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Do current vampire bat (*Desmodus rotundus*) population control practices pose a threat to Dekeyser's nectar bat's (*Lonchophylla dekeyseri*) long-term persistence in the Cerrado?

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The Cerrado is rapidly losing space to agriculture, pastures and urbanization. Current management practices to control rabies outbreaks through the eradication of vampire bat populations may put other bat species in peril. Our objective is to evaluate if the current vampire bat population control practices could pose a threat to *Lonchophylla dekeyseri*'s persistence, an endemic bat of the Cerrado. We used the VORTEX program to model different vampire bat management scenarios, causing low (25%), medium (50%) or high (75%) incidental mortality to *L. dekeyseri* populations. Inbreeding depression has been identified as a threat to the species, therefore we also modeled scenarios evaluating such effects. Results show that current vampire bat management practices have serious impacts on populations of *L. dekeyseri*. In all cases marked declines in population sizes were observed (even when there was no decline in survival probabilities). For medium and high incidental mortality management scenarios, we also observed decreases in survival probability and in genetic diversity. In those scenarios evaluating vampire bat management and inbreeding depression together, the models suggest that such interaction results in more pronounced declines. Habitat loss and fragmentation in the Cerrado are severe threats and have already negatively impacted *L. dekeyseri*. Unfortunately, if currentpopulation control practices dealing with vampire bats are not changed, inappropriate rabies management may be the coup de grace to the long-term persistence of this species.

Key words: Cerrado, *Desmodus*, *Lonchophylla*, population viability analysis, rabies, roost

Introduction

The Cerrado is the most extensive woodland-savanna in South America and one of the world's 34 biodiversity hotspots (Myers *et al*., 2000; Mittermeier *et al*., 2004). The rapid expansion of agriculture and cattle ranching severely affected the biome and reduced it to 21.6% of its original area (Mittermeier *et al*., 2004). A quarter of all grain produced in Brazil and nearly 40 million heads of cattle represent important economic activities that impact the biome, with steady growth projected in both industries, as well as in charcoal production. Low levels of investment in biodiversity research, and a small protected areas network (both in number of protected areas and in total area under protection) only make the Cerrado conservation more urgent (Klink and Machado, 2005).

Bats compose more than 50% of the mammal fauna in the Cerrado (Aguiar and Zortéa, 2008), and they play key roles in ecosystem processes and services, as pollinators of native plants (e.g., Martins and Batalha, 2006), as seed dispersers that help to restore degraded areas (e.g., Bizerril and Raw, 1998), and as predators that help to regulate and control agriculture pests (e.g., Aguiar and Antonini, 2008). Bats are also the mammals most commonly involved in transmission of rabies to humans (Schneider *et al*., 1996; Belotto *et al*., 2005). In addition to rabies-related public health problems, disease transmission by vampire bats to herbivorous species, chiefly cattle, is also a major constraint to livestock production in Latin America (Belotto *et al*., 2005).

Although the magnitude of the economic impact is difficult to assess due to the limited information available, conservative estimates suggest that the annual direct and indirect losses to livestock production due to rabies transmission by vampire bats in a 9-year period are in excess of US$ 50 million, with over 30,000 animals being infected with rabies annually (Steele, 1966; Belotto *et al*., 2005). With cattle ranching industry expansion, ranchers have complained of livestock losses due to rabies outbreaks. Not surprisingly, the vampire bat (*Desmodus rotundus*) is now an important issue and this species has become the target of population control activities both by local communities and by governmental agencies. Indiscriminate actions against vampire bats, such as poisoning and roost destruction, are routine in central Brazil and may cause incidental mortality of non-vampire bat species (Mayen, 2003), putting their long-term persistence in jeopardy. For example, Aguiar *et al*. (2006*a*) observed cases of private land owners blocking cave entrances, destroying native vegetation to open space for pasture, and/or using warfarin to kill bats, regardless of the species.

Analyses of the factors that influence population viability are important tools for informed decision-making and improving the management of wildlife populations (Morris and Doak, 2002). Understanding factors influencing persistence is particularly important for microchiropteran bats, because in addition to their importance in maintaining ecosystems services, 51% of these species are listed as threatened (Critically Endangered, Endangered or Vulnerable), Data Deficient or Near Threatened (Hutson *et al*., 2001).

Lonchophylla dekeyseri is an endemic bat of the Cerrado (Gardner, 2008) that occurs in 36 localities, structured into six isolated populations (Aguiar *et al*., 2006*a* — see also Fig. 1). It requires caves to roost and these are found in dry forests associated with calcareous outcrops (Gardner, 2008; Sampaio *et al*., 2008). Aguiar *et al*. (2006*a*) recaptured

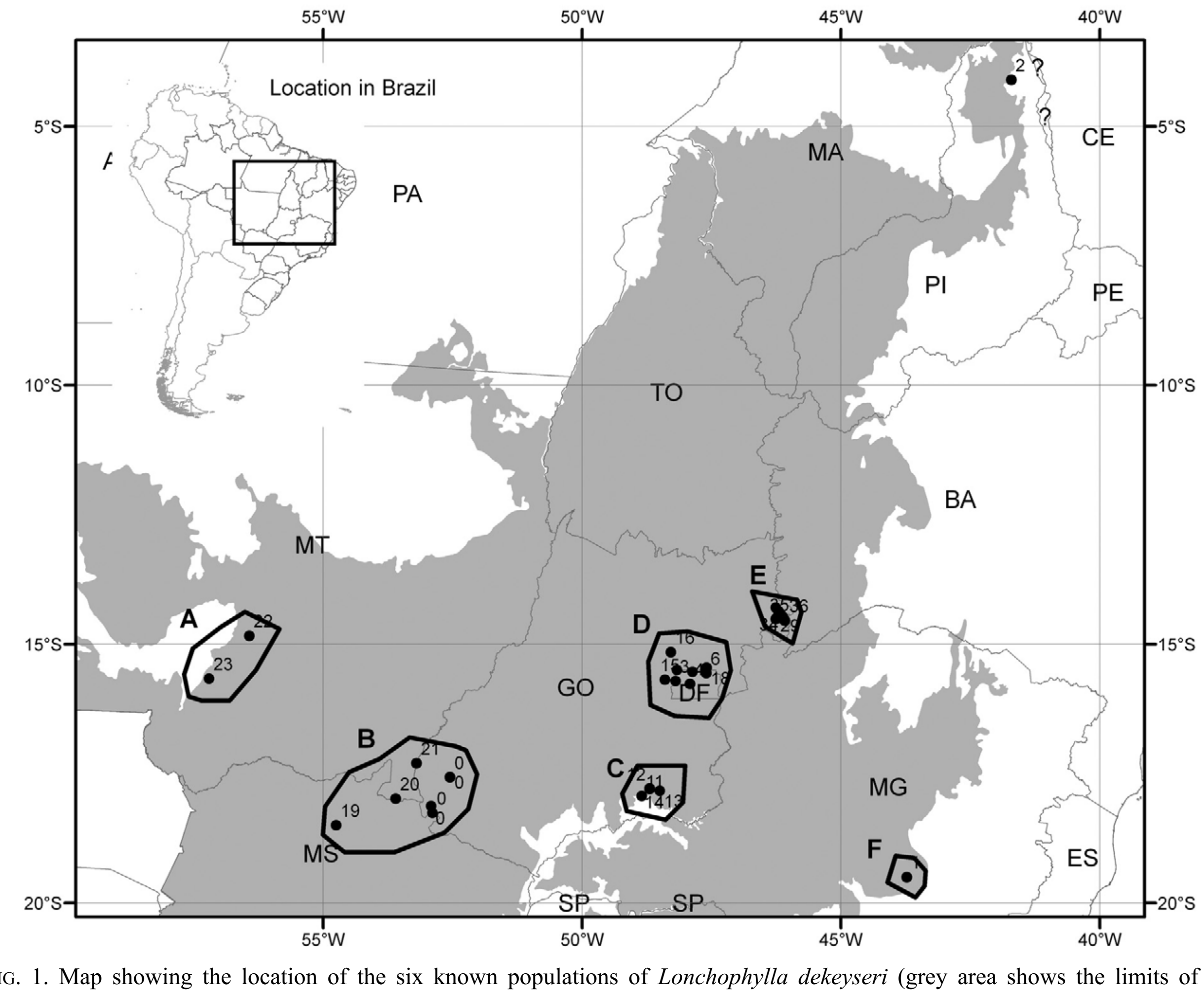

FIG. 1. Map showing the location of the six known populations of *Lonchophylla dekeyseri* (grey area shows the limits of the Cerrado biome)

individuals that used the same roost for at least seven years, thus highlighting the importance of caves for this species. *Lonchophylla dekeyseri* is known to share roosts with *D. rotundus* (Aguiar *et al*., 2006*b*), and as vampire bat control programs threaten these roosts, such associations may bring incidental mortality to *L. dekeyseri*.

Rabies control programs have been identified as a threat to the long-term persistence of *L. dekeyseri*, particularly through the destruction of roosts (Sampaio *et al*., 2008). There is an urgent need to better evaluate how incidental mortality due to vampire bat and rabies management may affect the viability of this endemic bat (Sampaio *et al*., 2008). In this context, our objective is to evaluate if the current practices to manage vampire bat populations and control rabies within the Cerrado, a region where cattle ranching is economically important, could pose a threat to the persistence of *L. dekeyseri*.

Materials and Methods

PVA Model

The computer simulation software VORTEX version 9.57 was used (Miller and Lacy, 1999). VORTEX is a Monte Carlo simulation of the effects of deterministic forces as well as demographic, environmental and genetic stochasticity and catastrophes on the dynamics of wildlife populations (Lacy, 1993, 2000; Miller and Lacy, 1999). This software is one of the most often used for population viability analyses (PVA) focusing on threatened populations, including in workshops with officers from conservation and land management agencies (Lindenmayer *et al*., 1995).

Life History Data

The demographic data of *L. dekeyseri* used in this study were taken from previously published field studies of the species (Bredt *et al*., 1999; Coelho and Marinho-Filho, 2002; Esbérard *et al*., 2005; Aguiar *et al*., 2006*a* — Table 1). The majority of the demographic data available comes from a population ecology project that captured 73 individuals from one population estimated to have 97 individuals (Aguiar *et al*., 2006*a*). Current knowledge shows the existence of six populations of *L. dekeyseri* (Aguiar *et al*., 2006*a*), with no dispersal among them (Coutinho, 2007). Each population uses a complex of caves and/or cavities, and is estimated to contain around 120 individuals, giving an estimated total population of only 720 bats in the wild (Aguiar *et al*., 2006*a*). The mean home range size of *L. dekeyseri* is estimated at approximately 600 ha, and the species has a mean movement rate of 1,350 m per night, with a maximum distance traveled of 3,837 m. Adults first breed at two years of age, and produce one young per litter, that can be carried by its mother (Aguiar *et al*., 2006*a*). The longest lifespan recorded for the species in the wild is 10 years (Aguiar *et al*., 2006*a*).

Table 1. Life history parameters of *L. dekeyseri* used as input to the VORTEX program (data from Aguiar *et al*., 2006)

Parameter	Value
Breeding system	Polygynous
Age of first reproduction	2
Maximum breeding age	10
Sex ratio at birth	1:1
% adult males in the breeding pool	25
% adult females breeding	75
Litter size	1
Mortality rate (males/females)	
Age class 0–1	22.5 / 15.0
Age class 1–2	18.7 / 12.5
Age class adult	15.0 / 10.0

Modeling Scenarios

Our baseline scenario comprises the six known populations of *L. dekeyseri*. Each of these populations has 120 individuals that exhibit some degree of site fidelity to their roosts (Aguiar *et al*., 2006*a*). For the baseline scenario, we used the demographic data for the species (Table 1), but did not consider inbreeding depression or vampire bat management.

Previous genetic studies showed very low levels of genetic diversity within and among populations of *L. dekeyseri* (Aguiar *et al*., 2006*a*; Coutinho, 2007), suggesting this may be the result of inbreeding depression, which might pose an additional threat to the persistence of *L. dekeyseri* (Aguiar *et al*., 2006*a*; Coutinho, 2007). Knowing this, we decided to include a scenario that evaluated the potential deleterious effects of inbreeding on *L. dekeyseri* persistence. We used the reported median of 3.14 lethal equivalents per individual, based on a survey of the effects of inbreeding on mammalian species (Ralls *et al*., 1988).

Since the populations are structured into subpopulations, that occupy roosts both inside and outside protected areas, we modeled different scenarios of vampire bat management by applying different mortality rates to the population: low mortality (25% of the population is exterminated), medium mortality (50% of the population is exterminated) and high mortality (75% of the population is exterminated), with a 10% probability of occurrence per year for each population. We also modeled scenarios in which both threats (inbreeding depression and rabies management) affected the populations synergistically.

Populations were considered viable when there was a ≥ 95% chance of persistence (Shaffer, 1981) and ≥ 90% of their original heterozygosity was retained (Foose *et al*., 1986; Foose, 1993). For each scenario modeled we ran a total of 1,000 iterations. As the six populations had similar sizes, and depicted similar results, we presented the mean results for the populations, and the results for the metapopulation separately (Miller and Lacy, 1999). A metapopulation consists of a group of spatially separated populations of the same species which interact at some level (Hanski, 1999).

Results

Our results indicate that even though the populations and the metapopulation are small, they show low probabilities of extinction under the baseline scenario (Fig. 2). However, individual populations showed a marked decline in genetic diversity (Fig. 3, baseline scenario), even though the metapopulation maintained acceptable levels of genetic diversity (Fig. 3, baseline scenario), mainly through between-population differences, as genetic drift eliminates and fixes different alleles in different populations.

The scenarios modeling inbreeding depression alone, and low mortality management alone, showed no decrease in survival probability either for populations or for the metapopulation (Fig. 2). However, populations showed marked declines in genetic diversity (Fig. 3), population size (Fig. 4) and growth rate (r — Table 2). The metapopulation maintained acceptable levels of genetic diversity (Fig. 3B), but showed declines in growth rate (Table 2) and in metapopulation size (Fig. 4). The medium mortality management scenario resulted in a decrease in the probability of persistence, in the genetic diversity, and in the final size for populations (Figs. 2–4), but it had no significant effect on metapopulation survival and heterozygosity (Figs. 2 and 3). However, it decreased growth rates and population sizes both for populations and for the metapopulation (Fig. 4 and Table 2). This is the first scenario where populations went extinct (mean time to population extinction: 63.0 years), even though no metapopulation extinctions were recorded (Fig. 2). The high mortality management scenario resulted in very low chance of persistence, serious declines in heterozygosity, population sizes (Figs. 2–4), and growth rates (Table 2), both for populations and for the metapopulation. In addition to the extinction of populations we also observed a high probability of metapopulation extinction in this scenario (Table 2).

When modeling scenarios with both inbreeding depression and vampire bat management scenarios acting synergistically, we observed distressing

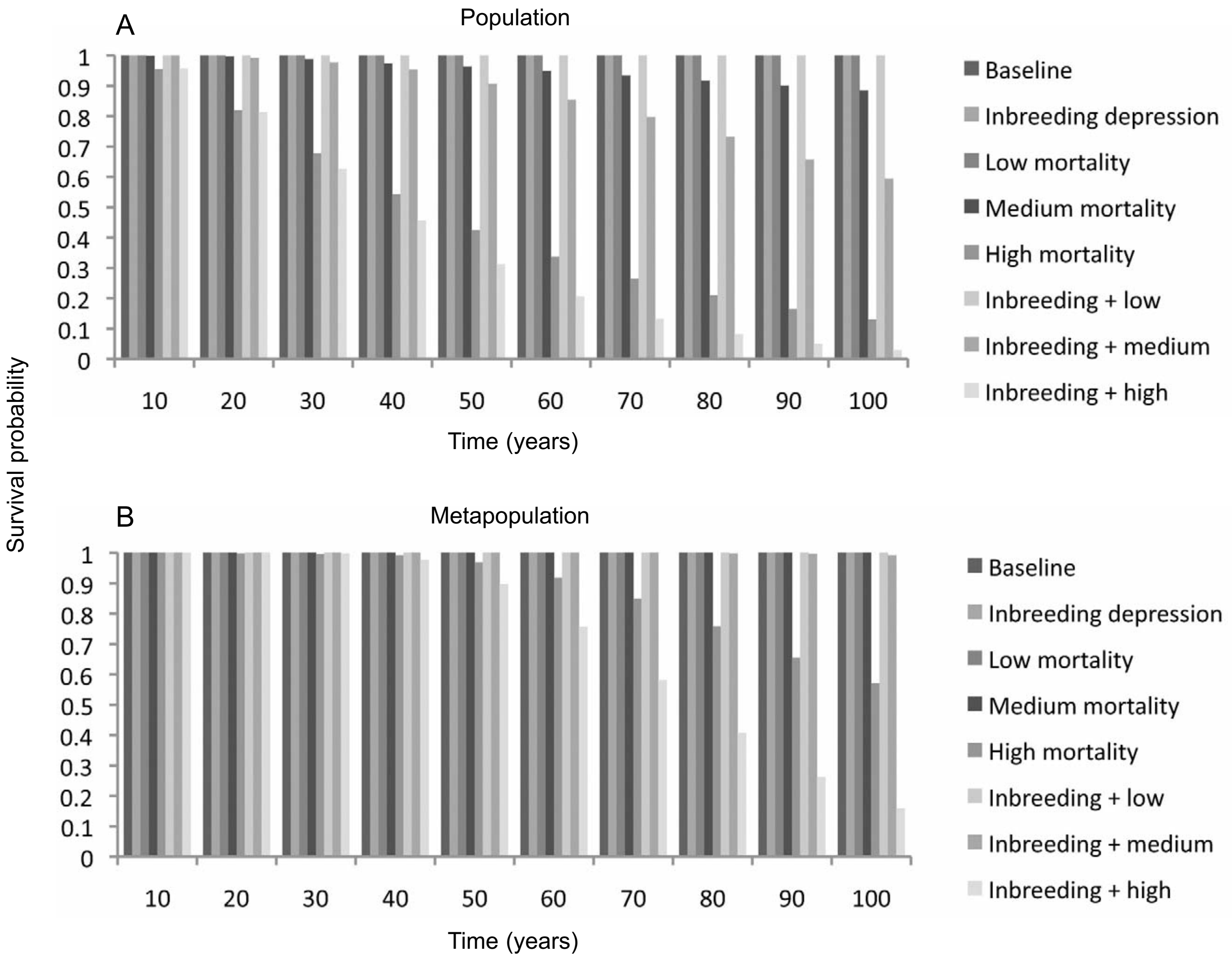

FIG. 2. Survival probabilities for *L. dekeyseri* populations (A) and metapopulation (B) under different scenarios (for scenario descriptions see Materials and Methods) in the Cerrado

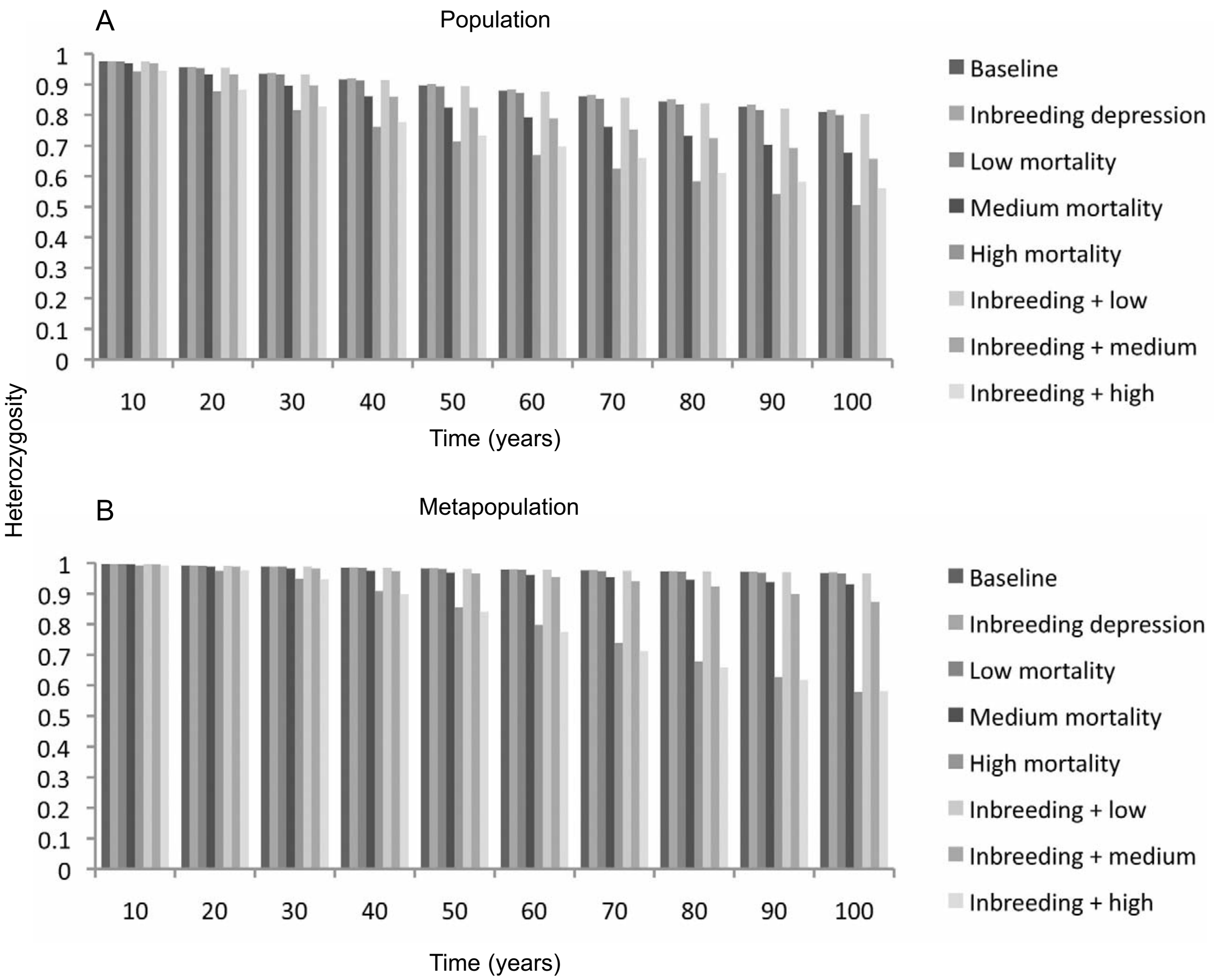

FIG. 3. Genetic diversity, measured as heterozygosity, for *L. dekeyseri* populations (A) and metapopulation (B) under different scenarios (for scenario descriptions see Materials and Methods) in the Cerrado

results (Figs. 2–4). The scenario modeling inbreeding depression and low mortality management did not have a different result than the baseline scenario regarding survival probability and heterozygosity (Figs. 2 and 3), but it resulted in declines in growth rate and population size (Fig. 4 and Table 2). However, the scenarios modeling inbreeding depression coupled with medium and high mortality management resulted in marked declines in the survival probability, heterozygosity, growth rate and population size both for populations and the metapopulation (Figs. 2–4 and Table 2).

DISCUSSION

Anthropogenic changes in the landscape may be related to recent vampire bat-related rabies outbreaks (Rosa *et al*., 2006). Whereas several bat species are threatened by habitat loss and fragmentation (IUCN, 2008), *D. rotundus* seems to cope well with the transformation of natural habitats into rural landscapes. In contrast, the available habitat of *L. dekeyseri* is already under pressure from habitat loss and fragmentation (Sampaio *et al*., 2008), related to the rapid transformation of the Cerrado into rural areas or urban centers (Mittermeier *et al*., 2004). The strong dependence of *L. dekeyseri* on caves and cavities (Sampaio *et al*., 2008) make this species highly susceptible to accidental (or incidental) mortality from vampire bat control techniques traditionally used in Brazil. In the 1960s, more than 8,000 caves used as roosts were destroyed in Brazil (Walker, 2001). Farmers, local communities and governmental agencies still destroy caves with explosives, set traps and nets across cave openings, and cement cave entrances and exits closed (Mayen, 2003). Even now, the reduction of bat populations is often presented as the method of choice to control rabies, and widespread eradication of

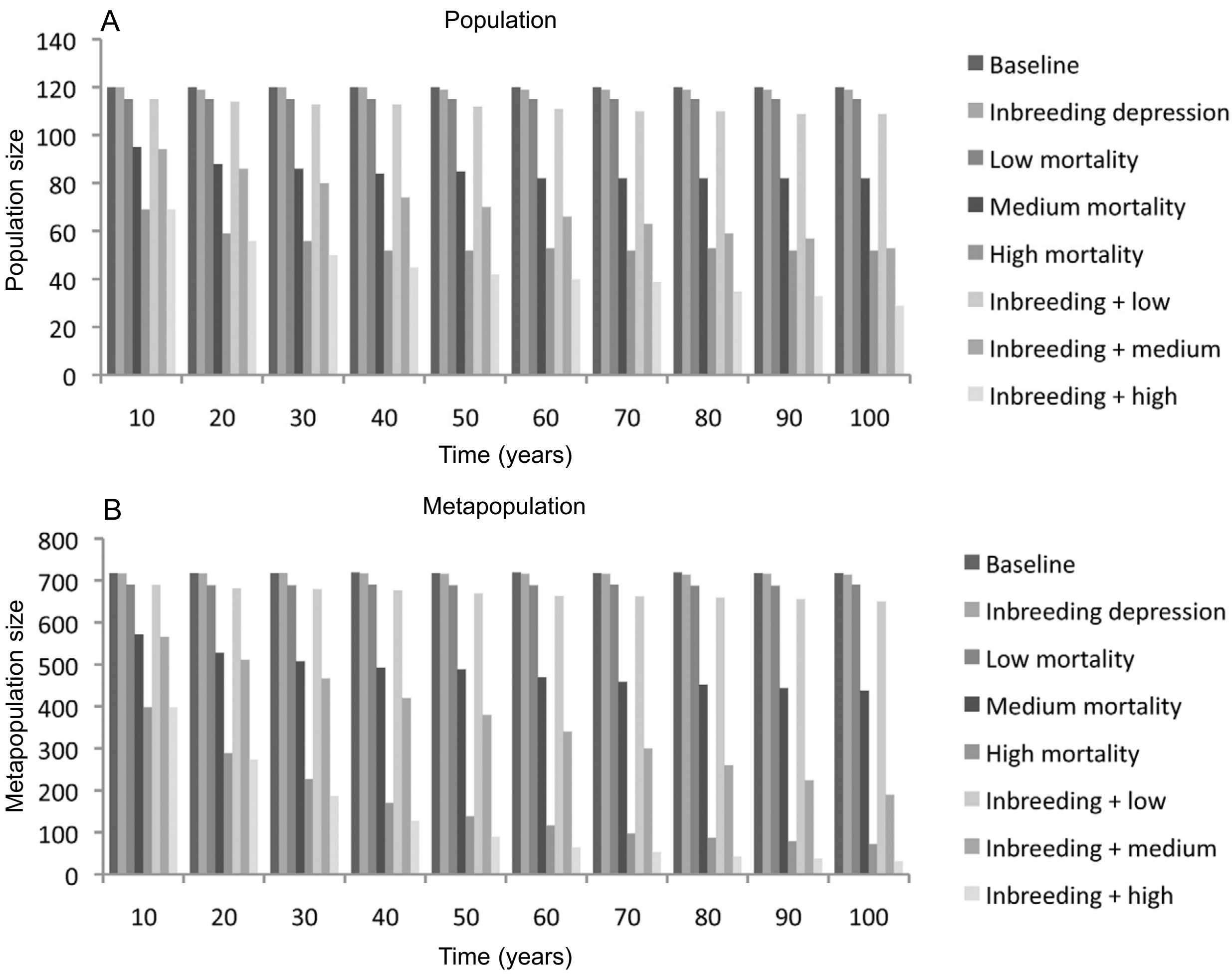

FIG. 4. Population (A) and metapopulation (B) sizes, for *L. dekeyseri* under different scenarios in the Cerrado (for scenario descriptions see Materials and Methods)

non-vampire bat species is ongoing (Massad *et al*., 2001; Almeida *et al*., 2002). Our results show that rabies management has a serious impact on *L. dekeyseri* populations, and poses a serious threat to their persistence. Inbreeding depression, if present, would have a secondary deleterious effect.

It is neither feasible, nor desirable to control rabies through programs that reduce non-vampire bat populations (CDC, 1999) and destroy caves. However, large numbers of bats were, and are, killed in government-supported programs in Brazil. These actions are regarded by farmers and local and

TABLE 2. Growth rates (*r*) and mean time to extinction (TE, in years), for *L. dekeyseri* populations (A) and metapopulation (B) under different scenarios (for scenario descriptions see text) in the Cerrado. Significance of the difference in output between the baseline and other scenarios was tested using a Student's two-tailed *t*-test (* — $P < 0.01$)

Scenarios	Population		Metapopulation	
	r (SE)	TE (SE)	*r* (SE)	TE (SE)
Baseline	0.1055 (0.0019)	–	0.1069 (0.0001)	–
Inbreeding depression	0.0853 (0.0019)*	–	0.0866 (0.0001)*	–
Low mortality	0.0764 (0.0034)*	–	0.0810 (0.0001)*	–
Medium mortality	0.0339 (0.0072)*	63.02 (0.74)*	0.0527 (0.0003)*	–
High mortality	-0.0246 (0.0132)*	42.73 (0.75)*	0.0011 (0.0009)*	75.90 (0.77)*
Inbreeding depression + low mortality	0.0549 (0.0034)*	65.00 (0.00)*	0.0597 (0.0001)*	–
Inbreeding depression + medium mortality	0.0038 (0.0073)*	67.90 (0.66)*	0.0220 (0.0003)*	93.71 (2.79)*
Inbreeding depression + high mortality	-0.0466 (0.0130)*	40.25 (0.68)*	-0.0323 (0.0010)*	70.44 (0.55)*

national authorities as necessary control measures against the 'plague' of bats and the danger of rabies transmission (Mayen, 2003). Alternative, vampire-specific, control techniques should be implemented to control vampire bat populations in the case of rabies outbreaks. Some methods are already in place and should be favored instead of the non-selective traditional methods, such as cattle vaccination; the number of animals vaccinated is steadily increasing in Brazil (Goulart, 2002), but the vaccination is mandatory only in regions with rabies outbreaks or in regions where the disease is common, we suggest that vaccination should be mandatory as a preventive measure and more widespread in the country.

The ineffective bat-extermination policy currently being used to reduce *D. rotundus* populations is a threat to other bat species. This species and other non-vampire bats are extremely important for ecological processes and ecosystem services in the Cerrado (Coelho and Marinho-Filho, 2002; Aguiar *et al*., 2006*a*). Such inadequate management practices, coupled with other threats (e.g., habitat loss and fragmentation, inbreeding depression), may lead to the rapid extinction of *L. dekeyseri.* Habitat loss and fragmentation are severe threats that represent the first blow to the persistence of the species, making it more vulnerable to inbreeding depression and stochastic events (Brito and Fernandez, 2000). Unfortunately, if current management practices dealing with vampire bats are not changed, inappropriate rabies management may be the coup de grace to the long-term existence of *L. dekeyseri*.

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