

Population Viability Analysis of Black Rhinoceros (*Diceros bicornis michaeli*) in Lake Nakuru National Park, Kenya

Thuo DN^{1*}, Junga JO¹, Kamau JM², Amimo JO¹, Kibegwa FM¹ and Githui KE³

¹Department of Animal Production, College of Agriculture and Veterinary Sciences, University of Nairobi, Kenya

²Department of Biochemistry, College of Health sciences, University of Nairobi, Kenya

³Molecular Genetics Laboratory, National Museums of Kenya, Kenya

*Corresponding author: David Njoroge Thuo, Department of Animal Production, Kangemi, Nairobi, Kenya, Tel: +254-722680087; E-mail: david_thuo@yahoo.com

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Abstract

Drastic decline of the black rhinoceros population both in numbers and range distribution have created a puzzle on its long term survival. We developed simulation models to identify crucial anthropogenic parameters that are essential for the successful development of conservation actions of this species in Lake Nakuru National Park under different scenarios. The roles of multiple anthropogenic parameters were evaluated to assess changes affecting population declines and extinction risk. Population Viability Analysis (PVA) simulations were done using individual-based program. A baseline simulation allowed for the assessment of the status of the species based on estimates of extinction risk and population declines under current conditions of abundance and habitat availability. The baseline simulation showed that Lake Nakuru National Park subpopulation has 0.00 probability of extinction during the next seventy five years. However, continuing threats, including declines in abundance and browse unavailability, make this species highly vulnerable to any change. Sensitivity analysis of anthropogenic impacts showed that small increases in habitat loss (2%) and population harvesting (3%) had drastic effects on population decline with a 100% probability of extinction. Our findings shows the need for conservation actions aimed at preventing poaching activities, modulating translocation programs and promoting the conservation of available black rhino habitats.

Keywords: Anthropogenic factors; Black rhinoceros; Critically endangered; Kenya; PVA

Introduction

Historically, vast populations of large wildlife mammals traversed throughout most of the sub-Saharan Africa, providing substantial resources and economic income [1]. However, during the past few decades; habitat loss, diseases, overexploitation and poaching have decimated a majority of these mega herbivore species to the extent that they are now restricted to protected areas [2].

The black rhinoceros (*Diceros bicornis*), hereafter referred to as black rhino, has suffered one of the most dramatic decline of all mammals in the recent history [3]. The species currently categorized as critically endangered under the criteria of the International Union of Conservation for the Nature Red List [4] is believed to have thrived in excess of hundreds of thousands only a century ago [5]. By 1992 the number were globally decimated to a low population size of approximately 2300 individuals [5,6]. In Kenya alone black rhino numbers decreased catastrophically from an estimated 20,000 individuals in 1970 to 398 in 1991 and to about 631 in 2014 [7]. This drastic decline has mainly been attributed to poaching.

It is well established that when populations become small and isolated; genetic, demographic, and environmental stochasticities increase the probability of extinction, making population more vulnerable [8,9]. On the contrary, large populations are more likely to be irrepressible to stochastic changes given that random events among individuals are less prominent within larger groups [10,11]. Consequently, conservationists have defined the concept of Minimum

Viable Population (MVP) in an effort to characterize a quantifiable measure of extinction risk. MVP estimates the minimum number of individuals in a population that has a given probability of surviving for a specified period of time [12]. Nonetheless, its applicability in conservation management has not been ascertained thus prompting the need for a quantitative analysis of the risk of population extinction.

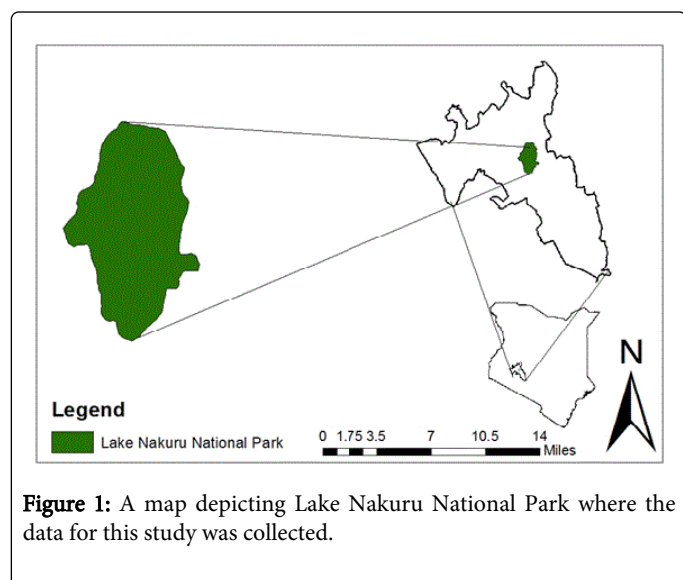
As a result, population viability analysis (PVA) technique has been used to determine extinction risks and population declines [13]. PVA allows for the estimation of extinction probabilities by incorporating identifiable threats to population survival into stochastic models of the extinction process [14]. In addition, it predict the future size of a population, estimates the probability of a population going extinct over a given period of time and also it evaluates management or conservation strategies aimed at maximizing the probability of population persistence [15]. This renders PVA a useful tool in assessing population decline under different scenarios subject to demographic, genetic and environmental stochasticities [16].

Considering the strengths, limitations, and assumptions of the available programs for PVA we selected individual-based program VORTEX version 9.50 [17]. This program models the effects of demographic rates, environmental variation as well as other stochastic events acting on a population. In the present study, we used a fifteen years population monitoring data collected by the Kenya Wildlife Service to examine how anthropogenic factors such as habitat loss and harvesting affect the population decline of the black rhinos in Kenya. This study provides information that is essential for the successful development of conservation actions for the long term survival of this species.

Material and Methods

Study area and input data

Lake Nakuru National Park (LNNP) is situated approximately 150 km North-West of Nairobi in Kenya's central Rift Valley on grid reference point 36° 7'E and 0° 15'S (Figure 1) and covers an area of 140 km². The mean altitude is 1759 m and average annual rainfall is 876 mm. The habitat consists of grassland, scrub woodland, acacia woodland, and vegetation characteristic of saline water ecosystems. Among other wildlife species the park hosts one of the largest populations of black rhino in Kenya with a current population of 60 individuals (33 males and 27 females). The park is also a major site for flamingos in Kenya [8]. We obtained data of the black rhino population for Lake Nakuru National Park from the Kenya Wildlife Service (KWS). Whenever specific data of black rhino sub population was unavailable in LNNP, information from other black rhino subpopulations were used from published and gray literature or records.



The input data used for the PVA is specified in Table 1. The species has a polygynous mating system reaching sexual maturity at the average age of nine years old (Unpublished, KWS), giving one calf per parturition. In order to satisfy 'number of young per year' which must be a whole number, a year was adjusted from 365 days (default) to 490 days. The gestation period of a rhino is 15.33 months (460) days [18] so as to enter a whole number (i.e. 1) instead of a fraction (i.e. 0.8), a 'year' was calibrated to reflect 490 days to accommodate one birth per year, plus an additional 30 days which is the minimum time required to become pregnant again. This was done to avoid over-estimating the number of births in the simulations. The adjusted year is referred to as the 'gestational year'. Data on sex ration in the wild did not exist; nevertheless, the ratio was approximated at 1:1 based on KWS personnel observations at LNNP and formal discussions with other rhino experts.

The major reason for the decline of the black rhino in the wild is assumed to be related to poaching associated with the trade of horn for traditional medicine in Asia [19,20]. In addition, habitat loss [21,22] has likely played a major role in decreasing the availability of feeding and breeding sites.

PVA simulations

PVA simulations were performed using VORTEX, version 9.50 [16]. VORTEX uses mortality rates and calculates fertility based on the number of females and males in the breeding pool and the mean number of progeny per year. VORTEX models variability in the percentage of breeding; this means that the environmental variation in reproduction is incorporated as a standard deviation of the percent of females producing off-spring [23]. Sensitivity tests were performed to measure the impact of specific parameters on population decline. In all simulations, we used the baseline as a template changing the value of the specific parameter of interest (e.g. Carrying capacity and harvesting) for each alternative simulation.

Based on the apparent distribution of the populations all simulations were run over a 75 year period, using 1000 iterations to estimate decline, extinction probabilities and estimates of population growth rates. The following simulation scenarios were performed:

Parameters	Values
Number of populations	1
Number of iterations	1,000
Number of years	75
Carrying capacity	71
Initial abundance	50
Reproductive system	Polygynous
Breeding age	7years(males) 6 years(females)
Maximum breeding age	28 years
Environmental variation	10%
Sex ratio	50:50
Maximum number of progeny	1

% Adults breeding	Females=67% Males=47%
Mean number of offspring	1

Table 1: Input data used for the population viability analysis of the LNNP black rhino subpopulation. Values and annual average rates used for the baseline Simulation were obtained from the Kenya Wildlife Service and previous Studies on the black rhino species.

Baseline simulation: This simulation was based on current demographic data obtained for the species (Table 1). Complete input files for VORTEX are provided as additional materials. For the programs' outcome comparisons we ran the baseline simulation for 50, and 75 years, each with 500 and 1000 iterations. Varied time periods were run to evaluate how much the year to year variation could affect predictions on extinction probabilities. Different numbers of iterations were tested to assess effects of parameter estimates on measures of variation, including standard errors and confidence intervals.

Anthropogenic simulations: Poaching (Modeled as harvesting) which has been and still is considered the most serious threats to the survival of black rhino species [3] for their highly valued horn in the back market was modeled. Harvesting of individuals 3 years and above (sub-adult and adults) over a consecutive period of 50 years was simulated to assess the effects of poaching on the population decline. Probabilities of extinction were assessed under different harvesting quotas including 0.5, 1, 2, 3 and 5% during 50 and 75 years, respectively.

In addition, habitat loss attributed to the increased water level of the lake due to the recent rehabilitation of Mau forest which is the major source of rivers draining into Lake Nakuru was simulated. This increased water flowing into the lake has consequently reduced the browsing area for the black rhino as well as increase inter-competition for the available resources with other wildlife herbivores. Moreover, the growth of an invasive species (*Solanum incunum*) has also contributed in increasing the rates of habitat loss (KWS, unpublished). A recent estimate of water level increase was 0.05% as reported by Kenya Wildlife Service (KWS, unpublished). To assess the effects of habitat loss, a series of simulations modeling water level increase and invasive species as a decrease in carrying capacity (K) over time. These simulations included 0.5, 1, 2, 3 and 5% decreases in carrying capacity each year.

Results

PVA simulations

The baseline simulation using all individuals resulted in a probability of extinction of 0.00 for the subpopulation over the 75 gestational years (101 calendar years) with a growth rate (λ) of 1.254 (Table 2). The subpopulation increased by 30% for the first 10 years of simulation and then stabilized for the remaining years of simulations.

As expected, population performance of black rhino in terms of decline and extinction probabilities showed varying fluctuating patterns under different percentages of habitat loss (modeled as decrease in carrying capacity) and harvesting, thus, increasing the probability of extinction (Table 2 and Figure 2). Simulation with 0.5% of habitat loss had a little effect on the subpopulation (Table 2 and Figure 3). Although, the difference caused was not statistically

significant the final population decreased by 20% from the initial population size at the end of the simulation.

A 1% loss of habitat each year had a significant impact (i.e. 0.11) on the subpopulation decline, reducing the subpopulation size by 46% during the first 40 years and 66.67% after 50 years. As expected, 2% had even greater impact on subpopulation extinction, decreasing by 90% the number of individuals during the first 40 years of simulation and wiping out the whole population before the end of the 75th year.

Simulation with 3% and 5% of habitat loss had a more drastic effect causing the population to run extinct at 40 and 30 years respectively (Figure 2).

Percentage changes	λ	Habitat loss	Harvesting
		PE	PE
Baseline	1.254	0.00	0.00
0.5%	1.254	0.01	0.04
1%	1.254	0.11	0.13
2%	1.254	1.00	0.76
3%	1.254	1.00	1.00
5%	1.254	1.00	1.00

Table 2: Habitat Loss and Harvesting PVA Simulations. Population Growth Rate (λ) and Probabilities of Extinction (PE).

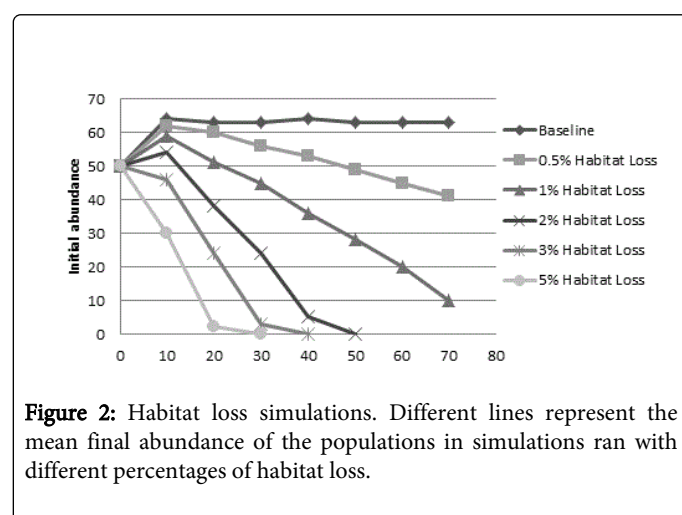


Figure 2: Habitat loss simulations. Different lines represent the mean final abundance of the populations in simulations ran with different percentages of habitat loss.

Harvesting different percentages of individuals during the first 10 years over a 75 year period resulted in slight population increase (at 0.5% and 1% harvest) while reducing the population of the other percentages of harvesting (Figure 3). Simulation showed that starting at 0.5% of harvesting, probability of extinction became significantly

different from that of the baseline simulation (Table 2). The harvesting at 5% on yearly basis showed a greatest impact on the population decline and extinction probabilities.

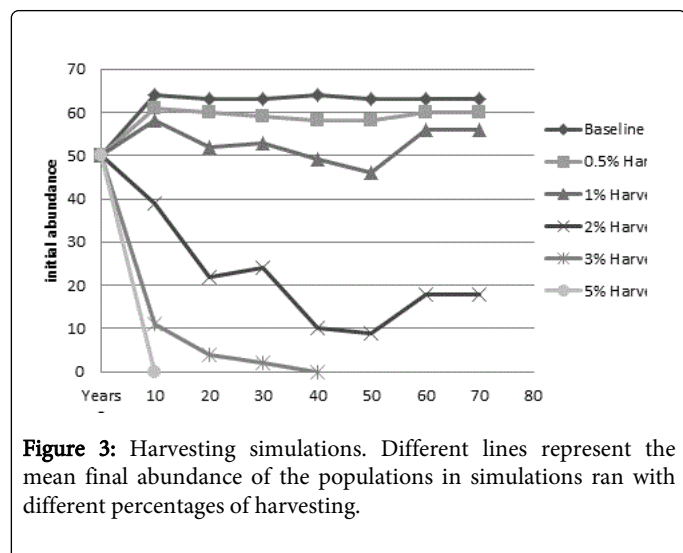


Figure 3: Harvesting simulations. Different lines represent the mean final abundance of the populations in simulations run with different percentages of harvesting.

Discussion

The eastern black rhino is a critically endangered species with abundance estimates of 800 individuals in the wild [24]. Like many other iconic species, its main threats include habitat loss and the illegal trade of wildlife trophies. Nonetheless, there is no quantitative information about the impact of these activities on LNNP black rhino persistence. Results of the PVA baseline simulation suggest that, under current conditions, the LNNP black rhino has a 0.00 probability of extinction over the next 75 years. This scenario is particularly so considering the high level of protection and adequate security to keep off potential threats. Moreover, high levels of genetic variation as reported by Muya et al. [25] could also be a contributing factor to the long survival of the species observed. However, growth rate estimates (1.254) did not reach the rate of replacement necessary to maintain the populations over a longer period of time, making the species more vulnerable to any change or threat. This suggests that the park may be maintained as a nucleus breeding site for the potential translocation or reintroduction to other rhino sanctuaries in Kenya. In order to achieve this goal however, the KWS rhino team would be required to formulate a more effective management program which targets on maintaining an effective population size as well as managing other wildlife herbivores in the park.

Sensitivity analysis on the effects of poaching and habitat loss under different percentages proved to be important limiting factors for the LNNP black rhino. A 1% loss of habitat per year reduced the population abundance by more than half in the first 30 years of simulation. As expected, 2% had an even greater impact on subpopulation extinction, decreasing by 90% the number of individuals during the first 40 years of simulation and wiping out the whole population before the end of the 75th year. These results were particularly relatable given that increased water level in the lake (habitat loss) raised the competition pressure from other herbivores depending on similar browse resources. The results are consistent with those of Landman and Kerley [26] that showed black rhinoceros population sharing habitats with other browsers in Addo National Park, South Africa may be limited due to resource competition.

Competition for the available resources may also result in calf mortality rate as well as extending inter-calving interval thereby reducing the population growth in black rhino population [27]. The effects of poaching were tested through different harvesting quotas set during a consecutive 75 year period and indicated that a 3% rate of harvesting had a significant effect on the subpopulation over a short period of time. This result was also obtained by Soka et al. [28] in a study of black rhino where harvesting of 2 males and 2 females year after year showed a mean growth rate of 0.035 in the first five years, but the population declined considerably before becoming extinct after 45 years. Findings from the anthropogenic PVA simulations showed that poaching and habitat loss pose great threats for the long term survival of the LNNP black rhino, particularly given the constant pressure of illegal trade of wildlife trophies and continued increase in lake water levels.

Our results suggest there is need to implement effective measures to curb habitat loss as well as enforcing laws against poaching and illegal trade of rhino trophies. Overall, this study provides an initial step in assessing and quantifying potential threats affecting black rhino in Lake Nakuru National Park, Kenya, in terms of the potential effects of anthropogenic factors on a long-term survival of this species.

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