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SHORT COMMUNICATION

Probabilistic assessment of the risk of black rhinoceros (*Diceros bicornis*) species extinction

Suares Clovis Oukouomi Noutchie

School of Mathematical and Statistical Sciences, North-West University, Potchefstroom, South Africa

Correspondence
Suares Clovis Oukouomi Noutchie, School of Mathematical and Statistical Sciences, North-West University, Potchefstroom, South Africa.
Email: clovis.oukouominoutchie@nwu.ac.za

Abstract

The black rhinoceros (*Diceros bicornis*), distinguished by its distinctive horned snout and imposing size, stands perilously close to the precipice of extinction. The survival of this majestic species is threatened by a combination of factors, necessitating urgent scientific inquiry into the underlying causes. In this research article, a nonlinear stochastic Ricker model is employed to investigate the challenges faced by the population of black rhinoceros. By integrating innovative mathematical approaches with ecological understanding, the aim is to unravel the intricate dynamics contributing to the endangered status of the black rhino. The critical role of habitat loss and illicit poaching activities in driving the decline of this remarkable species is highlighted by the analysis. These findings emphasise the need for immediate and decisive action to protect the black rhinoceros and mitigate the risk of its extinction. It is imperative that comprehensive conservation efforts be implemented to ensure the long-term survival of the black rhinoceros and preserve its invaluable place within the ecosystem.

Résumé

Le rhinocéros noir (*Diceros bicornis*), qui se distingue par son museau cornu et sa taille imposante, elle se rapproche dangereusement du gouffre de l'extinction. La survie de cette espèce majestueuse est menacée par un ensemble de facteurs, ce qui nécessite une enquête scientifique urgente sur les causes sous-jacentes. Dans cet article de recherche, un modèle stochastique non linéaire de Ricker est utilisé pour étudier les défis auxquels est confrontée la population de rhinocéros noirs. En intégrant des approches mathématiques innovantes à la compréhension de l'écologie, l'objectif est d'élucider les dynamiques complexes qui contribuent au statut d'espèce menacée du rhinocéros noir. L'analyse met en évidence le rôle critique de la perte d'habitat et des activités illicites de braconnage dans le déclin de cette espèce remarquable. Ces résultats soulignent la nécessité de mesures immédiates et décisives pour protéger le rhinocéros noir et atténuer le risque de son extinction. Il est impératif que des efforts de conservation globaux soient mis en œuvre pour assurer la survie à long terme du rhinocéros noir et préserver sa place inestimable au sein de l'écosystème.

1 | INTRODUCTION

The black rhinoceros (*Diceros bicornis*), a majestic and iconic species, is facing a severe crisis as its population has plummeted by over 90% in just a few decades. According to the International Union for Conservation of Nature, there were an estimated 65,000 black rhinos in the 1970s, but by 2021, that number had dwindled to <5500. These alarming statistics highlight the urgent need to address the challenges threatening the survival of this magnificent creature (IUCN, 2022). The primary driver of the black rhino's population decline is poaching for its valuable horn. The rhino horn holds significant allure in illegal wildlife trade markets, particularly in Asia, where it is falsely believed to possess medicinal properties and is considered a status symbol. The soaring demand and high value of rhino horn on the black market have fuelled the poaching crisis (Biggs et al., 2013).

The illicit trade in rhino horn not only decimates the black rhino populations but also has devastating consequences for their overall survival. Poaching disrupts the natural balance of male–female ratios, diminishes genetic diversity and hinders reproduction rates. The loss of individuals, particularly reproductive females, profoundly impacts population growth and recovery (Chanyandura et al., 2021). To combat poaching, numerous conservation organisations, governments and local communities have implemented a range of strategies. These initiatives include increasing ranger patrols, employing advanced surveillance technology like drones and camera traps, establishing anti-poaching units and strengthening law enforcement efforts (Battisti & Cerfolli, 2021; Biggs et al., 2017). Furthermore, international collaborations and agreements have been forged to curb the demand for rhino horn and reinforce legal frameworks (Colchester, 2004; Kidwai et al., 2019). Despite the formidable challenges faced, there is hope in certain regions where dedicated conservation efforts have yielded promising results. Population recoveries in these areas demonstrate the potential for the black rhino's survival and growth (IUCN, 2022). However, the survival of black rhinos is not only threatened by poaching; habitat loss and fragmentation also pose significant risks. Human activities, such as agriculture, logging and infrastructure development, have led to the conversion of rhino habitats into farmland or urban areas, reducing the availability of suitable living environments (Chanyandura et al., 2021). The clearance of forests for timber and fuelwood extraction has had a profound impact on black rhino populations. Forests play a crucial role in providing rhinos with food, shelter and protection against poaching. Deforestation disrupts these ecological functions, forcing rhinos to seek alternative habitats that may not adequately meet their needs (Goheen et al., 2018; Law et al., 2015). Moreover, the construction of roads, railways and fences has fragmented black rhino habitats, isolating populations and impeding gene flow between groups. Fragmentation restricts the rhinos' movement and access to vital resources, making them more vulnerable to poaching, predation and inbreeding (Haddad et al., 2015; Salafsky et al., 2008). Smaller fragmented habitats have reduced carrying capacity and are more susceptible to disturbances, making it challenging for rhino populations to recover (Crooks et al., 2017). The combination of habitat loss and fragmentation has directly contributed to the decline of black rhino populations. As rhinos lose access to suitable habitats and resources, their survival is increasingly threatened. Fragmented populations face higher risks of local extinctions and demographic stochasticity, further exacerbating the species' vulnerability (Chanyandura et al., 2021). The fragmented habitats resulting from human activities not only make it easier for poachers to locate and target black rhinos but also hinder gene flow between populations, leading to increased inbreeding and reduced genetic diversity. Low genetic diversity diminishes the species' ability to adapt, making it more susceptible to diseases, environmental changes and other threats (Haddad et al., 2015). In order to secure the survival of the black rhino population, it is essential to employ effective methods to comprehend and influence the population's progression. Utilising stochastic differential equations to simulate the population's evolution provides a robust and adaptable approach that effectively considers the inherent uncertainties associated with real-world populations. This research extensively investigates a nonlinear stochastic Ricker model, which captures the development of the rhino population considering random factors like carrying capacity, poaching rate and growth rate. The key questions examined in this article are:

- What are the underlying causes contributing to the endangered status of the black rhino?
- How can a nonlinear stochastic Ricker model be employed to investigate the challenges faced by the black rhino population?
- What insights can be gained from the numerical investigation?
- What is the importance of implementing robust measures to safeguard the natural habitat and discourage illicit poaching activities?
- How can these findings serve as a reminder of the urgent need for immediate and decisive action to protect the black rhinoceros and prevent its potential extinction?
- What comprehensive conservation efforts should be undertaken to ensure the long-term survival of the black rhinoceros and preserve its invaluable place in the ecosystem?

By addressing these key questions, the study aims to provide a deeper understanding of the factors impacting the black rhino population, enabling a better understanding and the formulation of strategies to ensure its survival.

2 | STOCHASTIC MODEL AND METHOD

The Ricker model (Bjorkstedt, 2012) presents a distinct alternative to the logistic population model, offering a different perspective on population dynamics. Unlike the logistic model, the Ricker model demonstrates an exponential decrease in population growth as the population size increases, but at a faster rate. This framework effectively captures the fluctuations in growth rate experienced by populations due to environmental factors such as weather variations or disease outbreaks. Unlike the logistic equation, the nonlinear Ricker equation allows for more intricate dynamics, including oscillations, population crashes and chaotic behaviour. Many species,

including the black rhino population, can exhibit nonlinear patterns such as boom-and-bust cycles due to various ecological factors. By employing the stochastic Ricker equation, these complex dynamics can be accurately represented, providing a comprehensive understanding of the population's evolution over time. An important aspect of the Ricker equation is its explicit consideration of density dependence, wherein population growth rates vary with population size. As the black rhino population reaches high densities, limited resources and intensified competition lead to decreased growth rates. The Ricker equation successfully captures this density-dependent regulation, resulting in population oscillations or other intricate dynamics. This study introduces a modified version of the Ricker model that incorporates stochastic elements to account for the impact of various sources of randomness such as poaching, genetic abnormalities and habitat loss. The core equation used in this modified model represents the evolutionary dynamics in this context and is expressed as follows:

$$dN_t = N_t e^{r_t(1-N_t/K_t)}d_t + \sqrt{D}N_t dB_t - \upsilon_t N_t d_t.$$

In this equation, the variable N_t represents the population size at time t, while r_t denotes the intrinsic growth rate. The carrying capacity of the environment is denoted by K_t which represents the maximum sustainable population size. To account for the impact of randomness, the diffusion coefficient D quantifies the intensity of the noise affecting the population dynamics. The term $\sqrt{D}N_t dB_t$ incorporates the random fluctuations driven by a standard Brownian motion represented by B_t. Additionally, the mortality rate is represented by υ_t. By introducing randomness into the carrying capacity, growth rate and death rate variables, we acknowledge the inherent uncertainty and variability present in ecological systems. To gain insights into the long-term dynamics of the black rhino population, simulations will be conducted using the Euler–Maruyama method, as referenced in Bayram et al. (2018). This computational approach will generate multiple projections, providing valuable information about the potential outcomes and trends of the black rhino population over time.

3 | RESULTS AND DISCUSSION

This section aims to conduct simulations that will enable us to make projections about the future of the rhino population. These simulations will encompass two distinct scenarios: one that involves the implementation of comprehensive conservation efforts and another that represents a scenario where no such efforts are put into place. The simulations will incorporate stochastic elements in order to ensure a realistic portrayal of the rhino population's evolution. These stochastic elements will introduce randomness into crucial ecological features, including carrying capacities, growth rates and poaching rates. By accounting for the inherent uncertainty in these factors, the objective is to capture the dynamic nature of the rhino population and the various potential outcomes that may arise. The starting point for the simulations will assume an initial population size of $N_0 = 1000$. This point will serve as the baseline from which the population's future trajectory will be projected. By comparing the results of the simulations conducted under the two scenarios (with and without conservation efforts), insights will be gained into the potential impact of conservation initiatives on the rhino population's overall trajectory and its likelihood of survival.

3.1 | Dynamics with adequate conservation efforts

In this subsection, the foundation is built upon the assumption that the presence of sufficient measures aimed at combatting the pervasive issue of illegal wildlife trade has been considered. The tireless and conscientious efforts being made to safeguard the natural habitat of the rhinoceros population, ensuring their long-term protection and preservation, are crucial and deserve acknowledgment. These endeavours encompass a multifaceted approach, including habitat conservation, anti-poaching initiatives, international collaborations and strict law enforcement, all aimed at curbing the illegal trade in rhinoceros products.

As the focus shifts towards delving into the visual representation of the dynamics, Figure 1 assumes a central role, shedding light on the growth patterns amidst varying circumstances. The first graph illustrates growth under moderate random noise, indicating a controlled and relatively stable progression. In this scenario, it is assumed that the influencing factors and parameters exhibit a degree of predictability and consistency, enabling a measured and manageable growth trajectory. In contrast, the second graph presents growth with a relatively high level of random variation of the parameters. In this scenario, the inherent uncertainties and unpredictability that can arise within the complex web of ecological dynamics and external influences are reflected. The potential impact of these random variations on the growth of the rhinoceros population is vividly illustrated by the graph. It serves as a reminder that, despite diligent efforts and effective measures in place, external factors and fluctuations can significantly influence the overall trajectory, necessitating the implementation of adaptive and resilient conservation strategies. This visualisation underscores the need for proactive and adaptive management strategies to navigate the intricacies of conservation efforts, ensuring the long-term sustainability and survival of the rhinoceros population in the face of dynamic and evolving challenges.

3.2 | Dynamics without proper conservation efforts

In this subsection, the existence of significant weaknesses and inadequacies in the ongoing battle against rhino poaching is acknowledged. Unfortunately, the tragic demise of these magnificent

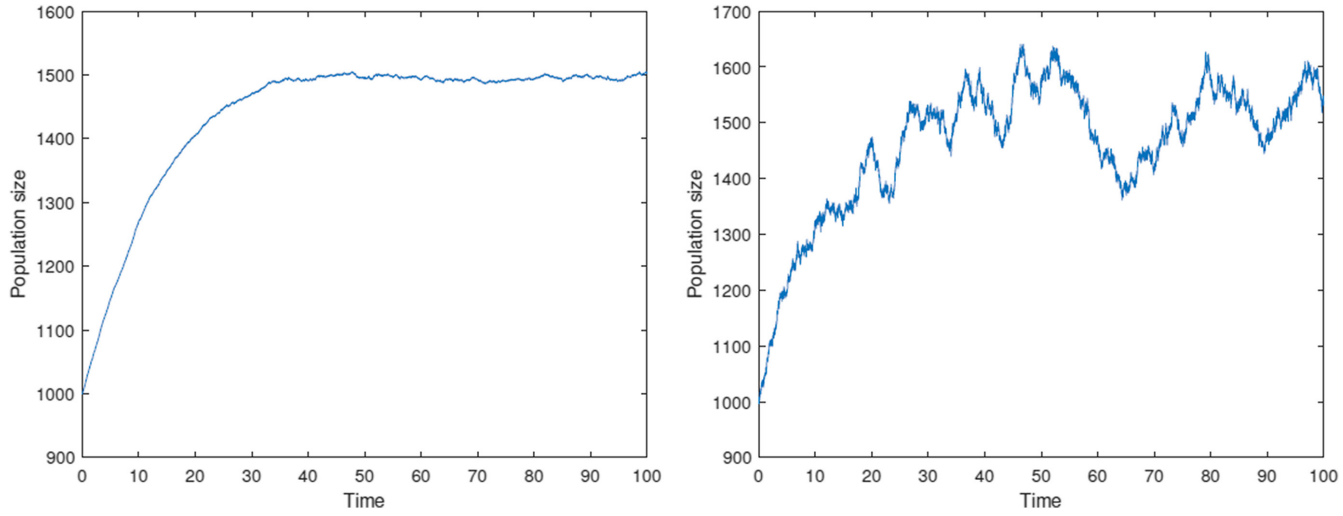

FIGURE 1 Dynamics with adequate conservative efforts.

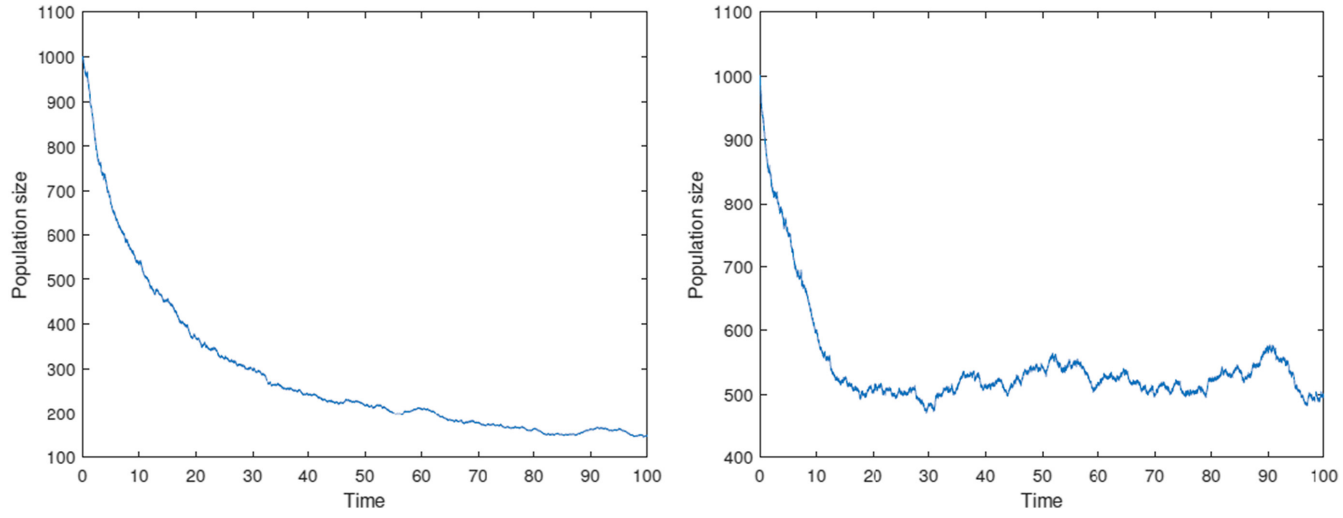

FIGURE 2 Dynamics with inadequate conservation efforts.

creatures and the subsequent illegal trade of their valuable horns in the thriving black market have been caused by these shortcomings. To better understand the complexities at play, Figure 2 is presented, which provides a visual representation of the dynamics involved. Figure 2 is composed of two graphs that shed light on different aspects of the situation.

The dynamics with low noise disturbance are illustrated in the first graph, displaying a nearly deterministic decay. The gradual decline of the rhino population and the associated consequences resulting from the inadequacies in the anti-poaching efforts are represented by this graph. The deterministic decay suggests a predictable pattern of decline, where the rhino population is steadily eroded by the impact of poaching and other factors. The decay with relatively high noise is portrayed in the second graph of Figure 2, signifying the persistent interference and disturbance inflicted upon the rhino habitat. This noise can stem from various sources, such as deforestation activities, habitat destruction and other contributing factors. The presence of high noise indicates the unpredictability and volatility of the challenges faced in combatting rhino poaching. By visualising these dynamics, Figure 2 emphasises the urgent need for comprehensive reform and a holistic approach to address the weaknesses and inadequacies in the fight against rhino poaching. The importance of tackling the root causes of poaching, such as improving law enforcement, enhancing conservation efforts and addressing socioeconomic factors that drive the demand for rhino horns, is underscored.

4 | CONCLUDING REMARKS

This study extensively examined a stochastic model governing the dynamics of the black rhino population. Utilising the Euler–Maruyama method, the researcher explored the intricate dynamics of the population by incorporating random variables like

carrying capacity, growth rates, death rates, as well as external factors such as poaching and habitat loss. These insights underscore the significance of conservation efforts directed towards protecting the remaining black rhino population and their habitats. Despite the challenges posed by external threats, it is crucial to prioritise and strengthen these conservation initiatives. Considerable progress has already been made through dedicated anti-poaching measures, proactive habitat conservation, well-executed translocation programs, active community engagement and robust international cooperation. These commendable actions have contributed to preserving black rhino populations and their natural habitats. However, it is imperative to recognise that sustaining these achievements demands unwavering commitment and continuous efforts. Ensuring the long-term survival and eventual recovery of the black rhino population necessitates a steadfast and multifaceted approach. To secure a brighter future for black rhinos, it is essential to further enhance and implement these conservation measures. This includes intensifying anti-poaching operations by utilising advanced technology, strengthening law enforcement effectiveness and imposing stricter penalties for illegal wildlife trafficking. Expanding habitat conservation initiatives through the establishment of protected areas, promotion of sustainable land use practices and mitigation of habitat fragmentation is also crucial. Moreover, expanding translocation programs to facilitate the movement of black rhinos to suitable habitats with ample resources and reduced poaching risks is important. Empowering local communities and involving them in conservation efforts through education, capacity building and alternative livelihood programs can foster a sense of ownership and shared responsibility. International cooperation is vital in addressing the transnational nature of wildlife crime and habitat conservation. Strengthening collaborations between countries, sharing best practices and coordinating efforts can enhance the effectiveness of conservation strategies and ensure the long-term viability of the black rhino population. Successfully implementing these comprehensive measures will not only protect the black rhino population and their habitats but also preserve the ecological balance of their ecosystems. Furthermore, it will enable future generations to experience and appreciate the remarkable beauty and ecological significance of this iconic species.

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ORCID

Suares Clovis Oukouomi Noutchie https://orcid.org/0000-0003-4662-8007

REFERENCES

Battisti, C., & Cerfolli, F. (2021). From citizen science to citizen management: Suggestions for a pervasive fine-grained and operational approach to biodiversity conservation. *Israel Journal of Ecology and Evolution*, *68*(1–4), 8–12. https://doi.org/10.1163/22244662-bja10029

Bayram, M., Partal, T., & Orucova Buyukoz, G. (2018). Numerical methods for simulation of stochastic differential equations. *Advances in Difference Equations*, *17*, 1–10. https://doi.org/10.1186/s13662-018-1466-5

Biggs, D., Cooney, R., Roe, D., Dublin, H., Allan, J., Challender, D., Skinner, D., & Martin, R. (2017). Developing a theory of change for a community-based response to illegal wildlife trade. *Conservation Biology*, *31*(1), 5–12. https://doi.org/10.1111/cobi.12796

Biggs, D., Courchamp, F., Martin, R., & Possingham, H. P. (2013). Legal trade of Africa's rhino horns. *Science*, *339*(6123), 1038–1039. https://doi.org/10.1126/science.1229998

Bjorkstedt, E. P. (2012). Ricker model. In A. Hastings & L. Gross (Eds.), *Encyclopedia of theoretical ecology* (pp. 632–636). University of California Press. https://doi.org/10.1525/9780520951785-111

Chanyandura, A., Muposhi, V. K., Gandiwa, E., & Muboko, N. (2021). An analysis of threats, strategies, and opportunities for African rhinoceros conservation. *Ecology and Evolution*, *11*(11), 5892–5910. https://doi.org/10.1002/ece3.7536

Colchester, M. (2004). Conservation policy and indigenous peoples, conservation policy and indigenous peoples. *Environmental Science & Policy*, *7*(3), 145–153. https://doi.org/10.1016/j.envsci.2004.02.004

Crooks, K. R., Burdett, C. L., Theobald, D. M., King, S. R. B., di Marco, M., Rondinini, C., & Boitani, L. (2017). Quantification of habitat fragmentation reveals extinction risk in terrestrial mammals. *PNAS*, *114*(29), 7635–7640. https://doi.org/10.1073/pnas.1705769114

Goheen, J. R., Augustine, D. J., Veblen, K. E., Kimuyu, D. M., Palmer, T. M., Porensky, L. M., Pringle, R. M., Ratnam, J., Riginos, C., Sankaran, M., Ford, A. T., Hassan, A. A., Jakopak, R., Kartzinel, T. R., Kurukura, S., Louthan, A. M., Odadi, W. O., Otieno, T. O., Wambua, A. M., … Young, T. P. (2018). Conservation lessons from large-mammal manipulations in east African savannas: The KLEE, UHURU, and GLADE experiments. *Annals New York Academy of Sciences*, *1429*, 1–19. https://doi.org/10.1111/nyas.13848

Haddad, N. M., Brudvig, L. A., Clobert, J., Davies, K. F., Gonzalez, A., Holt, R. D., Lovejoy, T. E., Sexton, J. O., Austin, M. P., Collins, C. D., Cook, W. M., Damschen, E. I., Ewers, R. M., Foster, B. L., Jenkins, C. N., King, A. J., Laurance, W. F., Levey, D. J., Margules, C. R., … Townshend, J. R. (2015). Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science Advances*, *1*(2), e1500052. https://doi.org/10.1126/sciadv.1500052

IUCN. (2022). *The IUCN red list of threatened species. version 2022-2*. https://www.iucnredlist.org. [Accessed 11 July 2023]

Kidwai, Z., Jimenez, J., Louw, C. J., Nel, H. P., & Marshal, J. P. (2019). Using N- mixture models to estimate abundance and temporal trends of black rhinoceros (*Diceros bicornis* L.) populations from aerial counts. *Global Ecology and Conservation*, *19*, e00687. https://doi.org/10.1016/j.gecco.2019.e00687

Law, P. R., Fike, B., & Lent, P. C. (2015). Dynamics of an expanding black rhinoceros (*Diceros bicornis* minor) population. *European Journal of Wildlife Research*, *61*, 601–609. https://doi.org/10.1007/s10344-015-0935-3

Salafsky, N., Salzer, D., Stattersfield, A. J., Hilton-Taylor, C., Neugarten, R., Butchart, S. H. M., Collen, B., Cox, N., Master, L. L., O'Connor, S., & Wilkie, D. (2008). A standard lexicon for biodiversity conservation: Unified classifications of threats and actions. *Conservation Biology*, *22*(4),897–911.https://doi.org/10.1111/j.1523-1739.2008.00937.x

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