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Faculty of Veterinary Medicine and Animal Science

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Abstract

The aim of this study was to evaluate the effect of different sire breeds on calving traits when used in dairy herds. Records from 1,423,851 calvings from 1990-2016 were collected from the Swedish milk recording scheme from Swedish Holstein, Red dairy cattle, Hereford, Charolais, Aberdeen Angus, Limousin and Simmental sires mated with Swedish Holstein, Red dairy cattle or crossbred dams. Calving ease was defined in two categories, easy or difficult calving. Stillbirth was defined as dead at calving or within 24 hours of birth. The data were analyzed for both traits for first and later parities separately.

The frequencies of difficulties at calving in first parity ranged from 3.2% to 7.6%. The highest frequencies were found for Charolais and Simmental sires, and the lowest for Aberdeen Angus and Red dairy cattle sires. The incidence of stillbirth ranged from 1.4% to 5.0% in first parity, where Swedish Holstein sires gave the highest incidence of stillbirth and Hereford and Aberdeen Angus the lowest. The frequency of difficulties at calving and the incidence of stillbirths were in general lower in later parities compared to first parity.

Swedish Holstein and Red dairy cattle sires gave significantly less difficulties at calving compared to Charolais, Hereford, Limousin and Simmental sires in first parity, but were not significantly different from Hereford sires in later parities. Aberdeen Angus sires were performing significantly better than all other beef breeds in first parity, but were not significantly different from Hereford sires in later parities. Charolais gave significantly more difficulties at calving than all sire breeds, except for Simmental in first parity. Swedish Holstein sires gave significantly higher incidences of stillbirth than Aberdeen Angus, Hereford, Limousin and Simmental sires in first parity. All beef breeds gave significantly lower incidence of stillbirth than sires in both dairy breeds in later parities. There was no significant difference in the incidence of stillbirth between beef breeds in later parities. There was some re-ranking of beef sire breeds depending on which breeding values (based on records from purebred beef herds or from beef-dairy crosses) had been used.

Sammanfattning

Syftet med denna studie var att utvärdera effekten av olika faderraser på kalvningsegenskaper när de använts i mjölkbesättningar. Information från 1 423 851 kalvningar från 1990-2016 samlades in från den svenska kokontrollen. Kalvarna var från renrasiga Svenska Holstein-, Nordiska röda-, Hereford-, Charolais-, Aberdeen Angus-, Limousin- och Simmentaltjurar parade med Svenska Holstein-, Nordiska röda- eller blandraskor. Kalvningsförloppet klassificerades i två kategorier, lätt eller svår kalvning. Kalven räknades som dödfödd om den var död vid kalvning eller inom 24 timmar efter kalvning. Datamaterialet analyserades separat för första och senare kalvning för båda kalvningsegenskaperna.

Andelen kalvningssvårigheter vid första kalvningen varierade mellan 3.2 % och 7.6 %. Charolais- och Simmentaltjurar gav högst frekvens av svåra kalvningar. Aberdeen Angus- och Nordiska röda tjurar hade de lägsta frekvenserna av svåra kalvningar. Andelen dödfödslar varierade från 1.4 % till 5.0 % vid första kalvning. Tjurar av Svensk Holstein gav den högsta frekvensen av dödfödslar vid första kalvning, och Hereford- och Aberdeen Angustjurar de lägsta. Frekvenserna av kalvningssvårighet och dödfödslar var generellt sett lägre vid senare kalvningar jämfört med första kalvning.

Svenska Holstein- och Nordiska röda tjurar gav signifikant färre kalvningssvårigheter jämfört med Charolais-, Hereford-, Limousin-, och Simmentaltjurar vid första kalvning, men var inte signifikant skilda från Herefordtjurar vid senare kalvning. Angustjurar var signifikant överlägsna de andra köttraserna vid första kalvning, men det fanns ingen signifikant skillnad med Herefordtjurar vid senare kalvningar. Charolaistjurar gav signifikant svårare kalvningar än alla andra raser förutom för Simmentaltjurar vid första kalvning. Svenska Holsteintjurar gav signifikant fler dödfödslar än Angus-, Hereford-, Limousin- och Simmentaltjurar vid första kalvning. Alla köttraser hade signifikant lägre frekvenser av dödfödslar än mjölkrastjurar för senare kalvningar. Det fanns ingen signifikant skillnad för dödfödslar mellan köttraserna för senare kalvningar. Resultaten för köttraserna varierade något beroende på vilka avelsvärden (baserade på registrering från renrasiga köttrasbesättningar eller från kött- och mjölkraskorsningar) som hade använts.

Table of Contents

Introduction

Sweden has a long tradition of recording traits in cattle, and the importance of calving traits has been recognized since the 1960s (Philipsson & Lindhé, 2003). The incidences of calving difficulty and stillbirth have however increased during the latter part of the 20th century in both the Swedish Holstein and the Swedish Red population, which is a big welfare issue (Steinbock *et al.*, 2003; Steinbock *et al.*, 2006). Calving traits are not only interesting from an animal welfare point of view but also because they affect the production and herd dynamics (Dematawewa & Berger, 1997; Berry *et al.*, 2007; Bicalho *et al.*, 2008). In 2016, 3.7 % of first parity Holstein cows had a difficult calving and the stillbirth rate was 8.3 %. In first parity Swedish red, calving difficulty and stillbirth measured 3.3 % and 5.3 %, respectively (Växa, 2017).

It is common practice in Sweden that calves not needed for replacement in the dairy industry are reared specifically for beef production. Approximately 61 % of all beef produced in Sweden are from these surplus dairy calves (LRF, 2017). It is however becoming more common in Europe to use semen from beef breeds to inseminate dairy cows that are not used to breed replacements heifers (Fouz *et al.*, 2013; Viking Genetics, 2017). This is a good way to make the most out of dairy cows with a lower potential for milk production and at the same time have a possibility to achieve higher economic revenue from the crossbred calves sold for beef production (Wolfova e*t al.*, 2007; Dal Zotto *et al.*, 2009; Vallée *et al.*, 2013). However, a development towards increased use of beef semen in dairy herds is not an ethical or sustainable alternative breeding strategy if the calves from these beef-dairy matings cannot be born easily and survive until they are ready for slaughter. Furthermore, beef-dairy crosses have not been studied to the same extent, in terms of calving traits, as dairy-dairy or beef-beef breed crosses (Fouz *et al.*, 2013).

The aim of this study was to analyze data from Swedish dairy herds with respect to the effect of different sire breeds on calving traits. The main focus was to evaluate the performance of different beef breed sires for difficulty at calving and stillbirth when mated to dairy dams and compare them to the performance of dairy breed sires mated with dairy dams. The secondary objective was to evaluate breeding values of beef sires from two different genetic evaluations. Lastly, comparisons were made between dairy breeds in the study and estimations from the Nordic cattle genetic evaluation. The long term goal is to help producers make informed decisions when planning herd dynamics with a possibility to increase revenue from slaughtering crossbred calves.

Literature Review

Calving performance

Trait definition and recording

Calving traits are usually measured as categorical traits, where lower scores often indicate a better calving performance. The number of categories, definitions and methods for gathering data can however vary, making it more complicated when comparing calving performance between countries, studies and breeds (Meijering, 1984). Meijering (1984) defined a difficult calving as "a delivery requiring more assistance than desirable." Calving ease is recorded in two or more categories (Phocas & Laloë; 2003; Steinbock *et al.*, 2003; Fouz *et al.*, 2013; NAV, 2013). Stillbirth is usually defined as calf mortality just before, during and shortly after birth. The time period allowed before and after the actual birth can vary in order to distinguish the trait from other influencing factors, such as abortions or infections. The time period before birth is usually limited by a fixed gestation length and a period of 24 or 48 hours is usually allowed after birth (Philipsson *et al.*, 1979; Meijering, 1984).

Both calving ease and calf survival are in general recorded on farm by the producer. Approximately 80.0 % of all dairy cows and 74.4 % of dairy herds are in the Swedish milk recording scheme (Jordbruksverket, 2017; Växa, 2017). Calving ease was previously recorded in 2 categories in dairy breeds in Sweden, easy and difficult calving (NAV, 2017). Four categories were introduced in 2012 (Växa, 2016a; NAV, 2017). Both scoring systems were used during a transition period of four years. The countries participating in the Nordic cooperation "Nordisk avelsvärdering" (NAV) (Denmark, Sweden and Finland) are now using the same categories and definitions for measuring calving traits due to the change in the Swedish recording (NAV, 2013; NAV, 2017). The categories used to measure calving ease are defined as: easy calving without assistance (score 1), easy calving with assistance (score 2), difficulty calving without veterinary assistance (score 3) and difficult calving with veterinary assistance (score 4). Calf survival is recorded as a binary trait, where stillbirth is defined as dead at calving or within 24 hours of birth (NAV, 2017).

Breed variation

Dairy breeds

The Swedish Holstein (SH) and the Swedish Red (SRB) are the most common dairy breeds in Sweden. Frequencies of calving difficulty and stillbirths in heifers and cows have been summarized from the literature and the annual report from Växa (2017) in Table 1. The mean values from the annual cattle statistics are somewhat lower than reported in the literature. Approximately 3.7 % of SH heifers suffer a difficult calving, compared to 3.3 % in SRB. The frequency is much lower in later parities for both SH and SRB. The same pattern can be found for the incidence of stillbirth (Växa, 2017).

Calving difficulties in the US Holstein have been particularly noticeable with frequencies over 10 %. This is alarming because a lot of their genetic material has been imported from North America and incorporated into some of the Scandinavian (mainly the Black and White) breeds (Philipsson & Lindhé, 2003; Steinbock *et al.*, 2003; Hansen *et al.*, 2004a). The performance in calving traits also changed in SRB lately, though, not as alarmingly as in the SH (Steinbock *et al.*, 2006). The Norwegian red was performing well compared to other breeds (Heringstad *et al.*, 2007).

Table 1. Frequencies of difficulties at calving and stillbirth (in %) in dairy breeds found in literature

	First parity		Later parity		Not specified		
Breed[1]	CD[2]	SB	CD	SB	CD	SB	Ref.
SH					15.5	7.1	Berglund & Philipsson, 1987
		10.3					Berglund *et al.*, 2003
	8.3	7.1	4.5	2.7			Steinbock *et al.*, 2003
	3.7	8.3	1.6	4.3			Växa, 2017
SRB					11.0	3.1	Berglund & Philipsson, 1987
						5	Berglund *et al.*, 2003
	4.0	3.6	1.9	2.5			Steinbock *et al.*, 2006
	3.3	5.3	1.6	3.8			Växa, 2017
DH					11.5	10	Hansen *et al.*, 2004a
NR	2-3	3	1	1.5			Heringstad *et al.*, 2007
US H	19.0		7.45				Dematawewa & Berger, 1997
	12.9	4.3	7.2	2.8	23.7	7.1	Johanson & Berger, 2003
		10.7		4		6.5	Bicalho *et al.*, 2008
IH					10.6		Hickey *et al.*, 2007
SpH					2.5	6.7	Fouz *et al.*, 2013
NZ HF					7	6	Berry *et al.*, 2007

[1]SH = Swedish Holstein, SRB = Swedish Red cattle breed, DH = Danish Holstein, NR = Norwegian Red, USH= US Holstein, IH = Irish Holstein, SpH = Spanish Holstein, NZ HF = New Zealand Holstein Friesian, SIM = Simmental.
[2]CD = calving difficulty, SB = stillbirth.

Beef breeds

Seven beef breeds are genetically evaluated in Sweden - Aberdeen Angus, Blonde d'Aquitaine, Charolais, Hereford, Highland Cattle, Limousine and Simmental (Växa, 2017). Charolais, Hereford and Simmental had higher frequencies of difficulties at calving as found in the literature compared to Angus and Limousin (Table 2). The incidence of stillbirth was highest in Charolais, Hereford and Angus. Similarly to dairy breeds, the mean percentages for both calving traits tend to be higher in first parity compared to later parities cows for both traits.

Table 2. Frequencies of difficulties at calving and incidence of stillbirth (in %) in purebred beef breeds found in literature

	First parity		Later parities		Not specified		
Breed[1]	CD[2]	SB	CD	SB	CD	SB	Ref.
ANG	3.2	1.3	0.3	0.4			Berger *et al*., 1992
	3.7	4.4	0.6	1.6			Växa, 2017
CHA					6.8		Phocas & Laloë, 2003
	6.6	5.9	1.0	1.8			Eriksson *et al*., 2004a
	7.0		1.1				Eriksson *et al*., 2004b
	6.1	1.3					Mujibi & Crews, 2009
	2.8	3.3	0.9	2.5			Växa, 2017
HER	6.2	5.6	1.2	1.8			Eriksson *et al*., 2004a
	6.4		1.2				Eriksson *et al*., 2004b
	4.3	5.8	0.5	2.7			Växa, 2017
LIM	2.9	3.9	0.2	1.3			Växa, 2017
SIM	3.9	3.7	1.0	1.6			Växa, 2017

[1]ANG = Aberdeen Angus, CHA = Charolais, HER = Hereford, LIM = Limousin, SIM = Simmental.
[2]CD = calving difficulty, SB = stillbirth.

Crossbreeding

The majority of Swedish beef is produced from surplus dairy calves. However, purebred dairy breeds do not have as good carcass traits (net daily gain, carcass conformation) as beef breeds (LRF, 2017). Using beef breed semen in dairy herds can therefore be an efficient way to increase revenues from excess calves sold for meat production (Wolfová *et al.*, 2007; Dal Zotto *et al.*, 2009, Växa, 2016b). Approximately 26 % of the Swedish beef production in Sweden is from crossbred animals (LRF, 2017). The heterosis effect will also improve the performance of crossbreds, especially in low heritability traits such as health and fertility (Oldenbroek & van der Waaij, 2015). Beef-dairy crosses have not been studied to the same extent, in terms of calving traits, as dairy-dairy or beef-beef breed crosses (Fouz *et al.*, 2013). The frequencies of difficult calvings and incidence of stillbirth recorded from beef-dairy matings found in the annual cattle statistics are somewhat higher than their purebred equivalents (Table 3).

Table 3. Frequencies of difficulties at calving and incidence of stillbirth (in %) in sire beef breeds mated with dairy breed dams found in literature

	First parity		Later parities		Not specified		
Breed[1]	CD[2]	SB	CD	SB	CD	SB	Ref.
CHAxD[3]	6.7	6.6	5.4	4.6			Växa, 2017
HERxD	4.4	7.6	1.6	3.5			Växa, 2017
LIMxSpH					3.5	6.8	Fouz et al., 2013
SIMxD	6.5	6.8	3.0	4.3			Växa, 2017

[1]CHAxD = Charolais sires mated with dairy breed dams, HERxD = Hereford sires mated with dairy breed dams, LIMxSph = Limousin sires mated with Spanish Holstein dams, SIMxD = Simmental sires mated with dairy breed dams.
[2]CD = calving difficulty, SB = stillbirth.
[3]D = Dams of unspecified dairy breed.

Herd variance

Calving traits are measured in the herd by the farmer. These subjective measurements will introduce some bias to the data because of difference of opinion between herdsmen (Luo *et al.*, 2002; Berglund *et al.*, 2003; Vallée *et al.*, 2013). This increases the risk of lower precision in the records (Luo *et al.*, 2002). There was also a large variation in the frequency of stillbirths between herds in the study by Bicalho *et al.* (2013), where some herds reported incidences at 4.1 % while others recorded incidences as high as 14.3 %. This variation could indicate the importance of farm management and routines in the herds (Bicalho *et al.*, 2008; Vallée *et al.*, 2013). Furthermore, all calvings are not monitored in the field and the proportions of monitored calving events will differ between herds. How these calving events are scored compared to their "true" value and how individual studies choose to handle these recordings may also vary (Everitt *et al.*, 1978). This emphasizes the need for herd identification and to adjust for herd effects (Hickey *et al.*, 2009; Vallée *et al.*, 2013).

Causes of calving difficulty and stillbirth

Non genetic factors

The most important causes of calving difficulties are feto-pelvic incompatibility (FPI), malpresentation of the calf, poor dilatation of the cervix, torsion of the uterus and weak labor. FPI is likely the most important cause for difficulties at calving in heifers while poor dilatation, uterine torsion and weak labor are more common in older cows (Meijering, 1984; Noakes *et al.*, 2001). The cause of stillbirth is more difficult to explain. There are in general two scenarios; one where stillbirth is preceded by calving difficulty and one where stillborn calves are born at seemingly normal calving events (Meijering, 1984). Between 40 - 60 % of all stillborn calves are thought to be born during normal calvings (Philipsson, 1976; Berglund *et al.*, 2003; Steinbock *et al.*, 2003; Eriksson *et al.*, 2004a), suggesting vitality issues (Meijering, 1984; Berglund *et al.*, 2003).

Cow oriented parameters

Body weight ratio

The body weight ratio of the calf and cow is one of the main reasons for FPI (Meijering, 1984; Noakes *et al.*, 2001; Berglund *et al.*, 2003; Berry *et al.*, 2007). The relative birth weight is described as the weight of the calf divided by the weight of the cow. Apart from their relative weights, this ratio can for instance be affected by breed and parity of the dam, and sex of the calf (Meijering, 1984; Berglund & Philipsson, 1987; Berry *et al.*, 2007). Berglund & Philipsson (1987) reported that the birth weight of calves increased with parity of the dam and that the mean relative birth weight was higher in earlier parities compared to later. Since calving difficulties are more common in first parity compared to later, they suggested that the cows managed to compensate the increase in birth weight of the calf once they had finish growing themselves, thus minimizing the effect of the body weight ratio (Berglund & Philipsson, 1987). Johanson & Berger (2003) found that the ratio of calf's birth weight to dam's weight (%) had a significant effect in their model for stillbirth. It was however not significant in the model for calving difficulty. Instead, they suggested that the effect of the pelvic area of the cow was better to use to account for the size of the cow when analyzing calving difficulty. They found that 1 dm^2 increase in the pelvic area of the dam decreased the probability of difficulties at calving with 11 % (Johanson & Berger, 2003).

Parity of the dam

Both difficulties at calving and stillbirth are in general more common in first parity cows compared to cows in later parities (Meijering, 1984; Berger *et al.*, 1992; Eriksson *et al.*, 2004a; Berry *et al.*, 2007). First parity cows had for instance a 2.4 higher risk [95 % CI: 1.84-3.28] of stillbirth than cows in later parities in a study by Johanson & Berger (2003). Berger *et al.* (1992) reported a significant effect of parity in both calving difficulty and stillbirth in Angus, where cows had significantly less problems at calving compared to heifers. Cows in that study were for instance 11.9 (SE ± 4.14) times more likely to not need any assistance at calving and 2.7 (SE ± 0.40) times more likely to have a liveborn calf compared to heifers (Berger *et al.*, 1992). Furthermore, Berry *et al.* (2007) did not find a significant difference in calving difficulties between later parities.

Calf oriented parameters

Birth weight

There is a non-linear relationship between birth weight and calving ease, where the proportion of difficult calvings increases when the birth weight of the calf passes certain thresholds at either end of the scale (Berglund & Philipsson, 1987; Berger *et al.*, 1992; Eriksson *et al.*, 2004a; Vallée *et al.*, 2013). As the calf weight increases so does the probability of a difficult calving. However, too low birth weight is also an issue because it will likely compromise the viability of the calf and increase the incidence of stillbirths. The thresholds where these extremes are experiencing problems are affected to a large extent by the breed and parity of the dam (Meijering, 1984; Eriksson *et al.*, 2004a). Berger *et al.* (1992) reported more unassisted births in Angus heifers when the calf was lighter than 31 kg. They also found lower incidence of stillbirth when birth weights were between 26 and 35 kg, and highest above 35 kg (Berger *et al.*, 1992). Johanson & Berger (2003) suggested that the probability that the cow would experience a difficult calving increased by 13 % per kg increase in birth weight.

Registration and inclusion of data about birth weight in genetic evaluations differs between countries. Calf size is for instance not measured in Sweden or Finland, but it is measured in four categories in dairy breeds in Denmark (Hansen *et al.*, 2004a; NAV, 2017). The Danish data is then included in the Nordic evaluation (NAV, 2017). There is also a difference in which traits that have estimated breeding values from the dairy and the beef breed evaluation. Breeding values are for instance available for birth weight from the Swedish (purebred) beef breed evaluation but not from the genetic evaluation for dairy breeds (Växa, 2016a; NAV, 2017).

Sex of calf

The birth weight of calves is significantly affected by the sex of the calf (Berglund *et al.*, 2003) and significantly lower birth weights have been reported for heifer compared to bull calves (Berry *et al.*, 2007). Difficulties at calving are also suggested to be more common when the calf is a bull compared to a heifer (Berger *et al.*, 1992; Luo *et al.*, 2002; Eriksson *et al.*, 2004a; Fouz *et al.*, 2013). Steinbock *et al.* (2006) found, for instance, that SRB bull calves had higher frequencies of calving difficulties and stillbirth in both first and later parities. The same pattern has been reported in Holstein (*e.g.* Luo *et al.*, 2002; Hickey *et al.*, 2007) and Angus (Berger *et al.*, 1992). Berry *et al.* (2007) found that giving birth to a bull calf increased the risk of a difficult calving by 1.4 times [95 % CI: 1.02-1.98], compared to giving birth to heifer calves. They also suggested that other differences exist between sexes (such as conformation) that influence calving ease since the effect of sex was still significant even after adjusting for birth weight (Berry *et al.*, 2007). Berger *et al.* (1992) estimated that the probability of unassisted calving in Angus was 2.4 (SE ± 0.69) times greater for heifer compared to bull calves. They also reported that heifer calves were 1.5 times more likely (SE ± 0.21) to survive the first 24h compared to bull calves (Berger *et al.*, 1992). There are also some studies where no significant differences were observed between sexes of calves (Meijering, 1984; Johanson & Berger, 2003).

Gestation length

The gestation length is another factor that may influence the birth weight of the calf (Meijering, 1984; Mujibi & Crews, 2009; Fouz *et al.*, 2013). Longer gestation length can result in larger calves and thus affect calving ease (Meijering, 1984). It could then be expected that the heavier breeds would have longer gestation length. Fouz *et al.* (2013) reported significantly longer gestation length in Limousin-Holstein crossbred calves compared to purebred dairy calves. However, they did not find more difficulties at calving with longer gestation length (Fouz *et al.*, 2013). Berglund & Philipsson (1987) found only small changes in gestation length between first and second parity. The breed of the dam also plays a significant role (Berglund & Philipsson, 1987). A shorter gestation length can also be an issue if it compromises the viability of the calf (Meijering, 1984).

Genetic factors

Heritabilities – direct and maternal effects

The heritability is used to express, on a scale of 0 to 1, the amount of the total phenotypic variation in a trait that is due to the (additive) genetic variation in individuals. Calving traits are so called low heritability traits partly because it is difficult to measure and determine the true phenotype for all animals in categorical traits (Oldenbroek & van der Waaij, 2015). The phenotype is affected by the genotype of the animal, which in turn partly consists of additive genetic effects, such as direct and maternal genetic effects. The direct effects are related to the effect that the genotype of the calf itself will have on the trait (Philipsson *et al.*, 1979; Meijering, 1984), whereas the maternal effects are related to the influences from the genotype of the cow (for instance body size of the dam, uterine conditions and the dam’s influence on calf size) (Philipsson *et al.*, 1979; Meijering, 1984; Oldenbroek & van der Waaij, 2015). Heritabilities for direct effects are in general higher than for maternal effects in cattle (Philipsson *et al.*, 1979; Meijering, 1984).

It is also common to find higher estimated heritabilities in earlier parities compared to later, which is partly explained by the difference in incidence between first and later parity cows (Philipsson, 1976; Meijering, 1984). The number of categories used in the recording system can also affect the heritability estimates, where more categories will help explain the trait more fully compared to the all-or-nothing character in binary recordings. Higher estimates can be achieved by transforming heritabilities to the underlying normal distribution of the traits (Philipsson, 1976; Philipsson *et al.*, 1979).

Heritabilities for calving difficulty in the literature ranges between 4 % and 18 % in first parity and between 0.4 % and 10 % in later parities (Luo *et al.*, 2002; Eriksson *et al.*, 2004a; Eriksson *et al.*, 2004b; Hickey *et al.*, 2007; Wiggans *et al.*, 2008). Stillbirth has even lower estimated heritabilities than calving difficulty (Steinbock *et al.*, 2003; Steinbock *et al.*, 2006), between 0.1 % to 3.8 % in first parity (Eriksson *et al.*, 2004a; Hansen *et al.*, 2004b; Wiggans *et al.*, 2008) and between 0.3 % and 1 % in later parities (Eriksson *et al.*, 2004a; Wiggans *et al.*, 2008). There are a few studies that have reported extremely high estimates for direct and maternal effects in calving traits (*e.g.* Phocas & Laloë, 2002; Hansen *et al.*, 2004b).

Genetic correlations

The genetic progress is affected by genetic correlations between traits (Philipsson, 1976). The direct and maternal effects are for instance often negatively correlated in calving traits (*e.g.* Steinbock *et al.*, 2003; Eriksson *et al.*, 2004a; Mujibi & Crews, 2009), which means that favoring one trait would give a deterioration in the other (Meijering, 1984). Some studies have however reported positive genetic correlations between direct and maternal effects in calving difficulties and stillbirths (Eriksson et al., 2004a; Eriksson et al., 2004b; Hansen et al., 2004a).

Positive genetic correlations have been reported between first and later parities, for both direct and maternal effects, in calving difficulty and stillbirth (Luo et al., 2002; Steinbock *et al.*, 2006; Wiggans *et al.*, 2008). This means that selection for better performance in first parity would also indirectly improve the performance in later parities. Some studies have also reported rather high correlations between first and later parities, suggesting that they are genetically the same trait and could be treated as one trait instead of separate (Phocas & Laloë, 2003; Steinbock *et al.*, 2006). The mixed results between studies may be due to different scoring systems, methods of data collection, subjective recording of farmers (Luo *et al.*, 2002) and which breed or population that was studied (Johanson & Berger, 2003; Steinbock *et al.*, 2003).

High genetic correlation has also been reported between birth weight of calves and calving ease (Meijering, 1984; Mujibi & Crews, 2009; Vallée *et al.*, 2013). Vallée *et al.* (2013), for instance, found a genetic correlation of 0.87 when studying Charolais × Holstein crossbred calves. This antagonistic relationship means that it is difficult to improve both traits simultaneously (Meijering, 1984; Mujibi & Crews, 2009; Vallée *et al.*, 2013) because a lower calving score would also decrease the birth weight of the calf. Birth weight is in turn positively correlated with growth rate later in life and with some carcass traits, and so a decrease in birth weight would also entail lower performance in these traits (Philpsson *et al.*, 1979; Meijering, 1984; Eriksson *et al.*, 2004a). High genetic correlation has also been reported between calving ease and calf survival (Philipsson, 1976; Steinbock *et al.*, 2003).

Effects of calving difficulty and stillbirth

Production

Calving difficulties and stillbirths have been studied to large extent, partly because of their influence on dairy productivity. Reduced production levels have been documented in cows that experienced calving difficulties (Philipsson *et al.*, 1979; Meijering, 1984; Dematawewa & Berger, 1997; Johanson & Berger, 2003; Berry *et al.*, 2007; Fouz *et al.*, 2013). Difficult calvings have also been shown to decrease the amount of fat and protein (kg) produced during lactation in Holstein (Dematawewa & Berger, 1997; Berry *et al.*, 2007; McGuirk *et al.*, 2007).

Dematawewa & Berger (1997) studied milk, protein and fat yield in US Holstein. They reported higher losses in yield traits for cows in earlier compared to later lactations. They also found that first calving cows that experienced difficulties at calving had larger losses of milk, fat and protein yield as the degree of calving difficulty increased. First calving cows that needed slight assistance experienced significant losses in 305-d milk and protein yield, while cows in need of more assistance at calving had significant losses in all three yield traits in first parity. The losses in yield decreased in later parities, where cows in second parity only experienced significant losses after needing considerable force at calving. Cows in third or later parities only showed significant losses in 305-d milk and protein yields when experiencing extreme difficulties at calving (Dematawewa & Berger, 1997).

Similarly, McGuirk *et al.* (2007) reported that slight difficulties at calving decreased fat yield by 4.2 and protein yield by 3.7 kg per day, compared to cows that did not experience any difficulties during calving. Fat and protein yields decreased by 11.8 kg and 10.4 kg per day, respectively, after the cow suffered serious difficulty at calving (McGuirk *et al.*, 2007). Berry *et al.* (2007) reported that cows that experienced difficulties had 42.0 and 61.9 kg less yield in total 60- and 270-d milk yield, respectively, compared to cows that had a normal calving event. However, only the decrease up to 60 days in milk (DIM) was significant suggesting that the production losses later on in the lactation are negligible. Significantly reduced concentrations of fat and lactose in cows that had experience difficult calvings have also been reported, both in 60 DIM and 270 DIM. These cows also produced significantly lower concentrations of protein in 60 DIM (Berry *et al.*, 2007).

Another important aspect of calving difficulty at calving is how it affects the calves. A difficult calving will take longer time than a normal calving process and jeopardizes the oxygen supply of the calf. A consequence of this may be lower viability of the calf and higher risk of mortality. The growth of the calf may also be depressed and thus also the beef production (Meijering, 1984).

The production level of the dam is also affected by stillbirths (Berry *et al.*, 2007; Bicalho *et al.*, 2008). In the study by Bicalho *et al.* (2008), the loss of milk due to stillbirths during 305-day lactation was 323.3 kg (±30.5) in Holstein. This was a significant reduction by 1.1 kg per day compared to cows that did not give birth to a stillborn calf. They suggest that these losses are similar with the approximated losses associated with mastitis and lameness. First parity cows had significantly larger losses in daily milk yield compared to cows in later parities.

They also reported larger losses of milk in the beginning of lactation, but they had almost subsided by 270 DIM (Bicalho *et al.*, 2008). Similarly, Berry *et al.* (2007) found that stillbirth had a significant effect on total 60d milk yield, where the milk yield dropped by approximately 51.9 kg in cows that had a stillborn calf.

Fertility and health

Calving difficulties are also associated with an increased risk of long term effects on fertility and health traits (Meijering, 1984; Berry *et al.*, 2007; McGuirk *et al.*, 2007). Like production losses, the effect on fertility is more severe in earlier compared to later parity cows. Dematawewa & Berger (1997) found that number of days open and number of services increased significantly as calving difficulty scores increased in first parity cows compared to cows that experienced a normal calving. The number of days open was significantly increased in second parity cows if the cow required assistance at calving. The number of services required was only significantly higher in cows that needed assistance or considerable force at calving. Third and later parity cows showed a significant increase in number of days open if any assistance was required, but no “consistent trend” was found in number of services (Dematawewa & Berger (1997). Likewise, McGuirk *et al.* (2007) reported that cows suffering slight and serious difficulties at calving had 9.2 and 21.5 more days open, respectively, compared to cows with no difficulties at calving. These cows also required 0.7 and 0.13 more services per conception, respectively, in subsequent parities compared to cows that experienced a normal calving (McGuirk *et al.*, 2007).

Berry *et al.* (2007) reported a significant effect of difficulty at calving on somatic cell score at 60 DIM; however, they found no significant increase in the average SCS during the whole lactation. Despite the significant effect at 60DIM, clinical mastitis was not affected, neither during early nor throughout the whole lactation. There was also a significant difference in lactation average SCS following stillbirth, however the effect was no longer significant after adjustment for calving difficulty score. Stillbirth was not associated with higher probability of clinical mastitis (Berry *et al.*, 2007).

Economy

The consequences from calving difficulties and stillbirth put a strain on farm economy by increasing costs in the herd. These traits are for instance associated with veterinary assistance, additional labor during delivery and management (Johanson & Berger, 2003; McGuirk *et al.*, 2007; Fouz *et al.*, 2013; NAV, 2017). NAV (2017) suggests that 12 min of extra labor are necessary during an easy calving with assistance compared to one without. Difficult calvings normally take 1.5 hours of extra labor, and 3.0 hours of extra labor is to be expected at caesareans and/or dissections. This adds up to a considerable amount of increased labor because approximately 20 % of all difficult calvings that require veterinary assistance ends with caesarean or dissections. Furthermore, it takes an extra 0.25 hour of labor to dispose of a stillborn calf (NAV, 2017).

In the worst case, calving difficulty can lead to the loss of the calf and/or the cow which can be quite costly (Dematawewa & Berger, 1997; Noakes *et al.*, 2001; Johanson & Berger, 2003;

McGuirk *et al.*, 2007). Noakes *et al.* (2001) names stillbirth and early calf mortality as the most important financial consequence of difficulties at calving and Bicalho *et al.* (2008) estimated the loss of replacement heifers alone to account for $125 million per year in the United States. However, Dematawewa & Berger (1997) found that reduced fertility, mainly increased number of days open, was of higher economic importance and it accounted for as much as 32.33 % of the total cost of calving difficulties over the first three parities. The loss of milk yield during a 305-d lactation accounted for 18.93% and the loss of protein yield for 15.35 %. They reported calf losses as the third largest trait, making up 17.18 % out of the total cost. The total cost associated with calving difficulties at calving was on average $29 and $10 for heifers and cows, respectively (Dematawewa & Berger, 1997). McGuirk *et al.* (2007) also used the estimated effects from Dematawewa & Berger (1997) when assessing dairy herds. They found that the increased demand for labor was of highest economic importance in the category of “slight calving difficulties,” followed by increased number of days open and losses in milk protein. Serious difficulties were associated with higher costs for the death of the cow, increased number of days open and death of the calf (McGuirk *et al.*, 2007).

The decrease in production, fertility and health will also affect cow longevity and increase the risk of culling (Dematawewa & Berger, 1997; Noakes *et al.*, 2001; Johanson & Berger, 2003; McGuirk *et al.*, 2007). For instance, 3.1 % of cows suffering serious difficulties at calving were culled and 10.5 % died in the study by McGuirk *et al.* (2007). This influences the investment cost in the herd and it creates an earlier need for replacement heifers.

Material and methods

Collection of data

Observations from 11,580,229 calvings were collected from the Swedish milk recording scheme operated by Växa Sverige. The data included information about animal identification (individual, dam and sire); date of birth for the individual calf and its dam; calving ease and calf survival; gender; whether embryo transfer was used; identification number of herd; breed of calf, dam and sire; and number of calves born at each calving (single or multiple calves born). Calving ease has been recorded differently during the last few years. It was recorded in three categories prior to 2012, defined as easy (score 1), difficult calving (score 2) and malpresentations (score 3). A new scoring system with four categories was introduced in 2012, and used alongside the old scoring system until November 2016, after which only the new categories have been used. The four new categories are defined as easy calving without assistance (score 11), easy calving with assistance (score 12), difficulty calving without veterinary assistance (score 13) and difficult calving with veterinary assistance (score 14). Information about abortions (< 215 days of gestation) and early calving (215-240 days of gestation) was also available. Calf survival was recorded as a binary trait, where live born calves were classified as 0 and stillborn calves were classified as 1. Stillbirth was defined as dead at calving or within 24 hours of birth.

Estimated breeding values (EBVs) for 2017 were collected from the Nordic Cattle Genetic Evaluation (NAV) for dairy breeds and from Växa Sverige for beef breeds, to account for the genetic differences of sires. EBVs and accuracies (R_{TI}) for both direct and maternal effects for calving ease and calf survival were available for RDC and SH sires, however, only the direct effects were used. Results from two different genetic evaluations for calving traits for beef sires were used, one based on recordings in (purebred) beef breeding herds from the breeding scheme "Kött-Avel-Produktion," (KAP), and one based on calving results when potential AI-sires from different beef breeds are tested in dairy herds in the AI-program "Seminavelsprogrammet" (SAP). The purebred KAP EBVs were available for calving ease only, while SAP EBVs were estimated for both calving traits. The SAP EBVs were from sires tested on heifers and cows separately, whereas dairy and KAP EBVs had one value for all parities.

Data treatment

Data were edited to include information from the following purebred sire breeds: Swedish Red (SRB), Swedish Ayrshire (SAB), Danish Red (DR), Swedish Holstein (SH), Hereford (HER), Charolais (CHA), Aberdeen Angus (ANG), Limousin (LIM) and Simmental (SIM). The Swedish Red, Swedish Ayrshire and Danish Red were categorized as the same breed in this study and are from now on referred to as Red dairy cattle breeds (RDC). All dams included in this study were purebred RDC, SH or crossbreds between the two. The crossbred dams (*i.e.* RDCxSH and SHxRDC) were combined into one group. Data were restricted to include first to fifth parity dams and dams had to be born between the year 1980 and 2013.

Age at first calving was required to be 17 to 38 months and calving intervals between consecutive calvings outside the range 250-600 days were removed from the data.

Calves were required to be born between the years 1990 and 2016 to be included in the analyses. They were also assigned one out of five sub-year groups depending on their birth year (1 = 1990-1995, 2 = 1996-2000, 3 = 2001-2005, 4 = 2006-2010, and 5 = 2011-2016). The information about number of calves born at each calving event contained a few errors and some individuals that were registered as single born, but seemed to be born at twin births, were removed from the data. Furthermore, only one calf was kept from each calving when parity number and calving intervals were calculated. Approximately 23 % of the stillborn calves had missing information about their sex. These calves were therefore assigned a gender based on the last number in their ID, where 60 % of the calves were assumed to be bull calves and 40 % heifer calves like in Växa's evaluations. Calves without information about their herd or sire were removed. Another 405 sires and their calves were removed because of errors in breed registration, *e.g.* sires appearing in the data with different breed codes at different calving events.

Four seasons were created based on calving dates; Dec-Feb (season 1), Mar-May (season 2), Jun-Aug (season 3) and Sep-Nov (season 4). The division was based on common practice in dairy herds, *i.e.* what achieved the most even distribution of calvings over the year, while also taking the Swedish pasture period into consideration.

The categories for calving ease were changed to mimic the older recording system in order to handle the mixed recording during the transition period (2012-2016). Score 1, 11 and 12 were considered as a normal calving event and score 2, 13 and 14 as difficult calving. The distribution of these new scores was compared between different time periods to ensure that it was not severely altered because of the change in scoring system. Some errors were found where scores different from those in the recording scheme had been used. These were set to missing, as were malpresentations. Calves from embryo transfer, abortions and early calving were removed. Calves that lacked information about both calving ease and calf survival were also excluded. Only single born calves were kept for further analysis. Lastly, data were edited to only include herds with at least 5 crossbred calves from beef breed sires within the sub-year groups.

Data structure

In total, 4,438 herds and 1,423,851 observations; from 18,902 sires and 628,059 dams; fulfilled the criteria and were used for further analysis (Appendix 1 and 2). SH was the most frequently used sire breed in both first and later parities followed by RDC (Table 4). Hereford and Angus were used more frequently in first parity compared to other beef breeds; while Charolais, Limousin and Simmental were used more frequently in later parities. The mean age at first calving was approximately 28 months (SD 3.4) and the mean age at calving in cows was 53 months (SD 13.3).

Table 4. Distribution of different sire breeds used in first and later parities

	Parity				
	First		Later		Total
Sire breed[1]	N	%	N	%	N
RDC	191,755	31.8	411,186	68.2	602,941
SH	220,764	31.2	486,886	68.8	707,650
HER	10,233	38.2	16,550	61.8	26,783
CHA	991	3.5	27,552	96.5	28,543
ANG	6,100	47.7	6,690	52.3	12,790
LIM	3,489	22.7	11,855	77.3	15,344
SIM	2,587	8.7	27,213	91.3	29,800
Total	435,919	100.0	987,932	100.0	1,423,851

[1]RDC = Red dairy cattle, SH = Swedish Holstein, HER = Hereford, CHA = Charolais, ANG = Aberdeen Angus, LIM = Limousin, SIM = Simmental.

The overall distribution of calving ease, gender, twinning rate and calf survival before the last edits prior to analysis are presented in Table 5. Lack of herd identification and demand of crossbreeding with beef breed sires within the sub-year groups were the most common reasons why observations were excluded from the data set. Out of the final 1,423,851 observations, 52,584 calves (3.7 %) lacked information about calving ease and 1,304 calves (0.09 %) lacked records for calf survival.

Table 5. Frequencies of calving ease, gender, twinning rate and calf survival (in %) prior to final editing of the data with requirements on number of crossbred calves per herd and time period and prior to removal of abortions, early calving, multiple born calves and sires with more than one breed recorded (from total of 3,905,026 observations)

Trait	%
Calving ease	
Easy calving	97.45
Difficult calving	2.34
Abortions	0.00
Early calving	0.30
Gender and twins	
Bull calves	51.81
Heifer calves	48.19
Twinning rate	2.79
Calf survival	
Liveborn	96.45
Stillborn	3.55

Statistical analysis

Statistical Analysis Software (SAS) version 9.4 was used to edit data, obtain descriptive statistics and perform statistical analysis (SAS Institute, 2012). The FREQ and MEANS procedures were used for descriptive statistics. Data were analyzed in three sets for both calving traits using the HPMIXED procedure. All observations were used in the first analysis, regardless of whether the calves had sires with EBVs or not. Both the second and third analyses included only calves with sires with EBVs, where the second did not include EBVs in the model, but the third did include EBVs. The third analysis was made twice for calving ease, one for each kind of beef EBVs (SAP or KAP) in order to see if there would be any difference between the two evaluations. EBVs for dairy breed sires were used consistently in both. The data were analyzed for first parity and later parities separately.

The LSMEANS statement was used to obtain least square means and the statement option PDIFF was used to obtain pairwise comparisons between the sire breeds. Numerous models were tested and the final models chosen for the three analyses for both calving traits are described below, where Model 1 was used for the first two analyses and Model 2 for the third analysis:

Model 1: $Y_{ijklmnpq} = \mu + S_i + D_j + P_k + G_l + YS_{mn} + b_1 \times age + b_2 \times age^2 + 5yH_p + HY_q + e_{ijklmnpq}$

Model 2: $Y_{ijklmnpq} = \mu + S_i + D_j + P_k + G_l + YS_{mn} + b_1 \times age + b_2 \times age^2 + 5yH_p + b_{3i} \times EBV(S_i) + HY_q + e_{ijklmnpq}$

where

Y – observed value

μ – mean of the population

S_i – fixed effect of breed of sire *i* (RDC, SH, HER, CHA, ANG, LIM, SIM)

D_j – fixed effect of breed of dam *j* (RDC, SH, dairy crossbreeds)

P_k – fixed effect of parity *k* (1-5)

G_l – fixed effect of gender of calf *l* (bull or heifer)

YS_m – fixed effect of m^{th} combination of birth year (1990-2016) and season of birth (1-4)

age –age at calving (17, …, 111 months)

age^2 –age at calving squared

b_1, b_2 – fixed coefficient of linear and quadratic regression on age

$5yH_p$ – fixed effect of p^{th} combination of year group (1-5) and herd

$EBV(S_i)$ –EBV of sire nested within breed of sire *i*

b_{3i} – fixed coefficient of linear regression on EBV, nested within breed of sire *i*

HY_q – random effect of q^{th} herd and birth year combination

$e_{ijklmnpq}$ – random residual effect

Results

Descriptive statistics

Difficulties at calving

The mean for calving performance after final edits, during the whole time period across all sire breeds and parities, were 97.8 % easy (score 1) and 2.2 % difficult calving (score 2), respectively (Appendix 3). There were a few differences in frequencies of calving ease if all calves were used or only those from sires with EBVs. The mean percentage of difficulties at calving in first parity across all sire breeds was 4.1 %, compared to 1.4 % in later parities when all observations were included (Table 6). These values increased by 0.1 % with sires with EBVs. RDC sire gave the lowest mean value in first parity, followed by ANG in both data sets. The order of HER and SH sires changed between the two data sets in first parity. The highest mean percentage for calving difficulty was found for the heavier beef breeds; LIM, SIM and CHA. All sire breeds gave higher values for calving difficulties in first parity compared to later.

Table 6. Frequency of difficulty at calving and stillbirth for each sire breed in first and later parities separately when all calves and calves with sires with EBVs are used

Calving performance	RDC[1]	SH	HER	CHA	ANG	LIM	SIM	Total
All calves								
Calving difficulties								
First parity (%)	3.2	4.8	3.7	7.6	3.3	5.7	6.8	4.1
Later parities (%)	1.3	1.4	1.4	3.3	1.3	2.1	2.7	1.4
Stillbirths								
First parity (%)	2.6	5.0	1.5	3.2	1.4	2.4	2.2	3.7
Later parities (%)	2.9	3.0	1.4	1.8	1.2	1.5	1.6	2.8
Calves with sires with EBVs								
Calving difficulties								
First parity (%)	3.2	4.9	5.4	8.5	3.6	6.5	8.0	4.2
Later parities (%)	1.3	1.4	1.7	3.5	1.4	2.1	2.7	1.5
Stillbirths								
First parity (%)	2.5	5.1	1.5	3.1	0.8	2.3	1.8	3.8
Later parities (%)	2.8	3.0	1.5	1.8	1.3	1.5	1.6	2.8

[1]RDC = Red dairy cattle, SH = Swedish Holstein, HER = Hereford, CHA = Charolais, ANG = Aberdeen Angus, LIM = Limousin, SIM = Simmental.

SH dams had the highest mean percentage of difficult calvings in both first and later parities (Table 7). RDC dams had the lowest mean percentage in first parity and crossbred dams in later parities. The three dam breeds all had higher values for calving difficulties in first parity compared to later parities.

Table 7. Frequency of difficulties at calving and stillbirth in dam breeds in first and later parities separately when all calves and calves with sires with EBVs are used

Calving performance	RDC[1]	SH	Cross	Total
All calves				
Calving difficulties				
First parity (%)	3.2	5.0	3.5	4.1
Later parities (%)	1.4	1.5	1.3	1.4
Stillbirths				
First parity (%)	2.4	5.0	3.3	3.7
Later parities (%)	2.7	2.9	2.6	2.8
Calves with proven sires				
Calving difficulties				
First parity (%)	3.2	5.1	3.6	4.2
Later parities (%)	1.4	1.5	1.3	1.5
Stillbirths				
First parity (%)	2.4	5.1	3.4	3.8
Later parities (%)	2.7	2.9	2.6	2.8

[1]RDC = Red dairy cattle, SH = Swedish Holstein, Cross = RDCxSH, SHxRDC.

Stillbirth

The mean for stillbirth in the whole data set was 96.9 % live (score 0) and 3.1 % stillborn (score 1) calves, respectively (Appendix 3). When considering all observations and all sire breeds, the total frequency of stillbirth in first parity was 3.7 % compared to 2.8 % in later parities (Table 6). The frequency increased to 3.8 % in first parity with calves only from sires with EBVs. Overall, ANG and HER sires gave the lowest mean percentage of stillbirth. CHA and SH gave the highest mean values out of all sire breeds. RDC was the only breed where the mean value for stillbirth was lower in first parity compared to later parities when all observations were included. When only calves from sires with EBVs were used, both RDC and ANG gave higher mean percentages in later parities. HER gave the same frequency in first and later parities. All other sire breeds gave higher values in first parity compared to later in both data sets.

SH dams had the highest mean percentage of stillbirths (Table 7), followed by RDC and crossbred dams had the lowest mean percentage. The frequencies were higher in first parity compared to later parities in SH and crossbred dams, whereas RDC dams had higher mean percentage in later parities.

EBVs

The mean value for EBVs in calving ease and calf survival in dairy breeds was approximately 101 and 99, respectively, with mean R_{TIS} of 0.83 (Appendix 4 and 5). The mean values for both traits in SH were approximately 95 and 96, respectively, with mean R_{TIS} of 0.85. The KAP EBVs for calving ease were on average between 99 and 103, with mean R_{TIS} between 0.50 and 0.72. The EBVs from SAP were fairly even between breeds and parities. The mean EBVs for calving ease were between 96 and 100. Similar means were obtained for EBVs in calf survival. The correlation between EBVs from first and later calvings was 0.77 for calving ease and 0.56 for stillbirth. R_{TIS} were quite low for all EBVs in the SAP evaluation, with the lowest R_{TIS} in first parity EBVs.

Pairwise comparison of least squares means

Difficulties at calving

Difficulties at calving in first parity were significantly less frequent when SH sires were used compared with HER, LIM, SIM and CHA sires (Table 8). ANG and RDC sires were significantly better than SH in the first analysis but not significantly different in the second or third where only calves from sires with EBVs were included. RDC sires were significantly better than all beef breeds, except for ANG, in all three analyses. CHA gave significantly more difficulties at calving than all sire breeds except for SIM in the three analyses. ANG was performing significantly better than all other beef breeds.

Table 8. Estimated differences in calving difficulty in first parity (% of least square means) between sire breeds from different analyses

Breed of sire[2]		Analysis [1]		
		1	2	3
SH	RDC	0.5***	0.3	-0.3
	HER	-0.8**	-2.3***	-2.6***
	CHA	-4.0***	-5.0***	-6.2***
	ANG	1.1***	0.6	0.2
	LIM	-1.9***	-2.3***	-3.1***
	SIM	-3.3***	-3.6***	-4.0***
RDC	HER	-1.3***	-2.6***	-2.4***
	CHA	-4.5***	-5.3***	-5.9***
	ANG	0.6	0.2	0.5
	LIM	-2.3***	-2.6***	-2.8***
	SIM	-3.8***	-3.9***	-3.8***
HER	CHA	-3.2***	-2.7*	-3.5**
	ANG	1.7***	2.9***	2.8***
	LIM	-1.1*	0.0	-0.5
	SIM	-2.5***	-1.2	-1.4
CHA	ANG	5.1***	5.6***	6.4***
	LIM	2.1*	2.7*	3.0*
	SIM	0.7	1.5	2.1
ANG	LIM	-2.9***	-2.8***	-3.3***
	SIM	-4.4***	-4.1***	-4.3***
LIM	SIM	-1.5*	-1.3	-0.9

[1]In analysis 1 all calves were included, in analysis 2 only calves with sires with EBVs were included but EBV was not in the model, and in analysis 3 sire EBV (SAP) was included in the model.
[2]SH = Swedish Holstein, RDC = Red cattle breeds, HER = Hereford, CHA = Charolais, ANG = Aberdeen Angus, LIM = Limousin and SIM = Simmental.
*P <0.05; **P<0.01; ***P<0.001.

All sire breeds gave significantly lower incidence of difficulties at calving than CHA in all three analyses in later parities (Table 9). SH sires gave significantly lower calving difficulties than LIM and SIM in all three analyses, but was not significantly different from ANG or RDC in any of the analyses. Both RDC and HER sires were significantly better than LIM, SIM and CHA in all three analyses. ANG gave significantly less calving difficulties than LIM and SIM in all three analyses. Calving difficulties were significantly lower in LIM compared to SIM sires in later parities.

Table 9. Estimated differences in calving difficulty in later parities (% of least square means) between sire breeds from different analyses

Breed of sire[2]		Analysis [1] 1	2	3
SH	RDC	0.0	0.0	-0.1
	HER	-0.2	-0.3*	-0.3*
	CHA	-2.2***	-2.3***	-2.5***
	ANG	0.1	0.1	0.0
	LIM	-0.8***	-0.8***	-0.9***
	SIM	-1.5***	-1.5***	-1.7***
RDC	HER	-0.2	-0.3*	-0.2
	CHA	-2.2***	-2.3***	-2.4***
	ANG	0.1	0.1	0.1
	LIM	-0.8***	-0.8***	-0.8***
	SIM	-1.5***	-1.5***	-1.7***
HER	CHA	-1.9***	-2.0 ***	-2.2***
	ANG	0.3	0.4	0.4
	LIM	-0.6***	-0.5**	-0.6***
	SIM	-1.3***	-1.2***	-1.4***
CHA	ANG	2.3***	2.3***	2.6***
	LIM	1.3***	1.5***	1.7***
	SIM	0.6***	0.8 ***	0.8***
ANG	LIM	-0.9***	-0.8***	-0.9***
	SIM	-1.6***	-1.6***	-1.8***
LIM	SIM	-0.7***	-0.7***	-0.8***

[1]All calves were included in analysis 1, in analysis 2 only calves with sires with EBVs were included but EBV was not in the model, and in analysis 3 sire EBV (SAP) was included in the model.
[2]SH = Swedish Holstein, RDC = Red cattle breeds, HER = Hereford, CHA = Charolais, ANG = Aberdeen Angus, LIM = Limousin and SIM = Simmental.
*P <0.05; **P<0.01; ***P<0.001.

Overall, there were five pairwise comparisons that gave different results depending on the model used when calving difficulties were analyzed in first parity. These breed combinations were SH-ANG, SH-RDC, HER-LIM, HER-SIM and LIM-SIM. They only differed between the first and second analyses. No differences were found between the second and third analyses in first parity. Three breed comparisons were different when calving difficulties were analyzed in later parities. These were SH-HER and RDC-HER in the first and second analyses, and RDC-HER in second and third analyses.

Comparison between results from models with different types of EBVs

In general, the differences between sire breeds were similar when KAP or SAP EBVs were used in the model (Table 10). There were three differences between the evaluations, two in first parity and one in later. HER sires were significantly better than LIM sires when KAP

EBVs were used, but these breeds were not significantly different with SAP EBVs in first parity. Calving difficulties were also significantly less frequent with LIM sires than CHA sires with SAP EBVs in first parity, but not significantly different with KAP EBVs. There was also a difference in RDC compared to HER in later parities, where RDC sires were significantly better than HER sires when KAP EBVs were used but they were not significantly different with SAP EBVs.

Table 10. Estimated differences in calving difficulty in first and later parities (% of least square means) between sire breeds in the third analysis

		First parity		Later parities	
Breed of sire[1]		SAP[2]	KAP[3]	SAP	KAP
SH	RDC	-0.3	-0.3	-0.1	-0.1
	HER	-2.6***	-2.9***	-0.3*	-0.4**
	CHA	-6.2***	-6.4***	-2.5***	-2.8***
	ANG	0.2	-0.2	0.0	-0.1
	LIM	-3.1***	-4.6***	-0.9***	-1.1***
	SIM	-4.0***	-3.9***	-1.7***	-1.6***
RDC	HER	-2.4***	-2.7***	-0.2	-0.4**
	CHA	-5.9***	-6.1***	-2.4***	-2.7***
	ANG	0.5	0.0	0.1	0.0
	LIM	-2.8***	-4.3***	-0.8***	-1.1***
	SIM	-3.8***	-3.6***	-1.7***	-1.5***
HER	CHA	-3.5**	-3.5**	-2.2***	-2.3***
	ANG	2.8***	2.7***	0.4	0.4
	LIM	-0.5	-1.6*	-0.6***	-0.7**
	SIM	-1.4	-1.0	-1.4***	-1.2***
CHA	ANG	6.4***	6.2***	2.6***	2.7***
	LIM	3.0*	1.8	1.7***	1.6***
	SIM	2.1	2.5	0.8***	1.2***
ANG	LIM	-3.3***	-4.3***	-0.9***	-1.1***
	SIM	-4.3***	-3.7***	-1.8***	-1.5***
LIM	SIM	-0.9	0.7	-0.8***	-0.5*

[1]SH = Swedish Holstein, RDC = Red cattle breeds, HER = Hereford, CHA = Charolais, ANG = Aberdeen Angus, LIM = Limousin and SIM = Simmental.
[2]EBVs from beef sire breeds tested in dairy herds in “Seminavelsprogrammet.”
[3]EBVs from purebred beef breeding scheme “Kött-Avel-Produktion.”
*P <0.05; **P<0.01; ***P<0.001.

Stillbirth

The use of SH sires gave significantly higher incidence of stillbirth compared to ANG, HER, SIM and LIM sires (Table 11). Stillbirths were also significantly higher when SH sires compared to RDC sires were used in the first and second analyses. RDC sires gave significantly more stillbirths than HER, ANG and SIM sires in all three analyses. The incidence of stillbirth was also significantly higher with RDC sires compared to LIM sires in the first analysis. ANG gave significantly lower incidences of stillbirth than LIM in all three analyses.

Table 11. Estimated differences in stillbirth in first parity (% of least square means) between sire breeds in different analyses

Breed of sire[2]		Analysis[1] 1	2	3
SH	RDC	0.4***	0.4*	0.2
	HER	1.9***	1.4***	1.5***
	CHA	0.9	1.1	0.7
	ANG	2.4***	2.4***	2.4***
	LIM	1.2***	1.2*	1.0*
	SIM	1.4***	2.3***	2.0**
RDC	HER	1.5***	1.0*	1.2**
	CHA	0.5	0.7	0.5
	ANG	2.0***	2.0***	2.2***
	LIM	0.8*	0.7	0.7
	SIM	1.0*	1.9**	1.7*
HER	CHA	-0.9	-0.3	-0.8
	ANG	0.5	1.0	0.9
	LIM	-0.6	-0.3	-0.5
	SIM	-0.4	0.9	0.5
CHA	ANG	1.4	1.3	1.7
	LIM	0.3	0.1	0.3
	SIM	0.5	1.2	1.3
ANG	LIM	-1.1*	-1.3*	-1.4*
	SIM	-0.9	-0.1	-0.4
LIM	SIM	0.2	1.1	1.0

[1]In analysis 1 all calves were included, in analysis 2 only calves with sires with EBVs were included but EBV was not in the model, and in analysis 3 sire EBV (SAP) was included in the model.
[2]SH = Swedish Holstein, RDC = Red cattle breeds, HER = Hereford, CHA = Charolais, ANG = Aberdeen Angus, LIM = Limousin and SIM = Simmental.
*P <0.05; **P<0.01; ***P<0.001.

All beef breeds gave significantly lower incidence of stillbirth than both SH and RDC in the three analyses in later parities (Table 12). RDC experienced significantly higher incidences of stillbirth than SH. None of the beef breeds were significantly different from each other.

Overall, there were two pairwise breed comparisons that gave different results depending on the model used to analyze stillbirths. These were RDC-LIM in the first and second analyses, and SH-RDC in the second and third. There were no significant differences between analyses in later parities.

Table 12. Estimated differences in stillbirth in later parities (% of least square means) between sire breeds from different analyses

Breed of sire[2]		Analysis[1] 1	2	3
SH	RDC	-0.4***	-0.4***	-0.5***
	HER	0.9***	0.8***	0.7***
	CHA	0.9***	0.9***	0.9***
	ANG	1.1***	1.0***	1.0***
	LIM	0.9***	0.9***	0.9***
	SIM	1.0***	1.0***	0.9***
RDC	HER	1.3***	1.1***	1.2***
	CHA	1.3***	1.3***	1.4***
	ANG	1.5***	1.4***	1.5***
	LIM	1.2***	1.3***	1.4***
	SIM	1.4***	1.4***	1.4***
HER	CHA	0.0	0.2	0.2
	ANG	0.2	0.3	0.3
	LIM	-0.1	0.1	0.2
	SIM	0.1	0.2	0.2
CHA	ANG	0.2	0.1	0.1
	LIM	-0.1	0.0	0.0
	SIM	0.1	0.0	0.0
ANG	LIM	-0.3	-0.1	-0.1
	SIM	-0.1	-0.1	-0.1
LIM	SIM	0.1	0.1	0.0

[1]In analysis 1 all calves were included, in analysis 2 only calves with sires with EBVs were included but EBV was not in the model, and in analysis 3 sire EBV (SAP) was included in the model.
[2]SH = Swedish Holstein, RDC = Red cattle breeds, HER = Hereford, CHA = Charolais, ANG = Aberdeen Angus, LIM = Limousin and SIM = Simmental.
*P <0.05; **P<0.01; ***P<0.001.

Linear regression on EBVs

Calving difficulties

Figure 1 illustrates the estimates from the linear regressions on EBVs in first and later parities, respectively, where the bars indicate the estimated effect in calving difficulty per increased unit in EBVs for each sire breed. The estimates for SH and RDC are the same in graph a-b and c-d because the NAV EBVs have been used consistently in both analyses in first and later parities. According to graph a, with EBVs from NAV and SAP, approximately 0.1 % less calving difficulties can be expected for each unit increase of EBVs in ANG in first parity. The performance of SH, RDC, HER and LIM sires could improve by 0.2 %; CHA by 0.4 %; and LIM by approximately 0.5 % per unit increase. Some of these estimated effects were higher compared to graph b with EBVs from NAV and KAP, where HER and ANG could improve by 0.1 %; SH, RDC and CHA by 0.2 %; and LIM and SIM by 0.3 % per unit increase of EBVs. The estimated effects were much smaller in later parities, graphs c and d, for all three evaluations. In all beef breeds, the estimated effect of the sire EBV on calving difficulty was stronger when using SAP EBVs compared with KAP EBVs. All effects were significantly different from zero except for ANG in graph d.

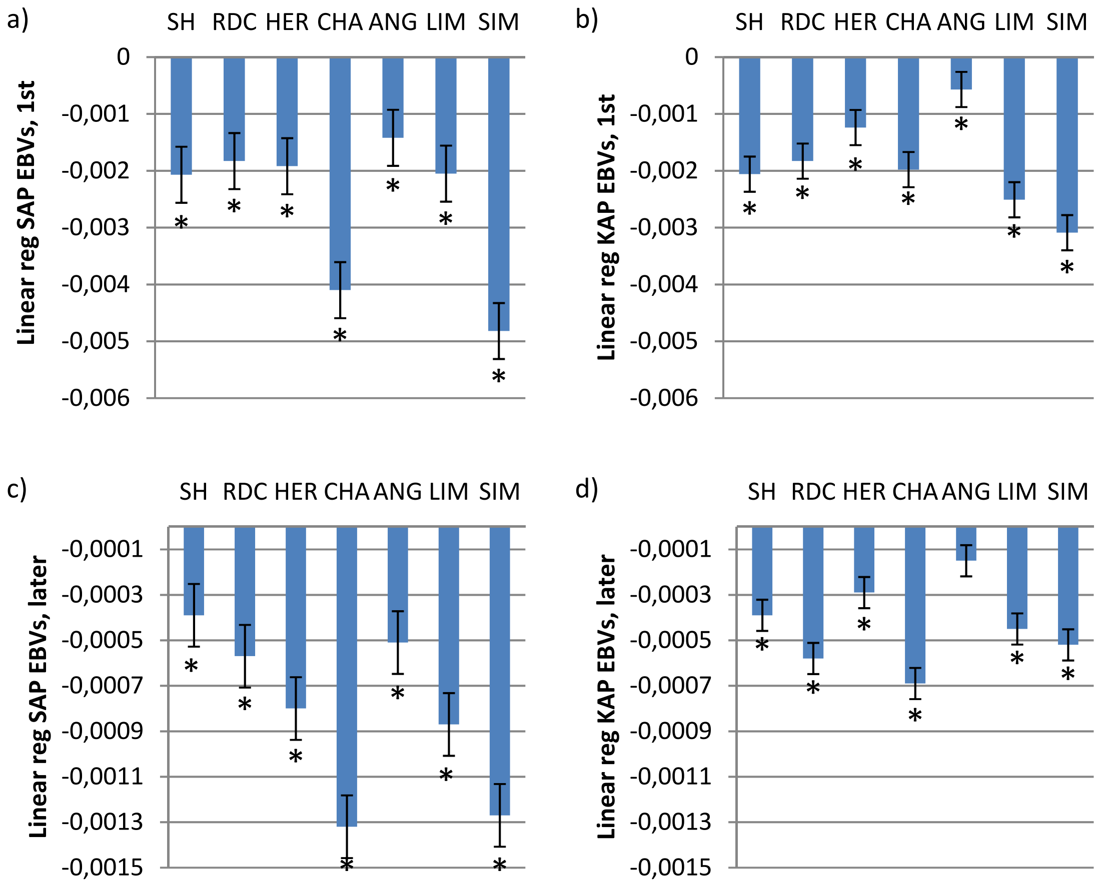

Figure 1. Fixed linear regressions of EBVs with standard error for calving difficulty in first and later parities with SAP (a, c) and KAP EBVs (b, d), respectively. NAV EBVs have been used consistently for SH and RDC. Asterisks (*) indicate estimates significantly different from zero. SH = Swedish Holstein, RDC = Red cattle breeds, HER = Hereford, CHA = Charolais, ANG = Aberdeen Angus, LIM = Limousin and SIM = Simmental. NAV = EBVs from dairy breed evaluation, SAP = EBVs from beef breeds tested in dairy herds in "Seminavelsprogrammet", KAP = EBVs from purebred beef breeding scheme "Kött-Avel-Produktion."

Stillbirth

The estimated effects for the sire breeds SH, RDC and SIM in first parity indicate an improvement in stillbirth by 0.16 %, 0.09 % and 0.08 %, respectively, per increased unit in their EBVs (Figure 2). The positive estimates for HER, CHA, ANG and LIM indicate that these breeds would have 0.04 %, 0.02 %, 0.03 % and 0.02 % more stillborn calves in first parity. These unfavorable effects levels out in later parities, where ANG was the only breed with a positive estimated effect of approximately 0.01 %. One unit higher EBVs in RDC and SIM would improve the trait by 0.06 %. Both HER and CHA would improve by 0.04 %; SH by 0.03 % and LIM by 0.01 % in later parities. Estimates for SH and RDC in first and later parities were significantly different from zero. Only CHA and SIM in later parities were significantly different from zero out for all beef breeds.

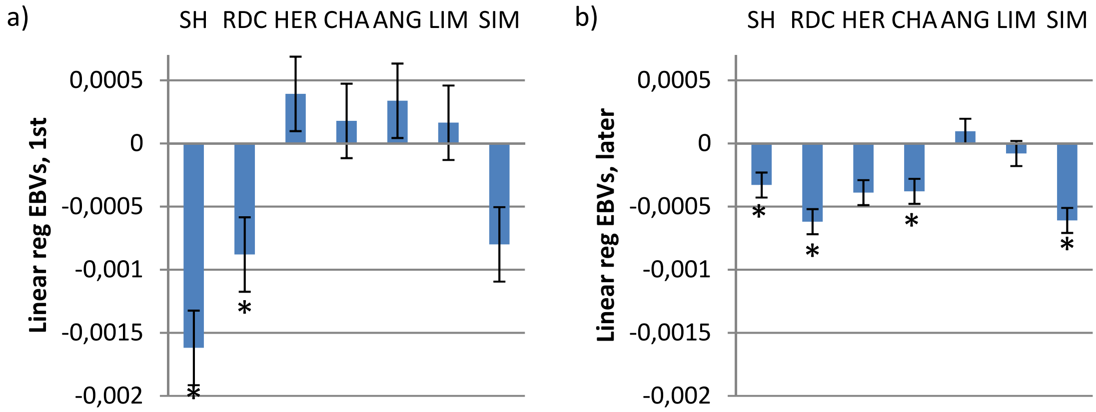

Figure 2. Fixed linear regressions of NAV and SAP EBVs with standard error on stillbirth in first (a) and later parities (b), respectively. NAV = EBVs from dairy breed evaluation, SAP = EBVs from beef breeds tested in dairy herds in "Seminavelsprogrammet." Asterisks (*) indicate estimates significantly different from zero. SH = Swedish Holstein, RDC = Red cattle breeds, HER = Hereford, CHA = Charolais, ANG = Aberdeen Angus, LIM = Limousin and SIM = Simmental.

Comparison with estimates from NAV

Figure 3 and Figure 4 illustrate comparisons between dairy breeds in the dataset and information from NAV (2017) for calving difficulties and stillbirths, respectively. The bars in Figure 3 represent the estimated effect that each 10 unit increase in EBVs would have on the performance of SH and RDC sires for calving difficulties. The estimated effect for SH sires in the data set was approximately 2.1 % in first parity and 0.4 % in later parities, to compare with the estimation made by NAV of 3 % in first parity and 1 % in later parities. The effect for RDC sires was approximately 1.8 % in first parity and 0.6 % in later parities in the data set. NAV estimated that a 10 unit increase in EBVs for RDC would improve the performance in calving difficulty by 2 % regardless of parity.

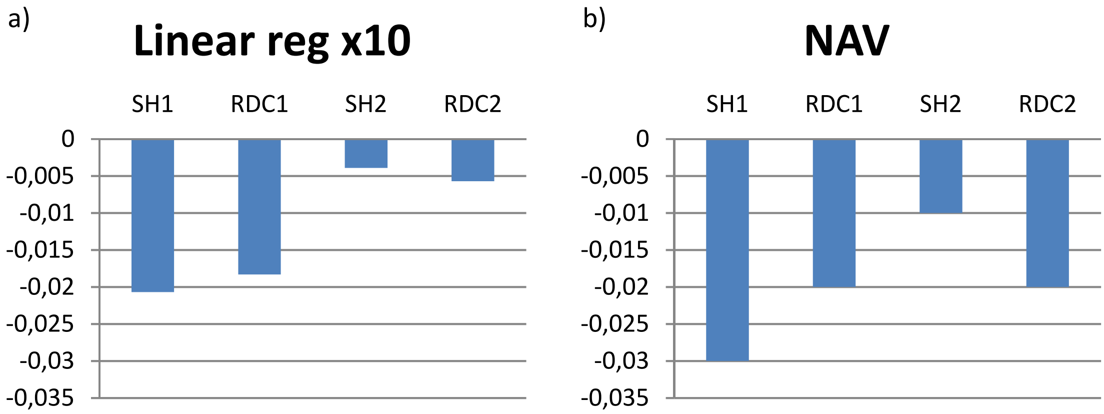

Fig 3. The estimated effect in the performance of the sire from each ten units increase in the estimated breeding value of the direct effect for calving difficulty in the data set (a) compared to estimates by NAV (2017) (b). SH1 = Swedish Holstein first parity, SH2 = Swedish Holstein later parities, RDC1 = Red cattle breeds first parity, RDC2 = Red cattle breeds later parities

The estimated effect from each ten unit increase for SH in the data set was approximately 1.6 % and 0.3 % in first and later parities, respectively (Figure 4). The effect was 0.9 % and 0.6 % in RDC in first and later parities, respectively. NAV estimated that a ten unit increase in EBVs for SH would improve the performance in stillbirth by 1.0 % in first parity and 0.3 % in later parities. The estimated effect for RDC was 0.9 % in first parity and 0.5 % in later parities.

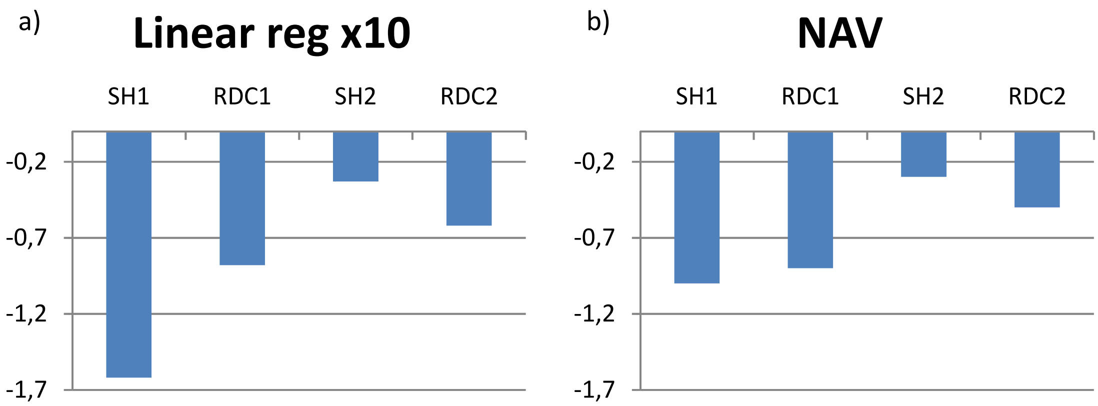

Figure 4. The estimated effect of the performance of the sire from each ten units increase in the estimated breeding value of the direct effect for stillbirth increases in the data set (a) compared to estimates by NAV (2017) (b). SH1 = Swedish Holstein first parity, SH2 = Swedish Holstein later parities, RDC1 = Red cattle breeds first parity, RDC2 = Red cattle breeds later parities

Discussion

The aim of this study was to evaluate the performance of different sire breeds for calving traits when used in dairy herds. Beef breeds have been shown to have better carcass traits which increases the revenue from the calves sold for beef production. Inseminating with beef breed semen can therefore be a good alternative for dairy cows that are not used to breed replacement heifers (Fouz *et al.*, 2013; Viking Genetics, 2017). Although carcass traits are important when evaluating the effect of sire breeds, easy calvings with high calf survival must also be maintained in order to increase profit from slaughtering crossbred calves. It is therefore important to further investigate the effects of this alternative breeding strategy in dairy herds.

Approximately 80 % of all Swedish dairy cows are in the Swedish milk recording scheme (Växa, 2017) which constitutes a good foundation for research purposes and genetic evaluations. It is for instance necessary that large quantities of data are available when doing research categorical traits. Calving difficulty was previously recorded in 2 categories, easy and difficult calving, in dairy breeds in Sweden but four categories were introduced in 2012. Using more categories in the recording scheme might help explain more of the variation in the trait, compared to binary trait recording (Philipsson, 1976; Philipsson *et al.*, 1979; Meijering, 1984). Categorical traits are however difficult to handle because of the large variation in frequencies within and between breeds (Heringstad *et al.*, 2007), and between farms (Bicalho *et al.*, 2008). The subjective nature of the scoring system also emphasizes the importance to adjust for herd effects (Hickey *et al.*, 2009; Vallée *et al.*, 2013).

In this study, first and later parity calving traits were analyzed separately because the main problems are seen in first parity, whereas there are generally no significant differences between later parities (Berry *et al.*, 2007). The lighter British beef breeds ANG and HER were the most used as sire breeds in first parity, while the heavier Continental European beef breeds CHA, SIM and LIM were used more in later parities (Table 4). This corresponds quite well with the general advice to inseminate dairy heifers with lighter rather than heavy-type beef breed sires to avoid difficulties at calving and higher incidences of stillbirth. Crossbreeding with beef breed sires was also more common in later parities in the annual report from Växa (2017). In later parities, when cows have reached their mature size they can easier compensate for a larger calf (Berglund & Philipsson, 1987).

The average phenotypic frequencies of difficulties at calving in first and later parities in this study were close to values found in the literature review. RDC sires gave however lower incidences of stillbirth than reported by both Steinbock *et al.* (2006) and Växa (2017). The average frequency of difficulties at calving for SH sires in first parity was within the range found in the literature. The incidence of stillbirth in SH sires in first parity was however lower than reported by Steinbock *et al.* (2003) and Växa (2017). Mean values in later parities were close to or within the range found in the literature. The results of dairy breed sires were expected to be somewhat different from findings in the literature. The data used in this study was selected in that only dairy herds inseminating some of the heifers or cows with beef semen were included. Furthermore, the SRB, SAB and DR were categorized as one breed in this study which might explain some of the differences between results in this study and results from SRB in the literature.

HER sires in the study gave lower frequencies of difficulties at calving and lower incidence of stillbirth in first parity when all observations were included than found in the literature review. However the average value of difficulties at calving increased to 5.4 % when only calves with sires with EBVs were used. This corresponds well with values in the literature where Eriksson *et al.*, 2004a reported a frequency of 6.2 % in purebreds and Växa (2017) 4.4 % from crossbreeding with dairy dams. The incidence of stillbirth in first parity in HER sires was much lower than what has been reported in the literature. The frequency of difficulties at calving in later parities were higher than found in the literature review, while the incidence of stillbirth was close to what was reported by Eriksson *et al.* (2004a). The frequencies of difficulties at calving in ANG sires in first parity were close to findings in literature, but the averages in later parities were higher than reported by Berger *et al.*, (1992) and Växa (2017). The incidence of stillbirth in first parity was similar to findings in the literature but the incidence was somewhat lower when only comparing with calves from sires with EBVs. The incidence of stillbirth in ANG sires in later parities was within the range found in the literature.

CHA sires gave higher mean values of difficulties at calving in first parity in this study than what was found in the literature. The frequency in later parities was closer to the value reported from crossbreeding with dairy dams by Växa (2017) compared to frequencies found in studies with purebreds (Eriksson *et al.*, 2004a; Eriksson *et al.*, 2004b; Mujibi & Crews. 2009). Incidences of stillbirth were within the range reported in the literature review. The mean frequencies all four traits in LIM sire in this study were much higher than the values reported from purebreds by Växa (2017). The frequency of difficulties at calving was much higher in this study than reported from LIM sires mated with Spanish Holstein dams by Fouz *et al.*, 2013. They reported an incidence of stillbirth at 6.8 % in the same population, while frequencies found in this study ranged between 2.4 % and 1.5 % depending on parity. Difficulties at calving in first and later parities in SIM sire were between 4.2 % and 6.8 %, which is within the range of 3.9 % to 6.3 % reported by Växa (2017). The incidence of stillbirth in first parity was lower than mean values reported by Växa (2017) when all calves were included. However, the incidence was 3.8 % when only calves with sires with EBVs were used which is within the range of 3.9 % to 6.7 % found by Växa (2017). Incidences of stillbirth with SIM sires were within the range (1.6 % to 4.3 %) in both data sets in later parities.

The frequencies of calving difficulty and stillbirth found in this study may differ to frequencies found in literature because of certain criteria in data editing, *e.g.* demand of crossbreeding in herds, removal of twins, calves with unknown sires or herds and malpresentations. The distribution of sire breeds used in first compared to later parities (Table 4) might influence the estimations of sire breed effects.

The largest estimated effects per increased unit in bull EBVs for the calving traits were found in first parity. This was expected because of the reports of higher frequencies in first parity cows (*e.g.* Berger *et al.*, 1992; Eriksson *et al.*, 2004a; Berry *et al.*, 2007). The lowest effect per unit increase in both the SAP and KAP EBVs was seen for ANG. This might be because ANG sires already perform relatively well and have on average low frequencies of difficulties at calving. The largest effects of the EBVs were in CHA (-0.4 %) and SIM sires (-0.5 %) in first parity using SAP EBVs, whereas SIM and LIM sires had a greater effect using KAP EBVs (both -0.3 %). The Continental beef breeds had the highest frequencies of difficulties at calving and could benefit more from each unit increase in the EBVs of sires.

The linear regressions of stillbirth on EBVs gave a less clear picture, with positive estimates for some beef sire breeds although not significantly different from zero (Figure 2). There are no EBVs available for stillbirth in the genetic evaluation of purebred beef breeds, but the correlated trait calving ease is included and selection aimed at fewer difficulties at calving would give an indirect response in stillbirth (Philipsson *et al.*, 1979; Meijering, 1984; Steinbock *et al.*, 2003), at least in the cases where calving difficulty is a contributing factor to the incidence of stillbirth.

The estimated effect from each ten units increase in EBVs in dairy breed sires differed somewhat from previous estimations made by NAV (2017). The estimated effect for calving difficulty in SH in the data set was approx. 30 % lower in first parity and 60 % lower in later parities compared to NAV (Figure 3). The estimated effect in RDC was 10 % lower in the data set compared to NAV in first parity, and 70 % lower in later parities. The estimations in stillbirth in SH was 62 % higher in first parity and 10 % higher in later parities compared to previous estimations by NAV (Figure 4). The estimated effect in RDC was 2 % lower in the data set compared to NAV in first parity and 24 % higher in later parities. The difference in the estimated effects might for instance be due the inclusion of data. This study used data from 1990 to 2016 whereas the genetic evaluation includes Swedish data from 1982. Only data from Swedish herds were used in the study while NAV also includes Danish and Finnish dairy herds. Furthermore, the data were not representative of all Swedish dairy herds because this study excluded herds that did not use beef breed semen during the time period. The models used and the effects included in the statistical analyses are also different in this study compared to the genetic evaluation (NAV, 2016).

Conclusion

The Continental beef breeds, and especially CHA sires, gave in general more difficulties at calving compared to dairy sires. Calving ease in the British breeds were equal to, and sometimes better than, dairy breeds. Most beef breeds gave lower incidence of stillbirth compared to dairy breeds. The choice of sire breed is particularly important in heifers because difficulties at calving and stillbirths are more common in first parity compared to later parities.

The results from this study indicate some differences in the estimated effect of sire breeds in calving traits depending on if the sire of the calf had breeding values or not. There was some re-ranking of beef sire breeds depending on which breeding values had been used. The estimated effect of the breeding values on calving difficulty was stronger when using values from the crossbred breeding scheme compared to the purebred one. The estimated effect in dairy breed sires differed somewhat from previous estimations in the Nordic cattle genetic evaluation. This was however expected because of criteria in data editing and statistical modeling.

Both calving ease and stillbirth should be considered, either directly or through correlated traits, in breeding programs for purebreds in order to continue improving performance within breeds. Sires should also be evaluated according to how they are used in practice. Accounting for the effect different sire breeds have on calving traits can help facilitate better matching of sire and dam breeds in dairy herds. More research is needed to further evaluate the use of beef breed sires in dairy herds, especially if this practice is becoming more common in an attempt to increase farm revenues.

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Appendices

Descriptive statistics

Appendix 1. Number of calves born each year by sire breed

Year of birth	RDC[1]	SH	HER	CHA	ANG	LIM	SIM
1990	688	908	34	12	3	49	27
1991	1046	1320	134	49	4	140	87
1992	1566	1871	184	102	3	251	149
1993	2317	2798	164	143	9	232	171
1994	3060	3511	174	172	39	249	159
1995	3767	4174	183	280	53	259	170
1996	19518	16570	232	547	91	564	407
1997	21490	18742	290	615	116	582	508
1998	21978	19362	415	848	258	643	719
1999	20875	18616	743	1423	517	787	1131
2000	19912	18253	1217	1755	667	872	1388
2001	41276	36393	1515	2119	729	1020	1778
2002	41308	37940	1455	2155	855	910	1799
2003	41563	38932	1686	2056	1101	921	1957
2004	40113	40658	1891	2075	1128	943	1948
2005	37245	39582	2111	2105	1194	886	2033
2006	32918	37948	2314	1622	1054	749	2201
2007	31188	36818	1962	1387	865	585	1989
2008	31260	37620	1641	1081	760	558	1649
2009	30054	37536	1263	851	430	417	1009
2010	27674	36967	1293	811	407	403	1193
2011	34919	52212	1111	884	390	442	1109
2012	31842	51550	1159	1184	430	551	1150
2013	29145	48489	1095	1391	479	652	1195
2014	21539	39183	1274	1290	605	747	1527
2015	11862	23740	923	1152	454	687	1698
2016	2818	5957	320	434	149	245	649
Total	602941	707650	26783	28543	12790	15344	29800

[1]RDC = Red dairy cattle, SH = Swedish Holstein, HER = Hereford, CHA = Charolais, ANG = Aberdeen Angus, LIM = Limousin, SIM = Simmental.

Appendix 2. Distribution of total number of sires and dams of each breed

Breed	N	%	Cum. N
Sires			
RDC	6398	33.85	6398
SH	9169	48.51	15567
HER	1249	6.61	16816
CHA	571	3.02	17387
ANG	438	2.32	17825
LIM	311	1.65	18136
SIM	766	4.05	18902
Dams			
RDC	291249	46.37	291249
SH	309726	49.31	600975
Crossbreeds	27084	4.31	628059

[1]RDC = Red dairy cattle, SH = Swedish Holstein, HER = Hereford, CHA = Charolais, ANG = Aberdeen Angus, LIM = Limousin, SIM = Simmental, Crossbreeds = RDCxSH, SHxRDC.

Appendix 3. Number of observations and mean values for calving difficulty and stillbirth in different parities across all breeds

	Calving difficulties		Stillbirths	
Parity	N	%	N	%
1	419370	4.1	435597	3.7
2	402860	1.3	417554	2.5
3	288430	1.4	298881	2.9
4	172779	1.6	179247	3.2
5	87829	1.8	91268	3.5
Total	1371267	2.2	1422547	3.1

Appendix 4. Number of sires, means, standard deviations (SD), minimum and maximum values for EBVs for each breed for calving difficulty and stillbirth

Breed[1]	N	Mean	SD	Minimum	Maximum
RDC[2]					
NAV_{CD}[3]	2,734	101	9	54	121
NAV_{SB}	2,734	99	9	25	122
SH					
NAV_{CD}	3,805	95	10	37	124
NAV_{SB}	3,805	96	10	45	121
HER					
KAP_{CD}	58	101	13	68	129
SAP_{CD1}	60	97	11	65	118
$SAP_{CD\geq2}$	60	98	9	63	114
SAP_{SB1}	60	100	8	77	116
$SAP_{SB\geq2}$	60	99	8	81	116
CHA					
KAP_{CD}	94	103	12	71	141
SAP_{CD1}	104	99	8	66	122
$SAP_{CD\geq2}$	104	98	12	31	125
SAP_{SB1}	104	99	7	81	122
$SAP_{SB\geq2}$	104	99	9	76	119
ANG					
KAP_{CD}	34	100	14	67	127
SAP_{CD1}	38	100	9	68	115
$SAP_{CD\geq2}$	38	99	7	81	108
SAP_{SB1}	38	99	10	69	118
$SAP_{SB\geq2}$	38	97	13	33	113
LIM					
KAP_{CD}	51	99	13	73	122
SAP_{CD1}	55	96	9	68	118
$SAP_{CD\geq2}$	55	96	9	69	112
SAP_{SB1}	55	98	10	69	120
$SAP_{SB\geq2}$	55	98	9	67	120
SIM					
KAP_{CD}	128	100	10	62	128
SAP_{CD1}	228	100	6	72	119
$SAP_{CD\geq2}$	228	100	8	68	117
SAP_{SB1}	228	99	6	80	118
$SAP_{SB\geq2}$	228	99	7	79	119

[1]RDC = Red dairy cattle, SH = Swedish Holstein, HER = Hereford, CHA = Charolais, ANG = Aberdeen Angus, LIM = Limousin, SIM = Simmental.
[2]NAV = dairy breed evaluation, KAP = evaluation for purebred beef breeds, SAP = beef breed sires evaluated with dairy breed heifers (1) and cows (≥2).
[3]CD = calving difficulty, SB = stillbirth.

Appendix 5. Number of sires, means, standard deviations (SD), minimum and maximum values for accuracies for EBVs for each breed in the different evaluations

Breed[1]	N	Mean	SD	Minimum	Maximum
RDC					
$R_{TI\ NAV}$[2]	2,734	0.83	0.08	0.41	1.00
SH					
$R_{TI\ NAV}$	3,805	0.85	0.11	0.23	1.00
HER					
$R_{TI\ KAP}$	58	0.72	0.30	0.00	0.97
$R_{TI\ SAP1}$	60	0.20	0.07	0.14	0.45
$R_{TI\ SAP\geq 2}$	60	0.26	0.12	0.16	0.69
CHA					
$R_{TI\ KAP}$	94	0.69	0.34	0.00	0.99
$R_{TI\ SAP1}$	104	0.15	0.02	0.14	0.24
$R_{TI\ SAP\geq 2}$	104	0.28	0.12	0.16	0.70
ANG					
$R_{TI\ KAP}$	34	0.62	0.28	0.00	0.94
$R_{TI\ SAP1}$	38	0.20	0.09	0.14	0.51
$R_{TI\ SAP\geq 2}$	38	0.23	0.10	0.16	0.57
LIM					
$R_{TI\ KAP}$	51	0.57	0.36	0.00	0.96
$R_{TI\ SAP1}$	55	0.19	0.06	0.14	0.44
$R_{TI\ SAP\geq 2}$	55	0.28	0.12	0.16	0.74
SIM					
$R_{TI\ KAP}$	128	0.50	0.38	0.00	0.99
$R_{TI\ SAP1}$	228	0.15	0.02	0.14	0.27
$R_{TI\ SAP\geq 2}$	228	0.22	0.09	0.16	0.63

[1]SH = Swedish Holstein, RDC = Red cattle breeds, HER = Hereford, CHA = Charolais, ANG = Aberdeen Angus, LIM = Limousin and SIM = Simmental.

[2]$R_{TI\ NAV}$ = accuracies in dairy breed evaluation, $R_{TI\ KAP}$ = accuracies in evaluation for purebred beef breeds, $R_{TI\ SAP}$ = accuracies for beef breed sires evaluated with dairy breed heifers (1) and cows (≥2).