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Population Viability Analysis on Kurd Horse Breed

Research Article

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ABSTRACT

The primary purpose of this research was to investigate the current status of the Kurd horse population and provide information for the conservation and development programs for this breed. To check the current status of the population, after collecting demographic data, demographic, genetic, and geographical criteria were examined in the four endangerment assessing systems of the Food and Agriculture Organization (FAO), European Union (EU), European Federation of Animal Science (EAAP), and private organizations. The results showed that, based on geographic and genetic criteria, this breed is not at risk of extinction. However, owing to demographic criteria, it is in a vulnerable or transitional state. The scenario of future dynamics of the population assuming the continuation of existing conditions was simulated to provide the information required for the conservation and extension programs. For conducting population viability analysis (PVA), Vortex simulation program version 10.5.6 was used. Besides collecting demographic information, the simulation required parameters that were collected via the available resources and interviews with horse owners during the years of the project implementation. The future dynamics simulation of the population showed that assuming the continuation of existing conditions, the Kurd horse population will have an increasing trend in the next 25 years with a mean growth rate of 0.0648 ± (0.0638) before reaching its carrying capacity. The genetic diversity and inbreeding of the population also had slight changes at the end of the simulation. In this research, the mortality of foals, percentage of adult breeding females, and crossing with other breeds had the highest effect on population viability measures, respectively. The results of this research prepare a suitable framework for providing a conservation and development program.

KEY WORDS endangerment criteria, future dynamics simulation, Kurd horse, population viability analysis, viability measures.

INTRODUCTION

The hilly areas of western Iran are the primary source of the Kurd horse, one of the Iranian horse breeds. Despite having its main origins in the western provinces of Kurdistan, Kermanshah, West Azerbaijan, and Ilam, which are home to the majority of the Kurdish population, the Kurd horse is now found throughout most of the country, particularly in the western and central provinces. There are currently 3800 or so Kurd horses in the nation, according to research done for the Kurd horse monitoring and registration project (Bahmani, 2022b). The Kurd horse is a medium-sized horse with a compact and muscular body, strong bone structure, and a well-proportioned body. This horse has a robust neck, muscular shoulders, and a broad chest. In Kurd horses, the neck and tail are raised, and the mane and tail are bushy. The anterior and posterior movement organs of the Kurd horse are proportional and robust so that the horse can pass through mountainous and rocky areas without any problems. The Kurd horse's physical attributes and abilities make it an excellent choice for sports like polo, dressage, and especially free riding. Kurd horses are boisterous and lively, yet they are also trainable and well-behaved. In other words, they ride with great energy while remaining highly calm in the horse stables. Compared to the horses of the Darehshori and Turkmen, this breed is less graceful and larger than the Caspian horse (Yousefi-Mashouf *et al.* 2020; Bahmani, 2022b).

Horse breeding has a long history in the country. Kurd horse breeders are often wealthy owners and use horses for riding or sports. Great interest in horse breeding and the socio-cultural role of Kurd horses in Kurdish society are the main reasons for their persistence (Bahmani, 2022b). For many centuries, breeders of horses have kept them pure. Unfortunately, with the change in the attitude of horse breeders, crossing between different horse breeds has recently increased. This problem requires responsible organizations and breeders to take adequate measures to conserve the horse's genetic resources. Livestock have great socio-economic and cultural value in various societies around the world. Gandini *et al.* (2004) have mentioned the social and economic value of local livestock breeds for rural communities, their contribution to the management of agroecosystems, and the maintenance of rural cultural diversity. Some animals, particularly indigenous horse breeds, provide a window into the culture and history of the country that produces them. For instance, the Turkmen horse represents the history and culture of the Turkmen people, as is the Canadian horse, which has been designated as the country of Canada's national horse. The history and culture of the Kurdish people include the Kurd horse.

Population viability analysis (PVA) includes quantitative analysis methods that specify population extinction probability. The most appropriate definition for PVA is the usage of quantitative methods to estimate the viability probability of a population under a selected model of population dynamics, a defined set of environmental and biological parameters, and suppositions about human actions and their effects on the system (Lacy, 1993; Lacy *et al.* 2021). PVA has two characteristics. It is a model to explain the process of extinction and quantify threats to population existence. It starts with modeling the extinction process (Clark and Seebeck, 1990). Population viability analysis can provide a framework for integrating needed knowledge into species conservation efforts by assessing multiple factors that threaten the population's existence (Lindenmayer *et al.* 1993). Population viability analysis of endangered wildlife populations has been widely carried out for different reasons (Lindenmayer *et al.* 1993; Brook *et al.* 2000; Slotta-Bachmayer *et al.* 2004). In livestock populations, this type of analysis has been used in fewer numbers and less than in wild animals (Bennewitz and Meuwissen, 2005; Al-Atiyat, 2009; Thirstrup *et al.* 2009; Al-Atiyat *et al.* 2016; Hertz *et al.* 2016; Gharedaghi, 2019; Bahmani, 2022a).

Vortex is an individual-based simulation model used to conduct PVA. It clarifies the impacts of deterministic and random, i.e., demographic, environmental, and genetic effects on the population dynamics (Lacy and Pollak, 2021). Vortex models population dynamics as discrete, sequential events (e.g., births, deaths, catastrophes, *etc.*) that occur according to defined probabilities. The preparation of this software is an attempt to model extinction elements that can threaten small populations' existence. By simulating the transmission of alleles from parents to offspring at a hypothetical neutral genetic locus, the software models the loss of gene diversity in a population. Vortex monitors remained alleles within the population, and the mean expected heterozygosity relative to the initial values. Vortex also models the effects of inbreeding depression by monitoring the inbreeding coefficients of each animal and its reduction in inbred animals. To model the total effects of inbreeding, vortex uses two effects of recessive lethal alleles and loci at which there is a heterozygote advantage. Therefore, each founder begins with a dominant non-lethal allele and a recessive lethal allele at up to five modeled loci (Lacy and Pollak, 2021).

So far, the conservation program for horses and none of the endangered livestock breeds in the country has not been developed and implemented. Demographic and biological information, population viability analysis, and their results can provide a suitable framework to prepare the Kurd horse conservation and development program. This research aims to investigate the biological parameters of the population (reproduction, mortality, *etc.*), threats and risks (demographic, geographic, and genetic) of the Kurd horse population, and its population viability analysis.

MATERIALS AND METHODS

Data collection

Two groups of information including demographic data, and parameters needed for assessing the current status of the population and the simulation model, were collected from the final report of the Kurd horse monitoring and registration project (Bahmani, 2022b), available sources, and questionnaires completed via interviews with horse owners. Information was collected from 78 experienced horse breeders who owned more than 500 Kurd horses and lived in Kurdistan, Kermanshah, West Azerbaijan, and Isfahan provinces from 2020 to 2022. The primary condition in selecting horse breeders was registering their horses as Kurd horses in one of the country's official authorities, i.e., I.R. Iran Equestrian Federation or Animal Science Research Institute of Iran.

Although the central provinces of Iran, such as Isfahan, have differences in climate compared to the western provinces, due to the exact origin of horses and similar management, there is no significant difference in Kurd horse breeding between them. Horses are usually kept in a stable, and horse riding and training are carried out in the area of the farm or boarding. They are commonly fed with forage and grains in stables 2 or 3 times daily. Information related to the breeding system, reproductive performance, survival and mortality in different age and sex groups, limitations and problems of breeders, and information about events and threats to the population's survival were the most critical data collected to form assumptions and estimate biological parameters.

Endangerment criteria

The demographic data of population size and number of breeding males and females, were used to calculate the effective population size and the rate of inbreeding in each generation. The effective population size (Ne) was estimated by considering the number of breeding males (Nm) and females (Nf) using equation (1), and the minimum inbreeding rate (ΔF) was calculated using equation (2) (Wright, 1931; Falconer, 1989).

$N_e = 4\ N_m\ N_f\ /\ N_e + N_f$ Equation 1

$\Delta F = 1\ /\ 2\ Ne$ Equation 2

The traits mentioned above and the population distribution to investigate three demographic, geographic, and genetic criteria in the four assessing systems: (a) Food and Agriculture Organization (FAO) (Henson, 1992; Scherf, 2000), (b) European Union (EU) (European Communities, 2002), (c) European Federation of Animal Science (EAAP) (Simon, 1999; Gandini *et al.* 2004) and (d) private organizations (Alderson, 2009) were used.

Simulation scenario

The future dynamics of the Kurd horse population in the next 25 years (from 2022 to 2047) was simulated using the population viability analysis model of the Vortex modeling program version 10.5.6 to check the survival of the population in the future. In this scenario, it was assumed that under the current management, the herds would continue to live, and no conservation program would be implemented. The modeling exercise required a set of parameters and assumptions to describe the biological characteristics and stochastic events of the Kurd horse dynamics. The parameters and assumptions that the population may experience in the coming period are summarized in Table 1.

In this scenario, 1000 “runs” were used to generate different distribu tions of fates that the population might experience (Figure 1). To avoid excessive overlap of lines related to different fates, the software only displays 100 replicates in Figure 1.

Table 1 The input parameters and assumptions used in the basic Vortex model for simulation of the Kurd horse population dynamics in the future

Input parameter/assumption	Value
Reproductive system	Polygynous
Initial population size	3800
Number of program’s runs	1000
Inbreeding depression?	Yes
Lethal equivalents	6.29
Recessive lethal	% 50
Environmental correlation between reproduction and survival?	Yes
Density dependent reproduction?	No
Age of the first offspring is born for male (year)	5
Age of the first offspring is born for female (year)	4
Maximum lifespan (year)	25
Maximum breeding age of female (year)	18
Maximum breeding age of male (year)	20
Maximum number of parturitions per year	1
Maximum litter size (foal)	1
Sex ratio at birth	(50% male,50% female)
Adult breeding females (%)	80
Females produce 1 progeny in a year (%)	100
Mortality of females between ages 0 and 1 (%)	20
Mortality of females between ages 1 and 2 (%)	10
Mortality of females after age 2 (%)	5
Mortality of males between ages 0 and 1 (%)	20
Mortality of males between ages 1 and 2 (%)	10
Mortality of males after age 2 (%)	5
Catastrophe: Competition of other breeds	
Frequency of occurrence (%)	100
Severity on reproduction (proportion of normal values)	0.85
Severity on survival (proportion of normal values)	1
Males in the breeding pool (%)	20
Carrying capacity	10000
Harvest?	No
Supplement?	No

In this scenario, inbreeding depression was considered. The software incorporates lethal alleles and other genetic mechanisms. In Vortex version 10, unlike the previous versions, lethal equivalents are assumed at 6.29 (O’Grady *et al*. 2006), and half of the inbreeding effects are due to lethal alleles that take into account the effects of inbreeding on the fertility and survival of the first year of individuals (Lacy *et al*. 2021).

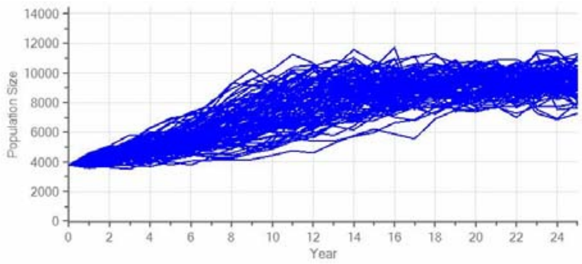

Figure 1 Simulation of the different destinies of the Kurd horse population in the next 25 years, from 2022 to 2047

In this research, contrary to the environmental correlation between survival and reproduction, the effect of population density on reproduction was ignored. Habitat carrying capacity for a specific population is described as the highest number of individuals that the habitat can support over time in the absence of unnatural interventions and the absence of adverse trends under the abundance of food resources needed for the population (MacNab, 1985).

Sensitivity testing of parameters

To investigate the effect of changes in each parameter on the viability measures of the population (extant population and stochastic growth rate) in the future simulation of the population, sensitivity testing of the Vortex was used (Lacy *et al.* 2021). In this analysis, each parameter is varied according to the defined range, while the other parameters remain fixed at the values of the base model (used in the future scenario). Therefore, according to the maximum, minimum, and defined interval in the range for each variable, about 106 simulations with 1000 "runs" were performed to do sensitivity analysis. Finally, it was determined which of the parameters and how they affect the viability measures of the population. Standardized spider plots of the software were used to determine the most important parameters affecting the investigated viability measures.

RESULTS AND DISCUSSION

The most critical vulnerability measures, including population size, number of breeding males and females, effective population size, and inbreeding rate for the Kurd horse population in 2022 are presented in Table (2). According to the basis defined by Scherf (2000), horse Kurd is not classified as an endangered animal because the population of breeding females in the country is more than 1000 heads, there is no significant decrease trend, and less than 20% of females are crossed with males of other breeds. According to another suggested method of the World Food and Agriculture Organization (FAO) (Henson, 1992), this breed is in a vulnerable state with a population between 1000 and 5000 heads, proper geographical distribution, and crossing of less than 20% of females with males of other breeds. The most critical problem of the demographic criteria proposed by FAO is not paying attention to the species and their differences concerning generation distance and fertility (Alderson, 2009).

Table 2 Population size (N), the number of breeding males (N_m) and females (N_f), effective population size (N_e) and inbreeding rate (ΔF) of the Kurd horse population in 2022

Year	N	N_m	N_f	N_e	ΔF
2022	3800	266	1900	933	0.0005

According to the European Union evaluation system, this breed is endangered since breeding females are less than 5000 heads (European Communities, 2002). Owners of horse breeds with such status in Europe use financial incentives.

Assuming the purity of 1900 heads of breeding females, the effective population size of (933) is much more than the base of (52) heads in the EAAP evaluation system. Even taking into account the possibility of the presence of some impure mares, as this breed has been bred in several herds across the country and is not in an unfavorable situation in terms of population changes and crossing with other breeds, it is not at risk concerning genetic criteria in the EAAP evaluation system.

The genetic variation begins to decrease at an accelerated rate once the Ne falls below 100. It was recommended to keep Ne more than 250 (Henson, 1992). Wright's (1931) equation has assumptions (such as random selection and Poisson distribution of progeny sizes) that do not occur in most livestock populations. Therefore, in populations in which selection is made, the level of inbreeding is likely higher than in unselected populations (Gandini *et al.* 2004). As a result, the calculated inbreeding rate (Table 2) provides a lower estimate than the actual value. Population viability analysis (PVA) in non-pedigree populations by simulating population dynamics using the PVA model results in a better estimate of inbreeding (Bahmani *et al.* 2015).

Some non-governmental organizations, including the rare breeds survival trust (RBST), use Alderson's plan (Alderson, 2009). Based on this plan, three demographic, geographic, and genetic criteria are considered to determine the degree of endangerment of the breed and place it in one of the five risk levels. Assuming the breeding females to be completely pure, the Kurd horse is placed in the last level of the five categories (Transitional) based on Alderson's demographic criteria (Alderson, 2009). Considering the number of breeding females between 1000 and 3000 heads, the significant distribution in the country, and the acceptable average of inbreeding in the next 25 years, the population of this breed is finally in a transitional state and should be periodically assessed.

According to different assessment systems, although the Kurd horse population is not at risk owing to geographical and genetic criteria, this breed is in a vulnerable or transitional state, concerning demographic criteria.

In this section, the results of the Kurd horse population dynamics simulation in the future and the possibility of its survival, assuming the continuation of the current management in the next 25 years, from 2022 to 2047, are presented and discussed. Population sizes (N), probabilities of extinction (PE), stochastic mean growth rates (rs), genetic diversities (GD), inbreeding coefficients (IC), and the mean number of extant alleles (A) of simulated Kurd horse population dynamics in the next 25 years from 2022 to 2047 are presented in Table 3.

Owing to defined assumptions and parameters (Table 1) and 1000 “runs” to reveal the distribution of fates that the population will experience, Table 3 and Figure 2 show that the population will have an increasing trend in the next 25 years with a stochastic mean growth rate of 0.0648 ± 0.0638 before reaching to its carrying capacity. Figure 3 shows that the population can reach its carrying capacity without stochastic factors with a deterministic mean growth rate of 0.0656. Before starting the simulation, the simulation program calculates the deterministic mean growth rate (rd) using a standard life table analysis (Krebs, 1994). This calculation provides an accurate long-term average in the minimal presence of stochastic variation (due to demographic stochasticity, environmental variation, catastrophes, and inbreeding effects). Life table analyses implicitly assume that age-specific birth and death rates are constant through time and there is no limitation of mates; they yield over-estimates of long-term population growth if there is any variation in demographic rates. The difference between the deterministic growth rate and the stochastic growth rate obtained from the simulation indicates the importance of stochastic factors as a threat to population persistence (Lacy *et al*. 2021). The slight difference between these two values shows the insignificant importance of stochastic factors in the population changes of Kurd horses. Stochastic factors are the main threat to population survival when populations have a declining trend and become significantly smaller (Bahmani, 2022a). In this research, the simulation of population dynamics in the future, with and without considering the effect of inbreeding, contained similar results. In other words, there was no difference in the population changes and viability measures considering the effect of inbreeding.

According to the population increase trend, the probability of extinction of the Kurd horse population after 25 years (proportion of 1000 'runs' of the program that end to extinction in the desired period) was zero at the end of the simulation. The existing concerns about the vulnerability of the population owing to demographic criteria, according to the biological parameters and assumptions examined in this research and the increasing trend of the population, are not significant, and the population can have an increasing trend with an acceptable mean growth rate until it reaches to its carrying capacity.

Empirically, the habitat carrying capacity for a given animal species could be estimated by calculating the total food supply appropriate for that species that is available in the habitat and dividing that value by the rate of that species’ consumption of its available food supply (Hobbs and Swift, 1985). Of course, we should not forget that the calculation of food resources available in the region and the amount of feed consumption in different physiological phases have many complexities and require to collection of a lot of accurate information. If detailed data are unavailable, a rough estimate of habitat carrying capacity can be generated using long-term data on population size (Lacy *et al*. 2021). Regarding the country's domestic horses, the decision about carrying capacity is possible considering the breeding system and taking into account the market situation and the effective socio-economic factors. It requires separate research. Considering the abundant desire for breeding and reviving Kurd horses on the one hand and the limitations of its breeding on the other hand, and since in former years, based on the opinions of the interviewees, there have been more than 10,000 Kurd horses in the country, in this research carrying capacity of this breed was assumed to be 10000 heads. Of course, this assumption could be less or more than this value.

Reality may differ from what is simulated. On the one hand, any change in the defined assumptions and parameters, and on the other hand, government policies and the critical role of breeders in maintaining or eliminating Kurd horse herds may significantly affect this process.

The genetic diversity (He) and observed homozygosity of the population had slight changes at the end of the simulation (Table 3). The first step in planning a development scheme in a breed, either for conservation or selection purposes, is to estimate the current state of diversity in the population and, more importantly, the predicted changes in the variation given the current size and use of parents. It is critical at very early stages to understand and analyze in which direction the variation is moving (Toro *et al*. 2011).

Several researchers, in different ways, have considered the critical value of inbreeding as 0.5% in each generation, which is equivalent to the effective population size of 100 (Meuwissen, 2009; Toro *et al*. 2011).

Table 3 Population sizes (N), probabilities of extinction (PE), stochastic mean growth rates (rs), genetic diversities (GD), inbreeding coefficients (IC) and the number of extant alleles (A) of simulated Kurd horse population dynamics in the next 25 years from 2022 to 2047 (mean and standard error)

Year	N	PE	rs	GD	IC	A
0	3800	0	0	1	0	7600
1	4060 (8.60)	0	0.0632 (0.0021)	0.9998	0	7019 (8.01)
2	4328 (11.58)	0	0.0639 (0.0021)	0.9998	0	6543 (9.80)
3	4626 (15.19)	0	0.0652 (0.0021)	0.9998	0	6173 (10.96)
4	4959 (18.39)	0	0.0647 (0.0020)	0.9998	0	5897 (11.64)
5	5300 (21.67)	0	0.0669 (0.0020)	0.9998	0	5674 (12.08)
6	5654 (24.48)	0	0.0681 (0.0020)	0.9998	0	5478 (12.30)
7	6049 (28.53)	0	0.0633 (0.0021)	0.9997	0	5307 (12.62)
8	6473 (32.60)	0	0.0651 (0.0020)	0.9997	0	5156 (12.78)
9	6889 (35.86)	0	0.0671 (0.0020)	0.9997	0	5017 (12.80)
10	7322 (38.06)	0	0.0633 (0.0020)	0.9997	0.0001	4891 (12.68)
11	7724 (39.59)	0	0.0677 (0.0020)	0.9997	0.0001	4770 (12.46)
12	8069 (38.68)	0	0.0652 (0.0020)	0.9997	0.0001	4651 (12.16)
13	8363 (37.56)	0	0.0637 (0.0021)	0.9997	0.0001	4534 (11.45)
14	8606 (35.64)	0	0.0650 (0.0020)	0.9996	0.0001	4418 (10.84)
15	8817 (32.86)	0	0.0666 (0.0021)	0.9996	0.0001	4306 (10.14)
16	8988 (30.84)	0	0.0620 (0.0019)	0.9996	0.0002	4195 (9.51)
17	9132 (28.44)	0	0.0671 (0.0020)	0.9996	0.0002	4088 (8.93)
18	9215 (27.24)	0	0.0642 (0.0020)	0.9996	0.0002	3980 (8.38)
19	9281 (26.36)	0	0.0641 (0.0020)	0.9996	0.0002	3872 (7.82)
20	9324 (26.51)	0	0.0645 (0.0020)	0.9996	0.0002	3764 (7.45)
21	9326 (25.58)	0	0.0682 (0.0020)	0.9995	0.0003	3676 (7.01)
22	9338 (24.98)	0	0.0635 (0.0020)	0.9995	0.0003	3594 (6.65)
23	9402 (24.97)	0	0.0639 (0.0021)	0.9995	0.0003	3517 (6.35)
24	9423 (25.16)	0	0.0613 (0.0021)	0.9995	0.0003	3440 (6.14)
25	9401 (24.53)	0	0.0626 (0.0020)	0.9995	0.0003	3363 (5.86)

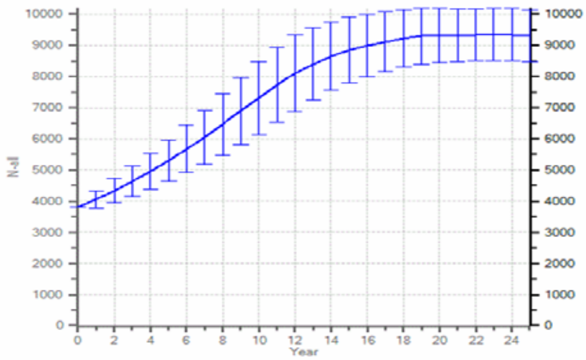

Figure 2 Plot of N *vs.* year relating to simulated Kurd horse population dynamics in the next 25 years from 2022 to 2047

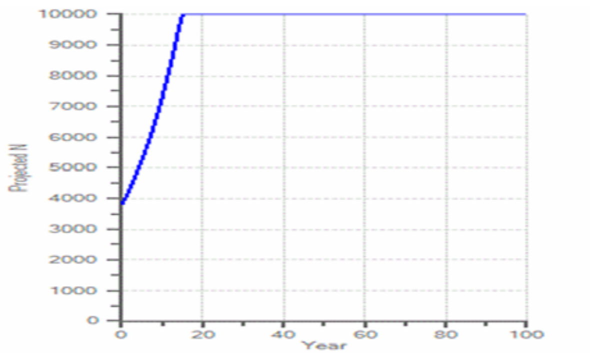

Figure 3 Plot of N *vs.* year relating to simulated Kurd horse population dynamics achieved by the deterministic calculations

The trend of increasing breeding males and females in this breed and increasing the effective population size means that the Kurd horses do not need an urgent conservation program. Of course, excessive use of some studs, and the application of some breeders' styles to generate Kurd horses with special characteristics that may not be approved by experts, are still considered as potential threats to this breed.

The more extended period and a greater number of generations examined in the simulation lead to better evaluation of random effects (Lande, 2002) and genetic losses caused by harmful alleles (Gilligan *et al.* 1997). The reliability of the population growth rate estimates is more accurate in the short-term span (Goodman, 1987), and the possibility of violating the assumptions of stability of environmental changes and demographic parameters is reduced. The mid-term period of 25 years examined in this research seems to have been enough to reach the accurate results.

Unlike wildlife species, few researchers have used the PVA model to investigate endangered livestock breeds. These researchers have successfully used PVA for livestock breeds and have recommended that PVA should be used, with some consideration, for endangered livestock breeds and designing conservation programs. Population dynamics of three Danish domestic horse breeds and their future extinction probability by Thirstrup *et al.* (2009) were simulated. According to the results, there was no probability of the extinction of 2 breeds, but the Frederiksborg breed would become extinct in the next 40 years. Investigating the extinction probability of the Brazilian Bergamasca sheep by population viability analysis determined that this breed will be extinct in the next 59 years if current conditions continue (Carneiro *et al.* 2014). Using PVA, the probability of extinction of native Jordanian, Danish, Hassawi and Sistani dairy cows has been estimated to be occurred in the next 10, 122, 21, and 10 years, respectively (Al-Atiyat, 2009; Al-Atiyat *et al.* 2016; Hertz *et al.* 2016; Gharedaghi, 2019). In contrast, PVA showed that the Crioula Lageana population has no risk of extinction in the following 500 years. The carrying capacity was the main limiting factor for its growing trend (Pezzini *et al.* 2017). It has been shown that the extinction probability of the Markhoz goat in the region will be possible in the next four years (the year 2025), and in the following years, this probability will increase. The mean time to the first extinction of this breed in its habitat is estimated to be 15.4 ± 2.53 years (Bahmani, 2022a).

It is critical to know which parameters affecting the population viability measures and how they work to prepare and implement the conservation and development programs. For this purpose, the effective parameters have been identified, and their impact on the population viability measures of the stochastic population mean growth rate and the extant population size are shown in Table 4.

Unlike the mortality of male foals, the increase in female foals' mortality caused a decrease in the stochastic mean growth rate and the size of the extant population in the simulation of population dynamics in the future. In single-bearing livestock with 11-month gestation and a relatively long generation interval of 4-5 years, keeping and caring for born foals, especially female foals, is critical.

Similar to the results of Thirstrup *et al.* (2009), the increase in the percentage of adult breeding mares increased the stochastic mean growth rate and the extant population size in the simulation. Reducing the percentage of Infertility and abortion of breeding mares, and preparing mares for the following pregnancy in the shortest possible time, requires good management of nutrition, health and mating, for which horse owners must have sufficient knowledge. Crossing this breed with other breeds in Kurdistan and Kermanshah provinces and by fanatical Kurd horse owners is uncommon. However, it happens sometimes in other regions, especially in the central areas of the country. Yousefi-Mashouf *et al.* (2021) have reported evidence of crossbreeding of some individual Kurd horses with Persian Arabian horses. This issue was entered into the simulation as a catastrophe and affected the viability measures. Food restrictions, drought, and excessive annual harvests as catastrophe were not considered in the simulation. Horse breeders are often wealthy and interested and have no incentive to sell or harvest the herd in challenging circumstances (Bahmani, 2022b). This research showed that the percentage of breeding stallions, like the mortality of male foals, did not have a noticeable effect on the viability measures. Figures 4 and 5 show that the mortality of female foals, the percentage of adult breeding mares, and the frequency of crossing with other breeds have the most significant effect on the viability measures of the population in the future simulation, respectively. The spider plots show the tested parameter in combination with other parameters. The steep slope of the test variable indicates that the variable has a significant effect on the results. In contrast a flat or very shallow slope indicates that the variation in that variable has little or no impact on the results. In standardized spider plots, the x-axis is standardized, and all variables are plotted on a 0 and 100 scale which accurate largely the difference in size and range of the variables.

Table 4 The effect of some parameters on the viability measures of the population in the future simulation of the Kurd horse population

Parameter	Value in the base model	The range of investigated variable	The range of change in stochastic growth rate	The range of change in extant population
Adult breeding females (%)	80	70-90	0.049-0.079	9062-9526
Mortality of female foals (%)	20	0-40	0.1025-0.044	9630-8492
Mortality of male foals (%)	20	0-40	0.063-0.065	9432-9402
Frequency of competition with other breeds (%)	100	0-100	0.080-0.064	9515-9321
Males in the breeding pool (%)	20	1-100	0.062- 0.064	9372-9354

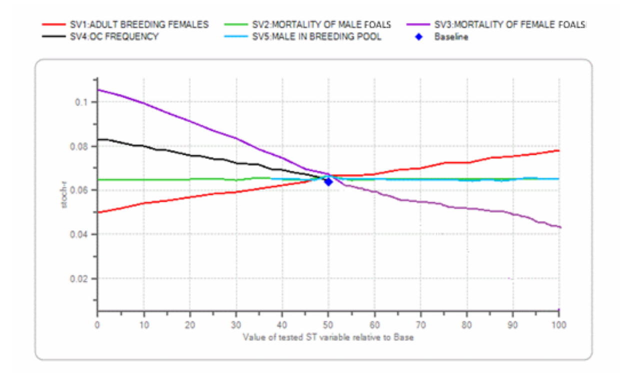

Figure 4 Standardized spider plot for the comparative study of the effect of different parameters on the stochastic growth rate in the Kurd horse population

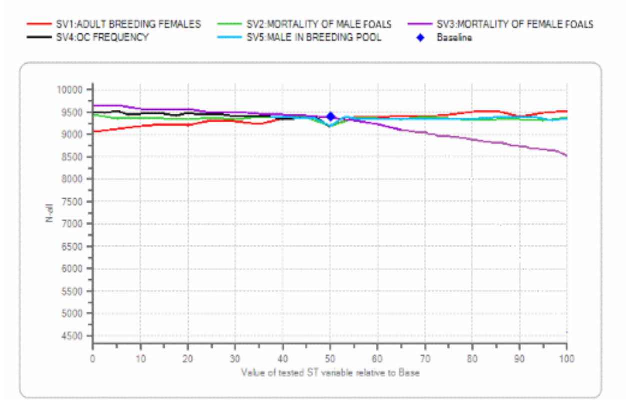

Figure 5 Standardized spider plot for the comparative study of the effect of different parameters on the remained population size in the Kurd horse population

The percentage of adult breeding mares as the most important trait in the population viability analysis of three Danish horse breeds (Thirstrup *et al.* 2009) and southwestern Mongolian horses (Slotta-Bachmayer *et al.* 2004) have been reported. In a study on the endangered Markhoz goat population, the frequency of food restriction, unusual harvesting of adult females, the percentage of adult breeding females, crossbreeding with the hairy breed, and the mortality of female kids had the most significant effect on the viability measures of the population, respectively. The decrease in the eco-social incentive of the breeders was the main reason for the decline in the Markhoz goat population, which caused the excessive harvest of breeding female goats. Food restriction in 30% of the years with an effect on reproduction and survival, 85% participation of breeding female goats in reproduction, crossbreeding with other breeds in all years with 10% effect on reproduction, and 12% mortality of female kids caused the Markhoz goat population to be at risk of extinction (Bahmani, 2022a).

CONCLUSION

According to the different assessing systems, the Kurd horse population is not at risk of extinction owing to geographical and genetic criteria. But this breed is in a vulnerable or transitional state concerning demographic criteria, especially the number of breeding mares. Assuming the continuation of existing conditions, the Kurd horse population will increase in the next 25 years with a mean growth rate of 0.0648 ± 0.0638 before reaching its carrying capacity. The genetic diversity (He) and observed homozygosity of the population had slight changes at the end of the simulation. The trend of increasing breeding males and females in this breed and increasing the effective population size means that the Kurd horses do not need an urgent conservation program. Of course, excessive use of some studs, and the style of some breeders to breed Kurd horses with special characteristics that may not be approved by experts, are still considered potential threats to this breed. Sensitivity testing of parameters showed that the mortality of female foals, the percentage of adult breeding mares, and the frequency of crossing with other breeds have a more significant effect on the viability measures of the population in the future simulation, respectively. The periodic assessment of these parameters is critical in determining the conservation status of this breed. This report has provided most of the demographic and biological information needed for the development programs of the Kurd horse breed.

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