Cost–Benefit Analysis of Managing the *Papuana uninodis* (Coleoptera: Scarabaeidae) Taro Beetle in Fiji

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J. Econ. Entomol. 107(5): 1866–1877 (2014); DOI: http://dx.doi.org/10.1603/EC14212

ABSTRACT Taro (*Colocasia esculenta* (L.) Schott) plays a prominent role in the economies and cultures of Pacific Island countries such as Fiji. Unfortunately, taro is highly susceptible to invasion from taro beetles, which burrow into the corms and weaken the plants, rendering them unmarkable and prone to rot. *Papuana uninodis* Prell, an invasive alien species that is native to the Solomon Islands and Vanuatu, was first reported on Viti Levu (Fiji's largest island) in 1984. Since that time, taro production on Viti Levu has fallen substantially. In this paper, we employ data from surveys of households and communities to document the impacts of *P. uninodis* on Viti Levu. We then identify three management approaches—chemical controls, cultural controls, and switching from taro to another staple crop—and conduct a cost–benefit analysis of each. We find strong arguments for pursuing chemical control, which derives a net present value of *monetised* benefits of about FJ$139,500 per hectare over 50 yr, or >FJ$21 for each FJ$1 spent. Still, any of the three management options is more efficient than no management, even without any attempt to quantify the benefits to biodiversity or forest protection, underscoring the value of actively managing this invasive alien species.

KEY WORDS taro beetle, invasive alien species, cost–benefit analysis, nonmarket valuation

Taro (*Colocasia esculenta* (L.) Schott) is a perennial aroid with a starchy, edible corm and large, edible leaves that grows in areas of high rainfall. Rich in vitamins (particularly vitamin B6 and vitamin E) and trace minerals (particularly manganese, phosphorus, and potasium), taro is believed to be among the earliest cultivated plants (Lebot and Aradhya 1991) and was a prominent staple of the Greek and Roman empires (Leach 1982). Originating in India and Bangladesh, taro spread to the Mediterranean via East Africa and Egypt, eventually reaching West Africa and the Caribbean. It also spread eastward throughout Southeast and East Asia (Plucknett 1976, Kuruvilla and Singh 1981) and into the Pacific, from Papua New Guinea to Hawai'i.

Although the precise pathway and date of its arrival is the subject of debate (e.g., Whistler 1991, Hather 1992, Matthews 2003, Horrocks and Bedford 2005), taro has been present in the Pacific for centuries. While Nigeria is the world's largest producer, taro represents a significantly larger share of the diet in Melanesia and Polynesia (Onwueme 1999). Following the significant migration of Samoans, Fijians, Tongans, and other Pacific islanders in recent decades, taro has also become a significant export crop, as taro consumption features prominently in group identity (Spickard et al. 2002). For example, the value of the 10,000 tons of Fijian taro exports to Australia and New Zealand in 2009—which combined have more ethnic Tongans than Tonga and nearly as many ethnic Samoans as Samoa—was estimated to be FJ$20 million[3] (McGregor et al. 2011).[4]

Taro is of cultural significance in the Pacific Island region. It is also used widely in traditional medicine, particularly for treating stomach disorders (e.g., Cambie and Ash 1994). Indeed, so important is taro to Pacific identity that taro plants feature on the coins of Samoa and Tonga and is celebrated annually on Taro Day in Fiji.

Unfortunately, taro in the Pacific is under threat from taro beetles, *Papuana* and *Eucopidocaulus* species, with eight of the 19 known species recorded as major pests (Thistleton 1984, Waterhouse and Norris 1987). Adult taro beetles burrow into the corms of taro and other aroids, leaving tunnels that degrade the marketable yield of the corm by up to 67% (Lal 2008) and that make the plant susceptible to fungal infection. Newly planted taro is susceptible to death while vigour and growth are retarded in established plants (Autar and Singh 1988). While taro beetles have been shown to attack other crops, including sweet potato, yams, tannia, sugarcane, banana, coconut, tea, cocoa,

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[3] At the time of writing, FJ$1 = US$0.53.

[4] Notably, taro exports in Fiji took off only after the invasive pathogen taro leaf blight (*Phytophthora colocasiae*) decimated Samoa's taro crop beginning in 1993 (Hunter et al. 1998).

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and coffee, the value of damage is relatively low (Lal 2008), although Onwueme (1999) observes that such attacks potentially set back plant growth.

Fields may not be replanted in taro after infestation. Hence, new forest areas is cleared for taro production, causing considerable hardship to taro farmers who must not only clear new land but also travel farther from home to tend their fields. Interest in taro farming has thus declined, and substitute crops have replaced taro as a staple in diets in several countries in which taro beetles are present (e.g., Bourke 2012).[5] In addition to this social hardship, clearing forests for new taro plots also contributes to deforestation and reduction of natural habitats, potentially reducing biodiversity.

Global trade and international travel have allowed some taro beetle species to establish in places that they could not have reached on their own. One example is *Papuana uninodis* Prell, which is native to the Solomon Islands and Vanuatu but which was first reported in Fiji in 1984 (Biosecurity Authority of Fiji 2014). *P. uninodis* has become established on Viti Levu, Fiji's largest island, extending from Sigatoka eastward to Tailevu and northward to Ra Province. It has recently also been found in Ovalau and Gau (Biosecurity Authority of Fiji 2014). Yields of marketable taro from infested fields fell precipitously, causing production of export-grade taro to shift to Taveuni (Lal 2008).[6]

P. uninodis is an invasive alien species (IAS) that seriously threatens Fiji's agriculture-based economy, environment, ecology, and cultural wellbeing. Nevertheless, scientific evidence demonstrates that many IAS may be managed and that their impacts may be reduced through prevention, eliminated through eradication, or reduced through control (e.g., Veitch et al. 2011). Quantifying the threat posed by *P. uninodis*, documenting practices for managing the species, and understanding the costs and benefits of various management options in Fiji may thus help decision makers to make more informed policies for managing this species and to set priorities for managing *P. uninodis* relative to other IAS.

Combining primary-source data collected via matched household and community surveys in Viti Levu, Fiji, with scientific reviews of the biology and ecology of *P. uninodis,* we find that many farmers have stopped growing crops in severely affected areas while others have switched production to alternative crops. We further find that Fijian farmers consider taro beetles to be extremely problematic and that the average household would volunteer 11 h per week to fully manage this IAS.

We also conduct a cost–benefit analysis (CBA) of three distinct management interventions for taro beetle in Fiji, including switching to cassava, implementing "cultural control" such as crop rotation and other best practices in crop management, and increasing insecticide use. We find that insecticides are both effective (as measured by the total net present value of the intervention) and efficient (as measured by the ratio of benefits to costs), making this a clear strategy for managing *P. uninodis.* Cultural control is somewhat less effective than insecticides but entails a significantly higher cost, making this management option less efficient. Switching crops yields the lowest economic gain but is nevertheless strictly more efficient than the baseline of no management at all.

The remainder of this article is organized as follows: "Biology of *P. uninodis*" describes the biology of *P. uninodis;* Sections "Survey Research Methods" and "Survey Results" describe the survey research methods and results, respectively. Sections "Cost-Benefit Analysis Methodology" and "Cost-Benefit Analysis Results" present our approach to CBA and the results, respectively. A sensitivity analysis is undertaken in "Sensitivity Analysis," and "Summary" concludes.

Biology of *P. uninodis*

P. uninodis eggs are laid in decaying organic matter, where they are incubated for two weeks before hatching. Larvae molt 3–5 times over the following 19–22 wk to eventually become 35–40 mm long. At this stage, larvae burrow chambers into the soil around the nesting area, in which they pupate for three weeks before emerging as adult beetles. Adult *P. uninodis* taro beetles are black, shiny, horned, and 15–20 mm in length (Macfarlane 1987, Autar and Singh 1988).

The elytron hardens in 1–2 wk, after which taro beetles glide to taro fields, where they feed and mate. Adult females stay in taro fields for 4–6 wk before departing to lay ≈140 eggs over the next 27 wk, half of which survive. Adults live for up to 22 mo in total (Lal 2008).

As with other biological invasions, total population is assumed to follow a logistical growth function (Cook et al. 2010). Daigneault and Brown (2013) refer to the population dynamics described above to calculate that carrying capacity is reached ≈20 yr after establishment and that the population growth parameter is ≈0.5. Thus, the population growth curve may be written:

$$N_{t+1} = N_t + 0.5N_t\left(1 - \frac{N_t}{100}\right) \qquad [1]$$

where N is the population of *P. uninodis* (as a percentage of carrying capacity) and t is the time period measured in years.

Several biocontrols for taro beetle have been proposed and tested. For example, the *Orytes* virus was found to have high adult-to-adult transmission rates, but the persistence of the virus was found to be very low (Zelazny et al. 1988). The nematode *Steinernema glasseri* was shown to be effective against larvae (but not adults); however, nematode trials have been aban-

[5] Declining soil fertility and the threat of taro leaf blight may also dissuade farmers from planting taro.

[6] Taro produced on Taveuni is the pink *Tausala ni Samoa* (*Taro niue*) cultivar favored by the Samoan diaspora. After years of steady growth, exports from Taveuni have declined in recent years, in the face of declining land productivity, increasing costs, and market access issues. We thank an anonymous referee for bringing this to our attention.

doned due to the difficulty of introducing them into beetle breeding areas (Theunis et al. 1997). The fungus *Metarhizium anisopliae* is a well-known pathogen of beetles that has been used effectively in pasture and sugarcane (Milner 1992, Rath 1992). Studies have shown that *M. anisopliae* can remain infective in soil for over 1 yr and can grow saprophytically (Milner and Lutton 1976), making it an attractive biocontrol candidate. However, Lal (2008) reports that *M. anisopliae* is less effective than some insecticides and that combining *M. anisopliae* with insecticide is less effective than using insecticides alone.

Lal (2008) undertakes extensive field testing in Fiji and Papua New Guinea to demonstrate that two insecticides, imidacloprid[7] and bifenthrin,[8] may be used to substantially limit damage to taro corms by attacking the central nervous systems of insects with which it comes into contact; their trials show that as much as 95% of the taro treated under optimal conditions is marketable, i.e., saleable in the domestic market if not the export market, which does not tolerate any damage. The Biosecurity Authority of Fiji (2014) also recommends the use of imidacloprid, which is marketed in Fiji as Confidor.

Cultural control is another widely recognized method by which damage from taro beetles may be restricted (Lebot 2009 provides a comprehensive discussion). Practices advocated by Biosecurity Authority of Fiji (2014) include rotating crops, using clean planting material, and destroying potential breeding sites near taro fields. However, Lal (2008) found that neither these practices nor manipulating planting time and depth, flooding taro fields, burning debris, nor applying wood ash was especially effective at reducing damage to taro corms. Indeed, Macfarlane (1987) reports that mulching increased attacks by taro beetle in the Solomon Islands.

Survey Research Methods

To better understand the social and economic impacts of IAS such as *P. uninodis* in the Pacific, we surveyed 360 households in 30 indigenous Fijian (i.e., *iTaukei*) villages on Viti Levu, Fiji's largest island. These villages were stratified by geography and randomly drawn from all villages on the eastern side of the island, where *P. uninodis* is well established per Biosecurity Authority of Fiji (2014). The distribution of sampled villages is shown in Fig. 1.

Within each of the 30 villages, households were selected at random from village rosters. Each survey was conducted directly with the head of household, and topics covered demographics; farming, fishing, wage work, and other income-generating activities; wealth and durables; education; health; and agricultural extension activities. The mean village comprises 44 households (Table 1), each with 5.2 household members. The mean household is headed by an individual with 9.5 yr of education. Household income averages FJ$22,929 and household wealth averages FJ$19,010, although both income and wealth demonstrate a high degree of variability. The average household plants 1.5 hectares in crops, spends 34.5 h per week raising its crops, and derives over 70% of its income from cropping. The average household also spends 6 h per week volunteering on behalf of the village.

Households were also queried about the economic impacts of IAS such as the cost of insecticides and the value of taro crops lost to *P. uninodis.* First, respondents were asked whether they agreed with, disagreed with, or were neutral toward a series of value statements pertaining to the taro beetle: specifically, "it is good that (or it would be good if) the taro beetle is found in this village," "people in this village are happy when they see taro beetles," "there are more negative aspects of taro beetles than positive aspects," and "I would like to have more taro beetles in this area." By asking a mix of positive and negative questions, we reduce concerns of yea-saying (i.e., the tendency to repeat answers in survey questions), a common problem in lengthy survey questionnaires (Blamey et al. 1999). Converting all questions and responses to the positive and summing the answers, we gain insight into relative strength of any stated preference for or aversion to taro beetles.

Second, respondents were asked to assume the role of Fiji's Minister for Finance and Strategic Planning, National Development, and Statistics and to reveal their spending priorities by allocating budgetary shares to a broad range of categories, including education, healthcare, public order, trade, infrastructure development, and environmental protection.[9] Respondents who allocated a portion of the mock national budget to environmental protection were further asked to prioritise controlling IAS relative to other environmental spending such as reef protection. Finally, respondents who indicated that they would allocate budgetary resources to controlling IAS were asked to prioritize control of various species, including the taro beetle. Thus, we are able to compare the perceived importance of controlling *P. uninodis* to the perceived importance of other budgetary priorities such as healthcare, education, public order, and managing other IAS.

Third, a series of questions was asked to elicit willingness to personally contribute to controlling IAS under a hypothetical scenario in which a solution was demonstrated to effectively manage their spread. In most developed countries, "willingness to pay" for environmental goods is identified via questions pertaining to tax increases; however, few rural Fijian households pay taxes while virtually all of them con-

[7] Imidalcoprid is variously marketed as Admire, Advantage, Confidor, Conguard, Gaucho, Hachikusan, Intercept, Kohinor, Mallet, Merit, Nuprid, Optrol, Premise, Prothor, Provado, Turfthor, Winner, and Xytect.

[8] Bifenthrin is marketed as Bifen IT, Bifen L/P, Bifenthrine, Brigade, Capture, FMC 54800, Maxxthor, OMS3024, Talstar, Torant, and Zipak.

[9] This exercise took the form of an interactive game in which 70 dried beans represented the approximately FJ$700 million spent on these budget categories in 2010. Participants were asked to separate the pile of beans according to spending priorities. See Daigneault et al. (2013) for additional details.

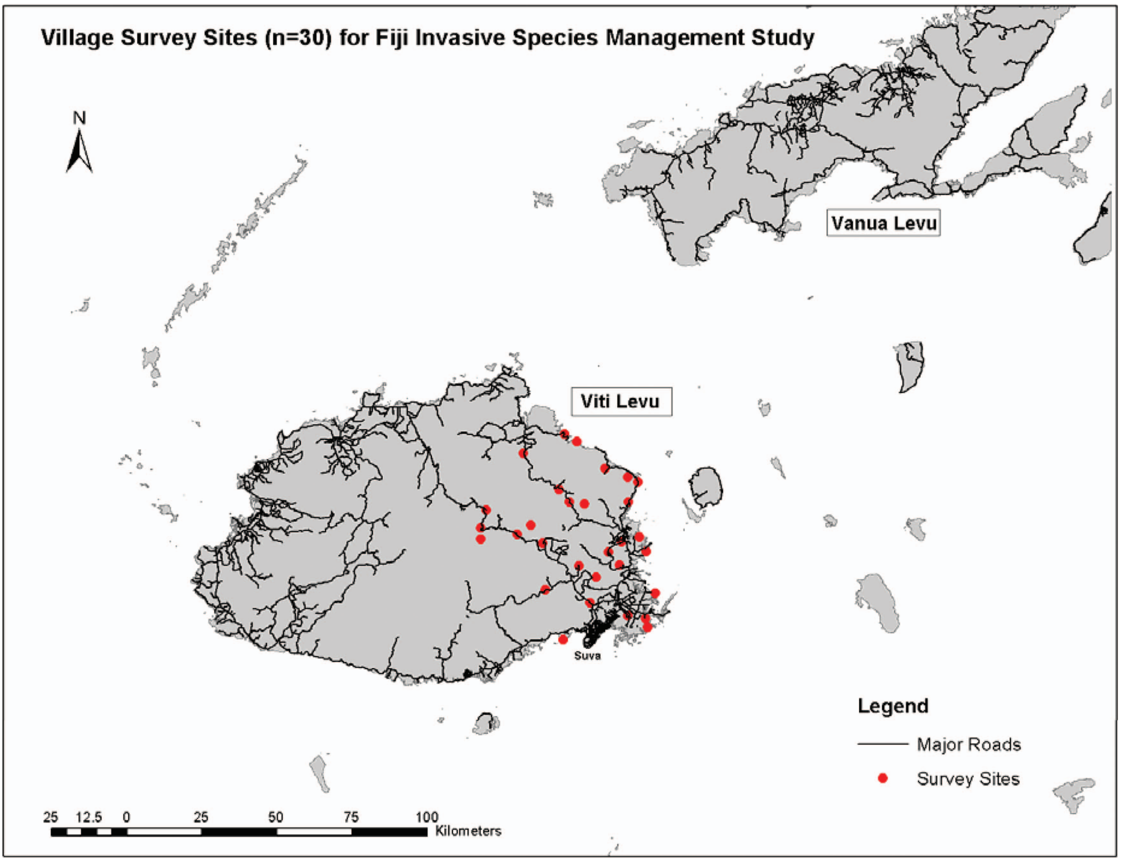

Fig. 1. Sampled villages. (Online figure in color.)

tribute labor to providing or maintaining public goods in the village. Thus, our question was posed in terms of willingness to volunteer labor time to manually control *P. uninodis.* Initial values for the number of hours was randomly assigned for each respondent via dice rolls to eliminate concerns about starting-point bias (i.e., ideas about the true value of a good inferred by asking whether a good is worth a specific amount; Boyle et al. 1985); values were systematically increased for respondents who agreed to volunteer the given level of time and were systematically reduced for those who did not, until final values were derived.

A complementary survey was conducted with focus groups consisting of residents from each of the 30 sampled villages. This survey form consisted of open-ended questions regarding the presence and current state of various IAS and, where applicable, the consequences of their presence and community practices for either encouraging or limiting their spread. Focus group participants identified *P. uninodis* from photographs and accurately described the damage that this species of taro beetle inflicts on taro crops. Notably, respondents were asked to reflect on both the negative and positive impacts of taro beetles and other species.

Table 1. Summary statistics

Variable	Unit	10th percentile	Mean	90th percentile
Households per village	Households	20	44.10	64
No. of people in the household	People	2	5.17	8
Education of household head	Years	6	9.50	12
Total household income	FJ$	1,959	22,929	60,764
Share of income derived from crops	%	13.02	71.14	100
Amt of land planted per household	Acres	0.24	1.47	3.58
Amt of land planted in taro	Acres	0.08	0.34	0.75
Time spent on cropping activities, per week	Hours	0	34.46	84
Time spent working for the village, per week	Hours	0	5.95	16

n = 360.

Table 2. Impacts of *P. uninodis* at the household level

Variable	Unit	Mean
Plant taro	percent	90.25
Share of land allocated to taro production	percent	23.4
Among growers in affected villages, experience loss due to *P. uninodis*	percent	53.4
Among growers with losses, share of taro damaged	percent	38.3
Among growers with losses, value of losses	FJ$	270.25

n = 360.

All surveys were undertaken by a team of trained staff and students at University of the South Pacific over a 4-wk period during July 2012.

Survey Results

P. uninodis is present in 83% of the villages in which the survey was conducted. In 92% of affected villages, focus group participants reported that the taro beetle had attacked taro corms, thereby significantly reducing the yield and marketability of taro. In 42% of affected villages, focus group participants reported that the taro beetle had further caused plants to be more susceptible to disease and rot. In contrast to many other IAS (e.g., *Spathodea campanulata* and *Merremia peltata*) that were discussed during village meetings, *P. uninodis* does not provide any recognized social or economic benefit to communities.

Based on the results of the household survey, 90.25% of households plant taro, which accounts for 23.4% of all cultivated land (Table 2). Within villages that are affected by *P. uninodis,* 43.9% of surveyed households that grow taro report experiencing losses from the taro beetle. Among those experiencing losses, 38.3% of the taro crop was damaged sufficiently to become unmarketable, on average, a loss valued at FJ$270.25.

Focus group participants in 44% of affected villages reported that insecticides and other chemicals were the principal strategy for controlling control taro beetle. In 20% of villages, focus group participants reported that affected taro fields were dug up and that taro plants were burned. In the remaining 36% of affected villages, villagers simply stopped growing crops in affected areas. Regardless of the primary management strategy, villagers in 32% of affected villagers stopped planting taro in favor of alternatives such as cassava. Such heterogeneity in approaches—even among neighboring villages—underscores the lack of publicly available information about the cost effectiveness of each management option; indeed, fewer than 7% of surveyed households had met with extension officers or other authorities to discuss best practice management of the taro beetle, suggesting that the dominant strategy adopted in any given village may have been ad-hoc.

Despite efforts to manage the taro beetle, *P. uninodis* is present in 83% of the surveyed villages and is increasing in 53% them (Fig. 2) according to focus group participants. However, focus group participants in a handful of surveyed villages reported that farmers had recently planted taro after several years' hiatus because the population of the taro beetle had declined. This outcome provides evidence that *P. uninodis* may be managed under certain conditions.

Respondents to the household survey were asked a series of four questions pertaining to their personal values and preferences regarding *P. uninodis.* As noted in the previous section, although some questions were asked in the negative, all questions were rewritten in the positive for the purpose of data analysis. Hence, aggregate scores ranged from −4 (extremely negative opinion) to +4 (extremely positive opinion).

More than 97% of survey respondents viewed the taro beetle unfavourably (i.e., the aggregate score was −2 or less), with 88% of survey respondents viewing the taro beetle extremely negatively (i.e., the aggregate score was −4). In contrast to other IAS about which we also asked, not a survey respondent held a favorable view of the taro beetle (Table 3).

Each survey respondent was asked to assume the role of Fiji's Minister for Finance and Strategic Planning, National Development, and Statistics to allocate budgetary shares to a broad range of spending categories. On average, respondents indicated that they would allocate 12.5% of the national budget to environmental protection and management of IAS (combined). By comparison, respondents would allocate 15.3% of the national budget to education; 12.9% to health; 10.5% to recreation, culture, and religion; 10.1% to social protection; and 9.1% to public safety. Thus, Fijian villagers consider environmental protection and control of harmful species to be a similar budgetary priority as health and more important than social protection or public safety on their own.[10]

Among the budgetary share allocated to environmental protection and control of harmful species, respondents would allocate 53.1% to controlling IAS. Of this, respondents would allocate 38% (or 2.6% of the total national budget) to controlling *P. uninodis.* In actual fact, <1% of the total budget allocated to these disparate activities was allocated to managing *all* IAS in 2012 (Fijian Government 2013).

An additional set of survey questions elicited each household's willingness to volunteer time to controlling taro beetle under the assumption that an effective, time-intensive solution to managing the species had been identified. Among those who view *P. uninodis* extremely negatively, the median household offered to volunteer 11.0 additional hours per week. The average household in surveyed villages currently spends 6 h per week volunteering on behalf of the village in

[10] Social desirability bias, in which survey respondents intentionally or unintentionally provide answers to please others, is a well recognized challenge in survey research (Paulhus 1991). Thus, while our primary interest in conducting the survey was to assess the impacts of IAS on households, the questionnaire was intentionally broad, incorporating topics such as health, education, and income as well as IAS. Because of this, we do not believe that respondents systematically overstated the relative importance of environmental protection and management of IAS.

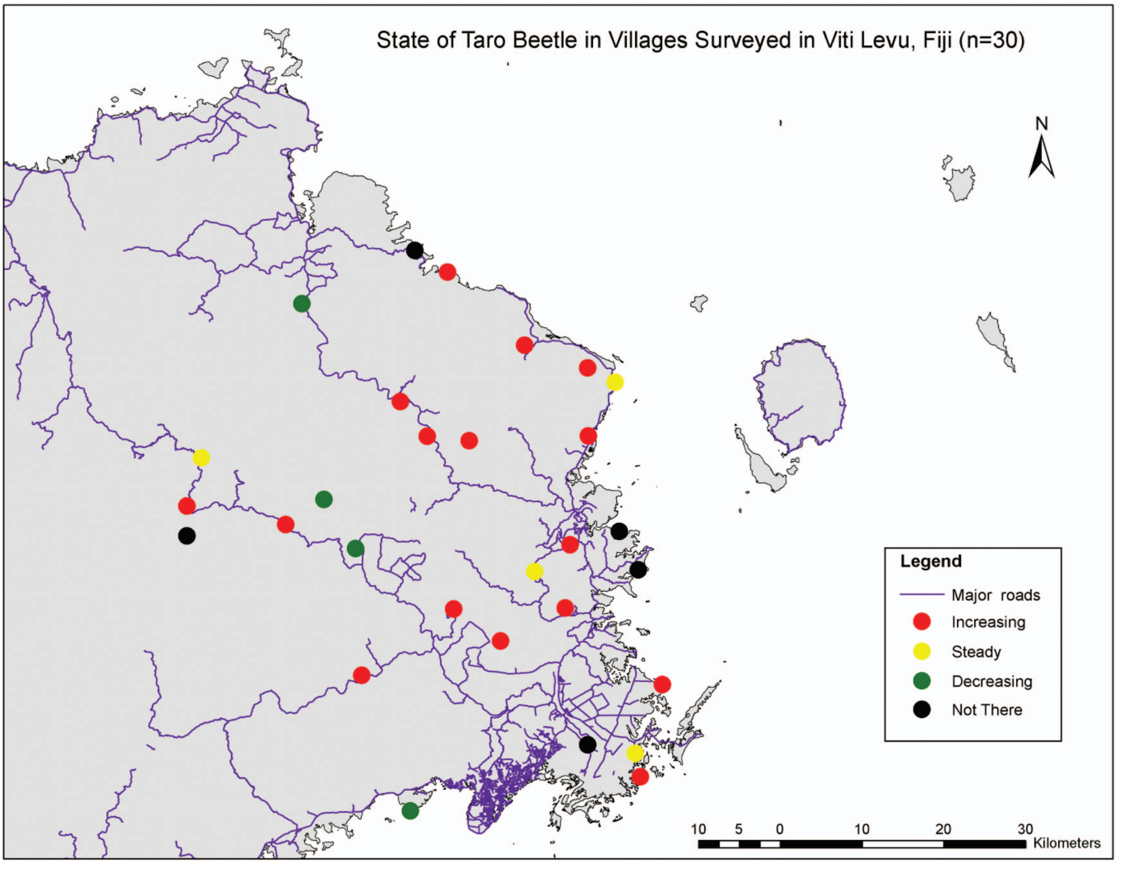

Fig. 2. State of taro beetle in sampled villages. (Online figure in color.)

activities such as maintaining public goods (e.g., roads and bus shelters) and spaces (e.g., churches and schools). That is, respondents would allocate 83% more time to controlling taro beetle than on other activities to benefit the church and community. Life in *iTaukei* villages revolves around the church and community governance (Belshaw 1964, Ryle 2005), underscoring the perceived importance of controlling the taro beetle among Fiji's rural, indigenous population.

Cost–Benefit Analysis Methodology

In undertaking CBA of various approaches to managing *P. uninodis,* we follow the approach pioneered in the Global Invasive Species Programme toolkit (Emerton and Howard 2008) and refined in the Buncle et al. (2013) guide to cost–benefit analysis for natural resource management in the Pacific. The latter is an especially useful template for this research because it offers a standardized approach to support decision making by Pacific Island governments and nongovernment organisations.

The population growth of *P. uninodis* is assumed to follow the logistical growth curve described in equation 1, with the current population of taro beetles (N_t) on affected taro plots eastern Viti Levu estimated at 50% of its carrying capacity, on average (Daigneault and Brown 2013). This assumption is consistent with evidence above that the taro beetle is increasing in >50% of the surveyed villages (Fig. 2), but it is relaxed later for sensitivity tests.

Table 3. Responses to *P. uninodis*

Variable	Unit	10th percentile	Mean	90th percentile
View of taro beetle	−4 = ext. neg., +4 = ext. pos.	−4	−3.72	−2
Share of national budget allocated to controlling taro beetle	Percent	0	2.60	4.29
Hours willing to volunteer per week to control taro beetle[a]	Hours	3	10.99	20

n = 360.
[a] Among households who identified *P. uninodis* as the worst IAS that they face.

The surveys and results described in "Survey Research Methods" and "Survey Results" provided detailed data on the damages caused by *P. uninodis,* the shadow value of labor, and management practices commonly pursued in Fijian villages.[11] Data pertaining to the costs associated with each management practice are derived from household surveys and from market surveys conducted by the Fiji Ministry of Primary Industries. Finally, we used a Delphi process (Dalkey and Helmer 1963, Brown 1968) in surveying pest management experts from Landcare Research, the Pacific Invasives Initiative, the University of the South Pacific, the South Pacific Regional Herbarium, and the Fiji Ministry of Fisheries and Forests to assess the relative effectiveness of each management option. In Delphi processes, the combined opinion of experts is used to offer interim solutions to pressing problems in the absence of empirical data (Egan and Jones 1997).[12]

Because costs accrue over the duration of the intervention, we calculate the present value of current and future costs by discounting future costs at the real rate of interest, i.e., the opportunity cost of money. We assume a time horizon of 50 yr[13] and a discount rate of 8%, which is the median discount rate used for long-term environmental management projects in the Pacific (Lal and Holland 2010). The present value of benefits was calculated similarly.

Recurring costs such as labor and insecticides are assumed to accrue at the end of each of the 50 yr in the life of the management intervention. Capital costs such as the cost of casssava plants, by contrast, are assumed to accrue only during the initial period. Information about the number of physical units of inputs under each management option is derived from the scientific literature, survey responses, and expert knowledge, and the total monetized costs of management are estimated by multiplying the unit costs incurred in each year by the number of physical units.

Finally, we calculate the net present value (NPV) of each management option by subtracting the present value (PV) of costs from the PV of benefits. We also calculate the benefit-cost ratio (i.e., the ratio of the present value of benefits to the present value of costs), which describes the relative efficiency of each management option.

Cost–Benefit Analysis Results

In this study, we consider four distinct management options: doing nothing, switching crops from taro to cassava, using cultural controls, and applying insecticides. The "do nothing" approach represents the baseline against which the costs and benefits of other management options are measured.[14]

Do Nothing. This option represents progressive growth and spread across the landscape in the absence of any management. Under this scenario, *P. uninodis* increases from 50% of carrying capacity to 100% of carrying capacity within ≈10 yr. There are no associated management costs, but it does result in damages to agricultural production that would have been avoided had the taro beetle been managed.

Crop Substitution. Under this management option, farmers in affected villages are assumed to replant all their taro fields with cassava. Based on survey results and consensus developed during the Delphi process, we assume that the taro beetle population dwindles to zero over 15 yr; however, this scenario also means that no taro is produced. While it is feasible that taro could be replanted after P. uninodis has been eliminated, for simplicity, we assume that the switch to cassava is permanent. Farmers who pursue this management option incur capital costs associated with purchasing cassava stem cuttings, but yield benefits beginning the following year from switching to the unaffected crop.

Cultural Control. Under this management option, farmers implement best practice management in their taro fields. Per Biosecurity Authority of Fiji (2014), specific activities include rotating crops, using clean planting material, and destroying potential breeding sites near taro fields. Costs associated with this management option stem primarily from additional labor required to manage and monitor the taro crop. Based on extensive testing as reported in Lal (2008), we assume that this management option allows the population of taro beetle to gradually be reduced to half the population as the initial period over 10 yr. However, this assumption is relaxed below.

Chemical Control. Following Lal (2008), this management option assumes that imidacloprid is applied with 1.5 ml per liter of water and that bifenthrin is applied with 2.5 m/s at 125 ml formulation per plant at the time of planting and again 3 mo after planting. To reduce the likelihood of resistance, the two approaches are employed in alternating years. Based on a consensus of expert opinion reached via the Delphi process described above, we assume that best practice application of insecticide gradually increases the share of marketable taro to 95% and fully controls *P. uninodis* in 10 yr. Assumptions regarding the efficacy of this management approach are relaxed below.

We also considered biological control using the fungus *M. anisopliae* as a viable management option. However, Lal (2008) demonstrates that *M. anisopliae* is less effective than imidacloprid and bifenthrin, ei-

[11] Impacts of *P. uninodis* on households are scaled up to the village level. The typical village in eastern Viti Levu comprises 45 households that each maintain 0.6 hectares of productive land. Scaling household results to the village level does not change results of the CBA because we assume constant economies of scale.

[12] Helmer and Rescher (1959) note that relying on expert opinion in the absence of clear empirical knowledge is justified because of the background knowledge of experts and because the high degree of agreement derived from Delphi Processes "precludes subjective whim".

[13] We choose a long time horizon to reflect the need for ongoing management against pest outbreaks. Nevertheless, in the estimates presented below, 85% of the discounted benefits accrue within the first 25 years of the intervention.

[14] Subsequent to conducting our study, using cover crops was raised with the authors, the basis being that Papuana spp. cannot live and breed in heavy canopies. This is an intriguing possibility that warrants further study and application in Fiji.

Table 4. Values per hectare to quantify benefits and costs of managing *P. uninodis*

Benefit and cost category	Unit	Value per unit	Years incurred	Units per year per hectare			
				Do nothing	Switch from taro	Cultural control	Chemical control
Benefits							
Avoided damages—taro production	FJ$/kg	FJ$1.42	1–50	0	0	0–7,000	0–9,700
New cassava production	FJ$/kg	FJ$0.98	1–50	0	15,000	0	0
Avoided damages—cultural value of taro	FJ$/kg	FJ$0.10	1–50	0	0	0–7000	0–9,700
Costs							
Labour	FJ$/person days	FJ$30	1–50	0	0	30	15
Insecticides	FJ$/liter	FJ$30	1–50	0	0	1	3
Cassava	FJ$/seedling	FJ$0.10	1	0	20,000	0	0
Chemical sprayer and protective gear	FJ$/unit	FJ$200	1	0	0	1	0

ther alone or in combination. Moreover, Biosecuirty Authority of Fiji (2014) reports that there is as yet no recommended procedure for using *M. anisopliae* to manage taro beetle in Fiji. In addition, a virus has been trialled without success (Invasive Species Specialist Group [ISSG] 2013).

This management option entails purchases of insecticides, application materials, and protective gear, as well as labor with which to apply it.[15] Importantly, we only focus on the direct costs of insecticide application and hence do not explicitly account for negative externalities that pesticides may entail.[16]

Benefits and Costs of Management. Potential benefits of managing *P. uninodis* include improved yield of marketable crops, restoration of cultural values associated with taro production, reduced pressure to clear additional land, and biodiversity protection.[17] We focus explicitly on the direct economic benefits of managing taro beetle, namely the benefits of avoided damages to crops. In addition, we account for cultural values provided by taro by attributing a nominal 10% of the market value of the crop to cultural services. Due to difficulties associated with monetising the value of protecting forests and biodiversity associated with less clearing for new taro fields, we do not account for these benefits to managing this IAS. However, we note that these nonmonetised benefits will also be positive; thus, the figures we derive likely underestimate the true benefit from managing taro beetle.

The specified benefits are expressed in terms of damage that would likely accrue under the baseline scenario in the initial period ($t = 0$). Based on the household survey and consensus developed during the Delphi process, we assume that the taro beetle initially reduces average taro crop yield in affected fields by 38%. As the taro beetle is known to destroy up to 67% of the taro crop (Lal 2008), damages are expected to increase over time in the absence of any intervention.

Costs of managing *P. uninodis* include labor, insecticides, and capital such as cassava stem cuttings and chemical sprayers. Specific costs are derived from survey responses, spot checks in local markets, and the Fiji Ministry of Primary Industry's routine market surveys. All costs are assumed to occur before the start of each period for the duration of the intervention, with the exception of capital costs, which only occur in the initial period (Table 4).

Note that these estimates reflect management in a prototypical study area and that the levels of chemical application, cultural options, and labor required in a specific area may vary. Moreover, we have not accounted for any of the indirect costs associated with chemical application which could impact other crops, animals, native flora and fauna, and human health (e.g., Pimentel et al. 1992, Pimentel 2005, Devine and Furlong 2007, Atreya 2011). Thus, following Wegmann et al. (2011), we recommend trialling a management program in each site before undertaking a large-scale management program.

Cost–Benefit Analysis. Estimated annual benefits for controlling the taro beetle under the four management options are shown in Fig. 3.

Comparing the present value of costs listed to the present value of monetized benefits (shown in Table 4), we find that chemical controls offer the highest NPV over the 50-yr period, at FJ$139,543. However, switching affected taro fields to cassava yielded the highest benefit–cost ratio (Table 5), indicating that this approach offers the highest value per dollar spent in the absence of funding constraints. Additionally, relying on cultural controls produces a positive NPV, indicating that all three management options are

[15] We assume that farmers follow best practice in pesticide application. That is, protective clothing and footwear are always worn, health and safety requirements are followed, and the application of pesticide does not result in any non-target damage.

[16] Examples of negative externalities associated with pesticide use may include environmental and societal damages; impacts on public health; impacts on livestock and livestock production; increased control expenses resulting from pesticide-related destruction of natural enemies and from the development of pesticide resistance in pests; crop pollination problems and honeybee losses; indirect crop product losses; and bird, fish, and other wildlife losses. See Atreya et al (2011), Devine and Furlong (2007), Pimentel et al. (1992), and Pimentel (2005) for further examples. Nevertheless, Pimentel (2005) estimated the benefit–cost ratio of pesticide use in the United States to be 4:1 due to reduced crop losses.

[17] Taro beetles attack several ornamental and cultivated aroid species (Ediblearoids.org).

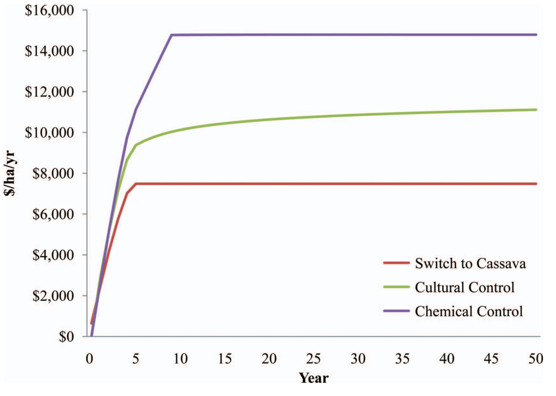

Fig. 3. Estimated annual benefits of control. (Online figure in color.)

strictly more efficient to the status quo in which *P. uninodis* is not managed.

The estimates presented in Table 5 reflect the NPV of each management option on a per-hectare basis and assume that the entire hectare is planted with taro. About 6,000 hectares of land is currently planted with taro in eastern Viti Levu (PacRIS 2013), and ≈53% of landowners in the study responded that their crop was affected by the taro beetle. Thus, the total NPV of using insecticide to manage areas affected by *P. uninodis* in the entire study area is at least FJ$447 million over the next 50 yr, while implementing cultural control or switching from taro to cassava yield net benefits of FJ$319 million and FJ$259 million, respectively.

Sensitivity Analysis

Economic analyses of IAS management often depend on strong assumptions, and this analysis is no different. For example, analyses use data from an array of sources with varying levels of quality and certainty. Some of the costs and benefits may be difficult to value accurately, and key biophysical data can be difficult to obtain. The population of the IAS in the initial period can also vary across space. As a result, we undertake sensitivity analyses to assess the robustness of our results. Specifically, we now analyze the results under the following variable assumptions:

1. Initial population (as a share of the carrying capacity)—0.5 and 2 times base assumption. This sensitivity analysis changes the initial population of *P. uninodis* from 50% of carrying capacity to 25% or 100%.

Table 5. Summary of benefit–cost analysis (per hectare)

Option	PV costs	PV benefits	Total NPV	Benefit–cost ratio
Do nothing	FJ$0	FJ$0	FJ$0	1.0
Switch from taro to cassava	FJ$2,000	FJ$83,006	FJ$81,006	41.5
Cultural control	FJ$11,377	FJ$110,966	FJ$99,589	9.8
Chemical control	FJ$6,806	FJ$146,349	FJ$139,543	21.5

Discount rate = 8%; time horizon = 50 yr; study area = 1 hectare.

2. Effectiveness of management—0.5 and 2 times base assumption. This sensitivity analysis adjusts the pathway of the population growth curves for the three intervention options. An option that is twice as effective implies that the maximum effectiveness of the intervention is cut in half, i.e., control via chemical control is achieved in 5 yr as opposed to 10 yr.
3. Discount rate—Rates of 4 and 12% are at the tails of the range of discount rates used for environmental management projects in the region.

Permutations of the above yield 81 possible combinations under which to evaluate the sensitivity of the results presented in the previous section. The NPV of each combination is presented in Table 6.

Assuming that the effectiveness of each option is a constant multiplier of the base effectiveness (e.g., that switching crops, cultural controls, and insecticides are all either as effective as the baseline, half as effective as the baseline, or twice as effective as the baseline), we find that the NPV of management is positive in all 81 combinations, even without monetizing benefits to biodiversity and reduced pressure to clear additional agricultural land. The analysis indicates that chemical control generally produces the highest NPV. However, in the case where the population of taro beetles approaches carrying capacity and thus maximum possible damage and there is a high discount rate, switching to cassava yields a slightly higher NPV.

Even in the most pessimistic scenario (i.e., in which there is a high initial population, low effectiveness of management, and a high discount rate), chemical control yields an NPV of FJ$45,731 per hectare, or >FJ$146 million across all affected taro fields in eastern Viti Levu over the next 50 yr. Thus, management is worthwhile even under these cynical assumptions.

Summary

By affecting the livelihoods and the *vanua* of the Fijian people, *P. uninodis* poses an enormous threat. The taro beetle can be managed and its impacts can be avoided, eliminated, or reduced. However, no large-scale, coordinated effort to manage taro beetle has been undertaken on Viti Levu, and neither the costs nor the benefits of management are particularly well understood.

In this paper, we undertake a cost–benefit analysis of managing *P. uninodis* in eastern Viti Levu, Fiji. This CBA was informed by first-of-its-kind primary-source data collected via matched household and community surveys, which hold major scientific significance in and of themselves. For example, the surveys document the economic costs of living with IAS, e.g., the value of crops lost to taro beetle and the cost of insecticides for infested taro fields. They also document heterogeneity in current management practices and personal attitudes toward *P. uninodis.* When asked to reallocate Fiji's national budget according to their own spending

Table 6. NPV (FJ$ per hectare) of sensitivity analyses for *P. uninodis* management options

Option	Effectiveness	Initial population (relative to carrying capacity)		
		25%	50%	100%
Discount rate = 4%				
Switch from taro to cassava	0.5 × base	FJ$125,202	FJ$151,567	FJ$168,161
	1.0 × base	FJ$125,202	FJ$149,567	FJ$168,161
	2.0 × base	FJ$125,202	FJ$151,567	FJ$168,161
Cultural control	0.5 × base	FJ$152,459	FJ$179,189	FJ$152,904
	1.0 × base	FJ$225,340	FJ$188,284	FJ$179,580
	2.0 × base	FJ$260,471	FJ$254,233	FJ$215,913
Chemical control	0.5 × base	FJ$275,216	FJ$260,584	FJ$230,859
	1.0 × base	FJ$291,841	FJ$267,511	FJ$242,919
	2.0 × base	FJ$299,757	FJ$285,547	FJ$248,949
Discount rate = 8%				
Switch from taro to cassava	0.5 × base	FJ$58,916	FJ$83,006	FJ$98,983
	1.0 × base	FJ$58,916	FJ$81,006	FJ$98,983
	2.0 × base	FJ$58,916	FJ$83,006	FJ$98,983
Cultural control	0.5 × base	FJ$77,969	FJ$97,015	FJ$76,650
	1.0 × base	FJ$116,654	FJ$99,589	FJ$87,198
	2.0 × base	FJ$134,942	FJ$136,524	FJ$105,468
Chemical control	0.5 × base	FJ$141,611	FJ$136,053	FJ$113,185
	1.0 × base	FJ$149,930	FJ$139,543	FJ$118,325
	2.0 × base	FJ$153,781	FJ$149,006	FJ$120,895
Discount rate = 12%				
Switch from taro to cassava	0.5 × base	FJ$31,988	FJ$54,167	FJ$69,595
	1.0 × base	FJ$31,988	FJ$52,167	FJ$69,595
	2.0 × base	FJ$31,988	FJ$54,167	FJ$69,595
Cultural control	0.5 × base	FJ$47,393	FJ$62,591	FJ$45,731
	1.0 × base	FJ$71,879	FJ$63,061	FJ$50,570
	2.0 × base	FJ$83,262	FJ$87,539	FJ$61,696
Chemical control	0.5 × base	FJ$86,766	FJ$84,757	FJ$65,607
	1.0 × base	FJ$91,729	FJ$86,743	FJ$68,163
	2.0 × base	FJ$93,965	FJ$92,749	FJ$69,440

Time horizon = 50 yr; study area = 1 hectare.

priorities, survey respondents would allocate ≈6.7% of the national budget for IAS management and 2.6% specifically to controlling taro beetle.

Cost–benefit analysis reveals that chemical controls typically represent the most beneficial means of managing *P. uninodis.* The net present value of chemical controls over the baseline "do nothing" approach amounts to some FJ$237 million across eastern Viti Levu over the next 50 yr. This result assumes that insecticide is applied efficiently and safely, with no damage to other crops, livestock, native flora and fauna, or human health, an admittedly strong assumption given the potential externalities. Switching to cassava is an inexpensive alternative to chemical controls that also yields positive net present values and high benefit–cost ratios in all scenarios, rendering it another attractive management option. Cultural controls are more expensive and less effective than chemical controls and are thus not recommended as a primary management strategy. Nevertheless, all three management strategies are more efficient than the case in which *P. uninodis* is not managed. Finally, although we found that many farmers made some effort to control the taro beetle, the measures undertaken still resulted in average taro yield losses of ≈38%. This suggests that considerable gains may be made in publicizing best practices in managing this invasive alien species.

Acknowledgments

The results presented in this paper are derived from a project conducted jointly by Landcare Research (LCR), the Pacific Invasives Initiative (PII), and the Institute of Applied Science at the University of the South Pacific (IAS/USP). We especially acknowledge Suzie Greenhalgh (LCR); Souad Boudjelas, John Mather, and Bill Nagle (PII); and Bill Aalbersberg, Apisai Bogiva, James Comley, and Randy Thaman (IAS/USP) for their many contributions to this project. Three anonymous referees also made insightful comments on this manuscript. We gratefully acknowledge the seven members of the Critical Ecosystem Partnership Fund, namely, L'Agence Française de Développement, Conservation International, the European Union, the Global Environment Facility, the Government of Japan, The John D. and Catherine T. MacArthur Foundation, and the World Bank, for funding this project. Anna Fink (Secretariat of the Pacific Community) reviewed the management options, pricing, and biological underpinnings of the CBA.

References Cited

Atreya, K., B. K. Sitaula, F. H. Johnsen, and R. M. Bajracharya. 2011. "Continuing issues in the limitations of pesticide use in developing countries." J. Agric. Environ. Ethics 24: 49–62.

Autar, M. L., and J. M. Singh. 1988. Biology of taro beetle (*Papuana uninodis* Prell) infesting taro (*Colocasia esculenta*) in Fiji. Fiji Agric. J. 50: 15–21.

Belshaw, C. S. 1964. Under the ivy tree: Society and economic growth in rural Fiji. University of California Press, Berkeley.

Biosecurity Authority of Fiji. 2014. Taro Beetle. (http://www.biosecurityfiji.com/campaigns/taro-beetle.html).

Blamey, R. K., J. W. Bennet, and M. D. Morrison. 1999. Yea-saying in contingent valuation surveys. Land Econ. 126–141.

Bourke, R. M. 2012. The decline of taro and taro irrigation in Papua New Guinea, pp. 255–264. *In* M. Spriggsa, D. Addison, and P. J. Matthews (eds.), Irrigated Taro (Colocasia esculenta) in the Indo-Pacific: Biological, Historical and Social Perspectives. Senri Ethnological Studies 78, National Museum of Ethnology, Osaka, Japan.

Boyle, K. J., R. C. Bishop, and M. P. Welsh. 1985. Starting point bias in contingent valuation bidding games. Land Econ. 61: 188–194.

Brown, B. B. 1968. Delphi process: A methodology used for the elicitation of opinions of experts. RAND Corporation, Santa Monica, CA. (http://www.rand.org/pubs/papers/P3925).

Buncle, A., A. Daigneault, P. Holland, A. Fink, S. Hook, and M. Manley. 2013. Cost-benefit analysis for natural resource management in the Pacific. Secretariat of the Pacific Community, Suva, Fiji.

Cambie, R. C., and J. Ash. 1994. Fijian Medicinal Plants. University of Auckland Press: CSIRO Publishing, Auckland, New Zealand.

Cook, D. C., M. Hurley, S. Liu, A.-B.M. Siddique, K. E. Lowell, and A. Diggle. 2010. Enhanced risk analysis tools. Cooperative Research Centre for National Plant Biosecurity Report CRC 10010.

Daigneault, A., and P. Brown. 2013. Invasive species management in the Pacific using survey data and benefit-cost analysis. *In* Paper presented at the 57th AARES annual conference, 5–8 February, Sydney, Australia.

Daigneault, A., P. Brown, S. Greenhalgh, S. Boudjelas, J. Maher, W. Nagle, and W. Aalbersberg. 2013. Valuing the impact of selected invasive species in the polynesia-micronesia hotspot. Landcare Research New Zealand Limited, LC1227. (http://www.isinz.com/documents/CEPF-valuing-invasives.pdf).

Dalkey, N., and O. Helmer. 1963. An experimental application of the Delphi method to the use of experts. Manag. Sci. 9: 458–467.

Devine, G. J., and M. J. Furlong. 2007. Insecticide use: contexts and ecological consequences. Agric. Human Values 24: 281–306.

Egan, A. F., and S. B. Jones. 1997. Determining forest harvest impact assessment criteria using expert opinion: A Delphi study. Northern J. Appl. For. 14: 20–25.

Emerton, L., and G. Howard. 2008. A toolkit for the economic analysis of invasive species. Global Invasive Species Programme, Nairobi, Kenya.

Fijian Government. 2013. Fiji Budget Estimates 2012. (http://www.fiji.gov.fj/Budget/Download-2012-Budget-Estimates-(pf).aspx).

Hather, J. 1992. The archaeobotany of subsistence in the Pacific World. Archaeol. Oceania 24: 70–81.

Helmer, O., and N. Rescher. 1959. On the epistemology of the inexact science. Manag. Sci. 6: 25–53.

Horrocks, M., and S. Bedford. 2005. Microfossil analysis of Lapita deposits in Vanuatu reveals introduced *Araceae* (aroids). Archaeol. Oceania 40: 67–74.

Hunter, D., K. Pouono, and S. Semisi. 1998. The impact of taro leaf blight in the Pacific Islands with special reference to Samoa. J. South Pac. Agric. 5: 44–56.

(ISSG) Invasive Species Specialist Group. 2013. Global Invasive Species Database. (http://www.issg.org/database/species/).

Kuruvilla, K. M., and A. Singh. 1981. Karyotypic and Electrophoretic Studies on Taro and its Origin. Euphytica 30: 405–413.

Lal, S. N. 2008. Taro beetle management in Papua New Guinea and Fiji, p. 38. AICAR Project Number CS2/2000/044. Secretarial of the Pacific Community, Noumea, New Caledonia.

Lal, P. N., and P. Holland. 2010. Economics of resource and environmental project management in the Pacific. IUCN and SOPAC Secretariat, Gland, Switzerland and Suva, Fiji.

Leach, H. M. 1982. "On the origins of kitchen gardening in the ancient Near East". Garden Hist. 10: 1–16.

Lebot, V. 2009. Tropical root and tuber crops: cassava, sweet potato, yams and aroids (No. 17). Cabi.

Lebot, V., and K. M. Aradhya. 1991. Isozyme variation in taro (*Colocasia esculenta* (L.) Schott) from Asia and Oceania. Euphytica 56: 55–66.

Macfarlane, B. 1987. Papuana beetles. South Pacific Commission Advisory Leafl. 21. South Pacific Commission, Noumea, New Caledonia.

Matthews, P. J. 2003. Taro planthoppers (*Tarophagus* spp.) in Australia and the origins of taro (*Colocasia esculenta*) in Oceania. Archaeol. Oceania 38: 192–202.

McGregor, A., P. Afeaki, J. Armstrong, A. Hamilton, J. Hollyer, R. Masamdu, and K. Nalder. 2011. Pacific Island taro market access scoping study. Secretariat of the Pacific Community (SPC) Facilitating Agricultural Commodity Trade (FACT) Project Report. p. 117. (http://archives.pireport.org/archive/2011/April/MARKET_ACCESS_STUDY_TARO_MARCH_2011%5B1%5D.pdf).

Milner, R. J. 1992. The selection of strains of *Metarhizium anisopliae* for control of Australian sugarcane white grubs, pp. 209–215. *In* T. R. Glare and T. A. Jackson (eds.), Use of pathogens in scarab pest management. Intercept, Andover, United Kingdom.

Milner, R. J., and G. G. Lutton. 1976. *Metarhizium anisopliae*: Survival of conidia in the soil, pp. 428–429. *In* Proceedings of 1st International colloquium on invertebrate pathology. Queen's University, Kingston, Canada.

Onwueme, I. 1999. Tarro Cultivation in Asia and the Pacific. Food and Agricultural Organisation of the United Nations, RAP Publication 1999/16.

(PacRIS) Pacific Regional Statistics. 2013. Prism: Explore the Statistics of the Pacific Island Countries and Territories. (http://www.spc.int/prism/).

Paulhus, D. L. 1991. Measurement and control of response biases. *In* J. P. Robinson, P.R. Shaver, and L. S. Wrightsman. (eds.), Measures of personality and social psychological attitudes. Academic, San Diego, CA.

Pimentel, D. 2005. Environmental and economic costs of the application of pesticides primarily in the United States. Environ. Dev. Sustain. 7: 229–252.

Pimentel, D., H. Acquay, M. Biltonen, P. Rice, M. Silva, J. Nelson, V. Lipner, S. Giordano, A. Horowitz, and M. D'Amore. 1992. Environmental and economic costs of pesticide use. BioScience 42: 750–760.

Plucknett, D. L. 1976. Edible Aroids: *Alocasia, Colocasia, Cyrtosperma, Xanthosoma*, pp. 10–12. *In* N. W. Simmonds (ed.), Evolution of Crop Plants. Longman, London and New York.

Rath, A. 1992. Metarhizium anisopliae for control of the Tasmanian pasture scarab (*Adroryphorus couloni*), pp. 217–222. *In* T. R. Glare, and T. A. Jackson (eds.), Use of pathogens in scarab pest management. Intercept, Andover, United Kingdom.

Ryle, J. 2005. Roots of land and church: The Christian state debate in Fiji. Int J. Study Christ Church 5: 58–78.

Spickard, P. R., J. L. Rondilla, and D. H. Wright. 2002. Pacific diaspora: Island peoples in the United States and across the Pacific. University of Hawaii Press, Honolulu.

Theunis, W., I. Aloali'i, R. Masamdu, and B. M. Thistleton. 1997. Pathogens tested on taro beetles (*Papuana* spp.) and their potential for biological control. *In* T. R. Glare and T. A. Jackson (eds.), Proceedings of the 3rd international workshop on microbial control of soil pests, February 1996, Lincoln, New Zealand.

Thistleton, B. M. 1984. Taro beetles. Entomol. Bull. Harvest 10: 32–35.

Veitch, C. R., M. N. Clout, and D. R. Towns. 2011. Island invasives: Eradication and management. *In* Proceedings of the International Conference on Island Invasives. CBB, Gland, Switzerland, and IUCN, Auckland, New Zealand.

Waterhouse, D. F., and K. R. Norris. 1987. Biological control: Pacific prospects, p. 454. Inkata Press, Melbourne, Australia.

Wegmann, A., S. Buckelew, G. Howald, J. Helm, and K. Swinnerton. 2011. Rodent eradication campaigns on tropical islands: novel challenges and possible solutions, pp. 239–243. *In* C. R. Veitch, M. N. Clout, and D. R. Towns (eds.), Island invasives: eradication and management. IUCN, Gland, Switzerland.

Whistler, W. A. 1991. Polynesian plant introductions, pp. 41–65. *In* P. A. Cox and S. A. Banack (eds.), Islands, Plants and Polynesians: An Introduction to Polynesian Ethnobotany. Dioscorides Press, Portland, OR.

Zelazny, B., M. L. Autar, R. Singh, and L. A. Malone. 1988. *Papuana uninodis*, a new host for baculovirus of *oryctes.* J. Invertebr. Pathol. 51: 157–160.

Received 19 May 2014; accepted 17 August 2014.