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ORIGINAL ARTICLE

Extinction probabilities of Hassawi cattle from Saudi Arabia using population viability analysis

Raed M. Al-Atiyat [a,b,*], **Riyadh S. Aljumaah** [a], **Bader M. Al-Shaer** [a], **Hussain Al-Sornokh** [a]

[a] *Animal Production Department, King Saud University, Saudi Arabia*
[b] *Department of Animal Production, Mutah University, Jordan*

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Abstract The sharp reduction in population size (N) of Hassawi cattle alarmed to estimate the possibility of extinction over a defined future time horizon. Two Hassawi cattle populations were considered for population viability analysis (PVA) in order to provide estimates of extinction probabilities (EPs). The EPs were estimated using Vortex® modeling program. The estimates of 2013 census and records on previous numbers were utilized in PVA models for two separated populations and their meta-population. The results of EPs and evolutionary growth rate were simulated for past and future, utilizing their demographic parameters and catastrophic events; like, feed scarcity, low production capability, crossbreeding and epidemic diseases. The simulated model concludes that the Hassawi cattle is facing extinction as the population size (N) and effective population size (N_e) were much less than those recommended to save endangerment. Therefore, the mimicked dynamic history of real Hassawi cattle population suggests that the assumed model was reasonable to mimic the likely fate faced by the Hassawi cattle population in the past. The future model concluded that the Hassawi cattle are indeed facing extinction after 21 years if assumptions of past model existed because both N and N_e were much lower than those recommended for escaping endangerment. Furthermore, PE increased with availability and severity of catastrophe events. The results of PVA and PEs should be considered into account to draw inferences about the expected future the Hassawi cattle dynamic because they are accurate data than those might extract from historical records. It is recommended that PVA may be considered in developing conservation strategy for the Hassawi cattle in order to conserve their valuable genetic resources, while the climate change is alarming.

* Corresponding author at: Animal Production Department, King Saud University, Saudi Arabia. Tel.: +966 1 4678475; fax: +966 1 4678474.
E-mail address: ralatiyat@ksu.edu.sa (R.M. Al-Atiyat).

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1. Introduction

Extinction is a process that starts with a downward trend in the number of breeding animals and ends with the loss of one breeding sex or both. The breeding animal number is the main criterion for assessing whether a species or a breed is endangered or in a situation of extinction. The condition numbers of less than 5000 breeding females, less than 20 breeding males and/or less than 10 breeding herds have been adopted (FAO, 1995; European Commission Union, 1992). The recommended solution to save such extinction is through a genetic conservation plan with better utilization and conservation of genetic resources.

The conservation start process may start by performing population viability analysis (PVA) (Simianer et al., 2003). PVA is a quantitative analysis that estimates the probability of extinction (PE) by incorporating environmental conditions, threats to persistence, and future management actions over defined time periods (Burgman et al., 1996; Gerber and González-Suárez, 2010). Many conservation geneticists have recommended PE estimates through a simulation of PVA performed on wild or domestic animals in captivity or nature conserved (Al-Atiyat, 2009; Pertoldi et al., 2014). In general, Shaffer (1993) mentioned that four factors, i.e., catastrophes, environment and demographic fluctuations, and genetic mutation drive a population into extinction. The catastrophic events usually occur at low probability but may drastically reduce the population size in a short time. The PE studies for domesticated breeds have provided insights into the best genetic conservation strategy (Reist-Marti et al., 2003; Al-Atiyat, 2009). In particular, the concern about the extinction of the indigenous domestic cattle breeds was emphasized by FAO (2000). The domesticated breeds are facing same living threats as those faced by wildlife species, in addition to artificial selection, crossbreeding and exotic breed replacement. The exotic breed replacement might be the major reason driving domesticated breeds of the developing countries into extinction (Garrick and Ruvinsky, 2014). Most of the developing countries are nearly crossing high producing exotics with indigenous animals to increase production. In the Kingdom of Saudi Arabia (KSA) also the number of exotic cattle/breeds is sharply increasing, with a sharp decrease in the number of indigenous cattle breeds (Al-Atiyat et al., 2015) and Saudi taurine cattle has become extinct, whereas Saudi indicus cattle is almost extinction (Al-Atiyat et al., 2015). In fact, the Saudi indicus cattle are two breeds, viz., Hassawi and Janoubi (ACSAD, 1988; Mohammed, 1997; Al-Atiyat et al., 2015). The number of Hassawi breed has steadily decreased over time in native areas of east parts of KSA. From genetic conservation point of view, the Hassawi cattle might be facing much rapid extinction than expected. The objective of this research was to simulate the extinction probabilities of Hassawi cattle breed of KSA in order to suggest the best conservation strategy.

2. Materials and methods

2.1. Data collection

The Hassawi cattle breed, Zebu (*Bos indicus*) cattle (for description refer to Mohammed, 1997; ACSAD, 1988; Al-Atiyat et al., 2015) (Fig. 1), is found in two populations in eastern parts of the Kingdom of Saudi Arabia (KSA). The two populations were in the Hofuf (Al-Hasa region; 5 farms with average 6–40 heads) and Qatif (2 farms with a total of 88 heads) cities reared under small-scale traditional production system. The total population was recorded during a survey conducted in 2013; while populations during different previous years were taken from statistical livestock records available with Saudi Agriculture Ministry (Saudi MOA, 2013; Table 1).

2.2. The PVA model

2.2.1. Estimation of extinction probability and model assumptions

Extinction probabilities (EPs) were estimated using population viability analysis (PVA) model of Lacy and Pollak (2015) using Vortex computer software. Vortex uses a Monte Carlo simulation of the effects of defined deterministic forces, and demographic, environmental and genetic stochastic events on the viability of living individuals. In brief, the program begins with creating individuals to form the starting population and then generates life cycle events on an annual basis (for explanations refer Lacy et al. (2015)).

The modeling scenarios required a set of input parameters of biological characteristics and stochastic events related to Hassawi cattle population (Table 2). Vortex simulated the populations by stepping through a series of events that describe an annual life cycle of a typical sexually reproducing organism, i.e., mate selection, reproduction, mortality, increment of age by one year, removals, supplementation, and then truncation to the carrying capacity. The input parameters of Hassawi cattle were derived from combination of published information (ACSAD, 1988; Mohammed, 1997; Al-Atiyat et al., 2015), supported with data collected from farmers and stakeholders. Breeding System was long-term polygynous, with new selection of mates each year, inbreeding depression using the lethal recessive alleles equivalent to 6.29 and 50% due to recessive lethal. Features of herd structure of different age classes as well as different sexes were specified for the Hassawi cattle populations. Stochastic events such as breeding success, progeny number, sex at birth and mortality rate were input data. The Catastrophe events were feed scarcity (drought), low production (exotic breed competition), crossbreeding and epidemic diseases. Each event was modeled as a separate type of catastrophe to simulate the effect on reduction in population size. The frequency of each type of studied catastrophe and the effects of the catastrophes on survival and reproduction was specified. Mortality figures that were used in the analysis are detailed in Table 2. The analyses were run for each starting population considering different mortality rates for each age class. Deterministic projections assumed no stochastic fluctuations, no inbreeding depression, no limitation of mates, no harvest, and no supplementation. In addition, mating was modeled as long-term polygynous. Initial population sizes of the real population (N = 188 animal) was set as carrying capacity. Vortex distributed the specified initial population among age–sex classes considering the mortality and reproductive schedule described initially for the model.

2.2.2. Simulation scenarios

A simulation model was used to compile the past population dynamics and future risk of extinction under similar

A. The first population of the Hofuf city B. The second populations of the Qatif city

Figure 1 Images of the Hassawi cattle found in the first population of the Hofuf city (A) and (B) and the second populations of the Qatif city.

Table 1 Number of Hassawi bulls, cows, bullocks and heifers during different calendar years.

Year	Cow	Bull	Heifer	Bullock	Total
1986	6269	522	2821	836	10,449
1990	4157	272	1840	545	6815
1993	2250	360	1125	765	4500
2003	1890	157	846	254	3147
2006	1405	200	609	342	2556
2010	134	11	55	16	216
2013	94	15	47	32	188

assumptions with three scenarios. The three scenarios represented the dynamic of population-1 from AlHafouf city, population-2 from AlQatif city, and meta-population of both populations. In simulation of the past population dynamic, the aim was to mimic the historical dynamics of the population over the studied time frame of 20 years. The assumptions of this time from 1993 to 2013, were used to estimate the PE of the future populations of 25 years into the future. The assumptions were estimate marginal diversities, reduction growth rate and harvest. In the future dynamic, the parameters of past population dynamics utilized for 25 years to estimate the PE. In other words, the incomes and outcomes of the simulations that mimic the reality, used to simulate the future population viability that population might experience in the coming future assuming 25 years. For both scenarios, the simulation of the population was iterated 1000 times to generate the distribution of fates that the population might experience. Consequently, each of the iteration of the model gave a different result and by running the model 1000 times, range of possibilities and outcomes were examined. Vortex provided with all events and biological parameters that were necessary for PVA model for the examination of the fate of each cattle individual through each year of its lifetime cycle. For the purposes of each simulation, the extinction was defined as any case where the population number was less than or equal to 1 ($N \leqslant 1$) and/or one sex was extinct. The PE was determined by dividing the number of iterations that went extinct by 1000. This produced a percentage of iterations that reached extinction during the simulation.

3. Results and discussion

3.1. Population decline

Available information (Table 1) suggests the decline of Hassawi cattle population from 10,449 in year 1986, to 188 in 2013 (1.89% of 1986 population). This decline was more noticed from 2006 (n = 3147) to 2010 (n = 216) when 93.14% of the population vanished. The further future decline would be expected in the population size as long as the existing threats persist. Under the FAO (1995) criteria a breed of cattle with a breeding population of <1000 females or <20 males is considered endangered to extinction. Therefore, Hassawi cattle in KSA in 2013 as survived by 94 breeding females and 15 breeding males (15) is endangered to extinction and the process of extinction is likely to accelerate in future. Gandini et al. (2004) suggested that population of cattle breeds with smaller number or low economic competitiveness are liable to extinction. Nevertheless population size of Hassawi cattle was not limiting, when decline started therefore it would be better to consider effective population size (N_e) instead of total population size. The current N_e of the Hassawi cattle was around 52 heads (N_e = 4(Nm*Nf)/(Nm + Nf); where Nm = Number of breeding males, Nf = number of breeding females: Falconer, 1989). Cattle populations with N_e <82 (FAO, 1995) or <84 are considered as Endangered. Therefore, Hassawi cattle with N_e of 52 is Endangered to extinction. The Hassawi cattle is used by their farmers for both meat and milk productions during the period of history until the introduction of exotic cattle breeds (Al-Atiyat et al., 2015). Ever since, the main reason to keep this breed no longer existed, but their genetic resources should be conserved. After a PVA is performed to analyze the main risk factors, *ex situ* and/or *in situ* conservation programs may be chosen to prevent extinction.

3.2. PVA simulation

The population viability analysis (PVA) simulation was developed for last 20 years which mimics the nature population dynamic which occurred in the past (Fig. 2). Fig. 2 shows that simulated population dynamic started with meta-population size of 4500 heads declining to 188 in 20 years. Similarly Population-1 started with a population of 2500 declining to

Table 2 Demographic input parameters for all simulated scenarios in the modeling past and future dynamics of Hassawi cattle using *Vortex* software.

Parameter	Population-1		Population-2	
Initial population size (K)	100		88	
Maximum parity size		2		2
Mean parity size		1.1		1
Maximum breeding age (senescence)	12		10	
Females breeding (%)		92		90
Males inbreeding pool (%)	100		100	
Females with one offspring/year (%)	88		85	
	Female	Male	Female	Male
Sex ratio at birth (%)	55	45	55	45
Annual mortality rates (%)				
Age 0–1	20	80	50	50
Age 1–2	20	50	10	10
After age 2	10	40	20	20
After age 3	0	10		10
Age class (/head)	Head			
Year: 1	25	10	22	11
2	17	8	15	8
3	12	2	11	1
4	7	2	6	1
5	5	1	4	1
6	2	1	2	0
7	2	1	2	0
8	1	0	0	0
9	1	0	1	0
10	1	0	1	0
11	1	0	1	0
12	1	0	0	0
Catastrophe event	Local impact (%)	Reproduction reduced (%)	Survival reduced (%)	
Feed scarcity	20	21	20	
Low production	45	16	25	
Crossbreeding	25	10	15	
Epidemic diseases	10	10	10	

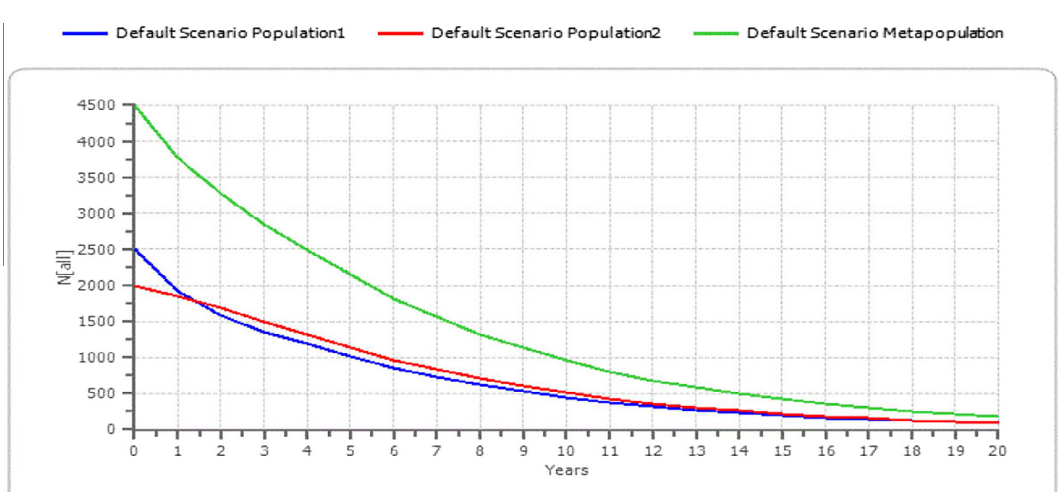

Figure 2 Plot of the individual iterations of the baseline *VORTEX* model of the simulated cattle population dynamics in 20 years of the past time.

100 and Population-2 starting with 2000 declined to 88. However none of these populations was extinct. Metapopulation had a mean stochastic population growth rate (r) of -0.008 ± 0.0001 each year of the simulation, prior to any truncation of the population size due to the population exceeding the carrying capacity.

Population growth was lowered and population size declined over years even though stochastic growth rate was positive. Such simulations were developed several times where population dynamics were compared across alternative connectivity and management scenarios in which the expected loss of diversity was a determinant of strong decline in population size to reach the actual population size recorded in the year 2013 (188 heads). The low growth rate in meta-population is related to low fitness of individuals which usually declines proportionately with reduced gene diversity and increased inbreeding (Meuwissen, 1997; Sonesson and Meuwissen, 2001). The individuals of the meta-population had reasonable fitness to save population from extinction till the end of this simulation. The high rate of decline seen in the model is without doubt due to pessimistic estimates of different parameters, such as, number of male breeding, age at first reproduction and threats/catastrophes occurrence proportions. The latter was applied for justified reasons as their effects were important but sometimes not realized by farmers. Changes in weather conditions (lower rainfall/drought) resulting in feed scarcity or to replacement with high producing exotic cows can be such catastrophes. In addition, their effects may vary for a shorter period of endemic diseases with high severity or for a long period of climate warming with low severity.

3.3. Extinction probabilities

Fig. 3 presents the predicted future Hassawi cattle population dynamic for 20 years. The dynamic was simulated to provide patterns of downward or upward changes with the passing time considering all input data of the past scenario. The figure suggests average meta-population growth rate of 0.026 ± 0.005 and the extinction probability of 100% over the next 21 years. The model concludes that meta-population of the Hassawi cattle is expected to rapidly decline to extinction within the next 21 years, while populations 1 and 2 may be extinct 2–3 year earlier. Someone can argue that 21 years is a long time therefore it requires no conservation plan, but it is a short time, i.e., only 10 generations of Hassawi cattle with a generation time of 2 years. Reliability of PVA becomes higher for a short period of time (Goodman, 1993; Brook et al., 2000), therefore, the present simulation model had high reliability. The Hassawi cattle population is reared on a small scale (6–40) at traditional farms (Al-Atiyat et al., 2015).

The present results on prediction of the future dynamic indicated a population crash at the beginning of the simulation. This might be a reflection of the severity of catastrophic events at the simulation beginning. In the simulated dynamic of Hassawi cattle meta-population was trying to recover (carrying capacity), but the small population was particularly susceptible to extinction due to the severity of catastrophes combination. The meta-population extinction occurred around iteration time step of 752 in this analysis. On the other hand, a few attempts were exhibited for recovery of population-2, while, population-1 made many attempts to recover during the early seven years when it sharply went into extinction and after 10 years the population size dropped to 20 heads. As a consequence, meta-population of Hassawi cattle was subjected to extinction as a result of the low number of breeding females. In all scenarios the model considered only four major catastrophic events, and other events were not considered. The certainty of the magnitude/severity of these events can result in earlier extinction. The most informative results of the applied PVA model are the plots of PE against a series of defined future horizons. The mean of EP values per year was 0.37, 0.26 and 0.63 for population-1, population-2 and meta-population, respectively. Many studies suggested that the EPs of the population have to be considered to predict the

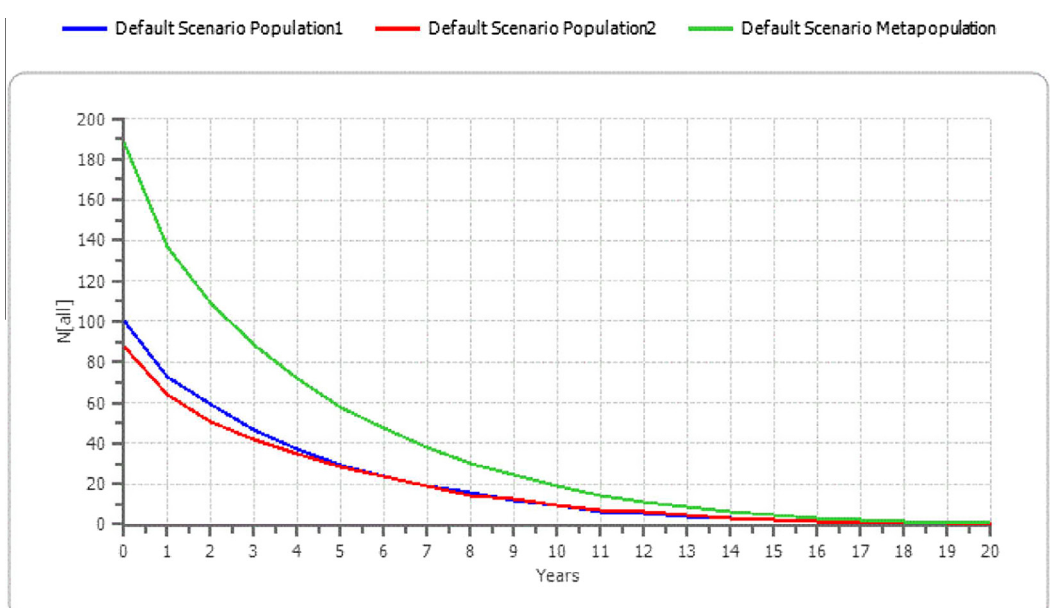

Figure 3 Plot of individual iterations of the baseline *VORTEX* model of cattle population dynamics in next 25 years.

future expected diversity from the present diversity (Weitzman, 1993; Simianer et al., 2003). Furthermore, the present study provided the estimation of the marginal diversity of the Hassawi population per year when monitoring is applicable. The marginal diversity is the diversity at the end of a predefined time when the EP is changed by a unit. As a consequence, the continuous monitoring of the Hassawi cattle dynamic becomes possible to ensure their genetic conservation under *in situ* scheme.

4. Conclusion

The Hassawi cattle population is endangered to extinction when its population size is lower than the recommended population sizes to escape endangerment. In such cases, the genetic conservation strategy might be a practical solution but implementing PVAs and EPs ahead. Resulted PVAs and predicted PE estimates in the light current catastrophic events mimicked the dynamic history of real Hassawi cattle population. In particular, the modeled PVA model predicted accurate fate of the Hassawi cattle population dynamics happened in the past. The simulated models of the future provide that the population is expected to decline to reach extinction in the next 21 years based on the assumptions of the past model. The PE values matched the availability and severity of catastrophic events. The PE of the Hassawi population has to be taken into account in order to draw inference from the present population dynamic to the expected future dynamic. Therefore, PVA model provides more accurate information about the future dynamic of any population than do historical records. Therefore, it is useful to simulate the livestock population dynamics considering past and recent census data in order to explore the future fate while the climate change is taking place.

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