Weed biocontrol scoping study in the Cook Islands

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Quentin Paynter and Sarah Dodd

Landcare Research

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195 Lambton Quay
Wellington 6011
New Zealand

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Landcare Research, 231 Morrin Road, St Johns, Private Bag 92170, Auckland 1142, New Zealand, Ph +64 9 574 4100, Fax +64 9 574 4101, www.landcareresearch.co.nz

Reviewed by:	*Approved for release by:*
Lynley Hayes Scientist Landcare Research	Andrea Byrom Portfolio Leader Managing Invasive Weeds, Pests and Diseases

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Contents

Summary

Project and Client

- The Ministry of Foreign Affairs and Trade (MFAT), acting through the New Zealand Secretary of Foreign Affairs and Trade, has engaged Landcare Research to undertake a scoping study to develop a weed biocontrol programme for the Cook Islands under the State Sector Development Partnerships Fund.

Objectives

- To identify a clear pathway for developing biocontrol of economically important weeds in the Cook Islands that will, in future, allow agriculture and tourism to be more sustainable in the Cook Islands, as follows:
- Identify and prioritise key weeds, and complete an effort and cost analysis.
- Complete a risk analysis and train Cook Islands (CI) Ministry of Agriculture (MoA) staff in risk assessment techniques.
- Identify key personnel and systems, foster relationships and develop importation protocols.
- Produce a final report which will include a recommended 5-year plan.

Methods

- We used a recently developed framework that allows the best and worst weed targets for biocontrol to be identified, to rank invasive weed species in the Cook Islands as biocontrol targets.
- Regional experts were consulted at a workshop attended by delegates with interests ranging from agriculture (forestry, horticulture, livestock), biodiversity conservation and biosecurity in the Cook Islands to rank the worst Cook Island weed species on the basis of their impacts (e.g. on primary production and biodiversity).
- Relevant data to parameterise a scoring framework that predicts the likely cost and impact of biocontrol were acquired by using international scientific literature (e.g. CAB Abstracts®), regional floras, relevant websites (e.g. the Pacific Island Ecosystems at Risk (PIER) website http://www.hear.org/pier/ and Wikipedia http://www.wikipedia.org/, and by consulting with regional experts.
- Weeds were ranked according to their importance (impacts) in the Cook Islands and the the predicted impact (risk of failure) and cost (effort) of implementing biocontrol against them.

Results

- The most serious invasive weeds in the Cook Islands were identified at the workshop, including a suite of vines (grand balloon vine *Cardiospermum grandiflorum*, mile-a-minute *Mikania micrantha*, red passionfruit *Passiflora rubra*, peltate morning glory

Merremia peltata) that threaten native forests by smothering and killing native trees, causing deforestation that threatens natural watershed systems on Rarotonga and other islands, and consequently the economy and quality of life of the islands; trees and shrubs (e.g. African tulip tree *Spathodea campanulata,* Strawberry guava *Psidium cattleianum*) that also threaten native forests; and herbs (e.g. cockleburr *Xanthium pungens*) and grasses (e.g. giant reed *Arundo donax*, elephant grass *Pennisetum purpureum*) that affect agricultural production.

- A literature survey indicated that many of these weeds have previously been, or are currently, targets of biocontrol programmes in other countries. Costly survey work to identify candidate biocontrol agents and host-range testing of candidate biocontrol agents has therefore already been undertaken for these species. Conducting 'repeat' biocontrol programmes against these weeds should be relatively inexpensive. Moreover, a review of plant traits that influence a weed's susceptibility to biocontrol and the past success of biocontrol programmes in other countries indicated that prospects for successful biocontrol are likely to be high for many of these weed species.
- Some important weed species, however, have not been the targets of biocontrol programmes in other countries (e.g. *S. campanulata, P. rubra, M. peltata*). Biocontrol of *P. rubra* may be able to proceed relatively cheaply as its herbivores have been well studied and native-range surveys may not be required to identify candidate biocontrol agents. Programmes against *S. campanulata* and *M. peltata* are likely to be more costly.
- *Merremia peltata* presents a particularly complex problem, as its status as a native or introduced plant on Rarotonga is unclear.

Conclusions

- The threat posed by invasive weeds requires an urgent response yet little is currently being done to halt weed invasions in the Cook Islands.
- Biocontrol may be the only feasible control option for weeds invading native vegetation and natural watershed systems, where control by conventional means (e.g. herbicide application, mechanical control) is often prohibitively expensive or impossible due to the rugged terrain.
- There are good prospects for successful biocontrol of many of the worst invasive weeds in the Cook Islands. Several species have already been targeted for biocontrol in other countries and could be targeted relatively cheaply and with a high likelihood of success. Nevertheless, three highly important weeds (*P. rubra, S. campanulata* and *M. peltata*) have not been targeted for biocontrol in other countries and would require greater funding for biocontrol to proceed. The native status of *M. peltata* in the Cook Islands requires clarification before biocontrol can proceed against this weed.

Recommendations

- A 5-year plan for weed biocontrol in the Cook Islands should proceed with:
- 'Repeat' programmes using already tested agents against the following weeds: *Arundo donax*, *Xanthium pungens, Cardiospermum grandiflorum, Mikania micrantha*, and *Psidium cattleianum.* 'Repeat' programmes for fully host-range tested agents simply require importation into containment, rearing for a minimum of one generation to

ensure the population is free of parasitoids and disease, followed by release from containment and mass-rearing. Depending on the life-cycle of the agent, this should cost from as little as c. NZ$35,000 to NZ$45,000 per agent (not including the cost of mass-rearing and releasing agents in the Cook Islands).

- The commencement of 'novel' programmes against *Passiflora rubra* and *Spathodea campanulata.* We estimate that a programme against *P. rubra* could cost as little as NZ$63,000 because the ecology of many *Passiflora* herbivores is well-known. We estimate that it should cost in the region of $200,000 to conduct native range surveys, test and import one agent for the biocontrol of *Spathodia campanulata*. More than one agent may be required for a weed to be effectively controlled.
- Molecular studies, to investigate the status (native or exotic) of *Merremia peltata* in the Cook Islands. This is likely to cost approximately NZ$90,000.

1 Background and introduction

Invasive plants seriously threaten native habitats throughout the Pacific region, including the Cook Islands (Meyer 2000), where numerous invasive weed species of agricultural concern are also present (Space & Flynn 2002).

Invasive species are a growing problem in the Pacific as global trade, travel and tourism bring increasing numbers of invasive species incursions, and troublesome species that are already present begin to naturalise and move out of lag phases. The number of weed (or potential weed) species present in the Cook Islands is already very large: according to the Cook Islands Biodiversity Database (http://cookislands.bishopmuseum.org/search.asp), some 333 naturalised flowering plants, gymnosperms and fern species already outnumber those species that are native to the Cook Islands (287 species).

Some of these invasive weed species are creating serious problems in the Cook Islands that require urgent action. We have summarised the information available on the impacts and costs of weeds below:

Impacts of weeds in natural habitats

Weeds are undoubtedly a dire threat to native biodiversity. For example, the Te Kou landsnail *Tekoulina pricei* is critically endangered (if not already extinct) due to invasive weeds that are modifying its habitat (Gerald McCormack, Director, Cook Islands Natural Heritage Project, pers. comm.).

Moreover, Matepi et al. (2010) point out that Rarotonga is dependent upon surface water for its entire supply and they argue that if nothing is done to halt the invasion by vines (they singled out *Cardiospermum grandiflorum*, *Mikania micrantha*, and *Merremia peltata*, but *Passiflora rubra* is also a major invasive vine in the Cook Islands) they may have a "devastating impact on the native vegetation and natural watershed systems on Rarotonga and other islands, and consequently on the economy and quality of life of the islands".

This is because these invasive vines are smothering and killing trees, causing massive deforestation and replacing the native forest with impenetrable vine thickets in its forested watershed. There is a growing understanding that invasive plants can adversely affect the hydrology of Pacific islands (Giambelluca et al. 2010). In Rarotonga, native trees form a dense network of interlocking roots (Fig. 1), that enables them to cling to steep slopes and stabilize the soil in the mountainous interior, which is frequently subject to extreme weather events (the Cook Islands have been affected by 143 cyclones between 1820 and 2006, with 119 affecting the Southern Group and 42 the Northern Group, with an average frequency of 0.8 cyclones per season; Matepi et al. 2010).

Figure 1 A heavily trampled area revealing a dense network of interlocking roots of native trees on the Cross-Island Track, Rarotonga.

When the trunks and roots of trees smothered and killed by invasive vines eventually rot, there is a significant risk that the remaining vegetation will be incapable of effectively binding the soil together, particularly during extreme weather events. Invasive vines already dominate more than 30% of the island interior (and possibly more than 50%) with virtually total coverage of at least two drainage basins (Matepi et al. 2010; Fig. 2). Invasive vines such as balloon vine have increased dramatically in recent years (McCormack 2002), perhaps as a result of elevated atmospheric CO_2 levels, which can favour invasive species over natives (Ziska & George 2004; Song et al. 2009; Bradley et al. 2010) and favour the growth of woody vines over forest trees (Schnitzer & Bongers 2011). This would suggest that the problems posed by invasive vines are likely to get worse as atmospheric CO_2 levels continue to increase. Indeed, Matepi et al. (2010) argue that several factors militate in favour of urgent action to counter the threat posed by invasive vines:

> *The first is the risk associated with deforestation, disruption of surface water supply, and sedimentation in the coastal zone impacting coral reefs. The second is the inevitable time lags in identifying and implementing an appropriate treatment to control the vines. Biocontrols show promise but must be tested and evaluated to ensure safe application. The third is the potential for climate change to amplify the effects of invasive vines. The fourth is the lack of alternatives to environmental degradation resulting from biological invasion in the small island developing state context.*

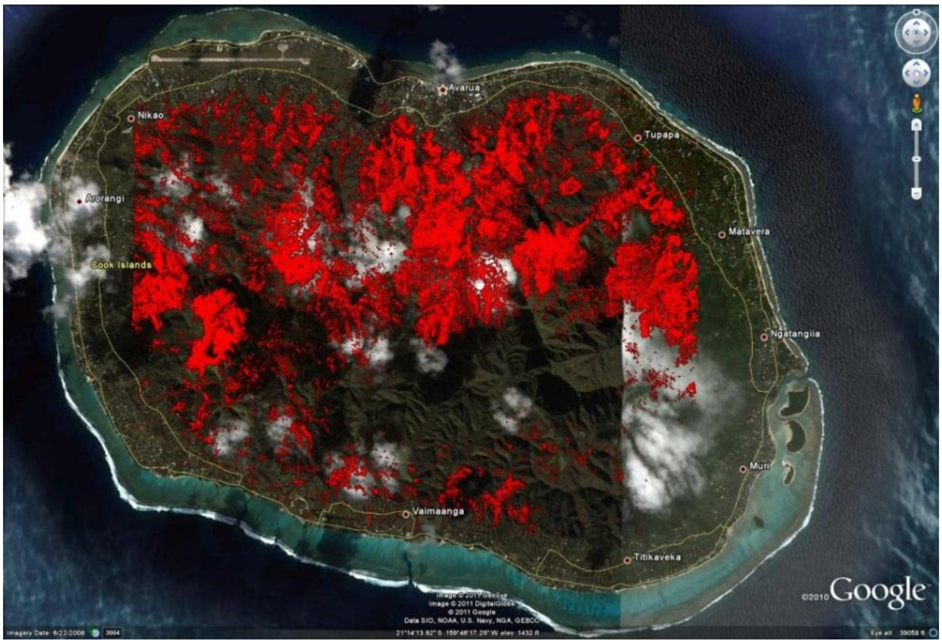

Figure 2 Remote-sensing image illustrating the extent of invasive woody vines on Rarotonga. Image copyright Benjamin White and Google Earth, all rights reserved (this image is depicted in Matepi et al. (2010); a high resolution image was downloaded from: http://www.theresilientworld.com/?tag=climatechange and is reproduced here with permission from the authors).

Weeds and tourism

Tourism is the mainstay of the Cook Islands economy: in 2003 annual tourism expenditure in the Cook Islands was around NZ$115 million, or 48% of gross domestic product (Hajkowicz & Okotai 2005). National income will be sensitive to changes in visitor arrivals: Hajkowicz & Okotai (2005) calculated that a 1% drop in tourist numbers would have resulted in lost income of around NZ$1.5 million.

The notion of a pristine natural environment – comprising clear water, clean beaches, lush tropical vegetation and wildlife – is central to the Cook Islands marketing package (Hajkowicz & Okotai 2005). Although the reefs and beaches are a major attraction, tourists also value the trees, mountains and lush tropical inland landscapes (Hajkowicz & Okotai 2005). If, as feared by Matepi et al. (2010), degradation of native forests due to invasive vines results in increased sedimentation in the coastal zone impacting coral reefs, there would undoubtedly be very major consequences for tourism. Furthermore, ecotourism in forested habitats is expanding, for example, a growing number of visitors pay to go on guided nature walks in the Takitumu Conservation Area, where rare endemic species such as the endangered Kakerori bird (*Pomarea dimidiata*) can be found (Tiraa & Wilmott 2001). Translocation of this species to Atiu resulted in a small ecotourism business on Atiu (Robertson et al. 2006), which has grown since the introduction of a second endangered bird species, the Rimatara lorikeet *Vini kuhlii* (Roger Malcolm, Managing Director, Atiu Villas, pers. comm.). Many tourists use the inland hiking tracks, such as the Cross-Island Track on Rarotonga. As noted above, the pristine nature of these areas is seriously threatened by invasive weeds (Fig. 2) and, unfortunately, the increased traffic of tourists into these areas increases the potential for accidental introduction of exotic plant species (Tiraa & Wilmott 2001).

Weed control costs

Estimating the cost of weed control will undoubtedly underestimate the cost the weeds impose on the Cook Islands economy, as for a number of reasons control is not always undertaken at present. For example, conventional weed control (using herbicides, slashing or manual control) is likely to be prohibitively expensive, if not physically impossible, in the rugged interior of many islands. In these areas invasions are continuing largely unchecked and, as noted above, may have devastating consequences for the Cook Islands economy. Biocontrol is likely to be the only cost-effective means of controlling invasive species in these areas (a definition of biocontrol and the steps involved in a biocontrol programme are given in Appendix 1). Even in agricultural areas it may not be economically worthwhile controlling a weed conventionally if the control costs exceed the value of the land. Under such circumstances weeds can cause the abandonment of formerly productive land, but such lost production costs are hard to quantify.

Although there is little published information on the impacts of weeds on agricultural production in the Cook Islands, some data regarding herbicide usage are available: The Cook Islands imported 1.86 and 1.58 tonnes of herbicide in 2008 and 2009, respectively (the last 2 years for which data were available; http://faostat3.fao.org/home/index.html#HOME). Economic data are not available for these years, but in 2007, the Cook Islands imported 1.5 tonnes or herbicides, costing US$29,000 (equivalent to NZ$40,000 in 2012; http://faostat3.fao.org/home/index.html#DOWNLOAD). This will be a fraction of the total spent controlling weeds with herbicides, because this figure does not include equipment (e.g. sprayers) and labour costs associated with herbicide use. It was shown, for example, that equipment and labour costs associated with knapsack spraying were approximately twice that of the cost of the herbicide (Glyphosate) when controlling the rangeland weed, larkspur (Nielsen et al. 1994). Assuming equipment and application costs are twice the cost of herbicides, then the total cost of herbicidal weed control in the Cook Islands should be in the region of NZ$120,000 per year. Moreover, there are some negative impacts associated with herbicide use, for example, herbicide run-off contributes to watershed pollution (Hajkowicz & Okotai 2005). In other countries, run-off from herbicides, such as glyphosate, has been demonstrated to cause mortality or deliterious sub-lethal effects in a diverse array of organisms, including those inhabiting coral reef ecosystems (Fabricius 2005; Ramade & Roche 2006). Successful biocontrol of key agricultural weeds, such as mile-a-minute (*Mikania micrantha*) and cockleburr (*Xanthium pungens*) may save growers money by reducing herbicide use and also help by reducing watershed pollution.

As well as herbicide use, weed control in the Cook Islands is achieved by slashing (e.g. with a mower attached to a tractor) and by labour-intensive manual removal of weeds (http://www.fao.org/ag/AGP/AGPC/doc/Counprof/southpacific/cook.htm). These control options are undoubtedly costly (being labour-intensive), but economic data are, to our knowledge, lacking.

To summarise, although current weed control costs are not that high (we estimate no more than several hundred thousand dollars per year) and the costs of lost agricultural production are unknown, weeds pose a huge threat to natural watershed systems and to tourism. Moreover, a priority for the Cook Islands agricultural sector is to increase the local production of livestock (pigs, poultry, goats) fruits, vegetables and root crops to cater for the increased demand on the local market brought about partly by the expanded tourism industry (http://www.agriculture.gov.ck/index.php/aboutmoa/sector-priorities). Improved management of key agricultural weeds should assist this goal.

Given the high diversity of invasive plant species, the limited resources for tackling weed invasions must be prioritised effectively. Considering a weed's impact is a vital component of weed prioritisation because the economic or environmental benefits of partially controlling a major weed can exceed the benefits of completely controlling a minor weed (Page & Lacey 2006). Nevertheless, prioritisation of weed control should not solely rely on determining weed impacts but should also consider the cost and feasibility of control. Rationales for the prioritisation of weed control were proposed by Hiebert (1997), who advocated the development of decision-making tools to rank weeds according to their current impacts, future threat, and the cost and feasibility of control. Building on this, a protocol for determining weed management priorities was recently developed for Australia by Virtue et al. (2006), which also emphasises determining the feasibility of control.

Many national schemes for setting weed management priorities have emphasised weed impacts (e.g. Thorp & Lynch 2000; Moran et al. 2005) more than the cost or feasibility of control because the latter may be hard to estimate before the commencement of a control programme. This deficiency is particularly pertinent to classical biocontrol, which can have high development costs (Fowler et al. 2000) and does not always succeed. Complete successes, where biocontrol is so dramatic that other control methods are no longer required, only account for approximately one-third of all completed programs (McFadyen 1998). Approximately one in six programmes have failed to have any detectable impact (Hoffmann 1995; Fowler et al. 2000).

A stimulus for this report was borne out of discussions held at the 2009 Pacific Biocontrol Strategy Workshop hosted by Landcare Research in Auckland. At the workshop it was recognised that pest management in the Pacific region could significantly benefit from an increased emphasis on biocontrol, which is the only economically feasible way of dealing with many pests (Dodd & Hayes 2009). In particular, there is huge potential for relatively low-risk investment in biocontrol by redistributing biocontrol agents, from regions where they have already proven to be successful, to countries where they are currently absent (Dodd & Hayes 2009). In addition, protocols have been recently developed (Paynter et al. 2009, 2012) that allow the best and worst weed targets for biocontrol to be identified, including novel targets, as well as redistributing already proven agents. Coordinating such a Pacific-wide programme would be a major undertaking. In this report we restrict our attention to the Cook Islands, where we collaborated with key stakeholders to apply these protocols to identify the best potential targets for weed biocontrol. If this programme proves to be successful, it could be expanded to include other Pacific nations. The Cook Islands is an ideal location for conducting biocontrol work in the Pacific region because there should be no unforseen barriers (regulatory or public opposition) to implementing biocontrol there. A legal framework for the importation and release of biocontrol agents already exists (section 68 of the Cook Islands Biosecurity Act) and biological control has already been successfully utilised against weeds (lantana *L. camara;* giant mimosa *Mimosa invisa*) and insect pests (e.g. glassy-winged sharpshooter *Homalodisca vitripennis*) there, so biocontrol is an already accepted pest management option.

1.1 Prioritising Cook Island weeds by their impacts

A number of the steps for prioritising weed management targets outlined by Virtue et al. (2006) have already been conducted for the Cook Islands. For example, high risk species that are currently absent from the Cook Islands but that should be excluded or eradicated if they do arrive have been listed (Space & Flynn 2002), and naturalised plant species that are currently present in the Cook Islands have been identified: The Cook Islands Biodiversity Database Website http://cookislands.bishopmuseum.org/search.asp recognises 333 naturalised plant species. Although the impacts (e.g. economic or environmental) of these introduced plants are not rigorously quantified, 179 of the 333 naturalised plants are listed as "invasive", of which a subset of 46 "most serious" invasive species is identified.

1.2 Prioritising Cook Island weeds by the cost and feasibility of biocontrol

1.2.1 What is biocontrol and is it appropriate?

Biological control (or biocontrol) of weeds is an environmentally sound and effective means of reducing or mitigating weed impacts through the use of natural enemies. A definition of biocontrol and the steps involved in a biocontrol programme are given in Appendix 1. A great advantage of biocontrol is that once implemented, it provides permanent weed supression, which makes it very cost-effective. Several economic analyses have reported impressive cost:benefit ratios for biocontrol. For example, it was reported that overall (including failed programmes), the benefit:cost ratio of Australian weed biocontrol programmes was 23:1 (Page & Lacey 2006). An analysis by van Wilgen et al. (2004) indicated that the benefit:cost ratios of programmes targeting 6 weeds in South Africa ranged from 34:1 for lantana to 4333:1 for golden wattle. Culliney (2005) report the cost:benefit analyses of a range of programmes including the USA (e.g. St Johns wort *Hypericum perforatum*, for which the benefit:cost ratio was 4000:1).

When contemplating biocontrol, the first consideration is whether it is appropriate for a particular weed species. Although biocontrol programmes have been conducted against native (indigenous) weeds in the past, Paynter et al. (2009) assumed that biocontrol of native weeds, in their natural range is not appropriate. As Pemberton (2002) noted, this is because it is impossible to limit biocontrol agents only to situations where the target native weeds are problems. Such programmes would no longer be sanctioned by most regulatory authorities (e.g. Barratt & Moeed 2005).

Weeds can have value in many ways including as food crops, pasture plants, for forestry, as garden plants, or as a resource for honeybees or other desirable fauna. When there are objections to biocontrol of a particular weed a cost:benefit analysis may be required to determine whether a program should proceed. Unrestricted biocontrol programmes are unlikely to be sanctioned for economically important crops. However, programmes that are 'restricted' to using introduced agents which attack plant reproductive structures only to reduce their invasiveness may be sanctioned (e.g. agents that attack plant reprodictive parts have been released against *Acacia* spp. that are valued for timber, tannin and firewood production; Moseley et al. 2009). In the past, programmes have been allowed to proceed against weeds that are valued by beekeepers, such as Scotch broom *Cytisus scoparius* in New Zealand (Jarvis et al. 2006) or valued as garden ornamentals (e.g. *Lantana* spp.) because alternative pollen and nectar sources or non-weedy alternative ornamental species are usually available.

1.2.2 Predicting the cost and impact and risks of implementing biocontrol

Assuming a weed is considered to be a suitable target, Paynter et al.'s (2009) framework can then be used to score weed targets on the basis of their amenability to biological control (feasibility) and the likely effort required to implement a biological control programme.

Paynter et al. (2009) determined the likely effort required to implement a biocontrol programme by reviewing factors that influence biocontrol programme cost. Factors influencing "effort" are:

- Whether the weed had already been targeted for biocontrol elsewhere
- Access and ease of working in the native range
- Literature regarding natural enemies available
- Presence of native or valued exotic plants that are related to the target weed

Whether a programme had already been conducted elsewhere was considered the biggest determinant of cost. This is because, for 'repeat' programmes, native range surveys and much, if not all, of the host-range testing required would have already been performed.

For pioneering programmes, factors associated with cost include the risk of non-target attack: the average duration of host-range screening is longer for agents that attack weeds that are closely related to native plants or valued exotic plants, compared with those that attack weeds that are unrelated to native or valued exotic plants. Other, less easily quantifiable determinants of effort include the ease of working (e.g. availability of suitable collaborators, acquiring permits, travel and accommodation costs, quality of infrastructure, safety) in the native range, and knowledge of the fauna in the native range (e.g. the insect fauna of European plants is so well known and documented that promising candidate agents can often be short-listed on the basis of published host records alone).

The benefit to cost ratio of successful weed biocontrol programmes can be so high, that the initial effort spent implementing biocontrol can seem trivial. Paynter et al. (2009) nevertheless, recognised that effort is important because, given limited resources, it may be economically prudent to tackle a higher number of "low effort" weeds versus fewer "high effort" weeds. Effort was scored out of 50 (the higher the score the more effort required). The scoring system used by Paynter et al. (2009) is given in Appendix 2.

To determine a weed's amenability to biocontrol Paynter et al. (2009) investigated a range of weed attributes that were hypothesised to be associated with biocontrol success. Data on the impact of biological control were collected in a variety of ways (e.g. percentage cover, stems m^{-2}, weed biomass). To allow comparison between weeds, these data were converted into an 'impact index', defined as the proportional reduction in weed density due to biological control. A scoring system was then developed that scored a weed according to attributes that were statistically significant indicators of impact index, namely:

1. Previous success or failure, if the weed had already been targeted for biocontrol elsewhere (because successes/failures are often repeated);
2. Habitat (mean impact of biocontrol against aquatic and wetland weeds is significantly greater than against terrestrial weeds);
3. Life cycle (mean impact of biocontrol against temperate annuals was significantly lower, compared with tropical annuals, biennials and perennials);
4. Reproduction (mean impact of biocontrol against species capable of vegetative reproduction was greater versus weed species reproducing solely by seed);
5. Abundance in native range: biocontrol impacts against species reported to be weeds (and therefore assumed to be abundant) in the native range were significantly lower, versus species not reported to be weeds in the native range);
6. Difficulty targeting multiple forms of a weed, or probability of replacement of the weed by forms or congeners of the target following successful biological control thereby negating benefits (for example, weeds with multiple closely related forms, such as blackberry *Rubus fruticosus* agg. and lantana *Lantana camara* are notoriously difficult targets, because biocontrol may only be effective against a limited subset of forms).
7. Growing in competitive environment (agricultural versus environmental weed, because the mean impact of biocontrol on agricultural weeds was lower than on environmental weeds).
8. Presence of a native or valued exotic congener to the weed. Even though this was not a significant factor influencing past success, Paynter et al. (2009) included it because when many past programmes were conducted, the risk of non-target attack on native plants was only a minor consideration. Consequently, a number of weed biocontrol agents were released that have been recorded attacking non-target plants. Subsequent concerns regarding non-target attack have resulted in increasingly risk-averse policies and fewer successful applications for the release of weed biocontrol agents. It is likely that past successful programmes against a number of weeds (e.g. the programmes against nodding and plumeless thistle *Carduus nutans* and *C. acanthoides* in the USA; St John's wort *Hypericum perforatum* in Australia, South Africa and the USA) would not be possible if they were current targets, due to the presence of native congeners and the potential for non-target attack (see Pemberton 2000; Groenteman et al. 2011; Fowler et al. 2012).

1.3 Updated scoring system for predicting the feasibility of biocontrol

The system developed by Paynter et al. (2009) was recently updated, using an expanded dataset and subjected to more rigorous statistical analysis using modern regression techniques (Paynter et al. 2012). This analysis indicated that a model with three traits provided good ability to predict biocontrol impact against novel species in novel regions. Biocontrol impact varied according to:

- Whether or not a weed was reported to be a major weed in its native range. Where a plant was characterised as a major weed in the native range if a CAB Abstracts search listed five or more references that described a plant as a weed in the native range (i.e. excluding articles reporting native range surveys for biocontrol agents). This was considered a more robust measure of relative abundance in the native range, compared to that used by Paynter et al. (2009), as some publications appeared to use the term weed as a generic term for wildflowers and species which were described as weeds on multiple occasions were more likely to be serious weeds in the native range.
- Mode of reproduction (sexual or asexual). Paynter et al. (2009) originally scored plants on the basis that biocontrol impact was greatest against species capable of vegetative reproduction versus weed species reproducing solely by seed or spores. Paynter et al. (2012) showed that a better predictor of biocontrol success is whether a species reproduces sexually or asexually (either by vegetative means or by apomixis). For example, host–pathogen interactions are often governed by single-gene differences; even limited genetic variability can cause a plant pathogen biocontrol agent to fail (Charudattan 2005), so species that are capable of both vegetative and sexual reproduction such as the thistle *Cirsium arvense* can be difficult targets (Paynter et al. 2012).
- Ecosystem (aquatic/wetland versus terrestrial).

As before, the presence of a valued congener did not influence impact of past programmes, though there is good reason to suppose it should influence the success of contemporary programmes.

Each of the three factors included in the updated system has only two levels, which limits the model's ability to differentiate between candidate target weed species to eight possible combinations of the factors. Nevertheless, as before, success appears almost guaranteed against 'good target' weeds with the best combination of factors for success (aquatic, clonal species that are not major weeds in their native ranges), while most programmes against 'difficult targets' (i.e. weeds with the worst combination of factors for success) have failed to result in a measurable impact. Table 1 contains the predicted values for the proportion reduction achieved for each of these eight trait combinations.

Table 1 Predictions of the proportion reduction achieved by biocontrol for each of the eight combinations of the predictor variables (Paynter et al. 2012)

Major weed in native range	Reproduction	Ecosystem	Percentage reduction from biocontrol
No	Asexual	Aquatic/wetland	93
No	Sexual	Aquatic/wetland	77
No	Asexual	Terrestrial	80
No	Sexual	Terrestrial	50
Yes	Asexual	Aquatic/wetland	69
Yes	Sexual	Aquatic/wetland	36
Yes	Asexual	Terrestrial	41
Yes	Sexual	Terrestrial	15

2 Objectives

- To identify a clear pathway for developing biocontrol of economically important weeds in the Cook Islands that will, in future, allow agriculture and tourism to be more sustainable in the Cook Islands as follows:
- Identify and prioritise weeds.
- Complete an effort and cost analysis.
- Complete a risk analysis and train Cook Islands (CI) Ministry of Agriculture (MoA) staff in risk assessment techniques.
- Identify key personnel and systems, foster relationships and develop importation protocols.
- Produce a final report which will include the recommended 5-year plan.

3 Methods

3.1 Selection of weed species for consideration as potential biocontrol targets

A meeting was held on 10th July 2012 at the Ministry of Agriculture, Head Office Arorangi, Rarotonga, to discuss the potential for biocontrol of key weed species in the Cook Islands. The minutes of this meeting, which prioritised the most important weed targets in the Cook Islands, are provided in Appendix 3. High initial implementation costs usually restrict investment in biocontrol to the most important weeds (i.e. weeds that are widespread, damaging and difficult or expensive to control by conventional means). Therefore, all 46 introduced weed species listed as “most serious” invasive species on the Cook Islands Biodiversity Database http://cookislands.bishopmuseum.org/search.asp were shortlisted for consideration.

Less important weeds may also be targeted for biocontrol if the development costs are low because they have already been targeted for biocontrol in other countries (as noted in the introduction, “repeat” biocontrol programmes are much cheaper to implement than novel programmes). We, therefore, searched the global weed biocontrol literature to identify which of the 179 Cook Island invasive weed species that are not listed among the 46 “most serious invasive species” have been targeted by biocontrol programmes in other countries. This search indentified three additional species (Azolla water-fern *Azolla filiculoides*, Water hyacinth *Eichhornia crassipes*, and Yellow bells *Tecoma stans*; Appendix 4). *Merremia peltata* was also included for consideration, even though some authorities consider it to be native to some of the Cook Islands; it is undoubtedly a recent introduction to Aitutaki, where it is considered invasive and it may well be an early Polynesian introduction to other Islands (Paynter et al. 2006). Two additional species (Job’s tears *Coix lacryma-jobi* and Elephant grass *Pennisetum purpureum*) were nominated by workshop delegates, bringing the total number of species selected for consideration as potential biocontrol targets to 52.

3.2 Data collection

3.2.1 Weed importance

Ideally, the relative importance of the 52 selected weed species should be based on their distributions, impacts and the cost and feasibility of conventional control. Obtaining quantitative data regarding, for example, how the selected weed species impact on primary production and biodiversity in the Cook Islands would be a major task, beyond the scope of this report. We therefore developed a scoring system to rank weeds rapidly, based on local expert opinion, which was done at a workshop attended by workshop delegates with interests ranging from agriculture (forestry, horticulture, livestock) to biodiversity conservation and biosecurity in the Cook Islands (Appendix 3).

An initial discussion first considered the beneficial aspects of the nominated weeds. This resulted in nine of the 52 shortlisted weed species being rejected as candidate biocontrol targets because it was considered there would be strong opposition to biocontrol due to their desirable properties (listed in Table 2, below).

Table 2 Species rejected as candidate targets for biocontrol

Weed Species	Common name	Reason why weed is valued
Azolla filiculoides	Azolla water-fern	Nitrogen-fixing plant: used as green manure
Coix lacryma-jobi	Job's tears	Cultural (e.g. pseudocarps used as beads)
Eichhornia crassipes	Water hyacinth	Nitrogen-fixing plant: used as green manure
Eugenia uniflora	Surinam cherry	Edible fruit
Falcataria moluccana (=Paraserianthes falcataria)	Albizia	Source of useful wood
Ocimum gratissimum	Wild basil	Culinary herb and cultural (e.g. used in the Ei)
Pimenta racemosa	Bay-rum tree	Spice
Psidium guajava	Common guava	Edible fruit
Syzygium cumini	Jambolan	Edible fruit

In addition, it was noted that while some introduced *Acacia* species are not particularly beneficial, some are useful forestry species and it would be difficul to find agents that only target the weedy species. *Acacia* species were retained in the list of target species because "restricted" biocontrol programmes that only introduced agents that attack plant reproductive structures to reduce the invasiveness of species without affecting a plant's beneficial properties (e.g. Moseley et al. 2009) could be conducted against such species. Other species with beneficial properties that were retained as biocontrol targets are listed in Table 3.

Table 3 Species not rejected as candidate targets for biocontrol that, nevertheless, have some valued properties

Weed Species	Common name	Reason why weed is valued
Acacia spp.	Wattle, acacia	Forestry, biofuels
Ardisia elliptica	Inkberry	Edible fruit
Bidens pilosa	Beggar's tick	Medicinal
Brachiaria mutica	Para grass	Fodder
Merremia peltata	Morning glory	In agricultural context, relatively easy to control and smothers 'worse weeds'
Mikania micrantha	Mile-a-minute	Medicinal
Passiflora maliformis	Hard passionfruit	Edible fruit
Psidium cattleianum	Strawberry guava	Edible fruit
Sorghum bicolor subsp. drummondii	Sudan grass	Fodder
Tithonia diversifolia	Tree marigold	Beekeeping

Two shortlisted species (giant sensitive plant *Mimosa diplotricha* and lantana *Lantana camara*) already have biocontrol agents released in the Cook Islands and the consensus was that biocontrol of these species is effective and that further investment in additional biocontrol agents is unwarranted. These two species were consequently excluded from further consideration.

The relative importance of the remaining 41 species was determined by 12 delegates who voted on which species they considered most important. This was achieved using a simple system where weeds were categorised by each delegate as "hot", "warm" or "cold" (where hot = the most important, and cold = least important). The votes in each category were then tallied and a total score, based on each Hot, Warm and Cold vote scoring 10, 5 and 1 point(s), respectively was then calculated. As there were 12 delegates, the maximum Total Score for a weed species was 120. To make the Total Score comparable with the Feasibility Score, a 'Weighted Total Score' was calculated by dividing the Total Score by 120 and then multiplying it by 100, so that the maximum importance score for a weed was 100.

3.2.2 Biocontrol feasibility and cost

We acquired relevant data on those attributes that are statistically significant indicators of biocontrol success and the cost of implementing biocontrol (see Introduction), including the current status of biocontrol programs, for each of the weed species. These data were gathered by using international scientific literature (e.g. CAB Abstracts®), regional floras, the World Wide Web, especially the Pacific Island Ecosystems at Risk (PIER) website (http://www.hear.org/pier/), and Wikipedia (http://www.wikipedia.org/).

3.3 Scoring

We applied the updated scoring system developed by Paynter et al. (2012) to predict the impact (feasibility) of weed biocontrol (see section 1.3 above). We replaced predicted impact scores with published biocontrol impact data where quantitative biocontrol impact data from programmes in other countries were available (because success in pioneering programmes predicts the success of repeat programmes; Paynter et al. 2012). Details of biocontrol programmes against invasive Cook Island weeds are given in Appendix 4.

As noted in sections 1.2 and 1.3 above, there is good reason to suppose the presence of a valued congener should influence the success of contemporary programmes. However, it is difficult to estimate to what extent the presence of a valued congener might reduce the likelihood of biocontrol success. Retrospective analyses have indicated that contemporary regulations would have prevented the release of several successful agents in the past (e.g. St John's wort beetles *Chrysolina* spp., Nodding thistle receptacle weevil *Rhinocyllus conicus*, and the thistle rosette weevil *Trichosirocalus horridus*) that have subsequently been reported to feed on non-target plants (see Pemberton 2000; Groenteman et al. 2011; Fowler et al. 2012). Programmes against these weeds would have likely failed had they been conducted under contemporary regulations. Therefore, we modified impact scores to reflect the increased risk of biocontrol failure for weed targets that have valued congeners (e.g. Samoan sword fern *Nephrolepis saligna*, and crassicarpa *Acacia crassicarpa*; Appendix 5) by multiplying their predicted impact scores (Table 1) by 0.5. We recognise that this is a somewhat arbitrary figure, but we consider the importance we have placed on this factor is not unrealistic. Note too that we did not modify the score for red passionfruit *Passiflora rubra* in this way. This is because *P. rubra* belongs to the subgenus *Decaloba*, while the edible *Passiflora* species grown in the Cook Islands belong to subgenus *Passiflora* and it is known that herbivores exist that are specific to certain *Passiflora* subgenera (e.g. Smiley 1985). In contrast, the other *Passiflora* weed, hard passionfruit *P. maliformis*, belongs to the same subgenus (subgenus *Passiflora*) as cultivated edible species, such as purple passionfruit *P. edulis*, making this weed a much harder biocontrol target.

We assume that, as in New Zealand, the potential non-target attack on garden ornamentals should be tolerated because the benefits of weed control are likely to outweigh the costs of either protecting ornamental plants (e.g. by treating them with pesticides) or replacing them with alternative ornamental species. We did not, therefore, reduce the predicted impact scores for Tree marigold *Tithonia diversifolia* and Honolulu rose *Clerodendrum chinense* that only have ornamental congeners in the Cook Islands. In addition, we did not reduce the score for Strawberry guava *Psidium cattleianum*, despite the presence of a congeneric fruiting tree (common guava *P. guajava*) because host-specificity data indicates that the biocontrol agent released against *P. cattleianum* in Hawai'i does not attack *P. guajava* (Wessels et al. 2007).

We applied the framework developed for Australia by Paynter et al. (2009), to predict the effort required to implement a biocontrol programme. Details of this scoring system are given in Appendix 2. Effort ranges from a minimum of 4, for the cheapest programmes, to 50, for the most expensive targets.

4 Results

The importance scores for the 41 shortlisted weed species are listed in Table 4. Nine species were unanimously 'unwanted', gaining 12 'Hot'votes each, namely:

Giant reed *Arundo donax* is a very tall (up to 10 m) and tough grass forming very dense thickets in moist areas. Native to Europe and Asia, this plant has become naturalised in the mild temperate, subtropical and tropical regions of both hemispheres, especially in the Mediterranean, California, the western Pacific, and the Caribbean. It forms dense stands on disturbed sites, sand dunes, in wetlands and riparian habitats (http://en.wikipedia.org/wiki/Arundo_donax). It is locally established in Rarotonga, but is becoming increasingly widespread and is very difficult to eradicate.

Grand balloon vine *Cardiospermum grandiflorum* is the most widespread high-climbing vine on Rarotonga. This fast growing plant forms large and dense smothering curtains of tangled stems that impede the growth of supporting vegetation (Fig. 3.), eventually killing trees by the heavy weight. Seedlings of native shrubs and trees are unable to establish under the stands of this plant, which is also highly invasive in South Africa and in Australia (http://www.hear.org/pier/species/cardiospermum_grandiflorum.htm).

Figure 3 Grand balloon vine *Cardiospermum grandiflorum* climbing on a coconut palm, Rarotonga (left) and Secondary growth heavily infested with peltate morning glory *Merremia peltata*, Aitutaki (right).

Burr grass *Cenchrus echinatus* is a common grass in disturbed places. It is disliked because it produces spiny burrs that detach easily from the spike and attach to clothing or animals and are painful to walk on barefoot.

Peltate morning glory *Merremia peltata* is considered to be a highly problematic weed. It occurs on several of the Southern Group of the Cook Islands where it can climb over and smother trees up to 20 m tall (Fig. 3.). There is, however, considerable uncertainty regarding its status in Rarotonga and throughout the Pacific region. As it was present in Rarotonga when the first European botanists (e.g. Cheeseman 1903) began documenting the flora, it is listed as native to Rarotonga, but it could have been an early Polynesian introduction. It is certainly invasive on Aitutaki, where it was unknown before 1974 (Paynter et al. 2006).

Mile-a-minute weed *Mikania micrantha* is a widespread weed occurring on most of the Southern Group of the Cook Islands. Another smothering vine (Fig. 4.), it is listed as one of the 100 world's worst invasive species (Lowe et al. 2000).

Figure 4 Mile-a-minute weed *Mikania micrantha* infesting agricultural land, Aitutaki (left), and red passionfruit *Passiflora rubra* smothering forest, Aitutaki (right).

Nephrolepis saligna (Samoan Sword fern), which ocurrs only on Nassau in the Northern Group of the Cook Islands, where it is invading coconut plantations and native forest.

Pennisetum purpureum (Elephant grass) is an invasive grass found on Rarotonga, Mangaia and Atiu. It colonizes along roadsides, ditchbanks, watercourses in marshy depressions, and in open places in forests. In moist rich places it can form reed jungles, thereby eliminating the use of such land for cultivation (http://www.hear.org/pier/species/pennisetum_purpureum.htm)

Passiflora rubra (red passionfruit Fig. 4.) is another invasive vine that occurs on several islands of the Southern Group of the Cook Islands. It is regarded to be the worst vine invader of makatea (limestone) forest in the Cook Islands (especially Atiu; Gerald McCormack, pers. comm.) and, unlike many other Passiflora species, it does not produce edible fruit.

Finally, Spathodea campanulata (African tulip tree) occurs on islands in both the southern and northern groups. It is an evergree tree that grows to 25 m and invades both abandoned agricultural land and closed forest (Fig. 5.). It is listed as one of the 100 world's worst invasive species (Lowe et al. 2000).

Figure 5 African tulip tree *Spathodea campanulata* invading native forest, Rarotonga (left) and dodder *Cuscuta campestris* infesting agricultural land, Rarotonga (right).

Four other species (cockleburr *Xanthium pungens*, dodder *Cuscuta campestris* (Fig. 5.), sicklepod *Senna obtusifolia*, and strawberry guava *Psidium cattleianum*) scored almost unanimously 'Hot'. *Xanthium pungens* is a serious agricultural weed found on Rarotonga and Ma'uke Island; *Cuscuta campestris* is one of the most widespread and destructive agricultural weeds on Mangaia and is present, but localised, in Rarotonga; *Senna obtusifolia* is only found on Ma'uke, where it is a serious weed throughout the volcanic inlands; and *Psidium cattleianum* is common on Mangaia and present (but not yet common) on Rarotonga, Atiu, Ma'uke and Mitiaro in the southern group of Islands and Manihiki, in the northern group.

Table 4 Voting on weed importance. Hot = (most important) and Cold = (least important). Each Hot, Warm and Cold vote score 10, 5 and 1 point(s), respectively. Weighted Total Score (in parentheses) = (Total Score/120) × 100 (so that the maximum score is 100)

Rank	Weed species	Common name	Number of votes			Total Score
			Hot	Warm	Cold	
1=	*Arundo donax*	Giant reed	12	0	0	120 (100)
1=	*Cardiospermum grandiflorum*	Grand balloon vine	12	0	0	120 (100)
1=	*Cenchrus echinatus*	Burr grass	12	0	0	120 (100)
1=	*Merremia peltata*	Peltate morning glory	12	0	0	120 (100)
1=	*Mikania micrantha*	Mile a minute	12	0	0	120 (100)
1=	*Nephrolepis saligna*	Samoan sword-fern	12	0	0	120 (100)
1=	*Passiflora rubra*	Red passionfruit	12	0	0	120 (100)
1=	*Pennisetum purpureum*	Elephant grass	12	0	0	120 (100)
1=	*Spathodea campanulata*	African tulip tree	12	0	0	120 (100)
10	*Xanthium pungens*	Cockleburr	11	1	0	115 (95.83)
11	*Cuscuta campestris*	Dodder	10	1	1	106 (88.33)

12	*Senna obtusifolia*	Sicklepod	9	3	0	105 (87.50)
13	*Psidium cattleianum*	Strawberry guava	10	0	2	102 (85.00)
14	*Mimosa pudica*	Sensitive weed	6	6	0	90 (75.00)
15	*Brachiaria mutica*	Para grass	6	4	2	82 (68.33)
15=	*Phyllostachys bissetii*	Bisset's bamboo	6	4	2	82 (68.33)
17	*Sorghum bicolor subsp. drummondii*	Sudan grass	4	8	0	80 (66.67)
18	*Hedychium coronarium*	White ginger	4	6	2	72 (60.00)
19	*Calopogonium mucunoides*	Calopo	3	7	2	67 (55.83)
20	*Acacia spp.*	Crassicarpa	1	11	0	65 (54.17)
21	*Clerodendrum chinense*	Honolulu rose	3	6	3	63 (52.50)
22	*Centrosema pubescens*	Centro butterfly-pea	2	8	2	62 (51.67)
23	*Cecropia pachystachya*	Cecropia	0	12	0	60 (50.00)
24	*Pueraria phaseoloides*	Tropical kudzu	1	9	2	57 (47.50)
25	*Ludwigia octovalvis*	Willow primrose	0	11	1	56 (46.67)
25=	*Syzygium jambos*	Rose apple	0	11	1	56 (46.67)
27	*Indigofera suffruticosa*	Indigo	1	8	3	53 (44.17)
27=	*Tithonia diversifolia*	Tree marigold	1	8	3	53 (44.17)
29	*Leucaena leucocephala*	Leucaena	0	10	2	52 (43.33)
30	*Cestrum nocturnum*	Night-blooming cestrum	3	3	6	51 (42.50)
31	*Triumfetta rhomboidea*	Triumfetta weed	1	7	4	49 (40.83)
32	*Elephantopus spp*	Elephant's foot spp.	0	9	3	48 (40.00)
32=	*Tecoma stans*	Yellow bells	0	9	3	48 (40.00)
34	*Ardisia elliptica*	Inkberry	0	8	4	44 (36.67)
35	*Sida rhombifolia*	Broom weed	0	6	6	36 (30.00)
36	*Stachytarpheta urticifolia*	Blue rat's tail	1	3	8	33 (27.50)
37	*Bidens pilosa*	Beggar's tick	0	5	7	32 (26.67)
37=	*Hyptis pectinata*	Comb hyptis	0	5	7	32 (26.67)
39	*Adenanthera pavonina*	Red bead tree	0	3	9	24 (20.00)
40	*Desmodium incanum*	Spanish clover	0	0	12	12 (10.00)
40=	*Passiflora maliformis*	Hard passionfruit	0	0	12	12 (10.00)

Feasibility and effort scores are given in Table 5. Five weed species are predicted to be highly amenable to biocontrol (feasibility scores > 75) either on the basis of the predictive traits used by Paynter et al. (2012) or, in the case of broom weed *Sida rhombifolia* and *Xanthium pungens*, because they have been successful biocontrol targets in other countries. Note that *Mikania micrantha* is given a medium feasibility score, based on plant traits in Table 5. Preliminary reports, however, indicate that a fungus *Puccinia spegazzinii* can significantly reduce the growth and density of *Mikania*, although quantitative data have yet to be published (Ellison & Day 2011). The status of this weed may change from 'medium' to 'high' feasibility once the impact of *P. spegazzinii* is quantified and formally published.

Many weeds had a feasibility score of 50, indicating that they shared the traits of sexual reproduction and terrestrial habitat, are not reported to be weedy in their native ranges, and lack valued congeneric plants. Seventeen species are considered difficult targets on the basis of plant traits. Note, however, that the score for *Merremia peltata* may underestimate the feasibility of biocontrol because the native range of this species is not well understood and records of it being a weed in regions where it is purported to be native may actually be from parts of its introduced range.

Eight species have low (< 20) effort scores; these are species where current or past biocontrol programmes have conducted sufficient host-range testing to indicate that agents exist that are sufficiently specific to be released in the Cook Islands. Three of the species with high feasibility scores (namely *Arundo donax*, *Sida rhombifolia*, *Xanthium pungens*) have low effort scores, indicating that biocontrol is likely to be both relatively cheap to implement and highly likely to have a major impact against these species.

Total scores (presented in Table 6) for the final rankings were calculated according to the formula:

Total Score	=	Weighted Weed Importance Score	+	Biocontrol Feasibility Score	–	Biocontrol Effort Score

Concern was raised at the workshop that the total score might have underemphasised the most important weeds. For example, *Cenchrus echinatus*, which ranked equal first by weed importance, ranked 25th by total score, while *Sida rhombifolia* ranked 8th overall, despite being given no 'Hot' votes and only six "Warm' votes and ranking only 35th by importance. This is because the biocontrol feasibility score for *S. rhombifolia* is very high – the leaf beetle *Calligrapha pantherina* reduced *S. rhombifolia* cover by 99% in Papua New Guinea (Kuniata & Korowi 2004) – and the effort score is very low as no host-range testing would be required: *C. pantherina* is specific to the genus *Sida*, which is absent from the Cook Islands native flora. To assist prioritisation, less important weed species (those with Weighted Importance Scores < 41) are highlighted in yellow on Table 6.

Another approach towards assisting prioritisation is given in Table 7, where a matrix of weed species is grouped according to their importance and the feasibility of biocontrol. Suitability of targets ranges from the worst targets (low importance and low feasibility; red shading) in the bottom right hand cell to the best targets (high importance and high feasibility; green shading) in the top left hand cell. Cells with the same shading should have similar suitability as targets for biocontrol. Thus, *Cenchrus echinatus* is given a similar ranking to *Sida rhombifolia*, demonstrating the trade-off between either targeting weeds of low importance for which biocontrol is highly likely to succeed (but the benefits would be relatively minor) and targeting weeds of high importance for which biocontrol is considered less likely to succeed (but, if successful there would be major benefits).

Table 5 The feasibility of biocontrol scores and effort scores for the 41 selected agents (ranked by most feasible at the top to least feasible at the bottom)

Weed species	Common name	Feasibility	Effort
Sida rhombifolia	Broom weed	99	8
Arundo donax	Giant reed	93	13
Xanthium pungens	Cockleburr	85	7
Clerodendrum chinense	Honolulu rose	80	29
Ludwigia octovalvis	Willow primrose	77	25
Mikania micrantha	Mile a minute	50	12
Cardiospermum grandiflorum	Grand balloon vine	50	14
Passiflora rubra	Red passionfruit	50	19
Psidium cattleianum	Strawberry guava	50	12
Tecoma stans	Yellow bells	50	8
Spathodea campanulata	African tulip tree	50	21
Tithonia diversifolia	Tree marigold	50	21
Hedychium coronarium	White ginger	50	25
Sorghum bicolor subsp. drummondii	Sudan grass	50	28
Phyllostachys bissetii	Bisset's bamboo	50	33
Calopogonium mucunoides	Calopo	50	33
Centrosema pubescens	Centro butterfly-pea	50	33
Cecropia pachystachya	Cecropia	50	33
Pueraria phaseoloides	Tropical kudzu	50	35
Leucaena leucocephala	Leucaena	50	33
Cestrum nocturnum	Night-blooming cestrum	50	33
Elephantopus spp.	Elephant's foot spp.	50	33
Ardisia elliptica	Inkberry	50	35
Hyptis pectinata	Comb hyptis	50	33
Adenanthera pavonina	Red bead tree	50	35
Syzygium jambos	Rose apple	40	50
Nephrolepis saligna	Samoan sword-fern	25	48
Brachiaria mutica	Para grass	25	35
Acacia spp	Crassicarpa	25	43
Triumfetta rhomboidea	Triumfetta weed	25	50
Passiflora maliformis	Hard passionfruit	25	48
Senna obtusifolia	Sicklepod	15	17
Cuscuta campestris	Dodder	15	28
Merremia peltata	Peltate morning glory	15	32
Pennisetum purpureum	Elephant grass	15	40
Mimosa pudica	Sensitive weed	15	33
Indigofera suffruticosa	Indigo	15	33
Stachytarpheta urticifolia	Blue rat's tail	15	33
Bidens pilosa	Beggar's tick	15	33
Desmodium incanum	Spanish clover	15	33
Cenchrus echinatus	Burr grass	7.5	47

Table 6 Final ranking of the 41 weed species. F = Feasibility; E = Effort; I = Weed Importance. Relatively minor weeds (Importance score 0-40) are highlighted yellow. Total score = Weighted Weed Importance Score + Biocontrol Feasibility – Biocontrol Effort Score

Rank	Weed species	Common name	F	E	I	Total Score
1	*Arundo donax*	Giant reed	93	13	100.00	180.00
2	*Xanthium pungens*	Cockleburr	85	7	95.83	173.83
3	*Mikania micrantha*	Mile a minute	50	12	100.00	138.00
4	*Cardiospermum grandiflorum*	Grand balloon vine	50	14	100.00	136.00
5	*Passiflora rubra*	Red passionfruit	50	19	100.00	131.00
6	*Spathodea campanulata*	African tulip tree	50	21	100.00	129.00
7	*Psidium cattleianum*	Strawberry guava	50	12	85.00	123.00
8	*Sida rhombifolia*	Broom weed	99	8	30.00	121.00
9	*Clerodendrum chinense*	Honolulu rose	80	29	52.50	103.50
10	*Ludwigia octovalvis*	Willow primrose	77	25	46.67	98.67
11	*Sorghum bicolor subsp. drummondii*	Sudan grass	50	28	66.67	88.67
12	*Senna obtusifolia*	Sicklepod	15	17	87.50	85.50
13	*Phyllostachys bissetii*	Bisset's bamboo	50	33	68.33	85.33
14	*Hedychium coronarium*	White ginger	50	25	60.00	85.00
15	*Merremia peltata*	Peltate morning glory	15	32	100.00	83.00
16	*Tecoma stans*	Yellow bells	50	8	40.00	82.00
17	*Nephrolepis saligna*	Samoan sword-fern	25	48	100.00	77.00
18	*Cuscuta campestris*	Dodder	15	28	88.33	75.33
19	*Pennisetum purpureum*	Elephant grass	15	40	100.00	75.00
20	*Tithonia diversifolia*	Tree marigold	50	21	44.17	73.17
21	*Calopogonium mucunoides*	Calopo	50	33	55.83	72.83
22	*Centrosema pubescens*	Centro butterfly-pea	50	33	51.67	68.67
23	*Cecropia pachystachya*	Cecropia	50	33	50.00	67.00
24	*Pueraria phaseoloides*	Tropical kudzu	50	35	47.50	62.50
25	*Cenchrus echinatus*	Burr grass	7.5	47	100.00	60.50
26	*Leucaena leucocephala*	Leucaena	50	33	43.33	60.33
27	*Cestrum nocturnum*	Night-blooming cestrum	50	33	42.50	59.50
28	*Brachiaria mutica*	Para grass	25	35	68.33	58.33
29	*Elephantopus spp*	Elephant's foot spp.	50	33	40.00	57.00
30	*Mimosa pudica*	Sensitive weed	15	33	75.00	57.00
31	*Ardisia elliptica*	Inkberry	50	35	36.67	51.67
32	*Hyptis pectinata*	Comb hyptis	50	33	26.67	43.67
33	*Syzygium jambos*	Rose apple	40	50	46.67	36.67
34	*Acacia spp*	Crassicarpa	25	43	54.17	36.17
35	*Adenanthera pavonina*	Red bead tree	50	35	20.00	35.00
36	*Indigofera suffruticosa*	Indigo	15	33	44.17	26.17
37	*Triumfetta rhomboidea*	Triumfetta weed	25	50	40.83	15.83
38	*Stachytarpheta urticifolia*	Blue rat's tail	15	33	27.50	9.50
39	*Bidens pilosa*	Beggar's tick	15	33	26.67	8.67
40	*Desmodium incanum*	Spanish clover	15	33	10.00	-8.00
41	*Passiflora maliformis*	Hard passionfruit	25	48	10.00	-13.00

Table 7 Matrix of weed species grouped according to their importance and the feasibility of biocontrol. Species with high feasibility and importance scores are assumed to be the best targets. Weighted Weed Importance: Low = 0–40; Medium = 41–75; High = > 75. Feasibility: High = > 75; Medium = 41–75; Low = 0–40. Suitability of targets range from the best targets (high importance and high feasibility; green shading) in the top left hand cell to the worst targets (low importance and low feasibility; red shading) in the bottom right cell. Cells with the same shading should have similar suitability as targets for biocontrol

		Weed Importance		
		High	Medium	Low
Feasibility of biocontrol	High	*Arundo donax** *Xanthium pungens**	*Clerodendrum chinense* *Ludwigia octovalvis*	*Sida rhombifolia**
	Medium	*Cardiospermum grandiflorum** *Mikania micrantha** *Spathodea campanulata* *Passiflora rubra* *Psidium cattleianum**	*Phyllostachys bissetii* *Sorghum bicolor subsp. drummondii* *Hedychium coronarium* *Calopogonium mucunoides* *Centrosema pubescens* *Ceropia pachystachya* *Pueraria phaseoloides* *Syzigium jambos* *Tithonia diversifolia* *Cestrum noturnum*	*Tecoma stans** *Elephantopus spp.* *Ardisia ellipta* *Hyptis pectinata* *Adenanthera pavonia*
	Low	*Merremia peltata* *Cenchrus echinatus* *Nephrolepis saligna* *Pennisetum pupureum* *Cuscuta campestris* *Senna obtusifolia **	*Acacia spp.* *Brachiaria mutica* *Mimosa pudica* *Indigophora suffruticosa*	*Stachytarpheta urticifolia* *Bidens pilosa* *Desmodium incanum* *Passiflora malformis* *Triumfetta rhomboidea*

*Denotes species with low effort (<20) scores (i.e. species where already tested biocontrol agents could be introduced at a relatively low cost).

5 Conclusions and recommendations

A number of “high importance” weeds are excellent prospective biocontrol targets in the Cook Islands. These include the herbaceous vines, grand balloon vine *Cardiospermum grandiflorum*, and mile-a-minute weed *Mikania micrantha*; a woody shrub, strawberry guava *Psidium cattleianum*; the grass giant reed *Arundo donax*; and an annual herb, cockleburr *Xanthium pungens*.

Arundo donax and *X. pungens* were identified as the two best targets by both Total Score (Table 6) and by the matrix of weed importance against the feasibility of biocontrol (Table 7). *Mikania micrantha*, *C. grandiflorum* and *P. cattleianum*, which ranked 3rd, 4th and 7th by Total Score (Table 6), are also extremely problematic weeds for which biocontrol agents are already available that could be released at relatively little cost.

(a) **(b)** **(c)**

Figure 6 Biocontrol agents on three prospective "high importance" weeds.
(a) *Puccinia spegazzinii* on mile-a-minute weed *Mikania micrantha* (Photo: Carol Ellison CABI Bioscience)
(b) *Tectococcus ovatus* galls on Strawberry guava *Psidium cattleianum* (Photo: US Forest Service http://www.fs.fed.us/psw/programs/ipif/strawberryguava/biocontrol.shtml)
(c) *Puccinia xanthii* on cockleburr *Xanthium pungens* (Photo: CSIRO http://www.csiro.au/Portals/Media/NoogooraBurr.aspx)

Red passionfruit *Passiflora rubra* ranked 5th by Total Score. It is possible *P. rubra* could be a difficult biocontrol target due to the risk of a non-target attack affecting closely related *Passiflora* species that are cultivated for their edible fruit. However, the edible species of *Passiflora* grown in the Cook Islands (*P. edulis*, *P. laurifolia*, *P. ligularis*, *P. maliformis*, and *P. quadrangularis*) all belong to *Passiflora* subgenus *Passiflora*, while *P. rubra* belongs to the *Passiflora* subgenus *Decaloba* (Hansen et al. 2006). *Heliconius* butterflies are a well-studied group and there is strong evidence that some species only utilise *Passiflora* plants that belong to the subgenus *Decaloba* as hosts (Benson et al. 1975). Indeed, Waage et al. (1981) report the ovipositional preferences and results of larval specificity tests for several Costa Rican *Heliconius* butterfly species that indicated *H. erato petiveranus* oviposited on *P. biflora* (subgenus *Decaloba*), but not on *P. vitifolia*, *P. oerstedii* or *P. ambigua* (subgenus *Passiflora*), and *H. charithonia* larvae did not develop on *P. edulis* or *P. quadrangularis*. Jiggins et al. (1997) reported that *Heliconius himera* is a specialist feeding only on *Passiflora rubra* and *P. punctata* (both subgenus *Decaloba*). Many species of *Heliconius* are readily available from livestock suppliers for butterfly houses (e.g. http://www.heliconiusworks.com/index.htm; http://www.butterflyfarm.co.cr/). It seems likely, therefore, that biocontrol of *P. rubra* could proceed fairly rapidly and cheaply, without the need for extensive native-range surveys although some additional host-range testing would be required to determine ovipositional preference and larval survival on all the *Passiflora* species cultivated in the Cook Islands. Within the Pacific region, *P. rubra* is only reported to be invasive in the Cook Islands (http://www.hear.org/Pier/species/passiflora_rubra.htm). It is therefore important to include *P. rubra* in the current 5-year plan as this is the only avenue for its biocontrol.

(a)  (b) 

Figure 7 Possible *Heliconius* butterfly biocontrol agents for *P. rubra*.
(a) *Heliconius himera* (Photo: Chris Jiggins: http://tolweb.org/Heliconius_himera/72241/2008.08.12)
(b) *Heliconius charithonia* (Photo Justin Lowery: http://tolweb.org/Heliconius_charithonia/72949)

Spathodea campanulata, ranked 6th by Total Score, is an important environmental weed for which biocontrol is predicted to have a medium feasibility. Preliminary surveys for candidate biocontrol agents funded by the Secretariat of the Pacific Community (SPC) have been conducted in Ghana, where this tree is native. Nevertheless, considerable investment would be required before weed biocontrol agents could be released in the Cook Islands. *Spathodea campanulata* is a major invasive weed throughout the Pacific Region. We recommend that biocontrol of this species should commence and that overseas collaborators be sub-contracted to continue surveys and host-range testing in Ghana.

Pragmatic decision making was required when deciding the priorities for a 5-year plan. At the workshop there was a concern among delegates that the most important weeds should be tackled, even if they are predicted to be difficult targets for biocontrol. This is because the benefits of partial control of a major weed can outweigh the benefits of complete control of a minor weed. Therefore, as noted by Paynter et al. (2012), species that are predicted to be difficult targets should still be targeted for biocontrol, provided they are sufficiently important to offset the increased risk of failure against the greater benefits of successful control. Assuming the cost of implementing biocontrol is similar, there was a preference that weeds in the bottom left cell of Table 7 (lower feasibility, higher importance) should be ranked higher than weeds in the top right cell of Table 7 (higher feasibility, lower importance) or the middle cell (medium feasibility, medium importance).

We do not recommend starting work on any “Medium Importance” weeds withinin the next 5 years, with the possible exception of *Tithonia diversifolia*. This is currently a biocontrol target in South Africa and it may become a higher priority if researchers demonstrate that the damaging agents currently held in containment in South Africa are adequately specific for release in the Cook Islands. Two other “Medium Importance” weeds (*Clerodendrum chinense*, *Ludwigia octovalvis*) are predicted to be highly feasible targets for biological control but, as for *S. campanulata*, additional native-range surveys and host-range testing would have to be done, so they are both relatively “high effort” targets.

We do not recommend starting work on any of the “low importance” weeds withinin the next 5 years, with the possible exception of *Sida rhombifolia*. This weed ranked 8th by Total Score (Table 6) because the biocontrol agent for this species, *Calligrapha pantherina*, could be collected in Australia at the same time as agents for *X. pungens* at very little extra cost and biocontrol would almost certainly succeed.

The remaining "High Importance" weeds (i.e. weeds with a Weighted Importance Score of > 75) are considered below:

As noted in the results, above, *Merremia peltata* is considered to be a highly problematic weed that can climb over and smother trees up to 20 m tall. There is, however, uncertainty regarding its status in Rarotonga and throughout the Pacific region. As it was present in Rarotonga when the first European botanists began documenting the flora, it is listed as being native to Rarotonga (Cheeseman 1903). However, Cheeseman (1903) noted that "it is remarkable that the botany of Rarotonga has not been previously investigated, seeing that it is now 80 years since the discovery of the island, and that for the greater portion of that time Europeans have been living upon it". This indicates *M. peltata* could conceivably have been introduced by Europeans, prior to the first botanical surveys of the Cook Islands. Moreover, although there are no records of enthnobotanical use of *M. peltata* in the Cook Islands, a decoction of the leaves of *Colocasia* and those of wabula (*M. peltata*) is reportedly used for the treatment of cysts in Fiji (Cambie & Ash 1994), so it could have been introduced as a medicinal plant that has subsequently fallen out of use. Indeed, Burkill (1966) reports numerous ethnobotanical uses of *M. peltata* including treatment for stomach ache, coughs, diarrhoea, mastitis, opthalmia, sores, wounds and as a vermifuge, which is another potential reason for it to be transported between islands. Polynesians arrived in Rarotonga around 800 AD (http://en.wikipedia.org/wiki/History_of_the_Cook_Islands), so there was ample opportunity for *M. peltata* to have introduced by Polynesians, either deliberately for medicinal purposes or accidentally. A report on the feasibility of biocontrol of *M. peltata* in the Pacific region (2006) recommended that the genetics of *M. peltata* should be investigated to determine, if possible, how and when *M. peltata* colonised the Pacific region. Similar studies have been done for other organisms, for example Austin (1999) presented convincing evidence that the lizard *Lipinia noctua* colonized the central and eastern Pacific as a result of human-mediated dispersal. Only if there is convincing evidence that *M. peltata* is a recent introduction should biocontrol proceed. Given the current concern regarding the impacts of *M. peltata* in the Cook Islands and elsewhere in the Pacific region, we recommend that this genetics work should be included in the current 5-year plan.

Nephrolepis saligna ranked highly, but it is predicted to be a very difficult and expensive target due to the presence of several native *Nephrolepis* species in the Cook Islands. It is also currently confined to one small island (Nassau; 1.3 km^2) in the northern group. Due to the undoubtedly high cost:benefit ratio of working on this species, we suggest it should be a low priority for biocontrol unless it invades other islands, which is a relatively low risk as there is no airport on Nassau, and the inter-island ship service from Rarotonga is very infrequent.

Cenchrus echinata, Cuscuta campestris, Pennisetum pupureum and *Senna obtusifolia* all ranked highly, but all are predicted to be difficult and costly targets (particularly *C. echinata*, due to the presence of a closely related and seriously endangered native Cook Island species: *C. caliculatus*). The most feasible target is likely to be *S. obtusifolia*, as candidate agents have already been identified and some have undergone host-range testing in Australia (Julien et al. 2012). The Australian programme was abandoned because the candidate agents fed on Australian native *Senna* spp. The Cook Islands have no native *Senna* species, so releases of these agents could be made, but they would have to be sourced from the native range in Mexico. All these species are major weeds throughout the Pacific Region, so the best course of action maybe to seek partners to apply for regional funding, thereby sharing the cost for work on these species.

5.1 A 5-year plan for biocontrol in the Cook Islands

A 5-year plan for weed biocontrol in the Cook Islands (see Table 8 for more details, including estimated costs) should proceed with:

'repeat' programmes using already tested agents against the following weeds: *Arundo donax, Xanthium pungens, Cardiospermum grandiflorum, Mikania micrantha* and *Psidium cattleianum.* 'Repeat' programmes for fully host-range tested agents simply require importation into containment, rearing for at least one generation to ensure the population is free of parasitoids and disease, followed by release from containment mass-rearing. Depending on the life-cycle of the agent, this should cost from as little as c. NZ$35,00–45,000 per agent (not including the cost of mass-rearing and releasing agents in the Cook Islands).

the commencement of 'novel' programmes against *Passiflora rubra* and *Spathodia campanulata.* We estimate that a programme against *P. rubra* could cost as little as NZ$63,000 because the ecology of many *Passiflora* herbivores is well known. We estimate that it should cost in the region of $200,000 to conduct native range surveys, test and import one agent for the biocontrol of *Spathodia campanulata*. More than one agent may be required for a weed to be effectively controlled.

molecular studies, to investigate the status (native or exotic) of *Merremia peltata* in the Cook Islands. This is likely to cost approximately NZ$90,000.

6 Summary

We summarise the conclusions in relation to each of the objectives (dot points) below:

- To identify a clear pathway for developing biocontrol of economically important weeds in the Cook Islands that will, in future, allow agriculture and tourism to be more sustainable in the Cook Islands

This report identifies a clear pathway for developing biocontrol of eight economically important weeds in the Cook Islands. A 5-year plan is outlined in Table 8, and section 5.1. The long-term and sustainable control of these weed achieved through the introduction of biocontrol agents will benefit both agricultural and tourism industries in the Cook Islands by reducing the negative impacts of these weeds on the Cook Islands, as outlined in the Introduction (section 1). Examples important to agriculture and tourism include protecting Rarotonga's water supply, reducing the need for expensive and on-going herbicide applications, reducing the effects of harmful herbicide residues (particularly in regard to run-off polluting the lagoon), and preserving the natural biodiversity of the islands, which is a valuable resource for the growing ecotourism industry.

- Identify and prioritise key weeds, and complete an effort and cost analysis

Regional experts were consulted at a workshop that was attended by delegates (invited by Dr Maja Poeschko and Gerald McCormack) who have interests ranging from agriculture (forestry, horticulture, livestock) to biodiversity conservation, and biosecurity in the Cook Islands. The delegates ranked the worst Cook Island weed species on the basis of their impacts (e.g. on primary production and biodiversity). The choice of delegates reflects the broad impacts weeds have in the Cook Islands, to ensure that decisions were representative and that key stakeholders were not neglected.

Fifty-two weeds were initially selected for consideration, based on a list of the worst invasive species in the Cook Islands derived from the literature, augmented with additional weed species nominated by experts attending the workshop and with a subset of lower priority weeds for which successful biocontrol agents are available. Nine species that were identified as having beneficial attributes at the workshop were rejected as biocontrol targets, resulting in 41 species being ranked according to their **importance** and plant traits that predict **biocontrol cost/effort** and **likely success**. At the workshop it was decided that 13 weeds on this list and of the highest importance should be given the highest priority for inclusion in the 5-year plan. The four medium and low-importance weeds that have a high probability of biocontrol success or that are targets of biocontrol overseas (namely *Clerodendrun chinense, Ludwigia octovalvis, Sida rhombifolia* and *Tithonia diversifolia*) were also considered, giving a total of 17 weed species considered for inclusion in the 5-year plan on a case-by-case basis, outlined in the discussion above.

Given the constraints regarding how many biocontrol agents can be housed and processed at the Landcare Research containment facility, we do not recommend working on weed species of medium or lower importance (*Clerodendrun chinense, Ludwigia octovalvis, Sida rhombifolia* and *Tithonia diversifolia*) within the 5-year plan, unless work on the higher priority weeds is unavoidably delayed (e.g. through failure to secure permits to export biocontrol agents from their countries of origin).

We also do not recommend working on five weed species that are considered to be difficult and costly biocontrol targets, with a relatively low probability of success (*Nephrolepis saligna, Cenchrus echinata, Cuscuta campestris, Pennisetum pupureum* and *Senna obtusifolia*). The final list was therefore reduced to seven species (*Arundo donax, Cardiospermum grandiflorum, Mikania micrantha, Passiflora rubra, Psidium cattleianum, Spathodea campanulata* and *Xanthium pungens*) which were considered to have a high or medium likelihood of biocontrol success. In addition one species that is considered to be a difficult biocontrol target – *Merremia peltata* – was included because it is one of the most important weeds throughout the Pacific region. We do not propose starting a biocontrol programme against this weed within the 5-year plan, but due to its apparent widespread invasive behaviour in the Pacific we do strongly recommend that molecular studies are conducted to indicate where this weed is native and therefore if it is a good candidate for biocontrol in the Pacific, and in particular the Cook Islands.

- Complete a risk analysis and train Cook Islands (CI) Ministry of Agriculture (MoA) staff in risk assessment techniques

At the workshop it was demonstrated how, by identifying the best and worst targets for biocontrol, the prioritisation system takes into account the risk of biocontrol failure and the risk of non-target attack from candidate biocontrol agents. Dr Dodd also gave a presentation to outline the stages of a weed biocontrol programme, including specificity testing where the risk of weed biocontrol agents attacking non-target plants is mitigated by host-range testing performed in containment. These tests are designed to demonstrate whether a candidate biocontrol agent is specific enough to be released from containment. During her visit to NZ, Dr Maja Poeschko visited Landcare Research's invertebrate containment facility at Lincoln to gain first-hand experience of weed biocontrol agent specificity testing. Other aspects of weed biocontrol risk were also discussed during Dr Poeschko's visit, including the risk of releasing a contaminated culture from containment. Dr Poeschko was taught how Landcare Research rears candidate agents through at least one generation in containment to ensure there is no contamination by parasitoids or micro-organisms and how Landcare Research is a world-leader in disease-testing biocontrol agents to ensure cultures are disease-free. Dr Poeschko learnt how line-rearing was used to eliminate bacterial and gregarine diseases from heather beetle and tradescantia beetle cultures, before these agents are released from containment in New Zealand. At Lincoln simple monitoring and assessment techniques were covered including a digital photo technique for which we provided Dr Poeschko software developed by Landcare Research. Dr Gary Houliston also explained our molecular capability to help correctly identify species or check for contaminants. Maja also spent time at the herbarium looking at the Cook Island collection and the opportunities it provides, e.g. insect pest damage on some specimens providing earlier dates of arrival than previously known. Finally, Dr Poeschko visited the Auckland campus of Landcare Research where she met taxonomists at the NZ Insect Collection and Fungorium, where samples of biocontrol agent cultures are routinely screened before release from containment to ensure that the agents have been correctly identified and the cultures are pure and free of cryptic species. She was introduced to the plant pathology team at Auckland where she learnt about strategies for controlling diseases that threaten native flora and the challenges of using diseases for weed biocontrol and how these are dealt with. Maja was also given a tour of the new plant pathogen containment facility and taken through the steps for host range testing novel agents and how we will produce pure cultures of bioagents before shipping them to the Cook Islands for release.

The visit to the Cook Islands by Drs Dodd and Paynter was important for gaining first-hand experience of the successful biocontrol programmes of giant sensitive plant on Aitutaki and lantana on Atiu, gaining a greater appreciation of the major problems caused by invasive weeds for which biocontrol is not currently available, and for developing working relationships with key personnel and stakeholders (e.g. Fred Charlie on Aitutaki, Roger Malcom on Atiu, and the workshop attendees on Rarotonga) who will be able to assist in the implementation of future weed biocontrol work. The workshop held in Rarotonga was essential for setting weed biocontrol priorities and gauging the level of support for biocontrol of the shortlisted weeds. For example, had we approached weed prioritisation on the basis of weed lists alone and without first consulting with local experts, we would have given both *Azolla filiculoides* and *Eichhornia crassipes* (both major weeds internationally) a high priority. However, discussions held at the workshop indicated that biocontrol is not desired for either of these weeds in the Cook Islands.

- Identify key personnel and systems, foster relationships, and develop importation protocols

Regional experts invited to attend the workshop were chosen by Dr Maja Poeschko and Gerald McCormack to reflect the broad impacts that weeds have in the Cook Islands, and to ensure decisions were representative and no key stakeholders were neglected.

Importation protocols were discussed at the workshop. Weed biocontrol has already been conducted in the Cook Islands, with successful programmes against lantana and giant sensitive plant. Therefore, there is institutional knowledge of biocontrol in the Cook Islands. The success of past programmes has undoubtedly contributed to high motivation for more biocontrol programmes against key Cook Island weeds and MoA representatives considered that current legislation (section 68 of the Cook Islands Biosecurity Act) and importation protocols should be adequate for further biocontrol introductions to progress smoothly. At the workshop (Appendix 3) Ngatoko Ngatoko, Director of Biosecurity, informed the group that legislation requires the importer to submit a comprehensive application with all the relevant information, including risk assessment research results. The application will then be assessed by a designated committee who will make the decision as to whether or not it can be imported and released.

The Cook Islands do lack a containment facility for processing weed biocontrol agents, so specificity testing and rearing to ensure cultures are clean will have to be done overseas. There are personnel in the Cook Islands with excellent knowledge regarding weed identification and ecology as well as staff with good knowledge of insect rearing. Gaps in knowledge (e.g. culturing plant pathogens) will be addressed by appropriate training in the 5-year plan.

- Produce a final report which will include a recommended 5-year plan.

The 5-year plan is summarised in section 5.1 and Table 8.

Table 8 5-year plan for work on biocontrol of weeds in the Cook Islands, all prices are exclusive of GST

Year	Weed species & related outputs	Cost	What will be done	Where it will be done & who will do it
Year 1	*Arundo donax*	$20,930.00	*Review literature regarding the host-specificity of Arundo agents and liaise with Cook Islands Ministry of Agriculure (MoA) to determine if further host-range testing is required (as both agents are purportedly specific to the genus Arundo, we anticipate that no further testing will be required)* *Obtain and maintain (pot up, water, deal with pest infestations etc.) Arundo donax plants for rearing agents in containment in NZ* *Obtain appropriate permits, liaise with overseas collaborators to arrange for shipments of candidate agents: Tetramesa romana (Hymenoptera: Eurytomidae) and Rhizaspidiotus donacis (Hemiptera: Diaspididae)*	Landcare Research will obtain and maintain plants for rearing agents at the Tamaki containment facility (Auckland) Agent shipments will be sought from USDA Agricultural Research Service
Year 1	*Cardiospermum grandiflorum*	$5,110.00	*Review literature regarding the specificity of Puccinia arechaveletae and liaise with MoA Cook Islands to determine if additional host-range testing is required (as this pathogen is purportedly specific to the genus Cardiospermum we anticipate that no further testing will be required)* *Liaise with overseas experts to arrange the export Puccinia arechavaletae from Argentina*	Landcare Research (Auckland) We will initially ask Dr David Simelane (ARC Plant Protection Research Institute), who runs the South African balloon vine biocontrol programme, if he can arrange a shipment
Year 1	*Merremia peltata*	$20,225.00	Obtain plant material from throughout the Pacific and East Asia for molecular analyses	Landcare Research (Lincoln) will obtain specimens from overseas collaborators and herbaria

Year	Weed species & related outputs	Cost	What will be done	Where it will be done & who will do it
Year 1	*Mikania micrantha*	$13,830.00	*Review literature regarding the specificity of Puccinia spegazzinii and liaise with MoA Cook Islands to determine if additional host-range testing is required (as this pathogen is purportedly specific to the genus Mikania we anticipate that no further testing will be required)* *Obtain and maintain Mikania plants for rearing Puccinia spegazzinii in containment in NZ. Liaise with overseas experts to arrange for shipments of Puccinia spegazzinii*	Landcare Research will obtain and maintain plants for rearing agents at the Tamaki containment facility (Auckland) Agent shipments will be sought from Annastasia Kawi (based at the National Agricultural Research Institute, Papua New Guinea, where this agent has been released)
Year 1	*Passiflora rubra*	$14,660.00	*Obtain plants and maintain (pot up, water, deal with pest infestations etc.) for rearing agents in containment in NZ and for host-range testing required*	Landcare Research
Year 1	*Spathodea campanulata*	$49,317.50	*Conduct native-range surveys and complete a genetic study (already underway and partially complete) to determine origin of S. campanulata in the Cook Islands*	Landcare Research will subcontract Iain Paterson (Rhodes University, Grahamstown, South Africa) to conduct surveys in Ghana, as he has already conducted preliminary surveys and genetic studies in West Africa
Year 1	*Xanthium strumarium*	$14,270.00	*Review literature regarding the specificity of Puccinia xanthii and liaise with MoA Cook Islands to determine if additional host-range testing is required. Some additional testing may be required as some varieties of sunflower may be partially susceptible (although there are few examples of infestation of sunflower in field conditions)* *Obtain and maintain X. strumarium plants for rearing agents and host-range testing that may be required in NZ*	Landcare Research will obtain and maintain plants for rearing agents at the Tamaki containment facility

Year	Weed species & related outputs	Cost	What will be done	Where it will be done & who will do it
Year 1	*Project management costs*	$12,860.00	Covers reporting, budgeting. etc.	Landcare Research, Auckland
Year 2	*Arundo donax*	$39,250.00	*Rear Tetramesa romana and Rhizaspidiotus donacis through at least 1 generation to ensure populations are disease and parasitoid-free and 'bulked up' in containment*	Landcare Research will rear the agents and ship them to Rarotonga
			Ship to Cook Islands for mass-rearing and release at Rarotonga	Cook Islands Ministry of Agriculture staff (MoA) will conduct the mass-rearing and field releases (with appropriate training from Landcare Research scientists)
Year 2	*Cardiospermum grandiflorum*	$15,520.00	*Obtain and maintain Cardiospermum plants for rearing agents in containment in NZ in anticipation of agent shipment*	Landcare Research will obtain and maintain plants for rearing agents at the Tamaki containment facility
Year 2	*Merremia peltata*	$40,100.00	*Conduct molecular analyses to determine origin of M. peltata in the Cook Islands*	Landcare Research will conduct the molecular studies at Lincoln
Year 2	*Mikania micrantha*	$28,570.00	*Rear Puccinia spegazzinii through 2 generations in containment, ship to Cook Islands for release on Rarotonga*	*Landcare Research will rear Puccinia spegazzinii and ship it to Rarotonga*
			Mass-rear Puccinia spegazzinii and field release	MoA will conduct the mass-rearing and field releases (with appropriate training from Landcare Research scientists)

Year	Weed species & related outputs	Cost	What will be done	Where it will be done & who will do it
Year 2	*Passiflora rubra*	$48,650.00	*Obtain shipments of candidate agents (e.g. Heliconius charitonius) and conduct host-range testing of key test plants* Assuming host-range testing indicates the candidate agent(s) is/are specific, arrange for shipments of candidate agent(s) for release on Rarotonga	Landcare Research will conduct host-range testing at the Tamaki containment facility and arrange shipments to Rarotonga MoA will conduct the mass-rearing and field releases (with appropriate training from Landcare Research scientists)
Year 2	*Psidium cattleianum*	$14,000.00	*Review literature regarding the host-specificity of Tectococcus ovatus and liaise with MoA Cook Islands to determine if further host-range testing is required (as Tectococcus ovatus is purportedly specific to strawberry guava, we anticipate that no further testing will be required)* Obtain plants for rearing agents in containment in NZ. *Liaise with overseas experts to arrange for shipments of Tectococcus ovatus.*	Landcare Research will obtain and maintain plants for rearing agents at the Tamaki containment Facility Agent shipments will be sought from US Forest Service, Hawaii
Year 2	*Spathodea campanulata*	$64,256.25	Continues native range surveys to identify potential biocontrol agents.	Surveys will likely be done in Ghana, and South Africa by Rhodes University

Year	Weed species & related outputs	Cost	What will be done	Where it will be done & who will do it
Year 2	*Xanthium strumarium*	$25,420.00	Shipment of rust from Australia. Conduct host-range testing of key test plants, if required. Assuming host-range testing indicates agent is specific, rear through >1 generation to ensure a clean culture for shipment to the Cook Islands Arrange for shipment to Cook Islands for mass-rearing and release on Rarotonga	Landcare Research will arrange shipments of the rust to the Tamaki pathogen facility and conduct host-range testing Agent shipments will be sought from DAF, Queensland MoA will conduct the mass-rearing and field releases (with appropriate training from Landcare Research scientists)
Year 2	*Sub-contract to MoA Arorangi*	$50,000.00	Subcontract covers MoA staff (two full-time technical staff who will receive training from Landcare research staff), travel and operating costs associated with mass-rearing and redistribution of agents & monitoring establishment and impact. It is likely additional staff will need to be hired to assist with these activities, building biocontrol capacity in the Cook Islands	Landcare Research
Year 2	*Agent monitoring*	$10,250.00	Cost for LCR to design and help set up monitoring (biocontrol establishment, dispersal, test for non-target and potential non-target impacts) to be run by MoA staff	Landcare Research
Year 2	*Project management costs*	$13,500.00		Landcare Research
Year 3	*Arundo donax*	Cost included in subcontract to MoA	*Maintain cultures of Tetramesa romana and Rhizaspidiotus donacis at MoA, Arorangi, Rarotonga for re-release and redistribution if required*	MoA, Arorangi

Year	Weed species & related outputs	Cost	What will be done	Where it will be done & who will do it
Year 3	*Cardiospermum grandiflorum*	$50,275.00	*Receive shipment of Puccinia arechavaletae and rear Puccinia arechavaletae through >1 generation in containment (I have put this in year 3, assuming it will take > 1 year for paperwork to obtain permit as Argentinian bureaucracy is slow)*	Landcare Research rear the rust at the Tamaki pathogen facility and subsequently ship it to the Cook Islands
			Ship to Cook Islands for mass-rearing release on Rarotonga	MoA will conduct the mass-rearing and field releases (with appropriate training from Landcare Research scientists)
Year 3	*Merremia peltata*	$30,050.00	*Finish molecular analyses to determine origin of M. peltata in the Cook Islands, interpret data and make recommendations on the suitability of M. peltata as a target for biocontrol in the Pacific region*	Landcare Research, Lincoln
Year 3	*Mikania micrantha*	Cost included in subcontract to MoA & monitoring	*Maintain a culture of Puccinia spegazzinii at MoA, Arorangi, Rarotonga for re-release and redistribution if required*	MoA
Year 3	*Passiflora rubra*	Cost included in subcontract to MoA & monitoring	Maintain cultures of agents at MoA, Arorangi, Rarotonga for re-release and redistribution if required	MoA
Year 3	*Psidium cattleianum*	$26,350.00	*Rear Tectococcus ovatus through 1 generation in containment, ship to Cook Islands for release on Rarotonga*	Landcare Research
			Mass-rear T. ovatus at Rarotonga for release and redistribution	MoA, Arorangi, Rarotonga

Year	Weed species & related outputs	Cost	What will be done	Where it will be done & who will do it
Year 3	*Spathodea campanulata*	$21,897.50	Begin host-range testing candidate agents in containment	Rhodes University, Grahamstown, South Africa
Year 3	*Xanthium strumarium*	Cost included in subcontract to MoA & monitoring	*Maintain a culture of Puccinia xanthii at MoA, Arorangi, Rarotonga for re-release and redistribution if required*	MoA, Arorangi, Rarotonga
Year 3	*Sub-contract to MoA Arorangi*	$50,000.00	As for year 2	
Year 3	*Agent monitoring*	$27,285.00	Cost for LCR to set up monitoring (biocontrol establishment, dispersal, test for on-target and potential non-target impacts) to be run by MoA staff	Landcare Research, Auckland (with field trip to Rarotonga to assist setting up of agent monitoring)
Year 3	*Project management costs*	$14,140.00		
Year 4	*Cardiospermum grandiflorum*	$15,600	*Receive shipment of seed-weevil Cissoanthonomus tuberculipennis from South Africa and rear through 1 generation in containment, ship to Cook Islands for release on Rarotonga* *Maintain Puccinia arechavaletae culture at MoA Arorangi, in case of failure to establish/more releases are required*	Landcare Research, Auckland MoA, Arorangi
Year 4	*Mikania micrantha*	Cost included in subcontract to MoA & monitoring	*Redistribution of Puccinia spegazzinii to other islands (Atiu, Aitutaki)*	MoA, Arorangi

Year	Weed species & related outputs	Cost	What will be done	Where it will be done & who will do it
Year 4	*Passiflora rubra*	Cost included in subcontract to MoA & monitoring	Redistribution of agents to other islands (Mangaiai, Aitutaki, Ma'uke, Mitiaro, Atiu), as required	MoA
Year 4	*Psidium cattleianum*	Cost included in subcontract to MoA & monitoring	*Redistribution of Tectococcus ovatus to other islands (e.g. Mangaia)*	MoA
Year 4	*Spathodea campanulata*	$22,037.50	Continue host-range testing candidate agents in containment	Rhodes University, Grahamstown, South Africa
Year 4	*Sub-contract to MoA Arorangi*	$50,000.00	As before	
Year 4	*Agent monitoring*	$37,130.00	Cost for LCR to assist supervision of monitoring (biocontrol establishment, dispersal, test for on-target and potential non-target impacts) run by MoA staff	Landcare Research, Auckland (with field trip to Rarotonga to assist agent monitoring)
Year 4	*Project management costs*	$14,780.00		
Year 5	*Spathodea campanulata*	$41,160.00	Complete host-range testing, if sufficiently specific agents are found, ship to Rarotonga for release	Rhodes University, Grahamstown, South Africa
Year 5	*Sub-contract to MoA Arorangi*	$50,000.00	As before	

Year	Weed species & related outputs	Cost	What will be done	Where it will be done & who will do it
Year 5	*Agent monitoring*	$51,950.00	*Cost for LCR to assist supervision of monitoring (biocontrol establishment, dispersal, test for on-target and potential non-target impacts) to be run by MoA staff, analysis of data (collaboration between LCR & MoA for Arundo donax, Cardiospermum grandiflorum, Mikania micrantha, Passiflora rubra, Psidium cattleianum, Xanthium strumarium)* Complete final report on the success of the biocontrol programmes	Landcare Research/MoA
Year 5	*Project management costs*	$14,920.00		
		$1,018,293.75		

Table 9 Total costs for the 5-year plan by year all prices are exclusive of GST

Year	Cost
1	$151,202.50
2	$349,516.25
3	$219,997.50
4	$139,547.50
5	$158,030.00
Grand Total	$1,018,293.75

Table 10 Totals by weed target and associated outputs all prices are exclusive of GST

Weed target and associated outputs	Cost
Arundo donax	$60,180.00
Cardiospermum grandiflorum	$86,505.00
Merremia peltata	$90,375.00
Mikania micrantha	$42,400.00
Passiflora rubra	$63,310.00
Psidium cattleianum	$40,350.00
Spathodea campanulata	$198,668.75
Xanthium strumarium	$39,690.00
Project management costs	$70,200.00
Agent monitoring	$126,615.00
Subcontract to MAF Arorangi	$200,000.00
Grand total	$1,018,293.75

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Appendix 1 – Defining classical biocontrol and the steps in a biocontrol project

Classical biological control (or biocontrol) of weeds is defined as "The intentional introduction of an exotic, usually co-evolved, biological control agent for permanent establishment & long-term pest control".

Using invertebrate herbivores or plant pathogens to control invasive weeds is internationally accepted as a practical, safe (Pemberton 2000; Barton 2004; Paynter et al. 2004), and environmentally beneficial weed management method applicable across both natural and agricultural ecosystems (Charudattan 2001). It rarely results in the eradication of a target weed, but aims to reduce target weeds to a lower level of abundance and vigour, permanently reducing weed impacts to below damage thresholds. Biocontrol 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). This agent has also been introduced into Aitutaki, Cook Islands, where it is also highly effective. In Hawai'i, 8 weed species have been successfully controlled by introduced biological control agents (Paynter et al. 2006). There has also been a long history of biocontrol in Fiji, with introductions of prospective biocontrol agents recorded as early as 1911 (Julien & Griffiths 1998). 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 & Griffiths 1998). There has also been 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 & Griffiths 1998). Good control of salvinia (Salvinia molesta) and broom weed (Sida acuta and Sida rhombifolia) has also been achieved.

Adherence to the international guidelines (FAO 1995) 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. The steps of a biocontrol programme are listed below:

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 containment, 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.

Appendix 2 – Scoring system for 'Effort', based on a slightly modified system to that used by Paynter et al. (2009)

EFFORT REQUIRED TO OBTAIN & HOST-RANGE TEST BIOCONTROL AGENTS	OUTCOME	Score
1. Has the weed been/is it a subject of adequately resourced biocontrol programme elsewhere?		
a. Yes, successful program	If specific agents are already known & host-range testing has already been conducted overseas, then programme is likely to be cheaper	1
b. Yes, unsuccessful program	Law of diminishing returns – if current known suite of agents is ineffective, finding new ones will be harder	15
c. Current target/too early/insufficient data to assess success elsewhere or variable success elsewhere	Potential for cost savings, but uncertainty factored into score	10
d. Current target agents released (available)/too early/insufficient data to assess success elsewhere or variable success elsewhere	Potential for cost savings, but uncertainty factored into score	5
e. No, never		20
2. Accessibility and ease of working in native range		
Difficult		5
Moderate		3
Easy		2

not applicable (if repeat programme)		1
3. Literature regarding natural enemies well known/accessible		
Yes		1
No	Formal identification of candidate agents (required for import/release permits) may be time consuming, delaying a programme	5
4. Plant phylogeny: How closely related is the target weed to indigenous/valued plants?		
None in same family/or already tested agent known to be sufficiently specific	Cheaper no-choice tests may be sufficient, larger pool of candidate agents/testing unlikely to be required for an agent that has already been shown to be specific during overseas host-range testing	1
Same Family		5
Same Genus	More extensive host-range testing may be required, more species may require testing before a sufficiently specific species is identified	20

Appendix 3 – Minutes of the weed biocontrol workshop

"Developing a five year plan for implementing weed biocontrol in the Cook Islands"

Summary

A meeting was held on 10th July 2012 (Ministry of Agriculture, Head Office Arorangi), to discuss the potential for biocontrol of key weed species in the Cook Islands.

Attendees

Dr Quentin Paynter, Dr Sarah Dodd (Landcare Research), Dr Matairangi Purea (Agriculture, Secretary), William Wigmore (Agriculture, Director of Research), Ngatoko Ngatoko (Agriculture, Director of Biosecurity), Pavai Taramai (Agriculture, Deputy Director of Biosecurity), Edwin Aperau (Agriculture, Livestock Officer), Dr Maja Poeschko (Agriculture, Entomologist), Noo Tokari (Agriculture, Project Officer, Forestry Programme Coordinator), Maria Tuoro (Agriculture, Policy and Project Director), Tiara Mataora (Agriculture, Nursery Technician), Elizabeth Munro (Environment, Senior Officer, Biodiversity Unit), Ian Karika (President of Te Ipukarea Society, Chairman of Natural Heritage Trust, and Chairman of Rarotonga Environment Authority), Teava Iro (Titikaveka Growers Association), Gerald McCormack (Director, Cook Islands Natural Heritage Project).

Agenda

9 am Morning presentations:

1. Cook Island TV interview explaining the purpose of the workshop
2. Welcome, introductions (Maja Poeschko) and opening prayers (Teava Iro)
3. Sarah Dodd– Outline of scoping study and presentation on philosophy of biocontrol – including the six steps to implementing biocontrol of a weed. (30 min)
4. Gerald McCormack/Maja Poeschko – presentation on weed problems and their observed impact on biodiversity/agriculture in Cook Islands. (30 min)

10.15 am Morning tea

1. Quentin Paynter– presentation on scoping study, results and presentation of priority list of weeds to be discussed after lunch (1hr +)

12.00 pm Lunch: -sponsored by MFAT

1.00 pm Open Discussions

1. Present weed list, discuss and finalise priorities (Quentin)

2. Discuss the most appropriate process for importing and releasing bioagents into the Cook Islands,

Nibbles and drinks 6-8pm at the Fishing Club – sponsored by Landcare Research

Meeting notes

Sarah Dodd outlined the purpose of the scoping study, which is to develop a five year plan to implement sustainable, feasible and cost effective biocontrol of the most important economic weeds of the Cook Islands. Sarah then gave a presentation on the philosophy of; and the practicalities of biological control of weeds. The full details of these presentations are provided in the attached PowerPoint presentation titled "Sarah Dodd Cook Island Weed Workshop July 2012.pdf".

Gerald McCormack gave a presentation about the worst weeds threatening the Cook Islands, with particular reference to biodiversity threats. Species he highlighted are listed below:

1. African Tulip tree (*Spathodea campanulata*) is listed among one hundred of the world's worst invasive species in the Global Invasive Species Database. It is found in the mountains and is spreading. The Flame Tree restaurant was named after this tree.

2. Cercropia tree (*Cecropia pachystacha*) is also called mountain weed. It isn't a problem in the lowlands. Locals value this weed to some extent because native pigeons like its fruit (so they have learnt to sit beneath this tree to hunt pigeons).

3. Night blooming Cestrum (*Cestrum nocturnum*) – Mountain weed

4. Lantana (*Lantana camara*) is found on exposed rock faces in the mountains of Rarotonga and lowlands of some other islands (e.g. Atiu). Effective biocontrol is available (a leaf-miner beetle *Uroplata girardi*): *Lantana* declined dramatically on Atiu, following redistribution of *U. girardi* from Rarotonga.

5. White Ginger (*Hedychium coronarium*) is a major threat to native land snails (e.g. *Tekoulina pricei*).

6. Red passionfruit (*Passiflora rubra*) grows rapidly in the hills, spread by the Cook Islands fruit dove. (which does have alternative food sources). It is the second worst weed in the Makatea forest of Atiu.

7. Giant Balloon Vine (*Cardiospermum grandiflorum*) was considered the worst weed of lowland inland forest in 1980s, but is now considered the second worst (after *Merremia peltata*). It sends out long tendrils that extend out from the host plant so a

strong wind can blow them up onto tall plants which it then over-grows. Native to South America, it was first recorded in Cook Islands in 1920s in an Avarua garden.

8. Mile-a-minute weed (*Mikania micrantha*) often co-invades with balloon vine (making a "terrible twosome"). The balloon vine invades first and mile-a-minute climbs over it.

9. Morning Glory (*Merremia peltata*) was considered native to Rarotonga, but it is behaving like a true invasive and may be an early Polynesian introduction. It is also rampant on Atiu and Aitutaki (it is certainly a recent introduction to the latter, where it was first discovered in 1974). A control programme in is underway in Vanuatu where they are injecting the vines with herbicide. Liz Munroe (Ministry for the Environment) has acquired an injector for the Cook Islands.

10. Giant Sensitive Weed (*Mimosa diplotricha*) was an important agricultural weed in Aitutaki and could become a problem if it spreads to other islands. It probably came from Samoa with hay for Cattle and was unintentionally spread via an agricultural tractor. In Aitutaki it is now under good biocontrol due to an introduced psyllid *Heteropsylla spinulosa.*

Gerald then made the comments that inter-island quarantine in the Cook Islands is almost non-existent. The easiest way to control a weed is to not introduce it in the first place. Therefore stopping the spread of weeds to additional islands should be a priority. This will require educating the public through TV, the local paper, posters, etc. to increase their awareness of weed issues.

Gerald then asked the other participants if there were other weeds they were concerned about and the following were discussed:

1. Wedelia (*Sphagneticola trilobata*). Is certainly a pest, but is also a valued landscaping plant and most people don't consider it a problem. Consequently attempts to eliminate it from Aitu, by removing it from gardens, had to be abandoned.

2. Albizia (*Falcataria moluccana*) – is a tree that is replacing the native fern lands, but is not a weed of native forests.

3. Leucaena (*Leucaena leucocephala*) – was introduced as a source of biofuel in the inland forest regions and has very hard wood. It has now been "knocked back" by a self-introduced psyllid.

4. Black Wattle (*Acacia auriculiformis*) – has been introduced to Rarotonga, Mangaia, Atiu and Mauke and is now considered highly invasive on the makatea islands and 'out of control', as is the case for all introduced Acacias.

Quentin Paynter gave a presentation outlining the development of a protocol for ranking weed biocontrol targets in the Cook Islands. This PowerPoint presentation is attached ("Quentin Paynter Cook Island Weed Workshop July 2012.pdf").

After lunch an open discussion took place to prioritise the most important weed targets in the Cook Islands. High initial implementation costs usually restrict investment in biocontrol to the most important weeds (i.e. weeds that are widespread, damaging and difficult/expensive to control by conventional means). For this reason, 52 weed species were shortlisted for consideration, including all 46 species listed on the Cook Islands Biodiversity Database http://cookislands.bishopmuseum.org/search.asp as the "most serious" invasive weed species. In addition, three lesser invaders (*Azolla filiculoides*, *Eichhornia crassipes* and *Tecoma stans*) that have been targeted for biocontrol in other countries (which should make them cheaper targets); two additional species (*Coix lacryma-jobi* and *Pennisetum purpureum*) that were "last minute nominees" suggested by workshop attendees and *Merremia peltata* was also included (even though some authorities consider it to be native to some of the Cook Islands it is undoubtedly a recent introduction to Aitutaki, where it is considered invasive).

An initial discussion considered the beneficial aspects of the nominated weeds. This resulted in nine of the 52 shortlisted weed species being rejected as candidate biocontrol targets because it was considered that there would be strong opposition to biocontrol due to their desirable properties (listed in Table 1, below).

Table 1 Species rejected as candidate targets for biocontrol

Weed Species	Common name	Reason
Azolla filiculoides	Azolla Water-fern	Nitrogen-fixing plant: used as green manure
Coix lacryma-jobi	Job's tears	Cultural (e.g. pseudocarps used as beads)
Eichhornia crassipes	Water Hyacinth	Nitrogen-fixing plant: used as green manure
Eugenia uniflora	Surinam cherry	Edible fruit
Falcataria moluccana (=*Paraserianthes falcataria*)	Albizia	Source of useful wood
Ocimum gratissimum	Wild basil	Culinary herb and cultural (e.g. used in the Ei)
Pimenta racemosa	Bay-rum tree	Spice
Psidium guajava	Common guava	Edible fruit
Syzygium cumini	Jambolan	Edible fruit

Two of the remaining species (Giant sensitive plant *Mimosa diplotricha* and Lantana *Lantana camara*) already have biocontrol agents released in the Cook Islands. Moreover, the general consensus was that biocontrol of these species is effective and that further investment in additional biocontrol agents is unwarranted. These two species were consequently excluded from further consideration.

Twelve workshop attendees, who are based in the Cook Islands, then voted on which of the remaining weeds they considered to be the most important using a simple system where weeds were scored as "hot", "warm" or "cold" (where hot = the highest priority and cold = lowest priority). The number of votes for each species is given in Table 2 (below).

Table 2 Voting on weed importance, where Hot = (highest priority) and Cold = (lowest priority). Total score based on weighting of Hot, Warm and Cold scoring = 10, 5 and 1 point(s), respectively

Rank	Weed species	Common name	Weed importance voting			Total Score
			Hot	Warm	Cold	
1=	*Arundo donax*	Giant reed	12	0	0	120
1=	*Cardiospermum grandiflorum*	Grand balloon vine	12	0	0	120
1=	*Cenchrus echinatus*	Burr grass	12	0	0	120
1=	*Merremia peltata*	Peltate morning glory	12	0	0	120
1=	*Mikania micrantha*	Mile a minute	12	0	0	120
1=	*Nephrolepis saligna*	Samoan sword-fern	12	0	0	120
1=	*Passiflora rubra*	Red passionfruit	12	0	0	120
1=	*Pennisetum purpureum*	Elephant grass	12	0	0	120
1=	*Spathodea campanulata*	African tulip tree	12	0	0	120
10	*Xanthium pungens*	Cockleburr	11	1	0	115
11	*Cuscuta campestris*	Dodder	10	1	1	106
12	*Senna obtusifolia*	Sicklepod	9	3	0	105
13	*Psidium cattleianum*	Strawberry guava	10	0	2	102
14	*Mimosa pudica*	Sensitive weed	6	6	0	90
15	*Brachiaria mutica*	Para grass	6	4	2	82
15=	*Phyllostachys bissetii*	Bisset's bamboo	6	4	2	82
17	*Sorghum bicolor* subsp. *drummondii*	Sudan grass	4	8	0	80
18	*Hedychium coronarium*	White ginger	4	6	2	72
19	*Calopogonium mucunoides*	Calopo	3	7	2	67
20	*Acacia spp*	Crassicarpa	1	11	0	65
21	*Clerodendrum chinense*	Honolulu rose	3	6	3	63
22	*Centrosema pubescens*	Centro butterfly-pea	2	8	2	62
23	*Cecropia pachystachya*	Cecropia	0	12	0	60
24	*Pueraria phaseoloides*	Tropical kudzu	1	9	2	57
25	*Ludwigia octovalvis*	Willow primrose	0	11	1	56
25=	*Syzygium jambos*	Rose apple	0	11	1	56
27	*Indigofera suffruticosa*	Indigo	1	8	3	53
28	*Tithonia diversifolia*	Tree marigold	1	8	3	53
29	*Leucaena leucocephala*	Leucaena	0	10	2	52
30	*Cestrum nocturnum*	Night-blooming cestrum	3	3	6	51
31	*Triumfetta rhomboidea*	Triumfetta weed	1	7	4	49
32	*Elephantopus spp*	Elephant's foot spp.	0	9	3	48
32=	*Tecoma stans*	Yellow bells	0	9	3	48
34	*Ardisia elliptica*	Inkberry	0	8	4	44
35	*Sida rhombifolia*	Broom weed	0	6	6	36
36	*Stachytarpheta urticifolia*	Blue rat's tail	1	3	8	33
37	*Bidens pilosa*	Beggar's tick	0	5	7	32
37=	*Hyptis pectinata*	Comb hyptis	0	5	7	32
39	*Adenanthera pavonina*	Red bead tree	0	3	9	24
40	*Desmodium incanum*	Spanish clover	0	0	12	12
40=	*Passiflora maliformis*	Hard passionfruit	0	0	12	12

Quentin then presented preliminary rankings (based on combining biocontrol feasibility scores with the importance scores). There was some discussion regarding how the importance scores should be weighted to give a total score. The group felt that the initial weighting of 3 points for hot, 2 for warm and 1 for cold did not emphasise the important weeds enough, and it was decided that 10 points for hot, 5 for warm and 1 for cold should ensure that the most important weeds were ranked sufficiently highly.

Action: Quentin will recalculate the biocontrol 'cost' scoring for the nominated Cook Island weeds where there are changes resulting from decisions made at the meeting. For example, voting at the meeting will result in a change in the 'cost' score for Rose apple *Syzigium jambos*. This is because it was decided that biological control of Jambolan *Syzygium cumini* is not desired, which means *Syzigium jambos* has a 'valued congeneric plant' in the Cook Islands, which is a predictor of programme cost. This is because it will be harder to find a sufficiently specific biocontrol agent for a weed that is closely-related to a valued plant species. The updated biocontrol feasibility and cost scores will be combined with the weed importance scores that were decided on at the meeting, to identify the best targets for biocontrol in the Cook Islands

Process for introducing bio-agents into the Cook Islands

Ngatoko Ngatoko the Director of Biosecurity informed the group that legislation regarding the process of importing bioagents into the Cook Islands is about to be passed into law. This legislation will require the importer to submit a comprehensive application with all the relevant information, including risk assessment research results. The application will then be assessed by a designated committee who will make the decision as to whether or not it can be imported and released. Gerald McCormack expressed concerns that the infrastructure of the CI government ministries was such that Biosecurity sat within the Ministry of Agriculture and may therefore not be impartial in its decision making.

Quentin Paynter, Sarah Dodd 25 July 2012

List and contact details of invited participants

Name	Institution & Position	Email address
Dr Matairangi Purea	Agriculture, Secretary	mat@agriculture.gov.ck
William Wigmore	Agriculture, Director of Research	research@oyster.net.ck
Ngatoko Ngatoko	Agriculture, Director of Biosecurity	nngatoko@agriculture.gov.ck
Pavai Taramai	Agriculture, Deputy Director of Biosecurity	ptaramai@agriculture.gov.ck
Edwin Aperau	Agriculture, Livestock Officer	eapera@agriculture.gov.ck
Noo Tokari	Agriculture, Project Officer, Forestry Programme Coordinator	noot@agriculture.gov.ck
Maria Tuoro	Agriculture, Policy and Project Director	maria@agriculture.gov.ck
Tiara Mataora	Agriculture, Nursery Technician	No email contact
Elizabeth Munro	Environment, Senior Officer, Biodiversity Unit	liz@environment.org.ck
Ian Karika	President of Te Ipukarea Society, Chairman of Natural Heritage Trust, and Chairman of Rarotonga Environment Authority	birds@oyster.net.ck
Teava Iro	Titikaveka Growers Association	No email contact

Appendix 4 – Cook Islands weeds that have been targeted for biocontrol elsewhere

Note: Xanthium pungens = X. strumarium

Weed species	Status of biocontrol programme(s)
Arundo donax	US host range testing has identified several candidate agents that are likely to be adequately specific for the Cook Islands, including a gall wasp and an armoured scale insect that feed only on *Arundo* spp. (Goolsby & Moran 2009; Cortes et al. 2011).
Azolla filiculoides	Complete control reported in South Africa, due to a specific frond-feeding weevil (McConnachie et al. 2004).
Cardiospermum grandiflorum	South African host-testing has identified two candidate agents (a seed-feeding weevil *Cissoanthonomus tuberculipennis* and a rust fungus *Puccinia arechavaletae*) that feed on, or infect only *Cardiospermum* and are, therefore, adequately specific for the Cook Islands. Further candidate agents are being tested (Simelane et al. 2011a). *Puccinia arechavaletae* is no longer being kept in containment in South Africa, so a fresh shipment from Argentina would be required (Dr David Simelane, personal communication).
Clerodendrum chinense	Preliminary surveys in north Vietnam and southern China identified promising candidate agents including a chrysomelid beetle *Phyllocharis undulata* (Julien 1993), which has not been released in the Pacific region, but was released in Thailand, although published impact and host-specificity testing data are lacking (Julien & Griffiths 1998).
Cuscuta campestris	Overseas surveys identified promising candidate agents including *Smicronyx* weevils, but host-specificity testing has not, to our knowledge, been done (Toth et al. 2008)
Eichhornia crassipes	Variable success (worldwide average reduction *c*. 67%). Control often excellent where the weed is not subjected to regular removal by periodic or annual flows, or mechanical and herbicide treatments (Gassmann et al. 2006).
Hedychium coronarium	Overseas surveys and preliminary host-range testing are being conducted by CABI-Bioscience, partly funded by Landcare Research
Lantana camara	Variable success worldwide depending on climate and the genetic variability of target weed. In the Pacific Region, anecdotal evidence indicates that biocontrol has had a major impact in some parts of the Pacific (e.g. Hawaii, Davis & Krauss 1962). Biocontrol agents (*Uroplata girardi, Teleonemia scrupulosa, Hypena laceratalis*) have already been released in the Cook Islands, where they provide good control.
Mikania micrantha	A rust pathogen *Puccinia spegazzinii* was first released in India (Ellison et al. 2008) and subsequent releases have been made in other countries including mainland China, Taiwan, Papua New Guinea (PNG) and Fiji. Comparative growth studies and field monitoring in PNG show that the rust can significantly reduce the growth and density of *Mikania* (Ellison & Day 2011).
Mimosa diplotricha	Successful control in many parts of Pacific e.g. 95% reduction in PNG (Kuniata 2009). Psyllid biocontrol agent already released in Aitutaki (Cook Islands), where it provides good control.

Psidium cattleianum	Permission to release a scale insect *Tectococcus ovatus* into Hawaii was recently granted. This scale insect is host-specific and will not attack common guava *Psidium guajava* (Wessels et al. 2007)
Senna obtusifolia	Host-range testing identified several species with feeding restricted to *Senna* spp. (Julien et al. 2012). They are, therefore, sufficiently specific for introduction into the Cook Islands, where, unlike Australia, there are no native *Senna* spp. There may be a biosecurity risk to *S. gaudichaudii*, which is native to some Pacific Islands (e.g. French Polynesia) as this plant was attacked by some agents tested in Australia (Julien et al. 2012).
Sida rhombifolia	Successfully controlled in Papua New Guinea, where the weed was reduced by 99% (Kuniata & Korowi 2004). Although the Cook Islands have no native *Sida* species, the risk to *Sida fallax* which is native to other Pacific Islands may need to be considered.
Spathodea campanulata	Preliminary surveys, funded by the Secretariat of the Pacific Community (SPC) have been conducted in Ghana which, on the basis of DNA evidence, is believed to be the origin of weedy populations of *S. campanulata* growing in Fiji (Iain Paterson, personal communication). These surveys identified some promising candidate agents, but specificity testing has not yet been conducted and funding to continue this work is being sought.
Tecoma stans	Several candidate agents exist, including a highly specific rust fungus that was recently released in South Africa, although it is too early to assess the impact of biocontrol (Madire et al. 2011).
Tithonia diversifolia	Work has been conducted against this weed in South Africa. Attempts to culture two candidate agents in containment failed and another candidate agent failed host-specificity testing, so there is currently no agent available for use in the Cook Islands (Simelane et al. 2011b). However, several promising candidate agents including a tortoise beetle and a stem-boring moth are currently being tested in containment (Dr David Simelane, personal communication).
Xanthium strumarium	An accidentally introduced fungus *Puccinia xanthii* has a major impact in humid regions of Australia. Contamination of wool by *X. strumarium* burrs reduced by 85% (Chippendale 1995). *P. xanthii* is likely to be adequately specific for use in the Cook Islands (Morin et al. 1993), although the test plant list would have to be reviewed to ensure key Cook Islands species have been tested.

Appendix 5 – Attributes of the 41 selected weed species

Habitat (T = terrestrial; A = aquatic/wetland; E = environmental; Ag = agricultural; B = both environmental and agricultural); Life cycle (A = annual; P = perennial/biennial); Rep = reproduction (S = sexual; C = clonal/apomict; S? = species assumed to be sexual); WeedNR = major weed in native range (Y/N). Synonyms: *Xanthium pungens* = *X. strumarium*; *Falcataria moluccana* = *Paraserianthes falcataria*; *Mimosa diplotricha* = *M. invisa*; *Stachytarpheta urticifolia* = *S. cayennensis*

Weed family and species	Native range of weed	Highly valued congeners (Y/N)	Habitat	Life cycle	Rep	WeedNR
Asteraceae						
Bidens pilosa	S America	N	T; B	A	S	Y
Elephantopus spicatus	Tropical America	N	T; Ag	P	S?	N
Mikania micrantha	Central & S America	N	T; B	P	S	N
Tithonia diversifolia	Central America	N (exotic ornamental *T. rotundifolia*)	T; Ag	P	S	N
Xanthium pungens	N America	N	T; Ag	A	S	Y
Bignonaceae						
Spathodea campanulata	W Africa	N	T; B	P	S	N
Tecoma stans	Caribbean	N	T; E	P	S	N
Convolvulaceae						
Cuscuta campestris	N America	N	T; Ag	A	S	Y
Merremia peltata	SE Asia, considered native to parts of the Pacific region, but may be an early introduction	N	T; E	P	S?	Y
Fabaceae						
Acacia crassicarpa	Australia, New Guinea	Y: exotic forestry spp.	T; Ag	P	S	N
Adenanthera pavonina	India to New Guinea; New Caledonia	N	T; B	P	S	N
Calopogonium mucunoides	S America	N	T; Ag	P	S	N
Centrosema pubescens	Tropical America	N	T; Ag	P	S	N
Desmodium incanum	N & S America	N	T; Ag	P	S	Y
Indigofera suffruticosa	N & S America	N	T; Ag	P	S	Y
Leucaena leucocephala	Mexico, Guatemala, Belize	N	T; Ag	P	S	N
Mimosa pudica	S America	N	T; Ag	P	S	Y
Pueraria phaseoloides	SE Asia	N	T; Ag	P	S	N

Weed family and species	Native range of weed	Highly valued congeners (Y/N)	Habitat	Life cycle	Rep	WeedNR
Senna obtusifolia	Tropical Americas	N[1]	T; Ag	A	S	Y
Lamiaceae						
Clerodendrum chinense	S China & N Vietnam	N (other exotic ornamentals)	T; Ag	P	C	N
Hyptis pectinata	Tropical Americas	N	T; Ag	P	S	N
Malvaceae						
Sida rhombifolia	Tropical & subtropical Americas	N[2]	T; Ag	P	S	Y
Triumfetta rhomboidea	Africa (Asia?)	Y: native *T. procumbens*	T; Ag	P	S?	N
Myrsinaceae						
Ardisia elliptica	India to New Guinea	N	T; B	P	S	N
Myrtaceae						
Psidium cattleianum	Central America & northern S America	Y: *Psidium guajava*	T; E	P	S	N
Syzygium jambos	SE Asia	Y: *Syzygium cumini*	T; E	P	C	N
Oleandraceae						
Nephrolepis saligna	Cook Islands, Fiji	Y: e.g. native *N. biserrata*	T; B	P	S?	N
Onagraceae[a]						
Ludwigia octovalvis	N & S America	N	A; Ag	P	S	N
Passifloraceae						
Passiflora maliformis	Tropical America	Y: exotic fruiting spp. e.g. *P. edulis*	T; E	P	S	N
Passiflora rubra	S America	Y: as above	T; E	P	S	N
Poaceae						
Arundo donax	Europe	N	A; Ag	P	C	N
Brachiaria mutica	Africa	Y: other exotic forage spp.	T; Ag	P	S	N
Cenchrus echinatus	N & S America	Y: native *C. caliculatus*	T; B	P	S	Y
Pennisetum purpureum	Tropical Africa	N	T; Ag	P	S	Y
Phyllostachys bissetii	China	N	T; Ag	P	S?	N
Sorghum bicolor ssp. *drummondii*	Africa	N	T; Ag	A	S	N
Sapindaceae						
Cardiospermum grandiflorum	S Mexico to Brazil	N	T; B	P	S	N

Weed family and species	Native range of weed	Highly valued congeners (Y/N)	Habitat	Life cycle	Rep	WeedNR
Solanaceae						
Cestrum nocturnum	West Indies	N	T; E	P	S	N
Urticaceae						
Cecropia pachystachya	Brazil, Paraguay Argentina	N	T; E	P	S	N
Verbenaceae						
Stachytarpheta urticifolia	Tropical & subtropical Americas	N	T; Ag	P	S	Y
Zingerberaceae						
Hedychium coronarium	Himalayas (Nepal & India)	N (other exotic ornamentals)	T; E	P	S	N

[1]*S. gaudichaudii* native to French Polynesia; [2]*S. fallax* native elsewhere in Polynesia; [a] = plant family not represented in the native Cook Island flora

Appendix 6 – Cook Islands weed biocontrol field trip report

The three islands (Aitutaki, Aitu and Rarotonga) of the 15 islands that make up the Cook Islands were visited by Landcare Research staff (Quentin Paynter and Sarah Dodd) and local officials (Dr Maja Poeschko, Gerald McCormack and Fred Charlie) to look for weed invasions. A total of 34 invasive weeds were observed, identified and documented (Table 1).

Trip Itinerary

Aitutaki

Aitutaki is an "almost atoll". It has a maximum elevation of approximately 123 metres with the hill known as Maunga Pu close to its northernmost point. The land area of the atoll is 18.05 km², of which the main island (Arutanga) occupies 16.8 km².

The barrier reef that forms the basis of Aitutaki is roughly the shape of an equilateral triangle with sides 12 kilometres in length. The southern edge of the triangle is almost totally below the surface of the ocean, and the eastern side is composed of a string of islets (motus). Two of Aitutaki's 15 islets are volcanic and the remaining 13 are made of coral.

The northern end of Arutanga consists of fertile volcanic soil, ideal for growing tropical fruits and vegetables.

Weds 4th July: Sarah Dodd and Maja Poeschko arrived in Aitutaki 4.20pm where they were met at the airport by Teariki George (Teking boat charters) and Tiraa Arere (Acting Island Secretary). Plans to visit the outer lagoon islets (motus) the following day were made and Sarah and Maja were taken to their accommodation at Rhino's. Quentin Paynter was already at Rhinos having arrived a day earlier.

Thurs 5th July: Sarah Dodd, Quentin Paynter, Maja Poeschko and an Aitutaki MAF officer (Fred Charlie) were picked up from Rhinos at 8.30am by Teking boat charters and taken to the wharf. The boat set off for the first islet at around 9am. Five of the 15 islets were visited and these included Rapota and Moturakau, which are the only 2 volcanic islets in the lagoon. These islets were locations for 'tribes' in the survivor TV series. Rapota was also the site of an old leper colony and consequently has a number of edible plants established (e.g. mangoes, papaya). We also visited Motukitiu (a protected reserve), Tapuaetai, (one foot island, cleared and regular tourist traffic) and Akaiami (Gina's beach lodge and old sea plane wharf). The lagoon shoreline of a sixth islet (Tekopuna) was also inspected from the boat. Later in the afternoon, Fred Charlie took Sarah, Quentin and Maja on a road tour of the main island (Arutanga) highlighting the main horticultural weed problems the island faces. The most frequently found weed on both the main island and the smaller islets, was the vine *Merremia peltata*.

Much to the surprise of the locals, Merremia peltata (morning glory) had taken over one end of the protected reserve islet Motukitiu where foot traffic is rare due to the fact that a permit is required to land on the island. This picture shows Merremia vine smothering the native vegetation and climbing up the coconut trees.

In the interest of minimising our impact, Sarah inspects One Foot Island from the shoreline.

Quentin and Maja having lunch on One Foot Island.

Fred Charlie examining an abandoned citrus orchard on Arutanga (the main island) over grown with Merremia and Mikania vines

An abandoned field behind the truck is overgrown with Tithonia diversifolia (Tree marigold) which has distinctive yellow flowers. Blue rats tail (Stachytarpheta cayennensis) can be seen as a ground cover in the foreground with its distinctive purple flowers.

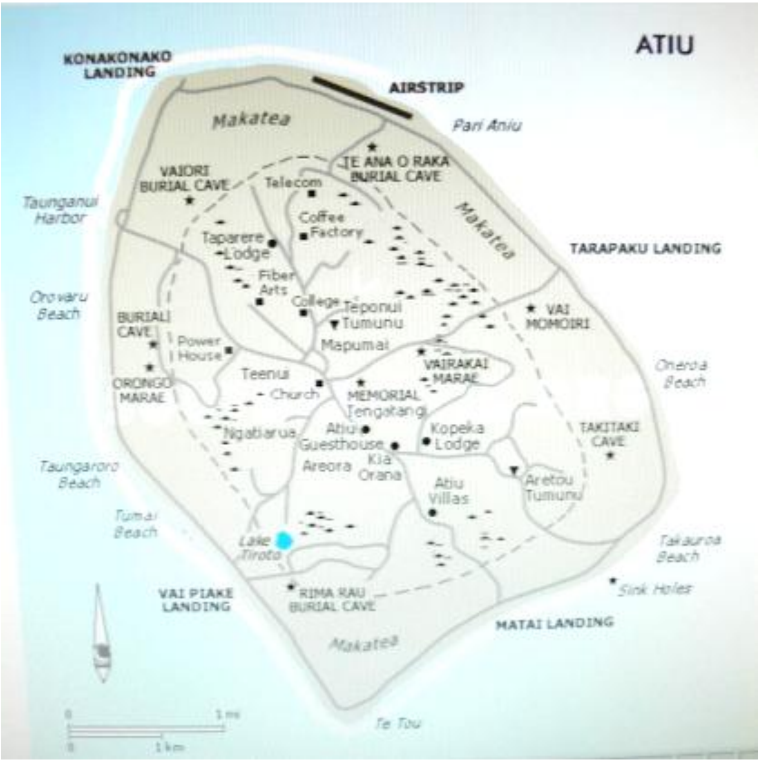
This picture shows a typical field cleared of Merremia vine for cropping. Land and vegetation adjacent to the crop is still smothered by the vine.

There was a high incidence of the Merremia vine present in the inner valleys of the main island.

Giant sensitive weed (*Mimosa invisa*) showing damage from the introduced sap feeding psyllid biocontrol agent (*Heteropsylla spinulosa*). Thanks to the biocontrol agent, this weed is now considered 'controlled' in the Cook Islands.

Aitu

Aitu is the third largest and third most visited island of the Cook Islands and is known for its natural forest and native bird life. It is 11 million years old and is still rising from the sea at a rate of 0.2 mm per year. Unlike most South Pacific islands the approx. 400 inhabitants of Aitu live in five villages in the centre of the island rather than along the coast. Gardening is only possible in the red volcanic soil of the interior. Surrounding this is an infertile coral ring known as the makatea where pigs are kept in pens. Taro is grown in swamps around the inner edge of the makatea where the volcanic soil meets the limestone.



Fri 6th July: Quentin and Sarah continued on to Aitu, whilst Maja returned to Rarotonga. The Landcare Research staff arrived in Aitu at 11 am where they were met at the airstrip by Gerald McCormack and Roger Malcolm (Aitu Lodges). Roger took them on a brief tour across the island on the way to the accommodation situated on the opposite side of the island from the airstrip. After checking in and dropping gear off at the lodges, Gerald took Sarah and Quentin on a tour of the island weeds and makatea forest. Similar to Aitutaki, the most commonly seen weed in the inner more fertile soils of Aitu was the Merremia vine, followed closely by the red passionfruit vine (*Passiflora rubra*).

Much of the inner island of Aitu is now covered by Acacia trees such as seen in this photo, which were introduced in the 1990's as a source of biofuel.

Stunted Lantana shrubs were seen on the island with obvious damage from the introduced biocontrol agent (*Uroplata girardi*). This plant is considered 'controlled' since the introduction of the agent.

Gerald McCormack and Quentin Paynter looking at a typical Merremia vine invasions on the edge of a coffee plantation field.

Red passionfruit vine (*Passiflora rubra*) was commonly found in both the inner island and the native makatea forest of the outer island.

Sat 7th: Sarah, Quentin and Gerald returned to Rarotonga to prepare for workshop.

Mon 9th workshop prep

Tues 10th Held workshop with local stakeholders at the Ministry of Agriculture premises.

Wed 11th: Quentin and Sarah joined Gerald McCormack for a tour of Rarotongan weeds

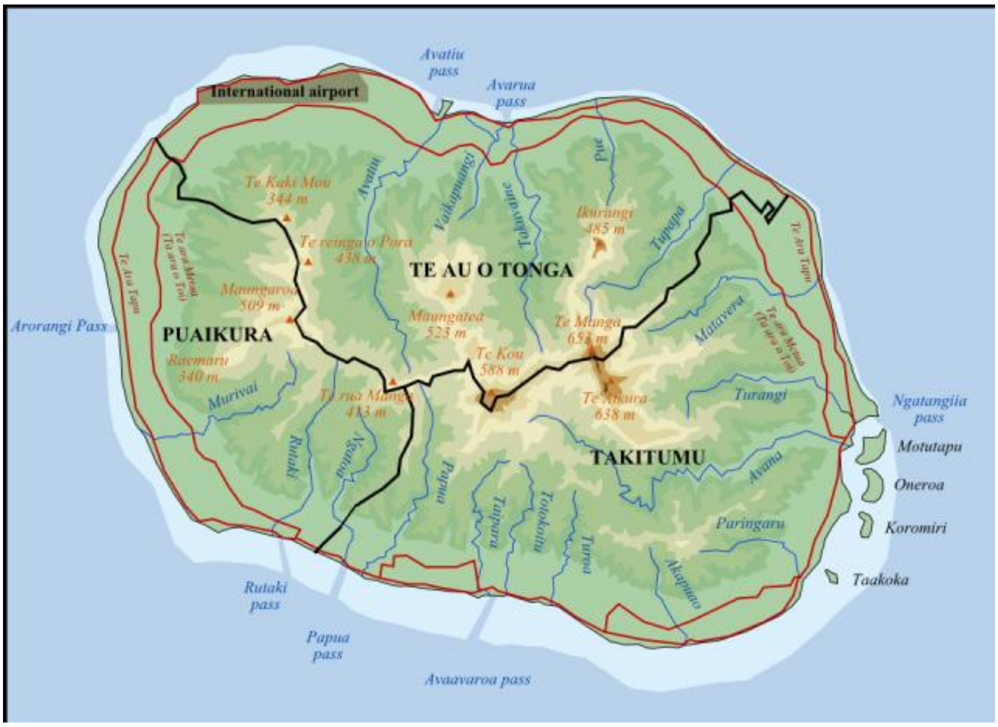
Rarotonga

Rarotonga is the most populous island of the Cook Islands. The island of Rarotonga stands over 14,750 feet (4,500 meters) above the ocean floor. It is 32 km (20 miles) in circumference and has an area of 67.19 km² (26 square miles). At a depth of 4,000 m (13,000 ft) the volcano is nearly 31 miles (50 km) in diameter. Te Manga, at 658 m (2,140 ft) above sea level, is the highest peak on the island.

The island is surrounded by a lagoon, which often extends more than a hundred metres to the reef, then slopes steeply to deep water. Agricultural terraces, flats, and swamps surround the central mountain area.

Along the southeast coast off Muri Beach are four small coral islets within a few hundred metres of the shore and within the fringing coral reef.

The interior of the island is dominated by eroded volcanic peaks cloaked in dense vegetation. Paved and unpaved roads allow access to valleys but the interior of the island remains largely unpopulated due to forbidding terrain and lack of infrastructure. A large tract of land has been set aside in the south east as the Takitumu Conservation Area to protect native birds and plants, especially the endangered kakerori, the Rarotonga Flycatcher.



As with the two other islands, Merremia vine and red passionfruit vine were commonly found smoothing vegetation in the lowland valleys of Rarotonga. In addition to these vines and unique to Rarotonga was the presence of grand balloon vine (*Cardiospermum grandiflorum*). Another common invasive weed seen in the valleys and advancing up the mountains was the African Tulip tree with its distinctive red flowers.

Grand balloon vine invading the crown of a coconut tree on the edge of an agricultural field

An interesting twist, here we see an African tulip tree which is being smothered by a co-invasion of Merremia and Grand balloon vines.

Typical inner valleys of Rarotonga with the red flowered African Tulip trees, and smothering Grand balloon vine, Merremia and red passionfruit vines.

Thurs 12th: Trip administration and planning of Maja's trip to Landcare Research in NZ

Table 1 Invasive weeds seen on trip

Scientific name	Common name	found on which of the three islands visited
Acacia spp.	-	Atiu, Aitutaki, Rarotonga
Adenanthera pavonina	Red bead tree	Atiu, Aitutaki, Rarotonga
Azolla filiculoides	Azolla water fern	Atiu, Rarotonga
Bidens pilosa	Beggar's tick	Atiu, Aitutaki, Rarotonga
Brachiaria mutica	Para grass	Aitutaki, Rarotonga
Calopogonium mucunoides	Calopo	Atiu, Aitutaki, Rarotonga
Canna indica	Indian shot	Rarotonga
Cardiospermum grandiflorum	Grand balloon vine	Rarotonga
Centrosema pubescens	Centro butterfly-pea	Atiu, Aitutaki, Rarotonga
Cecropia pachystachya	Cercropia	Rarotonga
Cestrum nocturnum	Night Blooming Cestrum	Rarotonga
Cinnamomum verum	Cinnamon tree	Rarotonga
Coix lacryma-jobi	Job's tears	Atiu, Rarotonga
Commelina diffusa	Commelina	Atiu, Aitutaki, Rarotonga
Cuscuta campestris	Dodder	Rarotonga
Eichhornia crassipes	Water hyacinth	
Falcataria moluccana	Albizia	Atiu, Aitutaki, Rarotonga
Hedychium coronarium	White ginger	Atiu, Aitutaki, Rarotonga
Hyptis pectinata	Comb hyptis	Atiu, Aitutaki, Rarotonga
Lantana camara	Lantana	Atiu, Aitutaki, Rarotonga
Leucaena leucocephala	Leucaena	Atiu, Aitutaki, Rarotonga
Ludwigia octovalvis	Willow primrose	Atiu, Rarotonga
Merremia peltata	Peltate morning glory	Atiu, Aitutaki, Rarotonga
Merremia umbellata	Hog vine/yellow wood rose	Aitutaki
Mikania micrantha	Mile-a-minute weed	Atiu, Aitutaki, Rarotonga
Mimosa invisa	Giant sensitive weed	Aitutaki
Mimosa pudica	Sensitive weed	Atiu, Aitutaki, Rarotonga
Momordica charantia	Balsam pear	Atiu, Aitutaki, Rarotonga
Ocimum gratissimum	Wild bazil	Atiu, Aitutaki, Rarotonga
Passiflora maliformis	Hard passionfruit	Atiu, Rarotonga
Passiflora rubra	Red passionfruit	Atiu, Aitutaki, Rarotonga
Pennisetum purpureum	Elephant grass	Atiu, Rarotonga
Pentas lanceolata	Pentas	Atiu, Rarotonga
Pueraria phaseoloides	Tropical Kudzu	Atiu, Rarotonga
Sida acuta	Short flower Sida	Rarotonga
Sorghum bicolor subsp. drummondii	Sudan grass	Atiu, Aitutaki, Rarotonga
Spathodea campanulata	African Tulip tree	Atiu, Aitutaki, Rarotonga
Stachytarpheta cayennensis	Blue rats tail	Atiu, Aitutaki, Rarotonga
Syzygium cumini	Jambolan	Atiu, Aitutaki, Rarotonga
Tithonia diversifolia	Tree marigold	Atiu, Aitutaki, Rarotonga

Appendix 7 – Newspaper articles and TV interview

Te reo o te KUKI AIRANI

Cook Islands NEWS

AS SOLID AS THE ISLANDS WE STAND FOR $2

Tuesday, July 10, 2012

Group tackles weed problem

THE ISSUE of biologically controlling common weeds will be discussed at a workshop today involving a group of plant control experts.

Plant pathologist Sarah Dodd and weed ecologist Quentin Paynter of Landcare Research New Zealand have teamed up with entomologist Dr Maja Poeschko and Natural Heritage Trust director Gerald McCormarck and are presenting their findings of a scoping survey aimed at controlling weeds biologically.

The workshop is being attended by a number of government agencies, including representatives from the Ministry of Agriculture and the National Environment Service.

The group are hoping to conduct a five-year programme at the end of the workshop aimed at controlling specific weeds biologically if funding is available.

Paynter will also present a 'ranking' of weeds determined by three factors – the cost of introducing biological control to the weed, the usefulness of the control upon the weed and whether the weed is enough of a pest to warrant such control.

The survey has been funded purely by the New Zealand Aid Programme.

■ Matiu Workman

Entomologist Dr Maja Peoschko (left), weed ecologist Quentin Paynter (centre) and plant pathologist Sarah Dodd (right) are presenting their findings at a weed control workshop today.

Follow up article on 8th August 2012

Weeds list highlights biological control

A LIST OF weeds needing biological control generated by local agricultural professionals will be updated when results of a feasibility study from two New Zealand experts is released.

A workshop last month examined the importance of controlling weeds biologically through the introduction of weed-specific bugs or bacteria to reduce the presence of overgrowing fauna.

Landcare Research's Dr Sarah Dodd presented the scoping study and shared how weeds were to be biologically controlled in six steps.

Fellow expert Quentin Paynter then presented on the study and provided the results of a rankings table indicating which weeds were needed to be biologically controlled from the local professionals' perspectives.

The 12 agriculture professionals – headed by agriculture secretary Dr Matairangi Purea – were asked to rank weeds in order of importance.

Using a points system that saw people choose hot (10 points), warm (five points) or cold (one point) for each weed, nine weeds were found to be first equal after all 12 members gave them the maximum of 10 points.

The weeds were giant reed (arundo donax), grand balloon vine (cardiospernum grandiflorum), burr grass (cenchrus echinatus), peltate morning glory (merremia peltata), mile a minute (mikania micrantha), samoan sword-fern (nephrolepis saligna), red passionfruit (passiflora rubra), elephant grass (pennisteum purpureum), and the African tulip tree (spathodea campanulata).

Dr Poeschko said while the list highlighted a number of weeds local professionals listed as a high priority, some would be easier to control than others.

"Nothing has been done about the [peltate] morning glory worldwide, so it would be very expensive to find out the best way of biological control," Dr Poeschko said.

In comparison, the 35th-ranked broom weed (sida rhombifolia), while not a high priority weed, had been superbly controlled biologically in Fiji with the import of a bug that eats the weed, which meant the cost of biocontrolling that specific weed would be cheap.

The weeds were identified in a six-page report by Dodd and Paynter. It also discusses the next step into which weeds are financially feasible to control.

"The updated biocontrol feasibility and cost scores will be combined with the weed importance scores that were decided on at the meeting, to identify the best targets for biocontrol in the Cook Islands," an except of the report read.

The updated list will be released at the end of October before a board of professionals will decide which weeds will be prioritised for biocontrol.

The project is funded by the New Zealand Aid Programme.

Dr Poeschko will be travelling to Auckland and Christchurch as part of an attached training. While in the country she will be exploring laboratories and facilities that cater to the controlling of weeds.

■ ***Matiu Workman***

Cook Islands TV interview

Biological control of weeds in the Cook Islands project can be viewed on YouTube at:

http://youtu.be/v1F8Bw2z3CE

Appendix 8 – Itinerary of Maja Poeschko's visit to New Zealand and training in risk analysis

Sunday 23rd - Lincoln

2.00pm	Lynley Hayes collects Maja from airport and drops off at Lincoln motel
5.30pm	Welcome meal at Lynley's house for Maja with other Lincoln staff

Monday 24th - Lincoln

9.00am	Lynley – introduction to Landcare Research, our people, facilities and research programmes
9.30am	Hugh Gourlay – containment, host-testing and mass rearing of agents
1.00pm	Ines Shonberger and Bill Sykes – herbarium tour including the Pacific and Cook Islands collection, and progress towards a flora of the Cook Islands.

Tuesday 25th - Lincoln

9.00am	Ronny Groenteman – invasive invertebrates including glassy-winged sharpshooter biocontrol
10.30am	Lynley and Simon Fowler - monitoring and assessment techniques
1.00pm	Lindsay Smith – gregarines and line rearing
2.00pm	Local field trip
3.30pm	Gary Houliston and Dagmar Goeke – molecular capability

Wednesday 26th - Auckland

1.00pm	Maja catches flight from CHCH to AKL
1.50pm	Sarah Dodd picks up Maja from airport and drops her off at Novotel Ellerslie

Thursday 27th - Auckland

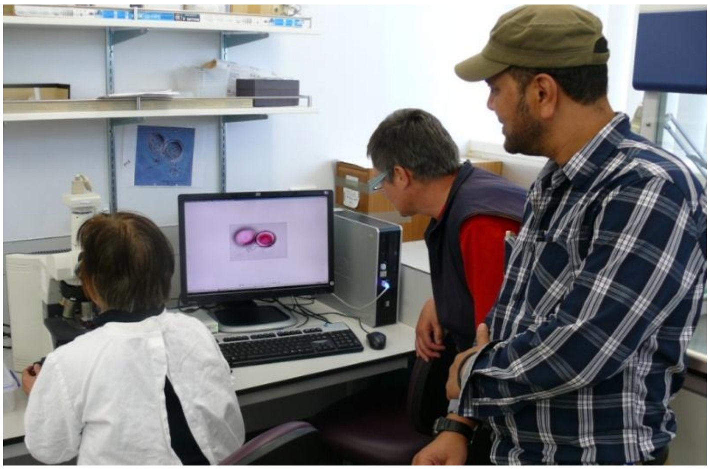
9.00 am	Sarah introduction
10.00am	Sarah/Stan Bellgard – tour of fungal collection, plant path labs and new Containment Facility
1.30pm	Quentin Paynter –tour of insect collection and labs
3pm	Quentin and Shaun Forgie talk about dung beetles and other invertebrate research (e.g. glassy winged sharp shooter)
7.00pm	Dinner out with Auckland group

Friday 28th - Auckland

9.00am - 12.00pm	Sarah and Quentin, go through and finalise report with Maja
1.00-5.00pm	Field trips – Chris Winks/Stan/Sarah/Quent weed biocontrol sites/Kauri dieback/bioherbicide trials

Dr Maja Poeshko (Cook Islands Ministry of Agriculture) and Dr Sarah Dodd (Landcare Research) tour the new Landcare Reseach containment facility at Auckland

Dr Maja Poeshko (Cook Islands Ministry of Agriculture) examines Tradescantia fluminensis foliage at Auckland. This weed comes from Brazil and is a current biocontrol target in New Zealand.



Maja Poeshko (centre) touring Landcare Research facilities at Auckland with Dr Stan Bellgard and Elsa Paderes

Maja Poeshko touring Landcare Research facilities at Auckland with Dr Stan Bellgard

Appendix 9 – Report on visit to Landcare Research in New Zealand by Maja Poeschko

Visit to Landcare Research in New Zealand 23rd -30th September 2012

Brief Report

Maja Poeschko, (Entomologist PhD), Ministry of Agriculture, Rarotonga, Cook Islands

During my visit in New Zealand I have had the opportunity to visit Landcare Reserach facilities in Lincoln near Christchurch and Auckland. In sessions with selected staff I was updated on successful conducted and future planned biocontrol programmes of weeds.

The containment and mass rearing facility in Lincoln has hosted many weed bio-control agent specificity testing trials. It is important to prove that potential bio-agents are not going to harm native plants but only attack the target weed. Once the host-specificity is confirmed mass rearing will commence.

One of the currently running programs is the dung beetle project. Several species which are likely to withstand the climate conditions in New Zealand have been selected. They are currently mass reared for the release in the near future. Once established they are hoped to be able to help process the large amounts of sheep and cattle dung in the country sites.

Of particular interest was the problem that occurred during the mass rearing of the tradescantia leaf beetle (Neolema ogloblini) a promising bio-agent for the control of the weed Tradescantia fluminensis. Routine testing revealed the beetles were infected with a gregarine gut parasite. Despite keeping strict hygiene and sterilizing the beetle eggs the colonies remained infested with the parasite. After years of research beetle populations free of parasites were successfully reared from isolated single female lines which were collected from the field in Brazil.

Similar effort was conducted in the past when heather beetles imported from the UK were released only after being cleared of a protozoan parasite.

This shows just how important it is to rear potential bio-agents through at least one generation under quarantined conditions. Landcare Research has the facilities and the know how to ensure only disease free specimens are released into the wild.

The development of a bio-herbicide draws also my attention. A natural occurring silver leaf fungus (Chondrostereum purpureum) is used to control stump sprouting tree species. A gel based formula of the fungus painted on cut tree stumps resulted in a successful infection. Further trials are under way to develop a marketable product. This could replace the current method of controlling willows and poplars applying glyphosate to cut stumps, or by drill-and –inject.

I had the chance to visit some of New Zealand's famous collections of organisms within Landcare Research including collections on behalf of Pacific Island Countries.

The International Collection of Micro-Organisms from Plants may not impress at the first glance but hearing hands on about the details of the collection and the work involved in the set up and maintenance was changing my mind. The use of modified plastic drinking straws as storage containers for the microorganisms in liquid nitrogen was a novelty.

At the Allan Herbarium in Christchurch I met the author of a nearly complete book about the flora of the Cook Islands. He was able to show me hibiscus plant specimens collected from the Cook Island in the early 70th. I was interested in it because I am cross breeding Hibiscus rosa sinensis on Rarotonga. This took Bill by surprise as he mentioned in his upcoming book that he never found seed pots of this hibiscus species in the Cook Islands. Together we went thru some chapters of his manuscript and made some amendments.

Details about the impressive collection at the Fungal and Plant Disease Herbarium in Auckland are currently entered into a computer database. The amount of work going into this process is overwhelming. Thousands of specimens are getting re-mounted and receive new labels with bar codes.

I was surprised to hear that on request specimens are being sent to other countries for different research purposes. The database will help to source and keep track on the specimens sent overseas.

Taxonomists working in the arthropod collection and fungorium use the reference collections to verify the species of a bio-agent prior to its release. They ensure populations and cultures are free of any other unwanted organism.

For the first time I was able to visit a specimen collection in ethanol as part of the New Zealand Arthropod Collection. Picking out random containers showed that a lot of collected insects, millipedes, centipedes etc. caught in pitfall traps are still in need to be sorted out. An estimate of 6 million specimens is stored in ethanol including immature stages of arthropods.

My visit was a great opportunity to discuss details about the occursion of the glassy winged sharpshooter Homalodisca vitripennis in the Cook Islands with the entomologist in Christchurch and Auckland. This pest is of extreme concern to New Zealand's economy as it can carry a disease that kills grape wines.

An attempt to eradicate the confined sharpshooter population using insecticides failed. The pest was brought under control by a parasitic wasp, the egg parasitoid Gnatocerus ashmeadi from Tahiti

The disease was not found in the Cook Islands.

The touring of the nearly complete new pathogen containment quarantine facility in Auckland was remarkable. The building will host the mass rearing programme of the two rust species selected for the bio-control programme of lantana in New Zealand once complete.

It may in one stage host a pathogen picked for the control of an invasive weed species in the Cook Islands.

During field trips I was shown selected sites were bio-agents for various weeds got established in the wild. The importance of a proper documentation of a weed status prior to the release of bio-agents was pointed out during the field observations. Only by comparing data before and after the release the success of a bio-agent can be analysed.

This makes the small island of Rarotonga a perfect place for a monitoring programme and assessment. The main road is a circle of only 32km. This makes roadside monitoring after the release of the bio-agent easy. Even an aerial few monitoring programme would be feasible as the local airline does provide a regular sightseeing service to affordable rates.

Once the target weed is decided on an island wide survey would be conducted. Photos would be taken from selected sites before and after the release. Computer software can be of assistance to analyse the impact of the released agent.

It was sad to see the some of the majestic kaui trees at the beach in Auckland infested with the pathogen that causes them to die. Since the discovery of the first infested trees 40 years ago a lot of research in combined efforts has been conducted to overcome the problem. Unfortunately until today there is no cure for “Kaui Dieback”. A public awareness programme is under way to prevent the further spread of the disease.

I met Landcare Research staff working on molecular biology carrying out DNA analysis. DNA-analyse are a helpful method to better understand plant and animal populations in order to achieve both, preserve or control them. It is used to trace back the origin of invasive weed species to look for natural enemies in the land of origin. It was interesting to hear that not all research runs smoothly as the technicians are currently struggling to isolate DNA from woody parts of plants from Japan.

Landcare Research provides a DNA-analysis service for national and international clients for biodiversity and bio security applications.

I would like to take this opportunity to thank Lynley Hayes and her team Sarah Dodd and Quentin Painter to take up the initiative and challenge to implement a bio-control programme for weeds in the Cook Islands.

I am convinced that I could train selected staff of the Ministry of Agriculture to handle, mass rear, release and monitor bio-agents, selected and imported with the help of the experts at Landcare Research.

Appendix 10 – Budget and Expenses

Overall budget and expenses for the entire project

The final overall expenses of the project exceeded the budget by 57% as Landcare Research agreed not to charge the full overhead costs to the project. If the overhead component is not taken into account the actual costs were approximately $1030 more than was estimated in the budget and these were all related to the travelling component.

Outputs to be produced	**Total indicative cost of Outputs NZD**	**Actual costs NZD**
Identify and Prioritise weeds Effort and cost analysis Risk analysis, train the Cook Islands Ministry of Agriculture staff Identify key personnel and systems, foster relationships and develop importation protocols Final report	27,000.00 (Fees at $100/hour)	48,600.00 (Costs at $180/hr)
Travel Expenses and Per diems	14,158.00	15,187.00
Less Contribution provided by Partner Agency	1,474.00	1,474.00
MAXIMUM PRICE	**39,684.00**[a]	**62,313.00**

[a]The original contract was for a maximum price of $35,000. An additional $4,684 was requested and contracted after it was decided a more comprehensive visit of the Cook Islands was necessary to get a better understanding of the challenges to be faced when implementing a weed biocontrol programme on the smaller islands, as well as the main island of Rarotonga. The extra funds covered the expenses incurred by visiting the additional islands of Aitutaki and Atiu.

	Expenses and Per Diems		
Item	Item breakdown	Total Budget NZD	Actual expenditure NZD
Per Diems	3 people x 2 days Aitutaki = $161 per person/day	$966.00	($410 accommodation + food estimate $420) $830.00
	4 people x 1 day Atiu = $136 per person/day	$544.00	($360 accommodation + 118.60 food) $478.60
	2 people x 8 days Rarotonga = $251 per person/day	$4016.00	($3480 accommodation + estimated $1600 food) $5080
	Subtotal	$5,526.00	$6,388.60
Airfares	Airfares for 2 people NZ to Rarotonga return	$1632.00	$2031.24
	Gerald McCormick Airfares Atiu to Rarotonga return(Gerald is based in Atiu	$396.00	$235.00
	Quentin Paynter, Sarah Dodd Aitutaki – Atiu – Rarotonga	$900.00	$900.00
	Maja Poeschko Airfares Rarotonga to Auckland & Christchurch return (to visit and work in Land Care Research facilities)	$1136.00	$1280.64
	Maja Poeschko Rarotonga – Aitutaki return	$528.00	$490.00
	Subtotal	$4,592.00	$4,936.88
Car hire	1 day Atiu	$100.00	$0
	2 days Aitutaki	$200.00	$0
	7 days in Rarotonga incl. insurance, fuel, driver's license	$750.00	$403.67 $72.47
	NZ taxi – to airport SD		$20.00
	NZ airport parking QP		$67.48
	NZ taxi's Maja		$117.39
	Subtotal	$1,050.00	$681.01
Boat charter		$750.00	$850.00
Workshop costs	Lunch 14 people x $30 per person	$420.00	$468.92
	Miscellaneous estimate (ie computers, powerpoint)	$80.00	$24.00 (interview DVD)
	Subtotal	$500.00	$492.92
Miscellaneous costs	Airport transfers and additional miscellaneous costs e.g. internet		($40 Aitutaki +$18 Aitu + $60 Rarotonga) $118.00 (3x $55 Rarotonga airport tax)

	Expenses and Per Diems		
Item	Item breakdown	Total Budget NZD	Actual expenditure NZD
			$165.00
	Subtotal	$250.00	$283.00
Insurance	Travel insurance	$340.00	LCR corp. rate $2.70 pp per day = (2x 10d + 9d) $78.30
Accommodation costs	NZ accommodation allowance for Maja Poeschko	$750.00	($676 + $435) $1111.00
Meal Allowance	NZ meal allowance for Maja Poeschko	$400.00	$350.00
Other miscellaneous	Cash withdrawal fee (a lot of places only accepted cash – no receipt)		(2x 4.50 + 1x 6.50) $15.50
Totals		$14,158.00	$15,187.21