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PREDICTING THE POPULATION TREND OF THE RHESUS MACAQUE (*Macaca mulatta*) AT SON TRA PENINSULA, DA NANG CITY

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Abstract. The Rhesus macaque (*Macaca mulatta*) population at Son Tra Peninsula, Da Nang city, is experiencing conflicts with both residents and tourists, manifested in aggressive foraging behaviors and frequent incursions into residential areas. This study evaluated whether the rhesus macaque population on the Son Tra Peninsula has approached the carrying capacity of the habitat and assessed its projected trajectory under different snaring scenarios. In this study, a transect survey method was used to estimate the number of individuals in the macaque troops and the total number of individuals in the entire Son Tra Peninsula area. The age and sex structure of the troops was also recorded using this method. Population size, age–sex structure, group composition, and relevant ecological and demographic parameters were entered into Vortex 10 to simulate population trajectories over the next 50 to 100 years. The results show that under current conditions, with a total of 1487 individuals observed, the Rhesus macaque population in Son Tra has the potential to increase to approximately 1922 individuals. If the rate of illegal snaring consistently exceeds 10% of the total population at that time, the population size will begin to decline and gradually become extinct within 100 years.

Keywords: *Macaca mulatta*, Rhesus macaque, population trend, Vortex, Da Nang.

1. Introduction

Human–wildlife interactions represent a pervasive challenge for biodiversity conservation and wildlife management, particularly in regions where primates coexist alongside dense human populations and intensive tourism activities (e.g., global reviews in human–wildlife conflict research). Human–macaque conflict has been documented across Asia and Africa, driven by enhanced access to anthropogenic food and habitat modification, often resulting in increased interactions, provisioning, and subsequent behavioural adaptations of primates [1], [2]. Rhesus macaques (*Macaca mulatta*), among the most widely distributed non-human primate species, are noted for their ecological flexibility and their ability to thrive in human-altered environments. These primates exhibit significant plasticity in adjusting diet, ranging patterns, and social behaviour in response to food provisioning and tourist activities, which can lead to increased human–macaque interactions, resource competition, and conflict, including food theft and aggressive encounters with people [3]. In regions with a significant human footprint, provisioning-both intentional and unintentional-alters macaque activity budgets, spatial ecology, and dependency on anthropogenic food sources, often reducing home range size and modifying natural behaviours [4]. Consequently, these anthropogenic subsidies can inflate local population densities beyond those sustained by natural ecological baselines. Such dynamics raise concerns about the sustainable size of macaque populations in semi-protected landscapes where tourism and human footprint are high, such as Sơn Trà Nature Reserve in Da Nang, Vietnam. Concurrently, *M. mulatta* populations face escalating anthropogenic threats that can compromise population viability. Illegal hunting, snaring [5], [6], and accidental mortality from traffic (Nguyen Thi Thanh Truc pers. comm) have been recognized as significant pressures on the macaque subpopulations, threatening both survival and demographic stability. The dual pressures of anthropogenic food subsidies and elevated mortality from human activities generate a complex socio-ecological system that may push a population toward or beyond its ecological carrying capacity while potentially accelerating a collapse if mortality rates surpass reproductive output. The concept of carrying capacity - the maximum population size that an environment can sustainably support given available resources is central to understanding population dynamics in such contexts. When a macaque population overshoots its carrying capacity due to increased resource availability or reduced mortality, ecological overshoot can lead to resource depletion and subsequent population declines [7], [8]. To date, studies from Son Tra have documented distribution patterns, but no study has quantified population size or evaluated long-term population viability under anthropogenic mortality [9].

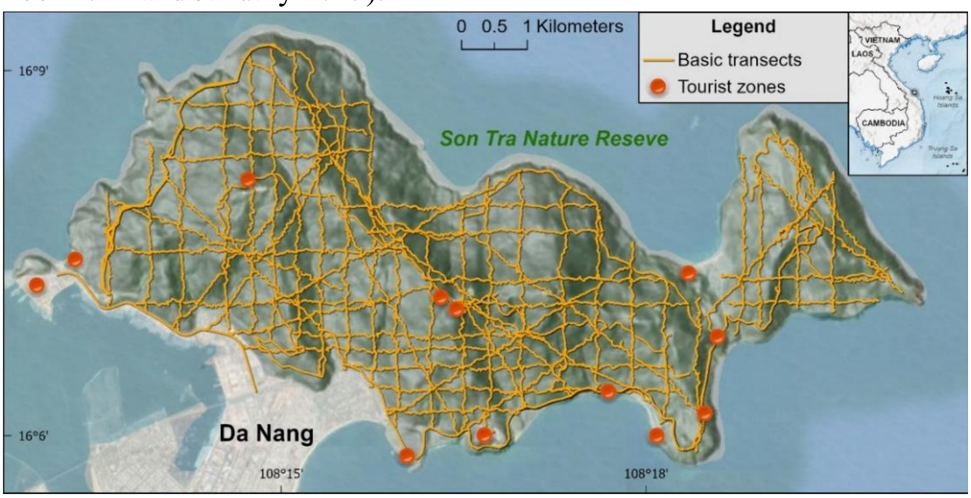
Given these considerations, this study hypothesizes that the *M. mulatta* population at Sơn Tra may have reached or surpassed the carrying capacity of its environment as a result of altered resource availability and human provisioning, while simultaneously facing increasing mortality from illegal snaring and other anthropogenic risks. This research aims to test this hypothesis by modeling population dynamics under varying scenarios of illegal snaring pressure and determining thresholds at which the population begins to decline, with implications for management actions to ensure long-term sustainability.

2. Content

2.1. Materials and methods

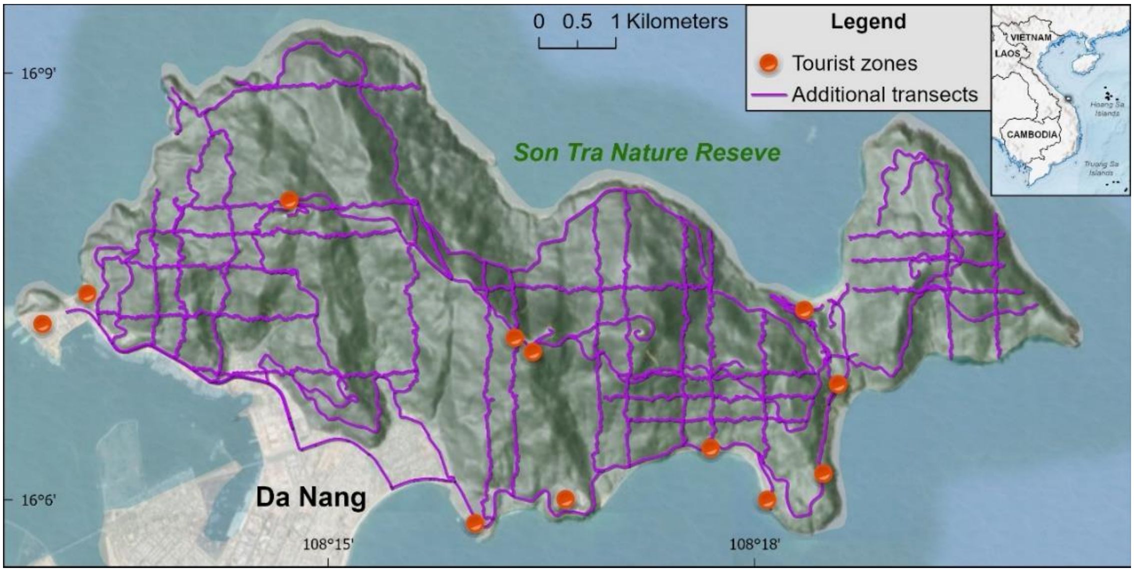
2.1.1. Transect survey

To collect information for calculating the population and distribution of macaque species, basic survey transects were designed and used. Transect lengths were areadependent, with an average length of approximately 4 km. The transects were established to be as representative as possible of the main habitats of Son Tra (Figure 1). Daily routes were established to cut across and along the area of Son Tra to increase the chances of encountering macaque troops moving on the forest floor. Each basic route set would gradually divide each area of the Son Tra peninsula in order from West to East [10]. In a survey group, the surveyor moved along the route at an average speed of about 0.5 - 1.0 km/h, and the distance between two adjacent people in the group was about 15 - 30 m. Observations were conducted using both the unaided eye and binoculars. Upon detection, teams recorded relevant parameters, including total count and demographic structure (age-sex classes). Upon detection, teams recorded relevant parameters, including total count and demographic structure (age-sex classes). To prevent double-counting, the three survey teams reconciled their daily findings by comparing sighting times, GPS locations, and unique morphological markers, such as scars or wounds. Final data were only recorded upon consensus among all teams. After completing all the basic transects used to investigate and determine the *M. mulatta* population, additional transects are used to find and record if there are more macaque species, as well as to confirm the information collected in the basic transects. Macaque troops recorded during the survey of the additional transects are not used to recalculate the population and density of the species, as they do not ensure continuity in time. However, the *M. mulatta* subpopulations recorded at the enhanced transects are still used to determine the reference habitat of the species in Son Tra. Following the primary surveys, supplementary transects - spaced 500 ± 100 m apart and oriented parallel to the original grid - were used to confirm findings and detect additional species. While data from these supplementary transects were used to characterize habitat preferences, they were excluded from population density calculations to maintain temporal consistency. In total, 98 spatially independent transects (96 main transects and 2 sub-transects) were carried out (Figure 1). The transects were surveyed during the summer (April, July, and August 2024) and surveyed again in the winter (December 2024 and January 2025).



A

Figure 1. Main transect surveys (A) and Supplementary transect surveys (B) used in Son Tra Peninsula, Da Nang



B

Figure 1. Main transect surveys (A) and Supplementary transect surveys (B) used in Son Tra Peninsula, Da Nang

2.1.2. Modelling the Rhesus macaque population using Vortex 10

Demographic data - including population size and age-sex ratios derived from transect surveys - were combined with life-history parameters from various sources [11]. These parameters included the mating system, age of first reproduction, maximum longevity, sex ratio at birth, litter size, and mortality rates, as well as anthropogenic factors such as snaring-related removals and reintroductions (Table 1).

Using these data, two simulation models were developed: a Baseline Scenario (Default) and a Sensitivity Analysis model. The latter incorporated a Holding Population to evaluate the impacts of illegal snaring and traffic-related mortality. All data were processed using Vortex 10 (Lacy et al., 2021) [12] to identify population tipping points and predict long-term demographic trends.

Table 1. Input parameters for the VORTEX 10 model

Parameters	Value	Sources
Adult sex ratio (Male: Female)	1:3	[11]
Adult to non-adult ratio	1:1.09	[13]
Mating system	Polygynandrous; 1 female mates with 3–4 males	[11]
Age at first birth (wild females)	Mean 4.9 years	[11]

Maximum lifespan (wild with supplemental food)	31.4 years	[11]
Birth sex ratio	Approximately 1:1 (107 males: 100 females)	[11]
Maximum number of offspring per litter	1	[11], [14]
Age at first reproduction (females)	Mean 3 years (provisioned)	[11], [15]
Age at sexual maturity (males)	Approximately 5 years	[16]
Infant mortality rate (first year)	7% – 32%	[11]
Annual adult mortality rate	2% – 10%	[11]
Home range area	Approximately 0.5 – 1.5 km²	[17]

2.2. Results and discussion

2.2.1. Estimated population size of Rhesus macaque at Son Tra, Da Nang

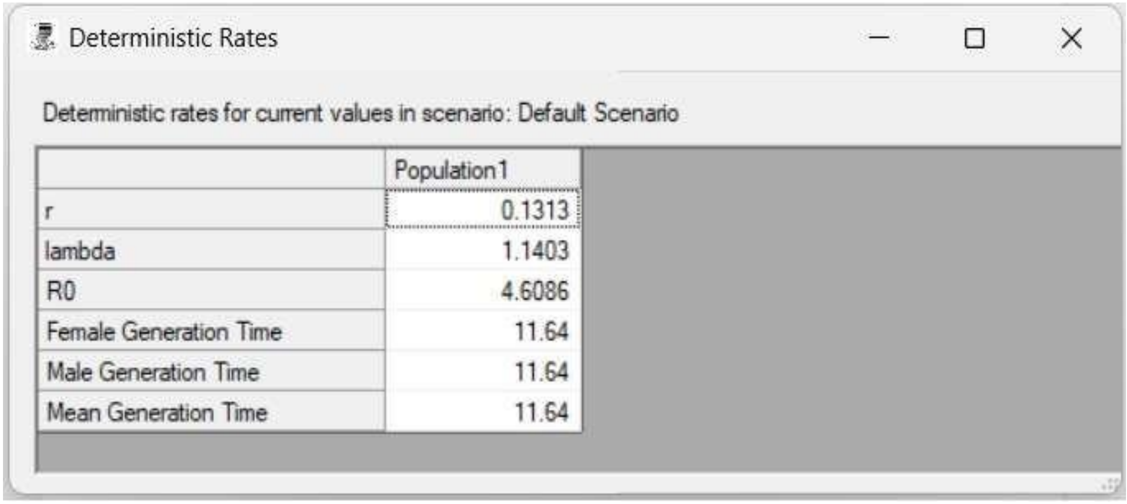
Direct observations from our transects recorded a total of 86 troops of *Macaca mulatta*, with a total of 1487 individuals. Around 850 km transects were surveyed, averaging 11.81 ± 4.02 km/transect, or around 5.90 ± 2.01 km/turn/transect, in 85 days.

The average adult male/female ratio of the *M. mulatta* in the Son Tra area is approximately 1:3, and the adult/non-adult ratio is approximately 1:1.09. However, if we separate the 13 *M. mulatta* troops near residential and tourist areas from the remaining 73 troops, the adult male/female ratio is approximately 1:5.03, and the adult/non-adult ratio is approximately 1:1.51 for the troops near residential and tourist areas. Conversely, for the remaining troops, the adult male/female ratio is approximately 1:2.26, and the adult/non-adult ratio is approximately 1:0.86. In other words, the *M. mulatta* troops near residential and tourist areas have significantly more breeding females and a much larger number of offspring compared to the natural populations.

2.2.2. Default scenario

This result reflects the population's state when biological parameters (reproduction, mortality) and current management pressures are kept constant.

• ***Deterministic rates:*** Values indicating that under ideal conditions (no random fluctuations), the population is capable of strong growth at a rate of approximately 14% per year. **(**A value of lambda = 1.1403 means that, in an ideal environment, each year's population will be 1.1403 times the size of the previous year. To find the annual percentage increase, we subtract 1 from lambda and multiply by 100 as follows: (1.1403 – 1) x 100 = 14.03%.



Deterministic Rates

Deterministic rates for current values in scenario: Default Scenario

	Population1
r	0.1313
lambda	1.1403
R0	4.6086
Female Generation Time	11.64
Male Generation Time	11.64
Mean Generation Time	11.64

Figure 2. Deterministic growth rate under the baseline scenario

• ***Stochastic results***: The default scenario graph shows the blue lines fluctuating steadily. The population starts at 1500 individuals, grows, and maintains around 1922 individuals (close to the carrying capacity of the environment). The simulations converged toward approximately 1,922 individuals, suggesting this value as an approximate carrying-capacity level under the model assumptions.

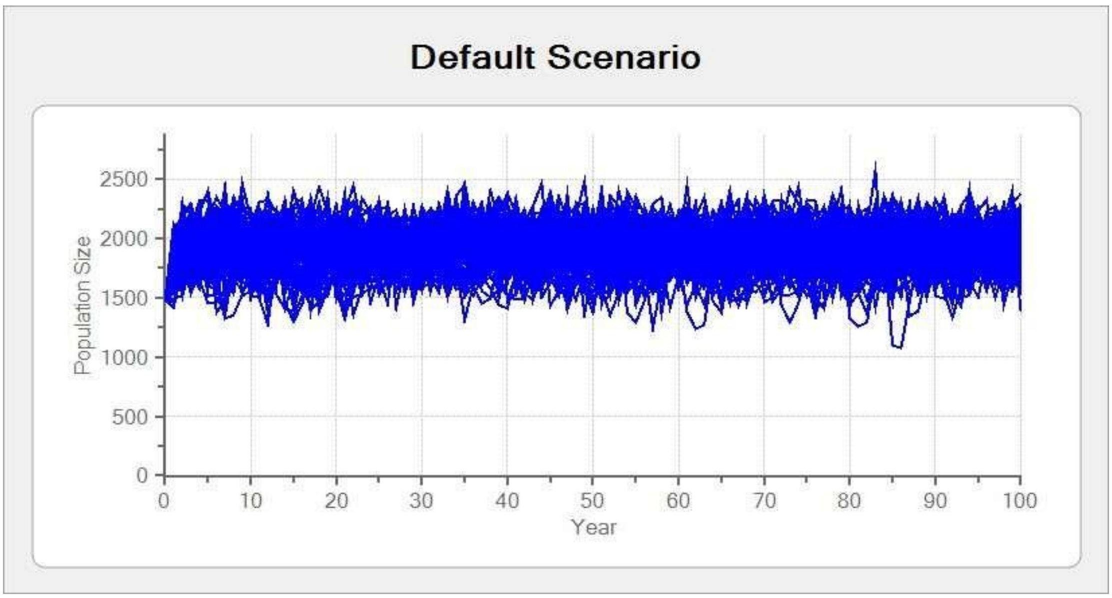


Figure 3. Stochastic results for the default scenario

• ***Safety:*** The baseline scenario indicated a negligible extinction risk over the simulated period (Figure 3). This means that the *Macaca mulatta* population in Son Tra will remain stable around this K level for a long time if the current state is maintained, and no unusual factors occur.

2.2.3. Sensitivity analysis (extinction threshold test)

This analysis was used to identify the population's critical removal threshold under increasing snaring pressure (variable SV1).

Key Tipping Points: Based on Figures 4, 5, 6, and the SV1 variable, the following results can be presented:

- Safety Threshold (SV1 from 0% to 8%): When the annual snaring rate is between 0% and 8%, the average population size remains high. The probability of survival remains at 1.0 (100%) (Figure 5).

- Decline Threshold (SV1 from 10% to 12%): This appears to be the model's critical transition zone. When the snaring rate exceeds 10%, the graph line begins to plummet very rapidly. At 12%, the stochastic growth rate reaches 0. This means that the number of macaques being captured begins to equal or exceed the number of macaques being born (Figures 4, 5, 6).

- Extinction Threshold: When the snaring rate reaches 15%, the probability of population survival drops below 50%. If the snaring rate remains at 20% or higher, the model predicts a very high probability of extinction within 100 years. The extreme results correspond to samples at the end of the value range (snaring ~30%), where the population is wiped out almost immediately (Figures 4, 5, 6).

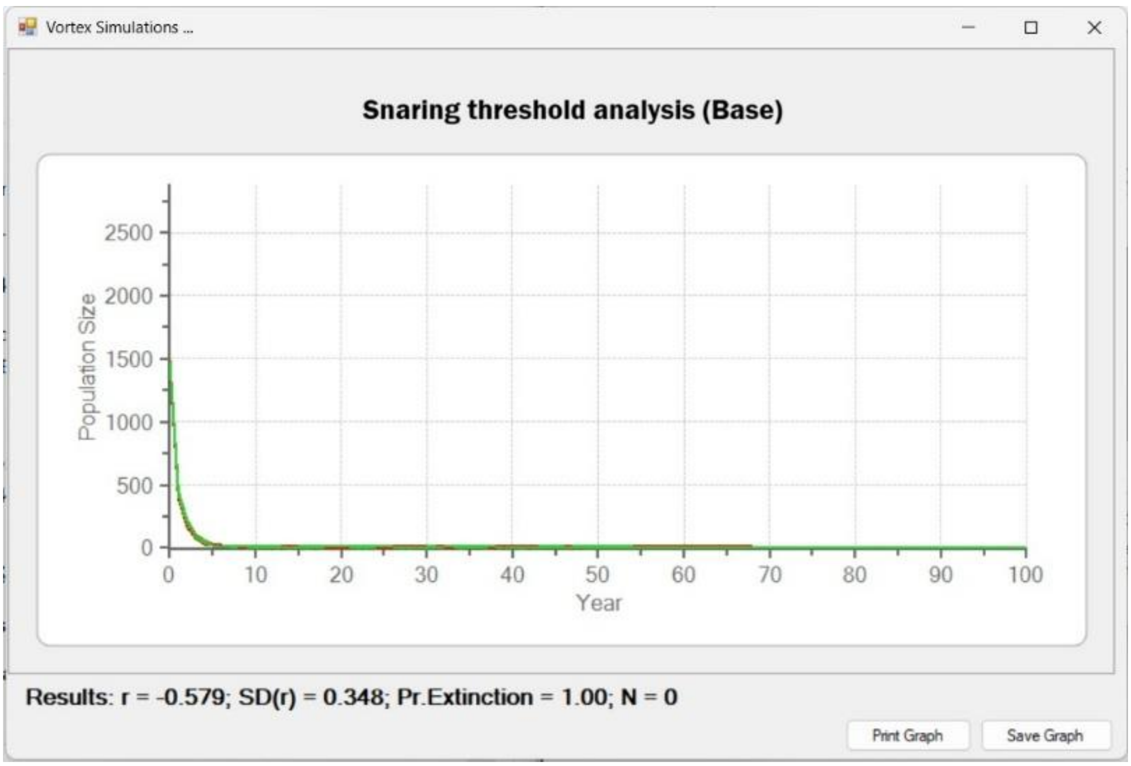


Figure 4. Sensitivity test under a 30% annual removal scenario

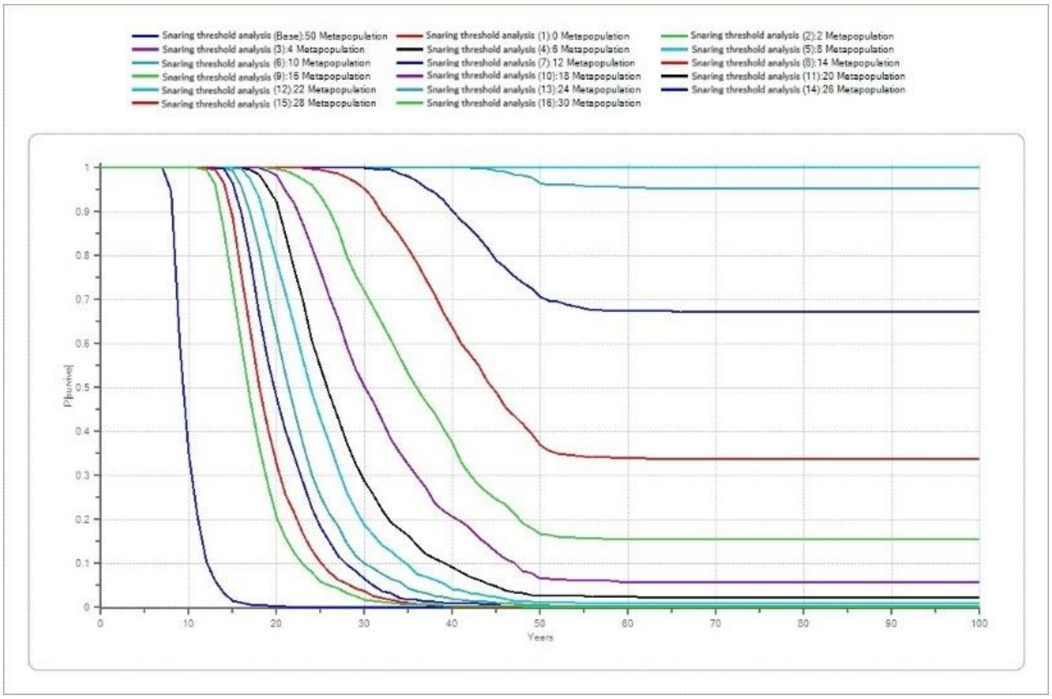


Figure 5. Survival probability under annual snaring rates of 10% - 30%

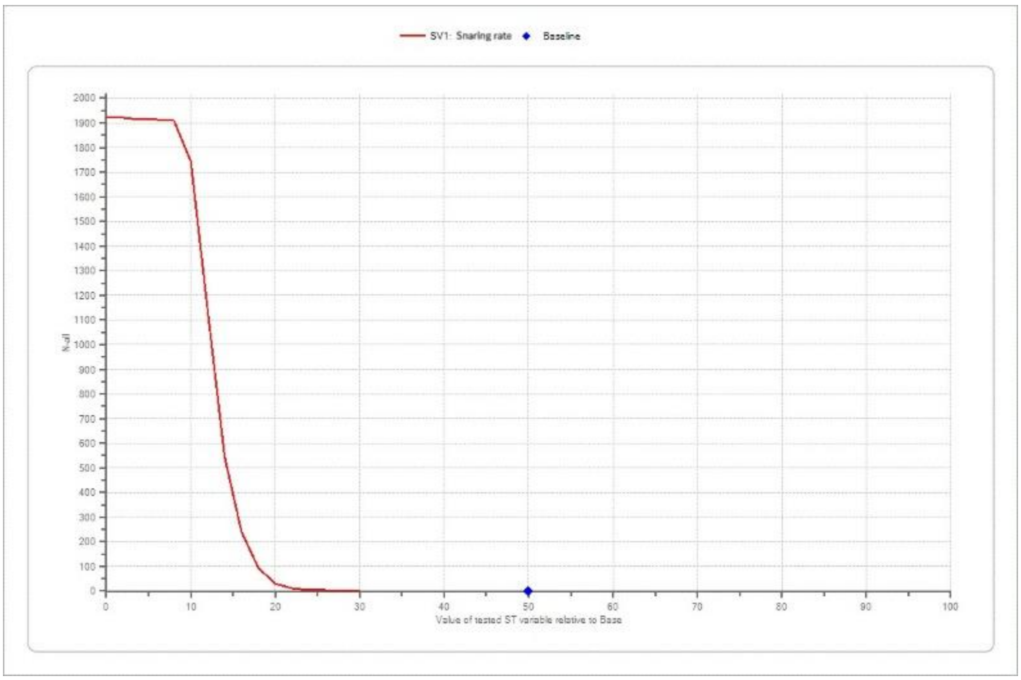


Figure 6. Population trajectory under a 30% annual snaring rate

**** Discussion***

Compared with Valle's study on *Macaca fascicularis*, which was carried out in 2024, important differences should be noted in terms of species, data sources, and study context [18].

Data on *Macaca fascicularis* were collected across four countries—Vietnam, Cambodia, Thailand, and Indonesia—and highlighted the scarcity and inconsistency of demographic data across a broad geographic range. In contrast, our study focuses on *Macaca mulatta* in a much smaller and well-defined area (Son Tra, Da Nang, Vietnam), where more specific local demographic data were available for model input.

Our analysis aims to identify a specific "tipping point" for snaring pressure. The results suggest that, for the Son Tra population, the safe threshold is below 8% of the total number of individuals. When the snaring rate reaches 10–12%, the population begins to decline rapidly, and extinction becomes highly likely if this rate exceeds 20% per year. However, Valle emphasizes that initial population size is a key determinant of extinction risk. In small populations, the annual removal of only 5% of adult females can lead to complete population collapse [18].

The two studies also differ in modeling approaches. Our study used a Holding Population scenario to simulate the loss of individuals due to pressures such as hunting or snaring and to evaluate the overall tolerance threshold of the population to human pressure. In contrast, Valle applied a Harvest modeling framework that examined five types of removal: capturing adult males, adult females, juveniles aged 1–2 years, random capture, and the removal of entire troops. This approach focused on assessing the sensitivity of different demographic groups to population stability, concluding that the removal of adult females has the most severe impact on long-term population persistence [18].

Differences in species, geographic scale, data availability, and modeling assumptions likely contribute to the different projections of population growth reported in the two studies. Valle presented relatively conservative growth projections, with the highest modeled growth rate reaching about 5%, whereas our model suggests that the *Macaca mulatta* population in Son Tra could potentially grow by up to 14% per year under favorable conditions.

3. Conclusions

- The population size of *Macaca mulatta* at Son Tra is 1487 individuals, and this number can reach 1922 individuals as the carrying capacity of the area.

- If the total number of macaques removed from the system (including illegal snaring, traffic accidents, and permanent relocation due to conflict) exceeds 10% of the total population (approximately 150-200 macaques/year), the Son Tra population may enter a critical decline phase and be unable to recover on its own.

- To ensure genetic diversity and long-term stability, human-induced removals should be minimized, ideally kept below 5% annually as a precautionary management threshold.

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