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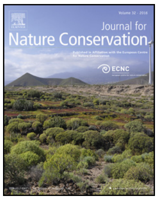

Does a reduction in the price of rhino horn prevent poaching?

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ABSTRACT

Rhino poaching around the world has increased inordinately, to the extent that concerns exist over the possible survival of the species. An open access rhino poaching model is developed for South African rhino. The model is a hybrid dynamical model, as both a system dynamics model as well as a Bayesian network model are developed. The system dynamics model is used to estimate the unknown parameter values (through optimisation) and also to determine the intervals for the parameters. These intervals are then used in the Bayesian Belief Network model to assess uncertainty. Hybrid approaches improve the ability to validate models compared with conventional modelling. The resultant model indicates that reducing the price of rhino horn would not be effective at curbing poaching, unless poacher costs are also increased. However, increasing poacher costs is not a realistic policy option since these costs are largely beyond the control of decision-makers. The insensitivity of price to poaching effort has implications for methods proposed to reduce the value of rhinos, such as introducing synthetic rhino horn and the de-horning of rhinos.

1. Introduction

Poaching of African rhino have increased immensely in recent years, threatening the very survival of the species. Data from CITES' 16th meeting of the Conference of the Parties in Bangkok, Thailand in 2013 (CITES 2013a, 2013b) paints a grim picture of the situation. Poaching has grown, on average, by 52% per annum for the period 2006–2012. One reason for the high incidence of poaching in South Africa is the relative abundance of rhinos in that country. The vast majority (90%) of all African rhino are poached from South Africa. At the end of 2012, the African white rhino (*Ceratotherium simum*) population comprised 20,405 individuals and the African black rhino (*Diceros bicornis*) comprised 5055 individuals. South Africa's rhino population comprises approximately 93% and 40% of the total white and black rhino populations, respectively. Another reason for the high poaching incidence in South Africa is the vast areas under conservation. The Kruger National Park alone spans 20,000 km^2, which is roughly the size of Wales (Markham, 2014). This makes patrolling very difficult. In spite of these alarming statistics pointing to a major poaching problem, very little modelling work has been conducted to understand wildlife/poaching dynamics in South Africa.

A number of approaches have been proposed to lower the price of rhino horn, arguing that this would eliminate the incentives to poach rhinos. These include the introduction of synthetic rhino horn as a substitute for real horn (Ball, 2015), de-horning of rhinos (Millner-Gulland, 1993; Milner-Gulland, 1999). Other approaches include a shock stockpile offload, episodic auctions, incremental releases of small batches, or through a closely regulated cross-continental legalised supply chain. The argument is that these would devalue the rhino and reduce the incentive to poach. Lee and Roberts (2016) assess the effect of de-horning using game theory. They found that only if all rhinos were dehorned would the incentive to poach be reduced. However, this was a theoretical analysis and the effect of a lower price for rhino horn on poaching has not been assessed using actual poaching data. This research study examines the effect of a decreasing in the price of rhino (either through introducing synthetic rhino horn, dehorning or any other methods) on poaching behaviour, using data for South African rhino.

A modelling approach that has gained increased prominence in modelling wildlife systems is system dynamics modelling (e.g. Ford, 1999). There are, however, few applications to rhino. Swart, Hearne, & Goodman (1990) developed a model for black rhino in South Africa which mainly focusses on fecundity and population dynamics. Although it was primarily used to determine optimal offtake, it was nonetheless historic as it was able to predict a recovery of black rhino to a genetically viable population of approximately 2000 individuals over 30 years, which is more or less the situation prevalent today. Crookes and Blignaut (2015) developed a system dynamics model for market demand that considers rhino

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populations, game farms and consumer demand. The model did not, however, explicitly model poaching behaviour. Crookes and Blignaut (2016a) found that policies aimed at the management of protected areas were more likely to be effective in the management of rhinos. Therefore, this study aims to examine in greater depth the conditions under which rhino populations may persist, by looking at a number of policy tools that aim at influencing poacher behaviour. These policy tools include: policies that affect the price of rhino horn, the costs of poaching, and enforcement policy tools such as the policies that influence the probability that a poacher is detected and convicted, and the magnitude of the fine.

It is important to take uncertainty into account when modelling and understanding the dynamics of ecological and economic systems (Bunnefeld, Hoshino, & Milner-Gulland, 2011). This study applies two methods to assess parameter uncertainty in the data. First, Monte Carlo simulation is used to define the interval boundaries of the study. This is conducted in the system dynamics software Vensim (Eberlein & Peterson, 1994). Second, these interval boundaries are used in a Bayesian Belief Network (BBN) model to assess the effect of parameter uncertainty on the outputs of the model. The BBN model is constructed using the software package Netica (Norsys Software Corp., 1997). In this sense, although the two models are distinct, data from the systems model is used as input into the BBN model, and vice versa. The model is, therefore, a hybrid dynamical system, as both continuous and discrete dynamic behaviour is captured (Goebel, Sanfelice, & Teel, 2009). The system dynamics model employs continuous (feedback) dynamics, and the BBN model incorporates discrete probability nodes. In the next section the hybrid SD/BBN model is presented along with the steps in the modelling process.

2. Methodology

2.1. System dynamics model

System dynamics modelling is an approach that simulate the behaviour of complex systems over time, with feedback loops and time delays characterising the interactions of the system. It is important to model feedbacks in conservation systems given the propensity of these systems toward counterintuitive behaviour (Larrosa, Carrasco, & Milner-Gulland, 2016). Eqs. (1) and (2) indicate the feedback dynamics of the system, which follows a predator-prey specification. These dynamics could be analysed in an excel spreadsheet. However, there are a number of reasons for analysing these two equations in a system dynamics modelling platform such as Vensim. First, it provides a visual display of the interactions between the different elements in the system which is called a stock flow diagram. Second, it enables the comparison of the model with actual data and facilitates calibration of the model with actual data. Statistical tests may then be performed on goodness of fit. Thirdly, a number of validation techniques may be employed on the model, for example dimensional (unit) consistency tests, behaviour reproduction and sensitivity analysis. It would not be possible to conduct the full range of validation tests on a spreadsheet model.

The system dynamics modelling framework makes it possible for the model to be interrogated in order to answer "what if"-type questions (Butterworth, Plag&nyi, Robinson, Moosa, & De Moor, 2015). This is done in two ways. First, the Synthesim^{TM} mode enables real-time analysis of the effects of changes in the different parameters on the model. This enables one to evaluate different ranges in parameters without having to enter values discretely. Second, Monte Carlo simulation may be used to conduct a sensitivity analysis on a range of management parameters, such as the probability of detection and conviction, the magnitude of the penalty, the poaching costs and the price of rhino horn on poaching behaviour, and ultimately what the impact would be on the persistence of rhino populations. These two approaches are fairly novel in system dynamics applications focussed on wildlife population modelling (see Crookes, 2012, 2016). Last, only model results need to be exported to excel for further analysis.

The Gordon-Schaefer model is not the only framework used by system dynamics modellers in wildlife population modelling. In South Africa, Swart et al. (1990) use an age-structured density-dependent model for rhino. Although the Gordon-Schaefer model is common in the wildlife literature (e.g. Leclerc, Bellard, Luque, & Courchamp, 2015), its suitability will be assessed by examining how well it is able to replicate the historical data. In the next section the Bayesian Belief Network framework is presented.

2.2. Bayesian belief network model

BBNs and SD modelling are both decision-support systems (DSS) used to model uncertainty (Cain, 2011). Netica is a probabilistic graphical model that uses the junction tree algorithm to obtain posterior distributions over hidden variables (Korb & Nicholson, 2010). It uses Bayes' rule for updating the distribution over parameters from the prior to the posterior distribution.

Vensim and Netica are similar in that both are used to model complex systems, and both are examples of decision support tools. Vensim uses Monte Carlo simulation by means of the Latin Hypercube sampling methodology. But the Bayesian inference is a more exact method of estimating uncertainty than Monte Carlo sampling (Cain, 2011). Also, in a BBN model, a range of prior distributions may be defined and its effect on the posterior distribution assessed. Netica is used for undirected networks and it is therefore not possible to include feedback in the model.

The approach adopted here is to use Monte Carlo simulation in the system dynamics package to define the boundaries of the different parameters, which are then converted into intervals in the Bayesian Belief Network (BBN) model. A steady state version of the model was then constructed for use in the BBN. The results of the BBN model were used to further validate the model, and also used for policy simulations.

2.3. Steps in the modelling process

This section presents the steps in the modelling process, with reference to the framework proposed by De Wit and Crookes (2013). These steps are based on a more generic systems analysis framework suitable for a variety of model types and draw from the natural resource management literature. The steps are the following:

1. Model conceptualisation – model and subcomponents are described and discussed
2. Model quantification – important empirical relationships underpinning the model are presented
3. Model evaluation – model validation is presented on the key relationships in the model
4. Model use – the model is used to estimate the value of unknown parameters and also to answer the research question
5. Improving system performance – revisit some of the key assumptions of the model and make recommendations on the way forward

2.3.1. Model conceptualisation

The model is based on two strands of literature: predator-prey literature and open-access fisheries literature.

A predator-prey model is developed using system dynamics modelling employing a Gordon-Schaefer fisheries model. This model is based on Nobel laureate Gary Becker's theory of crime