Negative Impact of an Invasive Small Indian Mongoose *Herpestes javanicus* on Native Wildlife Species and Evaluation of a Control Project in Amami-Ohshima and Okinawa Islands, Japan

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Abstract

The small Indian mongoose, *Herpestes javanicus* (Family Herpestidae, Order Carnivora, Mammalia), is one of the most urgent species to eradicate among invasive mammals in Japan. Recently, the Japanese government has begun full-scale control of the mongoose as a model case for conserving the biodiversity of Japan's subtropical islands. We review and assess the impacts of the mongoose and control practices on Amami-Ohshima Island and Okinawa Island based on recently acquired information. On Amami-Ohshima Island, a total of 9,960 mongooses were captured under the full-scale project of the Ministry of the Environment which ran for four years from 1999 to October 2003. According to the April 2002 mongoose census taken after three years of full-scale implementation, the population was estimated to be 1/4 (1,500-2,000 mongooses) less than in 1999. However, our investigation revealed that the remaining mongooses in the mountainous area are having negative impacts on native species, especially on the Amami rabbit, *Pentalagus furnessi*. People who are involved with the full-scale mongoose project should recognize that the investment in the project, at least regarding the number of traps and trapping period, is incredibly low at this stage and funding should be increased to achieve the goal. Further eradication projects should take into consideration the low density and partial distributions of the mongoose population in mountainous areas.

Key words: Amami-Ohshima Island, eradication, introduction, native animals, Okinawa Island, small Indian mongoose

1. Introduction

The small Indian mongoose *Herpestes javanicus* (Family Herpestidae, Order Carnivora, Mammalia) is a small carnivore and native to an area stretching from Iraq through northern India to southernmost China and Indonesia, the Malay Peninsula, Hainan and Java (Nowak, 1999). The external characteristics typically show a sexual dimorphism as follows: mean head and body length of 302 mm for females and 336 mm for males, tail length 223 mm for females and 241 mm for males, and mean body weight 456 g for females and 673 g for males on Amami-Ohshima Island (Abe, 1991). Both its habitat range and its population size are the largest among the Herpestidae family, so the species is thought to be highly adaptable to a wide variety of natural environments. The mongoose was widely introduced by people in order to control pest species such as rats and snakes in the West Indies during the early 1870s, and in the Hawaiian Islands and other areas including Japan later on (Simberloff, 2001).

In Japan, more than 40 species of exotic mammals have been identified so far (Ikeda, 2002). The main exotic predatory mammals (Order Carnivora) include the domestic dog, *Canis familiaris*; Siberian weasel, *Mustela sibirica*; domestic ferret, *M. putorius furo*; American mink, *M. vison*; raccoon, *Procyon lotor*; masked palm civet, *Paguma larvata*; and domestic cat, *Felis catus*. In addition, the Japanese weasel, *M. itatsi*; red fox, *Vulpes vulpes shrencki*; raccoon dog, *Nyctereutes procyonoides*; and Japanese marten,

Martes melampus melampus, have been colonized from their areas of indigenous distribution in Japan to non-native areas such as the Ryukyu Islands, Hokkaido and other places. Since the mongoose is one of the most urgent species to eradicate among invasive mammals in Japan, the Japanese government has recently started full-scale control of the species as a model case for preserving the unique biota of Japan's subtropical islands.

This paper reviews the impacts of the mongoose on native wildlife species and evaluates the effects of four years of the control project on Amami-Ohshima and Okinawa Islands.

2. The Worst Invasive Species in the World

The first instance of introducing mongooses to an island was in 1872, when four males and five females were brought to Jamaica from Calcutta. They were released on Espeut's Spring Garden Estate, where the population established itself and reproduced within a few months (Simberloff *et al*., 2000). Mongooses that were bred in Jamaica were sent to Cuba, Puerto Rico, Grenada, Barbados and Santa Cruz (Trinidad), as well four to eight individuals that were sent to St. Croix in 1882-1884 (Fig. 1). In 1883, 72 individuals from Jamaica were released on Hawaii Island and additional individuals were transported from the West Indies in 1885. The offspring of these early populations were released to other islands, i.e. Maui, Molokai and Oahu. In 1883, a pair of mongooses was sent from Calcutta to the Fiji Islands. In 1900, 16 males and three females were released on Mauritius from an unknown location in India. In 1910, 17 individuals including six males, six females and five individuals of unknown sexes were trapped in what is now Bangladesh and taken to Okinawa Island by Dr. S. Watase (Kishida, 1931). The latest instance of release on an island was on Amami-Ohshima Island, where 30 individuals were released, derived from Okinawa Island in 1979. Most of those islands were developed extensively for plantation agriculture, and mongooses were introduced in order to control rats to prevent crop damage.

Although mongooses were acclaimed for killing rats in the initial stage of the introductions, they gradually became one of the worst pest species by preying on poultry and damaging various crops even more severely than the rats had done. In addition, mongooses prey on native animals, so even pioneer populations were responsible for the extinction or endangerment of many wildlife species on most of the islands, because the native animals were not resistant to predation by invasive mammals such as mongooses, as their populations had evolved in the absence of predatory mammals. Therefore, in 2000 the small Indian mongoose was designated as one of the World's 100 Worst Invasive Alien Species (IUCN, 2000).

3. History of Introduction on Okinawa and Amami-Ohshima Islands

Okinawa Island is 1,202 km^2 in area and its highest peak is 503 m in elevation. Forests cover 40% of the island, and are especially concentrated in the north. The northern part of the island has many threatened species that are endemic to the Ryukyu Archipelago, located in the southwesternmost part of Japan. Amami-Ohshima Island, which is 150 km from

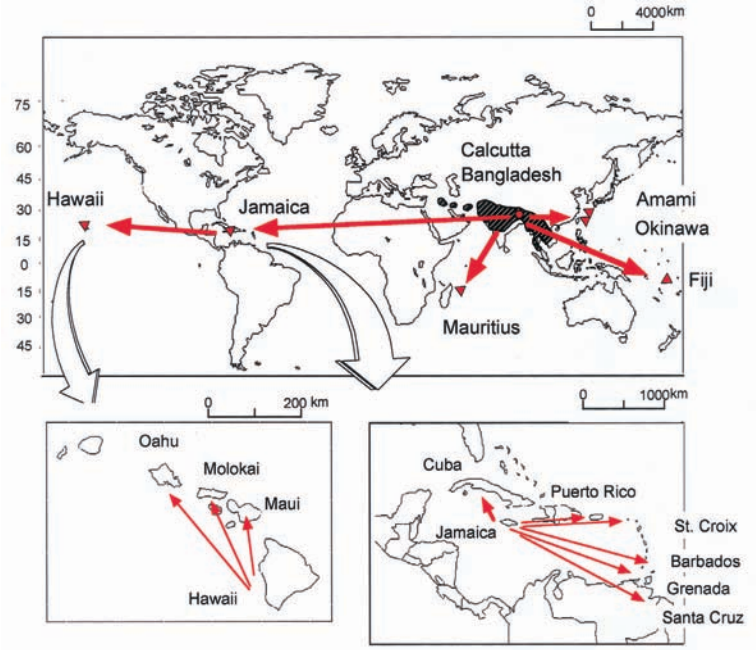

Fig. 1 The historical route of repeated introduction of mongooses from their native area to colonized areas (from Simberloff *et al.,* 2000). Native lands in south Asia are shaded with oblique lines.

Okinawa Island, is 710 km^2 in area, with a maximum elevation of 694 m, and is 86% forested. The island has also many endemic and threatened species. The Habu, *Trimeresurus flavoviridis*, a dangerously venomous pit viper, inhabits these and other islands with higher elevations in the Ryukyu Archipelago. Local people are terrified of the snake because of the high frequency of encounters and severe bite-induced injuries. The snake can be encountered on farmlands, along roads, and even in the vicinity of residential areas. On Amami-Ohshima Island, for instance, 3,600 people were bitten from 1954 to 1998, 50 of them fatally (Kagoshima Prefecture Office, 1999).

A variety of means to reduce the incidence of snakebite and fatalities have been successively employed, such as capturing, poisoning, alteration of habitat around housing, and serum development. Biological pest control has also been employed to reduce the populations of snakes and their principal prey, the black rat, *Rattus rattus*. On Amami-Ohshima Island, before releasing the small Indian mongoose, 871 Japanese weasels, *Mustela itatsi,* were introduced as snake and rat predators during 1954-1958, but none of them survived. More than 2,000 weasels were released on eight other small islands of the Amami archipelago during the same period. They failed to colonize six islands including snake-infested Amami-Ohshima Island, but did colonize three islands where there were no snakes. This is thought to be due to competition for the same prey as the snakes and also predation by the snakes because they are both nocturnal (Hayashi, 1979). In contrast, the small Indian mongoose has successfully colonized Amami-Ohshima Island.

In 1910, four mongooses were released on Okinawa Island to control snakes and rats and four others were released on Tonaki Island (1 km^2 in area) by Dr. S. Watase who had brought them from India (Kishida, 1931). Since then, the mongoose has been expanding its distribution from the release site in Naha City, in the southernmost part of Okinawa Island, toward to the north. Sometime around 1990 it reached the northern forests, where there are many endangered species (Fig. 2). In contrast, the mongooses on Tonaki Island died out relatively soon after their release.

In 1979, it is said that 30 mongooses were released to control snakes around a new facility opened for public education in a forested suburb of Naze City on Amami-Ohshima Island (Fig. 3). However, there is

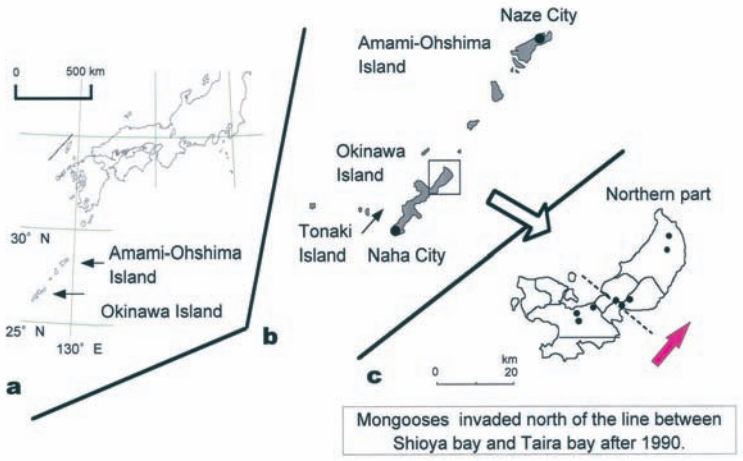

Fig. 2 Locations of Naha City on Okinawa Island, Tonaki Island and Naze City on Amami-Ohshima Island (a, b), and the invasion of the mongoose into the forest in the northern part of Okinawa Island after 1990, which many endangered species inhabit (c). In 1910, only four mongooses were originally released to control venomous snakes in Naha City. Their offspring reached the northern area over 80 years later.

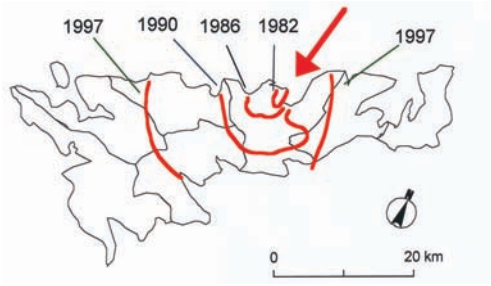

Fig. 3 Release site of mongooses at Naze City in 1979 and current distributions of mongooses.

no official record of the release. Since then, the mongoose has been expanding its distribution from the release site, covering an approximately 10 km radius by 1989 and a 20 km radius by 1997, encompassing half of the mountainous areas occupied by many threatened species, such as the Amami rabbit, *Pentalagus furnessi*. The rate of range extension is estimated to be *ca*. one kilometer per year. After 20 years the population was estimated to be 5,000-10,000 mongooses in 1999 (Environment Agency, 1999). A mtDNA analysis by Sekiguchi *et al*. (2001) indicated that the original mongooses on Amami-Ohshima Island came from Okinawa Island.

4. Negative Impacts on Agricultural Crops and Poultry

The mongoose has caused great damage to crop production (taros, sweet potatoes, melons, watermelons, loquats, etc.) and poultry on both islands. On Amami-Ohshima Island, for instance, economic losses caused by the mongoose rapidly increased, then declined slightly as follows: 1994 (US$7,000), 1995 (US$32,000), 1996 (US$64,000), 1997 (US$110,000), 1998 (US$100,000) and 1999 (US$80,000). Some farmers trapped mongooses to protect their crops before the local government began controlling mongooses in 1993. On Okinawa Island, 17 of the 100 egg farmers and four of the six chicken farmers reported damage caused by mongooses between 1990 and 1999 (Ogura, 2001). In the northern and central parts of Okinawa Island, the ratio of farmers who had damage to the total number of farmers was higher than that in the southern part, presumably because of higher mongoose density as well as the number of farmers there.

5. Negative Impacts on Native Species

On Amami-Ohshima Island, the mongoose, which invaded mountainous areas in the mid 1980s, has had a predatory impact on the native animals living there as Table 1 indicates. On the other hand, there has been no clear evidence that the mongooses prey on the snakes (Abe *et al.,* 1999; Environment Agency, 1999; Yamada *et al*., 2000). According to our analysis, insects (40%), other invertebrate animals (90%), amphibians and reptiles (60%), mammals (20%), and birds (15%) were found in 89 mongoose pellets collected in the habitat of the Amami rabbit (Yamada *et al*., 2000). Eight percent of the pellets contained traces of Amami rabbit. The mongoose preys chiefly on insects and birds throughout the year, but on amphibians and reptiles more frequently in summer and on mammals in winter. Recent changes in the distribution and abundance of the Amami rabbit suggest that the mongoose has reduced rabbit populations (Sugimura, 1998; Sugimura *et al*., 2000; Sugimura, 2002; Sugimura *et al*, 2003; Sugimura & Yamada, 2004) (Fig. 4).

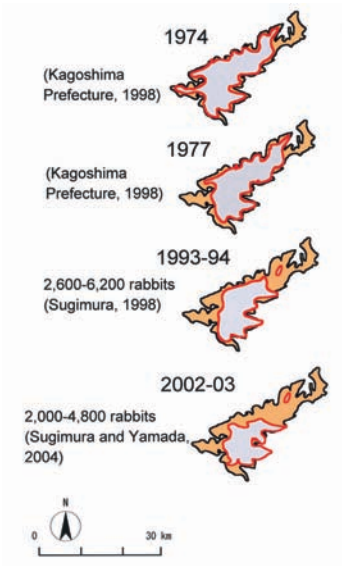

Fig. 4 Reduction of the area of the endangered Amami rabbit's habitat after invasion of mongooses on Amami-Ohshima Island. Note the sharp reduction in the northern area of the distribution of the Amami rabbit in 2002-2003 compared with 1993-1994, which was caused mainly by mongoose predation.

Table 1 Threatened native species categorised by IUCN on Amami-Ohshima Island and other islands that have been recorded in the diet of the mongoose. Identified mongoose food items are marked with an asterisk.

Category	Mammal	Birds	Reptiles	Amphibians
Critically Endangered		*Zoothera dauma major* 1,2		
Endangered	*Crocidura orii* 2 *Diplothrix legata* 1* *Tokudaia osimensis* 1* *Pentalagus furnessi* 1*	*Scolopax mira** *Dendrocopos leucotos owstoni* 1,2		*Rana ishikawae* 2?
Vulnerable		*Dendrocopos kizuki amamii* *Erithacus komadori* 1* *Garrulus lidthi* 1,2*	*Japalura polygonata** *Eumeces barbouri**	*Tylototriton anderson* *Rana amamiensis* *Rana subaspera* 2
Lower Risk	*Crocidura horsfieldii watasei**	*Columba janthina janthina* 1	*Achalinus werneri* *Calliophis japonicus japonicus* 2*	*Cynops ensicauda*
Other native species			*Cyclophiops semicarinatus**	

1: Japanese Natural Monument. 2: Endemic or main population on Amami Island.
Food species were cited from Environment Agency (1999) and Yamada *et al.* (2000).

As for native bird species, Sugimura (2002) concluded that populations of purple jay, *Garrulus lidthi,* and Ryukyu robin, *Erithacus komadori,* had been reduced by the mongoose invasion, for the following reasons. First, a statistical analysis indicated that their numbers decreased in the areas where mongoose capture rates were high, while no decrease was observed in the other areas where capture rates were low. Second, the two species are frequently observed on forest floors, where they feed on insects and acorns. In contrast, populations of other species, such as the white-backed woodpecker, *Dendrocopos leucotos*; pygmy woodpecker, *Dendrocopos kizuki*; and brown-eared bulbul, *Hypsipetes amaurotis*, which spend most of their time in the canopy layer, did not decrease after the mongoose invasion.

On Okinawa Island, an investigation by the Okinawa Prefecture Office and the Yamashina Institute for Ornithology showed that the Okinawa rail, *Gallirallus okinawae,* was severely affected by mongooses because the rail had disappeared wherever the mongoose was captured in the northern part of Okinawa Island (Tanahara, 2002). However, south of this area, Ogura *et al.* (2002) found that mongooses preyed on a variety of animals such as birds, mammals, amphibians and arthropods.

6. Mongoose Control

In the 1980s, local scientists on Amami-Ohshima Island carried out ecological studies of mongoose populations mostly near the release areas (Abe *et al.,* 1999). The local government, the Naze City Office, began to trap mongooses in order to reduce crop damage in farmlands around Naze City from 1993 and the Yamato Village Office began trapping in 1995. Fifteen to twenty trappers with 10-30 traps each captured as many as 1,100-1,500 mongooses during the pest control period of seven to nine months (May-March) (Fig. 5). Four or five skillful trappers captured approximately 60%-80% of those mongooses.

Recognizing the predation impact of the mongoose on endangered animals on Amami-Ohshima Island, the Ministry of the Environment of Japan's central government carried out preliminary investigations from 1996-1999 into the possibility of eradicating mongooses from the whole island. The investigations assessed the following: expansion of distribution, reproduction, food habits, estimated population size and annual growth rate (5,000-10,000 individuals and 30%, respectively, in 1999), and techniques for eradication by cage traps and wooden box traps using fish sausage as bait. Based on the results obtained from the pilot investigations, the Ministry of the Environment decided to begin a full-scale project to eradicate the mongoose from the whole island in 2000, employing two methods: 1) massive reduction of population using many traps during a short period (three years) over the whole island (annual target reduction of 4,000-5,000, including both the number caught around farmlands by the local governments, and the number trapped in mountainous areas by the Ministry of the Environment), and 2) long-term eradication until the species became extinct.

On Amami-Ohshima Island, a total of 9,960 mongooses were captured by the full-scale project of the Ministry of the Environment from October 2000 to October 2003, including the number of mongooses trapped by local governments (Fig. 5). This included 2,025 animals caught under pest control measures and 7,419 under the eradication project of the Ministry of the Environment. The total number of traps used during the four-year period ranged from 30,000 to 165,000 each year and the number of trappers ranged from 40 to 131 (Table 2). According to the April 2002 mongoose census conducted after the full-scale project had been going for three years, the population was estimated to be one-quarter (1,500-2,000 mongooses) less than it had been in 1999 (Ishii, 2003). However, the amount of reduction is thought to be

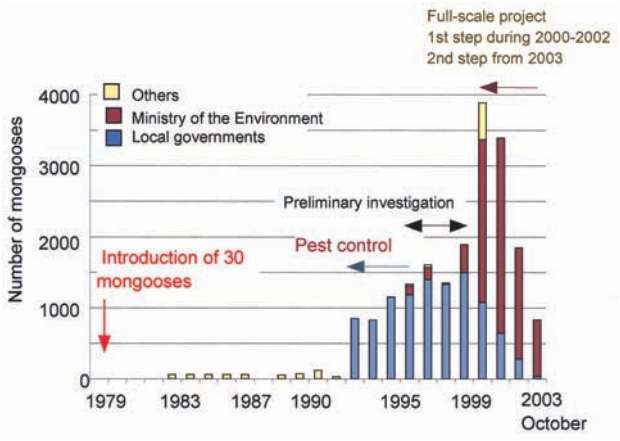

Fig. 5 Number of mongooses trapped by control projects on Amami-Ohshima Island.

Table 2 Number of trappers for pest control and for the full-scale control project, and number of traps/day on Amami-Ohshima Island.

Year	Number of trappers for pest control	Number of trappers for full-scale project	Number of trappers overlapping both projects	Substantial number of trappers	Number of traps/day by both
2000	32	26	16	42	43,000
2001	17	124	10	131	165,000
2002	6	46	6	46	147,000
until August, 2003	3	40	5	40	30,000
Total	58	236	37	259	385,000

(from the Ministry of the Environment)

skewed because the census was conducted in areas where the mongoose density became extremely low due to continuous trapping.

Trappers were paid a bounty of US$20 per mongoose by either the pest control or the eradication project upon taking the tails to either office, and a total of US$78,000 was spent on bounties on the island by both governments in the first year (2000). However, some trappers lost their incentive to trap because reduced capture efficiency after the first year, so the bounty was raised 80% to US$36 and a total of US$123,000 was spent on bounties in the second year (2001), and US$67,000 in the third year (2002). Therefore, a total of US$268,000 was spent on bounties for 9,960 mongooses captured during four years of the full-scale project. In 2003, the bounty was raised again to US$45 to increase trapper motivation, and three full-time trappers were employed for capturing mongooses living in low density area in the mountains.

On Okinawa Island, a total of 1,290 mongooses were captured by the projects of both the Okinawa Prefecture Office and the Ministry of the Environment from October 2000 to July 2003. Trapping techniques are too labor intensive for use over large areas, so the capture ratio was very low because the mongoose density in the northern part was very low, and the trappers had to check their traps every day because non-target animals including feral cats, rats, robins, rails, and others are also captured (Tanahara, 2002).

7. Monitoring the Effect of the Full-scale Project

It is necessary to monitor the remaining mongooses and the effect of eradication on restoring the native species. Some native species, such as the Amami rabbit, the Amami woodcock *Scolopax mira*, and others, are being monitored by some scientists as is the effect of mongoose removal on rats and native species of Amami-Ohshima Island, (Ishida *et al.,* 2003a; 2003b; Sugimura *et al.,* 2003; Yamada *et al.,* 2003). According to our investigation of the remaining mongooses conducted by auto-sensor camera during the full-scale project, the frequency of mongooses was high (7.9%) in the northern area (Naze City and Yamato Village, site A in Fig. 6(c), and medium (3.0%) in the southern area (Sumiyo Village, site D in Fig. 6(c) where rabbit density was high. Mongooses were also detected by the cameras in the areas where trappings had been discontinued due to low incentive of trappers or prohibition by landowners. In addition, our investigation also found that a mongoose entered into the breeding nest of a rabbit in daytime in the low mongoose density in the south (Fig. 7). Furthermore, the rabbit population, which was investigated during 2002-2003, was found to be rapidly decreasing and disappeared in less than eight years in relatively high-density mongoose areas, especially in the north (Fig. 4). These results indicate that if a small population of mongooses, even only one mongoose, re-

a

Site	Mongoose density	Native Species density	Agriculture
A	high	low	high
B	high	high	none
C	low	high	none
D	low	high	none

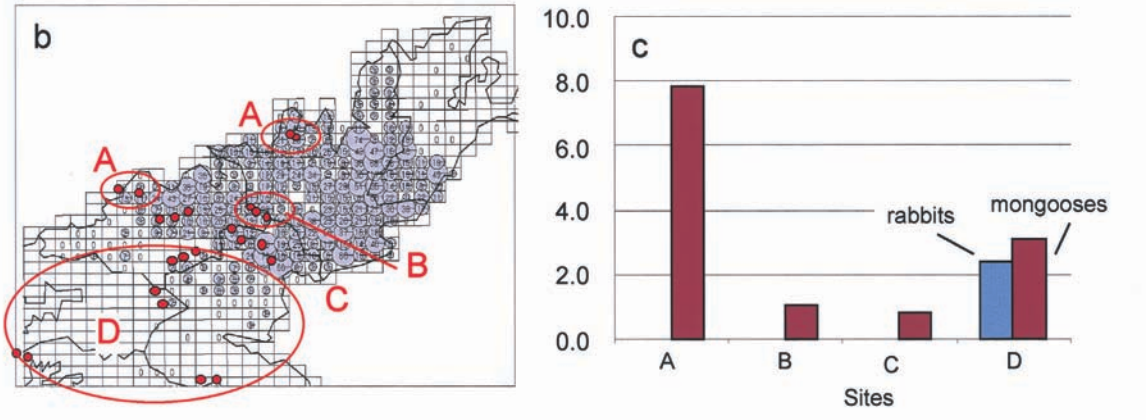

Fig. 6 Differences in frequency of numbers of photographs of mongooses and rabbits at each site, A-D, revealed by 30 auto cameras (c), placed at sites (A-D) of different density of mongooses and native species on Amami-Ohshima Island during the full-scale project (a, b). (Yamada *et al.,* 2003).

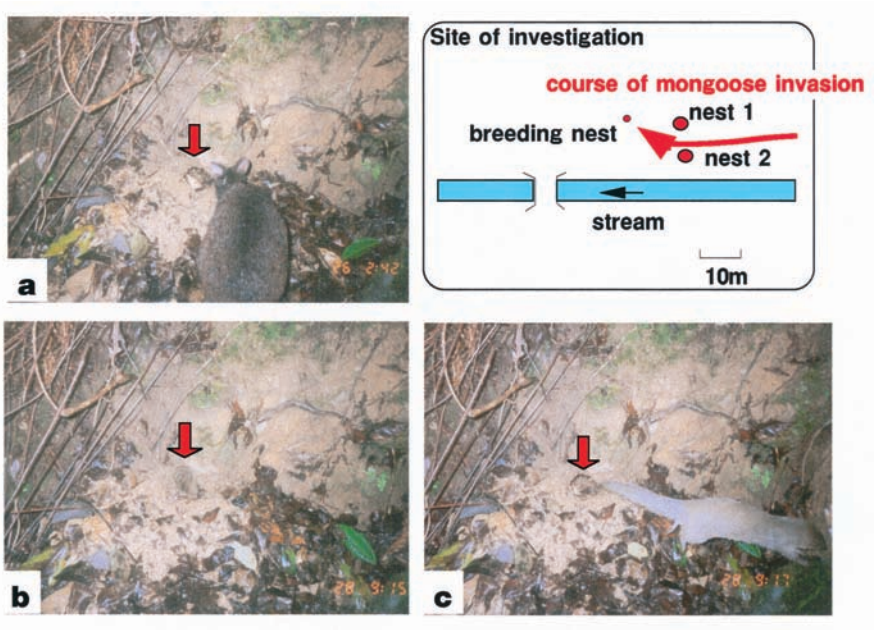

Fig. 7 A mongoose entering a breeding nest (arrows) of the endangered Amami rabbit, recorded by auto-sensor cameras on Amami-Ohshima Island during the full-scale project (Yamada *et al.,* 2003). A mother visited the breeding nest at 23:05 pm on December 25 and 02:42 am on December 26, 2002 (a). A mongoose entered into the breeding nest at 09:15 on December 28. The tail and hindfoot of the mongoose were observed at the entrance of the nest (b). The mongoose left the nest at 09:17 on December 28 (c).

mains in rabbit habitat, the rabbit will become extinct due to predation by mongooses not only on adult rabbits but also on juveniles inside the breeding nest. Therefore, it is necessary to eradicate mongooses in the habitat of the rabbit and to prevent their invasion into other rabbit habitat.

8. Problems and Conclusion

Because crop damage was not observed recently following the reduction of mongoose populations due to trapping, the pest control program of the local government was ceased in January 2004. In addition, the number of trappings rapidly decreased in 2003 (Table 2). However, our auto camera investigations have revealed that the mongoose persists in the farmlands and in non-trapping areas in the mountains. On the other hand, compared to the successful eradication in Britain of the coypu (Gosling, 1989), a large exotic rodent that was invading semi-aquatic environments, the total number of traps (385,000) in the full-scale mongoose control project on Amami-Ohshima Island for four years was only 24% of that (1,600,000) in the eight-year coypu control project. Furthermore, trapping efforts in the coypu control project increased relatively as the density of target animals became low and was continued for three years after no captures to confirm the eradication of the coypu. Eradication of the mongoose is thought to be more difficult than that of the coypu because of differences in biological and ecological characteristics, such as reproduction properties, food habits and habitat preference. People who are involved with the full-scale mongoose project should realize that the investment in the project, at least in the number of traps and trapping period, is incredibly low at this stage and must be increased to achieve the goal of eradication.

However, there are many problems remaining to be solved in the full-scale project on Amami-Ohshima Island and the northern area of Okinawa Island. Although there have been a few recent studies on controlling mongooses using chemicals in Hawaii (Smith *et al.,* 2000) and on management implications on Mauritius (Roy *et al.,* 2001), there have been no successful measures for mongoose eradication in areas colonized by mongooses so far (Simberloff, 2001).

The cases described here in Japan are recent and constitute the first trial of mongoose eradication. There are many difficulties to overcome to accomplish eradication on both islands (Yamada, 2002). For instance, on Amami-Ohshima Island, the target area is large in size, and is difficult to approach due to high mountains with steep slopes, and there are many endangered species including snakes. Furthermore, it will be necessary to 1) integrate the pest control and eradication project programs to establish year-round trapping and a strategy for eradication; 2) monitor the efficiency of eradication measures; 3) introduce and develop more effective techniques; 4) monitor the effects on recovery of the endemic animals and on the ecosystems, including rat control; and 5) exchange information with experts in other countries. A continuous and increased supply of money and manpower

as well as public information and research work will be necessary to achieve the goal of the project.

In additional projects, eradication of patches of mongooses surviving in low-density, mountainous areas must consider. It is obvious that more effective measures are necessary to eradicate this invasive predator in order to protect the Amami rabbit and other native animals on Amami-Ohshima Island as well as in the northern area of Okinawa Island.

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