Effects of management decisions on genetic evaluation of simulated calving records using random regression

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ABSTRACT: The objective of this study was to evaluate the effects of various data structures on the genetic evaluation for the binary phenotype of reproductive success. The data were simulated based on an existing pedigree and an underlying fertility phenotype with a heritability of 0.10. A data set of complete observations was generated for all cows. This data set was then modified mimicking the culling of cows when they first failed to reproduce, cows having a missing observation at either their second or fifth opportunity to reproduce as if they had been selected as donors for embryo transfer, and censoring records following the sixth opportunity to reproduce as in a cull-for-age strategy. The data were analyzed using a third-order polynomial random regression model. The EBV of interest for each animal was the sum of the age-specific EBV over the first 10 observations (reproductive success at ages 2–11). Thus, the EBV might be interpreted as the genetic expectation of number of calves produced when a female is given 10 opportunities to calve. Culling open cows resulted in the EBV for 3-yr-old cows being reduced from 8.27 ± 0.03 when open cows were retained to 7.60 ± 0.02 when they were culled. The magnitude of this effect decreased as cows grew older when they first failed to reproduce and were subsequently culled. Cows that did not fail over the 11 yr of simulated data had an EBV of 9.43 ± 0.01 and 9.35 ± 0.01 based on analyses of the complete data and the data in which cows that failed to reproduce were culled, respectively. Cows that had a missing observation for their second record had a significantly reduced EBV, but the corresponding effect at the fifth record was negligible. The current study illustrates that culling and management decisions, and particularly those that affect the beginning of the trajectory of sustained reproductive success, can influence both the magnitude and accuracy of resulting EBV.

Key words: estimated breeding value, reproduction, simulation

Transl. Anim. Sci. 2021.5:1-5
doi: 10.1093/tas/txab078

INTRODUCTION

Successful reproduction is among the most important traits in breeding objectives for beef cattle (e.g., Newman et al., 1992; Phocas et al., 1998; MacNeil, 2016). With the advent of whole-herd reporting, genetic evaluation for a variety of measures of sustained cow fertility becomes feasible. Stayability is a binomial trait defined by the success of a female remaining in the herd to a specified age given that she entered the herd (Hudson and Van Vleck, 1981; Snelling et al., 1995). For instance, a female that calves as a 2 yr old, indicating her having entered the herd, and calving again at or after 6 yr of age might be scored a 1 for stayability, whereas a female from the same 2-yr-old cohort that did not calve at or after 6 yr of age might be scored a 0. If it is assumed that females that

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Received January 11, 2021.
Accepted April 27, 2021.

fail to calve are culled each year, stayability may be interpreted as a measure of sustained cow fertility. Following Ducrocq and Sölkner (1994, 1998), survival analysis, wherein the end of productive life is defined by the first failure to reproduce, provides an alternative approach for genetic evaluation of sustained cow fertility (MacNeil and Vukasinovic, 2011). Principle advantages of survival analysis over a univariate analysis of stayability include the admission of censored records (Prentice, 1973), dynamic reformation of contemporary groups on an annual basis (Ducrocq et al., 1988), and accounting for the non-normal distribution of longevity data (Veerkamp et al., 2001). However, survival analysis complicates routine multitrait genetic evaluation using animal models and there are considerable practical advantages in using random regression analysis as an alternative (Veerkamp et al., 2001; Jamrozik et al., 2013). Alternative management decisions regarding the disposition of females that fail to calve may affect the ultimate genetic evaluation, but their consequences have not been fully elucidated. Therefore, the objective of this work was to examine bias and accuracy of estimated breeding value (EBV) for sustained reproductive success calculated using random regression as functions of the age-specific decision to retain or replace those females that do not calve or enroll females in embryo transfer programs as donors.

MATERIALS AND METHODS

No animals were used in the research that is reported herein. Therefore, this research was not subject to review by an institutional animal care and use committee.

To mimic a beef cattle population with observed reproductive success/failure phenotypes, reproductive phenotypes were simulated for animals belonging to an existing beef cattle pedigree. The pedigree used in this research originated from the Line 1 Hereford population raised at Fort Keogh Livestock and Range Research Laboratory near Miles City, MT. Line 1 was founded with two half-sib bulls mated to 50 unrelated cows and has remained a closed population since those initial matings (MacNeil et al., 1992; MacNeil, 2009). Relative to MacNeil et al. (2017), the pedigree was updated to include calves born in 2017 and before. Then, it was reduced to include only those animals that were parents. Thus, the pedigree that was used as the basis for the simulation contained 364 sires and 2,739 dams born subsequent to the founding of Line 1 in 1934, and 910 ancestral records.

Heritability of fertility in beef females, as variously defined, has been reported as being 5% to 7% for Hereford and 8% to 11% for Angus (Meyer et al., 1990); 4% to 13% for Angus, Limousin, Simmental, and South Devon (Roughsedge et al., 2005); an average of 11% (Mackinnon et al., 1990). Cammack et al. (2009) observed that estimates of the heritability for probability of pregnancy ranged from 0.05 to 0.57 with the majority of estimates being of low to moderate magnitude. For this study, a point estimate of 10% was assumed to be the parameter value for pregnancy rate. MacNeil et al. (1988) observed a straightbred calving rate of approximately 85%, and Rasby et al. (2014) reported a pregnancy rate of 91.8%, which when adjusted for a prenatal mortality rate of 4% (MacNeil et al., 1988) indicates an estimated calving rate of approximately 88%. Thus, a point estimate for calving rate of 86.5% was used for this study. The breeding season was assumed to be of length equivalent to three estrus cycles. In the absence of culling for fertility, the lifespan of a cow was assumed to be 14 yr (Buchannan Smith and Robison, 1931).

For each individual with unknown parents, a pseudorandom breeding value for calving rate was drawn from the distribution NID $(0, \sigma_a^2 = 0.0001139)$. Subsequently, a breeding value was simulated for each animal (BV_i) as: $BV_i = 1/2BV_s + 1/2BV_d + \gamma_i$ where BV_s and BV_d are the breeding values of the sire and dam of the ith individual, and γ_i is a value that corresponds to Mendelian sampling. The Mendelian sampling value was distributed as NID (0, $\sigma_{\gamma_i}^2$) where, $\sigma_{\gamma_i}^2 = (1/2 - (1/4)(F_s + F_d))\ \sigma_a^2$ with F_s and F_d, respectively, equal the inbreeding coefficients of the sire and dam of the ith individual (Bulmer, 1971). For the ith dam, the underlying random normal environmental effects (E_i) were distributed as (0, $\sigma_e^2 = 0.0010251$). Binomial phenotypes (S_{ij}) were then generated for the ith dam in the jth year beginning when she was 2 yr of age by comparing her underlying normally distributed phenotype ($P_i = BV_i + E_i$) with a random variate (r) that was uniformly distributed on the interval 0 to 1 $s_{ij}\ \{= {}^{1\ \rightarrow\ r\ \leq\ P_i}_{0\ \rightarrow r\ >\ P_i}$ where 0 and 1 were coded as failure and success, respectively. Each female had 12 opportunities to produce a record of reproductive performance. Consistent with the classical definition of stayability (Hudson and Van Vleck, 1981; Snelling et al., 1995), all of the 2-yr-old calving success observations were set to 1. To mimic the commonly recommended practice of culling nonpregnant females as a management tactic to increase production efficiency (Dziuk and Bellows, 1983; Azzam and Azzam, 1991), the record of each dam in the original dataset was truncated at the first occurrence of $S_{ij} = 0$ in a second data set, and all subsequent observations were set to a missing value.

The EBVs were predicted using a random regression model that contained only third degree polynomial effects for animal and residual. For all analysis, the estimates of EBV from the first data set were considered to be the true values. Heritability for cumulative success from the data set of complete records was estimated to be 0.26. The EBV of interest for each animal was the sum of the age-specific EBV over the first 10 observations. Thus, the EBV might be interpreted as the genetic expectation of number of calves produced when a female is given 10 opportunities to calve.

In addition to the two data sets described above, additional data sets were created in which the data structures were modified to mimic managerial interventions. The full data set described above was modified to assess the effect of retaining females that failed to reproduce for one additional record. One hundred and eighty-seven females were selected independently at random both in the data set in which all cows had 12 opportunities to reproduce and in the data set in which they were culled at the time of their first failure to mimic the managerial interventions. As though the females were selected to be donors for embryo transfer a missing record was generated at their second or fifth opportunity to reproduce. The data were also modified to mimic a cull-for-age strategy where the records from 187 cows were truncated following the sixth opportunity to reproduce.

The data were analyzed using age-specific *t*-tests to compare the EBV obtained from analysis of the full data set and the data set in which the records were truncated at the first time a cow failed to reproduce. Effects of the management practices were assessed using paired *t*-tests comparing the EBV for the sample of cows that were subject to the particular intervention with their EBV from the corresponding data set in which the managerial intervention had not been imposed.

RESULTS AND DISCUSSION

The phenotype "number of calves produced given 12 opportunities" to calve from the data where all cows had a complete record and the data where open cows were culled are compared in Figure 1. The average age at which a female first failed to

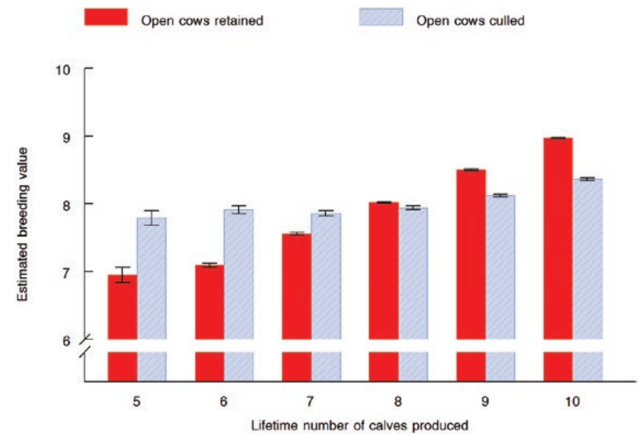

Figure 1. Relationship of the actual number of calves produced given 10 opportunities with the corresponding estimated breeding values and the SEs calculated without and with culling of females that fail to reproduce.

reproduce was 6.6 yr and 26% of all females were successful in annually producing a calf through 11 yr of age. The average EBV for those females subject to culling when first open was 8.4 with a SD of 0.7. The correlation of the EBV with the number of calves phenotype was 0.640. The average EBV for that same set of females when they were not culled was 8.7 with a SD of 0.6, and the correlation with the number of calves phenotype was 0.950. Clearly, culling cows when they are first open reduces the accuracy of the EBV to predict the number of calves. This was expected because more information (i.e., more calving events) should produce an EBV with greater accuracy due to a reduction in the environmental variance (Falconer, 1989). However, this increase in accuracy, and slight increase in EBV magnitude, may provide a seedstock breeder incentive to go against the widely held advice to cull open females. It is also noteworthy that the EBVs produced from data wherein females were culled for reproductive failure were relatively invariant with respect to the age when they were culled in the lifetime number of calves. However, culling females when they are first open also increases the range of this reproductive EBV. The range of the EBV when open females were culled was 4.2 to 9.9. In comparison, the range of the EBV when no females were culled was 6.4 to 9.9. This too might be expected because, with open females culled, that EBV reflects an extrapolation beyond the range of the data whereas if every cow has a full set of records then there is no such extrapolation. In reality, almost any reproductive success EBV generated using random regression methodology in a manner similar to its use in this study will involve some degree of extrapolation because not all females will survive long enough to produce a full set of observations. Similarly, Pool and Muewissen (2000) previously observed that analysis of a data set which contained 50% incomplete lactation records showed an increase in variance at the end of the lactation. In practice, a minority of cows would make a complete record for the number of calves phenotype and extrapolation is necessary to predict the EBV for many cows.

Not only does retaining a female that fails to reproduce increase the accuracy of her EBV, but it also increases the predicted genetic merit of the females that are retained after they are open (Figure 2). The magnitude of the difference in EBV between the females that are retained and those culled for reproductive failure decreases with their age.

A female designated as a donor for embryo transfer might have her observation set to missing for the time she was treated thusly and then with her data rejoining the genetic evaluation thereafter. The difference between the EBV for reproductive success when the embryo transfer (ET) donors were 3 yr olds vs. the same cows not being ET donors was highly significant and indicated a slight downward bias, and when open cows were retained there was a very slight bias upward as a result of setting the observation to missing (Table 1). When the ET donors were 6 yr old, the same comparisons against the situation where those cows were not donors were not significant. Because the statistical tests are quite powerful, fairly small differences can be detected. These effects may not be of a magnitude to be considered important relative to influencing selection decisions. However, they do indicate the potential of an effect associated with when the missing observation occurs with the effect being larger at the extremes of the reproductive profile than during the intermediate years ($P < 0.01$). This outcome results from the differing relative emphasis given to each observation in the series with polynomial regression. For random regression models, Schaeffer and Jamrozik (2008) noted that the genetic variances at the beginning and at the end of the time series of observations were usually much greater than those through the middle of the series.

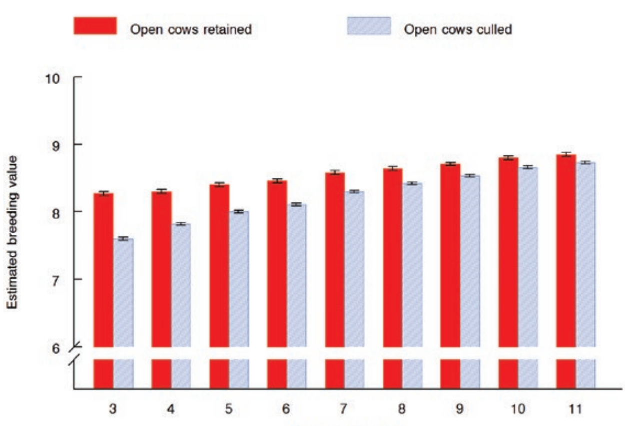

Figure 2. Effects of the decision to retain or cull cows that fail to reproduce at a given age on their predicted EBV (with their SEs) for number of calves given 10 opportunities.

In the interest of achieving rapid genetic improvement and to avoid losses in production associated with advanced age, some producers may invoke a policy of culling based on age. This practice was evaluated by censoring the reproductive record of some cows at 7 yr of age. Whether open cows were retained or culled the effects of censoring on the genetic evaluations were minimal (8.76 ± 0.04 vs. 8.76 ± 0.04, $P = 0.84$ and 9.05 ± 0.03 vs. 8.99 ± 0.02, $P = 0.07$, respectively). However, Sanchez-Castro et al. (2019) showed the accuracy of genetic evaluation for stayability that was estimated by random regression could be improved when data were collected beyond the age of 6 yr.

In summary, management practices alter the sequence of observations that indicate the continuity of reproductive performance. The number of calves EBV predicted by random regression on calving events can be influenced by management. Thus, a trade-off exists between the increased accuracy of the EBV resulting from a greater number of observations and the potential bias that results from the management effects on their prediction.

ACKNOWLEDGMENTS

We thank Daniela Lourenco, Animal Science Department, University of Georgia, for her help in scripting the genetic evaluation.

Table 1. Effect on the mean EBV for reproductive success of setting an observation at either 3 or 6 yr of age to missing due to a managerial decision such as having a cow serve as an embryo donor

Open cows culled			Open cows retained		
	Donor at 3	Donor at 6		Donor at 3	Donor at 6
Observation present	8.76 ± 0.04	8.76 ± 0.04	Observation present	8.95 ± 0.03	8.95 ± 0.03
Observation missing	8.71 + 0.04	8.79 ± 0.04	Observation missing	8.96 + 0.03	8.97 ± 0.03
SE difference	0.003	0.020	SE difference	0.003	0.012
P-value	<0.01	0.21	*P*-value	<0.01	0.47

Conflict of interest statement: The authors declare no conflict of interest.

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