The Mongoose in the Caribbean: Past Management and Future Challenges

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ABSTRACT: In the late 1800s, the small Indian mongoose was introduced to the Caribbean islands in one of the most widespread purposeful introductions of a mammalian predator in history. Intended as a biological control agent for introduced rats in sugarcane plantations, the mongoose quickly became recognized as a pest due to its predation on poultry and native fauna, and injuries to livestock. Over the last 40 years, the mongoose has also emerged as the primary vector and reservoir for rabies on several Caribbean islands. Due to the estimated costs associated with this introduced carnivore, as well as potential ecological impacts, the mongoose is now listed as one of the top 100 worst invaders by the IUCN. Past large-scale control attempts in the Caribbean have proven unsuccessful, and few to none are currently being implemented. In fact, despite its renown, very little is known about the actual impacts of the mongoose. It is likely that combined with increasing rates of development in some Caribbean islands, the impact of the mongoose on native faunal communities may become more serious. This paper provides an overview of mongoose management in the Caribbean. Although current management priorities center on the role and management of the mongoose as a disease vector, this paper will also discuss opportunities to pair this research with 1) an assessment of the ecological impacts of the mongoose on native species, and 2) the development of mongoose control methods. The Caribbean National Forest, Puerto Rico is used as a case study; however, these methods can potentially apply to other Caribbean islands.

KEY WORDS: adaptive management, Caribbean, exotic species, *Herpestes auropunctatus*, invasive species, mongoose, predator control, Puerto Rico, rabies, trapping

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INTRODUCTION

The introduction of the small Indian mongoose (*Herpestes auropunctatus*; synonym *H. javanicus*) to islands throughout the world is one of the most widespread intentional introductions to date. Today, mongooses are considered one of the top 100 worst invaders by the IUCN Invasive Species Specialist Group (IUCN 2004) and cause an estimated $50 million per year in damage (Pimentel et al. 2001). Mongooses are listed as a potential predator of nearly every threatened or endangered terrestrial species throughout the Caribbean, and the concern for the mongoose as a disease vector is growing in significance (Velez 1998).

Despite the global scale of mongoose impacts, there is a noticeable absence of information regarding the mongoose's biology and cumulative impact on island endemics at the population or ecosystem level (Henderson 1992, Vilella and Zwank 1993). It has even been suggested that most widespread damage caused by mongooses occurred shortly after their introduction, and that current populations exist in equilibrium with island natives that survived the initial impacts (Nellis and Everard 1983, Everard and Everard 1992). Perhaps because of this belief, and because total eradication of mongoose populations is infeasible, mongoose management has not been a primary concern in Caribbean islands, and most mongoose control is implemented on a small scale (Coblentz and Coblentz 1985). However, human population growth and development in the Caribbean continues at an ever-increasing rate. Such pressures have contributed to more recent declines of native faunal populations, that when coupled with the effects of mongoose predation, may result in the local extirpation of these species. Additionally, due to human health concerns, funds are increasingly becoming available for large-scale rabies control, and new management techniques are making rabies eradication possible (Slate et al. 2002). Comprehensive mongoose management for both of these issues may thus become a priority in the next 10 years, and the information needed to design management programs is lacking.

Any small-scale control program has the potential to provide a wealth of the information required to successfully implement large-scale programs. In most cases, current "opportunistic" management need only be slightly modified in order to maximize the amount of information gained– with only a negligible increase in time commitment. Here, we review the mongoose introduction to the New World and summarize the reported impacts since that introduction. We also discuss past and current management attempts, and we address the vital information regarding mongoose ecology and impacts that is still lacking. Finally, using the Caribbean National Forest in Puerto Rico as a case study, we suggest methods that can adapt a small-scale management program to answer larger ecological questions. Information gained in this manner will also 1) allow an assessment of the current management strategy, and 2) aid in assessing the feasibility of larger-scale management programs.

MONGOOSE INTRODUCTION

The mongoose's worldwide spread from its native range in southern Asia and India is directly attributable to the expansion of the sugarcane industry in the tropics in the 18th Century. Because of the scarcity of native predators on most of these small islands, sugarcane plantations were plagued by dense populations of black rats (*Rattus rattus*) and Norway rats (*Rattus norvegicus*) that had been brought unintentionally in ship cargo. To alleviate the high losses in sugarcane yield cause by rat damage, landowners attempted to introduce several species of predators to control rat populations, such as ferrets, weasels, stoats, ants, and frogs; however, none of these species were able to establish stable populations (Nellis and Everard 1983). W. B. Espuet of Jamaica undertook the first documented mongoose introduction to the Caribbean islands in 1872. The 9 individuals he imported from Calcutta bred quickly and successfully on his sugar plantation, and within months, rat populations were noticeably diminished (Espuet 1882). Over the next few years, neighboring estates were also reporting significant reductions in rat damage, and within 10 years, the mongoose was estimated to be saving Jamaican sugarcane growers some 150,000 pounds sterling annually. In light of this apparent successful biological control, animals from the Jamaican founder population were shipped to over 30 islands and several mainland countries throughout the Caribbean by 1900 (Hoagland et al. 1989, Nellis and Everard 1983, Hinton and Dunn 1967).

As quickly as their benefits were realized and extolled, mongooses came to be deemed a pest on most islands where they were introduced (Seaman 1952). Reductions in populations of ground-dwelling birds, agoutis, reptiles and amphibians were reported throughout the Caribbean (Henderson 1992, Seaman 1952). Mongooses caused significant agricultural losses, as they also preyed freely on domestic livestock, game animals, fruit crops and even sugar cane! Moreover, *R. rattus* populations had stabilized and increased; their semi-arboreal and nocturnal lifestyles minimizing predation risk by the diurnal, mostly terrestrial mongoose. By 1898, the Jamaican government contemplated enacting mongoose reduction measures, and a bounty system was established in Trinidad in 1902 (Seaman 1952). Additionally, beginning in the 1950s, the mongoose emerged as the primary vector and reservoir of rabies on several Caribbean islands (Everard and Everard 1992).

MONGOOSE IMPACTS TO NATIVE SPECIES

While mongooses are implicated in numerous species declines and extirpations, the evidence is primarily circumstantial. It is likely that the mongoose was only one of several factors that contributed to species declines, as many extirpations occurred before mongooses were introduced (Henderson 1992). The first reports of mongooses negatively impacting native species came from Espuet himself. He reported that although ground-dwelling birds and herpetofauna populations were depressed after the mongoose introduction, the decline was small compared to that already observed due to rats and snakes (Espuet 1882). Shortly after the turn of the century, declines and/or extirpations in native ground-dwelling birds (Clark 1905, Allen 1911), mammals (Allen 1911), lizards, snakes, and frogs (Allen 1911, Barbour 1930, Grant 1937, Schmidt 1928) were reported. Other species extinctions or declines that coincide with the mongoose introduction, as well as comparisons of faunal assemblages on islands with and without mongooses, provide additional circumstantial evidence of mongoose impacts (Henderson 1992). Mongooses are most likely to impact populations of extremely rare or endangered species (Nellis and Small 1983, Nellis and Everard 1983). High predation rates on sea turtle and seabird nests have been reported (Nellis and Small 1983, Seaman and Randall 1962, Coblentz and Coblentz 1985), and the mongoose has at least once preyed upon a fledgling of the extremely endangered Puerto Rican parrot (Engeman et al. *In Review*). However, it is difficult to extrapolate mongooses effects beyond these anecdotal and individually-based accounts. Little research has addressed native species population or ecosystem-level effects.

MONGOOSES AS A DISEASE VECTOR

Rabies in the Caribbean originated with domestic animals (Everard and Everard 1992). However, government-sponsored vaccination programs greatly reduced the rabies incidence in domestic animals by the late 1960s. Since then, the mongoose has been primarily responsible for reported rabies cases. Rabies currently exists in mongoose populations in Antigua, Cuba, Grenada, Hispanola, and Puerto Rico (Everard and Everard 1992). In Puerto Rico, mongooses have accounted for between 70 and 80% of all rabies cases reported in the last 25 years, and most cases reported in livestock are also attributed to mongoose bites (Everard and Everard 1992, Krebs et al. 2002). Additionally, the number of mongoose rabies reports has increased annually. In the Dominican Republic, mongoose rabies is a more recently recognized problem, with reports beginning in the late 1980s. Since then, while rabies in domestic animals has been controlled, the disease persists in mongoose populations (Everard and Everard 1992). Rabies "outbreaks" and cyclical disease prevalence has been observed in many other rabies species coinciding with breeding and dispersal timings (Loveridge and MacDonald 2001). However, while the presence of rabies has been shown, there is very little known about the epidemiology of rabies in mongoose populations (but see Everard et al. 1974).

MANAGEMENT

Mongooses can be managed locally for endangered species protection (Coblentz and Coblentz 1985). Large-scale management of the mongoose has been attempted only once in the Caribbean, on Buck Island off St. Croix in the U.S. Virgin Islands. An island-wide trapping campaign was conducted for several weeks; however, mongooses were found to still be present soon after trapping had ceased (Everard and Everard 1992). In the Caribbean National Forest, Puerto Rico, mongooses are trapped weekly in visitor use areas throughout the forest. However, it is unclear whether or not this program has a significant effect on mongoose numbers (F. Cano, USFS, pers. comm.). Additionally, while within-season benefits of mongoose control have been reported (Coblentz and Coblentz 1985), long-term effects have not been analyzed.

Documented, large-scale rabies management in mongooses in the Caribbean has been attempted only a few times. In the early 1980s the Cuban government instituted a control program in which over 1 million strychnine-laced eggs were placed across the island. No fewer than 500 people in each municipality worked daily throughout the duration of the project. However, sufficient population suppression was not achieved. In Grenada, a large-scale mongoose control program was undertaken in the 1970s. 840,000 sodium fluoroacetate (1080) baits were placed across the island in areas with high reported rabies incidence. Subsequent trapping indicated that mongoose populations were suppressed somewhat, but recovered to their pre-baiting levels within 6 months (Everard and Everard 1992). Due to the difficulties in securing further funding for the project, it was discontinued. In Antigua, baiting strategies for an oral rabies vaccination (ORV) program have recently been investigated, although the program itself has yet to be implemented (Creekmore et al. 1994). In other species, rabies cycles are used to determine timing of treatment programs (White et al. 1995). As mentioned above, very little is known regarding the behavior of the rabies virus in mongoose populations.

A Case Study in Puerto Rico

The Caribbean National Forest (CNF), Puerto Rico, exemplifies the complexities of management issues faced by many Caribbean islands. The largest remaining tract of virgin rainforest in Puerto Rico, the CNF is managed primarily by the United States Forest Service (USFS) for recreation and conservation. Because the forest is located just 40 km east of San Juan and sees up to 1 million visitors annually, the CNF recreational areas within the forest are extensively developed with trails, picnic areas, and visitor centers. However, visitor use is concentrated to approximately 4.6% of the total forest, with the remaining areas used primary for research and resource management by several agencies. The U.S. Fish and Wildlife Service (USFWS) maintains jurisdiction for recovery of federally listed endangered species within the forest, such as the Puerto Rican parrot (*Amazonia vittata*). Wildlife Services, a division of USDA-APHIS, works in partnership with USFWS and USFS to provide management for exotic species control (i.e., rats, feral cats, iguanas, mongooses, and honeybees) to protect human health and safety, and to support endangered species recovery. The USFS coordinates inventory and monitoring of other native species, and assesses impacts of recreation and land use on forest resources (USFS 1997).

Though mongooses are common in the CNF, they have played a relatively minor role in forest management. Perhaps because they were not considered a significant threat to native species, the most recent USFS forest plan did not require any specific control plan for mongooses. Thus, mongoose control has primarily been reactive, carried out when animals are reported in the visitor areas, and has not been conducted consistently (F. Cano USFS, pers. commun.). In more recent years, however, the concern for mongoose management in the CNF has grown. Several captive-bred Puerto Rican parrots have been released into the wild and have suffered heavy predation rates – in at least one case by a mongoose (Engeman et al. *In Review*). Mongooses are sighted with increasing frequency in the picnic areas, and attacks on visitors by rabid mongooses have been relatively common. A 1996 serosurvey of mongooses throughout the forest revealed that rabies antibody titers were present in ~20% (23/119) of the trapped population, although none of these animals tested positive for the virus (Velez 1998). It is anticipated that these observed mongoose impacts will only intensify over time, as more Puerto Rican parrots are scheduled for release and human recreation levels continue to increase annually. Calls have been put forth for more widespread, effective control measures (Velez 1998, Engeman et al. *In Review*).

A study was initiated in 2002 to collect baseline data to aid in assessing mongoose control options and the potential for implementing a rabies control program. While the study focused primarily on spatial behavior of mongooses, it noted an absence of data on several basic aspects of mongoose biology, impacts, rabies population dynamics and epidemiology in the forest. Moreover, although limited trapping had been occurring regularly for the past several years at a time expense of ~20 person-hours per week, little information that would inform a management plan could be gleaned from records produced by this effort. As is often the case, this mongoose management in the CNF was enacted with the intent of removing animals rather than collecting data. However, as a trade-off, managers are left with no knowledge of the effects of their management on mongoose populations, rabies incidence, or on other species' populations...although only slight adjustments in control activities could have provided this information with a minimal increase in time commitment.

WHAT DO WE WANT TO DO?

The goals of any mongoose management plan need to be established *a priori*, and will determine the structure of the plan. In the CNF, the goals for mongoose control through trapping and removal are to:

1. Decrease mongoose populations
2. Decrease rabies transmission rates
3. Increase populations of native species
4. Have no increase in populations of non-native species (i.e., rats, mice, cats)

With these goals in mind, the next question should be: How will we know if trapping achieves these goals? The answer to this question determines the information the control program should provide, namely:

1. Estimates of mongoose population densities
2. Measures of rabies incidence
3. Measures of factors that effect mongoose population densities and rabies incidence
4. Population density estimates of other species within the area of control

Upon first glance, the management program structured to provide this information may seem costly and labor intensive. However, in comparison with what is currently being implemented, we find that this is not the case. Below, we summarize the adjustments necessary to improve the current mongoose management plan (Table 1).

POPULATION MONITORING

Lethal control does not always decrease population density of the target animal. Density-dependent reproduction, the disruption of territorial structures, and creation of a population "vacuum effect" are all mechanisms that can cause population growth following control, thus undermining past management and creating the need for increased future management (Frank and Woodroffe 1999, Tuttyens et al. 2000, Bacon and MacDonald 1980). Additionally, reinvasion following population reduction may not be immediate, requiring only periodic control activities. Unless population density is monitored throughout control programs, managers have little means to detect unwanted effects or to determine reinvasion rates.

The actual mongoose trapping can provide an estimate of population density. To fulfill the assumptions of most population estimation techniques, the same locations should be trapped for consecutive days (until trap success declines). Traps can be placed in a grid formation, or the effective trap area can be estimated based on known home range size of mongooses (Quinn 2004). Density estimation software such as Program MARK (White and Burnham 1999) can produce population estimates using models for a variety of trapping designs. In conjunction with the 2002 mongoose behavior study, alternative methods of assessing population density were explored. Mongooses may have a tendency to be trap-shy. Thus, indexing methods such as trackplates and motion-sensor cameras, were established in areas with and without mongoose control. Data analysis to compare correlation of these indices with density estimates obtained through trapping is planned (Whisson and Quinn, unpubl. data).

Currently, when mongooses are trapped in the forest, traps are moved daily, and the precise locations of traps are not recorded. Thus, the only additions to the current control program are to 1) use and map locations of permanent trap stations, and 2) trap one location until no mongooses are trapped (we found 5 days to be sufficient). These adjustments add little to no time to current activities.

MEASURES OF RABIES INCIDENCE

Rabies testing can be performed by contracted veterinarians. Trapped animals can be periodically tested for the rabies virus as well as SN antibodies (see Velez 1998). Because blood samples are needed to test for antibodies, some time and training will have to be spent to establish techniques for animal immobilization, venipuncture, and sample preparation. Veterinary assistance will require an additional cost. However, disease monitoring can occur less frequently then every trapping event (i.e., every other month).

MEASURES OF FACTORS THAT AFFECT MONGOOSE POPULATION DENSITIES AND RABIES INCIDENCE

Mongoose population densities can fluctuate based on the timing of breeding and dispersal (Hays 1999, Nellis and Everard 1983, Pimentel 1955). There is also evidence that the presence of anthropogenic food in the picnic areas affects population densities, breeding, and spatial behavior (Quinn 2004). For example, juveniles were more abundant in human-use areas, suggesting increased breeding behavior there. Animals near the human areas also appeared more philopatric, while those in more natural areas tended to higher dispersal rates. Male animals tended to move much greater distances in the wet season (June - July). All of these factors combine to affect rabies transmission rates. In high-density areas, contact rates between individuals may be higher; however, the 2002 mongoose study also indicated that larger, more overlapped home ranges in low-density areas may lead to equally high contact rates (Quinn 2004). Thus, while rabies control may be necessary in both areas, and particularly during the wet season while mongooses are moving greater distances, population reduction may be required more frequently in the picnic areas because of increased breeding rates and higher population densities.

In current mongoose management, only sex of trapped animals is recorded. Trapping is focused primarily on areas of high human use, although these areas account for a small percentage of the total forest. By recording age and reproductive condition of trapped animals, seasonal breeding and dispersal cycles can be tracked (Hays 1999). Spanning trapping activities into more natural areas, as well as areas of high human use will encompass the range of conditions encountered in the forest– across which different patterns (with different management implica-

Table 1: A comparison of small-scale mongoose removal plans, and information gained by each.

Plan 1	*A better plan...*	***A really good plan...***
Trap when necessary	*Trap regularly (i.e. monthly, weekly)*	**Trap regularly (i.e. monthly, weekly)**
Trap where animals are seen	*Trap permanent stations*	*Trap permanent stations*
Dispose of carcasses	*Save carcasses for testing*	*Save carcasses for testing*
Record sex of animal	*Record sex, age and reproductive condition*	*Record sex, age and reproductive condition*
		Locate trapping in monitoring areas
		Locate trapping in areas representing use patterns
INFORMATION GAINED: • Presence/absence of mongooses. • Sex ratios	*INFORMATION GAINED:* • *Population density* • *Breeding cycles* • *Rabies cycles* • *Dispersal patterns* • *Reinvasion rates* • *Efficacy of control*	***INFORMATION GAINED:*** ***Same as before, plus...*** • ***Relative densities (high use v. low use)*** • ***Relative breeding behavior*** • ***Relative rabies transmission rates/cycles*** • ***Relative reinvasion rates*** • ***Effects of mongooses on other species*** • ***Effects of control on other species***

tions) may be observed. To provide the above information, managers would need to: 1) record approximate age and reproductive status of trapped animals, and 2) conduct trapping in natural, as well as highly-used areas. Again, the amount of additional time required for this adjustment is minimal.

POPULATION DENSITY ESTIMATES OF OTHER SPECIES

The USFS Forest Plan outlines the desired condition for native species in the forest, and also dictates monitoring plans needed to assess these conditions. Previous studies have indicated that mongooses feed primarily on invertebrates, lizards, frogs, and plant material (Vilella 1998, Vilella and Zwank 1993, Pimentel 1955). Thus, these species can be monitored in areas of mongoose control to assess whether mongoose removal has a beneficial effect. While mongooses prey only occasionally on mammals and birds, mongoose presence may discourage settlement by bird species, or may competitively suppress mammal populations. Mongoose control may then served to increase native bird (desired) or mammal (not desired) populations. These species can also be monitored.

Assessing population of other species causes no additional changes to a mongoose removal program. The assessment only requires that monitoring already implemented by the Forest Plan be structured to span areas with and without mongoose removal. The more independent sites of each type that are surveyed, the stronger statistical inferences can be made when comparing them.

CONCLUSION

The need for more comprehensive mongoose control programs in the Caribbean is clear and pressing. Initially, managers may be discouraged by the current lack of information needed to design and assess larger programs, and by the amount of preliminary work that may be required to attain this information. However, there is reason to be optimistic. We suspect that there are numerous, but undocumented small-scale control programs occurring throughout the Caribbean. Each of these is a valuable opportunity for research. With very little additional resources, these small-scale control programs can be adjusted to provide sufficient knowledge critical to implementing larger plans. Moreover, because of the widespread problem of mongooses throughout the Caribbean, and indeed across the globe, we can be assured that any information gathered can have extensive applicability.

The key to successful mongoose management in the Caribbean is proactive planning. This strategy assures that management time– and money– is well spent.

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