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Cost–benefit analysis of managing the invasive African tulip tree (*Spathodea campanulata*) in the Pacific

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ABSTRACT

Invasive alien species such as *Spathodea campanulata* (African tulip tree) threaten biodiversity in the Pacific islands as well as the economic, social, and cultural wellbeing of Pacific peoples. Despite the potential magnitude of these threats, our scientific understanding of the ecology and management of the African tulip tree is nascent. In this paper, we use data from novel surveys of households and communities to document the direct and direct impacts of African tulip tree in Fiji, focusing on those impacts which may be monetised. We use the same data to describe current management approaches and then describe a state-of-the-science, ''integrated'' management approach that employs different strategies for trees of different ages and sizes. These two approaches are then compared in a comprehensive cost–benefit analysis. We find strong arguments for pursuing the integrated management approach, which derives *monetised* benefits of $3.7 for each $1 spent. However, the less costly current approach is also strictly preferred to the baseline, ''do nothing'' approach, with monetised benefits of $2.7 for each $1 spent. Results of this analysis clearly show that managing African tulip tree is cost effective, even without explicitly considering biodiversity, culture, and other non-monetised benefits of control.

1. Introduction

Natural resources are critical to Pacific Island economies. At a regional level, the Pacific is among the most productive fishing grounds in the world (Seidl and 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 (Pacific Regional Statistics, 2013), and natural resources dominate the manufacturing and processing sectors across the region.

Natural resources are also 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*) refers to the land itself, to the people living on the land, and to the customs and value systems of those people.

Unfortunately, natural resources in the Pacific are under threat from pests and invasive alien species (IAS), which pressure agriculture, livestock, fisheries, and forests, and thus the economic, social, and cultural wellbeing of Pacific peoples. Given the magnitude of the potential problems caused or exacerbated by IAS, it is notable that data pertaining to their

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[1] Brown and Daigneault co-led the data collection, analysis, and write-up of this project. Following convention in the economics discipline, the authors are listed alphabetically.

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biological characteristics, the damages that they cause, and the effectiveness of management options is so scarce.

For example, despite the fact that *Spathodea campanulata* (African tulip tree) is considered to be among the 100 worst IAS by the International Union for the Conservation of Nature (Lowe et al., 2004), there are relatively few articles in the scientific literature that document its establishment and spread, its biological characteristics, or options for effective management, particularly in the Pacific. While local knowledge for managing the African tulip tree is abundant, this knowledge has not been harnessed, and there is little consensus on the physical effectiveness of various management strategies, even between neighbouring communities.

If the natural science literature on the African tulip tree is sparse, studies that describe the ecological, economic, social, and cultural impacts of this species in the Pacific are virtually non-existent. The costs of management are also poorly quantified, and as such, governments in the Pacific have done little to control its spread, putting livelihoods at risk and leaving individuals responsible for management.

Yet, evidence demonstrates that IAS may be managed and that their impacts may be avoided through prevention, eliminated through eradication, or reduced through control (Veitch et al., 2011). Quantifying the threat posed by African tulip trees, documenting practices for controlling the species, and understanding the costs and benefits of various management options could thus help decision makers to understand the threat posed by African tulip tree and to make more informed policies for managing this species.

Combining primary-source data collected via matched household and community surveys with expertise on the biology and ecology of African tulip tree, we quantify the monetisable costs and benefits of various management regimes in Viti Levu, Fiji, where this IAS is well established in farmed fields and on other disturbed lands (Auld and Nagatalevu-Seniloli, 2003). While multi-decision criteria analysis has recently been advocated for selecting among competing options in managing IAS (e.g., Born et al., 2005), few economic studies have adopted this approach. Accordingly, in this analysis, we employ cost–benefit analysis (CBA) – which is noted for its tractability, methodological transparency, and wide adoption among governments and makers of environmental policy (Pearce et al., 2006) – to rank management options.

The remainder of this paper is organised as follows: Section 2 describes the ecology of the African tulip tree; Section 3 summarises the use of CBA in the IAS literature; Sections 4 and 5 describe the survey research methods and results, respectively; Sections 6 and 7 present our approach to CBA and the results, respectively; and Section 8 concludes.

2. Ecology of the African tulip tree

In 1936, the African tulip tree was introduced as an ornamental plant to Fiji, where it thrived in gardens due to its preference for moist soils in sheltered tropical areas in elevations up to 1200 m (Smith, 1985; PIER, 2002). Its invasive characteristics, wind-blown seed, and vegetative propagation allowed the African tulip tree to escape quickly (World Agroforestry Database, 2014), and it now dominates disturbed lands – including agricultural areas and forest plantations as well as natural ecosystems. Mature stands typically contain up to 4000 plants per hectare (Francis, 1990), and stands of 12,000 plants per hectare have been recorded.

Mature African tulip trees, which have buttressed trunks and thick branches, grow to heights of 25 m or more. Native plants are eliminated by the shading effect of the large leaves, resulting in reduced biodiversity under the tree canopies (Weber, 2003).

Showy red flowers produce capsules containing tiny winged seeds that are dispersed by air, with mature trees producing thousands of seeds each season. Although the viability of seeds deteriorates quickly in Fiji's humid climate (World Agroforestry Database, 2014), seeds have been recorded as having viability rates of up to 80% (Fosberg et al., 1979), with higher germination rates in semi-shaded and highly disturbed areas such as farms and forest edges (Weber, 2003). Reproduction also occurs via suckering and via new growth from stem or trunk sections that have prolonged contact with soil (Space et al., 2004). Regrowth is especially vigorous from any trees cut at stump level and not treated with suitable herbicide.

The population of African tulip tree follows a logistical biological growth curve until it reaches a carrying capacity of about 4000 trees per hectare approximately 40 years after establishment (Lugo and Helmer, 2004). Half of the total carrying capacity is reached 20–25 years after forest establishment (Lugo and Helmer, 2004), indicating a population growth parameter of 0.18 (Daigneault and Brown, 2013). That is,

$$N_{t+1} = N_t + 0.18\left(1 - \frac{N_t}{4000}\right), \quad (1)$$

where N is the number of stems per hectare and t is the time period measured in years. The African tulip tree is notoriously difficult to control, although seedlings and small trees may be successfully pulled or dug out (Englberger, 2009). For larger trees and stumps, Englberger, 2009 suggests spraying glyphosate into 1-inch notches cut into the cambium while Motooka et al., 2003 suggests applying 2,4-D and triclopyr to basal bark of saplings. Traditional methods for controlling African tulip trees diverge considerably from these recommendations, as detailed in Section 5, and regrowth from the cut stumps, roots, and any plant material left in contact with the ground is pervasive.

Given the difficulty and expense of management, some farmers in the Pacific resort to clearing additional areas of natural forest and bush. While this solves the problem of encroaching trees in the short term, this practice ultimately provides additional disturbed land that the African tulip tree may colonise.

3. Cost–benefit analyses of managing invasive alien species

While we are unaware of existing studies that undertake rigorous economic analyses of managing African tulip tree in the Pacific or elsewhere, there exists a nascent literature on the costs and benefits of managing IAS more generally. The vast majority of these studies employ CBA – a widely used, systematic approach to identifying, valuing, and comparing costs and benefits projects – to justify allocating scarce financial resources across competing projects.

For example, Gaertner et al., 2012 conduct an economic analysis of restoring areas impacted by IAS in South Africa and conclude that active restoration may be more effective and less costly than passive restoration, depending on the density of invasion. Lehrer et al., 2011 use non-market valuation methods to estimate the economic value of ecological damage caused by *Acacia saligna* in Israel; they demonstrate positive net benefits for undertaking an eradication campaign in nature reserves even under extremely conservative assumptions of value. Wit et al., 2001 and McConnachie et al., 2003 calculate the benefit-cost ratio of controlling *Acacia mearnsii* and *Azolla filiculoides* in South Africa to be 2.5:1 and 2.6:1, respectively. In Australia, Cullen and Whitten, 1995 evaluate the costs and benefits of controlling *Rubus fructicosus* and *Echium plantaginetum* to calculate returns of $20–$43 for each $1 spent on management.

In the Pacific region, Burnett et al., 2012 monetise the costs and benefits of banning importation of non-seed *Myrtaceae* plant material in Hawai'i and conclude that the benefits to the forest plantation industry stemming from a complete ban outweigh the costs to other affected sectors. Similarly, Burnett et al., 2008 assess the return on investment from biosecurity measures to prevent *Boiga irregularis* from entering Hawai'i, actively searching for incursions, and passively searching for incursions, finding that biosecurity is a losing proposition while active searching has high payoffs. In Fiji, Brown and Daigneault, 2014a,b demonstrate the cost effectiveness of actively managing invasive *Herpestus auropunctatus* and *Papuana uninodis*; in both cases, they evaluate multiple management options and describe the robustness of their findings via sensitivity analysis.

Born et al., 2005 critically analyse ''economic'' studies on prevention, eradication, and control of IAS. While each of the 23 studies that they consider monetise costs or benefits of management, only 10 succeed in doing both. Among these 10, only three evaluated management *ex ante*; the remaining were used to legitimate measures already undertaken as opposed to assessing new mitigation strategies. Born et al., 2005 also note that serious cost–benefit analyses of managing IAS have concentrated on a handful of countries, most notably Australia, Germany, New Zealand, South Africa, and the United States.

4. Survey research methods

To better understand the social and economic impacts of IAS such as the African tulip tree 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 the African tulip tree is well established since first introduction nearly 80 years ago. 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; agricultural extension activities. The mean village comprises 44 households (Table 1), each with 5.2 household

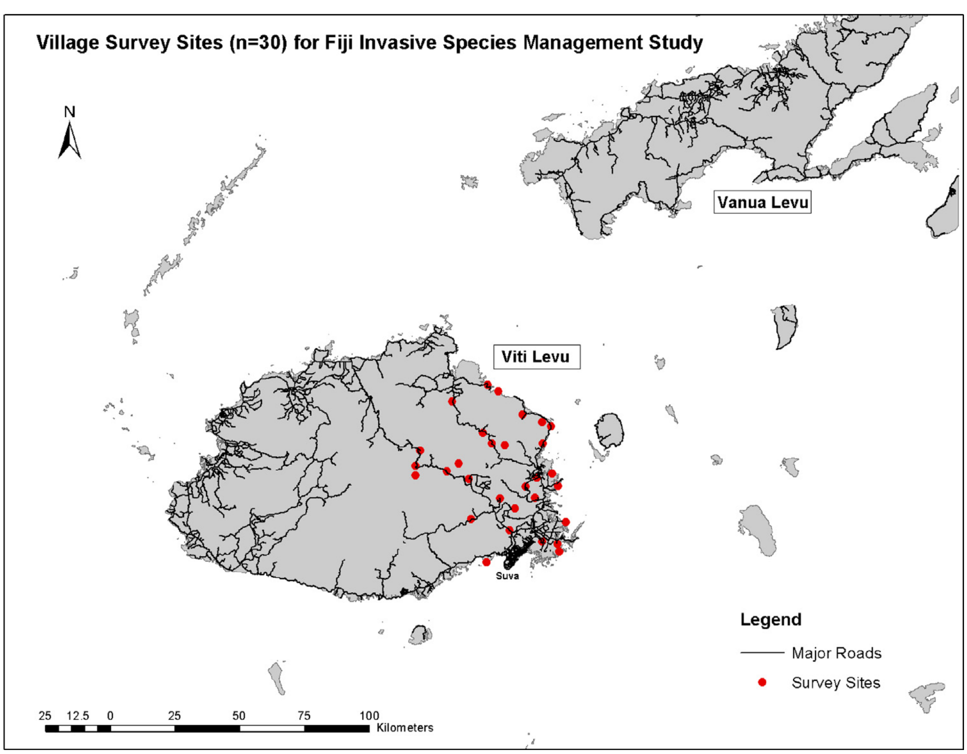

Fig. 1 – Surveyed villages.

Table 1 – Summary statistics.

Variable	Unit	10th Percentile	Mean	90th Percentile
Households per village	Households	20	44.10	64
Number of people in the household	People	2	5.17	8
Education of household head	Years	6	9.50	12
Total household income	FJ $	1959	22,929	60,764
Share of income derived from crops	%	13.02	71.14	100
Amount of land planted per household	ha	0.24	1.47	3.58
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

members. The mean household is headed by an individual with 9.5 years of education. Household income averages $FJ 22,929,[2] although household income demonstrates a high degree of variability. The average household plants 1.5 ha 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, including both direct impacts (e.g., the cost of herbicides for treating African tulip trees) and indirect impacts (e.g., the shadow value of time spent pulling saplings). The survey also included several novel elements pertaining to the social and economic impacts of this IAS. First, respondents were asked whether they agreed with, disagreed with, or were neutral towards a series of value statements pertaining to the African tulip tree: specifically, ''it is bad that the African tulip tree is found in this village'', ''people in this village are unhappy when they see the African tulip tree'', ''there are more positive aspects of the African tulip tree than negative aspects'', and ''I would like to have fewer African tulip trees 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 the African tulip tree.

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.[3] 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 prioritise control of various species, including the African tulip tree. Thus, we are able to compare the perceived importance of controlling African tulip tree to the perceived importance of other budgetary priorities such as healthcare, education, and public order.

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'' (WTP) for environmental goods is identified via questions pertaining to tax increases; however, few rural-Fijian households pay taxes while virtually all of them contribute labour to providing or maintaining public goods in the village. Thus, our question was posed in terms of willingness to volunteer labour time to manually control the African tulip tree. 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 derives.

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 each species and, where applicable, the consequences of its presence and community practices for either encouraging or limiting its spread. Notably, respondents were asked to reflect on both the negative and positive (if any) impacts of each species.[4]

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

5. Survey results

Although the African tulip tree is widely considered to be an agricultural pest among ecologists, focus group respondents in our sample of 30 villages reported several benefits provided by the tree. Specifically, focus groups in 9% of villages reported that the tree provides habitat for animal species, including some used for food. A handful of respondents noted that the

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

[3] This exercise took the form of an interactive game in which 70 dried beans represented the approximately $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.

[4] The importance of asking about the positive attributes of IAS is reflected in Shackleton et al. (2007), who report that many rural South Africans make extensive use of IAS for consumptive purposes and would prefer higher population densities.

Table 2 – Responses to African tulip trees.

Variable	Unit	10th Percentile	Mean	90th Percentile
View of African tulip tree	−4 = ext. neg., +4 = ext. pos.	−4	−3.38	−2
Time spent clearing tulip, per week	Hours	0	3.69	7
Total spent on herbicides	FJ $	0	101.77	261
Share of national budget allocated to controlling ATT	Percent	0	2.30	4.29
Hours willing to volunteer per week to control African tulip tree[a]	Hours	4	11.27	24

$n = 360$.

[a] Among households who identified the African tulip tree as the worst IAS that they face.

tree also provides some erosion control on Fiji's steep volcanic slopes as well carbon sequestration. Finally, respondents in 52% of villages reported that timber from the African tulip tree may be used for building and respondents in 27% of villages reported that the tree is sometimes burned for firewood. However, the value of these potentially important benefits depends critically on the counterfactual: specifically, while most trees provide these benefits over disturbed grasslands, there is as-yet little scientific evidence to suggest that the African tulip tree is either a more effective sequestration device than other native species[5] or more effective at erosion control. Likewise, focus group respondents reported that other (particularly native) tree species provided better habitat for desirable species of birds, bats, and other animals. Finally, the high moisture content of its wood renders timber from the African tulip tree inferior to that of other common species.[6] These desirable characteristics of the African tulip tree are thus not explicitly incorporated into the analysis that follows.

Focus group respondents also noted several important negative characteristics of the African tulip tree. Namely, respondents in 76% of villages stated that the African tulip tree competes with crops in agricultural land, thereby reducing agricultural output. In nearly half of these villages, the African tulip tree has prompted some respondents to stop planting in the most affected areas because they were unable to keep up with the African tulip tree's aggressive spreading. In addition, respondents in 36% of villages argued that the African tulip tree reduces the quantity of land available for grazing livestock. Finally, respondents in 48% of the surveyed villages reported that the African tulip tree competes with other, more desirable trees that are used for medicinal purposes and/or firewood.

Cutting the trunks of large trees and pulling/digging smaller suckers and young trees (either manually or with the aid of machinery) from the ground were the most commonly reported control techniques, with respondents in 82% of the surveyed villages in which the African tulip tree is present employing these techniques. In 31% of impacted villages, cutting/pulling is augmented by burning tree stumps, sometimes by first wrapping gasoline-soaked tyres around the stumps. In one impacted village, tree stumps are treated with herbicides such as glyphosates instead of burning. 10% of impacted villages employ all three techniques (i.e., cutting/pulling, burning, and applying herbicides). In 7% of impacted villages, the African tulip tree is controlled by fire without first cutting trunks. Finally, 10% of impacted villages undertake no active management strategies. Such heterogeneity in approaches – even among neighbouring villages – underscores the lack of publicly available information about the cost effectiveness of each management option.

Respondents to the household survey were asked a series of four questions pertaining to their personal values and preferences regarding the African tulip tree. As noted in the previous section, although some questions were asked in the negative, all questions were re-written in the positive for the purpose of data analysis. Hence, aggregate scores ranged from −4 (extremely negative opinion) to +4 (extremely positive opinion). Over 92% of survey respondents viewed the African tulip tree unfavourably (i.e., the aggregate score was −2 or less), with 78% of survey respondents viewing the African tulip extremely negatively (i.e., the aggregate score was −4). Fewer than 3% of survey respondents had a favourable view of the invasive tree, on balance, and none held an extremely positive view (Table 2).

Most respondents stated that the African tulip tree had negatively impacted their livelihoods, and some were spending considerable effort to address the problem. On average, surveyed households spent 3.7 h/week cutting, digging, pulling, burning, or applying herbicides to control the African tulip tree. Surveyed households spends 34.5 h per week managing their crops, on average (Table 1), suggesting that just over 10% of that time is allocated specifically to controlling African tulip tree. This figure equates to 24 full working days each year, a significant loss of potential productivity.

Despite putting some effort into managing the African tulip tree, more than 95% of villages that were surveyed indicated that the population of the tree was increasing (Fig. 2).

Each survey respondent was asked to assume the role of Fiji's Minister for Finance and Strategic Planning, National

[5] On the contrary, indigenous forests contain more biomass and sequester more carbon than those that those comprised largely of African tulip trees. For example, Green (2010) estimates that the average hectare of indigenous lowland tropical forest in Fiji has 235tonnes of biomass and that it sequesters 118tonnes of carbon. By contrast, Lugo et al. (2011) estimate that the average hectare of African tulip trees has 178tonnes biomass and that it sequesters 89tonnes of carbon.

[6] Some observers in the scientific community (e.g., Watling, reported in SPC, 2013) have suggested that the African tulip tree's high water content would make it a suitable fire break between disturbed land and newly replanted forest. However, we know of no evidence establishing this possibility or any practical suggestions for preventing the African tulip tree from colonising the newly replanted areas. As such, this desirable characteristic of the African tulip tree is omitted from the analysis.

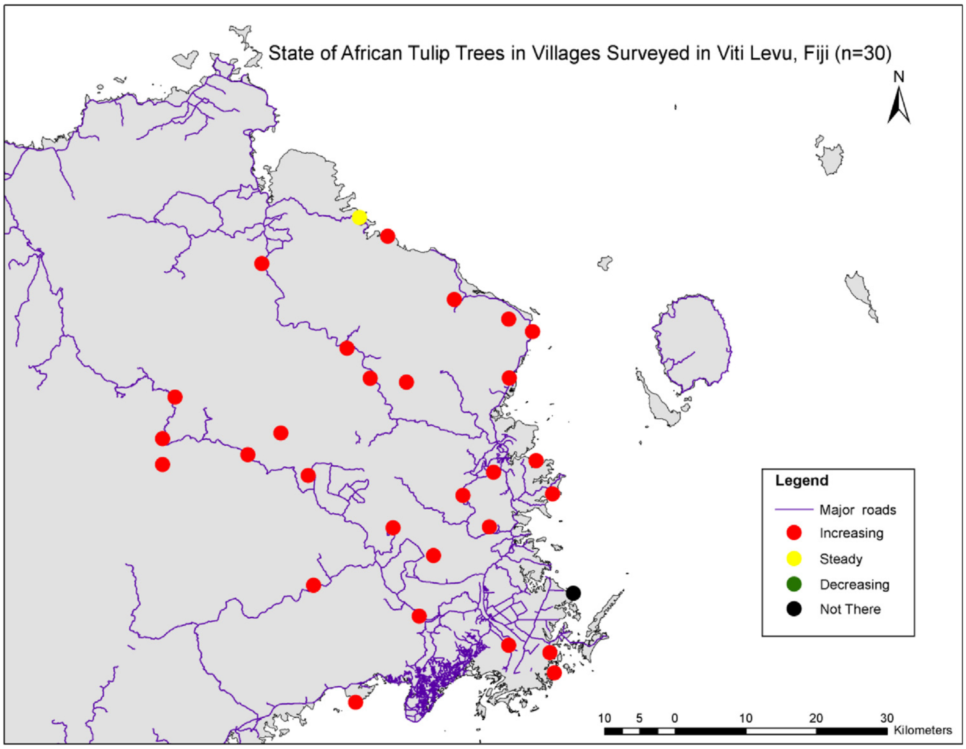

Fig. 2 – State of African tulip tree in villages surveyed.

Development, and Statistics in order 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 managing IAS. 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 IAS to be a similar budgetary priority as health and more important than social protection and public safety.

Among the budgetary share allocated to environmental protection and control of IAS, respondents would allocate 53.1% to controlling IAS. Of this, respondents would allocate 34.7% (or 2.3% of the total national budget) to controlling African tulip tree (Table 2). In actual fact, less than 1% of the total budget allocated to these disparate activities was allocated to managing all IAS in 2012 (Fijian, 2013).

An additional set of survey questions elicited each household's willingness to volunteer time to control African tulip tree under the assumption that an effective, time-intensive solution to managing the species had been identified. Among those who view the African tulip tree extremely negatively, the median household offered to volunteer 11.3 additional hours per week. The average household in surveyed villages currently spends 6 h per week volunteering on behalf of the village in activities such as maintaining public goods (e.g., roads and bus shelters) and spaces (e.g., churches and schools). That is, respondents would allocate 88% more time to controlling African tulip tree than on other activities to benefit the church and community. Life in *iTaukei* villages revolves around the church and community governance (Ryle, 2005), underscoring the perceived importance of controlling the African tulip tree among Fiji's rural, indigenous population.

6. Cost–benefit analysis methodology

In undertaking CBA of various approaches to managing African tulip tree, 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 standardised approach to support decision making by Pacific island governments and non-government organisations.

The population growth of African tulip trees is assumed to follow the logistical growth curve described in Eq. (1), with the current population of African tulip trees (N_t) on eastern Viti Levu estimated at 800 trees per hectare (tph), or about 20% of its carrying capacity (Auld and Nagatalevu-Seniloli, 2003). The surveys and results described in Sections 4 and 5 provided detailed data on the various pecuniary and non-pecuniary damages caused by the African tulip tree as well as common management practices.[7] Data pertaining to the costs associated with each management practice is derived from household

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

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 plant ecologists 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).[8]

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. 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 and Holland, 2010). Results were also calculated with 4% and 12% discount rates to better understand the robustness of our calculations. Prices, units, and the present value of benefits were calculated similarly.

Recurring costs such as extraction and monitoring are assumed to accrue at the end of each of the 50 years in the life of the management intervention. Capital costs, 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 monetised 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.

7. Cost–benefit results

In this study, we consider three distinct management options: doing nothing, maintaining the current management approaches (i.e., cutting/pulling, burning, and/or applying herbicides), and an integrated management approach that applies different control methods to trees of different sizes. The ''do nothing'' approach represents the baseline against which the costs and benefits of other management options are measured.

7.1. *Do nothing*

This option represents progressive growth and spread across the landscape in the absence of any management. Under this scenario, the African tulip tree eventually occupies all ecologically suited environments when it reaches carrying capacity of 4000 trees per hectare some 40 years after becoming established in each location. There are no management costs associated with this option, but it does result in damages to land-based production that would have been avoided had the species been managed.

7.2. *Current management approach*

As described in Section 5, 90% of affected surveyed villages actively manage African tulip trees, with cutting trunks and digging suckers and young trees, burning, and applying herbicides being the most common management strategies. Tractors and other heavy machinery are sometimes employed in these activities, although this disturbance often leads to increased germination of seeds in the seed bank. Incorrect herbicide application has resulted in poor levels of control.

Despite the fact that households allocate over 10% of their total time in agriculture to controlling the African tulip tree (Section 5), focus groups in 28 of the 30 villages included in our sample reported monotonic increases in the numbers and densities of the tree in their communities in recent decades (Fig. 2). Based on consensus reached during the Delphi process (Section 6), we estimate that the long-run population of the African tulip tree is reduced by 50% under current management practices, although the results and recommendations are robust to assuming that the current management reduces the long-run population by as little as 5% relative to the baseline, *ceteris paribus*.

7.3. *Integrated management approach*

The integrated management approach detailed in Appendix A represents a state-of-the-science suite of treatment methods to target trees of different sizes and ages. Specifically, a ''hack-and-squirt'' treatment method is used for all trees greater than 10 cm in diameter at breast height. Some of the larger trees are ring-barked while ''cut-stump'' treatment is used on saplings and small trees. Smaller seedlings are hand-pulled. These treatments can be followed by mechanical clearing using a bulldozer and replanting with crops or pasture. Subsequently, herbicides and/or hand-pulling are used to remove all seedlings that emerge after seeds blow in from distant stands of trees. Born et al., 2005 note that measures to control established invasives are not equivalent to eradication, and hence impacts may persist. Accordingly, based on the results of the same Delphi process, we assume that the long-run population of the African tulip tree is eventually reduced by 90%; however, the recommendation and results of the analysis hold if the long-run population is reduced by as little as 13%, *ceteris paribus*.

The population of African tulip trees over time under each of the three management regimes described above is shown in Fig. 3. Notably, the integrated management approach is less effective at controlling the population of African tulip trees than the current management approach in the short run; over time, however, the integrated management approach is significantly more effective than current approaches.

[8] 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''.

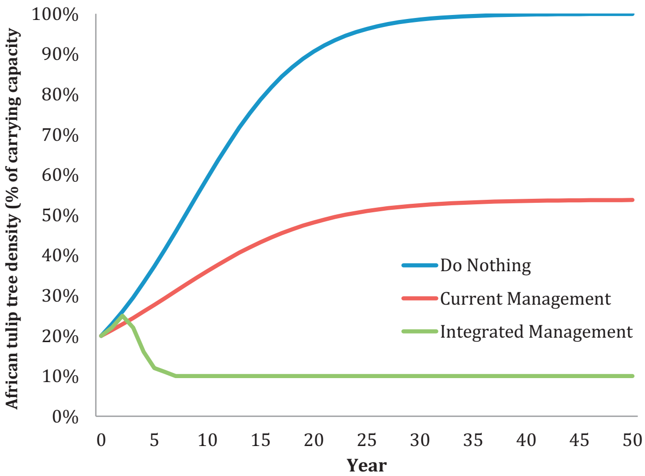

Fig. 3 – Population of African tulip tree as a share of total carrying capacity.

7.4. *Benefits and costs of management*

We focus explicitly on the direct economic benefits of managing the African tulip tree, namely the benefits of avoided damages to crop, livestock, and forestry yield. Although other benefits to managing this IAS – including biodiversity protection associated with less competition and reduced clearing of forests for agriculture (PIER, 2002; Webber 2003) – are undoubtedly significant, they are not quantified here. Based on informal discussions with Fijian villagers and staff from the Ministry of Fisheries and Forests, we assume that income derived from crop, livestock, and forestry production falls by the same percentage of the productive area invaded (i.e., 20% initially) when African tulip trees are present due to increased competition and to increased time allocated to clearing land.

Costs of managing the African tulip tree include labour, herbicides, fixed capital such as chainsaws and knapsack sprayers, and rental fees for major capital such as tractors, bulldozers, diggers, and other heavy machinery. Data for such costs were derived from household surveys and confirmed by the Fiji Ministry of Primary Industry's routine market surveys.

The values for the benefits (i.e., avoided damages) and costs (i.e., costs of inputs) assumed in this analysis are reported in Table 3.

7.5. *Cost–benefit analysis*

Estimated damages under the three management options are based on the population shown in Fig. 3. As above, the damages incurred under the integrated management approach are higher than those incurred under the current management approach in the short run; over time, however, the integrated management approach reduces damages by more than either of the other approaches.

Comparing the present value of costs listed in Table 1 to the present value of benefits from avoided damages, we find that the integrated approach yields the highest NPV and the highest benefit-cost ratio (Table 4), indicating that this approach offers the highest value per dollar spent in the absence of funding constraints. Importantly, however, the current management option also yields a positive NPV, indicating that current practices are preferred to undertaking no management at all.

The estimates presented in Table 4 reflect the NPV of each management option on a per-hectare basis. Given that about 6% of eastern Viti Levu's 411,000 hectares of land is comprised of arable land that is currently under cultivation (Pacific Regional Statistics, 2013), the total NPV of following an integrated management approach to control African tulip tree is at least $1074 million over the course of the project, while current management practice approach yields a positive NPV of $456 million.

To better account for uncertainty in the analysis (Cullen and Whitten, 1995; McConnachie et al., 2003; Born et al., 2005), we undertake sensitivity analyses to assess the robustness of our results. Specifically, we now analyse the results under the following variable assumptions:

Initial population (as a share of the carrying capacity) – 0.5 and 2 times base assumption. This sensitivity analysis

Table 3 – Values (per ha) to quantify benefits and costs of African tulip tree management.

Benefit and cost category	Unit	Value per unit	Years incurred	Units per year: Do nothing	Current approach	Integrated approach
Benefits						
Avoided damages – crops	kg	$1	0–50	0	0–8000	0–10000
Avoided damages – livestock	kg	$2	0–50	0	0–50	0–90
Avoided damages – forestry	m^3	$35	0–50	0	0–2.5	0–5
Costs						
Glyphosate herbicide	L	$15	1–50	0	5	20
2,4 D + dicamba herbicide	L	$125	1–50	0	3	0
Triclopyr herbicide	L	$45	1–5	0	0	1
Labour	Man days	$30	1–50	0	24	40
Bulldozer or digger hire	Days	$300	1	0	1	2
Machete, gloves, and hand saw	Number	$75	0	0	1	1
Knapsack sprayer	Number	$210	0	0	1	1
Precision drench gun	Number	$120	0	0	0	1

Table 4 – Summary of benefit-cost analysis (per ha).

Option	PV costs	PV benefits	Total NPV	Benefit-cost ratio
Do nothing	$0	$0	$0	1.0
Current management	$11,201	$30,305	$19,104	2.7
Integrated management	$16,255	$60,351	$44,097	3.7

Notes: discount rate = 8%, project length = 50 years, study area = 1 ha.

Table 5 – NPV ($/ha) of sensitivity analyses for African tulip tree management options2.

Discount rate = 4%				
Option	Effectiveness	Initial population (relative to max)		
		10%	20%	40%
Current management	0.5 × base	$31,875	$23,978	$23,944
	1.0 × base	$51,481	$50,229	$63,812
	2.0 × base	$72,006	$78,220	$107,598
Integrated management	0.5 × base	$65,925	$87,735	$69,315
	1.0 × base	$85,864	$106,951	$133,965
	2.0 × base	$95,629	$115,237	$147,814
Discount rate = 8%				
Option	Effectiveness	Initial population (relative to max)		
		10%	20%	40%
Current management	0.5 × base	$11,899	$8320	$8827
	1.0 × base	$18,748	$19,104	$27,472
	2.0 × base	$26,371	$31,258	$49,334
Integrated management	0.5 × base	$20.006	$34,445	$28,973
	1.0 × base	$30,158	$44,097	$64,553
	2.0 × base	$35,063	$47,858	$73,147
Discount rate = 12%				
Option	Effectiveness	Initial population (relative to max)		
		10%	20%	40%
Current management	0.5 × base	$4392	$2657	$3282
	1.0 × base	$7304	$8031	$13,818
	2.0 × base	$10,764	$14,440	$26,988
Integrated management	0.5 × base	$5455	$15,449	$13,925
	1.0 × base	$11,573	$21,184	$37,317
	2.0 × base	$14,488	$23,186	$43,540

Notes: project length = 50 years, study area = 1 ha.

changes the initial population of the African tulip tree from 20% of carrying capacity to 10% or 40%.

Effectiveness of management – 0.5 and 2 times base assumption. This sensitivity analysis adjusts the pathway of the population growth curves for the two intervention options. An option that is assumed to be twice as effective means that the species is controlled in about half the time as the initial assumption.

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.

Assuming that the effectiveness of each option is a constant multiplier of the base effectiveness (e.g., current management and integrated management are both 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 54 combinations (Table 5), even without monetising benefits to biodiversity and reduced pressure to clear additional agricultural land. The analysis indicates that integrated management produces the highest NPV. However, the current management approach still yields a positive net present value and is economically preferable over doing nothing.

Even in the most pessimistic scenario (i.e., in which there is a low initial population, low effectiveness of management, and a high discount rate), the integrated management option yields a total net benefit of $133 million for the entire study area while the current management option yields a net benefit of $107 million. Thus, integrated management continues to be preferred under these very pessimistic assumptions.

8. Conclusion

Consistent with its status as one of IUCN's 100 worst IAS, the African tulip tree poses an enormous threat in Fiji. Not only does it potentially harm biodiversity, but it also potentially affects the livelihoods and the *vanua* of the Fijian people.

Recent innovations have shown that the invasive African tulip tree can be managed and that its impacts can be avoided or reduced. Thus, we undertook a cost–benefit analysis of managing the African tulip tree in eastern Viti Levu, Fiji. This CBA was informed by first-of-its-kind primary-source data collected via matched household and community surveys that hold major scientific significance in and of themselves. For example, the surveys document the economic costs of living with IAS, both direct (e.g., the cost of herbicides for treating African tulip trees) and indirect (e.g., the time that individuals spend pulling saplings). They also document heterogeneity in current management practices and, importantly, personal attitudes towards the African tulip tree. Specifically, when asked to reallocate Fiji's national budget according to their own spending priorities, survey respondents would allocate approximately 6.7% of the national budget for IAS management and 2.3% specifically to controlling African tulip tree.

Cost–benefit analysis revealed that an integrated approach (which incorporates hack and squirt, ring-barking, stump cutting, hand pulling, and mechanical extraction methods to target trees of different sizes and ages) is more cost effective than current management practices for controlling the spread of African tulip tree. The net present value of such an approach over current management approaches amounts to some $618 million across eastern Viti Levu over the next 50 years. However, we hasten to note that current management practices are moderately effective and that they should continue to be used until an integrated management approach may be implemented; the net present value of current management practices relative to doing nothing is still a very significant $456 million.

These findings are robust to changing a variety of underlying assumptions regarding the discount rate, the relative effectiveness of management, and the current population density of African tulip trees, both singly and in combination. That being said, if current management is significantly more effective than our data suggest and if integrated management is significantly less effective than expert opinion suggests, then current management practices would offer greater returns on investment than integrated management.

Our analysis also relies on the assumption that the population of African tulip trees follows a logistical growth function with a growth parameter of 0.18 and a carrying capacity of 4000 trees per hectare. While these assumptions have been vetted by experts in the Delphi process described above, ecological uncertainty remains (Born et al., 2005), and our results may change if applied in a different setting (Yokomizo et al., 2009). Still, we have not yet encountered a plausible scenario in which doing nothing is preferred to active management of the African tulip tree in Fiji.

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Appendix A. Detailed explanation of integrated management methods

The integrated management approach incorporates hack-and-squirt, ring-barking, stump cutting, hand pulling, and mechanical extraction methods to target African tulip trees of different sizes and ages. These methods are summarised below; additional details may be found in the Resource Kit for Invasive Plant Management (PII, 2014)

A.1. Hack-and-squirt treatment method

This method is suitable for treating mature, standing trees. Using a hatchet or tomahawk, make a series of downward cuts around the entire circumference of the tree trunk. The cuts should be as close as practical to ground level (on mature trees, the cuts are likely to include the buttressed section of the tree trunk), with at least one cut per 10 cm of trunk diameter. Each cut should be between 1 cm and 3 cm long. Using a precision stock-injector gun, apply 100% glyphosate into all cuts at a rate of 10mls per 10 cm of diameter breast height. This procedure will gradually kill the tree, with the process taking up to two years to complete.

A.2. Ringbarking method

Ring-barking is a treatment method that requires cutting through the outer and inner bark, cambium, and phloem (not xylem) tissues and removing a 30–50 cm band of these tissues around a tree to prevent plant nutrients (i.e., sugars and starches) from reaching the roots, causing the tree to die from the roots up. This method is often time-consuming, but it does not normally require the use of herbicide.

A.3. Cut-stump treatment method

This method is well suited for treating saplings and small trees. The plant trunk is completely removed with a chainsaw or pruning saw, horizontally and as close to ground level as possible (the stump should not be any higher than 5–10 cm above ground level). Herbicide is then immediately applied to the top of the cut stump, paying particular attention to the cambium layer. Glyphosate with 1 part to 5 parts water is a suitable herbicide mixture and may be applied via a knapsack sprayer or via paint brush. Glyphosate can also be applied directly to the cambium layer in a 100% mixture with a suitable application tool such as a syringe. The cut tree trunks should be stacked, preferably off the ground, to avoid any trunks taking root and re-growing. To prevent re-invasion, the heap of trunks and cleared area must be monitored every two weeks and any regrowth or seedlings must be addressed immediately.

A.4. Hand pulling seedlings method

Destroy seedling plants by hand-pulling, removing all soil from the roots. Leave the plants off the ground so that they dry out and die.

A.5. Mechanical removal

This method may be undertaken in suitable weather conditions (i.e., before the rainy season) and on land with suitable topography (i.e., on land that is not steep). Areas of saplings or small trees are pushed or dug into heaps suitable for burning using heavy machinery. Grass seed from non-invasive species with low propensity for burning is sown to form a groundcover to minimise the amount of African tulip tree germination from dormant seed. In areas identified for grazing, selective herbicide (e.g., triclopyr) is applied to any newly emerging African tulip tree seedlings before they reach 35 cm in height. In areas identified for cropping, glyphosate should be used to treat African tulip tree seedlings at the rate of 1 part to 100 parts water, with application prior to seedlings reaching 20 cm height.

Note: Follow all requirements on the herbicide label. Protective clothing and footwear must be worn and health and safety requirements followed. Application of herbicide must not result in any non-target damage.

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