

Evaluating longevity of composite beef females using survival analysis techniques^{1,2}

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ABSTRACT: Objectives were to 1) identify risk factors affecting the longevity of beef females, 2) evaluate the utility of measures collected early in life in predicting longevity, and 3) estimate the heritability of longevity when females were culled primarily for not being pregnant following a 45-d breeding season. Data were from 1,379 Composite Gene Combination (CGC; ½ Red Angus, ¼ Charolais, ¼ Tarentaise) cows born from 1982 through 1999 at the USDA-ARS, Fort Keogh Livestock and Range Research Laboratory, Miles City, MT, and first calving at approximately 2 yr of age. The length of productive life was modeled using Cox regression to identify factors affecting the longevity of beef females. Age at first calving and calf birth weight did not influence longevity. Cows that experienced dystocia were at greater risk of being culled than those

that calved without assistance ($P < 0.01$). On average, as breeding value for cow weight increased, the risk of being culled decreased ($P < 0.01$), whereas the risk of being culled increased with increasing maternal breeding values for preweaning gain ($P < 0.05$). Traits measured before 1 yr of age were not useful in predicting the subsequent longevity of cows. The heritability of functional longevity was estimated to be 0.14. Relatively low heritability and the lack of indicators of longevity expressed early in life suggest that genetic improvement of longevity will be difficult. Matching the genetic potential of cows for size and milk production to the production environment such that rebreeding performance is not compromised by concurrent lactation seems to be a consideration in retaining beef females when open cows are culled.

Key Words: Beef Cattle, Productive Life, Risk, Survival

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Introduction

In beef production systems, the longevity of breeding stock has a substantial effect on economic efficiency. To be profitable, females remaining in production beyond their breakeven age must compensate for females that are culled earlier (Snelling et al., 1995). Increasing the longevity of females reduces annual production costs

associated with raising replacement heifers, increases the number of high producing mature cows, and reduces the number of cows that are culled involuntarily. However, the longevity of beef females remains a frequently overlooked aspect of genetic evaluation programs (Hunter, 1994).

The genetic evaluation of longevity is hindered by its expression late in life, by censoring, and by nonnormality of data. Progeny testing and waiting until all daughters of a sire have been culled before making selection decisions greatly increases the generation interval (Rendel and Robertson, 1950). Linear models are inadequate for a statistical analysis of longevity data due to violation of assumptions of normality (Lagakos, 1979). To consider records from cows alive at the time of evaluation as complete or to not include them in the analysis biases estimates of factors affecting longevity (Ducrocq, 1994). To overcome these statistical issues, survival analysis techniques are implemented in the genetic evaluation of longevity (Ducrocq et al., 1988).

Objectives of this research were to 1) identify risk factors affecting longevity of beef females, 2) evaluate utility of measures collected early in life in predicting

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Table 1. Arithmetic means and standard deviations for performance traits of Composite Gene Combination females and their progeny

Trait	Mean	SD
Female		
Birth wt, kg	36	5
200-d preweaning gain, kg	184	24
365-d wt, kg	348	39
Age at first calving, d	728	17
Breeding value maternal gain, kg	1.9	4.4
Breeding value cow weight, kg	-4.3	24.5
Length of productive life, d	967	743
First calf		
Birth wt, kg	35	5
200-d preweaning gain, kg	166	30
All progeny		
Birth wt, kg	37	6
200-d preweaning gain, kg	186	31

longevity, and 3) estimate the heritability of longevity, when females were culled primarily as a result of their not being pregnant following a 45-d breeding season.

Materials and Methods

Data

Data were from 1,379 Composite Gene Combination (CGC; $\frac{1}{2}$ Red Angus, $\frac{1}{4}$ Charolais, $\frac{1}{4}$ Tarentaise) cows born from 1982 through 1999 at USDA-ARS, Fort Keogh Livestock and Range Research Laboratory, Miles City, MT. To alleviate differences in the length of productive life due to breed composition of the cow, data were edited to remove founding generations of this composite so that only those females with breed composition $\frac{1}{2}$ Red Angus, $\frac{1}{4}$ Charolais, and $\frac{1}{4}$ Tarentaise were included in the analyses. However, pedigree information traced the lineage of all cows back to founding Red Angus, Charolais, and Tarentaise parents. Data were edited to include only those cows that calved at approximately 2 yr of age. Additional information on the development and general performance of the CGC population is available in Newman et al. (1993a,b).

Heifers and cows were exposed to CGC bulls during a 45-d breeding season, resulting in a subsequent 60-d calving season beginning in mid-March. The breeding scheme consistently used yearling bulls that had passed a breeding soundness examination for 1 yr, with a few of these bulls being used for a second year. Cow-to-bull ratio during the breeding season varied with the population size, in response to drought, and other experimental demands on the animal resources. Across all years, the bull-to-cow ratio averaged 1:15.2, with a low of 1:7 and a high of 1:29. Pregnancy rate averaged approximately 90% and was not affected by the bull-to-cow ratio within the range used at Fort Keogh (data not shown). Thus, most sires had a limited number of daughters in the herd. The number of daughters per

sire ranged from 1 to 19, with an average of 5.4 daughters with complete records and average of 1.2 uncensored daughter records. Sire effects were estimated for all sires having at least one daughter in the data ($n = 237$). Cows were weighed annually coincident with the weaning of their calves in the fall.

Two-year-old heifers were observed 22 h daily at the time of calving and assistance was provided to heifers not delivering the calf 1 h after being observed in Stage III of labor. Approximately 18% of heifers received assistance at parturition. Older cows were observed for difficulty in calving during daylight hours. Approximately 7% of all females experienced dystocia at some time in their life subsequent to their first calving. Arithmetic means and standard deviations for cow performance traits and her calf's performance traits are summarized in Table 1.

Statistical Analyses

The Cox regression for survival analysis (Cox and Oakes, 1984) was used to assess relationships of the length of productive life with various measurements. The dependent variable for all analyses was length of productive life, which was defined as the number of days between first calving and last weaning date. Females were culled the first time they were diagnosed as not pregnant. Additional culling was based primarily on unsoundness and disposition. Little if any culling was based on the performance of progeny. When necessary to maintain the inventory of females exposed for breeding at approximately 360 animals, older cows were removed from the herd without respect to either their phenotype or progeny performance. In addition, from 1995 to 1997, a sample of cows was also removed from the herd to initiate a project for mapping quantitative trait loci (MacNeil and Grosz, 2002). If a cow died, was not pregnant at weaning in the fall, or was sold with an unknown pregnancy status, then she was considered to have reached the end of her productive life and her record was uncensored. Records from pregnant cows that were sold or transferred to another project and records from cows that remained in the herd in 2001 were treated as right-censored (33%). For ease of interpreting results and to fit possible nonlinear responses, continuous independent variables were coded into evenly spaced categories. Although somewhat arbitrary, the categories were designed so that a sufficient number of individuals fell into each category.

Effects of independent variables are expressed as risk ratios, which represent the risk of the cow being culled, based on her level within a particular variable, with all other variables held constant. The risk ratio for the numerically lowest category within each effect was set to 1, and all other levels within the effect were expressed relative to this level. In comparing levels of effects, greater ratios indicate greater risk of being culled and conversely smaller ratios indicate a lower risk. Risk ratios for main effects of time-dependent vari-

ables should be interpreted with caution because the effect is dependent on time.

Breeding values for cow weight and 200-d gain from birth to weaning were also calculated in preliminary analyses to evaluate their relationships with longevity. Two single-trait analyses were conducted. In the first analysis, cow weights measured in the fall coincident with the weaning of calves was evaluated. Contemporary groups were formed as year-age subclasses, with cows older than 5 yr coded as 5 yr of age. There were 1,433 cows with at least one recorded weight and a total of 4,375 observations. The linear model for cow weight included fixed contemporary group effects, random direct additive effects, and uncorrelated random permanent environmental effects associated with repeated records of the cow. For the second analysis, 200-d preweaning gain ($n = 4,902$) was calculated as 200 times (weaning weight minus birth weight) divided by age at weaning. Contemporary groups were formed as year, sex, and age-of-dam subclasses. The linear models for 200-d preweaning gain included fixed contemporary groups, random direct and maternal additive effects, and uncorrelated random maternal permanent environmental effects of dams. Derivative-free multitrait REML (Smith and Graser, 1986; Graser et al., 1987) methods as implemented by Boldman et al. (1995) were used to predict breeding values upon convergence of estimates of the (co)variance components. Each analysis was assumed to have converged when variance of $-2 \log$ likelihoods in the simplex was less than 10^{-10} , and analyses of the data using different starting values converged to similar estimates of the variance components.

Five analyses were conducted using the Survival Kit (Ducrocq and Solkner, 1998) to address the specific objectives posed in this research. Model 1 considered factors affecting longevity regardless of the age at which they were expressed. Formally,

$$\lambda(t) = \lambda_0(t) \exp(BW + CD + PWG + YR + AGE + BV_{wt} + BV_{mg})$$

where

$\lambda(t)$ = the hazard function, which represents the risk of a female being culled after t days of her productive life

$\lambda_0(t)$ = the baseline hazard function, an arbitrary function that describes the natural aging process (Ducrocq et al., 1988)

BW = the fixed, time-dependent effect of birth weight of the cow's calf, with eight levels from <30 to ≥ 48 kg in increments of 3 kg

CD = the fixed, time-dependent effect indicating whether assistance was provided at parturition (0 = no and 1 = yes)

PWG = the fixed, time-dependent effect of level for calf 200-d preweaning gain, with six levels from <150 to ≥ 230 kg in increments of 20 kg

and a seventh level coding for calves without a weaning weight

YR = the random, time-dependent effect of the level of calving year, with 18 levels, 1984 ($yr = 1$) to 2001 ($yr = 18$)

AGE = the fixed, time-independent effect of age at first calving, with two levels, either ≤ 730 or > 730 d of age

BV_{wt} = the fixed, time-independent effect of breeding value for cow weight, with nine levels from <-46 to ≥ 38 kg in increments of 12 kg

BV_{mg} = the fixed, time-independent effect of breeding value for maternal preweaning gain, with nine levels from <-5 to ≥ 9 kg in increments of 2 kg.

Changes in time-dependent variables occurred annually. A preliminary analysis also included the fixed, time-independent effect of the cow's direct breeding value for preweaning gain, which was found to not approach significance ($P > 0.2$). An additional analysis similar to Model 1 was conducted in which BV_{wt} and BV_{mg} were replaced with corresponding producing abilities (i.e., breeding value + permanent environmental effect) for each cow. Results from the analysis including producing abilities as independent variables were similar to those obtained using Model 1 and are not presented. Model 2 evaluated risk factors associated with phenotypes resulting from the production of each cow's first calf. Thus,

$$\lambda(t) = \lambda_0(t) \exp(BW_1 + CD_1 + PWG_1 + YR_1)$$

where

$\lambda(t)$ and $\lambda_0(t)$ = hazard functions as defined previously

BW_1 = the fixed effect of the birth weight of the cow's first calf, with six levels from <30 to ≥ 42 kg in increments of 3 kg

CD_1 = a fixed effect indicating the 2-yr-old cow's need for assistance at parturition (0 = no and 1 = yes)

PWG_1 = the fixed effect of 200-d preweaning gain of the cow's first calf, with six levels from <135 to ≥ 195 kg in increments of 15 kg and a seventh level indicated missing values

YR_1 = the fixed effect of calving year, with 18 levels corresponding to years 1984 ($yr = 1$) to 2001 ($yr = 18$).

Model 3 evaluated risk factors associated with phenotypes measured early in the life of the cow. Thus,

$$\lambda(t) = \lambda_0(t) \exp(BW_{cow} + CD_{cow} + PWG_{cow} + YW_{cow} + BYR)$$

where

- $\lambda(t)$ and $\lambda_0(t)$ = hazard functions as defined previously
- BW_{cow} = the fixed effect of the cow's birth weight, with seven levels from <30 to ≥ 45 kg in increments of 3 kg
- CD_{cow} = the fixed effect that indicated whether or not the cow's birth was assisted (0 = no and 1 = yes)
- PWG_{cow} = the fixed effect of the cow's 200-d preweaning gain, with six levels from <155 to ≥ 215 kg in increments of 15 kg
- YW_{cow} = the fixed effect of the cow's 365-d weight, with six levels from <300 to ≥ 400 kg in increments of 25 kg
- BYR = the fixed effect of the cow's birth year, with 18 levels corresponding to years 1982 (yr = 1) to 1999 (yr = 18).

To handle missing phenotypes for independent variables in Model 3, we chose to assign cows the average phenotype of the herd rather than recode the missing values into separate categories. The number of observations that would have fallen into each "missing" category was very small, with a maximum number of 21 cows. Previous studies have assigned cows the average value of the herd, or an arbitrary value when information was not available for the cow (Neerhof et al., 2000; Vollema et al., 2000; Vukasinovic et al., 2001). Preliminary analysis of these data confirmed the effect of handling missing values in this way was negligible, in this investigation. Models 4 and 5 were used to derive heritability estimates for functional and true longevity, respectively, as defined by Ducrocq et al. (1988). The variance due to sires for functional longevity, longevity independent of level of production, was estimated with Model 4 as

$$\lambda(t) = \lambda_0(t) \exp(BW + CD + PWG + YR + AGE + \text{Sire} + \frac{1}{2}\text{MGS})$$

where

- BW , CD , PWG , YR , and AGE = fixed effects as defined for Model 1
- Sire and $\frac{1}{2} \text{MGS}$ = the random effects of the sire and maternal grandsire of the cow.

The random effects were grouped into a vector $\mathbf{s}$, which was assumed to follow a multivariate normal distribution with a variance-covariance matrix $\mathbf{A}\sigma_s^2$. Variance due to sires for true longevity, longevity that is dependent on level of production, was estimated with Model 5 as

$$\lambda(t) = \lambda_0(t) \exp(YR + \text{Sire} + \frac{1}{2}\text{MGS})$$

where all effects are as defined for Model 4. The independent variables BW , CD , PWG , and AGE were removed from the model because each contributes to, but

does not entirely define, the phenotypic description of level of production.

Following Neerhof et al. (2000) and Vollema et al. (2000), heritability was calculated as

$$h_{\log}^2 = [4 \text{ var}(\text{sire})]/[1 + \text{var}(\text{sire})]$$

where, $\text{var}(\text{sire})$ is sire variance. Yazdi et al. (2002) refer to heritability calculated in this way as effective heritability, finding little difference between this estimate and estimates from Weibull sire models with hazard increasing over time transformed to the original scale.

Results and Discussion

Life-Cycle Performance. Model 1 was used to assess risk factors contributing to the culling of cows over their entire life cycle. Despite limited variation in age at first calving (Table 1), its effect approached significance ($P = 0.08$). The trend indicated cows that were ≤ 730 d old at first calving were at less risk of being culled than cows > 730 d of age at first calving. This trend seems consistent with the rationale underlying the usual recommendation that heifers be bred to calve early relative to their subsequent intended calving date (Lienard, 1975; Bogart and Taylor, 1983). Previous studies of dairy cows found that the risk of being culled increased approximately linearly with increasing age at first calving (Ducrocq, 1994; Vukasinovic et al., 2001). The increased risk associated with late calvers may be attributed to decreased fertility (Vukasinovic et al., 2001). However, both Ducrocq (1994) and Vukasinovic et al. (2001) noted that the amount of variation in longevity explained by age at first calving was minimal and subsequently removed the variable from the analysis.

Although the birth weight of a cow's calf did not influence her risk of being culled, cows experiencing dystocia were at a 58% greater risk of being culled (Figure 1) than cohorts that did not experience dystocia ($P < 0.01$). Thus, in these data, birth weight per se was not a source of increased risk, except to the extent that excessive birth weights contribute to increased incidence of dystocia. The importance of birth weight as an indicator of calving difficulty has been supported by high genetic correlations reported between birth weight and dystocia (Bellows et al., 1971; Gregory et al., 1995). Furthermore, birth weight has been reported to be the single most important factor leading to the incidence of dystocia (Bellows et al., 1971; Colburn et al., 1997).

Cows with a missing value for 200-d preweaning gain of an offspring were approximately twice as likely of being culled as cows whose calves had a recorded 200-d preweaning gain ($P < 0.01$, risk ratios 1.66 vs. 0.83, respectively). The majority of missing values for 200-d preweaning gain are due to the cow not weaning a calf. The increased risk of being culled associated with calf mortality primarily reflects transient management decisions to remove the affected females from the herd

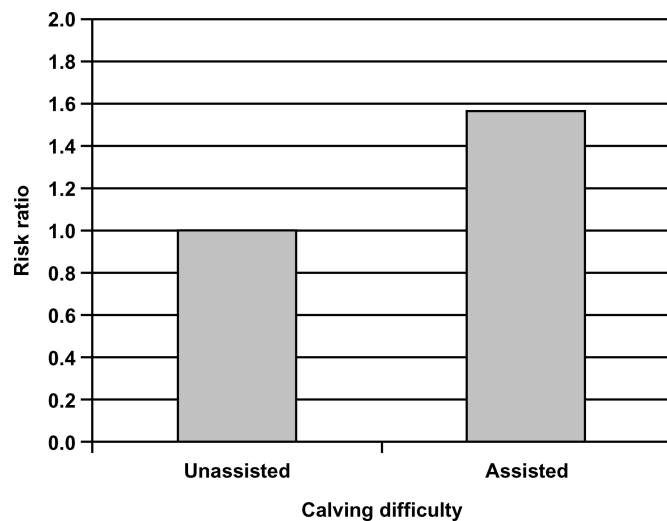


Figure 1. Average effect ($P < 0.01$) of calving difficulty, across all ages, on relative rates, expressed as risk ratios, of females from each class being culled at any point in time when a culling decision is made, all other factors held constant.

rather than a strict culling policy. When records for cows that lost calves were removed from the data set, the effect of gain of the calf from birth to weaning on the risk its dam being culled approached significance ($P = 0.06$) and a trend toward culling cows whose calves had low preweaning gain was observed (Figure 2).

Influence of breeding value (BV) for cow weight ($P < 0.01$) and BV for maternal preweaning gain ($P < 0.05$) on risk ratios for being culled are illustrated in Figures

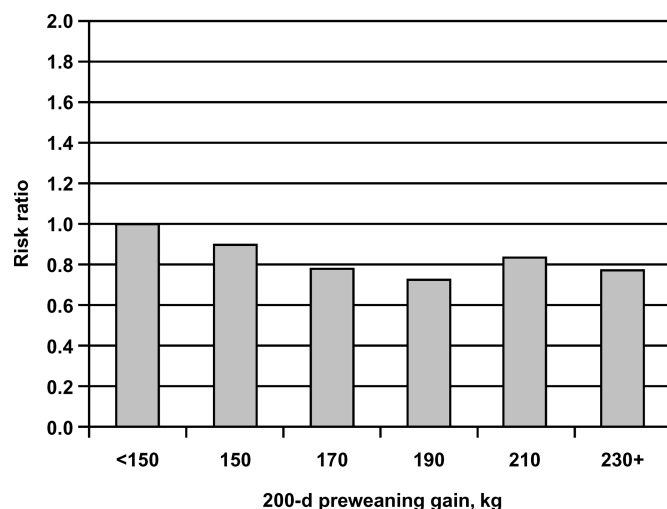


Figure 2. Average effect ($P = 0.06$) of calf 200-d preweaning gain on the relative rates, expressed as risk ratios, of females from each class being culled at any point in time when a culling decision is made, all other factors held constant. Values on the x-axis represent the lower bound of category range except the first value, which represents the upper bound.

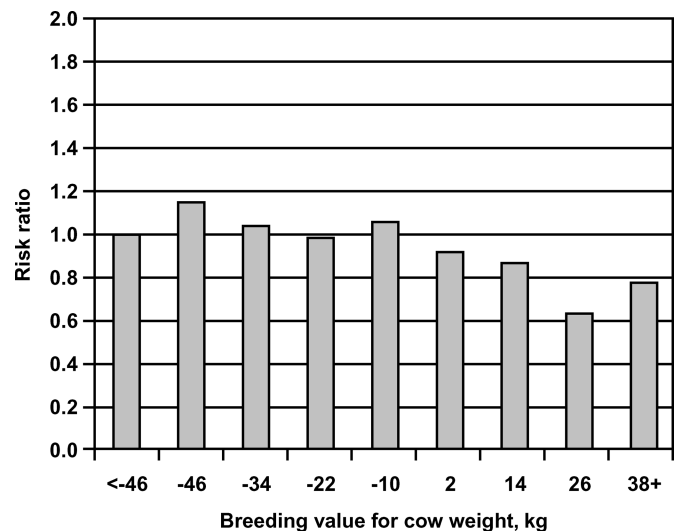


Figure 3. Average effect ($P < 0.01$) of breeding value for cow weight on the relative rates, expressed as risk ratios, of females from each class being culled at any point in time when a culling decision is made, all other factors held constant. Values on the x-axis represent the lower bound of category range except the first value, which represents the upper bound.

3 and 4, respectively. As the BV for cow weight—observed at weaning—increased, the risk of being culled decreased, whereas the risk of being culled increased with increasing BV for maternal preweaning gain. One possible explanation for these trends is that cows with lower milk production (i.e., lower maternal BV for pre-

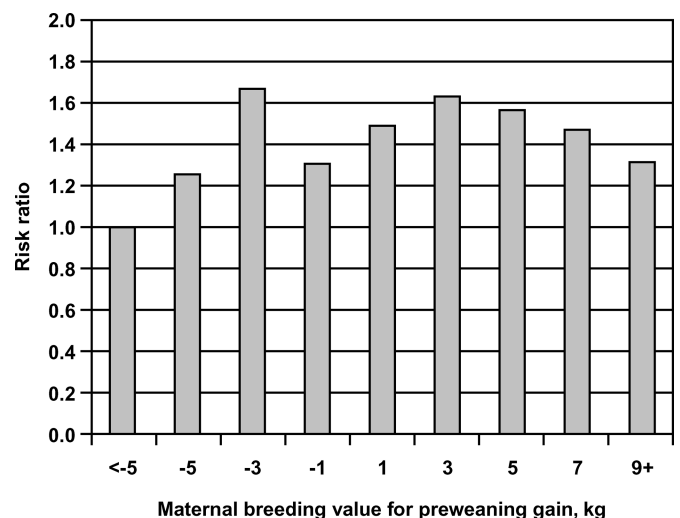


Figure 4. Average effect ($P < 0.05$) of maternal breeding value for preweaning gain on the relative rates, expressed as risk ratios, of females from each class being culled at any point in time when a culling decision is made, all other factors held constant. Values on the x-axis represent the lower bound of category range except the first value, which represents the upper bound.

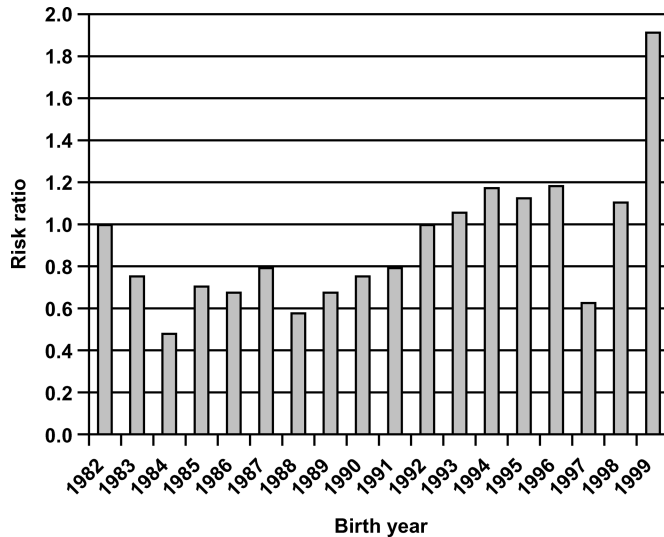


Figure 5. Effect ($P < 0.01$) of birth year of the cow on the relative rates, expressed as risk ratios, of females from each class being culled at any point in time when a culling decision is made, all other factors held constant.

weaning gain) may maintain and accumulate energy reserves during lactation and therefore be heavier at weaning than contemporaries with greater milk production (Davis et al., 1983). Conversely, cows producing more milk may have expended more of their body energy reserves and therefore be lighter and not in adequate condition to rebreed (Short and Adams, 1988). Likewise, Vollema et al. (2000) found that moderately high producing dairy cows were at a greater risk of being culled than low producing cows, possibly due to increased health and fertility problems. In contrast, a strong positive relationship between milk production and longevity has been observed in dairy cattle when culling was based, at least in part, on performance level (Ducrocq et al., 1988; Ducrocq, 1994; Vukasinovic et al., 2001).

The risk of a female being culled varied significantly among years ($P < 0.01$); however, no discernable trend was observed.

Early-in-Life Indicators of Future Longevity. Patterns of significance and direction of effects observed in Model 2 were similar to those observed for the corresponding source of variation in Model 1. This result was anticipated due to the part-whole relationship between sources of variation in the two models. Cows experiencing dystocia as first-calf heifers were at 25% greater risk of being culled than cohorts not experiencing dystocia ($P < 0.05$). The risk ratio associated with dystocia in first-calf heifers is less than half the corresponding risk ratio over all parities. This may result from closer observation of heifers at calving time and earlier intervention in difficult deliveries, relative to older cows. Neither calf birth weight nor calf gain from birth to weaning had a significant effect on subsequent longevity of the dam.

Birth year of the female affected her risk of being culled ($P < 0.01$, Figure 5). Culling policies are usually

more lenient when a herd is expanding in size, and cows within an expanding herd are at a lower risk of being culled in comparison to cows in a herd with decreasing size (Ducrocq, 1994; Vollema et al., 2000). This phenomenon was observed in the early years of this study when few animals of the breed composition $\frac{1}{2}$ Red Angus, $\frac{1}{4}$ Charolais, and $\frac{1}{4}$ Tarentaise had been produced. During the earlier part of the herd's development, fewer than 50 first-calf heifers calved each year, whereas approximately 100 first-calf heifers calved annually in later years. Across the birth years 1984 to 1998, there was a tendency for the risk of a female being culled to increase. This increase reflects a decrease in the length of productive life as the desired population size was attained, and increased culling did not compromise other research objectives. The risk ratio associated with females born in 1999 is artificially inflated due to the lack of uncensored observations from this cohort.

Effects of calving difficulty, birth weight, 200-d preweaning gain, and 365-d weight phenotypes expressed by heifers before 1 yr of age were assessed in Model 3. Each of these phenotypes had little effect on subsequent longevity of the females evaluated ($P > 0.1$). Thus, selection among heifers based on their birth weight, 200-d preweaning gain, or 365-d weight will have neither beneficial nor adverse effects on longevity. Similarly, weaning weight and yearling weight of the cow are not predictive of her life-cycle efficiency (Davis et al., 1983).

Heritability. Estimated sire variances for functional and true longevity were, respectively, 0.03738, with a support interval of 0.03672 to 0.03820, and 0.02813, with a support interval of 0.02746 to 0.02880. Corresponding heritability estimates were 0.14 and 0.11. In comparison, heritability estimates for functional longevity using data from dairy cows ranged from 0.02 to 0.2 (Vollema and Groen, 1998; Neerhof et al., 2000). **Stayability**, defined as the probability that a cow weans five calves given that she weans one, may be viewed as an alternative phenotype for genetic improvement of the length of productive life. Similar to results of this study, heritability estimates for stayability ranged from 0.11 to 0.14 in two herds of Angus cattle evaluated by Snelling et al. (1995).

Implications

The relatively low heritability and the lack of indicators of longevity expressed early in life suggest that the genetic improvement of longevity may continue to be difficult due to prolonged generation intervals and relatively little response per unit of selection applied. Matching the genetic potential of cows to the production environment, such that rebreeding performance is not compromised by concurrent lactation, seems to be a consideration in retaining beef females when open cows are culled. Calving difficulty seems to be an important risk factor contributing to the early culling of beef females, and management may seek to reduce its frequency or mitigate its effects.

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