Invasive species management in the Pacific using survey data and benefit-cost analysis

A. Daigneault and P. Brown
Landcare Research New Zealand Ltd

Contributed paper prepared for presentation at the
57th AARES Annual Conference, Sydney,
New South Wales, 5th-8th February, 2013

abstract

Invasive species pose an enormous threat in the Pacific: not only do they strongly affect biodiversity, but they also potentially affect the economic, social, and cultural wellbeing of Pacific peoples. Invasive species can potentially be managed and their impacts can potentially be avoided, eliminated, or reduced. However, neither the costs nor the numerous benefits of management are well understood in the Pacific. Thus, we undertook cost-benefit analyses (CBAs) of managing five species that are well established on Viti Levu, Fiji: *spathodea campanulata* (African tulip tree), *herpestus javanicus* (small Asian mongoose), *papuana uninodis* (taro beetle), *pycnonotus cafer* (red-vented bulbul), and *merremia peltata* (merremia vine). These CBAs are informed by extensive survey data that record the incidence, management, and impacts of the five species in Fiji. We find that the most cost-effective management option varies by species, precluding a universal solution. Nevertheless, the benefits of management often exceed the costs of management by a wide margin, arguing for a more concerted effort to control the spread of invasive species in the Pacific.

keywords: invasive species; cost-benefit analysis; non-market valuation

1 Introduction

Natural resources are of crucial importance in the Polynesia-Micronesia Biodiversity Hotspot. At a regional level, the Pacific is among the most productive fishing grounds in the world (Seidel & Lal 2010). At the national level, primary industries such as agriculture, fishing, and forestry constitute as much as 25% of GDP in Kiribati and 33% of GDP in the Solomon Islands (www.spc.int/prism). Natural resources also contribute to economic development across the region through secondary and tertiary industries, i.e., manufacturing and processing.

Additionally, natural resources are fundamental to social development in the Pacific, supporting national identity and culture. For example, the word for “land” in New Zealand Māori (*whenua*) is the same as that for “placenta” and the word for "land" in both Tuvaluan (*fenua*) and Fijian (*vanua*) also refers to the community located on the land and encompasses their customs, beliefs, and values.

Invasive species pose an enormous threat to biodiversity throughout the Pacific. By impacting crops, livestock, fisheries, and forests, invasive species also potentially affect the economic, social, and cultural wellbeing of Pacific peoples. Given the magnitude of the potential problems caused or exacerbated by invasive species in the Polynesia Micronesia Biodiversity Hotspot, the scarcity of data pertaining to their biological charactersitics, the damages that they cause, and the effectiveness of management options is notable. For example, despite the fact that the small Asian mongoose is considered to be among the 100 world’s worst invasives by International Union for the Conservation of Nature, we found few credible, published sources documenting its population growth rate or carrying capacity. Similarly, while the merremia is widely considered to be a scourge in the Pacific, many villages we visited in Fiji reported practical uses for the plant, including bundling twine, animal fodder, and medicinal qualities. Finally, while it is common practice in Fijian villages to manage the African tulip tree through mechanical extraction, application of herbicides, and targeted burning, neighbouring villages often take radically different approaches, underscoring the lack of publicly available information about the effectiveness of each management option.

Evidence demonstrates that invasive species may be managed and that their impacts may be avoided (through prevention), eliminated (through eradication), or reduced (through control) (Veitch et al. 2011). The costs of management may be significant, either because they are already well established or because monitoring to prevent establishment is costly. That being said, because invasive species management is in its infancy in the Pacific, its true costs are often poorly understood.

Likewise, our understanding of the ecological, economic, social, and cultural impacts of invasive species in the Pacific islands region is largely based on anecdotal evidence and/or benefits transfer data collected elsewhere. As such, the benefits of controlling many invasive species in the Pacific islands region have not been well established.

Understanding the costs and benefits of invasive species management could help decsion-makers to make more informed decisions regarding whether it is economically feasible to manage invasive species and, if so, the appropriate levels of resources to invest in prevention, eradication or control. Hence, we undertook cost-benefit analyses (CBAs) of managing five species that are well established on Viti Levu, Fiji: *spathodea campanulata* (African tulip tree), *herpestus javanicus* (small Asian mongoose), *papuana uninodis* (taro beetle), *pycnonotus cafer* (red-vented bulbul), and *merremia peltata* (merremia vine). These CBAs were informed by primary-source data collected via matched household and community surveys, and the resulting recommendations were subjected to rigorous peer review from regional experts to ensure both accuracy of underlying assumptions and feasibility of implementation.

We find that the most cost-effective management option varies by species, precluding a "one-size-fits-all" solution. Nevertheless, the benefits of management often (but do not always) exceed the costs of management by a wide margin, arguing for a more concerted effort to control the spread of invasive species in the Pacific.

The remainder of this paper is organised as follows: Section 2 describes the household and community surveys, including both design and analytical results; Section 3 describes management options for each species and analyses the cost effectiveness of each using data from the household surveys; and Section 4 concludes.

2 Survey Research

Methods and Instruments

We surveyed 360 households in 30 villages in eastern Viti Levu, Fiji to investigate the socio-economic impacts of invasive species. These villages were stratified by geography and randomly drawn; one village that was inaccessible by road due to construction was replaced with another remote village. The distribution of villages is shown in Figure 1.

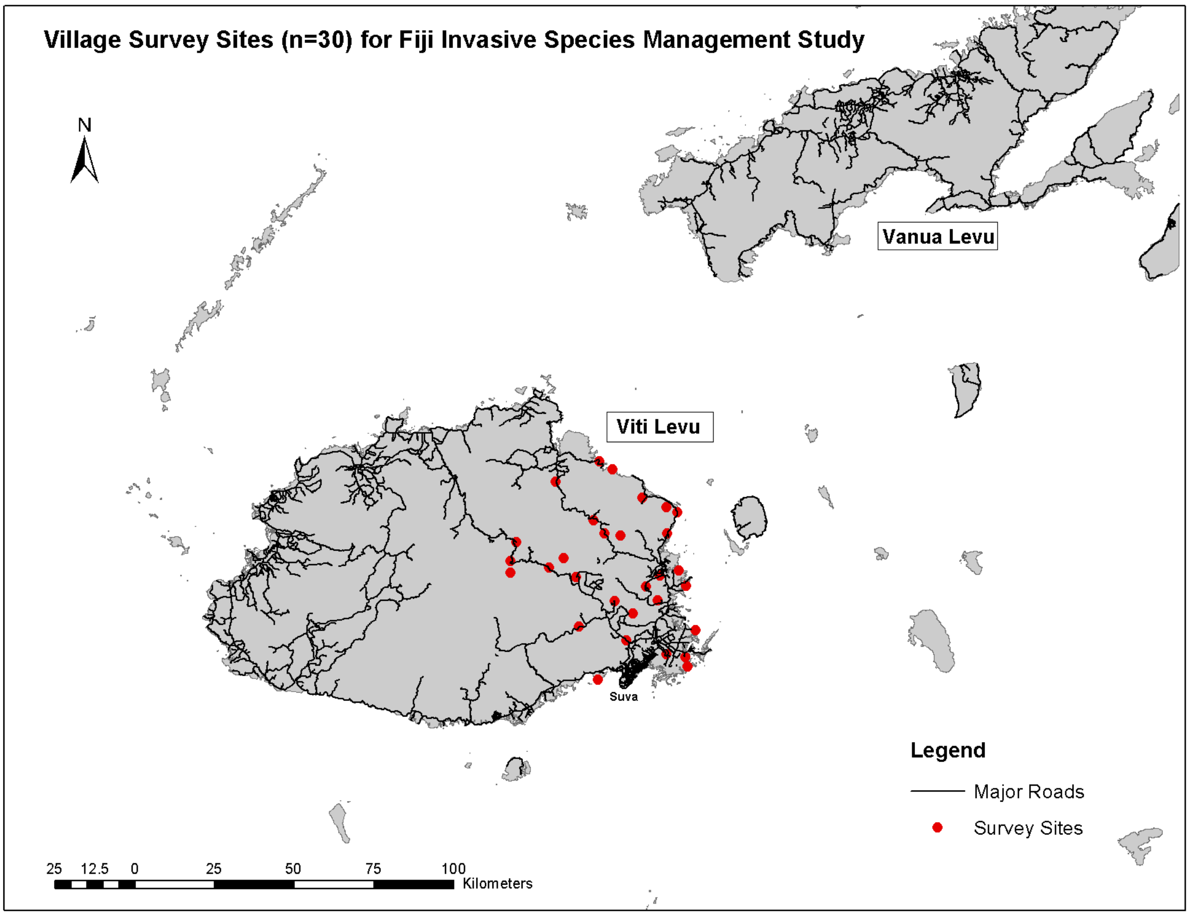

Figure 1 Villages surveyed (n=30)

Within each of the 30 villages, households were sampled 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; agricultural extension activities; and damages/losses due to invasive species. The survey also included several novel elements pertaining to the social and economic impacts of invasive species, as described below.

First, respondents were asked to assume the role of Fiji's budget minister and to identify spending priorities by allocating budgetary shares to a broad range of categories, including education, healthcare, public order, trade, infrastructure development, and environmental protection. Respondents who allocated money to environmental protection were further asked to prioritise controlling specific invasive species relative to other environmental spending.

Second, a series of questions was asked to elicit willingness to contribute personally to controlling invasive species via volunteer labour. In most developed countries, willingness to pay is identified via questions pertaining to tax increases; however, few rural Fijian households pay taxes while virtually all of them contribute labour to maintaining the village, demonstrating the cultural relevance of this approach. Opening values of initial hours willing to volunteer were randomly assigned for each respondent via dice rolls to eliminate concerns about starting point bias.

Third, respondents were asked to state the extent to which they agreed with a series of 20 statements pertaining to the value of controlling invasive species (e.g., "It is bad that the taro beetle is found in this village.") via a 5-point Likert scale. To eliminate concerns of yea-saying (i.e., the tendency to consistently give the same answer in survey questions), some statements read in the negative (e.g., "It is good that the mongoose is found in this village.").

A second, complementary survey was conducted with a focus group of residents in each of the thirty sampled villages. This village-level questionnaire consisted of open-ended questions regarding the presence and state of each species and, where applicable, the consequences of its presence and community practices for encouraging or limiting its spread. Notably, respondents were asked to reflect on both the negative and positive (if any) impacts of each invasive species.

The survey was undertaken by a team of staff and students at USP. An intensive 3-day training on survey design and enumeration was held in a Fijian village before the start of the fieldwork. The survey content was carefully vetted in both the classroom and the village setting, and the enumerators gained the confidence needed to work independently while conducting multiple mock surveys with the project leaders. Including experienced staff in each surveying team provided further opportunities for mentoring for first-time enumerators.

The surveys were conducted over a four-week period during July 2012.

Key Results – African Tulip Tree

Respondents to the community survey (n=30) identified a number of costs associated with the African tulip tree, including the following:

- 76% of villages stated that the African tulip tree reduces agricultural output
- 36% stated that it reduces the quantity of land available for grazing
- 48% of villages stated that it competes with other, more desirable trees that are used for medicinal purposes and/or firewood

However, 52% of villages reported using the tree for building materials and 27% used the tree as firewood for cooking, despite its high moisture content. About 9% of the villages stated that the African tulip tree attracts birds and wild animals. Nevertheless, about 30% of the villages reported that the invasive tree provides no benefit to their community.

To control the spread of the African tulip tree, 73% of villages report that they prefer to cut the tree down, with 42% of villages further burning the stump after removing the trunk. Some 36% of villages surveyed reported that some farmers had stopped growing crops altogether in severely impacted fields because they could not keep up with the African tulip tree's aggressive spreading.

Respondents to the household survey (n=360) were asked a series of questions pertaining to their personal views of the species. Over 92% of survey respondents viewed the African tulip tree unfavourably, with 78% of survey respondents viewing the African tulip extremely negatively. Fewer than 3% of survey respondents had a favourable view of the invasive tree, on balance, and none held an extremely positive view.

Most respondents stated that the African tulip tree had some negative impact on their livelihoods, and some were spending considerable effort to address the problem. On average, surveyed households spent 3.7 hours/week (about 24 days/year) clearing the African tulip tree from their land. To put this figure in perspective, the average household surveyed spends about 35 hours a week managing their crops, of which about 10% of that time is used specifically to control this invasive species. Despite putting some effort into managing the African tulip tree, more than 95% of villages surveyed indicated that the population of the tree was increasing (Figure 2).

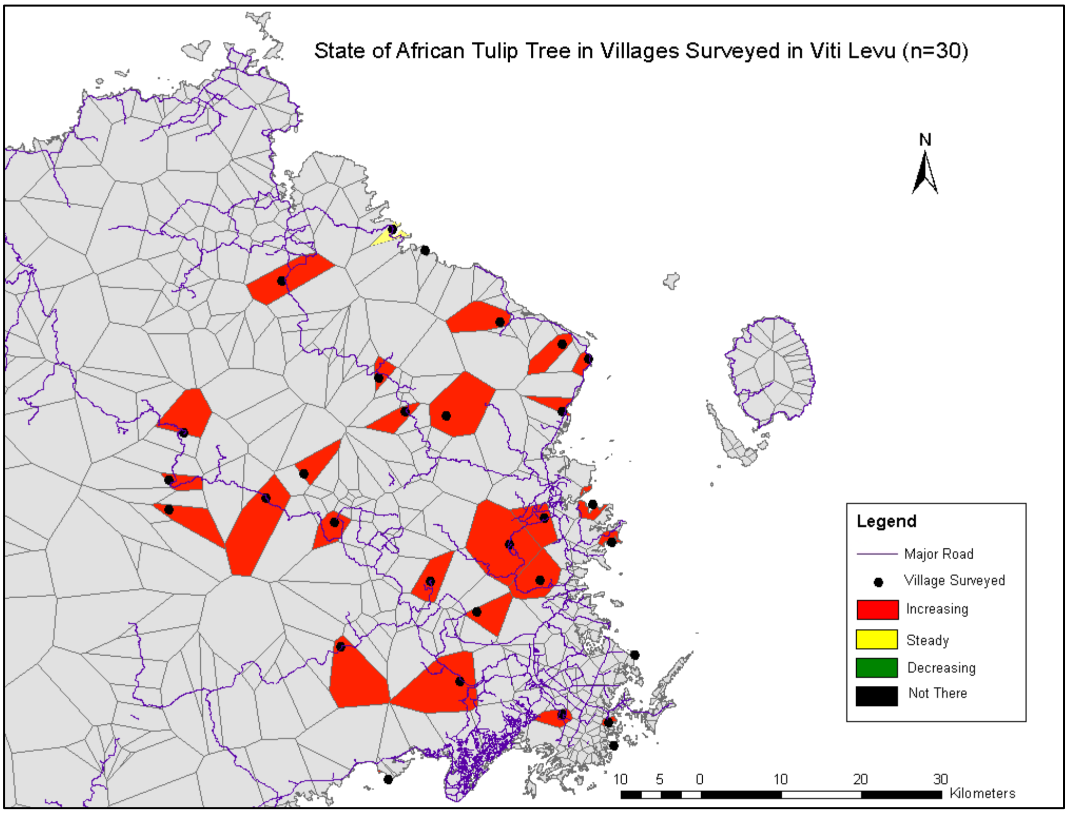

Figure 2 State of African tulip tree in villages surveyed (n=30)

Asked to reallocate Fiji's national budget according to their own spending priorities, respondents indicated that they would allocate approximately 7% of the national budget for invasive species management. They would further allocate 33% of that budget to control the African tulip tree. Furthermore, the median household among those who view the African tulip tree extremely negatively, offered to volunteer 10 additional hours/ household/week if their efforts would significantly reduce the density of the African tulip tree. The average household currently spends 6 hours/week on volunteer work, underscoring the perceived magnitude of the problem among Fiji's farmers. It also emphasizes their high willingness to work to alleviate the problem, provided the availability of effective control methods.

Key Results – Small Asian Mongoose

Respondents to the community survey (n=30) identified a number of costs associated with the mongoose, including:

- 83% of villages reported that mongooses had attacked livestock, primarily chickens
- 17% of villages reported that mongooses have reduced bird or animal populations
- 13% of villages have reported that mongooses have reduced agricultural output

Villagers also reported perceived benefits of the mongoose, however, including:

- 73% of villages reported that mongooses were eaten by villagers
- 27% of villages noted that the mongoose was useful for snake control

In addition, 17% of surveyed villages reported that mongooses brought no benefits to the local area.

Villagers in 87% of the surveyed villages actively trap mongooses and villagers in 47% of surveyed villages hunt it. These interventions are undertaken both for protecting crops live (e.g., bananas and plantains) and livestock and for food provision. Despite putting some effort into managing this, 90% of villages surveyed indicated that the population of the mongoose was increasing (Figure 3).

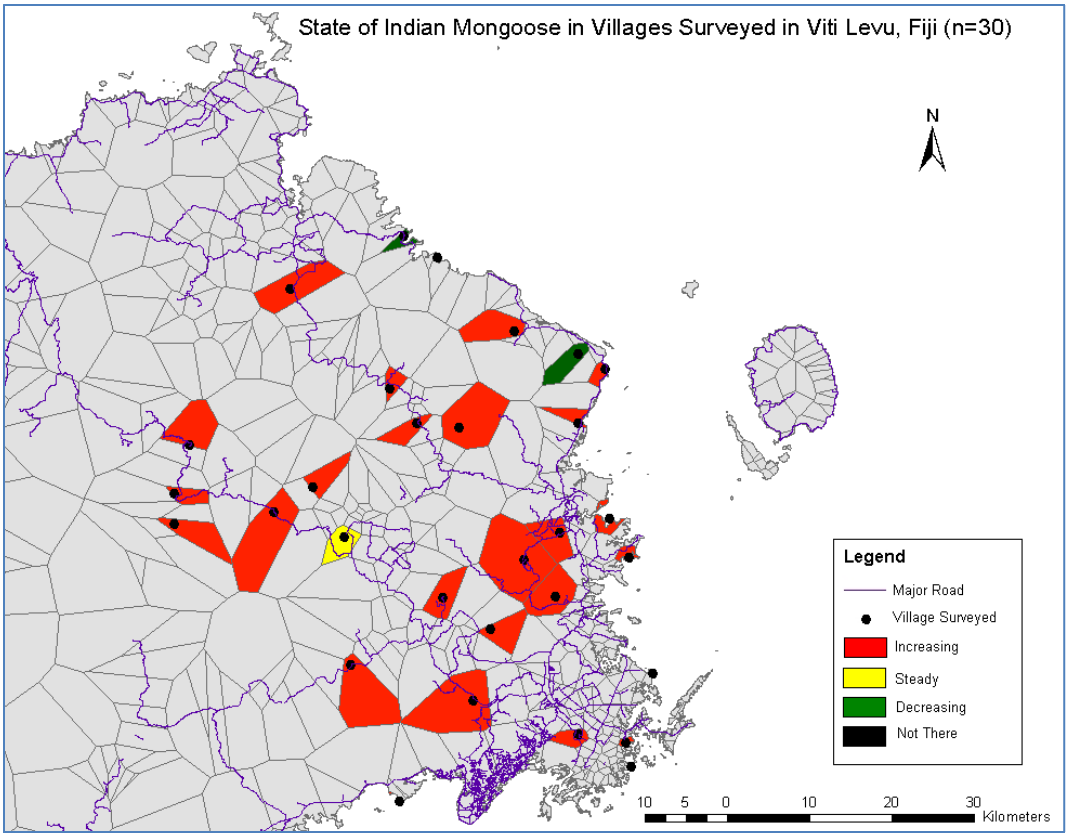

Figure 3 State of Small Indian Mongoose in villages surveyed (n=30)

Respondents to the household survey (n=360) were asked four questions on negative and positive attributes of the mongoose to elicit their personal views of the invasive. Only about 7% of survey respondents viewed the presence of the mongoose favourably, while 77% viewed the mongoose unfavourably. Of that, 56% of households answered all four attribute questions for the mongoose with an extremely negative response.

Despite the fact that respondents overwhelmingly held negative views of the small Asian mongoose and that most villages reported minor economic losses from the species, few respondents spent significant effort to address the presence of mongooses at the household level. On average, households in the surveyed areas spend just three minutes per week controlling mongooses through hunting and trapping activities. The maximum amount of time spent controlling mongooses was 8 hours/ week.

Asked to reallocate Fiji's national budget according to their own spending priorities, respondents would allocate approximately 7% of the national budget for invasive species management. They would further allocate 12% of that budget to control the small Indian mongoose. No respondents stated that the small Indian mongoose was the worst invasive species in their village.

Key Results – Taro Beetle

The taro beetle was found to be present in 83% of the villages surveyed. Respondents to the community survey identified two primary impacts associated with the beetle, including:

- 92% of villages observed that the taro beetle reduces agricultural output by burrowing into plant corms
- 42% of villages reported that the taro beetle caused plants to be more susceptible to disease

None of the villages surveyed stated that the beetle provided any biophysical or socio-economic benefits.

Some 44% of the villages used pesticides and other chemicals to reduce the incidence of the taro beetle, while 20% said that they dug and burned the affected crop. Approximately 36% of villages reported that farmers had stopped growing crops in severely impacted areas, and 32% noted that the taro beetle had prompted them to switch out of taro in favour of other crops such as cassava.

On average, surveyed households spent 0.7 hours/ week (about 4.5 person days/year) managing the beetle. To put this in perspective, the average household surveyed spends about 35 hours/ week managing their crops, of which about 2% of that time is used specifically to control this invasive species. Despite putting some effort into managing the beetle, 53% of the villages surveyed stated that the beetle has been spreading in recent years (Figure 4). Farmers in a few of the villages recently switched back to taro after many years because the beetle population had finally been reduced significantly, suggesting that the problem pest can be managed under certain conditions.

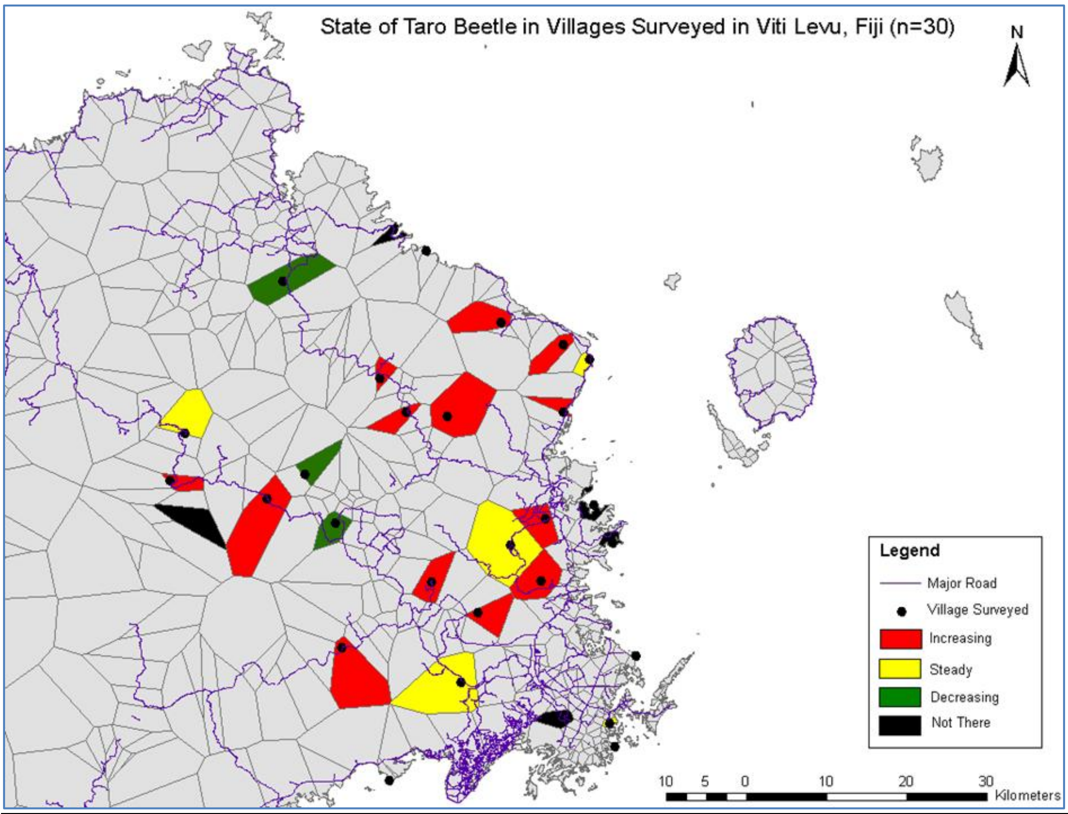

Figure 4 State of taro beetle in villages surveyed (n=30)

Respondents to the household survey (n=360) were asked a series of questions pertaining to their personal views of the species. Over 97% of respondents held negative views of the taro beetle, with 88% of respondents viewing the species extremely negatively. No respondent held a favourable view of this invasive pest.

Over 60% of respondents in areas in which the taro beetle is present experienced losses of taro crops due to the presence of pests in the year preceding the survey; the taro beetle was identified as the primary culprit in 89% of these households, reducing total output by an average of 8%.

Asked to reallocate Fiji's national budget according to their own spending priorities, survey respondents would allocate approximately 7% of the national budget for invasive species management. They would further allocate 38% of that budget to control the taro beetle. Furthermore, the median household among those who view the beetle extremely negatively, offered to volunteer 11 hours/ adult household member/week if their efforts would eradicate the taro beetle from their villages, underscoring the perceived magnitude of the problem among Fiji's farmers. It also emphasizes their high willingness to work to alleviate the problem, provided the availability of cost-effective control methods.

Key Results – Red-Vented Bulbul

The red-vented bulbul was present in 29 of 30 villages surveyed in Viti Levu. In the areas where this bird was present, 83% of villages noted that the bulbul reduces agricultural output, particularly for fruits. One village also noted that the bulbul has the potential to damage infrastructure by nesting inside the houses. The remaining villages stated that there were no socio-economic or biophysical impacts from this species.

About 47% of the village focus groups reported that the bulbul was good for their community. Key benefits identified include:

- 18% of villages responded that the bulbul is effective at insect control
- 12% of villages noted that the bulbul gives warning when a mongoose is about to attack chickens
- 12% stated the bulbul is occasionally eaten by villagers.

In terms of control, only 6% of the villages attempted to control the bulbul via hunting while 94% of the villages did nothing to control the species. As a result, 80% of villages surveyed indicated that the population of the bulbul was increasing or steady (Figure 5).

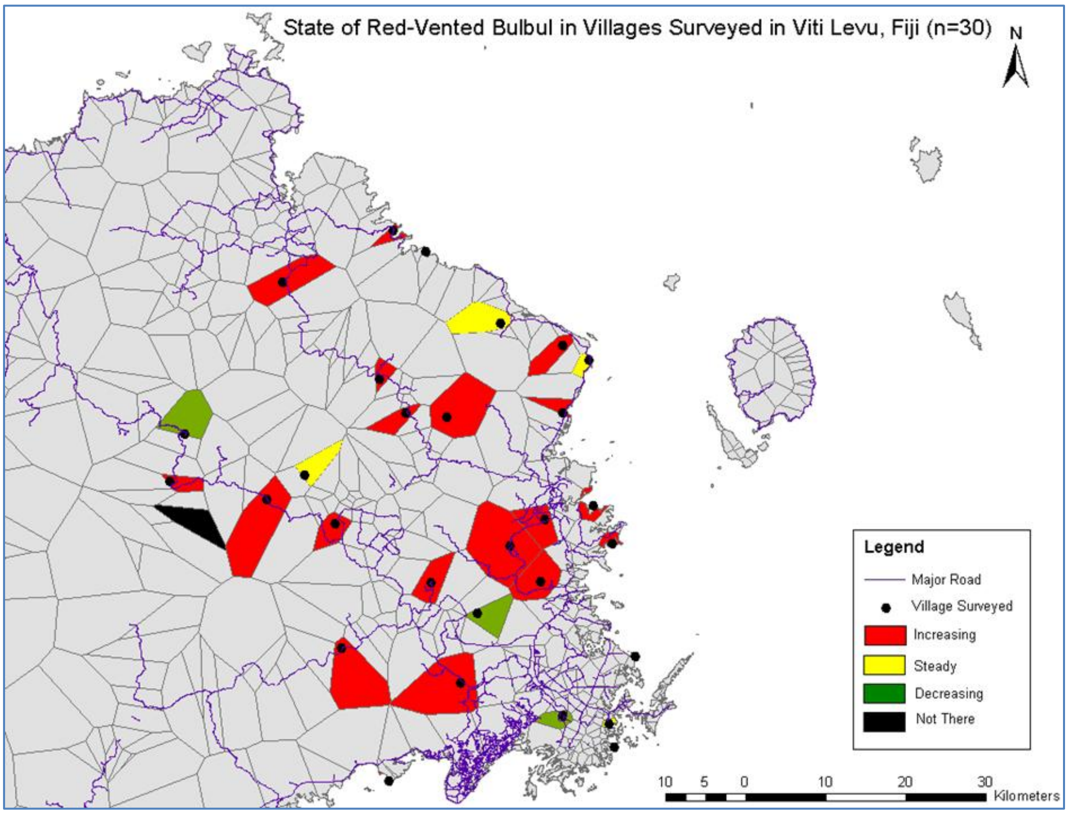

Figure 5 State of red-vented bulbul in villages surveyed (n=30)

Respondents to the household survey (n=360) were asked a series of questions pertaining to their personal views of the species. 55% of respondents viewed the red-vented bulbul unfavourably, with 31% of respondents viewing the invasive bird extremely negatively. Only 12% of respondents held favourable views of the bulbul.

Some respondents stated that the red-vented bulbul had some negative impact on their livelihoods, but none of the surveyed households reported taking any concerted effort to control them. Key crops impacted were pawpaw, plantain, and banana. Household surveys estimated that:

- Bulbuls affect 39% of surveyed households' pawpaw crops, reducing total output by 13%
- Bulbuls affect 16% of surveyed households' banana crops, reducing total output by 2%
- Bulbuls affect 14% of surveyed households' plantains crops, reducing total output by 12%

Tomato, vudi, chili, and guava were also reported to be affected in the study area. On average, a household affected by red-vented bulbul experienced $150 loss in the value of agricultural production in the preceding year.

Asked to reallocate Fiji's national budget according to their own spending priorities, survey respondents would allocate approximately 7% of the national budget for invasive species management. They would further allocate about 7% of that budget to control the red-vented bulbul, prioritising control of other invasive species over controlling the red-vented bulbul.

Key Results – Merremia vine

The merremia vine was present in 28 of 30 villages surveyed in Viti Levu (93%). Respondents to the community survey identified three primary costs associated with the vine:

- 42% of villages reported that merremia reduces agricultural output
- 37% of villages reported that merremia competes with medicinal trees and plants
- 26% of villages reported that merremia competes with trees used for building materials

Approximately 46% of the villages surveyed stated that there were no socio-economic or biophysical impacts.

More than 85% of the village focus groups reported that merremia was good for their community. Key benefits identified include:

- 53% of villages reported that merremia has important medicinal properties, including the ability to cure colds, stomach aches, and urinary tract infections.
- 50% of villages reported using merremia for bundling twine
- 25% of villages stated that it improved soil fertility
- 18% of villages reported that the merremia was used for witchcraft

Most villages nevertheless actively manage the vine to control its spread. Specifically:

- 76% of the villages regularly cut or pull merremia
- 16% of villages regularly burn merremia patches
- 11% of villages use herbicides to control the spread of merremia

Despite putting some effort into managing the invasive, 70% of the villages surveyed stated that the merremia population was still increasing (Figure 6).

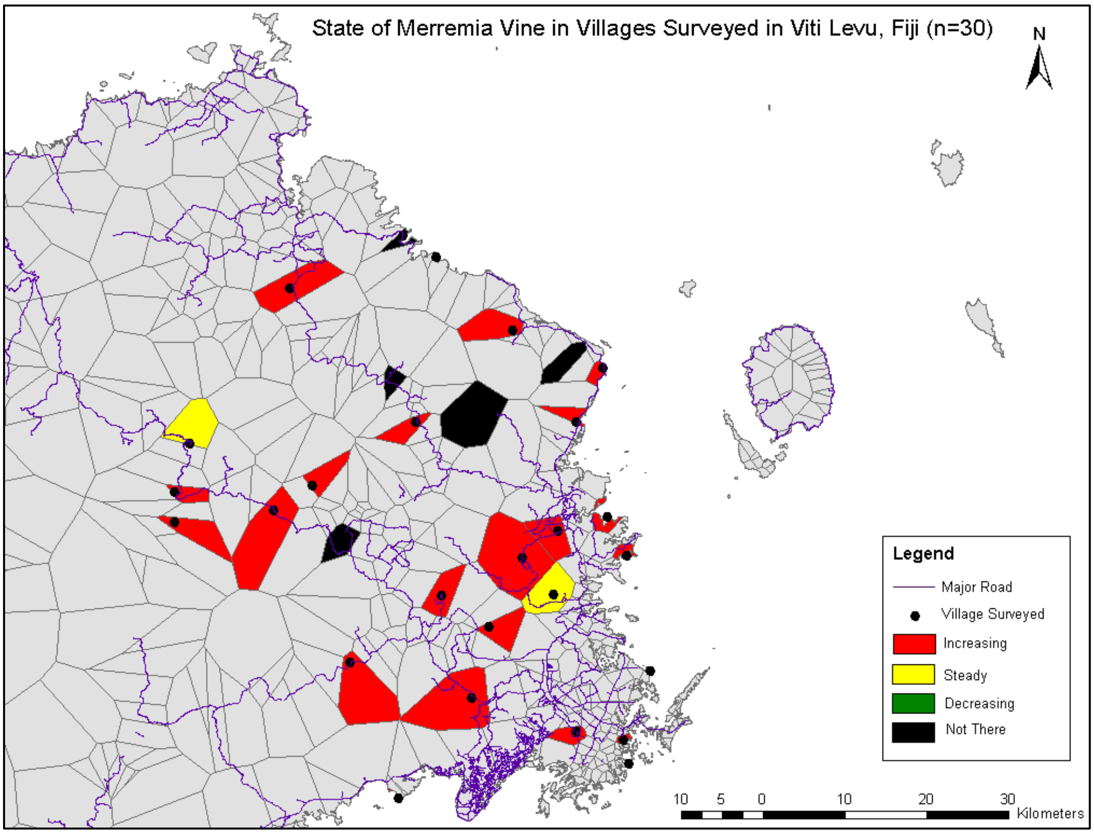

Figure 6 State of merremia vine in villages surveyed (n=30)

Respondents to a household survey (n=360) were asked a series of questions pertaining to their personal views of the species. Approximately 44% of the sampled households viewed the presence of merremia favourably, 34% viewed the presence of merremia negatively, and 22% was indifferent to its presence. Only a handful of respondents held an extremely negative view of the merremia vine, and none was entirely positive about its presence.

Some respondents to the household survey stated that the merremia had some negative impact on their livelihood, primarily by invading cassava and taro fields, but relatively few were taking any effort to reduce the problem. One-third of surveyed households spend time cutting and clearing merremia in a typical week, allocating on average about 1.8 hours/ week (about 13 person days/year) to the task. To put this in perspective, the average household spends about 35 hours/ week managing their crops, of which about 5% of that time is used specifically to control the invasive vine. The remaining two-thirds of surveyed households do not clear merremia from their land.

Asked to reallocate Fiji's national budget according to their own spending priorities, survey respondents would allocate approximately 7% of the national budget for invasive species management. They would further allocate 6% of that budget to controlling merremia, prioritising control of other species such as the African tulip tree and taro beetle over the merremia vine.

3 Cost-Benefit Analysis

Methods

In undertaking cost-benefit analyses of invasive species management, we follow an approach similar to that presented in the Global Invasive Species Programme (GISP) toolkit (Emerton and Howard 2008). Specifically, the surveys described above informed our analysis by providing detailed data on damages resulting from each invasive species, common management practices, and their associated costs. These data were augmented by scientific evidence on the biophysical growth of each species and the relative effectiveness of each management option obtained from the published literature and specialists in the region.

In our analyses, all costs other than capital costs are assumed to occur at the end of each period for the duration of the management intervention. Capital costs, by contrast, only occur during the initial period.

Information about the number of physical units of inputs under each management option (e.g., litres of pesticide to control taro beetle and traps needed to control small Asian mongoose) is derived from the scientific literature, survey responses, and expert knowledge. The total monetised costs are estimated by multiplying the unit costs incurred in each year by the number of physical units.

Because costs accrue over the duration of a project, 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. For this study, we assume a project length of 50 years and a discount rate of 8%, which is the median discount rate used for long-term environmental management projects in the Pacific (Lal & Holland 2010). Results were also calculated with 4% and 12% discount rate to better understand the robustness of our calculations. Prices, units, and the present value of benefits were calculated in a similar way.

Next, we calculate the net present value of each management option by subtracting the present value of costs from the present value 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. The benefit-cost ratio describes the relative efficiency of each management option.

Finally, estimates for individuals were scaled up to the village level. Specifically, a typical village in eastern Viti Levu comprises 45 households that each maintain 0.6 ha of productive land. Scaling up results does not change the overall ranking of management options because we assume constant economies of scale.

Key Results – African tulip tree

Different management options have differential impacts on the growth and spread of the African tulip tree. Management options considered in this analysis include doing nothing, maintaining the current management approach by the community, and adopting a more integrated management approach informed by expert opinion.

Do Nothing

This option represents typical progression of growth and spread across the landscape with little-to-no management. Under this scenario, the African tulip tree eventually occupies all ecologically suited environments when it reaches carrying capacity 40 years after being introduced to a given area. All other options are measured relative to the costs and benefits estimated under this option. Obviously, there are no management costs associated with this option, but it does result in damages to land-based production that could be avoided if the spread of the tree was controlled.

Current management approach

Based on survey findings, treatment methods include a mix of cutting, stacking and drying plant material, and later burning this material. Regrowth from the cut stumps, roots, and any plant material left in contact with the ground is pervasive.

Tractors and diggers have been used to pull smaller trees from the ground but this disturbance often leads to increased germination of seeds in the seed bank. Herbicides are sometimes used but incorrect herbicide application often result poor levels of control.

Most villages surveyed reported an increase in the number of trees in their community despite some management. Based on expert opinion, we assume that the long-run population of the African tulip tree is reduced by 50% relative to the "do nothing" scenario.

Integrated management approach

This approach targets trees of different sizes and ages. The "hack-and-squirt" control treatment method is used for all trees greater than 10 cm diameter breast height (DBH). Some of the larger trees are ring-barked while, "cut-stump" treatment is used on saplings and small trees . Smaller seedlings are hand-pulled. If possible, these treatments are followed by mechanical clearing using a bulldozer followed by replanting with crops or pasture. Subsequently, herbicides and/or hand-pulling are used to remove all emerging seedlings including, those of other invasive plant species.

Based on expert opinion, we assume that the long-run population of the African tulip tree is reduced to 10% of that under the "do nothing" scenario.

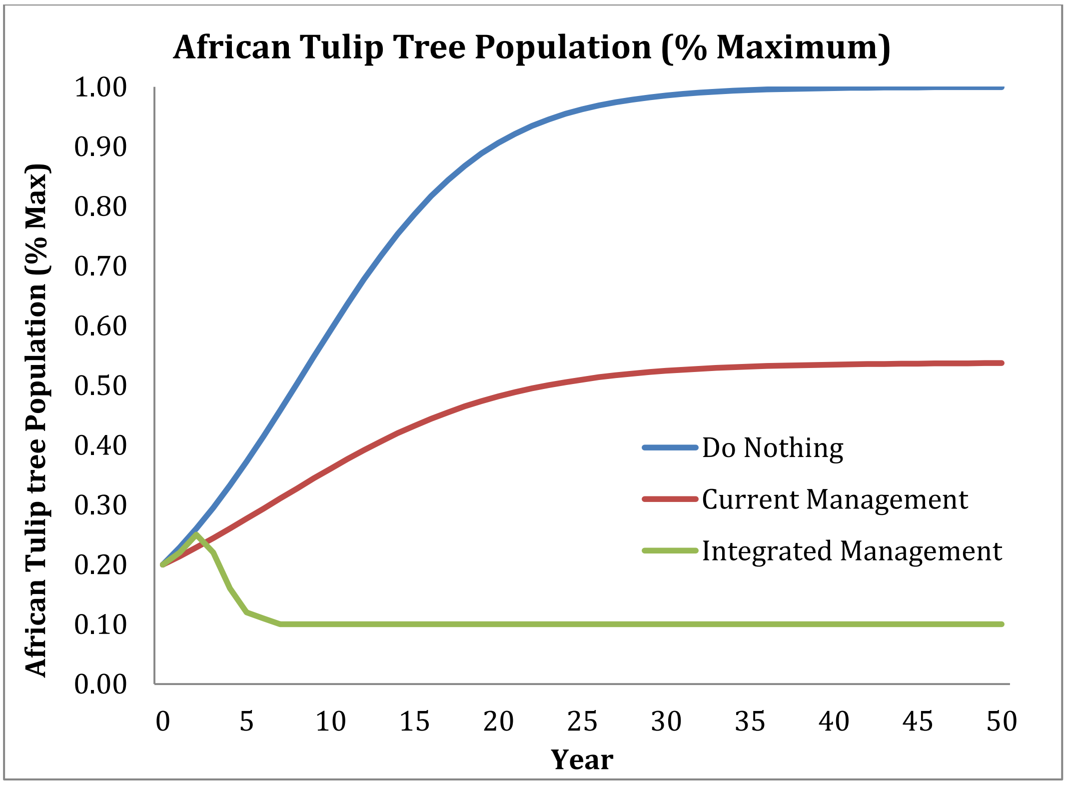

Figure 7 Change in African tulip tree population (as % carrying capacity) over time and management option

Benefits and Costs of Management

The focus of this analysis is on the direct economic impacts of the African tulip tree, namely the benefits of avoided damages to livestock, crop, and forestry yield. It is likely that other benefits such as biodiversity protection will also be positive as landowners are less likely to clear more natural forests for cultivation if the African tulip tree is controlled. We estimate that crop, livestock, and forestry production diminishes by 20% in the presence of African tulip trees due to competition under which scenario. Typical costs of controlling the African tulip tree include labour, herbicides, bulldozer or digger rental, and capital costs (e.g., chainsaws and herbicide sprayers).

Cost-Benefit Analysis

Estimated damages under the three management options are shown in Figure 78.

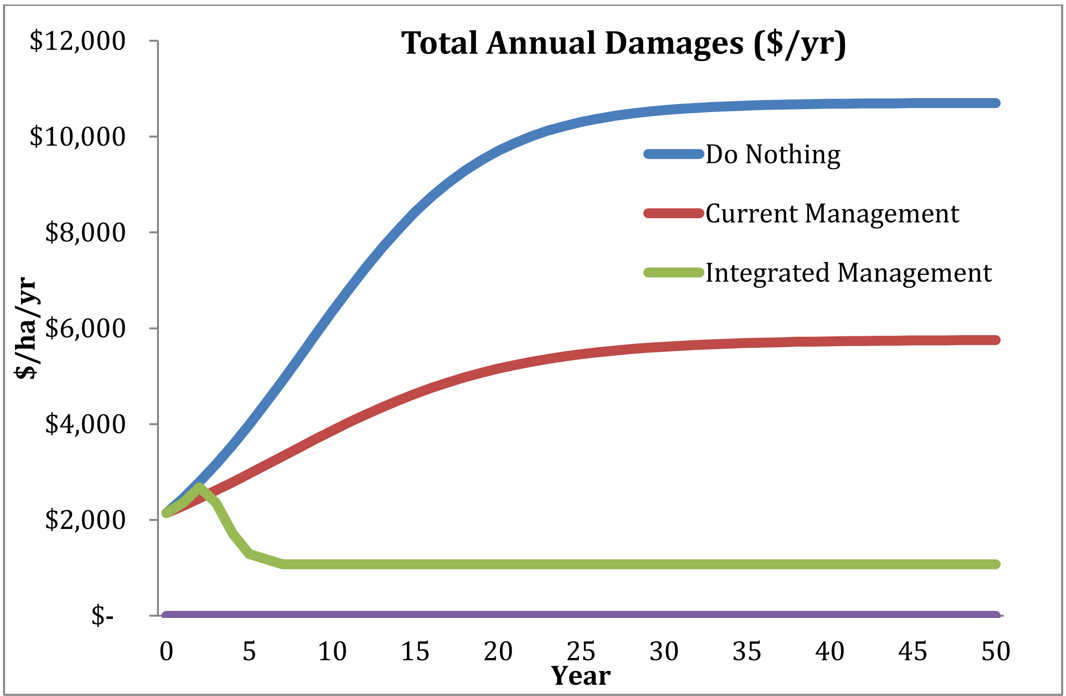

Figure 8 Total value of annual damages ($/ha) from for African Tulip tree under the three management options

Using pricing data from survey and government sources, we find that the integrated approach yields the highest net present value (Table 1) and is therefore the most efficient management option from an economic perspective, provided that people have the additional funding and knowledge to implement it. Nevertheless, the current management option also yields a positive NPV, indicating that it is preferred over undertaking no management at all.

Table 1. Summary of benefit-cost analysis (r = 8%, T= 50 years, study area = 1 ha)

Option	PV Costs	PV Benefits	Total NPV	Benefit-Cost Ratio	Rank
Do Nothing	$0	$0	$0	1.0	3
Current Management	–$11,201	$30,305	$19,104	2.7	2
Integrated Management	–$16,255	$60,351	$44,097	3.7	1

Key Results – small Asian mongoose

Different management options have differential impacts on the population of the small Asian mongoose. Management options considered in this analysis include doing nothing, live trapping, kill trapping, and hunting.

Do Nothing

This option represents typical progression of growth and spread across the landscape with little-to-no management. Under this scenario, the small Indian Mongoose continues to occupy all ecologically suited environments at its carrying capacity. All other options are measured relative to the costs and benefits estimated under this option. Obviously, there are no management costs associated with the do nothing option, but it does result in damages that could be avoided if the spread of the mongoose was controlled.

Live Trapping

Trapping is a relatively inexpensive approach that is often successful at removing animals in the short term. However, traps must be regularly maintained as mongooses can rapidly re-colonise trapped areas. Mongooses can follow scents up to 500 m, so relatively inexpensive live traps (e.g., Haguruma) are set on a grid every 200 m (or about 1 trap/ha) to ensure appropriate coverage for the entire village boundary (William Pitt, USDA, pers. comm.). Because mongooses appear not be selective and consume most bait types (Creekmore et al. 1994), trapping is likely to be highly effective. This method requires skilled and intensive labour as traps must be checked daily. Mongooses captured in live traps can be consumed as food.

Kill Trapping

Similar to live trapping, kill traps are set on a grid every 200 m (or about 1 trap/ha) for the entire village boundary (William Pitt, pers. comm.). Non-toxic bait should be used and mongoose captured in kill traps could be consumed as food if the kills are fresh. Traps must be checked daily initially (to refill stations) but longer term programs require less frequent checks. Key considerations include bait type, baiting density, non-target species, and timing (Barun et al. 2011). We assumed that this option can potentially reduce the mongoose population to less than 20% of carrying capacity over the project period, although it could vary by site and number of traps per hectare.

Hunting

This approach requires significant labour as well as capital for hunting (e.g. guns and ammunition). This approach could be effective when the population is high but could require a high level of effort per kill (e.g., search costs) for lower populations. Some experts have stated that hunting is not known to be employed or expected to be effective (Barun et al. 2011), althought our study found that it is currently being done in nearly 50% of the villages surveyed. Therefore, we assume this option is less effective than trapping at controlling mongoose population, reducing it to about 50% below carrying capacity.

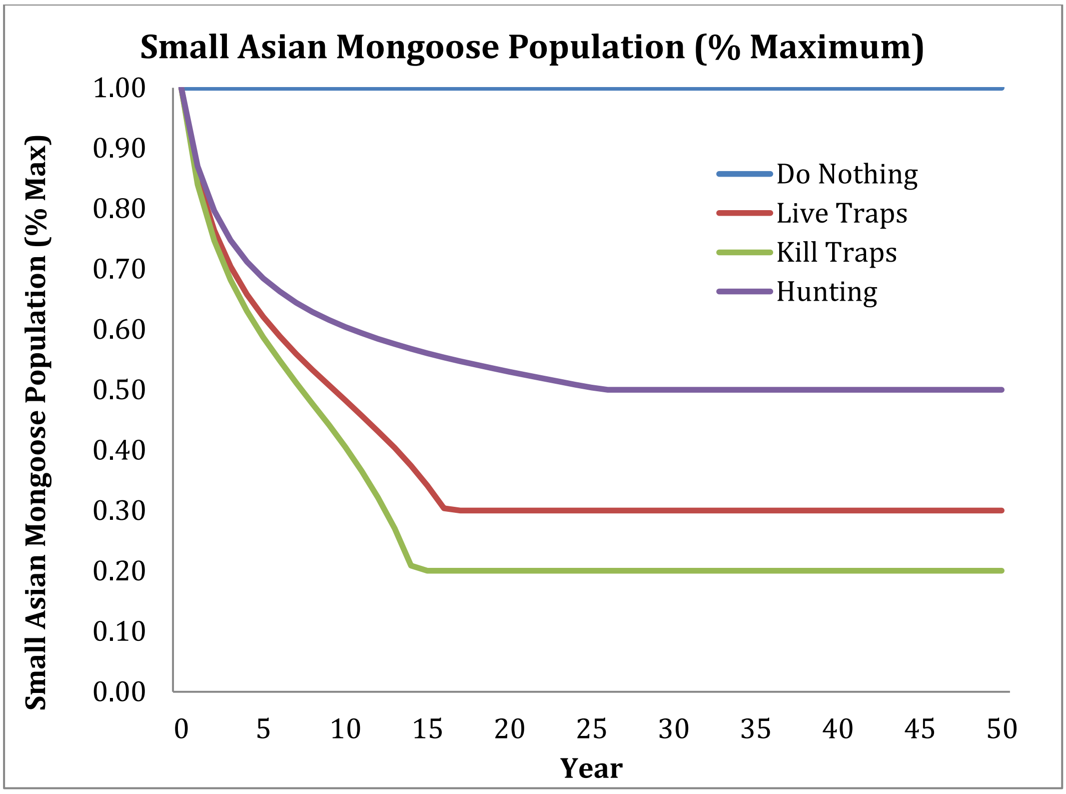

Figure 9 Change in small Asian mongoose population (as % carrying capacity) over time and management option

Benefits and Costs of Management

The focus of this analysis is on the direct economic impacts of the mongoose, namely the benefits of avoided damages in livestock and crop yields (e.g., bananas and plantains). It is likely that other benefits such as biodiversity protection will also be positive if the small Asian mongoose is controlled. Typical costs of controlling the mongoose include labour, non-toxic bait/lure, ammunition, maintenance and initial capital costs (e.g., guns and traps).

Cost-Benefit Analysis

Estimated damages under the three management options are shown in Figure 10.

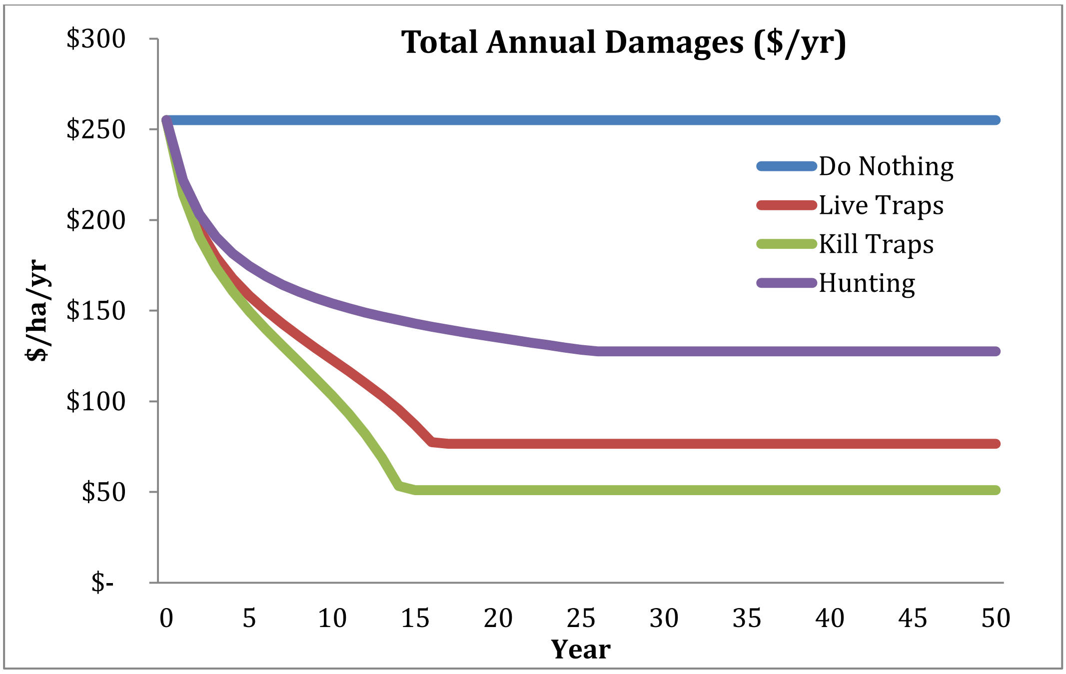

Figure 10 Total value of annual damages ($/ha) for small Asian mongoose under the three management options

Using pricing data from survey and government sources, we find that hunting yields the highest cost-benefit ratio (Table 2) and is therefore the most efficient management option from an economic perspective. Nevertheless, all three management options yield positive NPVs, indicating that they are preferred over undertaking no management at all.

Table 2. Summary of benefit-cost analysis (r = 8%, T= 50 years, study area = 1 ha)

Option	PV Costs	PV Benefits	Total NPV	Benefit-Cost Ratio	Rank
Do Nothing	$0	$0	$0	1.0	4
Live Traps	–$1,151	$1,533	$382	1.3	3
Kill Traps	–$1,201	$1,747	$546	1.5	2
Hunting	–$617	$1,140	$523	1.8	1

Key Results – Taro beetle

Different management options have differential impacts on the growth and spread of taro beetle. Management options considered in this analysis include doing nothing, switching out of taro into other crops, cultural control, and applying pesticides.

Do Nothing

Households currently spend close to zero time actively managing the taro beetle, thus allowing this invasive species to reach the estimated carrying capacity within about 10 years. At that time, taro yield will fall by approximately 30% (Lal et al 2008).

Switch cropping

If farmers in affected villages replant their taro fields with cassava, both the population of taro beetle and the total production of taro will fall to zero. While it is feasible that taro could be replanted after the beetle is eradicated, we assume that cassava is planted instead for the entire project period of 50 years.

Cultural control

Farmers are assumed to continue planting taro but also to implement more effective crop management practices, including more frequent crop rotation, using clean planting material, flooding, trap cropping, and destroying breeding sites. Additional costs will largely comprise labour required to closely monitor and manage the taro crop. In this scenario, the population of the beetle will be maintained at the same level as the initial period for the duration of the project.

Chemical control

Confidor applied at a rate of 5 g per plant could raise the yield of marketable taro corms to as much as 97% of the expected production with no beetle-related impacts (Lal et al 2008). As a result, we assume that annual spraying will eradicate the pest within 10 years.

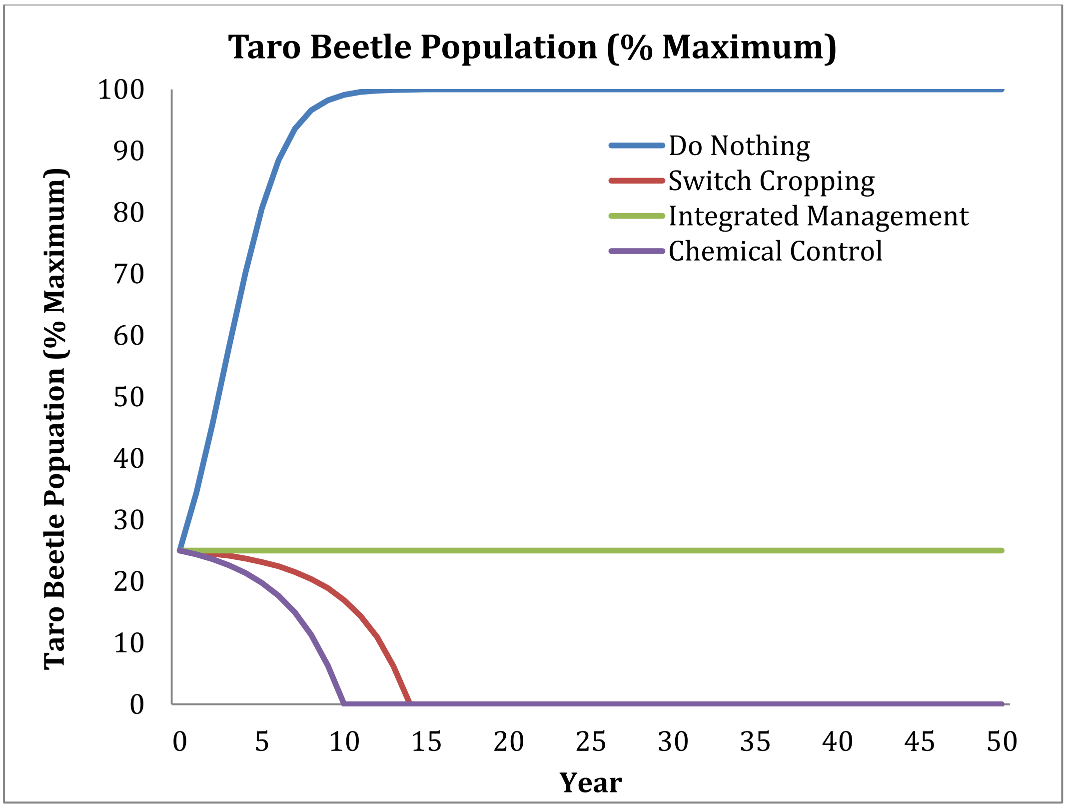

Figure 11 Change in taro beetle population (as % carrying capacity) over time and management option

A fourth option, biological control, was also considered. Trials of the ability for the fungus Metarhizium to reduce the impacts from taro beetles have been undertaken, but as yet there is no recommendation for farmers. Additionally, a virus has been developed, but it has not yet demonstrated success in reducing beetle population (ISSG Database). Given that the effectiveness of these options is not yet known, they were not included in the assessment.

Benefits and Costs of Management

The focus of this analysis is on the direct economic impacts the taro beetle, namely the benefits of avoided damages in crop yields. However, we also account for the cultural value of taro in rural Fiji by attributing an extra 10% of the market value of the crop.

Cost-Benefit Analysis

Estimated damages under the three management options are shown in Figure 712.

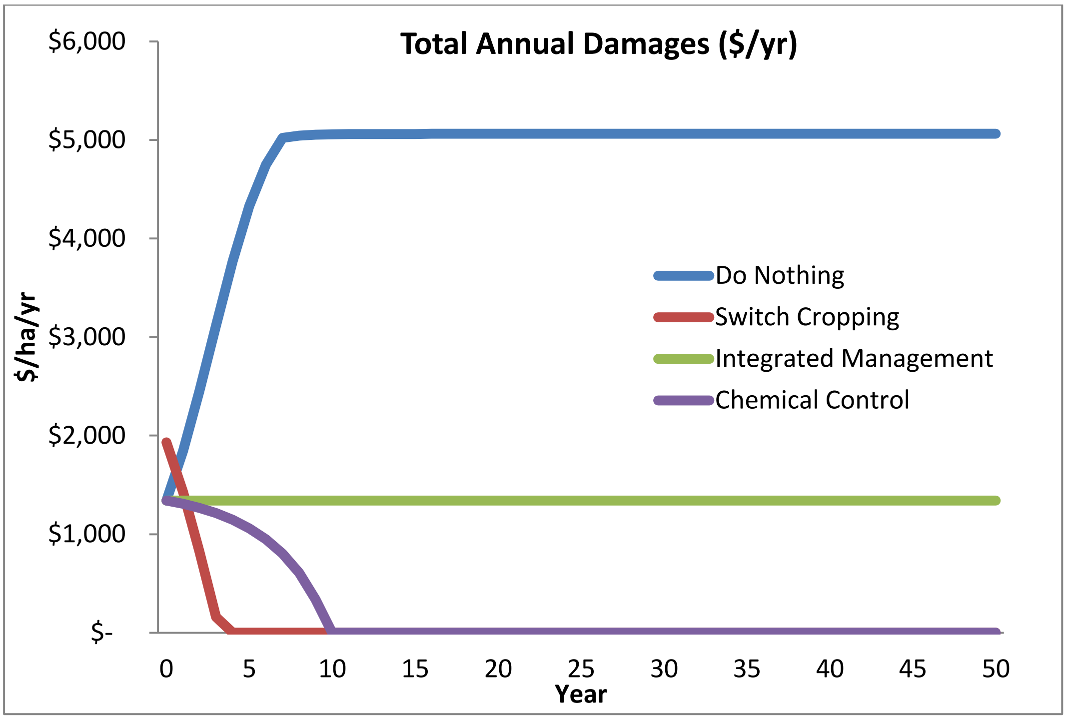

Figure 12 Total value of annual damages ($/ha) from for taro beetle under the four management options

Using pricing data from survey and government sources, we find that chemical control yields the highest cost-benefit ratio (Table 3) and is therefore the most efficient management option from an economic perspective. Nevertheless, all three management options yield positive NPVs, indicating that they are preferred over undertaking no management at all. This result holds even when accounting for the potential loss in cultural values from not growing taro, as in the case of the crop switching option.

Table 3. Summary of benefit-cost analysis (r = 8%, T= 50 years, study area = 1 ha)

Option	PV Costs	PV Benefits	Total NPV	Cost-Benefit Ratio	Rank
Do Nothing	$0	$0	$0	1.0	4
Switch Cropping	–$2,000	$11,293	$9,293	5.6	3
Cultural Control	–$11,377	$37,071	$25,693	3.3	2
Chemical Control	–$6,706	$47,100	$40,394	7.0	1

Key Results – Red-Vented Bulbul

Different management options have differential impacts on the population of the red-vented bulbul. Management options considered in this analysis include doing nothing and two interventions to limit damage to crops. We do not consider options such as trapping as there is limited knowledge of whether trapping is a viable management option in the Pacific.

Do Nothing

This option assumes that communities maintain the status quo of putting no noticeable effort into controlling the red-vented bulbul or into protecting crops. This approach results in the bird having a steady impact on agriculture.

Crop Management

The bulbul is attracted by edible weeds, so frequent weeding or applying herbicides reduces damage. Staking crops to raise them above ground may also increase yields. Hence, crop management entails investing more time and effort into weed control, applying herbicides, and staking crops. Some fruits and vegetables are also harvested earlier in the season and ripened under cover to avoid them being consumed by the bulbul when they are ripening. Such management interventions may reduce yield losses by half.

Crop Protection

Placing nets over vulnerable crops reduces damages caused by the red-vented bulbul. In this case, we assume that farmers place netting over all crops. Crops that cannot be covered with nets are harvested and stored under cover before they ripen, where possible. As with crop management, impacts from the bulbul are reduced by about one-half under this management option.

Benefits and Costs of Management

The focus of this analysis is on the direct economic impacts of the bulbul, namely the benefits of avoided damages in crop yields. Note that it is likely that the non-quantified benefits of control such as reduction in seed dispersal of invasive weeds will also have positive economic value, and thus the figures listed here are likely to be an underestimate of the total benefits from managing bulbuls.

Cost-Benefit Analysis

Estimated damages under the three management options are shown in Figure 713.

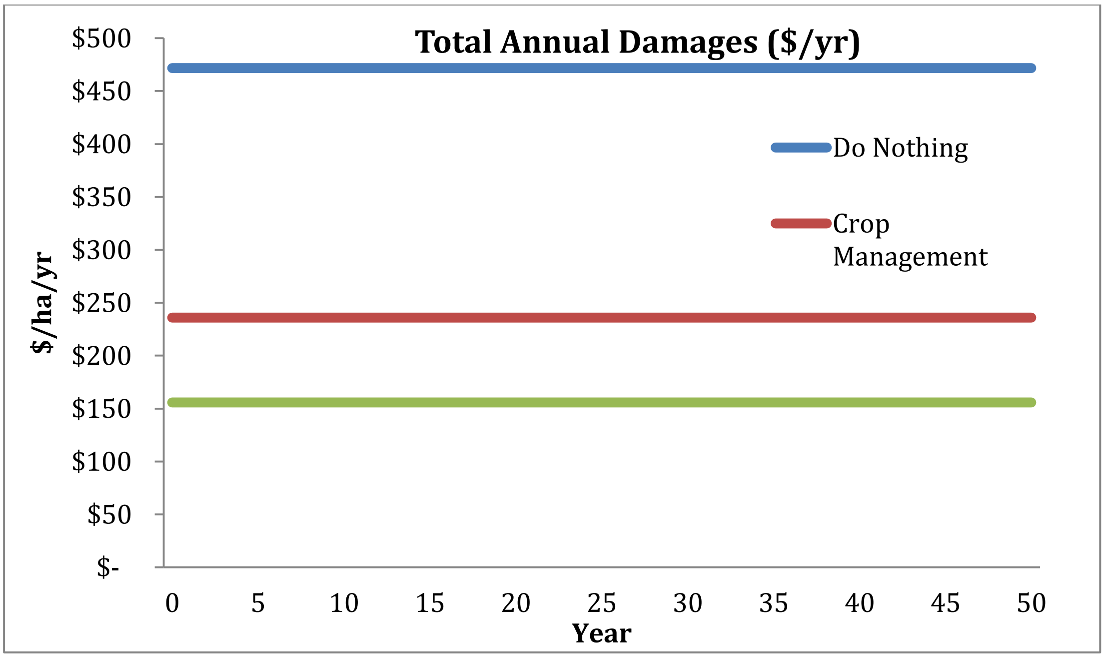

Figure 13 Total value of annual damages ($/ha) from for red-vented bulbul under various management options

Using pricing data from survey and government sources, we find that the present value of costs of implementing either management option outweighs the present value of benefits accrued over the same period compared to the status quo (Table 4). We thus recommend taking no action against the bulbul until such time as other benefits and or means of control have been field tested. Regardless, this result is in line with nearly all respondents to the surveys indicating that they spend little to no effort to mitigate the impacts of the red-vented bulbul on their agricultural yields.

Table 4. Summary of benefit-cost analysis (r = 8%, T= 50 years, study area = 1 ha)

Option	PV Costs	PV Benefits	Total NPV	Benefit-Cost Ratio	Rank
Do Nothing	$0	$0	$0	1.0	1
Crop Management	–$19,574	$3,122	–$16,451	0.16	3
Crop Protection	–$12,466	$4,184	–$8,282	0.34	2

Key Results – Merremia Vine

Different management options can have differential impacts on the growth and spread of the merremia vine. Management options considered in this analysis include the current community management approach, increased application of herbicides, and a more integrated management approach informed by expert opinion.

Do nothing

This option represents typical progression of growth and spread across the landscape with no management. Under this scenario, the merremia vine eventually occupies all ecologically suited environments when it reaches carrying capacity about 15 years after being introduced to the study site. All other options are measured relative to the costs and benefits estimated under this option. Obviously, there are no management costs associated with the do-nothing option, but it does result in damages to land-based production and native trees that could be avoided if the spread of the vine was controlled.

Current management approach

Based on survey findings, households spend the survey average of 13 person days/year clearing merremia. Treatment methods include a mix of cutting the vine, burning merremia patches, and using a small amount of herbicides. This approach can mitigate the potential damage caused by the invasive vine, but only to a certain degree. Most villages surveyed reported an increase in merremia in their community despite some management, and therefore we assume that the long-run population of the merremia vine is reduced by about 50% relative to the do-nothing scenario.

Chemical application

This option assumes that chemical herbicides are the primary way to control merremia. We assume that control work is undertaken on all disturbed land in the village as that is the area most sensitive to merremia infestation. Spot treatment is also done on significantly affected areas adjacent to the primary treatment sites. All rooting stems and tubers are treated with suitable herbicide, but the exact treatment method used depends on the site and number of established vines. Effort is also made to only apply herbicides to the target plant (i.e. treatment methods must avoid any off-target damage to native plant species). As a result, we assume that annually spraying herbicides at the recommended rate will keep the population of merremia steady at about 20% of carrying capacity.

Integrated management approach

This approach builds on the methods used in the other two management options but with a more integrated and rigorous manner. First, a machete can be used to slash merremia stems out of host trees, where vines are cut as close as practical to ground level. Second, all rooting stems and tubers are then treated with suitable herbicide in the same manner as the chemical application option. Third, emerging merremia plants are dug out or treated with suitable herbicide, and any seedlings germinating from seed can be hand-pulled. Fourth, trees are planted to promote shade and minimise spread of the vine to native vegetation areas.

Cost-Benefit Analysis

Estimated damages under the four management options are shown in Figure .

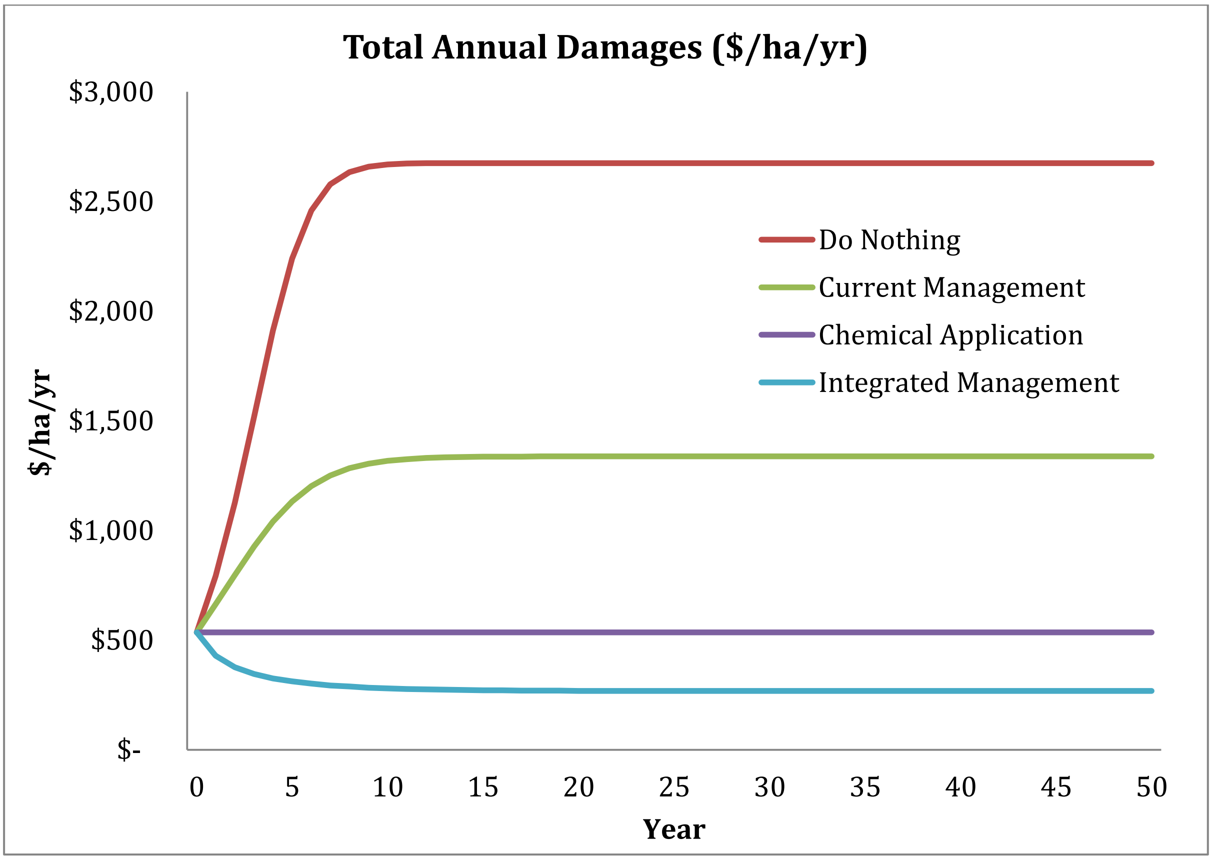

Figure 14 Total value of annual damages ($/ha) from for Merremia Vine under thefour management options

Using pricing data from survey and government sources, we find that the current management approach of using a mix of limited-levels of labour and herbicides to control the vine yields the highest net present value (**Table 5**). It is therefore the most efficient management option from an economic perspective, provided that people have the additional funding and knowledge to implement it. Nevertheless, the more intensive integrated management option also yields a positive NPV, indicating that it is preferred over undertaking no management at all.

Table 5. Summary of benefit-cost analysis (r = 8%, T= 50 years, study area = 1 ha)

Option	PV costs	PV benefits	Total *NPV*	Benefit–Cost Ratio	Rank
Do nothing	$0	$0	$0	1.0	3
Current management	-$6,044	$13,261	$7,216	2.2	1
Chemical application	-$21,669	$21,102	-$567	1.0	4
Integrated management	-$19,232	$23,920	$4,688	1.2	2

4 Summary

Invasive species pose an enormous threat in the Pacific: not only do they strongly affect biodiversity, but they also potentially affect the economic, social, and cultural well-being of Pacific peoples. Invasive species can be managed and their impacts can be avoided, eliminated, or reduced. However, neither the costs nor the numerous benefits of management are well understood in the Pacific.

In this project, we undertook cost-benefit analyses of managing five species in Viti Levu, Fiji: *spathodea campanulata* (African tulip tree), *herpestus javanicus* (small Asian mongoose), *papuana uninodis* (Taro beetle), *pycnonotus cafer* (red-vented bulbul), and *merremia peltata* (merremia vine). These CBAs were 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 invasive species, both direct (e.g., the values of crops lost to invasive pests such as the taro beetle) and indirect (e.g., the time that individuals spend pulling merremia vine). They also document novel management practices (e.g., some villages kill African tulip tree stumps by burning tyres around them) and, importantly, personal attitudes toward each invasive species. Specifically, when asked to reallocate Fiji's national budget according to their own spending priorities, survey respondents would allocate approximately 7% of the national budget for invasive species management.

Cost-benefit analysis revealed that an integrated approach (which includes cutting, stacking and drying, and burning) is more cost effective than current management practices for controlling the spread of African tulip tree. Kill traps are more cost effective than live traps and hunting for controlling small Asian mongoose. Given the importance of taro in Fijian culture, increased pesticide use is more efficient for controlling taro beetle than integrated approaches or switching out of taro in favour of cassava. The current approach (i.e., weeding and cutting) to managing merremia vine is more cost effective than either pesticides or integrated management. Finally, managing or protecting crops to alleviate damaged caused by the red-vented bulbul was not estimated to produce net economic benefits. These findings are reported in a series of short technical reports and factsheets, each covering a different target species, available by request from the authors.

5 Acknowledgements

The results presented in this paper are derived from a joint project with the Pacific Invasives Initiative (PII) and the Institute of Applied Science at the University of the South Pacific (USP). See Daigneault et al. (2013). Souad Boudjelas, John Mather, and Bill Nagle at PII generously shared their profound expertise about the spread and management of invasive species with the authors and won us over with their dedication. Bill Aalbersberg facilitated the research by opening every door we faced working in the Pacific.

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, without whom this work would not have been possible.

Randy Thaman (USP) was an indefatigable source of knowledge and enthusiastic participant in community surveys. Apisai Bogiva (USP) capably led data collection for the household survey. James Comley (USP) graciously coordinated data entry and helped to troubleshoot problems as they arose.

We also acknowledge Nature Fiji for contributing enumerators and extending data collection efforts to Taveuni.

Arne Witt (CABI), Kimberly Burnett (University of Hawaii), Chris Buddenhagen (independent), Sugoto Roy (The Food and Environment Research Agency), and Anna Fink (SPC) reviewed the management options, pricing, and biological underpinnings of the CBAs.

Aaron Bunkle (SPREP) and Paula Holland (SOPAC) contributed significantly to the CBA Manual.

Sunil Kumar, Jagdish Bhati, Gilianne Brodie, Dan Orcherton, Hilda Waka and Morgan Wairiu (USP), Iliasa Dakaica (Biosecurity Fiji), Don Stewart and Steve Cranwell (Birdlife International), Marita Manley (Deutsche Gesellschaft für Internationale Zusammenarbeit), Jonathan Bower (SPC), Li Dovey (SPREP), Scott Hook (Pacific Island Forum Secretariat), Bernard O'Calloghan (IUCN), and Padma Lal (Commonwealth Scientific and Industrial Research Organisation) were also instrumental in shaping this research.

Finally, we would like to thank our colleagues at Landcare Research, Pacific Invasives Initiative, and the Institute of Applied Science at the University of the South Pacific who provided valuable advice during all phases of this project.

6 References

Barun A, Hanson CC, Campbell KJ, and Simberloff D. 2011. A review of small Indian mongoose management and eradications on islands. In: Veitch CR, Clout MN, Towns DR eds Island invasives: eradication and management. Gland, Switzerland, IUCN. Pp. 17–25.

Boardman N 2006. Cost-benefit analysis, concepts and practice. 3rd edn. Upper Saddle River, NJ, Prentice Hall.

Creekmore TE, Linhart SB, Corn JL, Whitney MD, Snyder BD, Nettles VF 1994. Field evaluation of baits and baiting strategies for delivering oral vaccine to mongooses in Antigua, West Indies. Journal of Wildlife Diseases 30: 497–505.

Daigneault A, Brown P, Greenhalgh S, Boudjelas S, Maher J, Nagel W, Aalbersberg W 2013. Valuing the Impact of Selected Invasive Species in the Polynesia-Micronesia Hotspot, Landcare Research New Zealand Limited, LC1227. 239 p.

Emerton L, Howard G 2008. A toolkit for the economic analysis of invasive species. Nairobi, Kenya, Global Invasive Species Programme. 110 p.

European Commission undated. Guide to cost-benefit analysis of investment projects, available online at: http://ec.europa.eu/regional_policy/sources/docgener/guides/cost/guide2008_en.pdf.

European Commission 1997. Manual: financial and economic analysis of development projects: methods and instruments for project cycle management. Brussels, Belgium, European Commission.

Hanley N, Spash C 1993, Cost-Benefit Analysis and the environment. Cheltenham, UK, Edward Elgar.

HM Treasury 2003. The green book: appraisal and evaluation in Central Government: Treasury guidance, London. http://www.hm-treasury.gov.uk/data_greenbook_index.htm (accessed 28 August 2012).

Invasive Species Specialist Group (ISSG) 2013. Global Invasive Species Database, Pycnonotus cafer (bird). http://www.issg.org/database/species/references.asp?si=138&fr=1&sts=sss&lang=EN

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

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

Landcare Research 2011. Economic Impacts of Invasive Species in Fiji. Landcare Research Contract Report LC 727 Prepared for Critical Ecosystems Partnership Fund. 12p.

Mishan E 1988. Cost Benefit Analysis. London, Allen and Unwin.

OECD 2006. DAC guidelines and reference series applying strategic environmental assessment. Available online at: http://www.oecd.org/environment/environment-development/37353858.pdf

Seidel H, Lal PN 2010. Economic value of the Pacific Ocean to the Pacific Island countries and territories. Gland, Switzerland, IUCN.

SPREP, SPC 2009. Guidelines for invasive species management in the Pacific : a Pacific strategy for managing pests, weeds and other invasive species. Compiled by Alan Tye. Apia, Samoa : SPREP, 2009. 24p.

Tietenberg T 2006. Environment and natural resource economics. 5th edn. Reading, MA: Addison-Wesley Longman.

UNECE 2007. Final draft resource manual to support application of the UNECE Protocol on Strategic Environmental Assessment.

USEPA 2010. Guidelines for preparing economic analyses. Washington DC, Office of the Administrator. Report, EPA 240-R-10-001. 272 p.

Veitch CR Clout MN, Towns DR 2011. Island Invasives: Eradication and Management. Proceedings of the International Conference on Island Invasives. Gland, Switzerland: IUCN and Auckland, New Zealand: CBB. xii + 542pp.

Wills I 1997. Economics and the environment: a signalling approach. Sydney, Allen and Unwin.