An evolutionary game theory model for devaluing rhinos

Nikoleta E. Glynatsi, Vincent Knight, Tamsin E. Lee

Abstract

Rhino poaching has escalated in recent years due the demand for rhino horn in Asian countries. Rhino horn is used in Traditional Chinese Medicine and as a status symbol of success and wealth. Wild life managers attempt to minimise the rhino casualties with approaches such as devaluation of the rhino horn. The most common strategy of devaluing horns includes dehorning. In [1] game theory modelling was used to examined the interaction of poachers and wild life managers. A manager can either 'dehorn' their rhinos or leave the horn attached. Poachers may chose to to behave 'selectively' or 'indiscriminately'. The approach described in this paper builds upon [1] and investigates the interactions between the poachers using evolutionary game theory. Evolutionary game theory, allows us to explore the evolutionary stabilities of the strategies available to a poacher. The purpose of this work is to discover whether conditions which encourages the poachers to behave selectively, they only kill those rhinos with full horns, exist. Notwithstanding, the analytical results prove that poachers will never adopt a selective behaviour as long as there is the slightest gain from a partial horn. Additionally, poachers behaving indiscriminate can be proven to be stable and robust. Thus, we conclude that dehorning is not the dominant strategy for a wild life manager, and we suggest that money are spend on security.

1 Introduction

The illegal trade in rhino horn supports aggressive poaching syndicates and a black market (Nowell et al., 1992). This lucrative market entices people to invest their time and energy to gain a 'winfall' in the form of a rhino horn, through the poaching of rhinos. In recent years poaching has escalated to an unpresidented level resulting in concerns over their future existence (Smith et al., 2013). In response, rhino conservation has seen increased ilitarisation with 'boots on the ground' and 'eyes in the sky' (Duffy et al., 2015). An alternative method is to devalue the horn itself, one of the main methods being the removal so that only a stub is left. The first attempt at large-scale rhino dehorning as an anti-poaching measure was in Damordond, Namibia, in 1989 (Milner-Gulland and Leader-Williams, 1992). Other methods of devaluing the horn that have been suggested include the insertion of poisons, dyes or GPS trackers (Gill, 2010; Smith, 2013). However, like dehorning, they cannot remove all the potential gain from an intact horn (poison and dyes fade or GPS trackers can be removed). This paper builds on the work of [1] and considers the general strategy of devaluing horns, which includes dehorning.

Rhino populations now persist largely in protected areas or on private land, and require intensive protection (Ferreira et al., 2014). For wildlife managers law enforcement is often one of the main methods of deterring poaching, however rhino managers can remove the poaching incentive by devaluing their rhinos (Milner-Gulland, 1999). Milner-Gulland and Leader-Williams (1992) found the optimum proportion to dehorn using mean horn length as a measure of the proportion of rhinos dehorned. They showed, with realistic parameter values, that the optimal strategy is to dehorn as many rhinos as possible. A manager does not need to choose between law enforcement or devaluing, but perhaps adopt a combination of the two; especially given that devaluing rhinos comes at a cost to the manager, and the process comes with a risk to the rhinos.

A recent paper modelled the interaction between a rhino manager and poachers using game theory [1]. The authors consider a working year of a single rhino manager. A manager is assumed to have standard yearly resources which can be allocated on devaluing a proportion of their rhinos or spent on security. It is assumed that all rhinos initially have intact horns. Poachers may either only kill rhinos with full horns, 'selective poachers', or kill all rhinos they encounter, 'indiscriminate poachers'. If all rhinos are left by the rhino manager with their intact horns, it does not pay poachers to be selective so they will chose to be indiscriminate. Conversely, if all poachers are selective, it pays rhino managers to invest in devaluing their rhinos. This dynamic is represented in Fig. 1. Assuming poachers and managers will always behave so as to maximise their payoff, there are two equilibriums: either all devalued and all poachers selective; or all horns intact and all poachers indiscriminate. Essentially, either the managers win, the top left quadrant of Fig. 1, or the poachers win, the bottom right quadrant of Fig. 1. The paper concludes that poachers will always choose to behave indiscriminately, and thus the game settles to the top left quadrant, i.e., the poachers win.

Figure 1: The game between rhino manager and rhino poachers. The system settles to one of two equilibriums, either devaluing is effective or not.

The work of [1] did not take in to account the population dynamic effect of these strategies. In a population full of selective poachers would their be a benefit to a single poacher becoming indiscriminate or vice versa? This notion is explored here using evolutionary game theory [3]. The game is not that of two players anymore (manager and poacher) but an infinite population of poachers is considered. This allows for interaction between poachers over multiple plays of the game to be explored with the rhino manager being the one that creates the conditions of the population.

In evolutionary game theory, we assume infinite populations and in our model this will be represented by $\chi = (x_1, x_2)$ with x_1 proportion of the population using a strategy of the first type and x_2 of the second, denoted by s_1, s_2 respectively. We assume there is a utility function u_1 and u_2 that maps the population to a fitness for each type,

$$u_1(\chi) \qquad u_2(\chi).$$

In evolutionary game theory these utilities are used to dictate the evolution of the population over time, according to the following differential equations,

$$\begin{cases} \dfrac{dx_1}{dt} = x_1(u_1(\chi) - \phi), \\[2em] \dfrac{dx_2}{dt} = x_2(u_2(\chi) - \phi). \end{cases} \tag{1}$$

The overall population is assumed to remain stable thus, $x_1 + x_2 = 1$ and

$$\frac{dx_1}{dt} + \frac{dx_2}{dt} = 0 \Rightarrow x_1(u_1(\chi) - \phi) + x_2(u_2(\chi) - \phi) = 0. \tag{2}$$

As follows the average fitness can be written as,

$$\phi = x_1 u_1(\chi) + x_2 u_2(\chi). \tag{3}$$

By substituting (3) and $x_2 = 1 - x_1$ in (1),

$$\frac{dx_1}{dt} = x_1(1 - x_1)(u_1(\chi) - u_2(\chi)). \tag{4}$$

The equilibria of the differential equation (4) are given by,

- $x_1 = 0$,

- $x_1 = 1$,

- $x_1 \in (0, 1)$ for $u_1(\chi) = u_2(\chi)$.

Thereupon, two notions must be checked for the equilibria,

- stability. The notion of stability implies that the underlying differential equation does not move. Secondly,

- evolutionary stability. The notion of evolutionary stability implies that the differential equation ...

The notion of evolutionary stability can be checked only for the stable strategies. For a stable strategy to be an evolutionary stable strategy (ESS) it must remain the best response even an mutated population χ_ϵ. A mutated population is the post entry population, where a small proportion ϵ starts deviating and adopts a different strategy. The mutated population can be thought as a nudged. Assume Fig. 2, is illustrating two stable strategies. In Fig. 2a, though the population has reached a stable point once a nudge is applied the marble will lose it's position. In contrast, Fig. 2b illustrates a strategy that even when nudged the marble will bounce back to it's original position, making it ESS.

(a) A diagram of a stable strategy which is not ESS.   (b) A diagram of a stable strategy which is ESS.
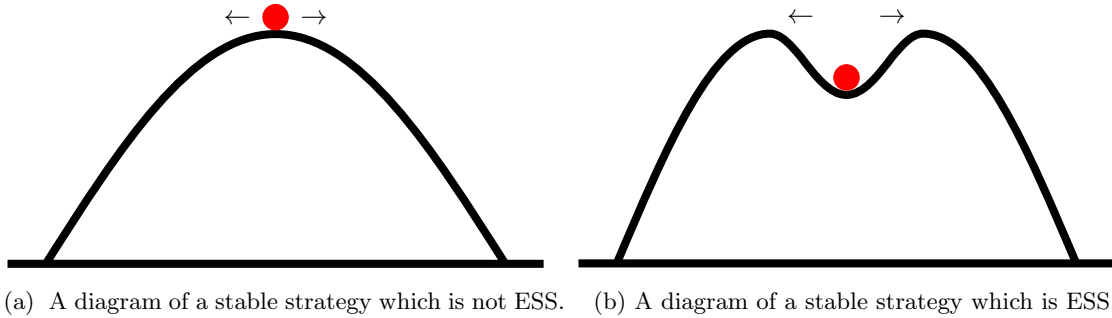
Figure 2: Diagrams of stable strategies.

In the following section, section 2, we determine expressions for u_1, u_2 that correspond to a population of wild rhino poachers and we explore the stability of the equilibria identified in [1]. The results contained in this paper are proven analytically, and more specifically it is shown that,

- all poachers behaving selectively is not a stable strategy,

- a mixed population where selective and indiscriminate poachers learn to co exist can not hold and

- finally all poachers adopting a indiscriminate strategy was proven to be a stable and an evolutionary stable strategy.

2   The Model

A wild rhino poacher can adopt two strategies, to either behave selectively or indiscriminately. Calculating the utility for each strategy, the gain and cost that poachers are exposed to must be taken into account. The poacher incurs a loss from seeking a rhino, and the risk involved. The gain depends upon the value of horn, the proportion of horn remaining after the manager has devalued the rhino horn and the number of rhinos (devalued and not).

Let us first consider the gain to the poacher, where θ is the amount of horn taken. We assume rhino horn value is determined by weight only, a reasonable assumption as rhino horn is sold in a grounded form [4]. Referring to Fig. 1, clearly if the horn is intact, the amount of horn gained is $\theta = 1$ for both the selective and the indiscriminate poacher. If the rhino horn has been devalued, and the poacher is selective, the amount of horn gained is $\theta = 0$ as the poacher does not kill. However, if the poacher is behaving indiscriminately, the amount of horn gained is $\theta = \theta_r$ (for some $0 < \theta_r < 1$). Therefore, the amount of horn gained in the general case is

$$\theta(r, s) = s(1 - r) + (1 - s)((\theta_r - 1)r + 1), \tag{5}$$

where r is the proportion of rhinos that have been devalued, and s is the proportion of selective poachers. Note that since $\theta_r, r, s \in [0, 1]$, then $\theta(r, s) > 0$. Standard supply and demand arguments imply that the value of rhino horn decreases as the quantity of horn increases. Thus at any given time the expected gain for a poacher is

3

$$H\theta(r,s)^{-\alpha}, \tag{6}$$

where H is a scaling factor associated with the value of a full horn, and $\alpha \geq 0$ is a constant that determines the precise relationship between the quantity and value of the horn. Fig. 3, verifies that the gain curve corresponds to a demand curve.
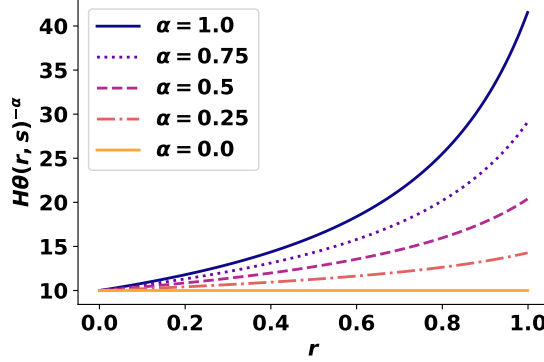

Figure 3: $H\theta(r,s)^{-\alpha}$ for values $H = 10, \theta_r = 0.3$ and $s = 0.2..$

An individual interacts with the population, denoted as $\chi = (x, 1-x)$. Thus, the gain is either

$$\begin{cases} \theta(r,1)H\theta(r,x)^{-\alpha} & \text{selective poacher} \\ \theta(r,0)H\theta(r,x)^{-\alpha} & \text{indiscriminate poacher} \end{cases} \tag{7}$$

depending on the chosen strategy of the individual, see Fig. 1.

Secondly we consider the costs incurred by the poacher. Let us denote the number of rhinos that will be considered at risk given r and s as $\phi(r,s)$. The rhinos **not** at risk are the devalued ones that cross the paths of selective poachers. Thus:

$$\psi(r,s) = 1 - rs. \tag{8}$$

Additionally, the poachers are also exposed to a risk. The risk to the poacher is the opposite of the proportion of rhinos devalued r, since the rhino manager can spend more on security if the cost of devaluing is low.

$$(1-r)^{\beta}, \tag{9}$$

where $\beta \geq 0$ is a constant that determines the precise relationship between the proportion of rhinos not devalued and the security on the grounds. Therefore, at any given time the expected cost for a poacher is,

$$F\psi(r,s)^{\gamma}(1-r)^{\beta} = F(1-rs)^{\gamma}(1-r)^{\beta} \tag{10}$$

where F and $\gamma \geq 0$ are constants that determine the precise relationship between the proportion of vulnerable rhinos and the probability of finding a rhino, such that γ close to zero indicates very sparse rhinos. Fig. 4, verifies the decreasing relationship between r and the cost.

Note that for a indiscriminate poachers $s = 0$ the seeking cost (9) will always be 1, thus the cost of finding a rhino is greater than the same cost for a selective poacher. However, a selective poacher needs more time to secure an 'available' rhino, if they exist at all. Hence, an additional cost that tends to infinity as $r \to 1$ must be applied,
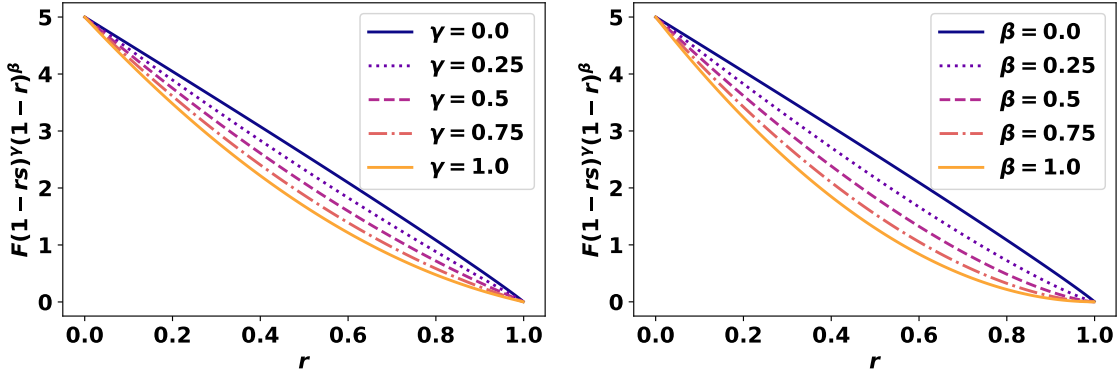
(a) For values, $s = 0.7, F = 5$ and $\beta = 0.95$.　　　(b) For values, $s = 1, F = 5$ and $\gamma = 0.95$.

Figure 4: $F(1 - rs)^{\gamma}(1 - r)^{\beta}$.

$$\begin{cases} \frac{1}{\psi(r,1)} = \frac{1}{1-r} & \text{selective poacher} \\ \frac{1}{\psi(r,0)} = 1 & \text{indiscriminate poacher} \end{cases} \tag{11}$$

To summarise, the cost incurred by a given individual when interacting with the population is given by

$$\begin{cases} \frac{1}{1-r}F(1 - rx)^{\gamma}(1 - r)^{\beta} & \text{selective poacher} \\ F(1 - rx)^{\gamma}(1 - r)^{\beta} & \text{indiscriminate poacher} \end{cases} \tag{12}$$

As a result, the utility of the poachers can now be defined. Let $\sigma = (s, 1 - s)$ denote the strategy of an individual. Thus $\sigma = (1, 0)$ represent an individual poacher who is selective and $\sigma = (0, 1)$ represent an individual poacher who is indiscriminate. Combining (7) and (12) gives the utility function for the individual poacher σ in the population χ,

$$u(\sigma, \chi) = su_1(\chi) + (1 - s)u_2(\chi), \tag{13}$$

where

$$u_1(\chi) = \theta(r,1)H\theta(r,x)^{-\alpha} - \frac{1}{1 - r}F\psi(r,x)^{\gamma}(1 - r)^{\beta}, \tag{14}$$

$$u_2(\chi) = \theta(r,0)H\theta(r,x)^{-\alpha} - F\psi(r,x)^{\gamma}(1 - r)^{\beta}. \tag{15}$$

Substituting (14) and (15) into (13) gives

$$u(\sigma, \chi) = H(\theta_r r(1 - s) - r + 1)\theta(r,x)^{-\alpha} - F\left(1 - s + \frac{s}{1 - r}\right)(1 - rx)^{\gamma}(1 - r)^{\beta}. \tag{16}$$

In section 3, the notions of stability and evolutionary stability of these two strategies as well as a potential mixed strategy will be investigated.

3　Evolutionary Stability

Using an evolutionary model to study the devaluation of wild rhinos allows us to gain insight on the evolutionary stability of the strategies and their conditions. By definition, for a strategy to be an ESS it must first be stable. In our model there are three possible stable distributions based on the equilibria of equation (4),

- All poachers are selective $s = 1$;

- All poachers are indiscriminate $s = 0$;

- Mixed population of selective and indiscriminate poachers.

Each of the equilibria is being examined is the following subsections.

3.0.1 All poachers are selective $s = 1$

All **selective**, $\sigma = (1, 0)$ is proven to be an unstable strategy.

Theorem 1 *For $\sigma = (1, 0)$ to be stable the utility of behaving selectively in a population of selective poachers must be greater than the utility of a poacher behaving indiscriminately in a population of selective poachers,*

$$u((1,0),(1,0)) > u((0,1),(1,0)) \tag{17}$$

where,

$$u((1,0),(1,0)) = H(1-r)^{1-\alpha} - F(1-r)^{\beta+\gamma-1}, \tag{18}$$

and

$$u((0,1),(1,0)) = H(\theta_r r + 1 - r)(1-r)^{-\alpha} - F(1-r)^{\beta+\gamma}. \tag{19}$$

Setting (18) to be greater than (19) gives the condition,

$$H\theta_r r < F[1 - (1-r)^{-1}](1-r)^{\gamma+\beta+\alpha} \tag{20}$$

This inequality states that the gain from partial horn available needs to be less than a given amount for selectiveness to be a stable strategy, and thus devaluing would be an effective strategy to deter poachers.

Note that the left-hand size will always be negative since $1 - (1-r)^{-1} \leq 0$ for any r, on the other hand the right-hand side is always positive. Thus, (20) can never hold, thus being selective is never a stable strategy.

Whilst, in [1], it was identified as an equilibrium for the corresponding stage game, we here have shown that it will never be selected in a population of poachers. Due the luck of stability evolutionary stability will not be examined for selective poachers.

3.0.2 All poachers are indiscriminate $s = 0$

Similarly, the stability of all **indiscriminate** is examined.

Theorem 2 *For $\sigma = (0, 1)$ to be stable the utility of a poacher behaving indiscriminately in a population of indiscriminate poachers must be greater than the utility of a poacher behaving selectively in a population of indiscriminate poachers,*

$$u((0,1),(0,1)) > u((1,0),(0,1)), \tag{21}$$

where,

$$u((0,1),(0,1)) = H(\theta_r r + 1 - r)(\theta_r r + 1 - r)^{-\alpha} - F(1-r)^{\beta}, \tag{22}$$

and

$$u((1,0),(0,1)) = H(1-r)(\theta_r r + 1 - r)^{-\alpha} - F(1-r)^{\beta-1}. \tag{23}$$

Setting (22) to be greater than (23) gives,

$$H\theta_r r > F[1 - (1 - r)^{-1}](1 - r)^\beta(\theta_r r - r + 1)^\alpha. \tag{24}$$

This inequality states that for indiscriminate behaviour to be stable, the value of a partial rhino horn available needs to be greater than a given amount.

Since $1 - (1 - r)^{-1} \leq 0$, the righ-hand side of the inequality is always negative where the left-hand side is always positive. Thus, inequality (24) holds for any r. So all indiscriminate is proven to be stable.

Thereupon, the evolutionary stability of the strategy can now be explored.

Theorem 3 *In order for all indiscriminate $\sigma = (0, 1)$ to be an ESS it must remain the best response in a mutated population, thus,*

$$u((0, 1), \chi_\epsilon) > u(\chi_\epsilon, \chi_\epsilon), \tag{25}$$

must hold. Where,

$$u((0, 1), \chi_\epsilon) = H(\theta_r r - r + 1)\theta(r, x_\epsilon)^{-\alpha} - F(1 - \chi_\epsilon)^\gamma(1 - r)^\beta, \tag{26}$$

$$u(\chi_\epsilon, \chi_\epsilon) = H(\theta_r r - r(1 - x_\epsilon)) + 1)\theta(r, x_\epsilon)^{-\alpha} - F(1 - x_\epsilon)^\gamma(1 - r)^\beta(1 - x_\epsilon + \frac{x_\epsilon}{1 - r}). \tag{27}$$

Let the difference of (26) and (27) be denoted as,

$$\delta = u((0, 1), \chi_\epsilon) - u(\chi_\epsilon, \chi_\epsilon), \tag{28}$$

$$\delta = H\theta(r, \chi_\epsilon)^{-\alpha}\theta_r r x_\epsilon - F(1 - x_\epsilon)^\gamma(1 - r)^\beta x_\epsilon(\frac{-r}{1 - r}) \tag{29}$$

all indiscriminate will be an ESS if and only if $\delta > 0$ for any small value of ϵ. Thus if and only if,

$$H\theta(r, \chi_\epsilon)^{-\alpha}\theta_r r x_\epsilon > F(1 - x_\epsilon)^\gamma(1 - r)^\beta x_\epsilon(\frac{-r}{1 - r}) \tag{30}$$

The right-hand of inequality (30) is always negative since $(\frac{-r}{1-r}) < 0$ for all r. On the contrary, the right-hand side is always positive for all r, thus the inequality holds. It is proven that all indiscriminate is an evolutionary stable strategy.

Whilst, the equilibrium where poachers win in [1], has been shown here to be stable and robust.

3.0.3   Mixed population of selective and indiscriminate poachers

The third potential stable solution is that of a **mixed population**. It is proven that for any reasonable scenarios a mixed population can never be stable.

Theorem 4 *A mixed population $\sigma = (s^*, 1 - s^*)$ is said to be stable for a given s^* if and only if,*

$$u((1, 0), (s^*, 1 - s^*)) = u((0, 1), (s^*, 1 - s^*)). \tag{31}$$

The left-hand side is,

$$u((1, 0), (s^*, 1 - s^*)) = H(1 - r)\theta(r, s^*)^{-\alpha} - F(1 - r)(1 - rs^*)^\gamma(1 - r)^\beta.$$

The right-hand side is

$$u((0, 1), (s^*, 1 - s^*)) = H(\theta_r + 1 - r)\theta(r, s^*)^{-\alpha} - F(1 - rs^*)^\gamma(1 - r)^\beta.$$

Substituting these into (31) gives an expression to solve for s^*,

$$-H\theta_r r\theta(r, s^*)^{-\alpha} + Fr(1 - rs^*)^\gamma(1 - r)^\beta = 0. \tag{32}$$

$$\frac{F}{H} = \frac{\theta_r}{(1 - rs)^\gamma} + \frac{1}{(1 - rs)^\gamma(1 - r)^\beta r(1 - s)} \tag{33}$$

Note that for any rational scenario $\frac{F}{H}$ should always be smaller than 1. F denotes the cost where H denotes the gain and for any reasonable scenario the cost of retrieving a horn should be smaller than it's value. On the contrary, the right-hand side of equation (33) if always greater to 1. Due $\frac{1}{(1-rs)^\gamma(1-r)^\beta r(1-s)} \geq 1$. Thus the stable condition can never hold for any s^*.

In this section we have studied analytically the stability of all the possible equilibria. We have proven the instability of the selective and mixed strategies and the evolutionary stability of the indiscriminate behaviour. In the section 4, we discuss some of the insights we gain from the results of this section.

4   Discussion and Conclusions

In this section we discuss the insights of your findings. Our results question the effectiveness of how wild life managers have been dealing with poachers for more than 20 years.

Dehorning wild rhinos was introduced in 1989 as a mean of securing the safety of the animal. However, dehorning can be effective if and only if poachers chose to behave in a selective manner. Exploring the dynamics of a selective population it was proven than being selective is not a best response not even in a population where everyone is behaving selectively. More specifically, even a mixed population with a small percentage of the population behaving selectively will never exist. Thus, a poacher would never adopt a selective strategy.

The only strategy that was proven to be stable is the indiscriminate one. Moreover, it was proven that to be evolutionary stable as well. Meaning, that for any given starting population, the poachers would start adopting an indiscriminating behaviour until the take over the population and that population would be robust. As shown in Fig. 5.
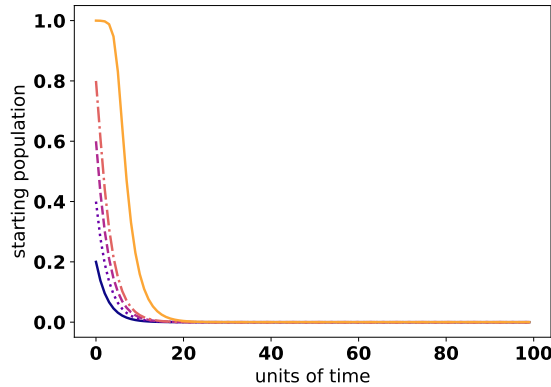

Figure 5:   The change of the population over time with different starting populations. For values, $F = 5, H = 50, r = 0.65, \alpha = 2, \beta = 2, \gamma = 1, \theta_r = 0.6$.

Poachers behaving indiscriminate is an undesirable case and the life of wild rhinos cannot be secured by dehorning. Our results disagree with the claim of Milner-Gulland and Leader-Williams (1992) that managers should dehorn as many rhinos as possible. We believe that the money of the wild farm so be assigned to security. Also we believe that new modern methods such as using drones for scouting the area [4]('The use of drones in rhino conservation') should start being adopted instead of devaluating methods.

References

[1] Tamsin E Lee and David L Roberts. Devaluing rhino horns as a theoretical game. Ecological Modelling, 337:73 – 78, 2016.

[2] Martin A Nowak. Evolutionary dynamics: Exploring the equations of life, 2006.

[3] J. Maynard Smith and G. R. Price. The Logic of Animal Conflict. <u>Nature</u>, 246:15 – 18, 1973.

[4] Save the Rhino. Save the rhino: Rhino conservation.