Management Methods of Small Indian Mongoose on Islands: A Comprehensive Review

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Abstract:

The mongoose, along with cats and rodents, is one of the most dangerous invasive alien species for biodiversity on the world's islands. This literature review examines methods for regulating and eradicating populations of the small Indian mongoose to provide information for future island conservation actions. Most introductions of this species to island territories were initially made for the purpose of biological control of undesirable species (rats, snakes) dating back to the 19th and 20th centuries. The negative impact on the native fauna of different islands has been well documented. The small Indian mongoose has been since successfully removed from only six small islands, five of which are in the Caribbean. When eradication is unrealistic, the most widely used approach is to manage populations at specific risk sites by reducing the small Indian mongoose population. Today's most common control method is live trapping, but only some islands have used lethal trapping and poisoning. However, more studies must be conducted on the effectiveness of the regulation campaign and the different methods. Indeed, the lack of published information on the effectiveness of control methods makes it difficult for conservation managers to design suitable and efficient control campaigns. Therefore, we stress the need to systematically evaluate the effectiveness of controlling the small Indian mongoose on islands and go towards adaptive management.

Keywords: invasive alien species, *Urva auropunctata*, eradication, trapping, island conservation

History and Impact of the small Indian mongoose

The small Indian mongoose (*Herpestes* or *Urva auropunctata*, see Patou et al., 2009) is originally from the eastern Middle East to southwest Asia. Because of its alleged effectiveness in controlling rats (Espeut, 1882) and venomous snakes, the small Indian mongoose has been deliberately introduced by humans in at least 64 islands (Hays & Connant, 2007; Barun et al., 2011; Lorvelec et al., 2021; Louppe et al., 2021b; see Figure 1).

Because of their high levels of endemism and their evolutionary isolation, island environments are particularly vulnerable to invasive alien species, which contribute significantly to reducing their biological diversity (Hays & Conant, 2007; Lewis et al., 2010). Indeed, island ecosystems, shaped by unique evolutionary processes, are home to many species that occur naturally only locally and have evolved without the pressure of predators or competitors, rendering them vulnerable to invasive alien predators, such as the small Indian mongoose (Roy et al., 2002; Courchamp et al., 2003).

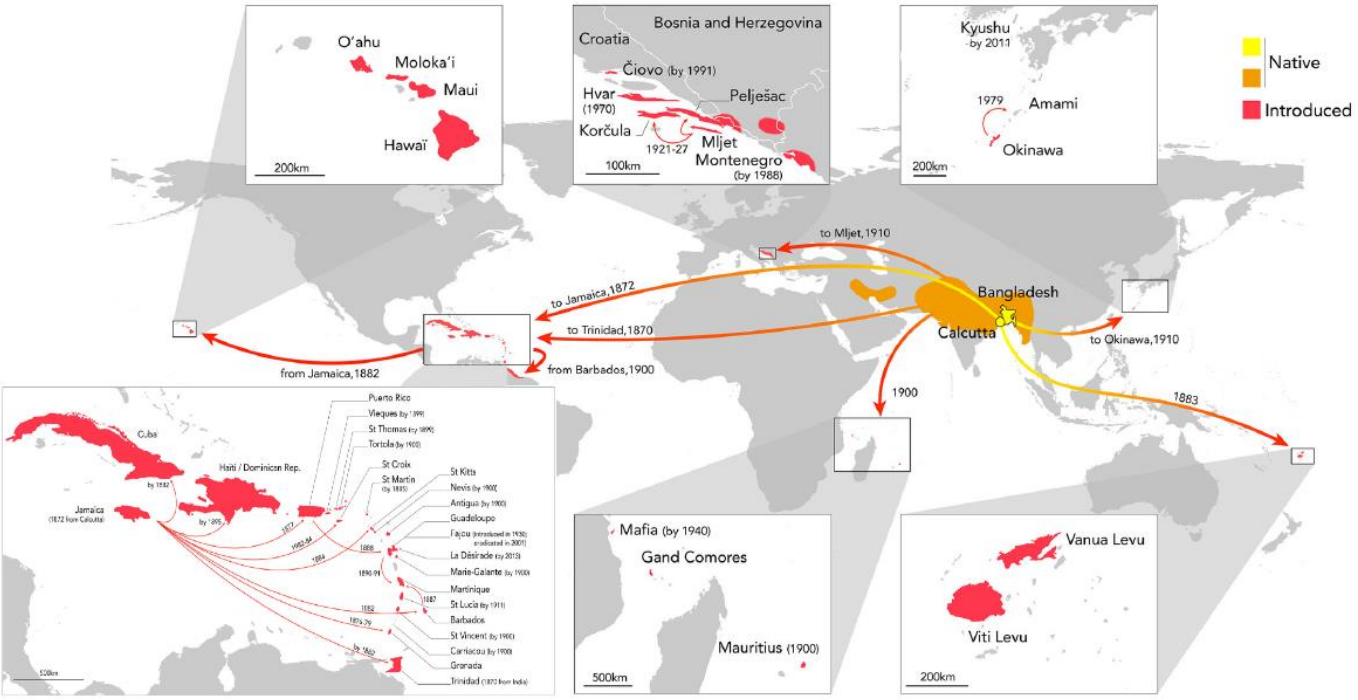

Figure 1: Historical and current global distribution of the small Indian mongoose, *Urva auropunctata*. Orange and yellow colours indicate native distribution. Red shows distribution in introduced regions. (© All rights reserved by Louppe et al., 2021b)

The impacts of the small Indian mongoose on the island's biodiversity have been well documented (Nellis, 1982; Hays & Conant, 2007; Watari et al., 2008; Barun et al., 2011b; Lewis et al., 2010). This species is considered responsible for many islands' declines and even the extinction of several species of ground-nesting birds, reptiles, invertebrates and small native mammals (Seaman & Randall, 1962; Nellis & Small, 1983; Coblentz & Coblentz, 1985; Roy, 2002; Lorvelec et al., 2004; Lewis et al., 2010; Owen, 2017). Its impact is such that it is now listed as one of the world's 100 most harmful invasive alien species (Lowe et al., 2007). In addition, this species is a vector of viral and bacterial diseases, notably rabies and Leptospira, which affect both wildlife and human populations (Berentsen et al., 2015; Shiokawa, 2019; Cranford, 2021).

In response to the problem of the small Indian mongoose, methods have been developed to eliminate the species from islands (Barun et al., 2011) or at least control these populations (Brown & Daigneault, 2015). However, the need for published information on the results or effectiveness of control techniques makes it difficult for conservation managers to design suitable eradication campaigns. Only one review has surveyed the various eradication and management attempts worldwide (Barun et al., 2011). The publication of experience feedback on control operation is required to improve methods to regulate the small Indian mongoose as an invasive alien species.

This review examined the different techniques used by eradication and control campaigns on islands against the small Indian mongoose. We compared and evaluated the different approaches to identify gaps and future directions for island conservation. Both data from the published and grey literature available were considered.

Literature research methods

First of all, an online search on Google Scholar, Springer and PubMed was conducted using various keywords such as "small Indian mongoose" or "*Urva auropunctata*", "eradication", "management", "control", "regulation", and “islands”. Other literature was collected through the literature available within my internship structure, which has access to technical reports from several islands of the Lesser Antilles. A second selection of articles corresponding to the previous keywords was made after identification of the different themes that I wanted to address in my study, namely the introduction and impact of the small Indian mongoose, then the different techniques that were identified through an initial reading of articles and a second keyword search on search engines with the words "trapping", "poisoning", "hunting" associated with "small Indian mongoose". In total, more than a hundred articles were studied, but only about fifty were selected for the following systematic review based on their relevance to the subject.

Eradication or regulation

To this date, small Indian mongoose eradication campaigns have been carried out on at least nine islands (Barun et al., 2011). Mongooses were eradicated with difficulty but successfully from six islands: Buck (Virgin Islands, US), Fajou (Guadeloupe, FR), Leduck (Virgin Islands, US), Praslin (Sainte Lucia), Codrington and Green (Antigua and Barbuda), the largest of which covered an area of 115 hectares. One previous eradication campaign on Piñeros (Puerto Rico), a more oversized island of 132 hectares, failed (Nellis, 1982; Pimentel,1955). A current eradication campaign in two islands of Japan (Ryuku and Kyushu) has been ongoing since 1993 and is programmed to be finished in 2027 (Yagihashi et al., 2021).

When the individuals cannot all be eradicated because the area to be covered is too large, the density of the small Indian mongoose is too high, or the resources are not enough to be deployed on a big scale, most islands set up population regulation campaigns. Overall, Barun et al. (2011) and others (Nellis & Everard, 1983; Roy et al., 2002; Hays & Conant, 2007) suggest that the current objective of mongoose management should be local control to protect species at risk while limiting the rate of disease transmission as much as possible. Thus, almost all efforts to manage mongoose populations in areas of introduction have focused on using techniques to remove individuals from ecologically sensitive areas where the small Indian mongoose threaten local species.

Control methods

The main methods used in eradication and regulation campaigns have been (1) trapping, (2) chemical control, and (3) hunting. There are also isolated cases of the involvement of private volunteers.

i) The importance of bait

For each control method, except for hunting, the choice of bait is essential to attract the animal. Baits used for trapping or poisoning have been extensively studied, with natural baits such as fish, eggs and chicken parts often being more effective at attracting mongooses than synthetics (Pitt & Sugihara, 2008; Coolman, 2016). Several studies have compared the attractiveness and palatability of different baits, showing that mongooses are not very selective and are attracted by baits that emit strong olfactory signals or are visually attractive, and food baits can attract mongooses away from their usual home range (Pitt et al., 2015). Several studies have also hypothesised that using specific chemical baits could be interesting (Barun et al., 2011; Pitt et al., 2015). The selection of baits is paramount for effectively managing this invasive mammalian predator.

ii) Trapping

Most eradication and control programs have used trapping to reduce the threat of predation in sensitive areas (Hays & Conant, 2007). There are two main types of traps: lethal and non-lethal traps.

Non-lethal traps were among the first mongoose control devices introduced on the islands. These traps must effectively capture the animal on its movement trajectory without killing it, be attractive at short range and avoid mortality in the traps. These traps are already used on many islands (Coblentz & Coblentz, 1985; Roy et al., 2002; Quinn et al., 2006; Lewis et al., 2010; Pitt et al., 2015; Coolman, 2016; Guzmán-Colón et al., 2019). Several non-lethal traps have been designed to specifically catch mongooses or other invasive species in the same area: cage traps, tomahawks, etc. Non-lethal traps were used in 2001 as part of the successful eradication of populations of small Indian mongoose on the Fajou islet (Lorvelec et al., 2004). Other islands use these traps in locally targeted control campaigns on sensitive sites or in nature reserves to control the population either constantly or periodically, as in Mauritius (Roy et al., 2002), Virgin Islands (Coblentz & Coblentz, 1985), Hawaii (Hays & Conant, 2003), Guadeloupe and Martinique (ONF, 2020). The main advantage of this technique is that it allows any live non-targeted species to be released. However, this method appears to be labour-intensive for several reasons: (i) traps require the manual elimination of trapped animals, which requires skilled handling; (ii) traps have to be checked daily for animal welfare reasons, which implies intensive handling; (iii) traps have to be disarmed in the event of an absence of more than one day, and (iv) traps have to be placed in the shade as much as possible to avoid mortality in the traps. The animals caught are then killed by breaking their necks, shooting with a pellet gun or asphyxiation (drowning).

Lethal traps are an alternative to live traps and offer several advantages over this method. Firstly, these devices are much less labour-intensive as they are not checked daily. Secondly, lethal traps have been designed to kill target species quickly and "ethically", so no human intervention is necessary. However, one of the main problems of these traps is that they can kill non-target species, which is an issue if a local endemic or protected species goes into the trap. In some countries, governmental permission could be needed to use lethal traps, which can only be set by qualified or authorised organisms. Several types of lethal traps are used on different islands, but studies of these types of traps are still recent and rare. An example of a lethal trap that triggers when the animal steps on a platform, killing it instantly, is the DOC250 (or DOC200), a spring-loaded, manually reset trap designed in New Zealand to control invasive exotic mustelids. They have been successfully tested on the mongoose in Hawaii (Kekiwi et al., 2022; Peters et al., 2011; Roerk et al., 2022), on the island of St. Croix (Pollock et al., 2022), and more recently in Martinique (Grelot, 2023). Another kind of lethal trap known as "gas traps" (Goodnature A24 and A18) has been used on mongooses, where the individuals enter their head into the device, which triggers a gas cartridge directly into the head, killing it instantly, the individual falls out of the trap which automatically re-arms itself. Predators then eat the corpse, and the bait continues to be effective in attracting other individuals. No independent studies have yet to be conducted to test their effectiveness or cost-effectiveness ratio on mongooses, but there are some studies on their efficacy on rats have been published (Shiels et al., 2019). They have tested in Martinique and Guadeloupe to control the small Indian mongoose in 2021, but with mixed results (Vincent, 2021). The main advantage of this type of trap would be to reduce the human and economic resources needed because it is unnecessary to check the device frequently. They are also supposed to be specific and enable trapped individuals to be killed instantly without the need to recover the corpse.

iii) Poisoning

Poisoning is also used on some islands, with toxic baits deployed in baiting stations in non-lethal or broadcast traps. The toxins used are thallium sulphate, 1080 sodium monofluoroacetate, strychnine sulphate and diphacinone (Pimentel, 1955b; Ruell et al., 2019). The latter is an anticoagulant that kills by internal bleeding and has been proven particularly effective against mongooses. For instance, Hawaii mongooses have been successfully poisoned with diphacinone (Hays & Conant, 2007). Other toxic products are currently being tested for mongooses (Sugihara et al., 2018). Thus, using toxic baits via the distribution of bait stations could effectively reduce the mongoose population in a given area or create buffer zones around ecologically sensitive areas. However, although this technique is sometimes considered, its potential impact on the environment and other non-target species has led to it not being used on other islands (Roy et al., 2002; Hays & Conant, 2007). Indeed, it is often challenging to have toxic baits and baiting stations specific to a target, which is often considered a significant problem regarding the unintentional poisoning of native endangered species. For this reason, chemical control is not permitted for mongooses on many islands (Lorvelec et al., 2004).

Non-lethal chemical control has also been considered a technique for controlling the fertility of small Indian mongooses by placing baits to sterilise them, but it has not yet been used and is an expensive technic. Moreover, this kind of regulation does not prevent predation in the short term, and there is no guarantee that it reaches every individual (Roy et al., 2002).

iv) Hunting

Hunting can be effective when the mongoose population is high, but it requires more and more effort as the mongoose population decreases, and it requires a lot of funding and skilled agents (Barun et al., 2011). In addition, this technique is rarely used today for mongoose control.

v) Special case: involving the residents

In Amami-Oshima, the government has set up a system whereby voluntary mongoose trappers are paid (around 15 euros) for each mongoose tail brought back to the Japanese National Office. More than 16,000 mongooses were hunted by residents between 2000 and 2004, making this trapping campaign very effective nationally (Yamada, 2002; Yamada & Sugimura, 2004; Barun et al., 2011). However, this method was replaced with trained and paid field agents after 2004 and has yet to be replicated for mongooses on other islands.

Choice of control methods

All control methods vary in protocols between islands and campaigns, including the time of the campaign, the number of traps and poison stations used, and the area of the control. Thus, reliable comparisons require specific research.

Only a few studies have tested the difference in effectiveness between the different control methods. An initial study in Hawaii showed that DOC200 traps killed more mongooses than Tomahawk live traps (Peters et al., 2011), but the sample size was small and statistical analysis was not carried out. In contrast, Roerk et al. (2022) found that Tomahawk live traps and DOC250 lethal traps were equally effective at removing mongooses. However, when labour costs were considered, DOC-200s were more cost-effective at capturing mongooses because they could be checked once a week. Another study by Brown and Daigneault (2015) in Fiji conducted a cost-benefit analysis of live trapping, kill trapping and hunting. Their analysis included the resources cost and labour in conjunction with a personal survey of residents on their views regarding the presence of mongooses. They found that lethal traps were also the most cost-effective control method. However, this is without integrating the ecological costs, i.e., the effectiveness of some traps to be demonstrated and the death of non-target species (see Table 1).

Table 1. Summary of the impact of each control technique of the small Indian mongoose according to criteria other than effectiveness in the literature.

	Live trapping	**Lethal trapping**	**Poisoning**	**Hunting**
Economic cost	Low initial cost, high cost in the long term	High initial cost, low cost in the long term	High	High
Time cost	High, with daily check-ups	Low, with weekly or monthly check-ups	Low	Medium
Trained operator necessity	Yes, to kill	No	Yes, formation is mandatory	Yes, to kill
Environmental impact	Low	High if not specific enough	High if not specific enough	Low
Animal welfare	Medium, stress or injuries could be induced	Low	High	Medium, injuries could be induced
Public acceptance	Medium	Low	Low	Medium

Measuring the control methods' effectiveness

In order to improve management and control options for the small Indian mongoose in areas where it has been introduced, it is necessary to assess these campaigns' effectiveness systematically. Only a few studies are aimed at studying the dynamics of the target population (by radiotracking, camera trapping, for example, see Roy, 2001) and estimating the population density or abundance in order to monitor the effect of the regulation and its effectiveness by comparing with data from before regulation or from a control area (Roy, 2001; Quinn et al., 2004; Yagihashi, 2021).

Furthermore, in many islands, any improvements in the ecological management of *Urva auropunctata* will require a greater understanding of its ecology on site. Indeed, most management methods are based on historical data on the invasive species to be controlled or other invaded areas rather than on data collected during the eradication operation, which could reduce the uncertainty of predictions. Indeed, the type of method used and the protocol, such as trapping density, depends on several environmental and behavioural factors, which are very different between islands where the mongoose is established (see Barun et al., 2011; Guzmán-Colón et al., 2019; Louppe et al., 2021a).

Only some studies currently address an adaptive approach, i.e., collecting data during the eradication process, analysing and processing these data, and using the eradication results to make objective decisions that can be fed back into field operations. For example, this could give a precise idea of the number of individuals to be removed before a control campaign and an estimate of the effectiveness of culling afterwards and enable the management and application of resources to be optimised for a problem that already has a scientific basis. Data on operational elements, such as catch per unit effort and unit effort per area, are just as important as ecological data but are rarely collected during monitoring campaigns. Trapping efficiency studies are an example of adaptive management in that they use the management campaign to obtain new information, enabling the methods to be adapted after the campaign (Roerk et al., 2022; Grelot, 2023). With limited resources in terms of time and cost, this is also a way of gathering critical information and conducting research while undertaking management actions.

Conclusions and recommendations

The management of the small Indian mongoose has often been conducted without clear guidelines, resulting in indiscriminate and uncertain measures. However, more and more studies or technical reports are being carried out on successful eradication and regulation campaigns, and it is possible to improve ongoing management by learning from these past experiences.

We highlight the need for further studies on the effectiveness of the different control measures, particularly lethal traps, which have the advantage of requiring less handling and can create more permanent control pressure if left on sensitive sites over the long term.

Moreover, to improve the management of the small Indian mongoose, it is necessary to systematically assess the effectiveness of these campaigns and document the results. Detection methods to confirm management success should be carried out systematically. These trap efficacy tests should study mongoose density before and after regulation to test the actual effect of trapping, particularly on small-scale programmes, and to detect remaining individuals.

This review has aimed to bring together the different methods used to control the small Indian mongoose to give an overview of the approach to be adopted to continue these controls against this invasive alien species. However, we stress the need to adapt control technics to the target population through adaptive management alongside cost-benefit analyses.

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