridae	<i>Hyposidra incompertaria</i>	Solomon Islands; Vanuatu	Polyphagous
Gracillariidae	<i>Acrocercops praesecta</i>	Fiji	Also recorded on <i>Ipomoea batatas</i>
Pterophoridae	<i>Ochyrotica cretosa</i>	Solomon Islands; Vanuatu	Also found on <i>M. pacifica</i>
Pterophoridae	<i>Ochyrotica salomonica</i>	Solomon Islands	No records from other host-plants
Sphingidae	<i>Agrius convolvuli</i>	Fiji	Polyphagous
Pyrilidae	<i>Antiercta ornatalis</i>	Fiji	Also recorded on <i>Ipomoea batatas</i>
Pyrilidae	<i>Tabidia insanalis</i>	Vanuatu	Pest of <i>Ipomoea batatas</i>
DIPTERA			
Agromyzidae	gen. et sp.?	Vanuatu	Mines on upper leaf surface

### ***Inundative biological control: developing a mycoherbicide***

Another approach to using plant pathogens for weed control is inundative biological control, where a highly concentrated inoculum source of the pathogen is formulated and applied to weeds in a similar manner to chemical herbicides (Evans et al. 2001). The applied inoculum is called a mycoherbicide or bioherbicide. This approach can be used to augment natural populations of indigenous fungi or bacteria already present in the Pacific or to augment and target classically introduced pathogens to certain areas. Currently this approach is being developed in Hawai'i where a soil-borne bacterium, *Ralstonia solanacearum* has been formulated as a bioherbicide against Kahili ginger (*Hedychium gardnerianum*) in Hawaiian forests (Anderson & Gardner 1999). An advantage of the inundative approach is that it does not necessarily increase the risk of infection to non-target plants, as it uses endemic microorganisms already present in the environment combined with targeted applications to the target host.

Inundative biocontrol can also increase the choice of potential agents for weed control as a pathogen that does not offer potential as a classical biocontrol agent, because it spreads slowly or is only effective under a narrow range of environmental conditions, may still be developed

as a mycoherbicide. A mycoherbicide can be applied where and when it is needed and it may be possible to formulate the bacterium or fungus to persist in the environment until conditions become suitable for infection and disease development. Facultative necrotrophic fungal pathogens, e.g., *Colletotrichum* spp., are particularly amenable to development as they can be grown more easily on artificial media, which facilitates the mass production of an inoculum (Butt et al. 2001). Improved efficacy of mycoherbicides can also be achieved through formulation and application technologies, and/or integration with other weed control measures, e.g., chemical and mechanical methods.

A disease survey in both the native and introduced ranges would determine whether any suitable pathogens are present on *Merremia* that could be developed as a mycoherbicide. Given that there is natural variation in virulence between different strains of any disease and that a single pathogen may not be present across the entire distribution of *Merremia* in the Pacific, a combination of a classical and inundative approach may have to be adopted. That is, a mycoherbicide approach could also be used that introduces plant diseases to islands where they already occur naturally. However, the advantage of inundative biocontrol is that *Merremia* biocontrol could be targeted specifically to islands and communities that wish to adopt such a biocontrol programme, and avoid islands or communities where cultural and economic value is attached to the plant.

A potential candidate for a *Merremia* mycoherbicide is *Glomerella cingulata* (anamorph = *Colletotrichum gloeosporioides*), as this fungus has already been recorded from a leaf disease of *M. peltata* in the Pacific (Table 2). Host specialised strains of this fungus are already being used for weed control worldwide, including for *Miconia* biocontrol in Tahiti (Killgore et al. 1999), and this fungus has already been formulated into commercial products for weed biocontrol elsewhere (Evans et al. 2001). For example, Collego™ is a formulation of this fungus for the control of northern joint-vetch (*Aeschynomene virginica*) in the USA, and BioMal™ is another *Colletotrichum gloeosporioides* strain formulated for control of round leaved mallow (*Malva pusilla*) in Canada. A similar *C. gloeosporioides* based product, for use against *Merremia*, could benefit from and even adopt the significant progress made in formulating *Colletotrichum* strains for weed control.

Despite these successful examples, relatively few microorganisms have been developed and registered as bioherbicide products. Formulation is often the stumbling block when developing bioherbicides. It can be extremely difficult to get living microorganisms to behave predictably and reliably in the field, given the variety of conditions they encounter. Mixtures that look promising in laboratory trials often prove unsatisfactory in the field. Additionally each country has its own rules regarding registration, and meeting the requirements can be an expensive and drawn-out process (e.g., it took 5 years to register BioMal® in Canada). Developing an inundative approach for *Merremia* control may therefore require medium-term support (3–5 years, once the correct agent has been selected) to enable formulation criteria to be achieved for product registration.

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## 6. Conclusions and recommendations

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### 6.1. Prospects for achieving biological control of *M. peltata* in the Pacific region

Waterhouse and Norris (1987) recommended that a survey be conducted in the Malaysian-Indonesian region to investigate whether there are any promising natural enemies in the presumed area of origin of *M. peltata*, but such a survey has yet to be conducted. As a

consequence only limited published information regarding the pathogens and insects that attack *M. peltata* is available. Nevertheless, the presence of several fungal pathogens and insects with no other recorded hosts (Tables 2 & 3), and the very wide geographic range of *M. peltata* indicate host-specific biological control agents may exist.

However, the lack of agreement regarding the status of *M. peltata* throughout the region is problematic. The potential and desirability of using classical biological control against *M. peltata* in the Pacific region may depend on whether it is possible to determine the extent of its native and introduced ranges. Classical biological control programmes have, in the past, been conducted against native weeds. However, whether or not native weeds should be targeted for biological control has been the subject of disagreement and debate. Deloach (1981, 1985) argued for such control, and conducted research programmes on the use of biological control against native weeds of rangeland in the United States. Pemberton (1985) argued against targeting native weeds for biological control because many of these plants are ecological dominants that have importance in natural communities. In addition, it is impossible to limit biological control agents only to situations where the target native weeds are problems. The introduced insects or pathogens would spread to parks and other natural areas, where plants are valued native species. Projects against native weeds would be a wasted effort if permission would not be granted for the release of an imported natural enemy for the control of a native weed (Pemberton 2002). In addition, projects against exotic weeds have been favoured because it has generally been believed that the chance of finding useful natural enemies is greater for exotic weeds, given that native weeds may have a saturated community of specialist insects occupying most plants' niches (Pemberton 2002).

Despite these difficulties, native weeds have occasionally been targets of classical biological control. Two programmes against native weeds failed because the agents apparently did not establish. An Argentine weevil (*Heilipodus ventralis* Kuschel) was released against two native *Gutierrezia* spp. in New Mexico and Texas in 1988, but establishment of the weevil was not confirmed (Julien 1992), and in New Zealand, a sawfly from Chile *Antholcus varinervis* (Spin.), now *Ucona acaenae* Smith, was introduced in 1936 against the native plant *Acaena anserinifolia* Bur., but did not persist (Valentine 1970). However, biological control of native *Opuntia* species was successful on Santa Cruz Island, just off the California coast (Goeden et al. 1967) and in the Caribbean Island of Nevis (Simmonds & Bennett 1966).

The absence of suppressive specialized natural enemies is one of the primary reasons why populations of exotic weeds are thought to reach high pest densities. Of key importance regarding the status of apparently native but invasive populations of *M. peltata* will be to determine whether they are invasive despite the presence of a diverse assemblage of natural enemies, or whether their herbivore assemblages are impoverished, compared with other regions. Before any weed biological control programme is conducted, the first priority should therefore be to survey and record systematically any associated damage resulting from the invertebrate fauna and pathogens associated with *M. peltata* in both the Pacific region, where it is considered invasive, and in its accepted native range.

The native range of *M. peltata* is very large, so identifying where to survey for natural enemies may be problematic. Climate matching (e.g., van Klinken et al. 2003) could be used to identify those areas where *M. peltata* is considered native that have climates most similar to regions of the Pacific where it is invasive. Furthermore, it may prove most desirable to survey for potential biological control agents from native populations of *M. peltata* that are closest to the Pacific (for example, New Guinea, the Philippines or North Australia). This is because the use of classical biological control against invasive *M. peltata* populations carries a risk that biological control agents could then spread to native populations of *M. peltata*, where their presence may be undesirable. For example, the South American moth *Cactoblastis cactorum*

(Bergoth) has spread from introductions in Nevis in the Caribbean to Florida, where it is now attacking four native *Opuntia* species, including a federally listed endangered species (Pemberton 1995). Selecting biological control agents already present in native populations that are adjacent to weedy invasive populations (rather than from localities further afield, such as Madagascar) should prevent this from happening.

For overseas biological control candidates, an assessment of their efficacy as potential biocontrol agents *in situ* should allow fairly accurate predictions to be made regarding their likely success in Polynesia and Micronesia (Hasan 1988). Such assessments would eliminate all but the most likely candidate/s and are necessary because of the large number of potential agents and the extensive host testing required for each agent. The development and use of a commercial standard mycoherbicide is likely to cost more than development and use of a classical biological control agent. However, it is likely that several classical biocontrol agents would be needed to achieve effective widespread control and overall the costs of both approaches may therefore end up being similar.

There are several matters to consider regarding the prospects for successful biological control of *M. peltata*. First, like chemical and manual control methods, biological control targets the invasive species rather than the attributes of systems that make them invasible, which contradicts current theory regarding management of weed invasion (Hobbs & Humphries 1995; Mack et al. 2000). Therefore, while biological control may effectively manage *M. peltata*, it will not prevent invasion of other weeds that may occur with a reduction of *M. peltata*. Second, a better understanding of the long-term impact of *M. peltata* on native systems in the Pacific would enable a more effective assessment of the likely benefits of a biological control programme targeting this weed, particularly whether or not *M. peltata* persists, or at least persists long enough to alter the successional trajectory of the communities it invades. Third, it is essential to know the effect of removing *M. peltata* for each of these communities, and it would be useful to know the level of control required for protection of selected native species. Last, an economic cost-benefit analysis may be required to make a strong case for funding the project and to get permission to release agents. This would consider factors such as the cost of existing control methods, the cost of biocontrol (classical and inundative), and the cost of doing nothing.

In conclusion, there are many aspects that require further research before biological control could be developed for *M. peltata* in the Pacific region. An assessment of the benefits of such a biological control programme would be enhanced by a better understanding of the impact of *M. peltata*, and its removal, on the communities it invades, and some economic analysis. Once further information is available about the status of *M. peltata*, the likelihood of finding suitable biocontrol agents, and the cost-effectiveness of biocontrol, it would be highly desirable for effective dialogue to be undertaken with all affected Pacific Island countries and territories so they can decide collectively whether a project should proceed and if so for whom.

### Recommendations

- Conduct surveys in the Malaysian-Indonesian region to investigate whether there are any promising natural enemies in the presumed area of origin of *M. peltata* (this would likely take 2 years and cost about US\$120–180 K).
- Conduct concurrent surveys in Polynesia and Micronesia to ensure that promising natural enemies identified in the above survey are not already present (this would likely take 3 years and cost about US\$180–240 K, being logistically more complex than the previous survey).
- Perform concurrent surveys of the genetics of *M. peltata* to determine, if possible, how and when *M. peltata* colonised the Pacific region, and to narrow search area for potential agents within its native range (this would likely take 3 years and cost about US\$140 K; this does not include the cost of acquiring specimens which could be achieved through surveys for natural enemies).

- Perform ecological studies on the impact of *M. peltata*, and its removal, on the communities it invades (this would likely take 3 years and cost about US\$90 K if it could be done as a PhD study).
- Undertake a cost-benefit analysis for various methods of controlling *M. peltata* (including no control) (this would likely take less than 1 year and cost about US\$18–36 K).
- Once the information gathered above is available, undertake dialogue with Pacific Island countries and territories about whether or not a biological control programme should proceed, and if so for whom (this would likely take less than 1 year and cost about US\$30–60 K).
- If there is overwhelming evidence that *M. peltata* is introduced the Pacific region, and agreement that biocontrol is desirable, conduct a classical biological control programme (this would likely take 5 years or more and cost US\$300–900 K, depending on such factors as what is found in earlier surveys, how much testing is required, and how easy any potential agents are to work with).
- If there is overwhelming evidence that *M. peltata* is native to the Pacific region and agreement that biocontrol is desirable, an inundative mycoherbicide approach is recommended (this would likely take 3–5 years and cost US\$300–600 K). Note that this is after the right agent has been identified, i.e. subsequent to the 2–3 year survey in Malay Indonesia and Pacific regions, to enable assessment of whether there are any organisms worthy of using as a bio- or mycoherbicide).

Note that the costings in this section are indicative only and based on the assumption that the projects could proceed without any major impediments; the costings were prepared using an exchange rate of 0.60 from NZD to USD.

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## Appendices

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### Appendix 1: Glossary of terms (as used in the context of this report only):

Agent: see biological control agent.

Alien: an organism, especially a plant or animal, that occurs in or is naturalised in a region to which it is not native.

Anamorph: the imperfect (asexual) part of the life cycle of fungi – often has a different species name from the perfect or sexual stage.

Arthropod: any of numerous invertebrate animals of the phylum Arthropoda, including insects, crustaceans, arachnids, and myriapods.

Anthropogenic disturbance: disturbance caused by humans, such as logging or cultivation.

Biocontrol: see biological control.

Biodiversity: the number and variety of organisms found within a specified geographic region.

Biogeography: the study of the geographic distribution of organisms.

**Biological control:** when one living organism is used to control another.

**Biological control agent:** term for a living organism that is deliberately being used to control another living organism.

**Bioherbicide:** herbicide where the active ingredient is a living organism (e.g., fungi, bacteria protozoans) – see mycoherbicide.

**Clade:** a group of organisms that includes both their common ancestor and all of their descendants.

**Classical biological control:** where biological control agents are introduced from overseas and, once released, persist indefinitely.

**Cost-benefit analysis:** the comparison of benefits and costs in decision making. Dollar values are assigned to benefits and costs in most cost-benefit analyses.

**Cryptogenic species:** a species of obscure or unknown origin in a geographic region.

**Endemic:** naturally occurring in a country and nowhere else.

**Exotic:** a species that is from another place, not native.

**Facultative necrotrophic fungal pathogens:** fungi that can grow on dead organic tissues and other substrates such as agar (as opposed to obligate pathogens that can only grow and multiply on living host tissues).

**Fauna:** all the animal life in a particular region.

**Flora:** all the plant life in a particular region.

**Formulation:** a substance prepared according to a specified formula or recipe.

**Founder event:** the formation of a new population by individuals from another population.

**Fundamental host-range:** the plant species (one or more) on which the agent (insect or pathogen) is capable of surviving, i.e. those species on which complete development is possible.

**Generalist:** insect that feeds on a wide range of plants.

**Habitat:** the part of the environment where a particular species can live, either temporarily or permanently.

**Host-range:** the range of plants on which a biocontrol agent can feed and reproduce.

**Host-specificity testing:** testing to find the host range of a potential biocontrol agent.

**Indigenous:** native to a country but may also be found naturally elsewhere.

**Inoculum:** substance used to infect a plant with a pathogen, usually a solution containing spores.

**Inundative control:** creating a disease epidemic in a weed population by applying a large quantity of a bioherbicide. Unlike classical biological control, agents used in bioherbicides may not persist for long following application and may need to be reapplied.

**Inundative mycoherbicide approach:** see inundative control and mycoherbicide.

**Invasive/invasive alien:** tending to spread to where it has not been present before.

**Invertebrate:** small animal without a backbone or spinal column.

**Liane:** any of various climbing, woody, usually tropical vines.

**Littoral:** of, relating to, or being property abutting an ocean, sea, lake, or pond.

**Molecular phylogeography:** molecular techniques can be used to infer historic events by identifying geographic patterns of genetic differentiation across the range of a species.

**Monophagous/Monospecific:** feeding on only one species of plant. Used chiefly of insects. (See also oligophagous, polyphagous.)

**Mycoherbicide:** herbicide where the active ingredient is a fungus.

**Native:** occurring naturally in a country but perhaps naturally in other places too.

**Native range:** where an organism evolved and occurs naturally.

**Natural enemy:** organism that naturally attacks another organism.

**Naturalise:** to introduce and establish as if native.

**Niche:** the role of an organism or a population in its ecological community.

**Oligophagous:** feeding on a limited number of plant species. Used chiefly of insects. (See also monophagous, polyphagous.)

**Phylogenetic relationships:** the evolutionary or historic relationships of groupings of organisms.

**Phylogeny:** the evolutionary development and history of a species or higher taxonomic grouping of organisms.

**Phytophagous:** feeding on plants, including shrubs and trees. Used especially of certain insects.

**Plant pathogen:** a fungus or other organism (not plant or animal) that feeds and grows on plant tissues causing disease

**Polyphagous:** insect feeding on many different species of plant (see also monophagous, oligophagous).

**Primary plant pathogen:** a plant pathogen that initiates infection and disease on its host.

Specialist herbivore/plant pathogen: feeds only on a narrow range of plant species or varieties.

Specific: see host specific, monophagous(?)

Spore: tiny structures used by fungi to disperse and create new infections, equivalent to a plant seed.

Taxa: plural of taxon – a taxonomic category or group, such as a phylum, order, family, genus, or species, or even an individual, depending on context.

Virulence: the capacity of a pathogen to cause disease by breaking down protective mechanisms of the host.

## **Appendix 2: Steps in a Biocontrol Project**

A classical biocontrol programme typically works through the following steps, usually in a sequential manner, but some activities may occur concurrently.

1. Explore the feasibility of project. If project looks feasible, proceed.
2. Survey weed in places where biocontrol is desired. If any potential agents are found explore ways to maximise them. If any likely impediments are found look for ways to mitigate them.
3. Undertake molecular studies of the weed to help narrow down the best place in the native range to find natural enemies.
4. Unless natural enemies are already well known, survey weed in native range. Identify and study life cycles of natural enemies found.
5. Determine host range for potential agents. Abandon any species that do not appear to be safe or effective enough.
6. Apply to authorities for permission to release agents.
7. If permission is granted import, clear through quarantine, and develop rearing techniques for new agents (if not already known)
8. Mass rear and release agents over several years.
9. Monitor establishment success and dispersal of agents over several years.
10. Harvest and redistribute agents
11. Evaluate success of project. Decide if further agents are needed.

An inundative biocontrol programme where mycoherbicides are developed for use, typically works through the following steps in a sequential manner:

1. Survey the weed to look for potentially useful pathogens (if not already known)
2. Undertake glasshouse trials to explore host range and pathogenicity
3. Develop prototype formulation and test under field conditions
4. Refine formulation
5. Explore techniques for mass production and prospects for commercialisation
6. Undertake risk analysis and apply for registration

### **Appendix 3: The Pacific Invasives Initiative**

The Pacific Invasives Initiative (PII) is a programme of the Cooperative Initiative on Invasive Alien Species. The PII is hosted by the Invasive Species Specialist Group (ISSG), an expert group of the Species Survival Commission (SSC) of The World Conservation Union (IUCN). The ISSG was established in 1993 and its mission is ‘To reduce threats to natural ecosystems and the native species they contain, by increasing awareness of alien invasions and of ways to prevent, control or eradicate them’. The ISSG consists of 11 core staff based at its headquarters in Auckland, New Zealand, who bring together extensive global experience and skills in all areas of invasive species including: prevention and management of invasive species; ecology of invasive species; policy; training; information management and dissemination; and facilitation and coordination of invasive species management projects.

The core personnel are complemented by a global network of over 160 invasive species specialists distributed across 42 countries. This network constitutes a comprehensive knowledge base on which ISSG can call to provide information, technical and scientific advice to a variety of stakeholders. This network is considered to be a key strength of ISSG.

The goal of The Pacific Invasives Initiative is ‘To conserve island biodiversity and enhance the sustainability of livelihoods of men, women and youth in the Pacific’. This goal will be achieved through reducing negative impacts of invasive species (IAS) primarily by managing them at selected demonstration projects in Pacific Islands countries and territories. The capacity to network on a global scale is a major strength The PII can bring to this project.