A review of small Indian mongoose management and eradications on islands

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Abstract The small Indian mongoose (*Herpestes auropunctatus*) is one of the world's 100 worst invasive species. It is a generalist feeder blamed for many declines and extirpations of vertebrates on islands. Native to Asia, it has been introduced to at least 64 islands (Pacific and Indian Oceans, Caribbean and Adriatic Seas) and the mainland (Europe, South America, Australia and North America). Most introductions were in the late 19th and early 20th centuries to control rats in sugar cane fields, but also to control snakes. Although recent mongoose introductions are few, the risk of intentional or accidental spread remains high, and many island taxa are susceptible to their effects. The mongoose has been eradicated from at least six islands (≤115 ha: Buck, Fajou, Leduck, Praslin, Codrington and Green) by trapping and secondary poisoning, but eradication has proven challenging. Two earlier island eradication campaigns against mongoose failed on Buck (182 ha) and Piñeros (390 ha) and campaigns are currently underway on the large islands of Amami-Oshima and northern Okinawa. Attempts to control the mongoose were numerous in the past, and several programmes are underway using trapping and/or poisoning. New techniques are being developed and show promise for eradication. The mongoose can be eradicated with current approaches on small islands with the aim of benefiting endemic species or preventing further introductions. More efficient methods and strategies are needed for successful eradication on larger islands and may facilitate containment of mongoose on the European and South American mainlands.

Keywords: *Herpestes auropunctatus*, invasive, predator, control

INTRODUCTION

Native to the Middle East and much of southern Asia, the small Indian mongoose (*Herpestes auropunctatus,* hereafter mongoose) (Hodgson 1836; Veron *et al.* 2007; Patou *et al*. 2009) has been introduced successfully to islands in the Pacific and Indian Oceans, the Caribbean and Adriatic Seas, and to continental South America and Europe, but was unsuccessfully introduced to North America and Australia (Nellis and Everard 1983; Nellis 1989; Nellis *et al.* 1978; Barun *et al*. 2008). Most introductions were in the late 19th and early 20th centuries to control rats in sugar cane fields, but with questionable success as rat population estimates remained high (Hinton and Dunn 1967). The mongoose was also introduced to control native poisonous snakes including a pit viper, the habu (*Trimeresurus flavoviridis*), on several islands in Japan, the fer-de-lance (*Bothrops lanceolatus*) on Martinique and St. Lucia, *B. caribaeus* in the West Indies, and the horned viper (*Vipera ammodytes*) on Adriatic islands.

The mongoose is a generalist predator that has been identified as one of the world's 100 worst invasive species (IUCN 2000) because of its role in the decline and extirpation of native mammals, birds, reptiles, and amphibians (Baldwin *et al.* 1952; Pimentel 1955a; Seaman and Randall 1962; Nellis and Everard 1983; Nellis and Small 1983; Coblentz and Coblentz 1985; Nellis 1989; Case and Bolger 1991; Henderson 1992; Yamada 2002; Powell and Henderson 2005; Henderson and Berg 2006; Hays and Conant 2007, Barun *et al.* 2010). In their review of the effects of mongoose on native species, Hays and Conant (2007) found that greatest impacts were on native fauna with no past experience with predatory mammals. In addition, the mongoose carries human and animal diseases, including rabies and human *Leptospira* bacterium (Pimentel 1955a; Nellis and Everard 1983).

Eradication of introduced mammals is a powerful conservation tool (Genovesi 2007), but mongoose eradication has been attempted on few occasions and with limited success. A known total of eight eradication campaigns and many control campaigns have been conducted to remove or reduce island mongoose populations. However, even with their limited scope, these attempts probably prevented further declines or even extirpations of native species, although definitive data are lacking. Very few teams have the technical expertise to remove mongoose successfully, even from small islands. Such lack of expertise is reflected by past failures and little progress beyond local control programmes. In addition, most control and eradication efforts are published in the grey literature, if at all, so information is often hard to find for conservation practitioners contemplating mongoose eradication.

We reviewed data from the published and grey literature on eradication and control campaigns, focusing on assessing successes, failures, and challenges. We compiled a list of all islands with known mongoose populations and communicated with researchers and managers who work either directly with the mongoose or with species it affects. Our aim was to facilitate mongoose eradication efforts and direct researchers to areas of applied research that would aid this goal.

BIOLOGY OF THE MONGOOSE

The mongoose is entirely diurnal (AB pers. obs.) and can swim and climb trees (Nellis and Everard 1983), but rarely does so. Mongooses avoid water when possible; they reduce their activity during rainy periods and will not voluntarily enter water deeper than about 5 cm (Nellis and Everard 1983). Such characteristics may account for the failure of mongoose to invade islands only 120 m from occupied sites (Nellis and Everard 1983). However, in Fiji, mongooses get fish out of nets in the water (Craig Morley pers. obs.). This may be a behavioural adaptation specific to that site.

Mongoose home ranges average 2.2 - 3.1 ha for females and 3.6 - 4.2 ha for males; home ranges often overlap and can be as small as 0.75 ha (Nellis and Everard 1983). Areas in the Caribbean may harbour 1-10+ mongoose/ha (Nellis 1989), but populations generally average 2.5 individuals/ha (Pimentel 1955a). On O'ahu, Hawai'i, mean home ranges were 1.4 ha for females and five males shared a region of about 20 ha (Hays and Conant 2003).

Females are pregnant from February through August in Fiji (Gorman 1976b), the US Virgin Islands (Nellis and Everard 1983), and Hawai'i (Pearson and Baldwin 1953), but the mongoose on Grenada has a 10-month breeding season (Nellis and Everard 1983). Gestation takes 49 days, with litter size of 2.2 on average (range = 1 – 5) (Nellis and Everard 1983). The number of litters produced annually has not yet been determined. Pups begin accompanying their mother on hunting trips at six weeks of age (about 200 g body mass). The youngest wild-caught pregnant female was four months old (Nellis and Everard 1983).

STATUS OF MONGOOSE POPULATIONS

Previous eradication attempts

Globally, at least 64 islands harbour introduced mongooses (Table 1), which are also on the northeastern coastal fringe of South America (Guyana and Surinam; Nellis 1989) and in Adriatic Europe (Croatia, Bosnia and Herzegovina, Montenegro; Barun *et al.* 2008).

Mongoose have been eradicated from six islands and were prevented from establishing on mainland North America when the first few immigrants were caught on Dodge Island, Florida. On Praslin Island, one mongoose was caught in a baited box trap (Dickinson et al. 2001, Quentin Bloxam pers. comm.). The Virgin Islands Division of Fish and Wildlife eradicated a breeding population of mongooses in the 1970s from Leduck Island using 19 x 19 x 48 cm Tomahawk box traps with meat bait (Nellis 1982) and another population from Buck Island in the 1980s also with box traps. This latter success followed an earlier failed attempt (see below). Buck Is has since remained free of the mongoose (McNair 2003; David Nellis pers. comm.).

A campaign on the French West Indian possession of Fajou Island used box-trapping for mongooses and possibly secondary poisoning from a simultaneous rat (*Rattus rattus*) and house mouse (*Mus musculus*) eradication effort using 50 ppm bromadiolone paraffin baits (Lorvelec *et al*. 2004). All trapped mongooses were dissected and none showed toxic bait in the stomach or haemorrhagic syndrome. During a one-month campaign in 2001, 18 people worked full-time to eradicate these three species.

The Antiguan Racer Conservation Project eradicated very small mongoose populations from two islands off Antigua in the West Indies. On Codrington Island, mongoose were eradicated using secondary poisoning from ingesting rats (*Rattus rattus*) poisoned with brodifacoum. The bodies of two poisoned mongooses were found (likely the total number that had been present on this very small island). There is also anecdotal evidence that mongooses were present on Green Island at least one year prior to the rat eradication but were absent afterwards. However, no mongoose carcasses were found during the rat eradication campaign (Jennifer Daltry pers. comm.).

In 1976, the US Fish and Wildlife Service received reports of a mongoose sighting at the Port of Miami on Dodge Island, Florida. Trapping conducted in the area yielded one young female. Interviews with people in the area revealed that two other mongooses had been killed by vehicles a month earlier (Nellis *et al*. 1978).

Failed mongoose eradications include Isla Piñeros, Puerto Rico, and an early attempt on Buck Island. The latter eradication campaign was initiated by the US National Park Service in 1962 (Everard 1975; cited by Everard and Everard 1992). After 10 years of trapping and poisoning, mongooses remained, and eradication efforts were eventually stopped because the ranger conducting the programme was transferred (Nellis *et al.* 1978, Nellis pers. comm.).

On Isla Piñeros fish baits with thallium sulfate may have killed all adult mongooses, which ceased to appear in traps seven days after poisoning began. However, four months later several juvenile mongooses were trapped, indicating that either they had been present in dens, had been too small to spring the traps, and/or bait density had been insufficient to put these juvenile mongooses at risk possibly owing to a reduced home range (Pimentel 1955b).

Current eradication campaigns

We know of only two current island efforts to eradicate the mongoose. Both attempts are in Japan where the mongoose is present on Okinawa and Amami-Oshima in the Ryukyu Islands, and on the main island of Kyushu. The Kyushu population is regarded by some as a recent discovery, but according to locals, mongoose have been there for at least 30 years.

On Amami-Oshima, the Japanese Ministry of the Environment began intensive mongoose control in 2000. Earlier control by local governments of Naze city (1993-2003, 128 km^2), Sumiyo Village (1998-2002, 118 km^2), and Yamato Village (1995-2003, 90 km^2) captured 8,229 mongooses from 1993 until 1999. In an extensive alien eradication programme initiated by the Ministry of the Environment, mongooses were livetrapped by local residents, mainly on a bounty system from 2000 until 2004. Between 60,000 to 317,000 trap-nights and 40 to 131 trappers captured 16,636 mongooses over the five years. The trappers were paid about US$ 20 per mongoose the first year, about US$ 36 the second and third years, and about US$ 45 the last year to try to increase incentives at low abundance. In 2003, three full-time trappers were employed to capture mongooses in low-density areas and began using kill traps. In 2009, 44-48 people were working full-time as Amami Mongoose Busters. Over a five-year period from 2005 until 2009, the Amami Mongoose Busters captured over 7,500 mongooses. From 2000 until 2004 about US$ 1,140,000 (122,000,000 JPY) was spent on the Amami-Alien control programme and from 2005 to 2009 about US$ 7,224,000 (695,000,000 JPY) on the Amami-Mongoose eradication programme (Abe *et al.* 1991; Ishii 2003; Yamada 2002; Yamada and Sugimura 2004; Shintaro Abe pers. comm.). A continuing eradication effort is planned until 2014.

On Okinawa, the Okinawa prefecture and the Japanese Ministry of the Environment initiated an alien control programme (2000-2004) in the Yambaru area of the northern part of the island, and in 2005 this became an eradication campaign. By 2009, 30 people were employed as full-time Yambaru Mongoose Busters. About four km of mongoose-proof fence was constructed in 2005 and 2006 by Okinawa prefecture to separate the trapped area (about 30,000 ha) from the uncontrolled area. From 2000 until 2004, 1831 mongooses were captured with 555,000 trap-nights, and from 2005 until 2009 the Yambaru Mongoose Busters captured over 2680 mongooses with 2,431,000 trap-nights. The total cost for the eradication programme from 2005 until 2009 in the Yambaru area by Okinawa prefecture was about US$ 5,058,000 (486,000,000 JPY including fence construction) and for the mongoose eradication programme by the Ministry of the Environment was about US$ 2,352,000 (226,000,000 JPY) (Yamada and Sugimura 2004, Shintaro Abe pers. comm.).

Past and present "control"/management

Adriatic

In Europe, the mongoose is present on the Croatian islands of Mljet, Korčula, Hvar, Čiovo, Škrda, and Kobrava, as well as the Pelješac Peninsula. The species has recently spread along the coast in Croatia, Bosnia and Herzegovina, and Montenegro at least as far as the Albanian border (Barun *et al.* 2008, Ćirović *et al.* 2011), but the full extent of the range is unknown. The coastal spread of mongoose may have resulted from several separate introductions. Two private mongoose control campaigns are being conducted by local hunters on Hvar and on Čiovo. On Hvar, under the guise of predator control, hunters are required annually either to pay a fee (equivalent to C. $US100) or to submit three mongoose tails or one tail of a native stone marten (*Martes foina*). Most mongooses are trapped there in locally made cages or leg-hold traps. On Čiovo, the only Adriatic island with the mongoose and not the stone marten, the regional hunting organization distributes "rat" poison for mongoose control during the annual autumn meeting (this procedure is illegal in Croatia, so we could not determine which poison).

Caribbean

In the Caribbean, the mongoose is present on 33 islands, many of which have no control (Table 1). Of the occupied islands in the British Virgin Islands, only Jost Van Dyke (JVD) has ongoing mongoose control. The mongoose was introduced to JVD in the 1970s to get rid of the rear-fanged colubrid snake (*Borikenophis portoricensis*). In 2006, the JVD Preservation Society with the help of several volunteers started live-trapping mongooses (Susan Zaluski pers. comm.).

In Puerto Rico, the US Forest Service and USDA APHIS Wildlife Services livetrapped in El Yunque National Forest to protect the critically endangered Puerto Rican parrot (*Amazona vittata*). The US Forest Service annually spends about $10,000 a year with two personnel who trap periodically, so the cost for mongoose control alone is difficult to estimate. A scheduled control of rabies virus vectors was planned for 2010, and targets included the mongoose (Everard and Everard 1992; Pimentel 1955b; Felipe Cano pers. comm.).

In Jamaica, the Jamaican Iguana Recovery Group collaborated in 1997 with Fort Worth Zoo, Milwaukee County Zoo, Zoological Society of San Diego and the University of the West Indies, Mona, to initiate a mongoose control operation in the central Hellshire Hills to protect the critically endangered Jamaican iguana (*Cyclura collei*). Live traps are operational every day and >1000 mongooses have been trapped to date. The approximate cost is US$ 400/month for the salary for one person (Byron Wilson pers. comm.). Two islands near Jamaica, Goat Major and Goat Minor, have been proposed for simultaneous eradication of mongooses and cats, in addition to goats.

On the US Virgin Island of St. Croix, USFWS conducts small-scale mongoose control near sea turtle nesting sites during the turtle breeding season at Sandy Point National Wildlife Refuge (Claudia Lombard pers. comm.). Tomahawk traps are used along 200 to 500-m lines along the beach vegetation. A similar mongoose trapping programme by Virgin Islands National Park staff has been ongoing for five years on St. John. Mongooses are livetrapped on beaches at Hawksnest, Dennis, Jumbi, Trunk, Cinnamon, Maho, Francis, Leinster, Coccoloba, Western Reef Bay, Genti, Little Lameshur, Great Lameshur, and Salt Pond Bay; salt ponds; the National Park Service visitor center, and along some roadways on the north shore (Carrie Stengel pers. comm.).

On St Lucia, the Durrell Wildlife Conservation Trust and St. Lucia Forestry Department (Ministry of Agriculture, Lands, Forestry and Fisheries) conducted two short removal experiments using live traps with chicken bait at an iguana nesting site (Matt Morton pers. comm.).

In 1902, the Agricultural Society on Trinidad started a bounty system of paying per carcass turned in; 30,895 mongooses were turned in from 1902 to 1908 and 142,324 from 1927 to 1930. We do not know when the bounty system stopped operating (Urich 1931).

In 1977, between July and December, a mongoose control operation performed by the Public Health Agency on Guadeloupe yielded 15,787 mongooses (Botino 1977 in Pascal *et al*. 1996), but the capture technique details are unknown because all mongooses were submitted by local residents.

On Cuba, nation-wide mongoose rabies control was undertaken between 1981 and 1985. In the municipality of Arabos, Matanzas Province, in 1984, the mongoose control was carried out by injecting 1,161,682 eggs with strychnine sulfate. Eggs were placed in bamboo or tin pipes to protect them from other animals. Non-poisoned baits were used in mongoose traps that were spaced about 30 m apart over an unknown area. Five to ten people worked per team for a total of about 500 people during that entire operation (Everard and Everard 1992).

In the mid-1970s, mongoose rabies control was undertaken throughout Grenada using sodium fluoroacetate (1080) in 50g of glutinous boiled cowhide. Sixteen baiters/trappers and staff using two vehicles distributed about 300 baits per baiter every day for about nine months. Average mongoose densities dropped from 7.4 to 2.5, but within six months the population recovered (Everard and Everard 1992).

Pacific

In the Hawaiian islands, many sightings of mongooses and one road kill in the 1970s were reported on Kauai but none have been trapped recently despite an extensive effort over the entire island. Elsewhere, widespread control or eradication is not being attempted, but mongoose control is performed in many small (<100 ha) areas to protect birds in upland native bird sanctuaries, wetlands, and wet forests during the breeding season. Agencies involved include the US Fish and Wildlife Service, Hawaii Nature Conservancy, Hawaii State Department of Land and Natural Resources (Wildlife Division), US National Park Service, USDA Wildlife Services, (Department of Army) along with private landowners. Live-traps (Tomahawk) and registered (SLN-Hawaii) diphacinone (50 ppm) wax bait (in bait stations) are employed. The US Department of Agriculture on the island of Hawaii has recently completed field studies evaluating various lures, attractants, and bait types (Pitt and Sugihara 2009). Staff performing mongoose control work are also responsible for other duties, so it is difficult to estimate the total cost for the State of Hawaii (Robert Sugihara pers. comm.).

The small Indian mongoose occurs on 13 islands in Fiji, where a recent molecular study also identified some populations of the Indian brown mongoose, *Herpestes fuscus* (Morley 2004, 2007; Patou *et al.* 2009). Currently there are no attempts to eradicate either mongoose species from any of the Fijian islands (Craig Morley pers. comm.).

Table 1 World list of islands separated into geographic areas and mainland areas where the small Indian mongoose was introduced; islands marked + are interconnected; GID # is Global Island Database number for each island; if the status column is empty then there are no known control attempts.

Island	GID #	Country	Area (ha)	Humans	Status	Refs (presence)	Refs (control)
Adriatic							
Hvar	6760	Croatia	29,737	Yes	Hunters trapping	53; 2	2
Korčula	7300	Croatia	27,840	Yes		53; 2	
Mljet	13790	Croatia	9800	Yes		53; 2	
Škrda	129520	Croatia	200	No		53	
Kobrava	240130	Croatia	52	No		25	
Čiovo	28550	Croatia	2900	Yes	Hunters poisoning, low pop, bridge to mainland	53; 2	2
Caribbean							
Jost Van Dyke	58740	British Virgin Is	850	Yes	JVD Preservation Soc traps	40	52
Tortola +	19250	British Virgin Is	5570	Yes		40	
Beef Island	88670	British Virgin Is	372	Yes		40	
Praslin	No	St Lucia	1	No	Eradicated	15	15; 47
Trinidad	1110	Trinidad & Tobago	476,800	Yes		59	54
Antigua	7140	Antigua & Barbuda	28,100	Yes		40	
Codrington	84837	Antigua & Barbuda	0.5	No	Eradicated	26	26
Green	28660	Antigua & Barbuda	43	No	Eradicated	26	26
Nevis	14620	St Kitts & Nevis	9300	Yes		40	
St Kitts	9890	St Kitts & Nevis	16,800	Yes		40	
St Martin	14960	France/Netherl'ds[1]	8720	Yes		40	
Barbados	5200	Barbados	43,100	Yes		40	
Piñeros	170660	US, Puerto Rico	390	No	Failed eradication attempt; no control	46	46
Vieques	11440	US, Puerto Rico	13,500	Yes		40	
Buck Island	389000	US	72	No	Eradicated	38	38; 33; 44
St Croix	8350	US	21,466	Yes	Localised control	40	11
St John	20180	US	5080	Yes	Localised control	40	12; 9
Leduck	75128	US	5.7	No	Eradicated	39	39
St Thomas	16970	US	8090	Yes	Low population	40	
Water Island	18293	US	199	Yes		40	
Hispaniola	210	Haiti/Dom.Rep.	7,648,000	Yes		40	
Carriacou	26610	Grenada	3770	Yes		20	
Grenada	6510	Grenada	34,400	Yes	Rabies control	40	17
Puerto Rico	790	USA	910,400	Yes	Rabies control	40	17; 46; 18
St Lucia	4090	St Lucia	63,980	Yes	Localised control	40	32
St Vincent	6160	St Vincent	38,900	Yes		40	
Cuba	150	Cuba	11,086,100	Yes	Rabies control	40; 3; 4	17
Romano	4030	Cuba	77,700	Yes		3; 4	
Sabinal	----	Cuba	33,500	Yes		3; 4	
Jamaica	660	Jamaica	1,118,960	Yes	Localised control	16	7
Goat Major +	---	Jamaica	200	No		20	24
Goat Minor	174550	Jamaica	335	No		20	24
La Desirade	35740	France, DOM	2,064	Yes		40	
Fajou	18	France, DOM	115	No	Eradicated	28	28; 34
Grande-Terre, Guadeloupe +	2330	France, DOM	63,900	Yes		40	5
Basse-Terre, Guadeloupe	2330	France, DOM	87,570	Yes		40	5
Marie Galante	10280	France, DOM	15,800	Yes		40	
Martinique	2710	France, DOM	112,800	Yes		40	
Africa							
Mafia	5130	Tanzania	39,400	Yes		59	
Grand Comoro	2840	Comoros	114,800	Yes		29; 58	
Mauritius	1970	Mauritius	204,000	Yes	Localised control	30	49; 8

Table 1 continued

Island	GID #	Country	Area (ha)	Humans	Status	Refs (presence)	Refs (control)
Pacific							
Beqa	25200	Fiji	3620	Yes		35; 13	
Kioa	37310	Fiji	1860	Yes		35; 13	
Macuata-i-wai	102480	Fiji	306	fishermen		35; 13	
Malake	84630	Fiji	453	Yes		35; 13	
Nananu-i-ra	111410	Fiji	270	Yes		35; 13	
Nananu-i-cake	127260	Fiji	300	1 family		35; 13	
Nasoata	25		74	1 family		13	
Vanua Levu	980	Fiji	553,500	Yes		35; 13	
Viti Levu	680	Fiji	1,038,700	Yes		36; 35; 13	
Yanuca	134480	Fiji	154	Yes		35; 13	
Druadrua	90100	Fiji	390	Yes		35; 13	
Mavuva	49	Fiji		Yes		35; 13	
Rabi (Rambi)	66040	Fiji	6878	Yes		35; 13	
Hawaii	700	USA, Hawaii	1,043,200	Yes	Localised control	6	51; 48
Kauai	2360	USA, Hawaii	162,400	Yes	Seen 1970s, not since	55; 10	48
Maui	1950	USA, Hawaii	188,700	Yes		41; 19	
Molokai	3700	USA, Hawaii	67,600	Yes		41; 19	48
Oahu	2210	USA, Hawaii	157,400	Yes		42; 19	48
Amami-Oshima	3610	Japan	71,200	Yes	Ongoing eradication	1	1; 56; 57; 23
Okinawa	2630	Japan	227,130	Yes	Localised control	27	50
Kyusyu	330	Japan		Yes	Recent find, but present about 30 years	37	
Ambon	3470	Indonesia	77,500	Yes		19	
Upolu	2680	Samoa	111,500	Yes	Recent intro Aleipata area	31	
New Caledonia	490	New Caledonia		Yes	Recently introduced	45	
MAINLAND							
Guyana	----	South America	Unknown	Yes		40; 21; 22	
Suriname	----	South America	Unknown	Yes		40; 21; 22	
Croatia (incl Pelješac Pen.)	----	Europe	Unknown	Yes	Coastal area, no known control	53; 2	
Bosnia and Herzegovina	----	Europe	Unknown	Yes	Coastal area, no known control	2	
Montenegro	----	Europe	Unknown	Yes	Coastal area, no known control	2, 14	
Florida	----	USA		Yes	Eradicated	43	

References to Table 1. [1]Abe *et al.* 1991; [2]Barun *et al.* 2008; [3]Borroto-Paez 2009; [4]Borroto-Paez 2011; [5]Botino 1977 in Pascal *et al*. 1996; [6]Bryan 1938; [7]Byron Wilson pers. comm.; [8]Carl Jones and Vikash Tatayah pers. comm.; [9]Carrie Stengel pers. comm.; [10]Case and Bolger 1991; [11]Claudia Lombard pers. comm.; [12]Coblentz and Coblentz 1985; [13]Craig Morley pers. comm.; [14]Ćirović *et al*. 2010; [15]Dickinson *et al.* 2001; [16]Espeut 1882; [17]Everard and Everard 1992; [18]Felipe Cano pers. comm.; [19]Hays and Conant 2007; [20]Horst *et al*. 2001; [21]Husson 1960; [22]Husson 1978; [23]Ishii 2003; [24]Hanson 2007; [25]Ivan Budinski pers. comm. [26]Jenny Daltry pers. comm.; [27]Kishida 1931; [28]Lorvelec *et al.* 2004; [29]Louette 1987; [30]Macmillan 1914; [31]Mark Bonin and James Atherton pers. comm.; [32]Matt Morton pers. comm.; [33]McNair 2003; [34]Michel Pascal pers. comm..; [35]Morley 2004; [36]Morley *et al.* 2007; [37]Nakama and Komizo 2009; [38]Nellis 1978 *et al.*; [39]Nellis 1982; [40]Nellis and Small 1983; [41]Nellis 1989; [42]Nellis and Everard 1983; [43]Nellis *et al.* 1978; [44]Nellis pers. comm.; [45]Patrick Barriere pers. comm.; [46]Pimentel 1955b; [47]Quentin Bloxam pers. comm.; [48]Robert Sugihara pers. comm.; [49]Roy *et al.* 2002; [50]Shintaro Abe pers. comm. ; [51]Smith *et al.* 2000; [52]Susan Zaluski pers. comm.; [53]Tvrtković and Kryštufek 1990; [54]Urich 1931; [55]USFWS 2005; [56]Yamada 2002; [57]Yamada and Sugimura 2004; [58]Walsh 2007; [59]Williams 1918

Recently, mongooses were seen in the Aleipata area of Upolu Island, Samoa and in New Caledonia. One male mongoose was captured during initial trapping on Upolo by the Samoan National Invasive Task Team (Mark Bonin and James Atherton pers. comm.). On New Caledonia, a mongoose infestation was recently reported in Nouméa, and two individuals were trapped (Patrick Barriere pers comm.).

South America

The mongoose is present in Suriname and Guyana but we are unaware of control efforts. Previous reports of the mongoose in French Guiana (Nellis 1989) are not supported by recent evidence (Michel Pascal pers. comm.; Soubeyran 2008).

Africa

On the main island of Mauritius, the Mauritian Wildlife Foundation started a control programme in the Black River Gorges National Park in 1988 as part of the Pink Pigeon Project of reintroduction and predator control (cats, rats, mongooses). Year-round control is conducted with 10-12 students, staff, and volunteers. Wooden box traps (live drop traps) baited with salted fish are primarily used, but for elusive individuals a mix of live/kill traps and change of bait is employed. Estimated total cost is C. US$ 20,000 per year (Roy *et al*. 2002; Carl Jones and Vikash Tatayah pers. comm.).

The mongoose was introduced to Grand Comore during the colonial period (Louette 1987), but no control programme has been reported (Michel Louette pers. comm.). We have no information on mongoose control efforts on the Tanzanian island of Mafia, but the presence of mongoose was confirmed in a recent report (Walsh 2007).

ERADICATION METHODS

Traps and baits

Trapping and toxic baiting have been employed for mongoose control and eradication (Lorvelec *et al.* 2004; Nellis 1982; Nellis *et al.* 1978; Pimentel 1955b; Yamada and Sugimura 2004). Hunting is not known to be employed or expected to be effective.

Mongooses appear susceptible to live traps, particularly box traps, which have been the primary method used to control and eradicate the mongoose. However, anecdotal evidence suggests some animals may become trap-shy or are naturally wary and cannot be trapped with this method (Tomich 1969; AB pers. obs.). Padded leg-hold traps have been used successfully in Hawaii for adult mongooses, but juveniles often do not exert enough pressure to trigger traps unless the trigger is very sensitive (James Bruch pers. comm.). Live traps have the advantage that non-target captures can often be released unharmed, but ethical regulations require them to be checked frequently. Kill traps have been used on Okinawa and Amami-Oshima with great success. Recent trials of the Doc250 kill traps in Hawaii demonstrate that they may be more effective than box traps (Peters *et al*. 2011). Kill traps have the advantage that they do not require routine checks except to re-bait/scent or remove carcasses. Where housings around kill traps can eliminate (or reduce to acceptable levels) the risk to non-target species, kill traps would be the preferred trap type. For eradication campaigns, multiple trap and bait/scent types should be considered, as wariness or aversion to one combination may not be transferable to others.

Live traps have typically been deployed on grids. For eradications, at least one trap must be in each home range area, which is a minimum area of 0.75 ha (Nellis and Everard 1983). The successful campaign on Buck Island used box traps on a 50 x 50 m grid (National Park Service 1993), and that on Fajou used a 30 x 60 m grid (Lorvelec *et al.* 2004). As for other species, having key trap locations is more important than having traps spaced perfectly on a grid. GPS-marked trap locations can be reviewed later via GIS and any coverage gaps addressed. Eradication is possible in small-scale campaigns by trapping alone, but this requires significant manpower and resources.

To facilitate trapping, attractants such as varying types of food are often used. Nevertheless, using lures such as scent (glandular, etc), visual signs (feathers or fur), and auditory cues (prey distress/alarm call, or conspecific calls) may prove useful for mongoose removal or detection. Pitt and Sugihara (2009) found that perimeter baiting was effective, but artificial lures were not. Behavioural traits including home range marking, breeding behaviour, and continual hunting for prey (Gorman 1976b; Nellis 1989) suggest that including attractants might increase trapping and detection success.

Toxic baiting was advocated over 50 years ago as a means of increasing efficacy (Pimentel 1955b), yet few major advances have been made with this method. Because mongooses appear to have low selectivity and consume most bait types (Creekmore *et al.* 1994), baiting is likely to be highly effective. Key considerations include toxin type, bait type, baiting density, non-target species, and timing.

For a chemical to be lethal it must have a pathway and be in a sufficient dosage. Different species have different tolerances to each chemical, and this trait is leveraged to minimise risks to non-target species while putting target species at risk (e.g., Murphy *et al.* 2011). Several toxins have been used historically for controlling mongooses, including thallium sulfate, sodium monofluoroacetate (1080), and strychnine sulfate (Pimentel 1955b; Everard and Everard 1992). Mongooses are highly susceptible to diphacinone (LD50 0.2mg/kg BW), a first generation anti-coagulant, and commercial diphacinone bait blocks have been used in Hawaii with mixed results (Stone *et al*. 1994). Diphacinone is currently the toxin of choice for targeting mongooses alone.

Baits used for delivering toxins to mongooses include chicken meat, boiled cowhide, eggs, salted fish, and commercial flavoured blocks (Pimentel 1955b; Everard and Everard 1992). The main problem with using toxic baits for carnivores is that baits typically used to deliver the toxin become unpalatable after a few hours. Baits have been developed for carnivores that remain palatable for >2 weeks for two large-scale programmes. In Texas, a rabies vaccination programme uses bait blocks effectively for multiple species, while in Western Australia a meat sausage bait was used to target cats and foxes (Skip Oertli pers. comm. 2009; http://www.dshs.state.tx.us/idcu/disease/rabies/orvp/; Algar and Burrows 2004). These baits may be effective for mongoose programmes.

An important aspect of any eradication attempt using toxic baits is that bait must be available to every individual. The baiting density to achieve this goal varies depending on many environmental factors. Baiting densities for mongoose have already been investigated (Creekmore *et al.* 1994; Linhart *et al.* 1993; Linhart *et al.* 1997; Pimentel 1955b). A density of 24 non-toxic baits/ha has yielded a 96-97% efficacy rate on populations with 5.84 (±1.04 SE) and 5.75 (±1.04 SE) animals/ha (Creekmore *et al.* 1994). Bait consumption trials can be used to determine appropriate baiting densities required for mongooses in specific situations (Wegmann *et al.* 2011).

Maximising efficacy

Various methods with potential use against populations of mongoose may pose risks to non-target species of conservation, cultural, or social importance. In such cases, risk assessments should identify where mitigation methods may be needed or whether some methods should not be employed. Timing is a potential mitigation measure, as some non-target species may periodically be absent from islands. On some islands, native mammalian predators will complicate eradication. For example, Mafia has the Egyptian mongoose (*Herpestes ichneumon*), the Adriatic islands of Korčula, Hvar, and Mljet have the stone marten (*Martes foina*), and many islands have native rodents.

For other problem species of mammals, toxic baiting has been timed to maximise bait uptake by target species while avoiding times when young are being nursed or targets have restricted ranges. Bait uptake can be highest when the usual sources of naturally available food are constrained (Algar and Burrows 2004; Howald *et al*. 2007). Island-specific plans for mongoose should consider their breeding patterns following the increase in day length (Nellis and Everard 1983). Times when female mongoose are nursing young (and may have restricted home ranges) should be avoided. The young in dens may not contact baits but be sufficiently independent to survive, a likely reason for the failed eradication attempt on Isla Piñeros, Puerto Rico (Pimentel 1955b). Mongooses can breed year-round, so two pulses of baiting at an interval of 9 - 10 weeks are expected to be required. The experience on Piñeros Island indicates that a single pulse of baits can kill all adult mongooses, but independent young in dens survive (Pimentel 1955b). Two pulses of baiting have yet to be tried for the mongoose but have been effective on tropical rodents that also breed year-round. Until a single method can demonstrably remove all animals (like poison operations for rodents), eradication plans for mongoose should include other methods to detect and remove survivors, a procedure currently used for cat eradications (Campbell *et al.* 2011).

Aerial baiting may be the most cost-effective, efficient, scalable, and replicable method, because mongooses forage almost exclusively on the ground, where most bait will fall, and they readily take bait. Aerial baiting has successfully delivered baits to eradicate rodents and cats, reducing costs and overcoming issues with access caused by terrain and vegetation (Algar *et al.* 2001; Howald *et al.* 2007). Hand-baiting could be used inexpensively on a small area to mimic an aerial baiting programme and provide proof of concept.

Feral cats and mongooses are found together on many islands. Controlling or eradicating one and not the other may yield little conservation benefit. Targeting both species simultaneously may be an option. Although mongooses are susceptible to diphacinone, cats are approximately 70 times more resistant (LD50 14.7mg/kg BW; Smith *et al.* 2000; Stone *et al.* 1994), and adult cats typically weigh at least 4 times more than adult mongooses. Diphacinone is thus suboptimal for targeting both species simultaneously. Para-aminopropiophenone (PAPP) is proposed as an alternative toxin for cats and other eutherian mammals such as canids and stoats in Australia and New Zealand as they are highly susceptible compared to most non-target species on islands (Fisher and O'Connor 2007; Marks *et al.* 2006; Murphy *et al.* 2007; Murphy *et al.* 2011; Savarie *et al.* 1983). Although no lethal dose (LD) data currently exists for mongooses, it is expected they would be highly susceptible to PAPP. Even if mongoose were four times more resistant than cats, the smaller body weight of mongooses would offset their relative resistance. Research is required to identify the lethal dose for mongooses, palatability, and the probability of emesis. Encapsulated PAPP, as is being developed for feral cats, would mask any flavor of the active ingredient and reduce the likelihood of emesis (Johnston *et al*. 2011).

Most islands with introduced mongooses are inhabited, so methods will need to be acceptable to the local populace while still being effective enough to ensure eradication. Live traps, and possibly kill traps and toxic bait stations, will be the key methods in urban areas where aerial baiting is typically not acceptable. Tamper-proof housings that eliminate access by children, pets, and non-targets must be developed before kill traps and toxic baits can be used in urban areas. Educating communities to the health risks mongooses pose to humans and livestock (Everard and Everard 1992) may facilitate acceptance of a campaign and the required methods by the community.

As for cats, mongoose eradications will require detection methods to confirm success. Methods for detecting cats can be applied to mongooses (see Campbell *et al.* 2011). Historically, box trapping has been the only detection method used in eradication campaigns. Larger and more complex campaigns will require additional methods and management tools to detect remnant individuals and confirm eradication. Tracking tunnels currently used in rodent eradication campaigns should be trialed for efficacy in mongoose detection. On Amami-Oshima dogs and camera traps are being used to detect mongooses (Shintaro Abe pers. comm.), but we were unable to find assessments of their efficacy.

RECOMMENDATIONS

Research funding for mongoose eradication trials is urgently needed. Baiting density, suitable toxins, lethal dosage and bait palatability vary depending on many environmental and behavioural factors. We encourage mongoose trials at smaller scales that can be replicated over larger areas by aerial baiting. Several islands that harbour the mongoose are small and uninhabited, and they can be used to test methods with limited liability.

The best opportunities for eradicating or containing an alien invasive species are often in sites where an invasion is in its early stages, when populations are small and localized and not yet well established. Priority for eradication should also be given to islands that can serve as sources for introduction to other areas and those that harbour endemic fauna.

At present many islands inhabited by mongoose are too large for eradication. Intensive localized control could benefit species that are at risk until eradication methods are developed. If planned carefully, such control could be done during a period when the mongoose is at most risk.

As more mongoose eradications are attempted, it is important that lessons learned from each attempt (whether successful or unsuccessful) and the skills learned be shared to ensure success of future efforts.

ACKNOWLEDGEMENTS

We owe thanks to David Nellis, Sugoto Roy, Michel Pascal, Shintaro Abe, Craig Morley, Glen Gerber, Sandy Echternacht, Clive Petrovic, William Kilpatrick, Jennifer Daltry, Quentin Bloxam, Matt Morton, Blair Hedges, Gad Perry, Byron Wilson, Bob Henderson, Robert Powell, Francisco Vilella, Joe Wunderle, Felipe Cano, Claudia Lombard, Mike Treglia, Donald Hoagland, Carrie Stengel, Adrian Hailey, Peter Dunlevy, Robert Sugihara, Will Pitt, Katie Swift, Darcy Hu, Martin Walsh, Michel Louette, Carl Jones, Vikash Tatayah, Go Ogura, David Pimentel, Elaine Murphy, Susan Zaluski and Tsitsi McPherson for completing the survey or providing advice on the manuscript. Reina Heinz and Jessica Welch helped identify GID numbers. Dick Veitch, Dave Towns, and one anonymous reviewer improved the manuscript.

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