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# Economic selection index development for Beefmaster cattle II: General-purpose breeding objective

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# Economic selection index development for Beefmaster cattle II: General-purpose breeding objective[1]

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**ABSTRACT:** An economic selection index was developed for Beefmaster cattle in a general-purpose production system in which bulls are mated to a combination of heifers and mature cows, with resulting progeny retained as replacements or sold at weaning. National average prices from 2010 to 2014 were used to establish income and expenses for the system. Genetic parameters were obtained from the literature. Economic values were estimated by simulating 100,000 animals and approximating the partial derivatives of the profit function by perturbing traits 1 at a time, by 1 unit, while holding the other traits constant at their respective means. Relative economic values for the objective traits calving difficultly direct (CDd), calving difficulty maternal (CDm), weaning weight direct (WWd), weaning weight maternal (WWm), mature cow weight (MW), and heifer pregnancy (HP) were −2.11, −1.53, 18.49, 11.28, −33.46, and 1.19, respectively. Consequently, under the scenario assumed herein, the greatest improvements in profitability could be made by decreasing maintenance energy costs associated with MW followed by improvements in weaning weight. The accuracy of the index lies between 0.218 (phenotypic-based index selection) and 0.428 (breeding values known without error). Implementation of this index would facilitate genetic improvement and increase profitability of Beefmaster cattle operations with a general-purpose breeding objective when replacement females are retained and with weaned calves as the sale end point.

**Key Words:** beef cattle, general-purpose objective, selection index


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## INTRODUCTION

Following Hazel (1943), multitrait selection indices have become the method of choice for maximizing genetic gain in a specific breeding objective. Economic selection indices simplify comparisons of animals by combining EBV and the economic value of economically relevant traits (ERT) into a single value that represents the total genetic worth of each candidate for selection. As prerequisites, economic values for each ERT in the breeding objective are needed to ensure selection emphasis is proportional to the economic importance of the traits.

Most currently available indices are designed to be used by multiple breeders for specific marketing end points. These typically use industry economic averages to determine economic weights, and there is considerable evidence that index selection by this method is successful (MacNeil, 2003; Enns and Nicoll, 2008). Currently, Beefmaster Breeders United (**BBU**) reports 10 EBV but provides no tools that facilitate multiple-trait selection. Thus, economic selection indices are needed to assist producers with selection decisions. The objective of this study was to develop a selection index for use in Beefmaster cattle operations with a general-purpose breeding objective to increase profitability and accelerate genetic improvement.

## MATERIALS AND METHODS

Animal Care and Use Committee approval for this study was not obtained given the data were simulated.

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**Table 1.** Means and SD for objective traits

| Traits[1] | Mean | SD | Source |
|---|---|---|---|
| CDd, % | 26 | 2.6 | Ahlberg et al. (2016) |
| CDm, % | 26 | 2.6 | Ahlberg et al. (2016) |
| WWd, kg | 180 | 24.19 | BBU database[2] |
| WWm, kg | 50 | 11.99 | BBU database[2] |
| MW, kg | 567 | 47.55 | Costa et al. (2011) |
| HP, % | 78 | 1.08 | McAllister et al. (2011) |

[1]CDd = calving difficultly direct, CDm = calving difficulty maternal, WWd = weaning weight direct, WWm = weaning weight maternal, MW = mature weight, HP = heifer pregnancy.

[2]Beefmaster Breeders United (unpublished data).

### *Breeding Objective*

The breeding objective was to increase profitability in a system in which calves were born from a combination of heifers and mature cows. Male calves from the system were assumed to be sold at weaning, and heifer calves were either retained or sold at weaning alongside their male counterparts. Six objective traits were considered: direct (**CDd**) and maternal (**CDm**) calving difficultly, direct (**WWd**) and maternal (**WWm**) 205-d weaning weight, mature cow weight (**MW**), and heifer pregnancy (**HP**). Calving difficulty was included in the objective because the occurrence of dystocia results in additional expenses incurred from assistance needed at calving and opportunity cost incurred through calf mortality. Weaning weight direct was included because it affects income when calves are sold at weaning. Increased WWm also results in additional income through the weight of the calf at weaning and increases expense because of increased cow feed intake necessary to support milk production. Mature cow weight also influences both income and expense. Increased MW results in increased feed intake, yet heavier cows have greater salvage value. Increased HP results in increased income through additional calves to be sold and the decreased amount of feed used to develop replacement females.

### *Selection Criteria*

Ideally, the selection criteria would include EBV for all economically relevant traits in the breeding objective. However, in practice some traits in the objective are not readily observed; hence, indicator traits are used to predict phenotypes that have economic relevance. Selection criteria were selected from the 10 EBV currently reported by BBU. Selection criteria were birth weight (**BWT**), WWd, WWm, yearling weight (**YW**), and scrotal circumference (**SC**). Birth weight is an indicator trait for the objective traits CDd and CDm and was included among the selection criteria since an EBV for calving difficulty was not available. For a general-purpose objective, YW is an indicator of MW. Scrotal circumference was included among the selection criteria because it was the only trait with a nonzero genetic correlation with HP.

**Table 2.** Market prices for weaned calves and cull cows based on a 5-yr average (2010–2014)

| Animal type | Animal weight, kg | Price, $/kg | SE, $/kg |
|---|---|---|---|
| Weaned steer[1] | 159–181 | 3.838 | 0.980 |
| Weaned steer[1] | 181–204 | 3.711 | 0.942 |
| Weaned steer[1] | 204–227 | 3.690 | 0.920 |
| Weaned steer[1] | 227–250 | 3.532 | 0.873 |
| Weaned steer[1] | 250–273 | 3.466 | 0.898 |
| Weaned steer[1] | 273–295 | 3.309 | 0.794 |
| Weaned steer[1] | 295–318 | 3.312 | 0.871 |
| Weaned heifer[1] | 159–181 | 3.405 | 0.939 |
| Weaned heifer[1] | 181–204 | 3.295 | 0.882 |
| Weaned heifer[1] | 204–227 | 3.228 | 0.854 |
| Weaned heifer[1] | 227–250 | 3.150 | 0.838 |
| Weaned heifer[1] | 250–273 | 3.078 | 0.773 |
| Weaned heifer[1] | 273–295 | 3.043 | 0.718 |
| Weaned heifer[1] | 295–318 | 3.048 | 0.676 |
| Cull cow[2] | 408–499 | 1.698 | 0.510 |

[1]USDA Agricultural Marketing Service (2015).

[2]Livestock Marketing Information Center (2015).

### *Estimation of Economic Values*

Economic values for the objective traits were derived using methods as described by Ochsner et al. (2017). There were 3 traits considered that would routinely be recorded on a categorical scale: CDd, CDm, and HP. To estimate the economic value of these categorical traits, it was assumed that there was an underlying normal distribution of the categorically expressed phenotypes (Falconer and Mackay, 1996). The latent variable was simulated, and binary phenotypes (e.g., 0 or 1) were assigned by imposing a threshold on the normal distribution of latent variables according to the rate of incidence. To estimate the economic value for the threshold traits, the truncation point was perturbed by 1 percentile such that the incidence increased by 1 unit. The phenotypes for growth traits WWd, WWm, and MW were simulated from normal distributions. The mean and SD assumed in the simulation for all objective traits are summarized in Table 1. The relationships between traits were accounted for by a Cholesky decomposition applied to the phenotypic covariance matrix for all objective traits.

Income was derived from marketing calves and nonpregnant cows at weaning. Average sale prices and their SE per kilogram of animals ranging in weight from 159 to 318 kg were calculated from 5 yr of filtered data (2010 to 2014) from the USDA Agricultural Marketing Service (2015; Table 2). Data were filtered to include only Alabama, Arkansas, Florida, Georgia, Mississippi,

**Table 3.** Dry matter content, metabolic energy content, and prices of feedstuffs based on a 5-yr average (2010–2014)

| Feedstuff | Percentage of DM of feedstuff | Metabolic energy content,[1] Mcal/kg | Average price,[2] $/kg | SE of price, $/kg | Correlation[3] |
|---|---|---|---|---|---|
| Summer grazing | 100 | 2.42 | 0.105 | 0.022 | 0.90 |
| Winter grazing | 100 | 1.92 | 0.053 | 0.011 | 0.90 |
| Prairie hay | 91 | 1.74 | 0.140 | 0.022 | 0.66 |
| Corn | 90 | 3.25 | 0.211 | 0.051 | 1.00 |
| 44% Protein supplement | 89 | 3.04 | 0.436 | 0.060 | 0.87 |

[1]NRC (1996).

[2]USDA National Agricultural Statistics Service (2015).

[3]Correlation with the price of corn. Based on Barron Lopez (2013).

North Carolina, South Carolina, and Texas, which are states in the region where Beefmaster cattle are most prevalent. Average prices and SE of cull females represent a 5-yr average (2010 to 2014) obtained from the Livestock Marketing Information Center (2015; Table 2). Sex was randomly assigned using a uniform distribution. To account for the effect of sex on weaning weight, the weaning weight was multiplied by 0.95 for females and 1.05 for males. If the pregnancy status was simulated as being pregnant, income was calculated as the product of the weight of the calf and the price per kilogram assigned on the basis of sex and weight. If the pregnancy status was simulated as being open, income was derived from marketing the cull female. For a nonpregnant femail, the feed cost for a replacement heifer was multiplied by 2 to account for feeding an open female as well as feeding her replacement to maintain a constant herd size. The price of cull cows was used for the income from selling open heifers, and open heifer weight was simulated assuming each heifer would reach 70% of its MW by the time they were sold. Herd size was fixed, so the number of heifer calves retained as replacement females was equal to the number of cows that were culled.

A 5-yr (2010 to 2014) average and SE of prices for feedstuffs used in the production system was calculated using information obtained from the USDA National Agricultural Statistics Service (2015). The correlation between corn prices and other feedstuffs was accounted for in the simulation. Prices for each feed ingredient were simulated using a random normal distribution as a function of the average price, SE, and correlation with the price of corn. Feedstuff composition was extracted from NRC (1996). Dry matter content, metabolic energy content, and prices of feedstuffs can be found in Table 3. Energy cost per energy metabolized ($/kcal) was estimated on the basis of the price, DM content, and energy value of each component of the diet. Feed costs were calculated as the sum of costs for maintenance, growth, lactation, and gestation. These costs were estimated as a function of the ME requirement (kcal) and the cost per energy metabolizable ($/kcal). The ME requirements for maintenance, growth, lactation, and gestation were calculated using methods described by Barron Lopez (2013). Feed cost was estimated on the basis of the total metabolic energy requirement per animal ($\text{kcal}\cdot\text{animal}^{-1}\cdot\text{period}^{-1}$) and the cost of ME ($/kcal).

Feed cost was estimated for calves from birth to weaning (at 205 d), replacement heifers from weaning to breeding (at 450 d), replacement heifers from breeding to calving (at 730 d), and cows from calving to weaning (at 935 d). The assumed amount of feed consumed during each time period from 205 to 935 d is outlined in Table 4. To estimate the feed cost for calves from birth to weaning the energy content of milk consumed by the calves was subtracted from the total energy requirement of calves. Total energy that calves obtained from milk was calculated assuming 12.3 kg DM in milk, 5.45 Mcal energy/kg DM of milk (Chenette and Frahm, 1981), 0.88 ME per energy gross in milk (Webster, 1985), and 1.06 Mcal ME/kg of milk (NRC, 1996). Calving difficulty cost was calculated as a function of the frequency of calving difficulty incidences and the price of having incurred calving difficulty. Calving difficulty cost was assumed to be $169 for each incidence. Total expense was calculated as the sum of the simulated feed cost for calves, heifers, and cows and costs associated with calving difficultly.

Profit was calculated on a per animal basis by subtracting simulated expense from simulated income. Using methods described by MacNeil et al. (1994), economic values of the objective traits were determined by approximating partial derivatives of profit at the point of mean performance with respect to each driving variable. The model was parameterized, and a base profit was calculated. Each driving variable was then perturbed upward 1 unit in separate iterations of the simulation. The difference between the profits after a variable was perturbed by 1 unit and its base profit was used to determine the economic values for each driving variable. Economic values were expressed as dollars in profit/loss per unit change for each trait. The relative economic value (**REV**) of each objective trait was estimated as a product of the respective economic value and the genetic SD for that trait. Relative economic values recognize that economic return from a 1 SD increase in 1 trait will not be equal to the same increase in another trait and allow for a direct comparison of the economic importance across traits.

**Table 4.** Assumed feeding program[1]

| Period | | | Summer grazing,[2] kg/d | Winter grazing,[3] kg/d | Prairie hay, kg/d | Corn, kg/d | 44% Protein supplement, kg/d |
|---|---|---|---|---|---|---|---|
| Begin | End | Days | | | | | |
| | | | | Weaning to breeding | | | |
| Oct. 15 | Apr. 30 | 198 | 0 | 0 | 4.42 | 1.19 | 0.34 |
| May 1 | May 31 | 31 | 0 | 0 | 5.13 | 1.42 | 0.27 |
| Jun 1 | Jun 15 | 15 | 7.21 | 0 | 0 | 0 | 0 |
| | | | | Breeding to calving | | | |
| Jun. 16 | Aug. 31 | 77 | 7.21 | 0 | 0 | 0 | 0 |
| Sept. 1 | Oct. 31 | 61 | 8.24 | 0 | 0 | 0 | 0 |
| Nov. 1 | Dec. 31 | 61 | 0 | 8.24 | 0 | 0 | 0.83 |
| Jan. 1 | Mar. 23 | 82 | 0 | 0 | 7.15 | 1.24 | 0.4 |
| | | | | Lactation period | | | |
| Mar. 24 | May 31 | 69 | 0 | 0 | 6.59 | 1.89 | 0.82 |
| Jun. 1 | Oct. 15 | 137 | 13.29 | 0 | 0 | 0 | 0 |

[1]Based on feeding program assumed by Barron Lopez (2013).

[2]From June 1 to October 31.

[3]From November 1 to December 31.

### *Selection Index Coefficients*

Following Schneeberger et al. (1992), the equation to estimate index coefficients to be applied to EBV is

$$\mathbf{b} = \mathbf{G_{11}}^{-1}\mathbf{G_{12}}\mathbf{v},$$

where $\mathbf{G_{11}}$ is an $n \times n$ matrix of genetic (co)variances among the $n$ selection criteria, $\mathbf{G_{12}}$ is an $n \times m$ matrix of the genetic (co)variances among the $n$ selection criteria and $m$ objective traits, and $\mathbf{v}$ is an $m \times 1$ vector of economic values for all objective traits. Index coefficients to be applied to EBV for selection criteria were calculated using this method. Genetic covariances were calculated from the genetic SD and genetic correlations. The heritability and genetic variances of the objective traits and selection criteria used to calculate the matrices were extracted from literature (Table 5). Genetic correlations between the selection criteria and objective traits needed for calculation of the covariance matrices were also extracted from scientific literature (Table 6). It was ensured that the (co)variance matrix was positive definite.

### *Index Accuracy*

The following equation was used to calculate the accuracy of the index:

$$r_{HI} = \frac{\boldsymbol{b}'\mathbf{G}_{12}\boldsymbol{v}}{\sqrt{(\boldsymbol{b}'\mathbf{G}_{11}\boldsymbol{b})(\boldsymbol{v}'\boldsymbol{C}\boldsymbol{v})}},$$

where $\boldsymbol{b}'\boldsymbol{G}_{12}\boldsymbol{v}$ represents the covariance between the index and aggregate genotype, $\boldsymbol{b}'\boldsymbol{G}_{12}\boldsymbol{b}$ represents the index variance, and $\boldsymbol{v}'\boldsymbol{C}\boldsymbol{v}$ represents the aggregate genotype variance where $\boldsymbol{C}$ is an $m \times m$ genetic (co)variance matrix among the objective traits. This equation is comparable to the accuracy equation presented by Van Vleck (1993) for indices using phenotypic measures, with the exception of the substitution of $\mathbf{G_{11}}$ for $\mathbf{P}$, which was a matrix of phenotypic (co)variances in Van Vleck (1993). This substitution is accompanied by several assumptions. In presenting the index coefficient equations using EBV as the selection criteria, Schneeberger et al. (1992) explained that $\mathbf{G_{11}}$ is the genetic (co)variance matrix of the selection criteria that is assumed to be known without error. However, EBV would never be known with complete certainty given the heterogeneity of the residual variances. Thus, the index accuracy estimated herein would be the best-case scenario, presuming that the accuracy of each EBV included in the index for each animal was unity. We would expect the true accuracy of the index to lie somewhere between the 2 accuracies presented herein that were produced by assuming the index was composed of either phenotypic measures or EBV that are known without error.

### *Index Sensitivity*

Economic selection index coefficients are seldom known without error because of uncertainties in (co) variances and in economic values. One way to determine the sensitivity of indices to the (co)variances and economic values assumed is to calculate the efficiency of the index. The efficiency ($\boldsymbol{E}_{\mathbf{u}}$) is given as

$$\boldsymbol{E}_u = \frac{\boldsymbol{b}_u'\boldsymbol{G}_{12_t}\boldsymbol{v}}{\sqrt{\boldsymbol{b}_u'\boldsymbol{G}_{11_t}\boldsymbol{b}_u}} \times \frac{1}{\sqrt{\boldsymbol{b}_t'\boldsymbol{G}_{12_t}\boldsymbol{v}}},$$

$\boldsymbol{b}_u$ are index coefficients derived from "used" values, and $\boldsymbol{b}_t$ are "true" index coefficients. The used index coefficients are based on current belief, whereas the true

**Table 5.** Genetic and phenotypic parameters for selection criteria and objective traits[1]

| Traits | $h^2$ | $\sigma_a^2$ | $\sigma_p^2$ | Source |
|---|---|---|---|---|
| BWT, kg | 0.35 | 10.68 | 30.514 | Ahlberg et al. (2016) |
| WWd, kg | 0.22 | 128.72 | 585.090 | Schiermiester et al. (2015) |
| WWm, kg | 0.17 | 97.75 | 575 | Schiermiester et al. (2015) |
| YW, kg | 0.40 | 480.982 | 1,202.455 | Moser et al. (1998) |
| SC, cm | 0.36 | 1.587 | 4.41 | Knights et al. (1984) |
| CDd, % | 0.4 | 2.704 | 6.76 | Ahlberg et al. (2016) |
| CDm, % | 0.18 | 1.216 | 6.76 | Ahlberg et al. (2016) |
| MW, kg | 0.54 | 1,221 | 2,261.111 | Costa et al. (2011) |
| HP, % | 0.17 | 0.198 | 1.17 | McAllister et al. (2011) |

[1]Selection criteria: BWT = birth weight, WWd = weaning weight direct, WWm = weaning weight maternal, YW = yearling weight, SC = scrotal circumference. Objective traits: CDd = calving difficulty direct, CDm = calving difficulty maternal, MW = mature weight, HP = heifer pregnancy. $h^2$ = heritability, $\sigma_a^2$ = genetic variance, $\sigma_p^2$ = phenotypic variance.

index coefficients are assumed to be optimum. In reality, there are potential uncertainties associated with the assumed phenotypic and genetic parameter estimates and economic values, which is why it is important to calculate the efficiency and determine the impact of inadvertently using incorrect index coefficients.

Sensitivities to absolute changes in genetic correlations between objective traits and selection criteria of ±0.2 and ±0.4 were calculated. These changes in genetic correlations are equivalent to those investigated by Simm et al. (1986). It is important to note that in some cases these changes resulted in a change of sign. In instances where these changes would have resulted in a correlation greater than unity, the genetic correlation was assumed to be 1. Sensitivity to a 50% increase or decrease in the magnitude of the economic value of each trait in the breeding objective was also investigated. This also follows the methods of Simm et al. (1986), who calculated the efficiency of 2 selection indices following an increase or decrease of 50% in the economic value of each trait in the aggregate breeding value.

## RESULTS AND DISCUSSION

### *Economic values*

Economic values, REV, and the proportion of emphasis placed on each objective trait are presented in Table 7. Calving difficulty direct and maternal both had negative economic values, which is logical considering the veterinary costs, labor, and possible mortality associated with these traits. Economic values for both WWd and WWm were found to be positive, although WWm to a lesser magnitude. This result can be attributed to the fact that there is a feed expense associated with the added milk production of the dam. The economic value for MW was negative, which is sensible considering that an increase in MW will result in increased feed expenses for the cow herd. Heifer pregnancy had a positive economic value, which is logical considering that HP affects the number of calves available to be marketed at weaning time. Mature weight was the primary driver of the index receiving 49.2% of the emphasis, implying that decreasing MW will do the most to improve profitability of operations with a maternal objective. Weaning weight direct was the second highest priority, receiving 27.2% of the emphasis.

Hietala et al. (2014) derived the economic values of production and functional traits in Finnish Ayrshire cattle. Two marketing strategies for calves were investigated, one in which surplus calves were sold at a young age and one in which calves were fattened on dairy farms. Economic values of 21 traits were reported, which included milk production traits, calving difficulty traits, MW, daily gain, carcass traits, reproductive traits, and residual feed intake. The economic values for calving difficulty and MW presented by Hietala et al. (2014) were multiplied by their respective genetic SD and converted to U.S. dollars using the June 2016 exchange rate in order compare these values to the REV reported in the current study. In a Finnish dairy production system in which surplus calves were sold at a young age and no subsidies were applied, the REV for calving difficulty and MW were −\$3.92 and −\$37.63, respectively. These results are in agreement with the REV for calving difficulty and MW presented herein.

MacNeil et al. (1994) derived REV for specialized sire and dam lines of Canadian Beefbooster cattle, given their respective roles in a vertically integrated crossbreeding system. Traits in the breeding objective included MW, male and female fertility, calf survival, WWd, WWm, ADG, G:F, dressing percentage, percentage of A grade, and cutability percentage. The Beefbooster breeding scheme is based on 3 maternal strains and 2 specialized sire lines. Similar to the results from the current study, the results of MacNeil et al. (1994) reported positive REV for WWd and WWm, with the REV of WWm being lower in magnitude compared to WWd, and a negative REV for MW. The negative relationship between MW and profit has been documented by others (e.g., Graser et al., 1994). Mwansa et al. (2002) developed a multiple-trait genetic evaluation and selection tool for maternal productivity in Hereford cattle. The 4 component traits in the index were WWd, WWm, cow weight, and stayability. Although the authors expected a positive genetic trend in all component traits, increases in cow weight would be moderate.

### *Index Coefficients*

Index coefficients to be applied to EBV of BWT, WWd, WWm, YW, and SC were calculated as −1.371,

**Table 6.** Genetic correlations between selection criteria and objective traits

| Traits[1] | BWT | WWd | WWm | YW | SC | CDd | CDm | MW | HP |
|---|---|---|---|---|---|---|---|---|---|
| BWT | | 0.50[2] | −0.14[2] | 0.53[3] | 0.04[2] | 0.64[4] | −0.10[5] | 0.35[6] | 0.00[3] |
| WWd | | | −0.28[7] | 0.70[8] | 0.19[2] | 0.20[5] | −0.20[9] | 0.40[6] | 0.00[3] |
| WWm | | | | 0.00[5] | 0.19[2] | 0.00[3] | 0.00[3] | 0.00[5] | 0.00[3] |
| YW | | | | | 0.39[2] | 0.36[9] | −0.23[9] | 0.50[6] | 0.00[3] |
| SC | | | | | | 0.16[10] | −0.27[10] | 0.10[6] | 0.06[3] |
| CDd | | | | | | | −0.26[9] | 0.00[3] | 0.00[3] |
| CDm | | | | | | | | 0.00[3] | 0.00[3] |
| MW | | | | | | | | | 0.00[3] |

[1]Selection criteria: BWT = birth weight, WWd = weaning weight direct, WWm = weaning weight maternal, YW = yearling weight, SC = scrotal circumference. Objective traits: CDd = calving difficulty direct, CDm = calving difficulty maternal, MW = mature weight, HP = heifer pregnancy.

[2]Koots et al. (1994).

[3]Barron Lopez (2013).

[4]Ahlberg et al. (2016).

[5]Within the range of estimates reported by Koots et al. (1994).

[6]American Hereford Association genetic evaluation.

[7]MacNeil and Newman (1994).

[8]Bourdon and Brinks (1986).

[9]Bennett and Gregory (2001a).

[10]Bennett and Gregory (2001b).

1.426, 0.945, −0.660, and 2.725, respectively. The correlated responses per unit of selection intensity in goal traits were −0.856%, −0.051%, 2.519 kg, 7.307 kg, −8.449 kg, and 0.011% for CDd, CDm, WWd, WWm, MW, and HP, respectively. MacNeil and Newman (1994) calculated selection indices to use in specialized sire and dam lines of Canadian beef cattle. They derived index coefficients for BWT, day born, ADG, SC, and fat depth. For a maternal dam line, they reported a negative index coefficient for BWT and a positive index coefficient for SC. MacNeil and Newman (1994) also reported a negative index coefficient for MW, which is similar in sign to the negative index coefficient for YW derived in the current study.

Barron Lopez (2013) estimated index coefficients for a variety of general-purpose indices designed to improve beef cattle production efficiency. In total 13 selection criteria traits were considered, including ADG, MW, back fat, rib eye area, marbling score, calving difficulty, HP, BWT, WWd, YW, HCW, yearling height, and WWm. For the index that Barron Lopez (2013) recommended to improve the proposed breeding objective, the index coefficients for BWT was again found to be negative. For the index that included WWd, the index coefficient for WWd was positive. The index coefficient for YW was small but positive in an index recommended by Barron Lopez (2013) for a situation in which an EBV for ADG is not available. This index coefficient is different in sign than that derived herein because this index assumed differing sale end points (postweaning vs. weaning). Furthermore, an index that included MW derived by Barron Lopez (2013) had a negative MW index coefficient. Interestingly, the rank correlation between a terminal index for Beefmaster cattle reported by Ochsner et al. (2017) and the index reported herein was 0.446, suggesting a need to clearly delineate breeding objectives given the differences in traits included in these 2 indices.

The accuracy of the index lies between 0.218 and 0.428. The lower bound would be the accuracy estimate if phenotypic measures were the selection criteria. The upper bound of the accuracy estimate assumes that EBV known without error were the selection criteria. The accuracy of the maternal index could be improved if EBV for ERT were reported by BBU and could be included in the selection criteria. Some indicator traits (i.e., SC) were used because they were the only traits with a nonzero correlation to important breeding objective traits (i.e., HP). However, SC and HP are weakly correlated, meaning that SC is not a strong indicator of HP. Graser et al. (1994) concluded that selection strategies that utilized performance recording beyond the traditional weight measures were more profitable and that fertility measures were the most cost-effective additional selection criteria. Having EBV available for other ERT such as sustained female reproduction could improve the accuracy and response to selection of the index proposed in the current study. However, in the current study a metric of sustained female reproduction was not included among the objective traits because there were no correlated selection criteria available.

### *Index Sensitivity*

A change of ±0.2 in the genetic correlations between selection criteria and objective traits resulted in efficiencies ranging from 0.90 to 1.00, with the exception

**Table 7.** Economic values, relative economic values, and response of individual objective traits in the maternal selection index

| Traits[1] | Economic value, $/trait unit | Genetic SD[2] | Relative economic value (per genetic SD) | Relative emphasis,[3] % |
|---|---|---|---|---|
| CDd, % | −1.28 | 1.64 | −2.11 | 3.1 |
| CDm, % | −1.39 | 1.10 | −1.53 | 2.2 |
| WWd, kg | 1.63 | 11.35 | 18.49 | 27.2 |
| WWm, kg | 1.14 | 9.89 | 11.28 | 16.6 |
| MW, kg | −0.96 | 34.94 | −33.46 | 49.2 |
| HP, % | 2.68 | 0.45 | 1.19 | 1.7 |

[1]CDd = calving difficulty direct, CDm = calving difficulty maternal, WWd = weaning weight direct, WWm = weaning weight maternal, MW = mature weight, HP = heifer pregnancy.

[2]From additive genetic variances in Table 5.

[3]Relative emphasis was calculated by dividing the absolute value of the relative economic value of each trait by the sum of the absolute values of the relative economic values of all traits.

of correlations involving MW. Selection efficiencies after changing genetic correlations between MW and other traits ranged from 0.60 to 0.95. The increased sensitivity of the index to changes in genetic correlations between MW and other traits can likely be attributed to the fact that MW had the highest REV of all traits considered. A change of ±0.4 in the genetic correlations resulted in efficiencies ranging from 0.73 to 1.00, again with the exception of correlations between MW and other traits. Efficiencies resulting from changes of ±0.4 in genetic correlations between MW and other traits ranged from −0.21 to 0.92. Two negative efficiency estimates were calculated, indicating that selection based on an index calculated with the used parameters would result in a negative response in the aggregate genotype. The efficiency of −0.21 resulted from adding 0.4 to the true genetic correlation between WWd and MW, which indicates very high sensitivity of the index to the genetic correlation between these 2 traits. This makes sense because these 2 moderately correlated traits are being selected for in opposite directions and therefore are antagonistic relative to the breeding objective.

In many cases, deviating the assumed genetic correlation by 0.4 from the true genetic correlation is outside the biologically reasonable value and creates assumed genetic correlations that are not supported by the literature. To further investigate the sensitivity of the index, an intermediate value of 0.3 was added to the true correlation between WWd and MW. The efficiency was calculated as 0.13. Although this is still a low efficiency value, bringing the genetic correlation closer to what we assume to be true at least results in a positive efficiency value. Within the range of reasonable correlation values that could be assumed in the calculation of the index coefficients, the index was insensitive.

The sensitivity to changes in economic values is reported as the efficiency of the index after a 50% increase or decrease in the economic value of each objective trait, 1 at a time. For the maternal index, efficiency values ranged from 0.79 to 1.00. The index is most sensitive to changes in the economic values of MW and WWd. This result can likely be attributed to the fact that these 2 traits have REV of higher magnitude than other objective traits. The index proves to be reasonably insensitive to changes in genetic correlations and economic values, indicating that it can be used confidently regardless of uncertainties in genetic parameters and economic circumstances.

### *Conclusions*

In the present study, decreasing CDd, CDm, and MW while increasing WWd, WWm, and HP would increase profitability under the assumed production goals. Mature weight received the most emphasis in the general-purpose objective, implying that for the assumed parameters placing downward selection pressure on MW will do the most to increase profitability for a general-purpose objective with weaned calves as the primary source of revenue. Weaning weight direct was also a major driver of profit in the index. Although MW and WWd are antagonistic to each other relative to the breeding objective, since the assumed correlation between them is not unity, progress can be made in both traits simultaneously. The general lack of sensitivity suggests that the index developed herein should be relatively robust in improving profitability across diverse production environments.

## LITERATURE CITED

Ahlberg, C. M., L. A. Kuehn, R. M. Thallman, S. D. Kachman, W. M. Snelling, and M. L. Spangler. 2016. Breed effects and genetic parameter estimates for calving difficulty and birth weight in a multibreed population. J. Anim. Sci. 94(5):1857–1864. doi:10.2527/jas.2015-0161

Barron Lopez, J. A. 2013. Selection objective for improving efficiency of beef cattle. PhD Diss. Univ. of Nebraska, Lincoln.

Bennett, G. L., and K. E. Gregory. 2001a. Genetic (co)variances for calving difficulty score in composite and parental populations of beef cattle: I. Calving difficulty score, birth weight, weaning weight, and postweaning gain. J. Anim. Sci. 79:45–51. doi:10.2527/2001.79145x

Bennett, G. L., and K. E. Gregory. 2001b. Genetic (co)variances for calving difficulty score in composite and parental populations of beef cattle: II. Reproductive, skeletal, and carcass traits. J. Anim. Sci. 79:52–59. doi:10.2527/2001.79152x

Bourdon, R. M., and J. S. Brinks. 1986. Scrotal circumference in yearling Hereford bulls: Adjustment factors, heritabilities and genetic, environmental and phenotypic relationships with growth traits. J. Anim. Sci. 62:958–967. doi:10.2527/jas1986.624958x

Chenette, C. G., and R. R. Frahm. 1981. Yield and comparison of milk from various two-breed cross cows. J. Anim. Sci. 52:483–492. doi:10.2527/jas1981.523483x

Costa, R. B., I. Misztal, M. A. Elzo, J. K. Bertrand, L. O. C. Silva, and M. Lukaszewicz. 2011. Estimation of genetic parameters for mature weight in Angus cattle. J. Anim. Sci. 89:2680–2686. doi:10.2527/jas.2010-3574

Enns, R. M., and G. B. Nicoll. 2008. Genetic change results from selection on an economic breeding objective in beef cattle. J. Anim. Sci. 86:3348–3357. doi:10.2527/jas.2006-566

Falconer, D. S., and T. F. C. Mackay. 1996. Introduction to quantitative genetics. 4th ed. Longmans Green, Harlow, UK.

Graser, H. U., G. Nitter, and S. A. Barwick. 1994. Evaluation of advanced industry breeding schemes for Australian beef cattle. II. Selection on combinations of growth, reproduction and carcase criteria. Aust. J. Agric. Res. 45:1657–1669. doi:10.1071/AR9941657

Hazel, L. N. 1943. The genetic basis for constructing selection indexes. Genetics 28:476–490.

Hietala, P., M. Wolfová, J. Wolf, J. Kantanen, and J. Juga. 2014. Economic values of production and functional traits, including residual feed intake, in Finnish milk production. J. Dairy Sci. 97:1092–1106. doi:10.3168/jds.2013-7085

Koots, K. R., J. P. Gibson, and J. W. Wilton. 1994. Analyses of published genetic parameter estimates for beef production traits. 2. Phenotypic and genetic correlations. Anim. Breed. Abstr. 62:825–853.

Knights, S., R. L. Baker, D. Gianola, and J. B. Gibb. 1984. Estimates of heritabilities and of genetic and phenotypic correlations among growth and reproductive traits in yearling Angus bulls. J. Anim. Sci. 58:887–893. doi:10.2527/jas1984.584887x

Livestock Marketing Information Center. 2015. http://www.lmic.info/. (Accessed 10 August 2015.)

MacNeil, M. D. 2003. Genetic evaluation of an index of birth weight and yearling weight to improve efficiency of beef production. J. Anim. Sci. 81:2425–2433. doi:10.2527/2003.81102425x

MacNeil, M., and S. Newman. 1994. Selection indices for Canadian beef production using specialized sire and dam lines. Can. J. Anim. Sci. 74:419–424. doi:10.4141/cjas94-060

MacNeil, M., S. Newman, R. Enns, and J. Stewart-Smith. 1994. Relative economic values for Canadian beef production using specialized sire and dam lines. Can. J. Anim. Sci. 74:411–417. doi:10.4141/cjas94-059

McAllister, C. M., S. E. Speidel, D. H. Crews Jr., and R. M. Enns. 2011. Genetic parameters for intramuscular fat percentage, marbling score, scrotal circumference, and heifer pregnancy in Red Angus cattle. J. Anim. Sci. 89:2068–2072. doi:10.2527/jas.2010-3538

Moser, D. W., J. K. Bertrand, I. Misztal, L. A. Kriese, and L. L. Benyshek. 1998. Genetic parameter estimates for carcass and yearling ultrasound measurements in Brangus cattle. J. Anim. Sci. 76:2542–2548. doi:10.2527/1998.76102542x

Mwansa, P. B., D. H. Crews Jr., J. W. Wilton, and R. A. Kemp. 2002. Multiple trait selection for maternal productivity in beef cattle. J. Anim. Breed. Genet. 119:391–399. doi:10.1046/j.1439-0388.2002.00363.x

NRC. 1996. Nutrient requirements of beef cattle. 7th ed. Natl. Acad. Press, Washington, DC.

Ochsner, K. P., M. D. MacNeil, R. M. Lewis, and M. L. Spangler. 2017. Economic selection index development for Beefmaster cattle I: Terminal breeding objective. J. Anim. Sci. 95:1063-1070 doi:10.2527/jas.2016.1231

Schiermiester, L. N., R. M. Thallman, L. A. Kuehn, S. D. Kachman, and M. L. Spangler. 2015. Estimation of breed-specific heterosis effects for birth, weaning, and yearling weight in cattle. J. Anim. Sci. 93:46–52. doi:10.2527/jas.2014-8493

Schneeberger, M., S. A. Barwick, G. H. Crow, and K. Hammond. 1992. Economic indices using breeding values predicted by BLUP. J. Anim. Breed. Genet. 109:180–187. doi:10.1111/j.1439-0388.1992.tb00395.x

Simm, G., C. Smith, and J. H. D. Prescott. 1986. Selection indices to improve the efficiency of lean meat production in cattle. Anim. Prod. 42:183–193. doi:10.1017/S000335610001789X

USDA Agricultural Marketing Service. 2015. http://www.ams.usda.gov/. (Accessed 6 July 2016.)

USDA National Agricultural Statistics Service. 2015. Quick stats. https://quickstats.nass.usda.gov. (Accessed 24 June 2015.)

Van Vleck, L. D. 1993. Selection index and introduction to mixed model methods for genetic improvement of animals: The green book. CRC Press, Boca Raton, FL.

Webster, A. J. F. 1985. Differences in the energetic efficiency of animal growth. J. Anim. Sci. 61(Suppl. 2):92–102.