Managing the Invasive Small Indian Mongoose in Fiji

Philip Brown and Adam Daigneault

The small Indian mongoose is among the worst of invasive alien species, yet the implications of managing the species are poorly understood. To address concerns of interest to practitioners and policymakers, we analyze survey data to document the impacts of this species in Fiji and conduct a cost-benefit analysis of management approaches that are both culturally appropriate and readily implementable: live trapping, kill trapping, and hunting. We find that the monetized benefits of kill trapping exceed the benefits of live trapping and hunting. Still, all of these management options are preferred to the status quo of no management.

Key Words: cost-benefit analysis, *Herpestes*, invasive alien species, mongoose, nonmarket valuation, survey data

Global trade, international tourism, and transformation of natural habitats result in accidental and intentional introductions of plant and animal species to foreign places. In some cases, these introduced species are invasive and threaten the biodiversity and natural resources in host states.

Invasive alien species (IAS) are particularly problematic for small islands because of such islands' high degree of endemism of species and reliance on natural resources for economic production. For example, in many Pacific island nations, primary industries such as agriculture, fishing, and forestry constitute as much as one-third of a country's gross domestic product (GDP), natural resources dominate the manufacturing and processing sectors across the region, and native species feature prominently in the demand for tourism (Secretariat of the Pacific Community 2013). IAS pose a significant threat to such economies.

The small Indian mongoose (*Herpestes auropunctatus*) was introduced to Fiji in 1883 to control pests in sugar cane fields. As in other places where it was introduced, this species of mongoose has negatively affected Fiji's ecology and economy. Thus, it is no surprise that the International Union for the

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Conservation of Nature considers the mongoose to be among the 100 worst IAS in the world (Lowe et al. 2004). Although the small Indian mongoose has been eradicated from just a handful of Fiji's small islands, scientific studies have demonstrated that many IAS can be managed and that their impacts can be avoided through prevention, eliminated through eradication, and reduced through control measures (e.g., Veitch, Clout, and Towns 2011). Quantifying the threat posed by this mongoose, documenting practices used to manage the species, and understanding the costs and benefits of various management options thus may help decision-makers to make better-informed management policies and set priorities for managing the small Indian mongoose relative to other IAS.

Ecology of the Small Indian Mongoose

The small Indian mongoose (Hodgson 1836) is one of 33 mongoose species worldwide. It has a slender body, short legs, elongated head, distinctly pointed muzzle, short ears, tapered tail, and brown fur. Females average 54 centimeters in length; males are 5 centimeters longer on average and generally are stockier (Nellis 1989). The species is native to Saudi Arabia, Iran, Iraq, Afghanistan, Pakistan, India, Nepal, Bangladesh, and Myanmar. Thailand, Malaysia, Laos, Vietnam, and southern China are native habitats for the Javanese mongoose (*Herpestes javanicus*), which has been established as a separate species (Morley, McLenachan, and Lockhart 2007, Veron et al. 2007). The small Indian mongoose is highly adaptable. It is found in deserts and rain forests, on virgin and on highly degraded lands, in rural and in urban areas, and from sea level to 2,200 meters in elevation (Thulin et al. 2006).

Because of its purported effectiveness in controlling rats (Espeut 1882) and venomous snakes (Barbour 1930), the small Indian mongoose (but not the Javan mongoose) (Invasive Species Specialist Group 2013) was deliberately introduced to at least 64 islands in the Pacific and Indian Oceans, the Caribbean, and the Adriatic Sea (Barun et al. 2011), many of which are important sugar producers.[1] Indeed, the small Indian mongoose was first introduced to Fiji in 1883 to control rats in sugar cane fields (Veron et al. 2007, Patou et al. 2009) and is now established on 13 of Fiji's 332 islands—Viti Levu (1,038,700 hectares), Vanua Levu (554,500 hectares), and 11 small islands that range in size from 17 hectares to 6,878 hectares (Morley 2004). Trapping conducted in 2007 found individuals of a second species, the Indian brown mongoose (*Herpestes fuscus*), that had likely escaped from a private zoo (Morley, McLenachan, and Lockhart 2007, Veron et al. 2009). The distribution of that species so far is limited relative to the small Indian mongoose.

Female small Indian mongooses reach sexual maturity at ten months of age and breed two or three times per year, producing two to four pups per litter (Gilchrist et al. 2009). The mongoose's home range averages 2.2 to 3.1 hectares for females and 3.6 to 4.2 hectares for males; the ranges often overlap and can be as small as 0.75 hectares (Nellis and Everard 1983). Life expectancy in the

[1] Rats are attracted to sugar and snakes are difficult to spot in thick sugar cane fields, making control of these pests particularly important to sugar cane producers. Nellis (1989), Hays and Conant (2003), and Barun et al. (2011) reported that the small Indian mongoose was also introduced to mainland Australia, Europe, North America, and South America to control pests.

wild averages four years (Invasive Species Specialist Group 2013),[2] and the carrying capacity on some islands has reached ten small Indian mongooses per hectare (Nellis 1989) after ten years.[3] Thus, the population of this mongoose on islands follows a logistical biological-growth curve with a population-growth parameter of 0.5 (Daigneault and Brown 2013, Daigneault et al. 2013) and a carrying capacity of ten mongooses per hectare ten years after establishment:

$$N_{t+1} = N_t + 0.5N_t(1 - [N_t / 10]) \quad (1)$$

where N is the number of small Indian mongooses per hectare and t is the time period in years.

This mongoose is an agile predator; in addition to rats and snakes, it feeds on a variety of small mammals, reptiles, birds, invertebrates, and eggs (Veron et al. 2009). For example, extinction of the barred-winged rail (*Nesoclopeus poecilopterus*) in Fiji coincided with introduction of the small Indian mongoose there (Gorman 1975, Simberloff and Rejmánek 2011), and Morley and Winder (2013) demonstrated that the mongoose was causal in the decline of at least three ground-dwelling birds: the Pacific black duck (*Anas superciliosa*), the banded rail (*Gallirallus philippensis*), and the purple swamphen (*Porphyrio porphyrio*). It has also been implicated in declines in white-browed rails (*Nesoclopeus poecilopterus)*, sooty rails (*Porzana tabuensis*), and friendly ground doves (*Gallicolumba stairi*) (Watling 2001, Simberloff and Rejmánek 2011); extirpation of black emo skinks (*Emoia nigra*) and Gibbons' emo skinks (*Emoia trossula*) from Viti Levu and Vanua Levu (Simberloff and Rejmánek 2011); and declining populations of frogs and bats on Viti Levu (Veron et al. 2010). The small Indian mongoose also preys on domestic poultry (e.g., Abe 2013).[4]

In a study of more than 4,400 scats, Gorman (1975) concluded that, while invertebrates such as cockroaches are the main food source for the small Indian mongoose in Fiji, 23 percent of its diet is derived from plants, particularly fruit.[5] Horticulture is the fastest-growing component of Fiji's agricultural sector (McGregor 2007) so even minor predations of fruit could have important consequences for Fiji's economy. In addition, the mongoose is a carrier of human and animal diseases, including rabies and the human *Leptospira* bacterium (Collings 1984).

Control of the small Indian mongoose on islands that have a high degree of species endemism has been of interest since at least the 1950s (Pimentel 1955). Bounties and trapping have proven unsuccessful on the large islands (Nellis 1989), but the mongoose has been eradicated from at least six small islands (Buck, Fajou, Leduck, Praslin, Codrington, and Green, none exceeding 115 hectares) (Morley and Winder 2013). A campaign to eradicate the mongoose on 71,200-hectare Amami-Oshima in the Sunsunan islands has been underway since 1993 (Abe 2013).

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2 Gorman (1979) and Tomich (1969) provide additional details on the mongoose's biology.

3 The population density is as low as 2.5 individuals per hectare on the mainland sites (Pimentel 1955).

4 As noted later, respondents in 83 percent of the villages that we surveyed stated that the small Indian mongoose attacks livestock, particularly chickens.

5 Cavallini and Serafini (1995) reported that the mongooses on Korčula in the Adriatic are primarily frugivorous.

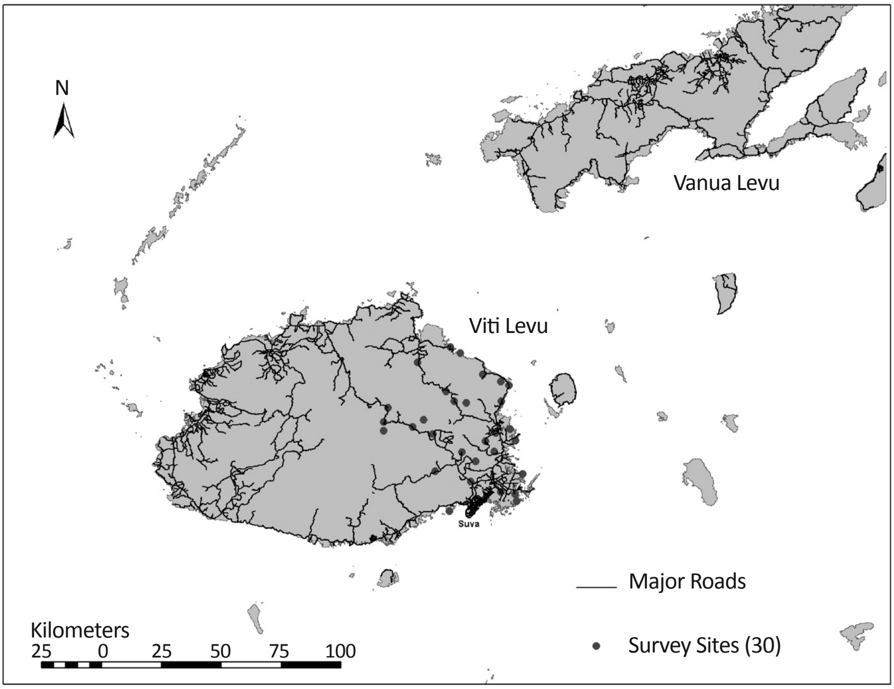

Figure 1. Village Survey Sites for the Invasive Species Management Study

Materials and Methods

Household and Community Surveys

While the small Indian mongoose has adversely affected biodiversity in Fiji and may have minor impacts on human health, this analysis is focused on impacts that are more easily monetized—social and economic impacts such as losses to agricultural productivity. To understand these impacts better, we surveyed 360 households in 30 indigenous Fijian (i.e., *iTaukei*) villages on Viti Levu, Fiji's largest island.[6] The island's villages were stratified by geography, and we randomly selected the 30 villages from a pool of all villages on the eastern side of the island, where the small Indian mongoose has become common. The distribution of the sampled villages is shown in Figure 1.

Within each village, households were selected at random from village rosters, and the survey was conducted directly with the head of each household. The survey covered demographic characteristics; farming, fishing, wage work, and other income-generating activities; wealth and durable assets; levels of education; the status of their health; and agricultural extension activities. The mean village was comprised of 44 households (Table 1) that had 5.2 members. The mean household was headed by an individual who had 9.5 years of education. Household income averaged FJ$22,929[7] and household wealth averaged FJ$19,010, although both income and wealth demonstrated a high

[6] The study area, which covered parts of Rewa, Naitasiri, Tailevu, and Ra provinces, constituted 250 villages so our sampling rate was 12 percent. The average village was comprised of 49 households, and we surveyed 25 percent of the households in a village on average.

[7] At the time of writing, FJ$1 equaled US$0.53.

degree of variability. More than 5 percent of the average household's income and 11 percent of its wealth were derived from livestock. Commonly owned livestock included beef and dairy cattle, pigs, and chickens, and the average household owned 2.9 chickens.

The households were queried about the economic impacts of IAS, including both direct impacts (e.g., the value of livestock and fruit lost to small Indian mongooses) and indirect impacts (e.g., the opportunity cost of time spent hunting mongooses reflected by available wages). The survey also contained a novel element related to the social and economic impacts of this IAS in which respondents were asked to assume the role of Fiji's Minister for Finance and Strategic Planning, National Development, and Statistics. Here, respondents revealed their spending priorities by allocating shares of the budget to a broad range of categories that included education, healthcare, public order, trade, infrastructure development, and environmental protection.[8] Respondents who allocated a portion of the mock national budget to environmental protection were further asked to prioritize control of IAS relative to spending on other environmental concerns such as reef protection. Finally, respondents who indicated that they would allocate a portion of the budget to controlling IAS were asked to prioritize the management of various species, including the small Indian mongoose.

In each village, a complementary survey was conducted with a focus group consisting of at least six residents. The survey consisted of open-ended questions regarding the presence and current state of thirteen IAS and, when applicable, the consequences of their presence and community practices for encouraging or limiting their spread. Notably, respondents were asked to reflect on both negative and positive impacts of these species (Brown and Daigneault 2014a).

[8] This exercise was conducted through an interactive game in which 70 dried beans represented the approximately FJ$700 million budget in 2010. Participants were asked to separate the pile of beans according to their spending priorities. See Brown and Daigneault (2014b) for details.

Table 1. Summary Statistics

Variable	10th Percentile	Mean	90th Percentile
Households per village	20	44.10	64
Number of people in the household	2	5.17	8
Education of household head in years	6	9.50	12
Total household income in Fiji dollars	1,959	22,929[a]	60,764
Share of income derived from crops – percent	13.02	71.14	100
Share of income derived from livestock – percent	0	5.34	21.10
Total household wealth in Fiji dollars	3,060	19,010	38,580
Share of wealth derived from livestock – percent	0	11.01	58.06
Cultivated land per household in hectares	0.24	1.47	3.58
Number of chickens owned	0	2.86	10

[a] The median household income is FJ$10,243, indicating that a minority of households are disproportionately wealthy.
Notes: n = 360.

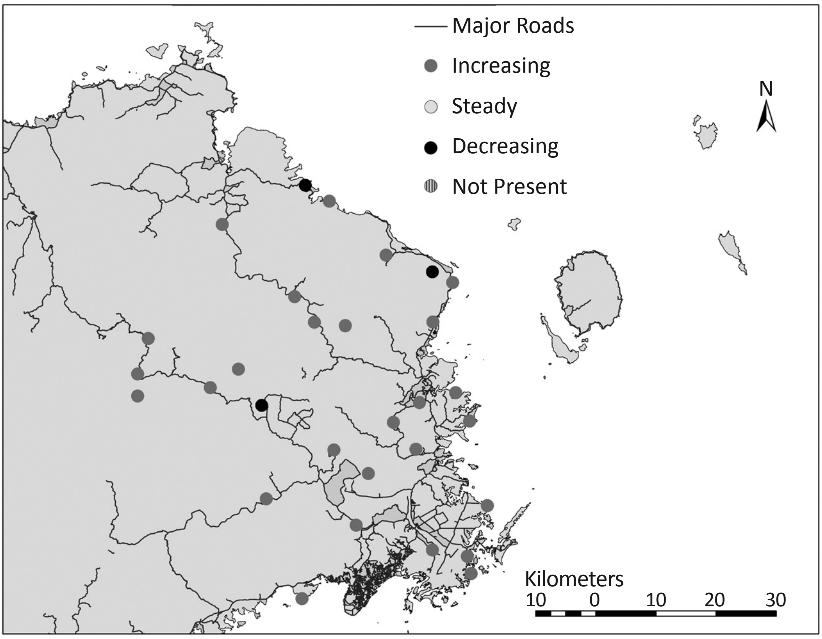

Figure 2. State of Small Indian Mongoose in Viti Levu Villages Surveyed

All of the surveys were conducted by a team of trained staff members and students from the University of the South Pacific during a four-week period in July 2012.

Cost-Benefit Analysis

In undertaking a cost-benefit analysis (CBA) of approaches to managing small Indian mongooses, we follow an approach pioneered in the Global Invasive Species Programme toolkit (Emerton and Howard 2008) and refined in Buncle et al.'s (2013) guide to cost-benefit analysis for natural resource management in the Pacific. The latter was an especially useful template for this research because it offered a standardized approach for supporting decision-making by governments and nongovernment organizations in the Pacific islands.

In the analysis, the population of small Indian mongooses is assumed to follow the logistical growth curve described in equation 1. The current population (N_t) on eastern Viti Levu is assumed to have reached the carrying capacity of ten mongooses per hectare (Nellis 1989). This assumption may be inconsistent with the observation that the mongoose population is increasing in 27 of the 30 villages included in the survey (Figure 2), but it is relaxed in the sensitivity analysis.

The surveys provide detailed data on the various pecuniary and nonpecuniary damages caused by the mongoose and identify common management practices. Hence, in this analysis, we consider four distinct management options that are feasible in Fiji: do nothing, live trap, kill trap, and hunt.

The *do nothing* option represents the progressive growth in numbers and spread of the species across the landscape in the absence of management. Under this scenario, the small Indian mongoose continues to occupy all ecologically suitable environments at its carrying capacity of ten per hectare.

No management costs are associated with this option, but it results in damage that would have been avoided if the species had been managed.

Live trapping represents a relatively inexpensive method of removing the animals in the short term. The mongoose can follow a scent as far as 500 meters so devices such as Haguruma cage traps can be set in a 200-meter grid, which is approximately one trap per hectare (Daigneault et al. 2013), along village boundaries. Pilot programs to test various baits have identified tinned sardines (Peters et al. 2011), fish sausages (Yamada 2011), fish meal (Creekmore et al. 1994), cat food (Peters et al. 2011), eggs (Everard and Everard 1992), and chicken parts (Everard and Everard 1992) as effective. Using nontoxic bait in the live traps allows other species caught in the traps to be released unharmed (Barun et al. 2011), and the captured mongooses can be used as food if desired.[9]

Because the small Indian mongoose appears to have low selectivity and will consume most types of bait (Creekmore et al. 1994), live trapping is likely to be highly effective. However, it requires skilled and intensive labor because the traps must be checked and maintained daily to prevent incidental deaths of other species and recolonization. In the model, we assume that live trapping will eventually reduce the population of the mongooses to 30 percent of carrying capacity, and we relax this assumption regarding efficacy in the sensitivity analysis.

Kill trapping involves the use of the Department of Conservation's Model 250 kill trap, which passed the National Animal Welfare Advisor Committee's humane guidelines for use against mustelids in New Zealand (Pautu and Warburton 2005) and has been successfully tested for trapping small Indian mongooses in Hawaii (Peters et al. 2011). This trap, and similar models, can be readily employed to kill small Indian mongooses in Fiji. The traps use the same nontoxic bait as live traps[10] and are set in boxes that have entry holes sized for the intended prey to minimize bycatch. After the trap is triggered by the animal stepping on its treadle, the animal is killed quickly and humanely. As with live traps, the kill traps are set in a 200-meter grid (one trap per hectare) along the entire boundary of the village. Initially, the traps must be checked daily to refill the bait, but they can be checked less frequently later since the animals' survival is not intended. Because they allow fewer escapes relative to live traps (Barun et al. 2011), kill traps are more effective, and in the model, we assume that a concerted trapping effort will reduce the mongoose population to less than 20 percent of carrying capacity. This assumption regarding the efficacy of kill traps is relaxed in the sensitivity analysis.

Hunting is the most labor and capital-intensive method analyzed since it requires guns and hunters. Three rifles are sufficient to cover the approximately 300 hectares of a typical Fiji village so we assume that 1/100th of a shotgun is required to hunt on a given hectare. Hunting can be effective when the mongoose population is large, but it requires an increasing amount of effort per kill as the mongoose population is reduced because of the cost of searching. As a result, Barun et al. (2011) and others have considered hunting to be less effective

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9 Per the preceding discussion, mongoose meat is assumed to have a low value, and the benefits of consumption are not monetized for the analysis. However, it is a trivial exercise to include the value of meat in communities in which the meat is commonly eaten.

10 Alternatively, toxic baits can be used in live traps to achieve the same outcome, but the toxic baits are more expensive, have the potential to cause secondary poisonings if the trapped animals are consumed by other animals, and generally require greater care on the part of the handler. Thus, use of humane kill traps with nontoxic baits is preferred.

than trapping. We assume that hunting reduces the population to 50 percent of carrying capacity, and that assumption is relaxed in the sensitivity analysis.

Data pertaining to the cost associated with each management practice were derived from the household surveys and from market surveys conducted by the Fiji Ministry of Primary Industries. In addition, a Delphi process (Dalkey and Helmer 1963, Brown 1968) was used to assess the relative effectiveness of each management option. The Delphi process entails a group of experts who come together to reach consensus about pressing problems despite inadequate data from which to reach a conclusion empirically (Egan and Jones 1997). Helmer and Rescher (1959) noted that relying on expert opinion in the absence of clear empirical information is justified because of the experts' background knowledge and because the high degree of agreement derived from Delphi processes "precludes subjective whim." Delphi processes are commonly used in the natural sciences but are less common in economics.[11]

New Zealand is recognized for being on the cutting edge of biosecurity research and implementation. For example, New Zealand is the world's largest user of sodium fluroacetate to control vertebrate pests, pioneered helicopter hunting to eradicate feral ungulates, and developed most of the traps used to control rodents and mustelids in the Pacific. Within New Zealand, Landcare Research and the Pacific Invasives Initiative are the leading experts on controlling vertebrate pests. The University of the South Pacific and the South Pacific Regional Herbarium have expertise in local capacities for species of plants and animals and have participated in eradication and management campaigns for IAS throughout the Pacific. Similarly, the Fiji Ministry of Fisheries and Forests has expert knowledge of management practices currently employed in Fiji. Hence, the Delphi process in this case involved representatives from all of those groups. Finally, an expert on mongoose ecology and management from the United Kingdom's Food and Environment Research Agency that was not formally part of the Delphi process validated the outcomes.

Because the costs of a project accrue over time, we calculated the present value of current and future costs by discounting future costs at the real rate of interest—the opportunity cost of money. In the model, we assume a project term of 50 years and a discount rate of 8 percent, which is the median discount rate used for long-term environmental management projects in the Pacific (Lal and Holland 2010). Recurring costs such as bait are assumed to accrue at the beginning of each of the 50 years in the life of the management intervention. Capital costs for items such as traps, on the other hand, accrue only during the period. Information about the number of physical units of inputs under each management option is derived from the scientific literature, survey responses, and experts. The total monetized cost of management for each method is estimated by multiplying the unit costs incurred annually by the number of physical units.

In assessing the benefits of managing the small Indian mongoose, we focus explicitly on direct economic benefits: avoided damage to livestock and crop yields. Although other benefits from managing this species, which include protection of biodiversity (Gorman 1975, Watling 2001, Veron et al. 2009,

[11] While we would prefer to use empirical data on the effectiveness of these options, we could find no empirical studies of the effectiveness of mongoose controls in Fiji or in any neighboring country. Benefit-transfer methods (i.e., applying empirical relationships derived in one area to fill a data void in another) informed the Delphi process, but benefit-transfer is inappropriate without expert validation of findings derived from a different biophysical and socioeconomic context.

Simberloff and Rejmánek 2011, Morley and Winder 2013) and a potential reduction in the risk of leptospirosis (Collings 1984), are undoubtedly significant, they are not quantified here. Note, however, that such benefits of managing the mongoose are weakly positive (indeed, very likely to be positive) so the results of this analysis are likely to underestimate the total benefit of managing the mongoose.

Results

Although the small Indian mongoose is widely considered to be a problematic IAS by ecologists, the 30 focus groups in the study reported two specific benefits it provides. In 27 percent of the villages, the focus groups reported that mongooses effectively control snakes. However, Viti Levu generally does not need a way to control snakes since the only venomous land snake in Fiji is the Taveuni blind snake (*Ogmodon vitianus*), which lives almost entirely underground and is so rare that fewer than 20 specimens have ever been collected (Watling, Wynn, and Zug 2010). The focus groups in 73 percent of the villages reported that mongoose meat is occasionally eaten there. However, mongoose is considered inferior to other types of meat,[12] and few young people reported having tasted it. Other villages reported that the mongoose brought no local benefit. Thus, any desirable characteristics of the presence of mongooses are negligible and are not explicitly incorporated into the analysis.

The respondents in the focus groups noted several important negative aspects of the presence of mongooses. Respondents in 83 percent of the village focus groups reported that mongooses frequently attack livestock in general and chickens in particular. The results of the household survey indicate that the average household loses one chicken to mongoose predation each year, but when we restrict the sample to households that regularly kept chickens, the mean number lost increases to 6.5 per year. Finally, focus group participants in a number of villages observed that mongooses regularly take ripening fruits and vegetables. Hence, we assume in the model that the small Indian mongoose reduces crop yields by 2.5 percent[13] and kills one chicken per household per year. Since the mongoose population has already reached carrying capacity, the amount of annual damage is assumed to be constant in the absence of management.

[12] A survey in Benin revealed that mongoose meat is disfavored "because of its unpleasant musky odor coming from their scent glands" (Djagoun et al. 2009, p. 29).

[13] For simplicity, we assume that the mongoose is opportunistic and that it consumes a proportionate share of all crops that are produced.

Table 2. Responses to Small Indian Mongoose

Variable	10th Percentile	Mean	90th Percentile
Hours spent hunting and trapping per week	0	0.05	0
Share of national budget allocated to control – percent	0	0.80	1.43

Note: n = 360.

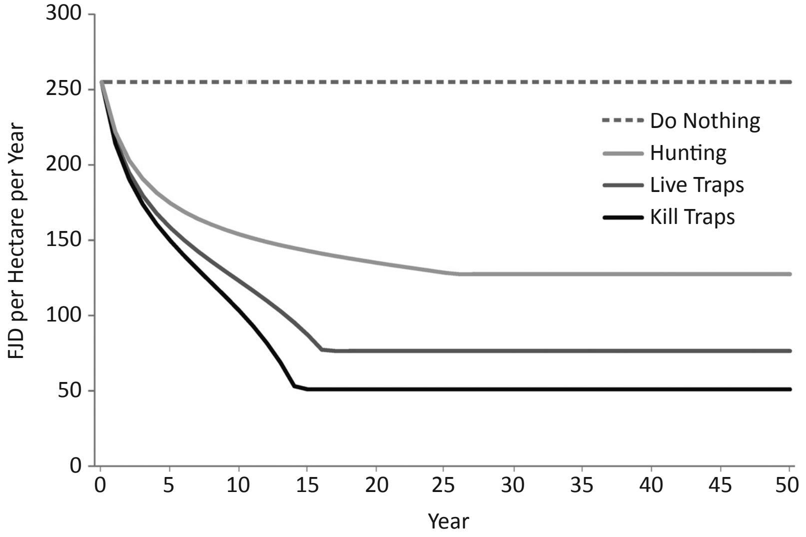

Figure 3. Total Value of Annual Damages from the Small Indian Mongoose under the Four Management Options in Dollars per Hectare

Villagers actively trap and hunt the mongoose in 87 percent and 47 percent of the villages, respectively. However, the surveyed households spend just 3.2 minutes per week on those activities (Table 2). Only 2 percent of the households reported spending an hour or more per week, and the vast majority of households allocated no time at all to managing mongooses. Nevertheless, in the budget planning exercise, respondents indicated that they would allocate an average of 12.5 percent of the national budget to environmental protection and managing IAS. By comparison, they allocated an average of 15.3 percent to education; 12.9 percent to health; 10.5 percent to recreation, culture, and religion; 10.1 percent to social protection; and 9.1 percent to public safety. Thus, Fijian villagers consider environmental protection and control of IAS to be about as important in terms of budgetary priorities as health and more important than social protection and public safety. Of the budget share allocated to environmental protection and control of harmful species, respondents allocated 53.1 percent to control of IAS and 12.1 percent of the invasive species budget (0.8 percent of the total budget) to mongoose control. In fact, the Fijian government allocated less than 0.8 percent of the total budget to managing *all* IAS in 2012 (Fijian Government 2013).

Figure 3 presents estimates of annual damage resulting from each management option.

We compare the present value of the costs listed to the present value of the benefits gained from damage avoided in Table 3 and net present values (NPVs) and benefit-cost ratios (BCRs) in Table 4. The NPVs monetize the effectiveness of each management approach and the BCRs describe the efficiency of each approach per Fijian dollar spent. Kill traps yield the highest NPVs; that is, the aggregated value of using kill traps to manage the small Indian mongoose exceeds the aggregated value of the other management options over time. However, kill traps entail the greatest capital cost, and the efficiency of hunting (return per dollar spent) is greater than the efficiency of the trapping options.

Table 3. Values per Hectare to Quantify Costs and Benefits of Managing the Small Indian Mongoose

			Units per Year			
Category	**Value per Unit**	**Years**	**Do Nothing**	**Live Traps**	**Kill Traps**	**Hunting**
Benefits						
Avoided crop damage – kilograms	$1	0–50	0	0–175	0–200	0–125
Avoided livestock damage – chickens	$5	0–50	0	0–0.7	0–0.8	0–0.5
Costs						
Live traps – each	$50	1	0	1	0	0
Kill traps – each	$100	1	0	0	1	0
Nontoxic bait – kilograms	$2	1–50	0	4	4	0
Rifles – each	$500	1	0	0	0	0.01
Ammunition – boxes	$20	1–50	0	0	0	1
Trap maintenance – dollars	$1	1–50	0	10	20	0
Labor – person days	$30	1–50	0	1.3	1	1

Table 4. Summary of Cost-Benefit Analysis

	Fijian Dollars per Hectare			
Option	**Present Value Cost**	**Present Value Benefit**	**Total Net Present Value**	**Benefit-Cost Ratio**
Do nothing	0	0	0	1.0
Live traps	–1,151	1,533	382	1.3
Kill traps	–1,201	1,747	546	1.4
Hunting	–617	1,140	523	1.9

Notes: The discount rate is 8 percent; the project length is 50 years; the study area is one hectare.

Thus, a budget-constrained management authority may prefer the inexpensive and efficient option of hunting to the more expensive but more effective option of kill traps. Live trapping, kill trapping, and hunting *all* yield positive NPVs, indicating that all are strictly preferred to the status quo of no management.

The estimates presented in Table 4 reflect the NPV of each management option on a per-hectare basis. A typical village in eastern Viti Levu consists of 44.1 households that, on average, maintain 1.47 hectares of productive land each (Table 1). Hence, the NPV of using kill traps for the typical village is FJ$37,581. Given that approximately 6 percent of eastern Viti Levu's 411,000 hectares is productive land under cultivation (Pacific Catastrophe Risk Assessment and Financing Initiative 2015), the total NPV of using kill traps is at least FJ$13.5 million over the next 50 years.[14]

[14] The relative cost-effectiveness of kill traps holds under alternative scenarios as well, such as if mongoose control is undertaken on both productive and unproductive land given constant economies

Sensitivity Analysis

Cost-benefit analyses of management of IAS often depend on strong assumptions, and this analysis is no different. For example, we draw on data from an array of sources that vary in terms of quality and certainty. Some costs and benefits can be difficult to value accurately, and important biophysical data can be difficult to obtain. The population of the IAS in the initial period could vary across space because some areas might not have reached carrying capacity. As a result, we conducted sensitivity analyses to assess the robustness of our results using the following assumptions:

1. *Initial population* (as a share of carrying capacity): 33 percent and 66 percent of carrying capacity.
2. *Effectiveness of management*: The pathway of the population growth curves for the three intervention options is adjusted to 0.5 and 2.0 times the baseline assumption. Thus, an option that is assumed to be twice as effective controls the population of the mongoose in half the time required under the initial assumption.
3. *Discount rate*: Rates of 4 percent and 12 percent, which are at the tails of the range of discount rates used for environmental management projects in the region.

Permutations of these assumptions generate 81 combinations under which to evaluate the sensitivity of the original estimates. The NPV of each combination is presented in Table 5.

Assuming that a method's effectiveness is a constant multiplier of the base effectiveness across the three management options (e.g., that live traps, kill traps, and hunting are all twice as effective as the baseline management assumptions), we find that kill traps *always* offer the greatest NPV under the 4 percent and 8 percent discount rates regardless of the size of the initial mongoose population. However, when the discount rate is 12 percent and the method's effectiveness is equal to or double that of the baseline, hunting can yield a marginally greater NPV than kill traps. Moreover, the NPV of management is positive in 79 of the 81 combinations—the two exceptions are live trapping of a large initial population (100 percent of carrying capacity) and low effectiveness of the management method (50 percent of baseline) with medium and high discount rates (8 percent and 12 percent). However, it is important to reiterate that the benefits of management to biodiversity and human health are not included in the analysis. Including those factors could produce positive NPVs for all 81 combinations.

Given the minor difference in cost between kill traps and live traps and the fact that the NPV of kill trapping is positive under every combination of discount rate, initial population, and effectiveness, we advocate kill trapping over live trapping unless it can be shown that, in reality, live trapping is considerably more effective than our baseline assumption and/or that kill trapping is considerably less effective than our baseline assumption. Regardless, both kill trapping and hunting yield positive NPVs even under the most pessimistic scenarios of a large initial population, poor management effectiveness, and high

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of scale. This would cease to be the case under decreasing economies of scale, an eventuality that we consider unlikely given increasing opportunities for specialization and spillover of knowledge.

discount rates, which demonstrate that these two management approaches are strictly preferred to the current approach of no management.[15]

[15] Kill trapping yields a positive NPV until the discount rate rises to 19 percent, *ceteris paribus*, and until effectiveness of the method falls to about 33 percent of the baseline assumption, *ceteris paribus*.

Table 5. Net Present Values in Fiji Dollars per Hectare from the Sensitivity Analysis

		Initial Population Relative to Carrying Capacity		
Option	**Effectiveness**	**33 Percent**	**66 Percent**	**100 Percent**
Discount Rate of 4 Percent				
Live traps	0.5 × base	3,377	1,113	67
	1.0 × base	8,312	2,925	1,070
	2.0 × base	10,577	3,578	1,425
Kill traps	0.5 × base	6,617	2,465	836
	1.0 × base	9,827	3,567	1,460
	2.0 × base	11,292	4,056	1,734
Hunting	0.5 × base	1,814	794	250
	1.0 × base	5,927	2,494	1,142
	2.0 × base	9,952	2,771	1,243
Discount Rate of 8 Percent				
Live traps	0.5 × base	1,488	543	-34
	1.0 × base	4,298	1,389	382
	2.0 × base	5,512	1,634	500
Kill traps	0.5 × base	3,311	1,210	302
	1.0 × base	5,108	1,687	546
	2.0 × base	5,876	1,884	645
Hunting	0.5 × base	617	385	125
	1.0 × base	2,959	1,265	523
	2.0 × base	5,219	1,329	545
Discount Rate of 12 Percent				
Live traps	0.5 × base	732	308	-72
	1.0 × base	2,639	777	130
	2.0 × base	3,413	882	175
Kill traps	0.5 × base	1,954	692	93
	1.0 × base	3,152	934	204
	2.0 × base	3,630	1,026	245
Hunting	0.5 × base	155	217	72
	1.0 × base	1,745	768	286
	2.0 × base	3,257	785	291

Notes: Project length is 50 years; the study area is one hectare.

Conclusion

The small Indian mongoose poses an enormous threat in Fiji. It not only harms biodiversity and human health but affects the livelihoods of Fijian people. The mongoose can be managed and its impacts can be reduced. However, so far, no serious, large-scale effort to manage it has occurred in Fiji, and neither the costs nor the benefits of management are well understood.

We aim to provide practical information for practitioners and policymakers through a cost-benefit analysis of three approaches for managing the small Indian mongoose in eastern Viti Levu. This analysis is informed by a first-of-its-kind primary source of data collected via matched household and community surveys that are scientifically significant. For example, the surveys document the economic cost, both direct (e.g., the value of livestock and fruit lost) and indirect (e.g., the opportunity cost of hunting), of living with the small Indian mongoose in Fiji. The surveys also document heterogeneity in the region's current use of various management practices and, importantly, in individual attitudes regarding the presence of the mongoose. When asked to allocate Fiji's national budget based on their personal spending priorities, survey respondents allocated approximately 6.7 percent of the national budget to management of IAS and 0.8 percent of the national budget specifically to controlling the mongoose.

The cost-benefit analysis reveals that kill traps are more cost-effective than live traps and hunting. However, kill traps are comparatively capital intensive. The modest capital cost and large cost-benefit ratio of hunting make it an attractive and less expensive alternative to kill traps. Live traps are less effective than kill traps and less efficient than hunting, making them the third-best option. However, under most assumptions regarding the size of the initial mongoose population, the management approaches' effectiveness, and the discount rate, even live trapping is preferred to the status quo of no management of the small Indian mongoose.

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