THESIS

HERITABILITY AND REPEATABILITY ESTIMATES OF FIRST SERVICE CONCEPTION AND FIRST CYCLE CALVING IN ANGUS CATTLE

Submitted by

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ABSTRACT

HERITABILITY AND REPEATABILITY ESTIMATEES OF FIRST SERVICE CONCEPTION AND FIRST CYCLE CALVING

Described as the ability of an individual to conceive and remain pregnant, fertility remains one of the largest economic impacts on cattle producers. Infertility and(or) sub-fertility in the cow herd can result in financial losses due to a reduction in calf crop, lower quality calves, and increased breeding and replacement costs. Improving reproductive efficiency via altered management and selection could prove useful for cattle managers to minimize these costs while increasing genetic gain and income. However, historically the investigation of fertility traits has been minimal due to the binary nature of many of the traits making analysis difficult. In addition, given the nature of the phenotypes, heritability estimates of fertility traits are generally low, suggesting minimal genetic influence and therefore slow rates of genetic gain. First service conception (FSC) is a binary trait that describes the outcome of the first service of artificial insemination (AI) with success or failure phenotypes. Furthermore, a trait termed first cycle calving (FCC) describes the ability of a female to calve within a 21-day period of the due date based on the initial opportunity for conception in the first 21 days of the breeding season. The objectives of this thesis included the further investigation of the influential factors, genetic and environmental, on the success of first service conception and first cycle calving with the end result estimates of heritability and repeatability for these traits in Angus cattle.

Data used for this analysis was sourced from the Colorado State University Beef Improvement Center (1985 to 2018; CSU-BIC; N = 8,206) near Saratoga, Wyoming where an

Angus cow herd is managed for research purposes. The data used included breeding and ultrasound records, as well as data on the resulting and previous calves. Model selection resulted in fixed effects of birth year ($P < 0.001$), mating type (insemination based on estrus or during mass mating; $P < 0.001$), contemporary group consisting of synchronization protocol, semen type, and mating year ($P < 0.001$), previous calving ease ($P < 0.001$), and covariates of mating age in days ($P < 0.01$), and post-partum interval ($P < 0.001$) for both FSC and FCC. Variance components for the two traits were estimated using a REML procedure and then combined into estimates of heritability and repeatability. Analysis resulted in estimates of 0.03 ± 0.02 and 0.15 ± 0.03 for FSC and FCC, respectively for both heritability and repeatability when considering the entire female reproductive lifespan. When observations were segregated into immature and mature categories of beef females one to four years of age at mating and five years or greater, differences in parameter estimates became apparent. Estimates of heritability for FSC in immature and mature females were 0.04 ± 0.04 and 0.02 ± 0.05, respectively while repeatability was estimated for the two categories at 0.04 ± 0.04 and 0.08 ± 0.04. These estimates for mature females suggested a detectable influence of the permanent environment; however, all estimates are considered low for their respective parameter. When estimating the parameters for FCC, heritability was estimated at 0.04 ± 0.07 and 0.21 ± 0.04 for immature and mature female categories, respectively; while repeatability values were 0.11 ± 0.07 and 0.21 ± 0.04, respectively. These estimates suggest a permanent environmental effect; however, estimates of both parameters for immature females were low, while those for mature females can be classified as moderate. The findings suggested that altering temporary environmental management should remain the most critical factor when improving female reproduction. The largest genetic

contribution was for FCC in mature females resulting in more potential for selection and culling based on the phenotype for that trait.

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CHAPTER 1

INTRODUCTION

The reproductive success of individuals in the herd remains one of the leading sources of economic loss for the cow-calf sector of the beef cattle industry (Toghiani et al., 2017). This economic loss is a result of females who fall into one or more of three categories including those that fail to conceive, those that fail to maintain pregnancy and females who conceive late in the breeding season and fail to rebreed in the subsequent breeding season. These sub-fertile females cause profit loss to an enterprise resulting from increased breeding expenses, a reduction in calf crop, smaller calves at weaning, and shorter reproductive lifespans (Rahbar et al., 2016). The average number of females in the United States culled from the reproductive herd annually was estimated at 4.5% as reported by Bellows et al. (2002) due to a failure to conceive and/or the loss of pregnancy. This further strengthens the need to improve reproductive success in the beef cattle industry. Further understanding and partitioning the genetic and environmental influences on fertility may help improve these rates with additional knowledge of female fertility potentially leading to more informed cattle management and selection decisions.

Unfortunately, the evaluation of fertility traits in cattle historically has not been widely investigated due to the difficulty associated with recording such traits and reporting performance from a breed association perspective, resulting in limited data when compared to the available data for easier to measure traits. Historically, the limited evaluation can also be attributed to the binary/threshold nature of the phenotypes associated with fertility traits resulting in analyses that are difficult to understand and/or evaluate (Bormann and Wilson, 2010). Of these binary traits that have been previously evaluated, first service conception (FSC) describes the success or failure of the first service of artificial insemination (AI) during the designated mating season. Another binary trait, one with limited evaluation to date, first cycle calving (FCC) describes the outcome of a female calving within the first 21 days of her predicted due date based on the first opportunity for conception and therefore results in a binary (success/failure) phenotype as well. The ability of a female to calve early during the calving season, or success of FCC is preferential over females who conceive late in the breeding season. Late season calving results in issues such as extended calving intervals, lighter calves, and increased female culling as described by Rahbar et al. (2016) and Lesmeister et al. (1973). The ability to conceive and calve early, FSC and FCC are considered good measures when identifying a female's ability to perform reproductively (Ghiasi et al., 2011; Bormann and Wilson, 2010; Meyer et al., 1990). Additional research on reproductive traits that indicate a female's ability to become pregnant and produce offspring is needed to better understand how current production systems can be altered to maximize reproductive efficiency. Further understanding environmental and genetic influences on these traits could result in the maximization of reproductive success and increased producer profit either through the alteration of the environment, genetic selection, or both.

Past research suggests minimal genetic influence on fertility traits in beef cattle in which studies typically report estimates less than 0.2 and are therefore considered lowly heritable. The primary influence of the environment on fertility traits is supported by literature where a wide range of environmental sources that may affect a female's ability to conceive, have been reported. Of these environmental factors, body condition score (Shorten et al., 2015; Cumming, 1972), post-partum interval (Senger, 2012; Johnson and Funston, 2013), previous calving ease (Johnson and Funston, 2013), estrus synchronization protocol (Perry et al., 2013), and artificial insemination skill (Barth, 1993) among others, have been shown to influence the ability of an individual to become pregnant. While these environmental/managerial influences have been commonly reported along with heritability estimates, the estimation of repeatability for fertility traits in beef cattle has been limited. Estimating this parameter for both FSC and FCC could also indicate the existence of any permanent environmental influence on the trait and further guide what approach should be taken for improving performance. Past research of FSC heritability ranges from 0.02 to 0.22 however studies vary in cattle age, type, and sample size (Rahbar et al., 2016; Ghiasi et al., 2011; Gonzalez-Recio and Alenda, 2005; Bormann et al., 2006; Peters et al., 2013; Dearborn et al., 1973). While repeatability for the same trait has only been estimated once based on our review, the estimate, 0.02 by Rahbar et al. (2016), suggests that the trait is lowly repeatable and minimally influenced by genetics and permanent environmental effects. Heritability for traits similar to FCC such as calving day (CD), which has been measured with multiple approaches, has been estimated between 0.05 and 0.25. For example, Rasali and Crow (2004) estimated heritability of CD in both Angus heifers and cows and reported estimates of 0.16 and 0.25, respectively. Similarly, Meyer et al. (1990) estimated heritability of CD, recorded as the number of days between the initial opportunity for conception and the subsequent calving date, at 0.05, 0.08, and 0.09 for Hereford, Angus, and Zebu cross females, respectively. Repeatability for traits similar to FCC includes estimates of 0.10 to 0.22, 0.09 to 0.11, and 0.09 for traits days to calving, calving group, and days open, respectively (Meyer et al., 1990; Lesmeister et al., 1973; Oyama et al., 2002).

Therefore, the objective of this study was to determine the relative importance of genetic and environmental influences on FSC and FCC in commercial Angus cattle. An additional goal was to estimate the repeatability of these traits at different life stages. To carry out the study, current and historical records were obtained from the Colorado State University Beef

Improvement Center (CSU-BIC), a commercially managed, beef cattle operation near Saratoga, Wyoming. Due to the cost associated with infertility in beef cattle herds, additional knowledge of first service conception and first cycle calving could lead to more informed cattle management and selection decisions. Understanding how genetic and environmental influences vary between growing and mature females may be telling of how improving reproductive success should be approached when considering different age categories within the herd.

CHAPTER 2

REVIEW OF LITERATURE

Success and economic viability of beef cattle production relies on the reproductive success of heifers, cows, and bulls in an operation. While there are differences between the fertility traits of both males and females, selection on these traits is desirable in both sexes as fertility is reliant on both sexes. Determination of male fertility is primarily dependent on semen quantity and quality, as well as the ability of that bull to cover females when natural service is employed (Meyer et al., 1990). Alternatively, female fertility is described as the ability of the heifers/cows in the herd to conceive during a fixed-length breeding season, maintain that pregnancy to calving, and wean calves that meet the goals of the producer (Toghiani et al., 2017; Lamb et al., 2008). Females that negatively impact this economic viability are those which do not meet at least one of the requirements for a productive beef cow. These infertile females can fall into one of three categories; those who do not conceive during the designated breeding season, those who conceive but do not maintain the pregnancy, and females who conceive late in the breeding season. Females that do not meet fertility productivity requirements are the main source of economic loss for producers (Lamb et al., 2008). These monetary losses result from a reduction of the number of females from the herd due to culling, a smaller calf crop, longer calving intervals, increased breeding expenses, and shorter female reproductive life spans (Rahbar, Aminafshar, Abdullahpour, and Chamani, 2016). By failing to produce a marketable calf, these cows will not produce an economic return the following year in a conventional one breeding season per calf produced operation (Lamb et al., 2008).

Female reproductive failures often result in elimination from the herd via non-pregnant culling. As reported by Bellows et al. (2002), on average 4.5% of females in the herd are culled annually due to failure to conceive and/or maintain a pregnancy. Due to the cull rates of open cows, identifying fertile females, or those who can conceive early in the breeding season and maintain their pregnancy to calving, in addition to further understanding how fertility is impacted is vital for maximizing economic viability of a cow-calf operation. To limit the economic loss that comes from open females, the implementation of a sound breeding program is widely used to maximize pregnancy rates. A commonly implemented technology in beef industry breeding programs, artificial insemination (AI), is used to allow the insemination of a large number of females to high quality, superior sires whose progeny's performance can be more accurately predicted to possess favorable phenotypes for the economically relevant traits of interest to the producer. In many operations that utilize AI, the service is often followed by natural service which remains the breeding method until the close of the season. This additional breeding method maximizes pregnancy rate by providing the opportunity to conceive to females who did not settle from the AI service and therefore reduces losses due to open females. While sire quality is important in the selection of AI semen used, females that are bred using natural service are covered by bulls who are also selected based on economically relevant traits, however these bulls can only service a limited number of females per breeding season (Perry, Dalton, and Geary, 2011). When insemination and natural service are paired in the breeding system, cleanup bull cost should also be considered. In an economic analysis by Hughes (2013), natural service bulls result in a cost of $56/female for each year when considering bull feed and care input costs when a 1:20 bull to female ratio is used. This particular style of breeding program involves costs for both AI and natural service, if fertility traits could be maximized an increase in conception rates and profit with a decrease in cover bull costs could result. However, improvement of the number of females in the herd who conceive early could also prove beneficial when considering advantages in calf weaning weight and rebreeding success compared to those who conceive late (Funston et al., 2012; Lesmeister et al., 1973).

Section 1: Environmental and Management Factors and their Impact on Female Fertility

While identifying and selecting females who are fertile through trait evaluation can maximize operation profitability and productivity, evaluating fertility traits has been historically difficult resulting in limited data and analysis for such traits (Bormann and Wilson, 2010). The difficulty is unfortunate as fertility and reproductive traits are some of the most economically relevant traits in beef cattle production. However, the use of selection to improve genetic gain and predictive accuracy of fertility traits could be a promising tool to maximize reproductive performance in the beef cattle industry (Toghiani et al., 2017). While economically important and influential on cow-calf operation success, reproductive traits are typically classified as lowly heritable redirecting focus to management techniques to effectively maximize reproductive efficiency. Currently, proper management and heifer development play key roles in reproductive performance as pregnancy rates can be affected by a number of factors including age/maturity, nutrition, body condition score, and other management tactics (Shorten, Morris, and Cullen, 2015).

1.1 Heifer Development

Of the vast number of factors that can affect female fertility in both beef and dairy cattle, reproductive success of a cow-calf operation is dependent on the management of the breeding herd, contributing to this success is the selection of animals for replacements. At the root of the breeding herd are the replacement heifers that get introduced to the herd to expand or continue production (Payne, Vander Ley, and Poock, 2013). According to Hughes (2013), 12% to 14% of the females in cowherds in the mountain states are replaced each year with newly introduced heifers taking the place of females culled for poor performance or to increase herd size. With the introduction of new females, the development and management of heifers up to breeding age and throughout their life is vital for maximizing reproductive success (Payne, Vander Ley, and Poock, 2013). Performing an economic analysis on the cost of developing replacement females, Hughes (2013) estimated the cost of conception of the heifer herself to the diagnosis of pregnancy after breeding at one year of age at $1,375 in which the average weaning market value of $881 was the opportunity cost of retaining a female. However, when accounting for heifers who fail to conceive, the cost for pregnant replacement heifers was $1,618 per head using an 85% pregnancy rate in a natural service program. While this cost fluctuates, heifer development remains a substantial expense for cattle managers. When heifer development is executed poorly, mistakes associated with nutrition or health for example can accumulate, causing long-term negative consequences that affect the performance and economic viability of an operation (Payne et al., 2013). Furthermore, if retained females were developed properly, they were generally more fertile and stayed in the cowherd longer. As a result, this developmental cost would be less per year over a longer productive lifetime of the cow. Commonly, the industry goal of beef cattle operations and endpoint of development is for a heifer to breed near 15 months of age, calving by two years of age if the breed reaches sexual maturity at approximately one year of age. To meet this goal, the heifer should be approximately 60-65% of their projected mature body weight and reach puberty prior to 15 months of age to be at an adequate maturity level to conceive during the breeding season and produce a calf in her second year of life (Hughes, 2013). Not only does the heifer need to conceive and gestate, she will need to lactate and maintain her calf, all while rebreeding the following season to stay in the herd. Important requirements for a heifer to fulfill, proper development in early life stages give the heifer her best opportunity of meeting these milestones. In summary, overall fertility is not only affected by existing cows, but by heifers entering the herd who will eventually become cows, thus historically the development of heifers to reach breeding goals is important for maximizing and maintaining fertility in the herd (Payne et al., 2013).

1.2 The Effect of Age, Nutrition, and Health on Female Fertility

Aside from heifer management that affects conception rates, age has been shown to have a detectable relationship with female fertility. A study by Shorten, Morris, and Cullen (2015) found a quadratic relationship between the age of the female at calving and pregnancy rate in Angus cattle. The pregnancy rates of the cattle in the study increased between the ages two and seven, but decreased between ages seven and eleven, effects independent of the culling strategies used. Results of this study suggest that pregnancy rate and overall fertility of females maximize once they reach a threshold age. While this specific threshold is not known, it potentially falls between five and seven years of age based on the findings of the study and is illustrated in Figure 2.1. (Shorten, Morris, and Cullen, 2015). Results show that an appropriately aged cowherd may result in higher pregnancy rates.

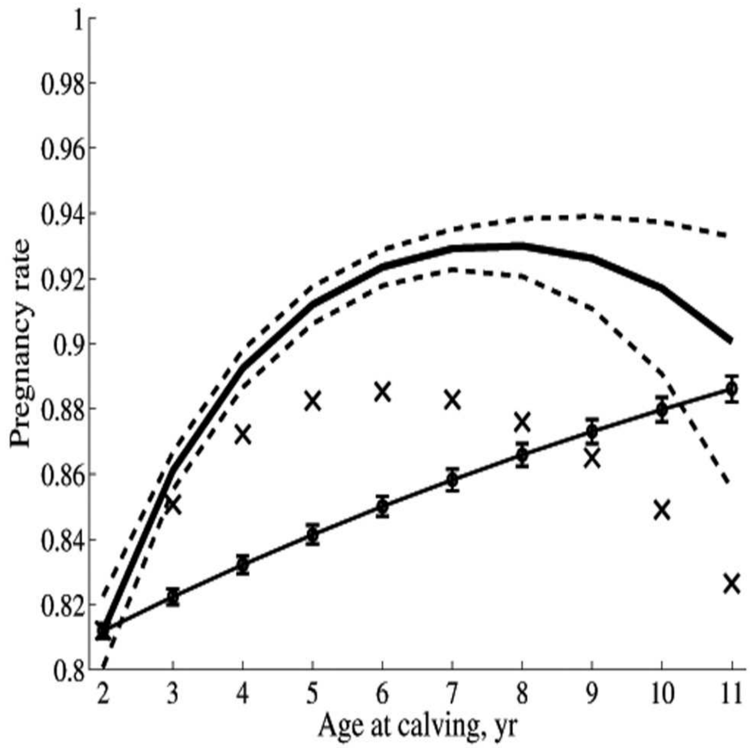

Figure 2.1 The relationship between age at calving in years and the pregnancy rate. The bolded solid line represents the quadratic fit of the data, showing a significant negative quadratic effect between female age at calving and pregnancy rate ($P < 0.01$). The thin solid line and circles reveal the relationship when nonpregnant culling is employed, the linear relationship shows an increase in pregnancy rate with increase in age. The crosses represent the difference between culling strategies and represent the relationship between age and pregnancy rate independent of culling strategy. Reprinted from "The effects of age, weight, and sire on pregnancy rate in cattle," by P. R. Shorten, C. A. Morris, and N. G. Cullen, 2015, Journal of Animal Science, 93, 1535-1545.

Body condition being another factor of interest, Shorten, Morris, and Cullen (2015) also investigated pre-breeding weight of females on fertility finding a significant quadratic relationship between weight and pregnancy rate. This relationship is likely due to the requirement of additional body reserves for pregnancy maintenance and resumption of estrous where females with low body weight at time of breeding had lower pregnancy rates.

Furthermore, cows whose weight decreased between breeding and weaning of their current calf had lower pregnancy rates. In general, weight which is largely influenced by the level of nutrition and body condition of cows has also been found to have a significant effect on pregnancy rate. Findings suggest that keeping females at an optimum weight and body condition, as well as increasing the plane of nutrition several weeks prior to mating can successfully improve pregnancy rates as illustrated in Figure 2.2. (Shorten et al., 2015).

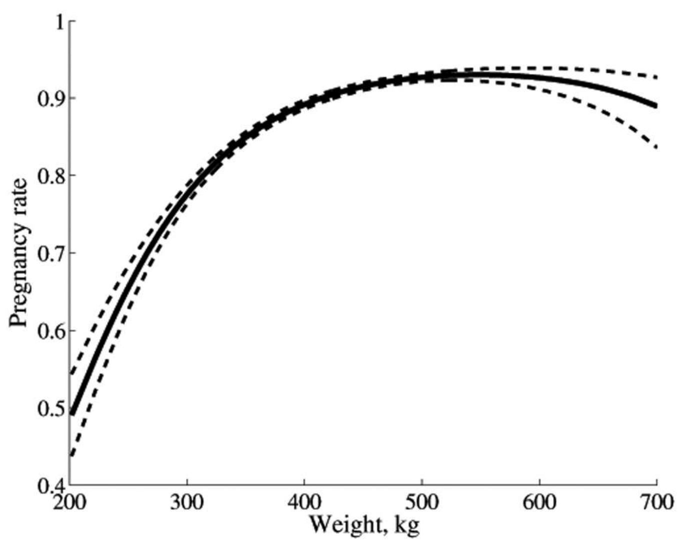

Figure 2.2 The relationship/effect of pre-breeding female weight on pregnancy rate. The bold solid line represents the quadratic fit of the data, the dotted line represents the standard error of the mean. The positive quadratic relationship is significant between the pre-breeding female weight and pregnancy weight ($P < 0.01$). Reprinted from "The effects of age, weight, and sire on pregnancy rate in cattle," by P. R. Shorten, C. A. Morris, and N. G. Cullen, 2015, Journal of Animal Science, 93, 1535-1545.

Results of the Shorten et al. (2015) study are consistent with findings of Cumming (1972) who found that there was a decrease in embryo survival in females who experienced a decrease in body weight near breeding, additionally animals who experienced a lower plane of nutrition had a greater rate of return to service.

In addition to age and body weight, calving date has also been reported to have a significant linear effect on pregnancy rate, in which cows that had calves later in the calving season had lower pregnancy rates the following breeding season (Shorten et al., 2015). This decrease on rate of pregnancy can be explained by anestrus following calving, the period of time a female does not ovulate or show estrus, and its effect on reproductive performance (Senger, 2012). Including the period of anestrus, the post-partum interval (PPI), the period of time between calving and rebreeding, is vital for allowing uterine involution and resumption of estrous. These physiological changes enable a female to conceive, and are influenced largely by nutrition, but also by the degree of uterine damage incurred during the previous parturition. This return to reproductive soundness is especially difficult for first calf heifers who are still allocating energy to growth, in addition to lactating, recovering from calving, and meeting the nutritional demands to conceive (Johnson and Funston, 2013). In summary, various factors affect conception ranging from female age, nutrition, and the consequences of previous calving (e.g. timing, dystocia, etc.). These factors are typically controlled using proper management to ensure females have the highest likelihood of becoming pregnant during breeding season (Gonzalez-Recio and Alenda, 2005).

The product of nutrition, development, and maturity positively impact heifer and cow fertility alike, however vaccination programs can further influence fertility by limiting reproductive damage or losses due to disease or illness. Health of animals is vital for both females already in the cow herd and those preparing to enter the reproductive herd due to the significant effect that health can have on reproductive soundness and fertility (Payne et al., 2013). Of the health factors that have been reported to affect female fertility or maintenance of pregnancy, the presence of disease or intestinal parasites can negatively impact reproductive success. Specifically, heifer development and breeding programs should include a vaccine protocol that is best suited for the operation and the risk that females may face leading up to conception and be based on the presence of disease vectors. These precautions are implemented to limit infectious diseases that may be detrimental to growth, development, and reproduction, resulting in reproductive and profit losses (Payne et al., 2013). Resulting in an estimated cost of $441 to $502 million in losses annually for beef cattle producers, reproductive diseases and conditions such as metritis, pyometra and retained placentas can impact the economic viability of an operation (Bellows et al., 2002). Other diseases needing specific consideration in more North American environments include bovine viral diarrhea virus (BVDV), infectious bovine rhinotracheitis (IBR), and leptospirosis. Infection of BVDV can severely impact success of beef production by causing early embryonic death, pregnancy losses, and deformed calves (Kendrick, 1976). Affecting both the respiratory and reproductive systems of females, IBR's impact on reproduction can result in losses due to abortions with reports higher than 50% in severe cases (Kirkbride, 1992). Lastly, leptospirosis is best known for causing late-term abortions, but it also plays a role in early death of embryos, birth of stillborn or weak calves, and general infertility (Leonard et al., 1992). Collectively, diseases pose a significant threat to reproductive success thus stressing the importance of an appropriate herd health program to minimize losses.

Aside from infectious disease, infestation of internal parasites such as roundworms can also result in decreased fertility and poor conception rates, specifically in young, growing females with naïve immune systems. The resulting poor reproductive performance can be credited to the parasites' effect on appetite and feed intake and subsequently delaying growth, maturity, and onset of puberty resulting in underdeveloped females at time of mating (Stromberg and Gasbarre, 2006). This effect on performance can be combatted using an effective parasite control program to limit parasitism's impact on both developing heifers and mature cows. However, different methods of applying parasite control products have varied in efficacy, for example a study by Walker et al. (2013) reported values for fecal egg count reductions per gram of feces when using pour-on and oral dewormers at 99.9 and 78.0, respectively. Limiting parasitism in heifers can prove beneficial by maximizing growth, sexual maturity, allowing them the highest probability of conceiving during their first breeding season and maintaining a place in the herd. Implementing both a vaccine and parasite control protocol that protects developing heifers as well as cows without causing any additional effect to reproduction or current pregnancies can allow elevated protection against disease and further limit reproductive losses (Payne et al,, 2013).

1.3 The Effect of Artificial Insemination, Estrus Synchronization Protocols, Semen Thawing and Insemination Technician on Conception

In addition to management of female environment, various reproductive technologies such as artificial insemination (AI) and ultrasound, have been utilized to further improve and manipulate female conception rates in both the beef and dairy industries (Barth, 2013). As reported by Senger (2012), the commonly utilized reproductive technology artificial insemination (AI) is considered the most important technology for accelerating genetic improvement. The development of technologies like AI, allows cattle managers to combine various procedures to create a program with the goal of maximizing reproductive success within their operation and producing a product more desirable to them. The producer developed program is implemented with the goal of improving reproduction, genetics, and economics of the operation through the maximization of reproductive performance. Use of such technologies, although beneficial, can be hindered by the need for adequate facilities, skilled labor, and the potential economic tradeoff (Patterson and Brown, 2013). The complexities associated with reproductive technologies, for example estrus synchronization, artificial insemination, and embryo transfer, have resulted in a regional difference in adoption of the tools in the United States. The use of reproductive procedures was lower in the eastern and south-central regions of the states in which only 22% and 32% of producers used any reproductive technologies, respectively. Higher adoption rates were associated with the western and central regions of the U.S. which when surveyed, 55% of western and 49% of central producers use at least one reproductive procedure in their program (NAHMSb, 1993-08). Although reproductive techniques are not in use by all operations, implementing these tools can prove useful in reaching reproductive and profit goals while accelerating genetic improvement when possible (Patterson and Brown, 2013).

An additional reproductive technology commonly used with AI is estrus synchronization, a technique to manipulate the cycles of a group of females eligible for breeding ensuring that they will be in estrus, or "standing heat", near a specific time. This synchronization of the estrous cycle of a group of females allows for a more concentrated group of females in heat permitting a shorter breeding window and fewer days needed for heat detection and labor for insemination and subsequent calving. Otherwise, heat detection and insemination would take place for over a 21-day span, the length of the average bovine estrous cycle. Estrus synchronization can be carried out by various protocols using a single hormone exclusively or in combination with others (Perry et al., 2011). These hormones include those such as progesterone, prostaglandin $F_{2\alpha}$ (PG), and gonadotropin-releasing hormone (GnRH) which are able to manipulate the estrous cycle accordingly, resulting in reduced anestrous period after calving, initiation of puberty on prepubescent heifers, or short cycling females who are cycling normally for example. The control over the estrous cycle via estrus synchronization results in an increased percentage of cows/heifers becoming pregnant during breeding season further allowing producers to maximize fertility (Perry et al., 2011). A study by Schafer, Brinks, and LeFever (1990), reviewing the impact of implementing estrus synchronization on calving dates and weaning weights, revealed that calves who were the result of estrus synchronization were on average born 13 days earlier than their counterparts and at weaning were 41 pounds heavier. These results further reveal the advantages of implementing estrus synchronization and other technologies in beef cattle production.

With advancements in reproductive technologies, artificial insemination can also be executed by beef producers without monitoring females for estrus (Patterson and Brown, 2013). An additional component of estrus synchronization is the utilization of timed artificial insemination (TAI), or the use of synchronization hormones to induce a predictable ovulation followed by the strategic timing of AI. This allows for the elimination of heat detection in females and the insemination of a group of heifers/cows at one time point, reducing labor associated with estrus observation and concentrating labor during the insemination process. However, success in terms of conception rates with TAI in comparison to insemination on standing heats alone have been conflicting (Perry et al., 2011). A study by Stevenson et al. (2002) found higher conception rates for females who were inseminated based on standing estrus (44%) in comparison to the rates of females who underwent TAI (33%) using the same protocol but with an additional injection of a GnRH on the day of insemination ($P < 0.05$). Conflicting results to those of Stevenson et al. (2002) include conception rates reported by Lemaster et al.

(2001) of females subjected to a TAI protocol at 31%, while females who were bred based on standing estrus averaged a rate of 21% ($P < 0.05$). It was suggested that the low rates reported by Lemaster et al. (2001) were likely due to the small proportion of cycling females at the start of the synchronization protocol. Conception varies based on AI protocols, though there are many more factors that affect conception rates.

While much of the success of AI is dependent on the synchronization protocols implemented with both breeding on heat and TAI, other factors are also vital in the success of AI. According to Barth (1993) in addition to accurate heat detection, the success of AI is influenced by semen quality and technician experience. Insemination is typically successful when the semen is properly placed in the uterus near the time of ovulation of the female, though this can be unsuccessful when the semen quality or volume is poor, it is thawed/handled incorrectly, and/or the semen is placed improperly (Barth, 1993). Of the factors resulting in AI failure, the mishandling of semen can be accentuated by poorly trained technicians handling and thawing semen straws during storage or immediately prior to insemination. Semen damage can take place during the cryopreservation process if done incorrectly but can also occur when the semen is not maintained at a low freezing temperature and allowed to thaw before its planned use. When the sample is allowed to reach temperatures above minus 130 degrees Celsius and then re-cooled, recrystallization may result and damage to the cellular structures will ensue, a phenomenon possible when lifting straws up to or above the neck of the semen storage tank. This damage to the spermatozoa can significantly reduce the ability of the sample to fertilize an oocyte in the female tract. In addition to semen temperature, experience level of the inseminator can also impact AI success. Conception rates for AI can be maximized when the technician deposits the semen in the uterus in an adequate amount of time with causing little to no damage to the cervix or uterus. As insemination time lengthens and reproductive tract damage occurs, AI success declines as conception fails to occur (Barth, 1993). Therefore, proper management of semen and efficient deposition by individuals with technical skills is vital for optimizing AI conception rates.

Section 2: Genetic Influence on Reproductive Traits

Due to the influence of various environmental factors, much of the effort placed on reproductive success by cow-calf producers has revolved around management strategies, both herd management and the adoption of reproductive technologies. This focus is likely due to reproductive traits being generally lowly heritable, suggesting that individuals are influenced less by their genetics and more by the environment they are managed in. By definition, heritability is a population measure that describes the strength of the relationship between the performance and the breeding values for a specific trait (Bourdon, 2000). If heritability is estimated as “high” for a particular trait, the phenotype is a good indication of the underlying breeding value associated with that trait. This allows the opportunity of selection based on breeding values or phenotypes of an individual’s parents for a trait. Alternatively, with “low” heritability, phenotypic values are poor indicators of breeding value and selection on the phenotype of the trait will provide little effectiveness in the prediction on their offspring’s performance (Bourdon, 2000).

A fertility trait with low heritability estimates suggesting minimal genetic influence as expected compared to reproductive traits in general is pregnancy rate, a measure of herd fertility calculated by the number of successful pregnancy observations at the end of the breeding season, or per 21-day period in the dairy industry, divided by the number of total females inseminated and/or exposed to a cover bull during breeding season (Bormann et al., 2006). However, a study by Hetzel et al. (1989) selected and sorted Brahman-Shorthorn females based on low and high pregnancy rates and found an improved rate of 0.12 of the high group over the low pregnancy group over a number of years, in addition the high pregnancy group conceived earlier in the breeding season on average than the low group. These findings suggest that selection of females based on pregnancy rate can potentially improve overall long-term fertility and reproductive performance of the herd (Hetzel et al., 1989). In addition to their investigation of factors affecting conception, Shorten et al. (2015) also estimated the heritability of pregnancy rate with the direct additive effect at $h^2_D = 0.0049$ and maternal additive effect at $h^2_M = 0.0041$, both levels considered as "lowly heritable". In a study by Bormann et al. (2006) heritability of pregnancy rate and conception rate were estimated and reported at 0.13 and 0.03, respectively. Due to the heritability of reproductive traits in general, genetic progress is typically slow, potentially explained by the results of the Bormann et al. study of 2006 and Shorten et al. of 2015 which suggests minimal genetic influence on the trait.

2.1 First Service Conception and First Cycle Calving

While pregnancy rate reflects the ability of the herd to conceive throughout the breeding season, conception rates of the first service of artificial insemination (FSC) is telling of a female's ability to conceive at her first opportunity (Bormann et al., 2006). According to Ghiasi et al. (2011), success of the first service of insemination is a good indicator or measure of a female's fertility and ability to become pregnant. This would be in comparison to females that conceive after several services of AI, or through natural services by a cover bull. Identifying females who conceive on their first service results in increased efficiency regarding semen and labor costs, as well as providing the potential to produce a heavier and higher quality calf resulting from AI rather than a calf of natural service. Additionally, females who conceive at first-service will calve sooner in the subsequent calving season, experience a longer post-partum interval (PPI), and have an advantage for conceiving on the first-service of the next breeding season (Bormann et al., 2006). A longer PPI allows for a longer period of time for uterine involution, tract repair, and recovery of body condition loss (Senger, 2012). Females who conceive late in the breeding season, a sign of infertility, calve later in the subsequent calving season and wean younger and lighter calves, becoming another threat to the economic viability of an operation. When AI is partnered with the use of estrus synchronization and herd FSC is high, breeding can be carried out during a shorter window of time resulting in a more uniform calf crop in which calves are older and heavier at weaning than the natural service counterparts conceived later in the breeding season (Perry et al., 2011).

In addition to FSC, the ability of a female to calve early in the calving season has also been considered as a good measure of female fertility (Meyer et al., 1990). Females who conceive and calve early produce calves which are associated with heavier birth weights as well as produce female progeny who have an increased ability to also conceive and calve early (Mousel et al., 2104). A trait representing the ability of a female to conceive and produce a calf, calving day (CD) is calculated based on the date of the first calf born effectively placing females in order of calving given that they all experienced the start of the breeding season at the same time (Bormann and Wilson, 2010). A study by Funston et al. (2012) investigated the effect of three 21-day period calving groups on heifers' calf performance as well as the ability for females to rebreed. Results revealed that females who calved in the first 21 days of the calving season had a group pregnancy rate that was 3% and 9% higher than the second and third calving groups, respectively. The influence of calving period was also shown to have an effect on the ability of progeny retained for replacement females to conceive when compared between calving groups.

Pregnancy rates for female progeny born to each of the three 21-day calving periods were significantly different (*$P = 0.02$*) at 90, 86, and 76%, respectively with fertility of the first mating decreasing with each advancing calving group (Funston et al., 2012). Furthermore, heifers who calved in the first 21-day period of the calving season were more likely to produce calves who would also calve in the first calving group when producing their first calf *($P < 0.01$)*. This difference in fertility between calves born in early, middle, and late groups was likely due to the importance of age at the time of mating rather than the rate of gain experienced by the calves from birth to breeding. However, there are clear advantages to retaining females who calve early in the calving season (Funston et al., 2012).

The study conducted by Mousel et al. (2014) who investigated effects of heifers calving in 21-day periods, found that there was a positive relationship between heifers who calve in the first calving group and female longevity and lifetime production. Heifers that calved in the first 21-day period experienced an average of 7% and 24% greater longevity compared to heifers who calved in the second or greater calving periods when tracking two different herds, respectively. In addition to the favorable increase in female longevity, first calving period heifers produced significantly heavier progeny at weaning ($P \leq 0.03$) for their 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, and 5^{th} calves. However, there was no difference in weaning weight between the 6^{th}, 7^{th}, 8^{th}, and 9^{th} calves of females who experienced differing calving periods when producing their first calf (Mousel et al., 2014). Concluded by Mousel et al. (2014), heifers who calve in the first 21-day period of their first calving season may be the best phenotypic indicator of female fertility due to its effect on female longevity.

A trait which is similar to the calving period investigated by Funston et al. (2012) and Mousel et al. (2014) which also takes into account the ability for a female to conceive and calve early is first cycle calving (FCC). A binary trait, FCC phenotypes are divided between females who calve within the first 21-day period, the length of the bovine estrous cycle from the due date based on the first opportunity for conception and those who do not. Similar to the benefits associated with females who conceive on their first service of AI, females who are able to calve early in the calving season will produce heavier calves at weaning due to the allowance of more time for calf growth (Funston et al., 2012). An advantage of further understanding the influences on FCC is the potential for the use of that information by both producers who utilize AI and those who utilize natural service only.

2.2 Heritability of First Service Conception and Traits Similar to First Cycle Calving

Since pregnancies resulting from the first service of AI is revealing of females' reproductive ability, there has been interest in improvement of the trait. Contrary to most performance traits, FSC is a binary trait, one that has two possible outcomes of success or failure. Females who can settle on the first service and maintain the calf to weaning improve the profitability of an operation by reducing the amount of labor and funds necessary to produce the resulting calf. Furthermore, these calves conceived from the first service are older, heavier and have the potential to be sired by high-quality, genetically superior sires selected based on traits economically relevant to the producer (Bormann et al., 2006). As suspected, the average rate of first service conception will be lower than pregnancy rate as there is only one opportunity for females to become pregnant in comparison to several opportunities spanning a breeding season. Bormann et al. (2006) findings revealed rates for both FSC and heifer pregnancy (HPG), a pregnancy rate specific to heifers, for Angus heifers at 60% and 93%, respectively, where Peters et al. (2013) reported rates at 53% and 78%, respectively. While substantially lower than pregnancy rate, improvement of FSC shows potential for increasing reproductive efficiency.

These studies and others also estimated the heritability of various fertility traits, and included FSC to determine the level of genetic influence on the traits resulting in a range of estimates between 0.02 and 0.22 (Rahbar et al., 2016; Ghiasi et al., 2011; Gonzalez-Recio and Alenda, 2005; Bormann et al., 2006; Peters et al., 2013; Dearborn et al., 1973) which are summarized in Table 2.1. A trial by Peters et al. (2013) estimated the heritability of FSC and HPG using 800 Brangus heifers composed of 3/8 Brahman and 5/8 Angus breeds. Their findings included estimates of heritability of both traits, FSC and HPG at 0.18 and 0.10, respectively. All considered low, estimates of Peters et al. (2013) are similar to those reported in the Bormann et al. study of 2006 who estimated the heritability of pregnancy rate and conception rate at 0.13 and 0.03, respectively. However, while Peters et al. (2013) utilized records of *Bos indicus* influenced Brangus heifers to estimate heritability, Bormann et al. (2006) used records of *Bos taurus* Angus heifers. The estimates for FSC and HPG found in this study, align with the generally low heritability of reproductive traits and those estimates of Shorten et al. (2015). Furthermore, these results are similar to those of Rahbar et al. (2016) who also investigated the heritability of various fertility traits in Holstein dairy cattle finding fertility traits as lowly heritable, and primarily estimated below 0.1. Another study using dairy cattle was led by Gonzalez-Recio and Alenda (2005) who investigated the heritability of fertility traits in Holstein Dairy cattle including the success of first service conception. Heritability estimates of the study were classified as low and ranged from 0.02 to 0.06, in which the heritability estimate for FSC was 0.04. Similarly, in a study conducted with Holstein cattle records by Ghiasi et al. (2011) who also estimated heritability of fertility traits, revealed a range of 0.03 to 0.08 for various traits. Of these traits, the success of first service of AI had the lowest estimation of heritability at 0.03.

Furthermore, Ghiasi et al. (2011) concluded that interval traits for fertility had higher estimates of heritability over the binary or categorical traits based on the results of their research.

Table 2.1 Summary of heritability (h^2) and repeatability (r) estimates of FSC and/or FCC similar traits in various cattle types.

Trait	h^2	r	References
First Service Conception	0.015	0.021	Rahbar et al., 2016
	0.03	-	Bormann et al., 2006
	0.03	-	Ghiasi et al., 2011
	0.04	-	Gonzalez-Recio and Alenda, 2005
	0.18	-	Peters et al., 2013
	0.22	-	Dearborn et al., 1973
Days to Calving	0.05 to 0.09	0.10 to 0.22	Meyer et al., 1990
	0.11	-	Johnston & Bunter
Calving Day	0.16 to 0.25	-	Rasali & Crow, 2004
Calving Group	-	0.09 to 0.11	Lesmeister et al., 1973
Days Open	0.05	0.09	Oyama et al., 2002

While heritability of FCC has not been previously estimated, there have been similar traits describing the ability of a female to conceive and calve early in which heritability estimates have been reported. Describing the ability for a female to produce a calf early in the calving season, calving day (CD) was previously investigated by Rasali and Crow (2004) for each heifers and cows of the Angus breed. The resulting estimate for heifers was reported at 0.16, while the parameter in cows was reported at 0.25. Another trait which describes the ability of a female to conceive and calve early is days to calving which has been estimated by Meyer et al. (1990) between 0.05 and 0.09 in different breeds and also estimated at 0.11 by Johnston and Bunter (2010), both suggesting minimal genetic influence. Estimated by Oyama et al. (2002) days open also expresses an individual's ability to rebreed, a heritability of 0.05 was calculated for this trait further suggesting the most impactful effect on the trait comes from the environment the female is currently managed in or has experienced in the past. Collectively, the literature available on FSC, traits similar to FCC, and other fertility traits support that they are lowly heritable and influenced little by genetics.

Section 3: Repeatability

3.1 Definitions and Applications of Repeatability

A parameter which is similar to heritability for prediction of future performance of a trait is repeatability. However, instead of a prediction for offspring performance, repeatability, denoted by r, is the reliability or correlation between the performance records of a repeated measure trait. A repeated trait is one in which an individual can have multiple measures or performance records for that same trait at various time points throughout their life. Examples of these traits include milk yield in dairy cattle, weaning weights of calves from the same dam, and litter size in sows. Estimating the repeatability of such traits could potentially allow more informed predictions of successive performance of an individual if the repeatability is found to be high, or greater than 0.4. Alternatively, low estimates of repeatability indicate one performance record cannot be relied on for prediction of future performance records (Bourdon, 2000). The estimation of repeatability requires at least two records on a repeated trait, this is telling of how well the second measure can be predicted based on the knowledge gained from the first record. Generally, the prediction is a function of the regression coefficient of the second record on the first (Falconer and Mackay, 2009).

While repeatability of a trait describes the strength of the relationship between repeated phenotypic values, there are multiple definitions of the parameter. Initially the concept can be viewed as the correlation between the measurements of a repeated trait for a specific population. In this scenario, a high repeatability measure indicates an individual's single performance record is generally considered a good indicator of that individual's subsequent records (Bourdon, 2000). However, an additional definition of repeatability is the strength of the reliability or consistency between an individual's single performance record and its producing ability, the sum of the genotypic value and permanent environmental effect for a repeated trait. When the repeatability of a trait is high, the performance record(s) is closely associated with the producing ability for that trait, however when the repeatability is low the producing ability has little to no correlation to the individual's performance. Both definitions of repeatability are correlations, either the correlation between repeated measurements of the same trait or the correlation between a single performance record and the producing ability for a specific trait. Additionally, the parameter can be viewed as the ratio of variances, the variance of producing ability to the phenotypic variance (Bourdon, 2000).

As mentioned, an alternate definition of repeatability involves the correlation between the producing ability for a trait and a single performance record. Producing ability (PA) reveals the overall potential for an individual's performance in a repeated trait. The individual's ability for producing milk, calf weaning weight, and piglet litter size is described by its PA as are other repeatedly measured traits. Affecting an individual's potential to perform, the producing ability includes all permanent factors in the genetic model, both genetic and environmental components. These permanent effects on production include the genotypic value determined at conception, the sum of breeding value and gene combination value effect (Bourdon, 2000). Additionally, PA is a function of the permanent environmental (E_p) effects influencing an animal's performance for every observation of a repeated trait. An example of such a permanent effect from the environment includes the influence of calfhood nutrition and potential over fattening on lifetime milk production in adulthood. Alternatively, environmental effects that do not permanently influence an individual's potential to perform, but can have influence over a single performance record, are temporary environmental effects (E_t). Forage digestibility for example is considered a temporary environmental effect, or having a short-term effect on an individual's phenotype, milk in this example. When digestibility is high, milk production will increase, however when digestibility is low milk production will be reduced. While digestibility can affect milk production in cattle, this is a temporary effect as forage digestibility during a period of time does not affect milk production over that female's lifetime (Bourdon, 2000).

The genetic model for repeated traits includes positive and negative deviations from the population mean for each of its components. Therefore, each of the components in the model average to zero across a population represented by the following:

$$\overline{BV} = \overline{GCV} = \bar{G} = \bar{E}_{p} = \bar{E}_{t} = \overline{PA} = 0$$

The basic components of this model, breeding value (BV), gene combination value (GCV), and the temporary and permanent environmental effects are considered independent of one another (although under certain management conditions there may be relationships present). For example, the temporary environmental effect of forage digestibility does not affect the genetic merit of an individual (Bourdon, 2000). Similarly, permanent environmental effects such as calfhood nutrition have no influence on the genotypic value of the individual as this is determined at conception. However, the producing ability is only independent of the temporary environmental effect as the components of PA are breeding value, gene combination value, and the permanent environmental effect (Bourdon, 2000).

Due to the unknown environmental effects that an animal may be temporarily influenced by, it is impossible to determine exactly what the individual's next record will be. This uncertainty can be lessened by predicting the producing ability mathematically using a MPPA, or most probable producing ability developed from performance data (Bourdon, 2000). The use of information is dependent on the goal of those using it. If one is more concerned with the performance of that animal, for example a cow calf producer, the MPPA or PA should be the main focus as this is the best predictor of the animal's own performance for repeated traits. Alternatively, a seedstock producer would be more interested in the breeding value of the animal half of which will be passed down to its progeny and independent of environmental effects. In short, producing ability is neither a result of strictly the genetics or the environment, but is a function of the permanent components of the genetic model of the individual (Bourdon, 2000).

Mathematically, there are two means to view repeatability based on the alternate definitions of the parameter and sources of data used. When using multiple performance records for a repeated trait the following can be used:

$$r = r_{\mathrm{P1,P2}}$$

Within this formula, the P1 and P2 subscripts represent the first and second performance records of an individual for the repeated trait. Using the producing ability and a single performance record to measure the relationship, the following is used:

$$r = r_{\mathrm{P,\,PA}}$$

This formula uses a single performance record for the trait (P) and it's producing ability (PA). However, when considering repeatability as a ratio of variances, the parameter can be calculated with the following formula:

$$r = \frac{\sigma_{PA}^2}{\sigma_P^2}$$

In this scenario, σ^2_{PA} represents the producing ability variance, while σ^2_P denotes the phenotypic variance. Like correlation, repeatability follows the same range and is measured from -1 to +1. More realistic measurements include those near zero where the trait is hardly repeatable, while an estimate near +1 means a trait is highly repeatable (Bourdon, 2000). Like heritability, the measurement of repeatability can be categorized as lowly, moderately, or highly repeatable. Exactly like heritability, the typical ranges are the same for repeatability in which any measurement below 0.2 is considered low, between 0.2 and 0.4 is moderate, and relationships greater than 0.4 are highly repeatable. The characteristic can also be viewed as a regression of producing ability on the phenotypic value, or the change in producing ability with every one unit change in a continuous phenotype. Using the calculated regression coefficient, the producing ability of an individual can be predicted based on the phenotype (Bourdon, 2000).

It is necessary to note that repeatability is a population measure and does not refer to one individual, but a population of individuals for a specific trait. Varying between populations and environments, repeatability is a characteristic that is not fixed much like heritability. This measure however can be used for culling and selection decisions by understanding the strength of the measure and the consistency between the repeated records of the same trait. Ideally, high heritability and high repeatability are preferred when making culling decisions as the estimates are better indicators of both breeding value and producing ability, respectively (Bourdon, 2000).

Many of the traits in which repeatability is calculated are continuous traits those which can assume any possible value of a range. Alternatively, a trait that exhibits a categorical phenotype by falling into success or failure categories, fertility is considered a threshold trait. Typical of threshold traits, fertility is a polygenic trait which is influenced by many genes with varying amounts of influence. Just as genotypic values, the breeding values and gene combination values, as well as the environmental effects are continuously distributed for quantitative polygenic traits, there is no difference in the underlying distributions of these threshold traits (Bourdon, 2000). While components of the genetic model follow a continuous distribution, the phenotypes of threshold traits are categorical and not continuous. However, behind the phenotypes of a threshold trait is a continuous scale, commonly called a scale of "liability." The sum of the individual's genetic values and environmental effects for the trait determine where they fall on the scale of liability and result in the phenotype we observe – a binary observation. Using the example of fertility, if the sum of the individual's genetic and environmental influences is below the threshold she will not conceive, however if the sum is above the threshold she will conceive (Bourdon, 2000).

3.2 Repeatability of Reproductive Traits in Beef and Dairy Cattle

Unfortunately, there have been few studies which have estimated the repeatability of fertility traits in cattle especially traits similar to FSC and FCC, however estimates are summarized in Table 2.1. A study conducted by Rahbar et al. (2016) investigated the heritability, repeatability, and genetic correlations of and between first service conception (FSC), number of inseminations (NI), insemination outcome (IO), estimates of days open (DO), gestation length (GL), calving interval (CI), and calving birth weight (CBW) of a dairy cattle population. Summarized in Table 2.2 adapted from the Rahbar et al. (2016) study, the repeatability of fertility traits were low to high and ranged between 0.021 and 0.411 for FCS and IO, respectively. With focus placed on FSC, researchers found heritability and repeatability the lowest for this trait out of those of interest. The findings that repeatability of a majority of fertility traits is generally low in dairy cattle populations suggests that reproductive efficiency is largely influenced by temporary environmental effects, specifically management practices that only affect fertility temporarily, as this influence is not included in producing ability. Considering the low estimates, the improvement of reproductive efficiency in females should revolve around using management strategies such as the control of the factors affecting conception rate and fertility in general (Rahbar et al., 2016). Collectively, the repeatability of fertility traits in dairy cattle investigated in the Rahbar et al. (2016) study reveal estimates that are generally low, therefore one performance record for a reproductive trait is not a good indicator of a female's additional records for the same repeated trait or the producing ability for that trait. However, repeatability estimates for reproductive traits in female beef cattle in the literature are further limited.

Table 2.2 The genetic variance (σ^2_{α}), permanent environment variance (σ^2_{pe}), residual variance (σ^2_e), heritability (h^2), and repeatability (R) including the standard error (SE) of various reproductive traits. Retrieved from "Genetic analysis of fertility traits of Holstein dairy cattle in warm and temperate climate," by R. Rahbar, M. Aminafshar, R. Abdullahpour, and M. Chamani, 2016, Acta Scientiarum Animal Sciences, 38, 333–340.

Traits[1]	$\sigma_a^2 \pm SE$	$\sigma_{pe}^2 \pm SE$	$\sigma_e^2 \pm SE$	$h^2 \pm SE$	R $\pm SE$
DO	7.23 ± 3.35	7.47 ± 5.16	417.54 ± 6.56	0.016 ± 0.01	0.034 ± 0.013
CI	11.34 ± 3.29	11.01 ± 4.57	363.20 ± 5.52	0.029 ± 0.009	0.057 ± 0.01
GL	3.58 ± 0.41	1.68 ± 0.4	23.71 ± 0.36	0.123 ± 0.104	0.181 ± 0.1
NI	0.06 ± 0.01	0.12 ± 0.02	1.43 ± 0.02	0.041 ± 0.025	0.115 ± 0.03
SF	0.002 ± 0.0009	0.001 ± 0.001	0.13 ± 0.001	0.015 ± 0.008	0.021 ± 0.008
CBW	2.88 ± 0.47	1.71 ± 0.53	27.73 ± 0.52	0.089 ± 0.037	0.142 ± 0.04
IO	0.05 ± 0.02	0.36 ± 0.03	0.60 ± 0.006	0.055 ± 0.017	0.411 ± 0.02

[1]DO = days open, CI = calving interval, GL = gestation length, NI = number of insemination services, SF = first service success, CBW = calving birth weight, and IO = insemination outcome.

Of the studies which have investigated repeatability of reproductive traits in female beef cattle, estimates reported were similar to those reported for dairy cattle. A study by Meyer et al.

(1990) estimated the heritability and repeatability of various fertility traits in Hereford, Angus, and Zebu-cross beef cattle in Australian production systems. Of the female fertility traits evaluated, including proportion conceived, proportion calved, calving rate, number of calves, days to calving, and calving success, the heritability was consistently low, however the estimates ranged from 0.05 to 0.36 with days to calving (Hereford) having the lowest value and number of calves (Zebu-cross) reported as the highest. Repeatability was estimated for days to calving (DC), the difference in days between the introduction of bulls to the females and calving date, and calving success (CS), being the success or failure of a female calving during one breeding/calving season. Repeatability of DC was estimated at 0.22, 0.10, and 0.18 for Hereford, Angus, and Zebu cross cattle, respectively, while estimates of CS were 0.91, 0.02, and 0.10 respectively (Meyer et al., 1990). The repeatability of CS was significantly higher in the Hereford females than the Angus and Zebu-cross cattle, this is likely due to categorical phenotypes associated with the trait and the culling of open females from the Hereford herd. As the females continued to produce a calf each year, their phenotypes would be recorded as a success until their last year in the herd in which they do not produce a calf, their phenotype is recorded as a failure, and they are then culled. It is suggested that the initial and sometimes continuous successes followed by one failure resulted in a high repeatability for the trait within this production system. The Angus and Zebu-cross females had estimates much lower due to their estimated variance of genetic and permanent environmental components being near zero, this results in the repeatability estimate being similar to the estimated heritability of the trait, calving success (Meyer et al., 1990).

An additional study examining repeatability of reproductive traits in beef cattle was that conducted by Oyama et al. (2002) on Japanese Black cattle in which all records used to perform the analysis were retrieved from the Wagyu Registry Association. Of the wide range of reproductive traits, repeatability was evaluated for gestation length (GL), days open (DO), and calving interval (CI). Results revealed repeatability estimates of 0.40, 0.09, and 0.09 for GL, DO, and CI, respectively. All three traits had similar estimates of repeatability to their heritability estimates, this is due to the minimal permanent environmental importance for the traits of interest. This indicates that much of the environmental influence on GL, DO, and CI is temporary and due to the environment affecting female reproduction for a short period of time only. However, the differences in heritability and repeatability of reproductive traits between breeds suggests that they should be investigated within each breed, discussed and used accordingly (Oyama et al., 2002). The low estimates for repeatability of the DO and CI traits found through the Oyama et al. study were likely the result of the little genetic influence on the traits and the large impact of herd management and AI success (2002). Heritability and repeatability estimates reported for traits similar to FSC and FCC in literature are summarized in Table 2.1.

Reproductive traits remain some of the most economically relevant in cow calf operations where the primary source of income comes from the sale of calves produced. Maximizing female fertility within the beef cow herd can maximize economic profits due to a decrease in female culling, replacement female costs, breeding expenses, and an increase in calf crop as well as the number of calves available for sale. It is this impact on operation success that has resulted in the interest of improving herd reproductive success (Rahbar et al., 2016). However, with the low heritability of fertility traits and little influence from genetics, producers have placed their focus on improving female environment to maximize the reproductive performance of their herd. As reported in the literature, heritability of first service conception has been estimated near zero to moderate ranging from virtually zero (Bormann et al., 2006) to estimates over 0.20 (Dearborn et al., 1973). The low to moderate heritability of FSC reveals that genetics has minimal influence on the trait and therefore genetic progress will be slow when this trait is selected on. Similar to FCC, heritability of the trait calving day (CD) represented by the number of days between the calving day of the first calf of the season and a female's actual calving day is telling of a female's ability to conceive and calve early. This trait has been previously investigated by Rasali and Crow (2004) in Angus heifers and cows, reporting estimates of 0.16 and 0.25 for the two maturity groups, respectively. An additional trait that describes the speed at which a female can rebreed after calving, days open (DO) has been previously investigated by Oyama et al. (2002) who estimated heritability of the trait at 0.05, making it lowly heritable. Furthermore, it is difficult to distinguish between female infertility due to genetics and the influences of management practices, AI events, and other factors that may alter first service conception and other fertility traits similar to FCC (Gonzalez-Recio and Alenda, 2005). Further investigation of heritability and repeatability of first service conception and first cycle calving in beef cattle could prove to be a useful tool in identifying the influences of genetics and the permanent environment dependent on the parameter estimates, there may be potential for selecting females who are more fertile, those who can maximize herd fertility and economic viability of a production system. Determining the correlation or reliability between successive performance records of repeated fertility traits such as FSC and FCC will allow the appropriate actions following the success or failure of a female to conceive on the first service of AI or early in the mating season, rather than the overall success of conception during the entire breeding season. While estimating repeatability could be revealing of the measure of reliability between records, these estimations will not eliminate the need for proper female management necessary for reproductive soundness and success.

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CHAPTER 3

GENETIC PARAMETERS OF FIRST SERVICE CONCEPTION AND FIRST CYCLE CALVING THROUGHOUT VARIOUS LIFE STAGES IN ANGUS CATTLE

Summary

Sub-fertility considered the largest source of economic loss in beef cattle production, reproductive efficiency in a cowherd is vital for the economic viability of a beef production system. With this potential for profit or loss, female reproduction and the progress within fertility traits such as heifer pregnancy, first service conception, and stayability remain an area of interest for both researchers and producers. Unfortunately, binary fertility traits historically have not been widely evaluated due to difficulty associated with their analysis and the limited amount of data recorded and submitted to breed associations, and therefore available for evaluation of such traits. A good indicator of female reproductive ability, or an individual's ability to conceive and produce a calf, first service conception (FSC) describes the success or failure of the first service of artificial insemination (AI). Apart from FSC, the ability of a female to calve in the length of the bovine estrous cycle or in the first 21-day period of her due date based on the first opportunity for conception is also telling of female fertility. This trait is known as first cycle calving (FCC) in which successful phenotypes are preferential to females who calve late in the season, due to the advantages an early-born calf has in terms of age and weight at weaning as well as in the female's ability to rebreed. Therefore, the objective of this study was to estimate the genetic and environmental variance components that control FSC and FCC using breeding and calving records representing observations of 8,206 pregnancies from 19 years of data sourced from the Colorado State University Beef Improvement Center (CSU-BIC) in Saratoga,

Wyoming. Results of this study may provide additional understanding of the influence of genetics and the environment on the outcome of FSC and FCC. Knowledge of the two parameters will further advise cattle managers how they can maximize reproductive efficiency either through selection or management practices, or both.

Determined through stepwise regression using the associated Akaike's information criterion (AIC) and P-values, the most significant parameters for both FSC and FCC as the dependent variables included the categorical fixed effects of birth year ($P < 0.001$), synchronization protocol combined with year ($P < 0.001$), mating type ($P < 0.001$), previous calving ease score ($P < 0.001$), and statistical significant covariates of mating age in days ($P < 0.01$) and post-partum interval (PPI; $P < 0.001$). Both heritability and repeatability parameters of FSC over the productive lifespan of females were estimated using a univariate model and a REML procedure resulting in the same value of 0.03 ± 0.02 for each. The same parameters over the lifespan for FCC were both estimated at 0.15 ± 0.03. These results suggested no permanent environmental effect on either FSC or FCC due to the similarity between heritability and repeatability estimates; though, higher heritability and repeatability estimates for FCC suggested a greater genetic influence on the trait than on FSC. However, when the observations were grouped by two female maturity categories, heritability and repeatability of FSC observations one through four years of age at mating (growing or immature) were estimated at 0.04 ± 0.04 and 0.04 ± 0.06, respectively. Observations of individuals five years of age and greater at mating resulted in heritability and repeatability estimates of 0.02 ± 0.05 and 0.08 ± 0.04, respectively. For FCC, heritability and repeatability were estimated at 0.04 ± 0.07 and 0.11 ± 0.07 for growing/immature females, and at 0.21 ± 0.04 and 0.21 ± 0.04, respectively for mature females. Collectively, with very minimal genetic influence on the traits, the findings suggest that the most critical factor when improving female reproduction should remain temporary environmental management when interested in first AI service success and early calving. While genetic influence is still considered low as the estimates calculated for first cycle calving indicate the trait was lowly heritable and lowly repeatable, there was a larger influence of genetics on FCC in mature females resulting in more potential for genetic improvement of the trait through selection.

Introduction

Fertility in beef cattle production remains one of the most impactful economically relevant group of traits in the cow-calf industry with reproductive efficiency considered five times more important than calf growth rate and 10 times more important than carcass quality (Colazo and Kastelic, 2012). The economic loss associated with sub-fertility is a result of reduced calf crops, increased breeding expenses, and shortened reproductive lifespans (Rahbar et al., 2016). Female infertility and subfertility can be categorized into three groups; females who do not conceive, those who conceive late in the breeding season, and those who conceive but do not maintain pregnancy (Lamb et al., 2008). Identifying sub-fertile females and understanding how to improve fertility in beef cattle operations may prove beneficial to the industry in terms of production efficiency and economic gain. However, the evaluation of fertility traits in beef cattle is generally limited, this is due to complicated measurements and therefore sparse data collection and the difficulty associated with the analysis of such binary traits (Bormann et al., 2010). Though expected progeny differences (EPD) are utilized by major breed associations and further improvement of beef cattle fertility traits could prove useful in terms of maximizing the efficiency of beef production as well as producer profit, more research is necessary to better understand how improvement should be approached.

A wide range of environmental effects have been reported in literature to have an effect on female fertility in beef cattle including female age (Shorten et al., 2015), weight and condition at mating (Shorten et al., 2015; Cumming, 1972), and previous calving ease (Johnson and Funston, 2013). With the extensive list of potential impacts on reproductive success, the adoption of reproductive technologies such as artificial insemination (AI) and estrous synchronization, have helped aid in the reproductive management of herds to improve their fertility performance Specifically considering AI, producers now have the opportunity to use and access semen from high quality sires which can significantly accelerate genetic progress for traits of interest (Senger, 2012). Of the various reproductive traits specifically related to the use of AI, a trait considered a good predictor of female fertility (Ghiasi et al., 2011), first service conception (FSC) describes the outcome of the first service of insemination (Ghiasi et al., 2011). In management systems that include one service of AI followed by natural service for the remainder of the breeding season, females who conceive on their first service are likely to produce higher quality, older, and heavier calves at weaning. These advantages are in addition to the benefits of more time during the post-partum interval (PPI) for reproductive repair of the female before rebreeding the following season (Bormann et al., 2006).

While a successful phenotype for FSC is preferred, a trait that accounts for first service and early breeding season conception, first cycle calving (FCC), describes the ability for a female to produce a calf within the first 21-day period of the due date based on the start of the breeding season or first service of AI. The advantages of early calving include heavier calves at weaning in addition to an extended PPI which allows for more time to repair and resume estrous cyclicity over late calving females (Lesmeister et al., 1973), and expectantly, an earlier conception after calving. Improvement of these traits could result in increased profit for beef cattle producers in terms of an increase in number of calves sired by higher quality sires, heavier and older calves at weaning, reduced breeding expenses, and females who have longer reproductive lifespans (Rahbar et al., 2016).

Understanding the genetic and environmental effects on specific traits, such as FSC and FCC, may reveal the best approach for improvement. A parameter that expresses the importance of genetic influences, heritability describes the strength of the relationship between phenotypic values and breeding values for a specific trait in a population (Bourdon, 2000). Calculating this measure on FSC and FCC could aid cattle producers and managers alike in the identification of the most appropriate management strategies to make improvements. Additionally, the estimation of heritability of these two traits at different maturity stages of a female's life may further explain when genetics have more or less influence on her fertility as physiologically younger females are reproducing under circumstances different than mature females. Understanding the genetic and environmental influences between growing and mature females could provide insight on how cattle should be managed at various life stages to maximize the reproductive success of the herd through selection, management practices, or both.

To further segregate the environmental effects, repeatability, a parameter similar to heritability, incorporates the permanent environmental effects in addition to the effects of genetics that are estimated through heritability. This parameter describes the strength of the relationship between records for a repeated measure trait. Understanding permanent environmental effects on FSC and FCC would provide insight into the importance of environmental management early in a female's life that may or may not permanently affect her lifetime fertility. While heritability gives insight into the potential for selection within the trait, adequate values for repeatability allow for cattle managers to make selection or culling decisions based on one record for a trait due to the likelihood of the consecutive phenotype(s) being similar (Bourdon, 2000). If repeatability is sufficient for FSC or FCC, producers could potentially use the outcome of one breeding season to make selection and culling decisions thus maximizing reproductive success in their herd in the future.

While estimates of heritability for fertility traits are generally low in beef cattle, prior investigation of FSC and FCC as reported in literature is limited (Cammack et al., 2009). Previous estimates of heritability for fertility traits reported in literature are generally low, suggesting minimal influence of genetics on such traits. First service conception (FSC) heritability has been previously estimated in various studies ranging from 0.02 to 0.22 and generally classified as lowly to moderately heritable (Rahbar et al., 2016; Ghiasi et al., 2011; Gonzalez-Recio and Alenda, 2005; Bormann et al., 2006; Peters et al., 2013; Dearborn et al., 1973), however, the estimates often involve differing biological types, breeds, and sample sizes. The near zero to moderately heritable estimates suggest varying potential for selection on the trait that would result in genetic change.

Dissimilar to FCS, the heritability of first cycle calving (FCC) has not been widely investigated. A trait definition likely similar is days to calving (DC; Meyer et al., 1990) or the length of time between the initial contact of natural service bulls to females and the birth of their resulting calf. While DC is a continuous trait and FCC is binary, the traits both describe the ability and rate to which females can conceive and produce a calf. In the Meyer study, the heritability for DC was estimated for three cattle types including Hereford, Angus, and Zebu-cross cattle and their estimates were 0.05, 0.08, and 0.09, respectively. An additional likely related trait describing the ability of a female to conceive and calve early is calving day (CD). Estimating the heritability for CD for Angus heifers and cows, Rasali and Crow (2004) reported estimates of 0.16 for heifers and 0.25 for cows revealing low to moderate levels of genetic influence on the trait. While the literature is limited on FCC and traits similar, the estimates by Meyer et al. (1990) and Rasali and Crow (2004) range from low to moderate suggesting the majority of influence on the traits is from an environmental source; however, repeatability estimates of the same traits provide insight to any permanent environmental effect that may have an impact of fertility.

While many reproductive traits are repeatedly measured, repeatability estimates of such traits are limited. This is likely due to the difficulty associated with the analysis of fertility traits which are often threshold traits or binary in nature and therefore requiring special, often compute-intensive statistical algorithms. Also contributing to the lack of such data, this difficulty is exacerbated by the infrequency of reproductive data collection when compared to the amount of data collected of traits that are easier to measure. Of the literature that reports repeatability estimates for various fertility traits, values are often low; however they range in literature in broad, 0.02 to estimates as high as 0.91 (Rahbar et al., 2016; Oyama et al., 2002; Meyer et al., 1990).

While available literature with repeatability estimates is more limited than heritability estimates for the same traits, there are reports of estimates of FSC repeatability. For example, Rahbar et al. (2016) calculated the heritability and repeatability for various fertility traits in Holstein dairy cattle including FSC reporting repeatability of the success of the first service of artificial insemination estimated at 0.021 (Rahbar et al., 2016). Furthermore, when comparing this repeatability value to the heritability estimate of 0.015 for the same trait in the study, the deviation between values suggested a minimal permanent environmental effect on the trait. However, considering the Rahbar et al. (2016) study investigated FSC in dairy cattle, understanding genetic and permanent environmental effects on other cattle breeds would require estimating the parameters within the breed of interest as suggested by Oyama et al. (2002).

While repeatability has been calculated for FSC in dairy cattle, there are few reports describing the repeatability of traits similar to the trait FCC. While FCC as a binary trait where there are only two possible phenotypes has not been previously investigated, Lesmeister et al. (1973) estimated the repeatability for calving that occurs in multiple categories of 21-day periods beginning 283 days after the natural mating season began. The repeatability was estimated for two different herds associated with the Montana Agricultural Experiment Station, one herd consisting of both Angus and Hereford cows while the other consisted of Hereford females only, resulting in 0.09 and 0.11 values, respectively (Lesmeister et al., 1973). Another trait similar to FCC, a trait termed “days to calving,” (DC) in beef cattle which describes the number of days between the initial introduction of a natural service bull and the subsequent calving date of the resulting calf (Meyer et al., 1990). The similarity between DC and FCC includes the ability for females to conceive and produce a calf earlier in the season. Repeatability for DC has been estimated in Hereford, Angus, and Zebu-cross cattle with estimates of 0.22, 0.10, and 0.18, respectively (Meyer et al., 1990). When compared to the heritability estimates of the three breeds for the same trait of 0.05, 0.08, and 0.09, a permanent environmental effect is suggested. While not directly comparable, DC is a continuous trait and FCC is a binary, threshold trait, they both describe the amount of time it takes a female to conceive and produce a calf. Additionally, repeatability estimates reported by Oyama et al. (2002) of days open (DO) and calving interval (CI) reported estimates of 0.09 and 0.09 for DO and CI, respectively and suggest that the traits are lowly repeatable and are influenced minimally by the permanent components of the genetic model, breeding value, gene combination value, and permanent environmental effect.

Based on literature, estimates for fertility traits such as FSC and those similar to FCC summarized in Table 2.1 are typically lowly repeatable, this suggested that single observations of such traits should not be used as an indicator of a female's performance for following records. However, additional investigation and estimation of repeatability of these traits will further explain the influence that genetics and the permanent environment have on FSC and FCC in different populations. With this knowledge, cattle managers can make more informed decisions when focused on maximizing reproductive efficiency whether that be through selection or cattle management strategies. Therefore, the objective of this study was to better understand and partition the genetic and environmental influence on first service conception (FSC) and first cycle calving (FCC) through the estimation of heritability and repeatability using data from Angus cattle. The estimation of the parameters of FSC and FCC will further explain the influences of genetics and the environment on the two traits, which may prove useful when employing strategies to improve reproductive efficiency in beef cattle operations.

Materials and Methods

Approval from the animal care and use committee was needed for the year 2018 in which the protocol number was 18-8367A. Approval was not necessary for the remaining data of this study due to the use of a preexisting historical dataset.

Cattle management

Data was sourced from records including the years 1986 to 2017 from the Colorado State University John E. Rouse Beef Improvement Center (CSU-BIC) near Saratoga, Wyoming. The facility maintains a herd of approximately 430 Angus cows managed in a commercial setting while facilitating a research environment. The breeding and calving data included records from primarily Angus females. While the operation currently is a pure Angus operation, some records in earlier years include crossbred cattle which have been shown to be positively associated with female fertility and longevity when evaluating pregnancy rates and the ability to produce a calf every year due to heterosis (Basarab et al., 2018). Within the designated breeding season, typically the 3rd week of May for heifers, and 21 days later for the cows, the herd was estrus synchronized followed by one service of artificial insemination (AI). Unless an experimental synchronization protocol is used, females are subjected to a protocol consisting of a gonadotropin releasing hormone (GnRH) injection and insertion of a controlled internal drug release (CIDR) insert at day zero, the CIDR is pulled at day seven and an injection of prostaglandin ($PGF_{2\alpha}$) is given, and females are then bred on heat or at a fixed time three days later. Females were typically bred 12 hours after expression of standing heat, or bred in a mass mating group on day ten if the individual did not express signs of estrus, although the protocols were modified over time due to research.

After the AI service was completed and a withholding period ranging from 10 to 14 days took place, subsequently, the females were put with a natural service (NS) bull for the remainder of the breeding season to account for any failed conceptions during the first service of AI. Breeding season length was approximately 60 days and to maintain the size of the reproductive herd, heifers were retained from the calf crop, developed, and selected based on early conception success and performance in which females enter the cow herd as a bred heifer at one year of age. Typically, heifers who were serviced during the breeding season and successfully conceived to AI or early in the season were selected while those who are open or display later conception, based on results of ultrasound scans or palpation for pregnancy were sold. Similarly, older females were culled from the cowherd when determined non-pregnant with use of ultrasound scans and/or manual palpation at calf weaning after the close of the breeding season approximately 120 days after the season start. Poor feet and leg structure or performance may also warrant culling of females when rates for non-pregnancy after breeding season were sufficiently low. This management resulted in multiple records for FSC and FCC for a majority of the females in the herd, thus allowing the calculation of repeatability for the traits.

Phenotype assignment

Data included calving records to confirm the ultimate success of breeding - producing a calf. Calving records were utilized to determine the success of the first service of AI for multiparous cows. Additionally data was also used for heifers who were bred and retained, it was not available for all heifers as many were sold as bred to other producers. The use of both AI and natural service at the CSU-BIC, in many cases, resulted in difficulty differentiating calves born as a result of an AI mating or those sired by a natural service bull. While management of mating includes various breeding season records, the parentage has been verified through DNA-based paternity for recent calving years. Therefore, determining with near perfect accuracy how the calf was conceived (AI or natural service) was difficult for individuals without DNA-based information.

In order to appropriately assign FSC phenotypes to each female for each breeding season, the resulting calves were sifted into one of two groups dependent on the pregnancy resulting from AI or natural service. This was achieved through the development of an algorithm illustrated in Figure 3.1 that utilized various records including ultrasound and palpation results, predicted gestation length based on the AI date, adjusted birth weights, and birth weight averages related to sex and Beef Improvement Federation (BIF) age of dam categories (2, 3, 4, 5 to 10, and 11 years or greater) for each calving year. Calf birthweights were adjusted to a gestation length mean from the potential gestation length if AI were a success. This was accomplished by using a late fetal growth rate of 0.36 kg per day (Herring, 1996) to adjust the birth weight to a mean of 281 days (King et al., 1985). That adjusted weight was then compared to the average weight of that calf given the respective sex, calving year and age of dam category to determine if the actual birth weight of the calf was representative of its potential gestation length if the dam conceived on her first service. For example, if a bull calf had a 291 day potential gestation length and birthweight of 34 kg, the birthweight would be decreased by 3.6 kg which was the product of birth 10 days beyond the average gestation length and the late fetal growth rate. The 3.6 kg adjustment was subtracted from the actual birthweight resulting in an adjusted weight of 30.4 kg which when compared to an example average birthweight of 35 kg for bull calves of the respective birth year and age of dam, the calf would then be considered a result of natural service. By taking into account all the information in the algorithm, every possible outcome of breeding and calving can be predicted and the information can be used to determine the most likely origin of the calf and an FSC phenotype could then be assigned.

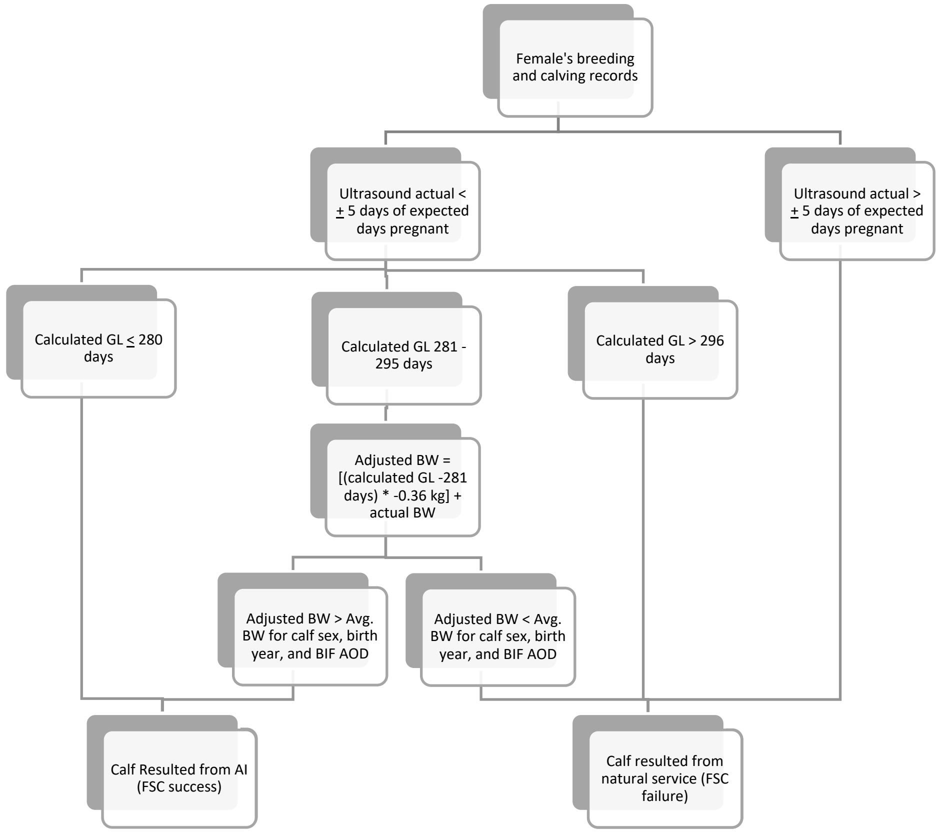

Figure 3.1 Each female's breeding and subsequent calving records were utilized to best determine the success and outcome of the first service of artificial insemination (AI). Of the information available, results of two ultrasound or palpation pregnancy checks (~55 and ~120 days after the AI breed date), the calculated gestation length (GL) based on the AI date, industry average (King et al., 1985) and standard deviation (King et al., 1982) of gestation length in beef cattle, and a late fetal growth rate (Herring, 1996) to adjust birthweights (BW) were used to sort pregnancies and calvings appropriately in terms of first service conception (FSC) success or failure.

By using both ultrasound results in the algorithm, we can determine which females conceived, those who failed to conceive at the first service, as well as females who conceived but failed to maintain pregnancy addressing the potential categories of female fertility described by Lamb et al. (2008). Considering females were inseminated and subsequently natural service bulls were introduced approximately 14 days later with one bull assigned to each sort group, early pregnancy diagnosis can aid in determining how a female conceived. If the difference between the determined number of days pregnant based on pregnancy diagnosis and the predicted number of days based on the AI date was within ±5 days, or one standard deviation of the gestation length (King et al., 1982), FSC was temporarily considered a success for that particular female and her information moved on to the next level of the algorithm. However, if the difference in actual and predicted days pregnant was beyond the ±5 days range, the pregnancy was automatically considered the result of natural service.

Females whose actual days pregnant based on ultrasound or palpation were within a five day range of the predicted number of days based on insemination date were then directed to the next level of the sifting algorithm which evaluated the predicted gestation length. The gestation length prediction was calculated as if all females conceived on the first service of insemination and was determined, simply by subtracting the insemination date from the calving date. For comparison purposes, a standard deviation of 5 days reported by (King et al., 1982) and an industry gestation length mean of 281 days in Angus cattle reported by (King et al., 1985) were utilized in the algorithm. If the predicted gestation length was greater than three standard deviations from the gestation length mean, the pregnancies were considered the result of natural service. Alternatively, those with gestation lengths within three standard deviations were directed to the next criteria of the algorithm.

In order to best judge if birth weights of the resulting calves were appropriate for the predicted gestation length, weights were adjusted to the mean of 281 days (King et al., 1985) for gestation length using a late fetal growth rate of 0.36 kilograms per day (Herring, 1996). If the adjusted birthweights were greater than or equal to the average birthweight for that sex of calf born to the BIF age of dam category for each birth year, the calf was sifted into the group resulting from artificial insemination and assigned a successful phenotype for FSC denoted by 1.

Alternatively, if the adjusted birthweight was less than the average birth weight associated with the calf sex, BIF age of dam, and the birth year, the calf was considered the result of natural service and therefore FSC is considered a failure denoted by 0. The algorithm accuracy was calculated using a single calf crop in which parentage was verified using DNA, this allowed for the calculation of the correlation between predicted and actual FSC success (n = 407).

Phenotypes for FCC were assigned based on the difference between the female's due date and calving date, based on the day of the initial opportunity for conception, and the actual calving date of the subsequent calf. If the difference was calculated within 21 days of the female's first potential due date, a success phenotype was assigned for FCC. However, if the difference in days was greater than 21, a failure phenotype was assigned for the trait. Once the pregnancies were assigned a binary phenotype for FSC or FCC of "0" or "1" (failure/success), the analysis was performed to estimate the heritability and repeatability of both traits using all data from various years, as well as the parameters for the traits at immature and mature life stages according to the maturity categories described by Kaps et al. (1999) which included immature females one to four years of age at mating and mature females including those five years or older.

Data

The final dataset included 8,206 pregnancy and calving events in which individuals had observations for both FSC and FCC. A three-generation pedigree was generated for use in the analysis and included individuals with observations and their respective sires, dams, grandsires, granddams, great-grandsires, and great-granddams. The resulting pedigree included 2,973 individuals with 540 unique sires, 302 of which were outside sires registered to the American Angus Association, and 1,800 unique dams.

Within the breeding and calving records that were obtained from the CSU-BIC, data included all breeding and pregnancy data consisting of, but not limited to, various measurements and scores describing the female reproductive tracts, heat and breed dates, type and time of insemination, synchronization protocols and semen type (sexed, cooled, frozen), thawing and AI technician records, multiple ultrasound results, and body condition and weight measurements. Some factors which have previously been reported to have an influence on female fertility included in this data were female age (Shorten et al., 2015), body condition (Shorten et al., 2015; Cumming, 1972), previous calving ease (Johnson and Funston, 2013), and AI service expertise (Barth, 1993). Additionally, ultimately describing mating success with the production of offspring, calf and dam information contained birthdate, sex, and weight of the calf; as well as calving ease score.

Mating type consisted of the females who were bred based on standing estrus, and were divided between females bred in the a.m. or those bred in the p.m., in addition to females inseminated after showing estrus others were bred at mass mating when timed AI was utilized. Considering insemination success relies on the combination of thawing and breeding technicians (Barth, 1933), these were combined to create a contemporary group for each insemination and consisted of 120 different combinations. An additional contemporary group used which included the pairing of estrus synchronization protocol and semen type with the mating year to account for any differences between similar protocols for various years resulting in 38 unique combinations. The data for synchronization protocol contemporary group included various management techniques, synchronization products, and semen types involving the use of calf removal for 24-hours prior to breeding, a melengestrol acetate (MGA) product, controlled internal drug release (CIDR) inserts, one or two injections of gonadotropin-releasing hormone (GnRH), Synchro-Mate

B implant, and the use of fresh to frozen, and/or sexed semen. The AI sire used at time of insemination was also recorded and included semen from 296 unique sires. Numerical fixed effects and covariates that were included in the full model are summarized in Table 3.1.

Table 3.1 Summary statistics for numerical, categorical effects and covariates included in the full model.

Trait	N	Mean	S.D.	Minimum	Maximum
Reproductive tract score[1]	345	3.69	0.78	2.00	5.00
Post-partum interval (days)[2]	6586	80.22	20.52	16.00	159.00
Previous calving ease (score)	5809	1.04	0.26	1.00	5.00
Body condition score[1]	1377	4.99	0.66	3.00	8.00
Mating weight (kg)[2]	1446	450.38	77.87	276.69	742.98
Mating age (years)[1]	8206	4.90	3.16	1.00	17.00
Mating age (days)[2]	5522	1928.65	1256.11	356.00	6677.00

[1]Categorical effect
[2]Covariate

Statistical analysis

To determine the significant effects that should be included in the model, a stepwise regression and the accompanying Akaike's information criterion (AIC) and P-values were used for model selection in the statistical software package RStudio 3.5.1 (R Core Team, 2018) for FSC and FCC individually using the full model. Of the measurements recorded at mating and calving, the categorical effects that were considered as potential influences on breeding success and included in the full model consisted of reproductive tract score, mating type, the contemporary group of the thawing technician and inseminator, the contemporary group of synchronization protocol paired with the breeding year, the age of the female in years, body condition score at insemination, the AI sire, as well as the previous calving ease that the female experienced with her previous calf if she had a previous calf. Potential covariates that could influence FSC or FCC which were considered in the full model included yearling pelvic area, the age of the female in days at mating, weight at breeding, as well as the post-partum interval (PPI) in days at insemination if the female produced a calf the previous year. Fixed effects within the final model were selected based on P-values in addition to the use of biological effects that have been shown to have significant influences on cattle fertility. The general model utilized was:

$$\boldsymbol{y} = \boldsymbol{Xb} + \boldsymbol{Zu} + \boldsymbol{Wp} + \boldsymbol{e}$$

Where the variance/covariance structure was:

$$var\begin{bmatrix}\boldsymbol{u}\\ \boldsymbol{p}\\ \boldsymbol{e}\end{bmatrix} = \begin{bmatrix}\sigma_A^2\boldsymbol{A} & 0 & 0\\ 0 & \sigma_{E_P}^2\boldsymbol{I}_1 & 0\\ 0 & 0 & \sigma_{E_T}^2\boldsymbol{I}_2\end{bmatrix}$$

and where $\boldsymbol{y}$ was the vector of phenotypic observations referring to trait (FSC or FCC), $\boldsymbol{X}$ was an incidence matrix used to relate the observations in $\boldsymbol{y}$ to the unknown solutions for fixed effects in vector $\boldsymbol{b}$. To accommodate the random effects of animal and permanent environment, $\boldsymbol{Z}$ and $\boldsymbol{W}$ were included as incidence matrices, relating the unknown solutions for both direct genetic effects and permanent environment effects, respectively to observations in $\boldsymbol{y}$. Unknown solutions for animal direct additive effects and permanent environmental effects are represented by vectors **u** and **p**, respectively. Corresponding to the residual error, vector $\boldsymbol{e}$ related the residual error to the vector of observations for each trait. Within the variance structure, the **A** denoted the Wright's numerator relationship matrix constructed with the pedigree generated, while $\boldsymbol{I}_1$ and $\boldsymbol{I}_2$

represented identity matrices with an order equal to the number of observations. Furthermore, the $\boldsymbol{\sigma_A^2}, \boldsymbol{\sigma_{E_P}^2}, \boldsymbol{\sigma_{E_T}^2}$ on the diagonal of the variance matrix represented the animal direct additive genetic, permanent environmental, and temporary environmental variances. Off diagonals of the matrix were zero due to the assumption that the animal direct additive effects, the permanent and temporary environmental effects were all independent of one another.

To estimate the two parameters of both FSC and FCC, the dataset was used and included 8,206 observations on 1,613 unique females experiencing multiple breeding seasons. A univariate model in the statistical software package ASReml 3.0 (Gilmour et al., 2009) was used to partition the phenotypic variance into its genetic (σ_A^2), permanent environment (σ_{PE}^2), and residual variance (σ_e^2) components in order to estimate heritability and repeatability of both traits, FSC and FCC. Heritability (h^2) was estimated by calculating the ratio of variances, specifically that of additive genetic variance to the phenotypic variance.

$$h^2 = \frac{\sigma_A^2}{\sigma_P^2}$$

While repeatability has more than one definition, within this study repeatability (r) was estimated as the ratio of the variance of producing ability (σ_{PA}^2) to the phenotypic variance (σ_P^2).

$$r = \frac{\sigma_{PA}^2}{\sigma_P^2}$$

Due to the binary nature of both traits, a PROBIT link function was used to transform the binary data to an underlying scale and results were expressed on this underlying scale (i.e. heritability and repeatability). To estimate the parameters for immature and mature females, data was reduced to observations between mating ages one and four years to represent growing females as well as observations at five years and greater to represent mature females, categories reported by Kaps et al. (1999). This division of observations was intended to separate mature females from individuals who were still growing and under greater biological requirements. Separation of observations resulted in 3,818 records for both traits in immature females and 3,026 records for the mature category. To calculate the above variance components for growing and mature females, a univariate model was used to estimate the same components $(\sigma_A^2, \sigma_{PE,}^2 \sigma_e^2)$ of the genetic model as done with the parameters estimated over a reproductive lifespan. Heritability and repeatability estimates were also estimated in the same fashion as previously with the pooled data.

Results and Discussion

Algorithm Results

The resulting accuracy of the algorithm using a single calf crop with DNA information in the form of a Pearson correlation was 0.87 between FSC success or failure based on the algorithm and the true FSC. After phenotype assignment using the developed algorithm, the resulting rates for both first service conception (FSC) and first cycle calving (FCC) averaged over all data were 50.02% and 77.44%, respectively. When comparing the rate of FSC to other rates in literature, the rate was elevated but similar to that found by Stevenson et al. (2002) who reported rates of 44% and 33% for females bred on heat and those bred using timed artificial insemination (TAI). The rates in this study were also higher than those reported by Lemaster et al. (2001) of 21% and 31% for conception to AI on standing estrus and on TAI, respectively. Bormann and Wilson (2010) however, reported first service conception rates of 52.6% ad 75.4% for two separate herds of Angus heifers with an average of 67.10% FSC success. Though, as described by Barth (1993) conception rates can vary due to differences in estrus synchronization protocols, semen quality, as well as the experience level of thawers and inseminators.

The rates for FCC, the percentage of females who calved in the first 21 days, was similar to rates reported by Deutscher (1991) at between 60% and 100% of females calving in a 20-day period in the calving season with different herds under various breeding programs with different standards for the length of the breeding and calving seasons. This could have encouraged culling of females who conceived late in the breeding season potentially biasing those results.

Resulting rates for FSC for immature and mature categories of one through four years at mating and five years and greater, respectively were 54.91% and 44.67%. This decrease in conception rate can be supported by the importance of female age on conception rate reported by Osoro and Wright (1992) who reported a decline in fertility after seven years of age in beef cattle. Considering FCC, the percentage of females calving within the first 21-day period included 81.85% and 72.61% for the immature and mature female categories, respectively. For both traits, there was a decrease in FSC and FCC rates from the immature female category to that of mature females of 10.24% and 9.24%, respectively. This was supported by the effect of age on pregnancy rates and female fertility, where females of age two to seven at calving experienced increasing fertility as compared to females who were between seven and 11 years at the time of calving (Shorten et al., 2015). Rates for each trait, averaged across and within observation category as well as the sample size within each category are summarized in Table 3.2.

Table 3.2 First service conception (FSC) and first cycle calving (FCC) rates resulting from the calf sifting algorithm and difference in days between initial breed date and calving date, respectively. Overall rates are shown for both traits as well as the rates within immature females and mature females and their respective sample sizes.

Trait	Immature Females[1]		Mature Females[1]		All Femlales	
	Rate	n	Rate	n	Rate	N
FSC	54.91%	4291	44.67%	3915	50.02%	8206
FCC	81.85%	4291	72.61%	3915	77.44%	8206

[1]Immature Females = individuals four years or younger at mating, Mature Females = individuals five years or older at mating.

Model Selection

The most appropriate model was selected based on Akaike's information criterion (AIC) and the P-values associated with fixed effects. The significant fixed effects for FSC were birth year ($P < 0.001$), synchronization protocol, semen type, and year as contemporary group ($P < 0.001$), mating type ($P < 0.001$), previous calving ease ($P < 0.001$); and biologically significant covariates of age in days at mating ($P < 0.01$) and PPI from the previous calving ($P < 0.001$). Random effects in the model included animal and permanent environmental effects to allow for the calculation of both heritability and repeatability of the traits. Model selection for FCC resulted in the significant fixed effects of birth year ($P < 0.001$), synchronization protocol, semen type, and mating year ($P < 0.001$), mating type ($P < 0.001$), previous calving ease ($P < 0.001$), and covariates of age in days ($P < 0.01$) and PPI in days from the most recent calving ($P < 0.001$). Similar to FSC, to allow for the estimation of the two parameters, random effects included animal as well as the permanent environmental effect.

Heritability

The heritability estimates of beef cattle reproductive traits are typically low as reported in literature. Rahbar et al. (2016) reported heritability estimates that ranged from 0.015 to 0.123

suggesting little genetic influence on fertility and thus indicating that the environment has the largest effect on females' ability to become pregnant. Due to these low estimates, it was suggested that there was minimal potential for selection on the traits and that would result in slow genetic progress over time. However, female fertility traits have not been widely evaluated due to the limit of available data and the difficulty associated with the analysis of binary traits in the past.

Heritability estimation over the reproductive lifespan of females with more than one observation resulted in a value of 0.03 ± 0.02 for first service conception (FSC) within the range of estimates reported in literature (0.015 to 0.18; Rahbar et al., 2016; Ghiasi et al., 2011; Bormann et al., 2006; Peters et al., 2013). This further confirms that the trait is lowly heritable and affected minimally by genetics. However, the values reported in various literature varied by cattle breed, use, age, and sample size of those evaluated. For example, the heritability estimated for FSC by Peters et al. (2013) was reported at 0.18 in *Bos indicus* influenced Brangus heifers, an estimate larger than that of 0.02 calculated in this study and nearing moderate heritability levels. Alternatively, Rahbar et al. (2016) estimated a heritability value of 0.015 for the trait in addition to other fertility traits in Holstein dairy cows. This is supported by the extent of environmental effects that have been shown to affect AI conception rates. These include but are not limited to body condition score (Shorten et al., 2015; Cumming 1972), female age (Shorten et al., 2015), previous calving ease (Johnson and Funston, 2013), PPI (Johnson and Funston, 2013), and differences in age of puberty among breeds (Gregory et al., 1979).

Categorized into groups of growing and mature females, FSC heritability was estimated as 0.04 ± 0.04 and 0.02 ± 0.04 for each of the groups, respectively. Both values falling into the range of 0.02 to 0.22 for FSC heritability previously reported (Rahbar et al., 2016; Ghiasi et al., 2011; Gonzalez-Recio and Alenda, 2005; Bormann et al., 2006; Peters et al., 2013; Dearborn et al., 1973); however, when compared to estimates in Angus, Bormann et al. (2006) reported a similar value of 0.03 to those reported in this study. The near zero estimates for both groups for FSC may be a result of the AI process which involves a high level of human management, meticulous timing in terms of estrous synchronization and insemination, as well as the skill of thawing technicians and breeders (Barth, 1993). This can be compared to a natural service program, the pregnancy rate of serviced females of 40, 59, and 62% for yearling, two-year old, and three-year old bulls, respectively, over a five-day breeding period. This suggested that when the system relies on bulls to heat detect and service, similar conception rates were reported; however, more opportunities for conception in a specified period of time were available in comparison to each AI service (Pexton et al., 1990). With AI being dependent on human management, an otherwise fertile female may fail to conceive due to an error in any part of the AI process. The similarity between resulting estimates do not suggest differences in cattle management in terms of FSC between immature and mature females, or the whole herd and provides little potential for selection on any of the groups for the trait.

Heritability of FCC over the entire reproductive lifespan was estimated at 0.15 ± 0.03, while the estimate is still considered lowly heritable, the genetic influence on FCC was considerably higher than that of FSC. Similar to FCC, a trait that also defines a female's ability to calve early or late during the calving season in comparison to the herd, calving day (CD) heritability was estimated by Rasali and Crow (2004) at 0.16 and 0.25 for Angus heifers and cows, respectively. While the estimates for the traits, CD and FCC, are similarly heritable, however, they are not measured using the same method. Furthermore, days to calving (DC) investigated by Meyer et al. (1990) reported heritability between 0.05 and 0.09 in different cattle breeds again suggesting minimal genetic influence on the trait. When comparing estimates over the reproductive lifespan for FSC and FCC, the difference between heritability estimates of 0.04 and 0.15 may be explained by the efficiency associated with natural mating over AI and the minimization for the potential of human error as described by Perry et al. (2011). Unmeasurable faults that occur during estrus synchronization protocols, semen thawing, and insemination may result in failed conceptions in otherwise fertile females, who then conceive naturally early in the mating season by natural service due to a high level of fertility.

When observations were categorized based on female age at mating, dissimilarities were observed between estimates of the parameter. Heritability of FCC for growing females with observations at ages one to four years resulted in a 0.04 ± 0.07 value. This can be compared to the estimate of 0.21 ± 0.04 for FCC observations for five years old or greater in mature females. This difference in heritability suggested that genetics holds a larger role on the fertility in mature females over that detected in females with observations one through four. This dissimilarity may be explained by the increased requirements for immature females for growth not experienced by females in the observation category of five and greater, thereby removing once source of contributing variability. As described by Johnson and Funston (2013), heifers and young growing females often face difficulties when returning to reproductive soundness and facing the demand to conceive due to the allocation of energy to growing and new requirements such as lactation. This suggested that the environment has a larger effect on immature females' ability to calve within the first 21-day period of the calving season compared to that of mature females. Additionally, it is important to note that the reduction of FCC success for growing females to mature females results in an increase of phenotypic variance and therefore allows for the detection of females who may be genetically superior for the trait. Considered moderately heritable, these results suggested that a cattle manager can use the success or failure of FCC in mature females to make improvement in the trait over time. Variance components determined in analysis for heritability of both maturity categories, as well as all females for FSC and FCC are summarized in Table 3.3.

Repeatability

When repeatability was estimated over the reproductive lifespan for FSC the resulting value was 0.03 ± 0.02, the identical estimate for FSC heritability suggesting no permanent environmental effect on the trait. This value was similar in comparison to the estimation of repeatability of 0.021 ± 0.008 for success of first service of AI as reported by Rahbar et al. (2016). However, a heritability estimate of 0.015 reported by Rahbar et al. (2016) for the same trait revealed a detectable but minimal influence of the permanent environment on the trait. Collectively, the results of this study and those of Rahbar et al. (2016) suggested that the trait was lowly heritable and repeatable. Since estimates reported in literature as well as within this study for FSC suggest that the trait was lowly repeatable, therefore, there is little potential for prediction of future records. More specifically a single record of FSC was not an adequate

Table 3.3 Estimates of phenotypic variances, genetic variances, permanent environment variances, residual variances, heritability (h^2), repeatability (r), and sample size (n) for observation categories of first service conception (FSC) and first cycle calving (FCC).

Trait	Observation Category	Phenotypic Variance	Genetic Variance	Permanent Environmental Variance	Residual Variance	h^2	r	n
FSC	Immature[1]	1.0388	0.0388	0.000	1	0.04 ± 0.04	0.04 ± 0.04	4291
	Mature[1]	1.0843	0.0220	0.0622	1	0.02 + 0.05	0.08 ± 0.04	3915
	All Females	1.0331	0.0331	0.000	1	0.03 ± 0.02	0.03 ± 0.02	8206
FCC	Immature[1]	1.1198	0.0447	0.0752	1	0.04 ± 0.07	0.11 ± 0.07	4291
	Mature[1]	1.264	0.2640	0.0000	1	0.21 ± 0.04	0.21 ± 0.04	3915
	All Females	1.1744	0.1744	0.000	1	0.15 ± 0.03	0.15 ± 0.03	8206

[1]Immature Females = individuals four years or younger at mating, Mature Females = individuals five years or older at mating.

predictor of a female's ability to conceive during the first service of AI for future first service mating events.

When segregated into growing/immature and mature females, repeatability was estimated for the growing/immature females with observations recorded at ages one through four at mating, at 0.04 $\pm$ 0.04 which shows minimal influence of producing ability, the combination of genetics and the permanent environment on FSC success. When comparing this estimate to the heritability of 0.04 $\pm$ 0.04 for the same trait within the same observation category, the estimates suggested no permanent environmental effect on FSC in immature females. However, these estimates were similar to the heritability and repeatability estimated by Rahbar et al. (2016) whose estimation of the same parameters in Holstein dairy cattle revealed a minimal effect of producing ability on first service success. When the parameter was estimated for females ages five years or greater, the resulting value was 0.08 $\pm$ 0.04 revealing minimal influence of the producing ability on the trait in mature females. A comparison between the heritability of 0.02 $\pm$ 0.05 and the repeatability for the same age category revealed a larger influence of a permanent environmental effect experienced by the female. While this may be an effect of a decrease in sample size, records per female, and an increase in standard error, this may be explained by the permanent effects that early breeding success have been reported to have on female fertility and longevity throughout her life. A study by Mousel et al. (2014) suggested that a female's ability to conceive and calve early with her first pregnancy can have a positive effect that carries over throughout her life on her ability to remain in the herd. It is suggested that this is due to the extra allotment of time that the female experiences between calving and breeding allowing for greater success for rebreeding (Mousel et al., 2014).

The repeatability estimated for FCC over the reproductive lifespan was 0.15 ± 0.03, considering the heritability estimate of 0.15 ± 0.03 for the trait, it was inferred that the permanent environment has no effect on FCC. This estimate was elevated but similar in comparison to the repeatability reported by Lesmeister et al. (1973) for early, middle, and late calving groups when separated into 21-day increments, estimates were 0.09 and 0.11 for a mixed herd of Angus and Hereford cows and a group of Hereford females only, respectively. While literature investigating the repeatability of FCC is limited, repeatability has also been estimated for similar traits such as days to calving (DC), or the difference in days between the beginning of the breeding season when bulls are introduced to the females and the birth of the resulting calf. Meyer et al. (1990) estimated the repeatability of DC at 0.22, 0.10, and 0.18 for Hereford, Angus, and Zebu cross cattle, respectively. The repeatability estimate of 0.15 in this study for FCC in Angus cattle was elevated in comparison to the estimate of 0.10 found by Meyer et al. (1990).

When considering the repeatability of growing/immature females and mature females (summarized in Table 3.3), the resulting estimates for FCC included 0.11 ± 0.07 and 0.21 ± 0.04, respectively. When compared to the heritability estimates of 0.04 ± 0.07 and 0.21 ± 0.04 of the same groups for FCC, a permanent environmental effect can be detected between the parameter estimates of the immature group only. The permanent environmental effect detected for the category of immature females may be the result of early calving dates effect on female longevity reported by Mousel et al. (2014). The repeatability of FCC in mature females was moderately repeatable, therefore the outcome of one mating and resulting calving is a better indicator for the female's ability to perform similarly for following conceptions and calvings over the performance of an immature female for FCC. This suggested that the most potential for selection remains on the outcome of mature females calving in the first 21-day period of the initial calving due date.

Conclusions

As reported previously in literature, female fertility can be influenced by a wide range of temporary environmental factors, including disease and parasites (Payne et al., 2013; Stromberg and Gasbarre, 2006; Kendrick, 1976), condition score (Shorten et al., 2015; Cumming, 1972), age (Shorten et al., 2015) post-partum interval (Johnson and Funston, 2013), semen quality as well as AI technician expertise (Perry et al., 2011, Barth, 1993). Due to the extensive list of environmental effects reported to have an effect on a female's ability to conceive and previous parameter estimates reported in literature, the resulting low estimates for the genetic parameters align with expectations.

Collectively, the heritability for both traits for all categories ranged from 0.02 to 0.21 and were classified as lowly heritable with the exception of the moderate heritability estimate for FCC in mature females. This suggests low to moderate influence of genetics on the traits. When comparing the traits to one another, FCC had higher heritability estimates than FSC suggesting that the trait was under larger genetic influence resulting in more potential for selection on the trait and slow progress over time. The values calculated for repeatability of FSC and FCC over the reproductive lifespan were also considered lowly repeatable with the exception of FCC in mature females. This suggested that the producing ability, the combination of breeding value and the permanent environment had minimal influence on the traits. The analysis and resulting estimates for both heritability and repeatability for FSC and FCC indicated that the most influential factor on the two fertility traits was the temporary environment that is specific to the observations.

Results of the analysis suggested that cattle managers should continue to alter female environment through management strategies to maximize reproductive success; however, there is some potential for managing immature and mature females for FCC differently. The minimal influence of genetics suggested through heritability estimation of FSC and FCC imply that the temporary environment that a female experiences is much more influential on both traits and therefore should be the main focus of cattle managers to improve female fertility. While the attention should remain on the temporary environment, if selection pressure is placed on either trait, extremely slow progress could be potentially made over time unless considerably more data were available and accuracy could be increased. However, the minimal potential for genetic selection on such traits further promotes the alteration of management practices such as nutrition, body condition, female age, and inseminator skill as the primary focus to maximize the success of FSC and FCC. This result further encourages cattle managers to alter the temporary environment through management strategies to maximize female fertility in beef cattle herds. Management practices that have been shown to improve fertility revolve around nutritional programs resulting in better conditioned females at breeding (Shorten et al., 2015; Cumming, 1972), adequate time for reproductive repair and return to cyclicity (Johnson and Funston, 2013), and experienced thawing and breeding technicians (Barth, 1993).

While the repeatability estimated for FSC and FCC were both considered low, the repeatability estimated for FCC was greater than that of FSC allowing for more potential for selection or culling based on female performance for the trait. If selection for FCC was used in a beef cattle operation, while slow, genetic progress could be made for cattle to conceive and calve early in the breeding and calving season respectively. While not as desirable for females who conceive on the first service of AI who can be mated to an elite sire, this progress would still prove beneficial when considering producing larger and older calves in the calf crop and allowing more time for the female to repair before entering the next breeding season.

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CHAPTER 4

SUMMARY AND IMPLICATIONS

The economic relevance of reproductive traits in beef cattle reveal a need for improvement in those traits. Female infertility remains one of the largest sources of economic loss for beef cattle producers resulting from increased breeding expenses, shortened reproductive lifespans, and lighter calves (Lamb et al., 2008). To combat these impacts on economic viability, understanding the genetic and environmental influences on the trait would inform cattle managers on how to approach improvement within such traits whether that be through genetic selection or management strategies. Both considered good measures of female fertility, first service conception (FSC) and the ability of a female to calve within the length of the first estrous cycle (21 day period) after the AI due date, termed first cycle calving (FCC) aid in the determination of the reproductive ability of females in the herd. Progress made for the improvement of FSC and FCC could potentially result in higher quality, heavier calves and more productive females.

When estimating the heritability over the entire reproductive lifespan of females, results for FSC and FCC were 0.03 ± 0.02 and 0.15 ± 0.03, respectively. Repeatability estimation resulting in identical estimates to heritability estimates suggests no permanent environmental effect on the traits. However, when females were divided into two categories of one through four years at mating and five years of age and greater, differences in the parameters became apparent. This grouping strategy may better indicate how females should be managed dependent on maturity category and which traits are of most importance to the producer. Heritability and repeatability estimates for FCC in mature females were the highest at 0.21 and 0.21, respectively when compared to the parameters estimated for both traits in all female categories. Low estimates for the parameters were estimated in all other groups for FSC and FCC. These results suggest that the most potential for application involves producers using a female's ability to calve in the first 21-day period of the AI due date, at or after the production of her fifth calf to make selections for female replacements. However, it is likely that producers are already doing so when selecting replacement females as calves born early and to mature females are likely to be heavier and more developed compared to late born calves born to young females. Furthermore, producers should place the most focus on providing the optimum environment for females through their fourth calf in which the temporary environment has the greatest influence on fertility then once a female is mature, selection can be placed on females who have successful phenotypes for the trait. Due to these parameter estimates and therefore minimal genetic or permanent environmental influence, it is recommended that cattle managers should continue to place focus on improving the temporary environment through management practices to maximize female fertility regardless of the female maturity.

As previously reported in literature, many environmental effects have been shown to have an effect on female fertility including but not limited to body condition score (Shorten et al., 2015; Cumming, 1972), female age (Shorten et al., 2015), previous calving ease (Johnson and Funston, 2013), post-partum interval (Johnson and Funston, 2013), and insemination skill (Barth, 1993). This is likely due to the addition of human management and risk for error during estrus synchronization, semen thawing, and insemination when AI is employed. Unmeasurable faults in the AI process or natural service bull fertility may result in a failed conception in an otherwise fertile female. As described by (Perry et al., 2011) the natural mating system is more successful and efficient than the simulated system created by cattle managers through manipulation of the estrous cycle and artificial insemination. Due to this gap of efficiency, allowing females to conceive early in a natural system is more telling of her fertility due to the elimination of human errors that may occur.

While the heritability and repeatability estimates over lifetime production are considered low to moderate, minimal improvement can be made when selecting on females who conceive at the first service or early in the breeding season. Selection on mature females who calve in the first 21-day period may prove beneficial for improving fertility of older females in the herd. However, this potential for selection will not replace the need for supplying the optimum environment for female fertility through management strategies. Further understanding fertility traits such as FSC and FCC in beef cattle would require whole-herd reporting resulting in more data paired with the improvement of binary trait analyses (Cammack, Thomas, and Enns, 2009). Additional investigation will better establish more accurate estimations of FSC and FCC heritability and repeatability, again further revealing the best strategy to improve the success of the traits.

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