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Stochastic Analysis of the Viability of the Oryx *(Oryx leucoryx)* Population in *Mahazat Assaid*, Saudi Arabia

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Abstract. This study is concerned with using the stochastic analysis in determining the risk of extinction facing the Oryx, *Oryx leucoryx*, population in *Mahazat Assaid.* It shows that the application of stochastic methods in biogeographical and conservation studies through the use of Monte Carlo Simulation methods makes it possible to determine the risk of extinction of threatened species. The risk that the Oryx is facing under current management conditions is found to be minimal. However, simulating the risk faced without management reveals that the species would be in a state that the IUCN (International Union for the Conservation of Nature) regards as vulnerable.

Introduction

Maintaining viable populations of rare species is a primary goal of conservation biology (Soulé, 1987), as rare organisms that live in variable environments are thought to be at the greatest risk of extinction (Menges, 1992).

To set a framework for the study of endangered species the International Union for the Conservation of Nature (IUCN) in 1994 defined different levels of extinction and revised these definitions in 1996. They are listed below in descending order of urgency.

1) Species that are labelled '*extinct'* are those that are no longer known to exist. Despite thorough and repeated searches of known and possible sites the species could not be found.

2) Species that are labelled '*extinct in the wild*' are now only found in cultivation, captivity or as naturalized populations well outside its original range. The species is no longer found in its known localities.
3) '*Critically endangered'* species are those with an extremely high risk of going extinct in the wild in the immediate future. Species whose numbers of individuals have been in decline and are so small that given the present trend survival of the species is unlikely are of particular concern. These species have a 50% or greater probability of extinction within 10 years or three generations, whichever is longer.
4) '*Endangered*' species are defined as species that have a high risk of extinction in the wild in the near future and where the possibility of becoming critically endangered exists. They have a 20% probability of extinction within 20 years or five generations.
5) Species are categorized as '*vulnerable*' if they have a high risk of extinction in the wild in the medium term future and if they may become endangered. Their probability of extinction within 100 years is at least 10%.
6) Species that are defined as '*conservation-dependent'* are not currently threatened. However, their survival depends on a conservation programme that is essential to prevent the extinction of the species.
7) Species that are close to being considered 'vulnerable' but are not currently deemed threatened, are categorized as '*near threatened'*.
8) Species that are neither considered 'threatened' nor 'near threatened' are of '*least concern'*.
9) Due to '*deficient data'* it is in many cases impossible to ascertain the risk of extinction for the species.
10) Species that have not yet been assessed for their threat level are categorized as '*not evaluated'* due to the lack of information.

Extinction presents a challenge to those who work in conserving biological species as intervention only occurs when the numbers of a species go below a critical value. Due to small numbers mistakes in conservation policies can lead to the eradication of the species that is to be conserved, as Darwin (1859) already pointed out that those species that are only represented by a few individuals will, during fluctuations in the season or in the number of its enemies, be very likely to go extinct.

For the protection of the species it is necessary to know the smallest number of individuals required to save the species from extinction. In order to do that conservation biologists use a tool called PVA (Population Viability Analysis) developed by Shaffer (1981 and 1987), which helps in the development of recovery plans by assessing the likelihood of an endangered species to be sustained with the implementation of a specific restoration plan.

It is necessary to consider what factors contribute to a species going extinct in order to be able to determine a minimum viable population (Shaffer, 1981). Shaffer (1981) identifies four kinds of variation or stochasticity that can be involved in this process. These are, firstly, demographic stochasticity reflecting random variations in birth and death rates. Secondly, genetic stochasticity concerned with the importance of inbreeding and the loss of genetic variation. Thirdly, variations in weather and biotic factors as causes for species decline are reflected in environmental stochasticity. These three factors have a continuous impact on all populations. In a natural population the viability of the Oryx *(Oryx leucoryx)* would be affected by these kinds of variation. However, there is a fourth factor that occurs irregularly. This fourth kind of variation is known as natural catastrophes which could take the form of floods, fires and volcanic eruptions. These factors explain the likelihood of populations going extinct due to chance. Shaffer (1981) also shows that sometimes extinction is deterministic, *i.e.* it is brought about by some inexorable change from which there is no escape, *e.g.* deforestation or glaciation, representing the loss of habitat or of essential resources.

Objectives

The objective of this study is to determine the viability of the oryx *(Oryx leucoryx)* population that went extinct in Saudi Arabia was reintroduced in 1987, and released into the wild 1990. The case study, which this paper is concerned with, is the oryx *(Oryx leucoryx)* population in the *Mahazat Assaid* reserve, so, the study aims to:

1) calculate the probability of the survival of the oryx *(Oryx leucoryx)* population taking into account the random variation of demographic factors in time and space.
2) build a working model to represent the threat facing the oryx *(Oryx leucoryx)* populations.
3) prove that PVA can be used as an effective tool in formulating conser- vation policies.

The Study Area

In 1987 the National Committee for Wildlife, Conservation and Development (NCWCD) set aside three areas for conservation. One of them is *Mahazat Assaid* (Fig 1). It was chosen with the purpose of reintroducing the oryx *(Oryx leucoryx)*. The reserve is situated on the Western side of Saudi Arabia, 175 km north east of Taif (between a latitude of 21°57’56” and 22°21’48”N and between a longitude of 41°32’56” and 42°15’17”E). The total area of the reserve is 2190 km^2, with a circumference of 220 km, making it the largest fenced nature reserve in the world.

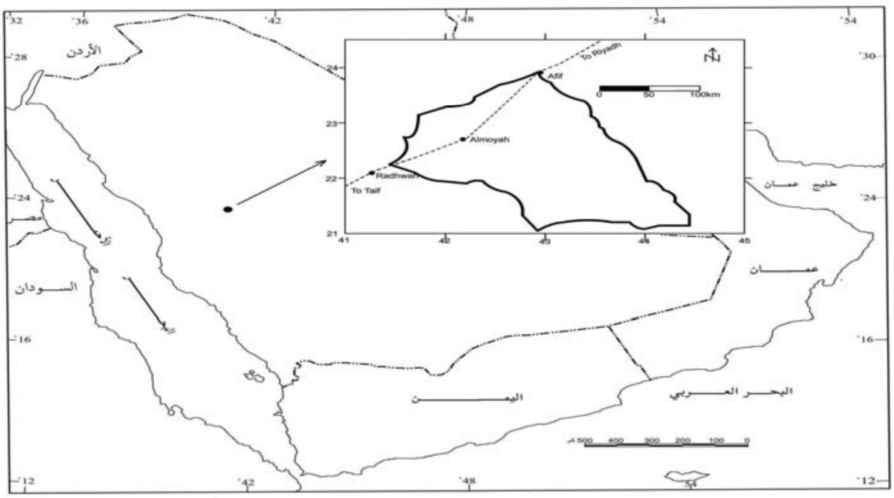

Fig. 1. The location of the study area *(Mahazat Assaid)*.

The altitude of the area varies between 980 m and 1036 m with a slope of 0.09 % in the south-north direction (Launay 1990). The elevated areas are mainly situated in the west-northwest parts. There are two further mountains, one in the southern part of the reserve with an altitude of 1036m, the other one in the centre of the reserve with an altitude of 1013m. The essentially basaltic reliefs (from Precambien basement, which consist of crystalline and metamorphosed rocks) are poorly accentuated. The surface of *Mahazat Assaid* is predominantly sandy (96.33%) with some basalt (3.65%) and other rocks, *e.g.* quartz (0.05%). In the centre there are two low areas with a salty top layer.

Human pressure has been very significant in *Mahazat Assaid*. 3.9% of the total area are covered by tracks, representing nearly half of the vegetation surface. The northwest-southeast axis between Al Muwayh and Al Khurmah has been particularly affected by this.

The vegetation of the study area was described by Launey (1990) as rather poor, with 111 species distributed in 91 genera. The number of families is rather small with 38. The most common genera are *Stipagrostis* (5 species) and *acacia* represented by 4 species (Gillet, H. and Launay, C. 1990).

The Oryx (*Oryx leucoryx*)

The Arabia or white oryx *(Oryx leucoryx)* belongs to the family of horse-like antelopes, the Hippotragini. It is of uniform white colour, with the lower limbs in brown to black. At birth the colour is brown for camouflage and changes to white at the age of 10 months. Facial markings are very typical with a black bar through the eyes merging with a triangular patch of black below the ear and following the line of the jaw. The body length lies between 140 and 180 cm, the shoulder height between 90 and 120 cm. The tail has a length of 19 to 25 cm. Very long horns (50-70 cm) are found in both sexes, 2/3 of which are straight, the remainder curved backwards. The adult male is somewhat heavier than the female, with 65 to 75 kg and 54 to 70 kg respectively, but the general appearance of the sexes is very similar (Stanley Price, 1989).

The Arabian oryx (*Oryx leucoryx*) is known to live in various desert types, *i.e.* sand dunes, stony plains and *wadis* which represent hotter and drier habitats than that of any other oryx (*Oryx leucoryx*) species.

Methods

Data for demographic analysis requires detailed information about births, deaths, immigration and emigration. Data for the demography was obtained from the National Committee for Wildlife Conservation and Development (NCWCD) up to the end of the year 2000, as it was found that sufficiently detailed information was only available up to that year.

To estimate the viability of the oryx *(Oryx leucoryx)* population a Monte Carlo simulation was used by writing a code in the program MatLab. In this program random numbers were generated in large replicates (15000) taking into account the law of large numbers to simulate the growth rate of the oryx *(Oryx leucoryx)* population. For the purpose of this simulation a determination of μ and σ^2 has to be performed, where μ is the mean of the log of the population growth rate and σ^2 is the variance of the log of the population growth rate. To achieve this, the method developed by Dennis *et al.* (1991) was adopted. The basic idea of this method was to take a pair of counts from the census, N(i) and N(j), from the years t(i) and t(j), respectively. From these two variables, x and y, are calculated where

$$x = \sqrt{t(j) - t(i)}$$

and

$$y = \ln(N(j)/N(i))/\sqrt{t(j) - t(i)}$$

(N) being the population number, (t) being the time.

From the resulting variables, x and y, a linear regression of y on x was performed, forcing the regression line to have a y-intercept of zero. This is done to enforce the rule that no change in population size is possible if no time has elapsed. The slope of the resulting regression line was used as an estimate of the parameter μ. The mean square residual from the regression analysis was used as an estimate of the parameter σ^2 (Dennis *et al.*, 1991). The regression procedure allows the placement of confidence limits on the parameters and to test assumptions for the underlying model. The underlying assumption of regressions is that variances are equal. To achieve this, we need to get rid of the time dependence by transforming the rate of population change and also the time elapsed. This is done by dividing both the log population growth rate and the time elapsed by $\sqrt{t(j) - t(i)}$, thereby making an equal variance for any time interval.

The simulation procedure mentioned above measures the risk of extinction of the oryx (*Oryx leucoryx*) population by calculating the cumulative distribution function (CDF) of extinction time.

$$G\left(T\middle|d,\mu,\sigma^2\right)=\phi\left(\frac{-d-\mu T}{\sqrt{\sigma^2 T}}\right)+\exp\left(-2\mu d/\sigma^2\right)\phi\left(\frac{-d+\mu T}{\sqrt{\sigma^2 T}}\right)$$

Where $\phi(z)$ (phi) is the standard normal cumulative distribution function

$$\phi(z)=\left(1/\sqrt{2\pi}\right)\int_{-\infty}^{z}\exp\left(-y^2/2\right)dy$$

(Dennis *et al*., 1991; Lande ad Orzack, 1988)

The parameters needed for the simulation were

1) μ, σ^2 and the 95% confidence interval of μ, which are determined by the regression procedure (see above)
2) the 95% confidence interval of σ^2 is given by the following equation

$$\left((q-1)\hat{\sigma}^2/\chi^2{}_{0.025,q-1,}(q-1)\hat{\sigma}^2/\chi^2{}_{0.975,q-1}\right)$$

where (q) is the number of data points.

3) The extinction threshold should not be zero. For the purpose of this simulation it was set to 25% of the current population.
4) The distance to the extinction threshold (d) is calculated by the equation:

$$d=\log\left(N_c/N_e\right)$$

Where N_c is the number of the current population and N_e the extinction threshold.

5) The number of years (T) for which the simulation should be run was set to 50. This was thought to be a meaningful time span for informed decisions in the management of the reserve.
6) The carrying capacity (K) for the reserve was estimated by the NCWCD to be 500, as this was thought to be the maximum number of oryx the reserve could sustain.

Result and Discussion

Since in natural populations losses through the death or emigration of individuals hardly ever match gains from the birth or immigration of others, these kinds of populations are not stable over time (Begon *et al.*, 1990). If populations decline for extended periods of time due to larger mortality than birth rates and a significant extinction risk results, it may be necessary to protect species.

Figure 2 shows the change in the size of the oryx *(Oryx leucoryx)* population in *Mahazat Assaid,* increasing steadily from 30 individuals in 1990 to 413 in 2000, getting close to the carrying capacity of the reserve.

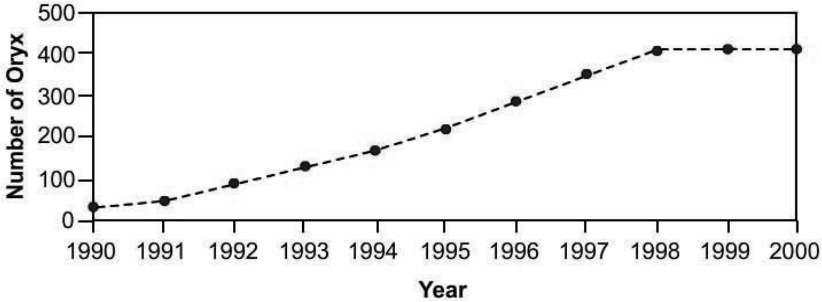

Fig. 2. Number of oryx in *Mahazat Assaid* reserve from 1990 - 2000.

The annual population size of the oryx *(Oryx leucoryx)* between 1990 and 2000 is not always the result of an actual count but in some instances of an estimate. It was thought that the regression analysis would be suitable for estimating the parameters μ and σ^2 for this type of data, as this method was recommended for situations where censuses are not taken at equal time intervals. This was the case in this study where real counts were taken irregularly.

Estimating the parameters μ and σ^2 by performing a regression analysis indicated that the slope of the regression line, which gives an estimate of μ, is 0.262 and the regression's error mean square, which gives an estimate of σ^2 is 0.036 (see Table 1).

Table 1. Estimated growth parameters (μ and σ^2) for the oryx population in *Mahazat Assaid*.

μ	0.262
σ^2	0.036
μ lower 95% confidence level	0.127
μ upper 95% confidence level	0.398
p-value (probability value)	0.002

It should be noted that the p-value (probability value) in the ANOVA table (see Table 1) showing the significance of the regression is not important in this context, as the purpose of using a linear regression here is to find the best-fit values of the parameters μ and σ^2 for the given data and not to test any particular hypothesis. The regression has another advantage, which is to detect outliers, *i.e.* years of unusually high population growth or loss.

The results of the regression analysis show a strong negative relationship between the population size and the growth rate of the population. This indicates that the population size is governed by density dependence (see Fig.3; Table 2), which means that a change in the density of the oryx population allows prediction of a change in its demographic parameters such as birth, death, immigration and emigration rates.

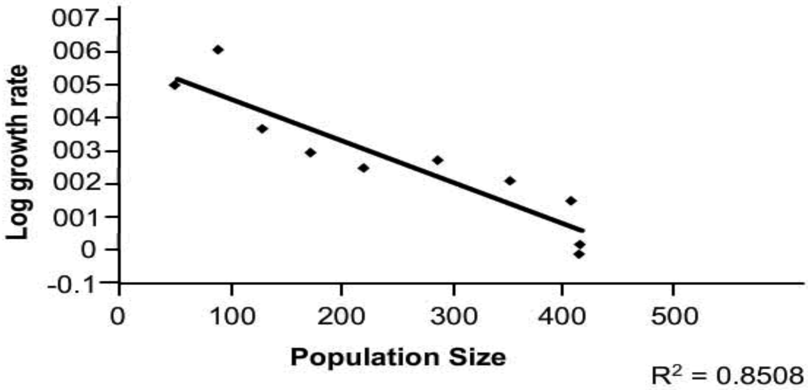

Fig. 3. The impact of density dependence on the growth rate of the oryx.

Negative density dependence means that the growth rate depends negatively on population size. According to Ginzburg *et al.* (1982) and Burgman *et al.* (1993) density dependence strongly influences the risk of extinction, because fecundity decreases as the population increases. This means that the larger the population gets, the slower it will be able to reach those numbers where extinction is not a threat.

Table 2. Results of the regression analysis for the impact of population density dependence on the growth rate of the oryx.

$R^2 = 0.8508$						
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	1	0.273903	0.273903	45.61925	0.0001444	
Residual	8	0.048033	0.006004			
Total	9	0.321935				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.57558	0.052467	10.97026	4.23E-06	0.45459	0.69657
X Variable 1	–0.00124	0.000184	–6.7542	0.000144	–0.001663	–0.00082

Durbin-Watson test was used to test for the existence of temporal autocorrelation in the population growth rate, *i.e.* whether environmental conditions (and thus population growth rates) are correlated from one inter-census interval to the next. (see Draper and Smith 1981 for further details). The calculated d-value of the Durbin-Watson test was 0.303, d_L 0.92, d_U 1.28. The test shows no conclusive evidence of the existence of significant autocorrelation.

The result of the simulation shows that the probability of extinction for the oryx*, (Oryx leucoryx)* population in *Mahazat Assaid* within the next 50 years is about 0.0002, *i.e.* it is very remote. This simulation assumes that the management is unchanged and the oryx*, (Oryx leucoryx)* population is kept below the carrying capacity of its habitat, and that the survival is kept constant at 0.90 (see Fig.4).

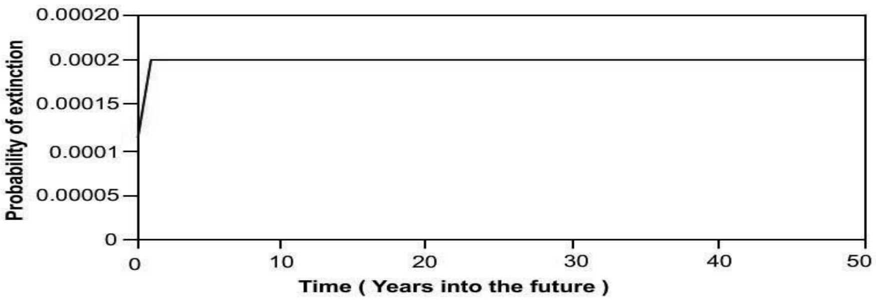

Fig. 4. The probability of the oryx population reaching the extinction threshold under current management.

The simulation was run again with a reduced level of management. Density dependence was allowed to be the main factor controlling the population, *i.e.* the oryx*, (Oryx leucoryx)* population was allowed to exceed the carrying capacity of its environment thereby leading to a reduction in numbers through a lack of resources rather than through management. The survival rate was determined randomly. The chance of extinction under these conditions dramatically went up to nearly 17%. This would put the oryx*, (Oryx leucoryx)* population into the category of ‘vulnerable species’, which the IUCN defined as those species with a 10% or greater probability of extinction within 100 years (IUCN, 1994, 1996). (see Fig. 5 and 6).

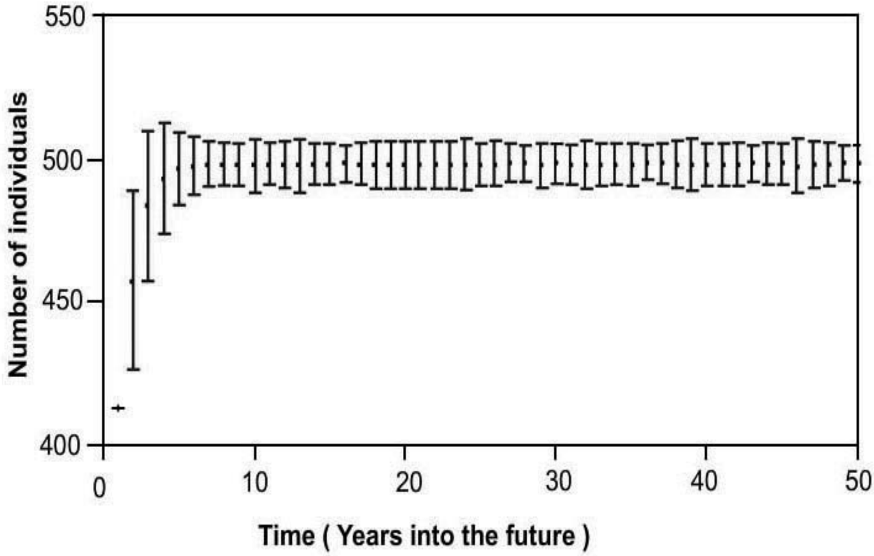

Fig. 5. The size of the oryx population under current management conditions in *Mahazat Assaid*.

Conclusion

The study shows that the oryx*, (Oryx leucoryx)* population cannot be left without management for the time being. This is supported by the experience of reintroducing the oryx*, (Oryx leucoryx)* in Oman which, while initially very successful with numbers increasing from an initial 10 individuals in 1982 to more than 400 in 1996, saw a reduction in numbers to 138 animals in 1998, which is a level at which the population is not considered viable any more (Spalton *et al.,* 1999). The reduction in numbers was mainly due to poaching (illegal hunting), this belonging to the fourth kind of variation that Shaffer (1981) has identified, which, though less frequent in governing the viability than the other factors, is the determining one in this case. These results show that a more protective level of management and a greater involvement of local people would have been required to save the Oryx *(Oryx leucoryx)* from going extinct in the wild for the second time.

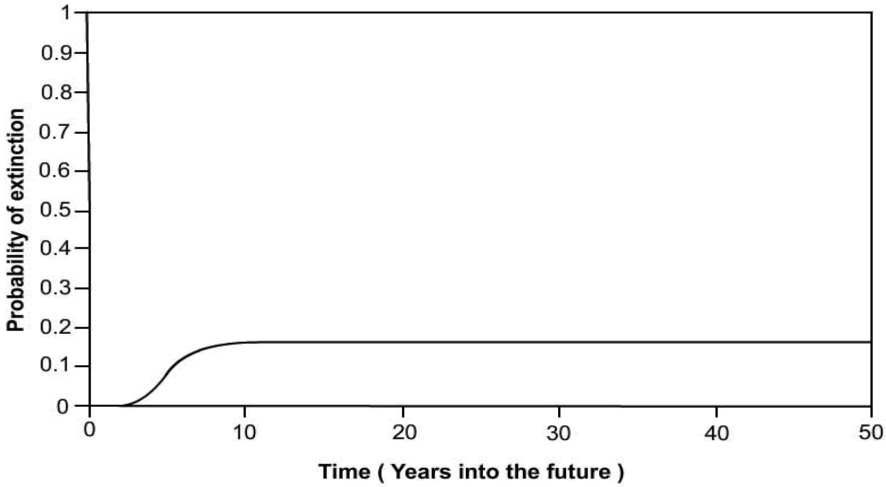

Fig. 6. The probability of oryx reaching extinction threshold without management.

The study shows that the goal of management is to find out whether intervention is likely to reduce the likelihood for the oryx population to go extinct. Since the ability to understand population dynamics and to predict the future is limited, there is a need for tools and methods that aid the understanding of the population viability. By bringing together diverse quantitative information stochastic models can enhance the understanding and allow making predictions about the future risks of extinction faced by populations. The usage of these methods is not restricted to forecasts about populations for which data exist. It is furthermore possible to use the analyses of well documented populations as a help in assessing the viability of less well studied populations and species.

Thus, one can say that in order to gain insight into the extinction risks faced by the oryx population and in order to formulate management policies that are based on this insight, stochastic models are an indispensable tool in the planning, conduction and evaluation of conservation policies.

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تحليل عشوائي لبقاء مجموعة مجموعة المها (*Oryx leucoryx*) في محازة الصيد بالمملكة العربية السعودية

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المستخلص. تهتم هذه الدراسة باستخدام طرق التحليل العشوائي في تحديد حجم خطر الانقراض الذي يهدد مجموعة حيوان المها *Oryx leucoryx* في محازة الصيد بالمملكة العربية السعودية. وقد أوضحت هذه الدراسة أهمية تطبيق التحليل العشوائي من خلال طريقة مونت كارلو في المحاكاة الحاسوبية في الدراسات التي لها علاقة بالجغرافيا الحيوية وحماية البيئة. وقد بينت نتائج هذا البحث أن حجم الخطر الذي يهدد حيوان المها بالانقراض كان محدودًا إذا تواصلت حمايته بنفس الطرق المتبعة حاليًا في منطقة الدراسة، وعندما استخدم أسلوب المحاكاة الحاسوبية في تحديد حجم خطر الانقراض الذي يواجه حيوان المها في حالة التوقف عن حماية وإدارة المنطقة التي يتواجد بها، تبين أن احتمالية انقراضه قد ازدادت بشكل كبير، لتجعل حيوان المها يصنف ضمن الحيوانات المهددة بخطر الانقراض حسب تصنيف الاتحاد العالمي لحماية البيئة.