Factors affecting calf production in Norwegian suckler herds

Philosophiae Doctor (PhD) Thesis

Sindre T Nelson

Department of Production Animal Clinical Sciences

Faculty of Veterinary Medicine and Biosciences

Norwegian University of Life Sciences

Adamstuen, 2016

Thesis number 2016:68

ISSN 1894-6402

ISBN 978-82-575-1976-6

Table of Contents

Acknowledgements

This thesis has been made possible by the cooperation of all the major contributors within the beef cattle production industry in Norway. Cattle farmers are doing a great job daily in their herds, and they contributed substantial data to this project through a unique cooperation known as Animalia. This thesis was also made possible by all those with a genuine interest in gaining knowledge about beef cattle production, medicine and welfare. I would like to acknowledge the Norwegian University of Life Sciences for giving me this opportunity and for providing financial support for its PhD students. Thanks to the contributions from Animalia, Geno, Tyr, and Nortura, and Dr Anna Hessle and the staff at Götala for making the Skara study possible.

My sincere gratitude goes to:

Professor Dr Ane Nødtvedt, my main supervisor. Thank you for your excellent guidance in epidemiology and for coping with my obsessive-compulsive attention to detail. Thank you for following me so closely all the way through, providing weekly supervision, and for the many gallons of coffee. Thank you for cheering me up the days I was down, and for sending me my favourite sweets across Scandinavia. Thanks for including me such an extraordinary, well-functioning and pleasant research group.

Adam D. Martin, BVSc Dip. LHP Cert. CHP MSc DBR PhD Dipl. ECAR MRCVS, my co-supervisor, colleague and friend. Thank you for including me in your initial ideas for this project, for providing support and finances for this project, and for the cold Kilkenny you shared in the warm Swedish summer night. Thank you for your honesty, for making me laugh, for your support and for your faith in me.

Professor Emeritus Dr Knut Karlberg, my co-supervisor for the first part of this project. Thank you for kicking this project off and for your humour and your knowledge. Thank you for sharing my joy for cakes.

Dr Ingrid Hunter Holmøy, my co-supervisor following Knut in this project. Thank you for your support, important input, and for helping me out with complex estimations. Thank you for calmly answering all my questions.

Caroline Sorknes Haadem, my colleague and co-author. Thank you for tolerating my odd ticks, for making the stay in Skara so nice, and for providing my favourite chocolate.
Lisbeth Jensen, thank you for believing in me, and for your staunch support in difficult times.
The librarians, thanks for your positive attitude, your excellent service, friendliness and support.
My personal ‘Nigella Lawson’, Åste, thanks for your love.
My father and mother, thanks for having raised me so well and for your everlasting support.
My friends Daniel, Hanne, Kent and Michael, thanks for being my friends.
My sister Borghild, and both my brothers Ronny and Hans-Marius, thanks for all the fun throughout the years.

List of papers

The thesis is based on the following papers, referred to in the text by their Roman numerals:

Paper I:

S.T. Nelson, C.S. Haadem, A. Nødtvedt, A. Hessle, A.D. Martin. 2017:
Automated activity monitoring and visual observation of estrus in a herd of loose housed Hereford cattle: Diagnostic accuracy and time to ovulation
Theriogenology 87: 205–211

Paper II:

S.T. Nelson, A.D. Martin, I.H. Holmøy, K. Karlberg and A. Nødtvedt, 2016:
A cross-sectional study of factors affecting birth weights of Norwegian beef calves
Preventive Veterinary Medicine 125: 59–65

Paper III:

I.H. Holmøy, S.T. Nelson, A.D. Martin and A. Nødtvedt. 2016:
Factors associated with the lifetime calf production of Norwegian beef suckler cows
Under revision: Preventive Veterinary Medicine

Abbreviations

AAMS	Automatic activity monitoring system
AI	Artificial insemination
BLUP	Best linear unbiased predictor of economic merit
EPD	Expected progeny difference
GnRH	Gonadotropin releasing hormone
IQR	Interquartile range
IRR	Incidence rate ratio
NBCRS	Norwegian Beef Cattle Recording System
NPV	Negative predictive value
PPV	Positive predictive value
Se	Sensitivity
Sp	Specificity
TAI	Timed artificial insemination

Summary

The overall aim of this project was to determine factors affecting productivity in Norwegian suckler herds by concentrating on four objectives: 1) to evaluate the usefulness of an automatic activity monitoring system (AAMS) for oestrus detection in a Hereford herd; 2) to evaluate the interval from detection of oestrus to ovulation; 3) to describe factors that affect the birth weight of beef calves; and 4) to describe lifetime calf production in suckler cows in terms of number of calves born. To achieve these four objectives, a field study of 40 Hereford cows and two database studies based on recordings of 20,000 dams and their offspring, were performed.

AAMS and visual detection had sensitivities of 90% and 77%, and specificities of 100% and 89%, respectively, for detection of oestrous activity. Oestrus was detected on average 23 and 21 hours before ovulation by the AAMS and visual detection, respectively.

Overall, calves born to heifers were heavier than calves born to cows. Male calves were on average 2.3 kg heavier than female calves, and calves born in the spring were 0.5 kg heavier than those born in the autumn. In general, beef cows in western Norway yielded lighter calves than cows in other regions. However, approximately 40% of the variation found in birth weights was caused by the random herd effect.

Median lifetime calf production in the study was two calves. A significant breed-region interaction indicated that performance of the breed depended on their geographical location, and both Limousin and Charolais had in general low lifetime calf production, but particularly in the northern and western regions of Norway. Cows in herds larger than 30 cows produced 11% more calves in their lifetime than cows in smaller herds. Severe dystocia resulted in 30% reduced lifetime calf production.

The results of this project indicate that Norwegian suckler herds have a large potential to improve their productivity. Selecting a breed suited to a given region and production system could potentially increase lifetime calf production. The use of artificial insemination (AI) to improve genetics is possible with an AAMS, but results may be improved if AI is performed earlier in Hereford cattle than recommended for Norwegian Red cattle. The large variations in output between farms, breeds and regions, suggest that advisory services have the potential to increase productivity through improved management.

Sammendrag

Det overordnede målet med prosjektet var å finne faktorer som påvirker produktiviteten i norske ammekubesetninger ved hjelp av fire delmål; 1) vurdere nytten av en automatisk aktivitetsmåler (AAMS) for brunstdeteksjon i en Hereford-besetning, 2) vurdere intervallet fra påvisning av brunst til eggløsning, 3) beskrive faktorer som påvirker fødselsvekter hos kjøttfe-kalver, og 4) beskrive faktorer som påvirker livstidsproduksjon til ammekyr, målt i antall kalver født.

For å oppnå delmålene ble det gjennomført en feltstudie i en Herefordbesetning bestående av 40 kyr og kviger, samt to database-studier basert på et datasett fra Storfekjøttkontrollen bestående av ca. 20,000 kyr og deres avkom.

AAMS og standardisert visuell påvisning hadde henholdsvis en sensitivitet på 90% og 77%, og en spesifisitet på henholdsvis 100% og 89% for påvising av brunst. Brunstaktivitet ble oppdaget i gjennomsnitt 23 og 21 timer før eggløsning av henholdsvis AAMS og visuell påvisning av brunst.

Ved kalving var kalver født av kviger tyngre enn kalver født av kyr. Oksekalver var i gjennomsnitt 2,3 kg tyngre enn kvigekalver, og kalver født på våren var 0,5 kg tyngre enn kalvene født på høsten. Generelt var kalvene født på Vestlandet lettere ved fødsel enn kalver født i andre regioner. Omtrent 40% av variasjonen i fødselsvekt ble funnet på besetningsnivå. Median livstidsproduksjon for ammekyrne var to kalver, men varierte med rase og region. Limousin og Charolais hadde spesielt lav produksjon i Nord-Norge og på Vestlandet. Kyr i besetninger med flere enn 30 mordyr produserte 11% flere kalver i løpet av livet enn kyr i mindre besetninger. Alvorlige fødselsvansker resulterte i 30% redusert livstidsproduksjon.

Resultatene i dette prosjektet antyder at norske ammekubesetninger har et stort potensiale for å øke produktiviteten på både nasjonalt og regionalt nivå, samt på besetningsnivå. Valg av egnet rase for de forskjellige regioner og produksjonssystem kan derfor potensielt øke gjennomsnittlig livstidsproduksjon for ammekyr. I tillegg kan økt bruk av inseminering (AI) ved hjelp av AAMS utnytte potensialet i genetikken, men AI må utføres tidligere hos Hereford-kyr enn hos NRF. På grunn av de store variasjonene i produksjonen på region, rase- og besetningsnivå, kan en rådgivningstjeneste på besetnings- og regionalt nivå potensielt økte produktiviteten i ammekubesetningene.

Introduction

Thesis background

In Norway, there is political consensus on four goals for agriculture: a) good food safety and supply, b) agriculture throughout the nation, c) improved agricultural economic output and d) sustainable agriculture (Meld st.9, 2011-2012). Because Norwegian agriculture is mainly suited to and used for forage-based animal production (Arnoldussen et al., 2014), something that is expected to be enhanced by ongoing climate change (Seehusen, 2016), cattle will continue to play a central role in Norwegian agriculture in the future.

During the past century, the Norwegian Red has been the dominant breed in Norwegian dairy farming (Geno, 2016). The Norwegian Red is a dual-purpose breed, which has been important for the supplementation of domestic production to meet the demand for both meat and milk. Considering overall energy utilization of domestically produced fodder and lowest possible emissions of greenhouse gases, combined milk and beef production is the most efficient method of production (Hume et al., 2011; Ruud et al., 2013). However, through professionalization of dairy farming over the past decades, milk production of Norwegian cows has increased (Ruud et al., 2013). This has caused the number of dairy cows to decrease considerably over the past 15 years because the Norwegian milk quota system limits total milk production and the same volume of milk can be produced with fewer animals. One result of this is that fewer animals are slaughtered. Consequently, the number of suckler cows increased by 50%, from 46,000 to 69,000, in the period from 2002 to 2012, and to almost 76,000 in the beginning of 2016 (Statistics Norway, 2016). Despite this increase, it is estimated that 14,600 tons of beef meat will be imported to meet domestic demand in 2016 (Nortura SA, 2016).

An important aspect of Norwegian farm animal production is the emphasis on ensuring animal welfare and freedom from infectious diseases. Norwegian legislation has superseded EU legislation, e.g. on restrictions on surgery and mandatory use of analgesics (Cozzi et al., 2015; Ministry of Agriculture and Food, 2004), and livestock imports are considered highly undesirable. Because live animal import is not desired, the use of semen and embryos for genetic improvement and diversity is even more important. Furthermore, Norwegian agriculture is heavily subsidized. For a beef producer, subsidies typically account for more than 60% of farm income (Åby et al., 2012). Direct subsidies, mostly independent of production output, are estimated to account for 39% of income for a typically 'heavy' beef breed herd and 45% for a typically 'light' beef breed herd (Nortura SA, 2015). The subsidy regimen might change in parallel with the changing economic situation, and future changes to stimulate production efficiency have been recommended by the industry (Ruud et al., 2013).

Specialized beef production is relatively new in Norway. Research on beef cattle production has mostly been performed under conditions and circumstances that are not directly comparable to those in Norway. Therefore, recommendations based on international knowledge must be carefully evaluated before implementation. There is great diversity within beef production in general, and producers adapt according to local conditions and personal preferences. However, the production of animals for slaughter and the production of replacement animals are important features of beef production worldwide. For the production of animals for slaughter, optimum returns on slaughtered animals are achieved through the most favourable combination of weight and carcass classification, which is realized through effective utilization of financial input factors (e.g. workload) at high feed efficiency in the animals (Ruud et al., 2013). For the production of replacement heifers, the animals should have good genetic merit, good maternal characteristics and be ready to be bred from a predefined point in time (Funston et al., 2004; Laster et al., 1973). For the production of animals for replacement and slaughter, the output is the calves. Calf production efficiency measurements are largely related to reproduction, which is the most important factor in the suckler herds and a key driver of efficiency and profitability (Diskin et al., 2014; Prince et al., 1987).

The Norwegian Beef Cattle Recording System

In a professional cattle production system, strict record-keeping is essential (Chenoweth, 2005b). The NBCRS is a national database for beef suckler herds run by the Norwegian Meat and Poultry Research Centre, Animalia (Animalia, 2015b). The database was established in 1995 based on knowledge gained from 20 years of experience with the Norwegian Cattle

Health Recording System for dairy cattle (Østerås et al., 2007). Producer membership in the NBCRS is voluntary, but at the end of 2012, almost 75% (n = 50,893) of the Norwegian beef suckler cow population (n = 67,542) was enrolled, representing 57% (n = 2,428) of Norwegian beef herds (Animalia, 2013; Statistics Norway, 2016). The database fulfils all criteria for mandatory reporting and regulations on traceability of beef and beef products, beef production and the use of veterinary drugs (Animalia, 2015a).

The database can be used as a multilevel tool for beef production, and includes information relevant to herd planning and management, information on genetics, livestock sales and relocation, preventive health care and disease prevention. Information necessary for general herd consultancy, research, statistics and forecasts can be displayed or printed as needed. The detailed information available in the system has been gathered from all databases related to the production, e.g. the abattoirs, the Norwegian Beef Breeders Association[1], the Portal for Reporting of Mandatory Health Data[2], the GENO SA insemination registry, and the National Livestock Register, in addition to the information reported directly by the producers. Individual animal characteristics, calf weight at birth and at 200 days (weaning), dystocia and prophylactic medications are examples of information producers might report to the system. However, the degree to which this type of information is reported varies highly among producers.

Beef production in Norway

Suckler cow population

The Norwegian suckler cow population (n = 67,542) accounted for 28% of the total cow population in 2012 when this project began, and for 33% (n = 75,633) of the total cow population in the beginning of 2016 (Statistics Norway, 2016). Beef cattle are currently distributed on 5000 farms, most of which are family-run (Statistics Norway, 2016). The number of cattle per herd has increased the past decade, from 10.3 suckler cows/herd in 2006 to 15.4 suckler cows/herd in 2016 (Statistics Norway, 2016). Herds with more than 20

[1] TYR, www.tyr.no/english
[2] Dyrehelseportalen. Website for reporting mandatory data, e.g. drug treatments individual level. http://www.dyrehelseportalen.no/dhp/index.aspx

suckler cows now account for 24% of the 5000 herds (Statistics Norway, 2016). In 2014, approximately 70% of the beef cattle population was localized in two regions, where the largest herds were also found (Animalia, 2016). Of the suckler cows, 47% were located in eastern Norway in the region surrounding Oslo, and about 21% were located in central Norway (‘Midt-Norge’). The remaining 33% were located in south-western, southern, western, and northern Norway.

Breeds

In the end of 2012, 50,893 beef cows are registered in the NBCRS, where 49% (n = 24,967) are defined as cross breeds (Animalia, 2015a). The four most numerous beef breeds enrolled in the NBCRS are two French breeds, Charolais (n = 6587) and Limousin (n = 3182), and two British breeds, Hereford (n = 6198) and Aberdeen Angus (n = 3716). The fifth most numerous breed is Simmental (n = 1258), which, along with the French breeds, is defined as a continental breed. Examples of other less numerous breeds are Blonde d'Aquitaine, Highland cattle, Belted Galloway and Tyrolese Grey cattle. The breeds have different desired characteristics, which have been described by several authors in the US and Europe (Arango et al., 2002a; Cundiff et al., 1993; Hampel, 2014; Martin et al., 1992; Roughsedge et al., 2001). Favourable characteristics typically seen in the continental breeds are high daily weight gain, good muscle to bone ratio, and good lean-to-fat ratio. Disadvantages of continental breeds might be that they are late maturing, have low milk yield, and are more prone to dystocia (Cundiff et al., 1993; Hampel, 2014). Positive characteristics of the British breeds are early maturation, medium size, higher milk yield and good maternal abilities, easy calving, and favourable hardiness and thriftiness. Disadvantages include lower weight gain and a tendency towards excessive fat deposition (Cundiff et al., 1993; Martin et al., 1992; Roughsedge et al., 2001). The continental breeds generally suit an intensive system with a high proportion of energy from concentrates and lush lowland pasture, and have carcasses of good quality with high return. Table 1 provides a comparison of traits by breed (Dufey, 2002). The above-mentioned continental breeds might sometimes be called ‘intensive’ breeds. The British breeds are, in general, more suited to an extensive system that is forage-based and that utilizes upland and marginal pastures (Dufey, 2002; Hampel, 2014). Therefore, the British breeds are often called 'extensive' breeds.

Table 1. Breed characteristics of selected beef breeds in Norway (Dufey, 2002)

Parameter / Breed	Ab. Angus/ Hereford	Simmental	Charolais	Limousin
Feed intake capacity	+++	++	++	++
Growth rate	+++	+++	+++	++
Feed utilization	+++	+++	+++	++
Maturing	+++	++	++	++
Carcass yield	+	+	++	+++
Meatiness	+(+)	+(+)	+++	+++
Bone structure	++	++	+++	++
Meat/fat	+	+(+)	++	++
Meat/bone	+(+)	+	+	++
Hindquarter %	+	++	+++	+++

+++ = very good ++ = good + = poor

Beef production systems

In Norway, specialized beef production is mainly based on suckler cow herds. The herds are all housed or sheltered in the winter and pastured in the summer. Both lowland and marginal pasture are common. Regardless of region, during the housed period the nutrition of the Norwegian suckler population is mainly based on grass fodder (Animalia, 2015a). The calving period defines the herds as either spring- or autumn-calving. The majority of calves are born in late winter/early spring (Animalia, 2015a) and the herds are therefore mostly defined as spring-calving herds. The number of cows kept during the winter housing season is most often adjusted in the autumn when the level of available forage for the indoor season is known. In most suckler herds, one or more bulls are present in the herd. Stock bulls can be purchased from the breeding organization, but buying local bulls, breeding bulls or exchanging bulls with other farms are all common practices. A bull is typically in service in a herd for two seasons with the same females. Roughly 60% of the suckler cows are crossbreeds. Crossbreeding is preferred to achieve heterosis[3] effect for desired traits (Ruud et al., 2013). Purebred animals of the five most numerous beef breeds – Charolais, Hereford, Aberdeen Angus, Limousin and Simmental – account for approximately 40% of the suckler cows (Ruud et al., 2013). Based on 2428 suckler cow herds registered in the NBCRS in 2012, the average herd has 21 suckler cows, an age at first calving of 27.4 months, and a calving interval of 12.9 months (Animalia, 2013).

Of the animals for slaughter, 90% are reared on the farm of birth (Ruud et al., 2013). Over the past decade, more finishing herds have emerged. These herds are often larger, rearing more than 100 animals annually (2012) (Ruud et al., 2013). Norwegian Red calves, which are considered good meat producers (Kirkland et al., 2007), account for approximately 70% of live calves marketed for beef production. Currently, most of the beef in Norway is still produced by the breed Norwegian Red, approximately 75% of the dams are of this breed (Ruud et al., 2013). However, Norwegian Red cows are primarily kept for milk production, and is hence not handled as a suckler unit nor further discussed in this thesis.

Productivity measures in suckler herds

'Effective' cow/calf production is characterized by a restricted breeding season, a good heifer replacement program, proper nutrition, good overall herd health, good record-keeping, and an effective cross-breeding program (Chenoweth, 2005b). Front-end loaded herds, in which the majority of the calves are born early in the calving season, are preferred (Larson et al., 2016). Production efficiency in suckler herds depends on the successful rearing of calves for slaughter and replacement and optimal lifetime calf production of each cow in the operation. The following sections will outline some important productivity measures applied to Norwegian suckler herds.

[3] Heterosis is defined as the advantage in performance of crossbred animals above the mid-parent mean of the two parent breeds (Simm, 1998b)

Calving season

The majority of Norwegian suckler herds are spring calving, but the optimal season and time within that season for calving should be determined for each farm. Housing facilities, pasture resources, production targets and farm and breed characteristics should all be considered to find best possible farm-specific period for calving (Cundiff et al., 1993; Larson et al., 2016). Unlike spring calving, calving in the autumn requires a longer total housed period and favours harvested forage over pasture (Matre, 2010). Pasture accounts for about 30% and 50% of annual nutrition intake for autumn- and spring-calving herds, respectively (Animalia, 2015a).The length of the breeding/calving season is important, and there are many benefits of a restricted breeding and calving season, e.g. 6 to 10 weeks (Larson et al., 2016). One benefit is healthier calves in herds with restricted calving season compared to herds with no set breeding season (Larson et al., 2005). Another benefit is a uniform feeding strategy when all pregnant females are in a similar stage of production. In Norwegian suckler herds, feed accounts for approximately 70% of the variable cost of production depending on the proportion of pasture (Nortura SA, 2012; Ruud et al., 2013). Thus, feeding efficiency has a large impact on profitability.

Front-end loading

If following the front-end loading concept, 60% to 65% of the calves should be born within the first 21 days of the calving season (Larson et al., 2016). For calves born early in the calving season, the pressure of typical infectious diseases affecting calves is still low in the herd (Larson et al., 2005). Calves born early in the calving season are larger at weaning, which provides a larger heifer pool for selection based on genotype and phenotype traits (Larson et al., 2016). A larger proportion of females can then be bred early in the following breeding season, when bulls have been found to be most healthy (Ellis et al., 2005; Larson et al., 2016). Therefore, a tight calving period enhances production efficiency and increases profitability (Troxel et al., 2009). Additionally, first calvers are more difficult to rebreed during the subsequent breeding season; thus, if heifers calve early in the calving season their chances of conceiving during the subsequent breeding season increases (Cushman et al., 2013).

Age at first calving

Traditionally, cows in a suckler herd are supposed to have an average age at first calving of two years. However, for late maturing breeds, producers might use other practices and might intentionally have older heifers at first calving (Hampel, 2014). There are several economic studies on age at first calving (Clark et al., 2005; Morris, 1980; Nunez-Dominguez et al., 1991; Wathes et al., 2014), which suggest that calving at two years of age is more cost effective than calving at three years of age (Nunez-Dominguez et al., 1991). Intentionally prolonged time to breeding of heifers seems commonly practised for Limousin cattle in Norway (Animalia, 2015a). Some producers use this strategy for other breeds as well, but little is known in general about how age at first calving affects Norwegian beef production.

Calving interval

A suckler cow ideally gives birth to one calf annually; it is thus necessary for her to conceive within 85 days post-partum. After returning to the oestrous cycle 35 to 70 days post-partum, this leaves cows one to three oestrous cycles for the establishment of pregnancy (Caldow et al., 2005; Chenoweth, 2005b; Larson et al., 2016). Primiparous cows have an even longer anoestrous period of 80 to 100 days post-partum (Ciccioli et al., 2003; Larson et al., 2016). This should be accounted for when breeding heifers to increase the chances of pregnancy of the primiparous females during the subsequent breeding season. Because cows are expected to have one calf annually, reducing the factors negatively influencing postnatal involution of the uterus or somehow causing a delay in return to oestrus, e.g. dystocia, is of great importance (Laster et al., 1973). Additionally, shortening the length of the calving season is one of the most cost-effective practices that can be implemented by a suckler calf producer to increase calf production (Deutscher et al., 1991; Troxel et al., 2009). However, a too-short breeding season is found to decrease production due to lower pregnancy rate (Deutscher et al., 1991).

Longevity and lifetime calf production of female cattle

Longevity of female cattle can be defined in two ways, either as total duration of survival in the herd or total length of production period in the herd (Arthur et al., 1993; Parish, 2010). Lifetime calf production is defined as a function of cow survival x reproductive performance, and survival x growth rate of the progeny (Cundiff et al., 1992). However, an alternative when progeny growth rate is not known, is to use cow survival x reproductive performance.

In the US, the cost of raising replacement heifers has been calculated to break even when a cow has produced three to five calves (Tozer et al., 2001). Another US study of economic efficiency showed maximum return when the terminal age of cows was six to nine years when calving as two-year-olds, and 8 to 9 years when age at first calving was three years (Nunez-Dominguez et al., 1991). Further advantages of increased longevity in the herd might be a need for fewer replacements, making more selective heifer replacement possible, lower total energy requirements of females finished growing, reduced environmental output, lower incidence of dystocia and heavier calves at weaning (Roberts et al., 2015). A disadvantage might be loss of genetic gain due to prolonged generation interval (Parish, 2010). Norwegian beef production is heavily subsidized (Åby et al., 2012), but emphasis on optimal lifetime production is necessary for the sustainability of the Norwegian beef production industry in the future. Therefore, knowledge from abroad, where beef herds traditionally have been less subsidized compared to the Norwegian production, might provide useful information which can be extrapolated to Norwegian conditions.

Record keeping and targets in suckler herds

In order to measure and achieve an increase in herd output, herd production status has to be established. Regular weighing and precise record-keeping are very important tasks that make it possible to evaluate production efficiency and performance. With sufficient and reliable record-keeping, each step in production in the herd can be evaluated separately, and performance can be benchmarked before targets are set. From the record database, it should be possible to generate printouts of a herd's performance at any time, and the key results should be presentable as annual reports. The NBCRS allows for this type of recording, but the extent to which producers record data varies considerably, and for many herds only mandatory registrations and abattoir registrations are available. When necessary recordings are kept, the production potential of the herd can be estimated, and the number of cattle that can be fed during winter might be estimated in the autumn when quantity and quality of total forage reserves are known. Targets can be set for most stages of production, and examples of reproductive targets relevant to Norwegian conditions are given in Table 2.

Table 2. Example of measures of reproductive performance and targets in a suckler cow herd relevant to Norwegian conditions.

Numerator	Denominator	Target
Actual age at first calving	Desired age at first caving	1 ± 0.1
Cows calving in first 21-day period	Total cows calving	> 65 per cent
Abortions	Total females mated	< 2 per cent
Heifers with dystocia	Total heifers calving	< 15 per cent
Cows with dystocia	Total cows calving	< 5 per cent
Perinatal losses	Total females calving	< 2 per cent
Weaned calves	Total females mated	95 per cent
Replacement rate	Total females mated	15 per cent

Adapted from Caldow et al., 2005

Cattle reproductive physiology

Time of onset of puberty varies between breeds, is a function of age and weight, and is relatively resistant to interactions with other traits (Larson, 2005; Martin et al., 1992). The early maturing breeds, such as Hereford and Aberdeen Angus, enter puberty at 12 to 14 months of age, and the later maturing breeds, like Charolais and Limousin, at 14 to 16 months of age (Diskin et al., 2014; Ferrell, 1982; Martin et al., 1992). After onset of puberty, beef cattle are non-seasonal polyoestrous breeders, which means they have repeated distribution of oestrous cycles throughout the year interrupted only by pregnancy or pathology (Peter et al., 2009). An oestrous cycle typically lasts 18 to 23 days and has two or three follicular growth periods (> 95%) (Jaiswal et al., 2009). The first postnatal oestrous cycle is an exception to this pattern, as it is often a short cycle lasting approximately 10 days with only one follicular growth period (Crowe et al., 2014; Murphy et al., 1990; Odde et al., 1980). The first postnatal ovulation is not preceded by signs of oestrus (Perry et al., 1991). Factors causing this first exception are, among others, lack of pre-oestrus hormonal effect on sex centres in the brain, ongoing replenishing of hormones in the anterior pituitary, and hormone negative feedback mechanism initiated by the presence, recognition and suckling of the dam's own calf (Yavas et al., 2000). The hormonal processes controlling reproduction are influenced by hormones involved in other processes of the body, e.g. hormones associated with nutrition and metabolism (Chagas et al., 2007). Oestrus expression is influenced by hormones released in response to stress and pain (Dobson et al., 2003), or the constant or recurring presence of a bull in the herd (Azzam et al., 1991; Landaeta-Hernández et al., 2004; Miller et al., 2008).

Oestrous behaviour and time to ovulation

Oestrus is detected by the bull in a manner still not completely understood. Likely, signals detectable by bulls are oestrus-related chemical signals in body fluids (Kiddy et al., 1984; Le Danvic et al., 2015). Oestrus first occurs at puberty, although heifers might display non-pubertal oestrous behaviour (Rutter et al., 1986). The duration of oestrus expression ranges from 11 to 21 hours (Floyd et al., 2009; Hurnik et al., 1987; Jaiswal et al., 2009; Rae, 2002; White et al., 2002; Wiltbank et al., 1967). However, there are factors that might affect duration of oestrus. First oestrus after calving in beef cows (Angus × Hereford) has a shorter duration of 5.6 ± 1.2 hours (Ciccioli et al., 2003). Several factors are suggested to affect duration of oestrus, including seasonal effects, climate, and environmental temperature (Orihuela, 2000; Roelofs et al., 2010; White et al., 2002). The primary sign of oestrus is standing to be mounted, whereas secondary signs include genital discharge of clear mucus, mounting other cows, restlessness, swelling and reddening of vulva, and decreased feed intake and milk yield (Diskin et al., 2000).

While the primary sign is commonly used to detect oestrus, it has its limitations. Standing to be mounted is not expressed by all female cattle in oestrus, and this sign loses practicability with increasing herd size (Hockey et al., 2010; Hurnik et al., 1987). Oestrus expression is also reported to vary individually depending on the number of animals in oestrus at the same time, the parity of the cow or diseases (Floyd et al., 2009; Hall et al., 1959; Morris et al., 2011; Roelofs et al., 2005a; Walker et al., 1996). Expression of oestrus is controlled hormonally. High correlation between expression of oestrus and blood concentration of oestradiol has been found (Lyimo et al., 2000; Roelofs et al., 2004). However, expression of oestrus does not seem to be directly proportional to oestradiol concentration. Rather, it seems oestradiol and progesterone play an all-or-nothing role in the onset of display of oestrous behaviour, with individually varying intensity (Allrich, 1994). Moreover, in order to perform AI at the right time, it is important to define time from oestrous behaviour to ovulation. Studies are often not directly comparable because of the different definitions used, e.g. time to ovulation from onset of oestrus, from onset of luteal activity, from activity peak, or from standing for mounting (Roelofs et al., 2010). Additionally, the expression of oestrus might differ between oestrous periods within the same female and among females, because many factors are involved, such as social interactions, management and environmental factors, nutrition, bio-stimulation, season, parity and genetics (Chenoweth, 2005a; Orihuela, 2000; Roelofs et al., 2010; White et al., 2002). Stress and temperature are known to have a considerable impact on the expression of oestrus (Dobson et al., 2003; Hall et al., 1959).

Temporal pattern of progesterone concentration for oestrous cycle evaluation

Progesterone analysis is a useful tool to evaluate detection of oestrus, and concentration of progesterone can be measured in both blood and milk. (Lesniewski et al., 1985; Roelofs et al., 2010). Serum progesterone concentrations in cyclic female cattle directly reflects the function of the corpus luteum (Peters, 1984). Thus, in prepubertal heifers, which have no corpus luteum, circulating progesterone is steady at basal concentration. During oestrus, plasma progesterone concentrations are below 1.0 ng/mL, averaging 0.4 ng/mL (Corah et al., 1974). Between two oestrous periods, plasma progesterone concentrations are well above 1.0 ng/mL (above 2 ng/mL by the sixth day of the oestrous cycle), because of the rapid rise in plasma progesterone caused by luteinization after ovulation (Corah et al., 1974; Stabenfeldt et al., 1969). If no pregnancy is established, prostaglandin $F_{2\alpha}$ of uterine origin causes luteolysis by minimizing luteal blood support (Ginther, 1974). The consequence is a rapid decline in blood progesterone concentration as the female approaches a new oestrus (Ginther, 1974; Knickerbocker et al., 1988). The temporal pattern of progesterone concentrations is illustrated in Fig. 1. During pregnancy, plasma progesterone concentration remains elevated until calving (Stabenfeldt et al., 1970). At calving, foetal induced prostaglandin production causes maternal progesterone production to cease. Post-partum, in sexual quiescence/anoestrus, progesterone stays at basal concentration until luteal activity resumes (Agthe et al., 1975; Schallenberger et al., 1978). After calving, the time to resumption of luteal activity depends on a number of factors, among others genetics and suckling by the calf. For time from calving to onset of luteal activity in French Charolais, a heritability (h^2) of 0.12 was found (Mialon et al., 2000). Suckling has been found to prolong postnatal anoestrus in beef cattle in US studies (Garcia-Winder et al., 1984; LaVoie et al., 1981). However, in beef cows, the first ovulation commonly occurs 35 to 70 days post-partum, after which plasma progesterone again rises due to luteinization (Larson et al., 2016; Murphy et al., 1990; Yavas et al., 2000).

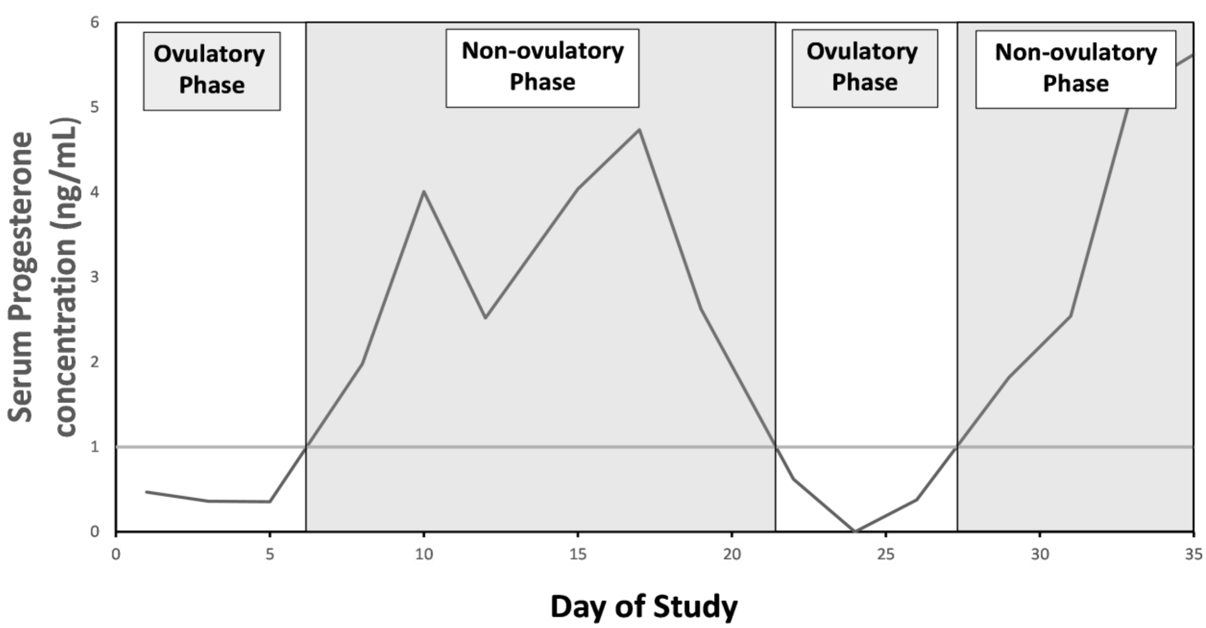

Figure 1. Example of a temporal pattern of progesterone concentration in blood sampled thrice-weekly for 5 weeks from a Hereford heifer (Figure drawn by ST Nelson)

Artificial insemination

Replacement animals from AI are reported to account for less than 5% of the global beef cattle population (Vishwanath, 2003). In closed herds, inbreeding might occur, and inbreeding has been shown to have negative effects on survival, overall production and perinatal mortality in beef cattle (MacNeil et al., 1989; Mc Parland et al., 2008). AI can be a useful tool to avoid inbreeding, and to increase the rate of genetic improvement (Nicholas, 1996). Within the dairy industry, AI has been reported to be important for disease control, genetic selection, and improved health, longevity and milk yield (Dransfield et al., 1998; Heringstad et al.).

In the NBCRS in 2014, the proportion of suckler cows registered as having received AI was 16% to 24% for the ‘intensive’ (continental) breeds, and 7% to 11% for the ‘extensive’ (British) ones (Animalia, 2015a). In comparison, the proportion of artificially inseminated females among Norwegian dairy cattle is 85% (Geno, 2015b). One reason for the lower uptake of AI in beef herds than dairy herds is that beef suckler cows are handled less frequently than dairy cows, and suckler cow producers are often involved in other on- or off-farm occupations. Another reason might be that dairy herds much more frequently have a veterinarian for consultations, who, in many regions in Norway, also performs AI (66% of first-time AI) (Geno, 2015a) on-farm.

A Canadian survey (Howard et al., 1995) found that beef farmers not using AI were more commercially oriented, were more likely to have crossbreeding strategies and had higher on- and off farm incomes, than those preferring AI to natural breeding. Breed, temperament, calving ease and maternal ability were the top-ranked criteria of importance for both AI users and non-users when selecting a breeding strategy, and the cost of AI or of a bull was ranked as least important. Convenience and difficulty of heat detection were ranked most important for using natural breeding (Howard et al., 1995). Technical aids for oestrus detection seem important for future cattle breeding. Studies evaluating automatic activity monitoring systems (AAMS) in beef herds are scarce, but such systems have been found to be very beneficial in dairy herds (Kamphuis et al., 2012; Neves et al., 2015).

Timing of insemination

The timing of AI relative to oestrus is important, and the 'right' time to perform AI is a compromise between low fertilization rate and high embryo quality for early AI and high fertilization rate and low embryo quality for late AI (Saacke et al., 2000). The optimal time for AI in dairy cattle has been reported to be 5 to 17 hours after increase in oestrous activity, and 2 to 14 hours after the commencement of standing to be mounted (Roelofs et al., 2006a), or 6 to 24 hours before ovulation (Parkinson, 1996). Within dairy herds, the 'AM-PM' rule is often used (Diskin et al., 2016; Rae, 2002). Following this rule, females in oestrus in the morning (a.m.) are inseminated the following afternoon (p.m.) while females in oestrus in the afternoon (p.m.) are inseminated the following morning (a.m.) (Dorsey et al., 2011; Graves et al., 1997). Research on the use of AI in beef suckler herds primarily focuses on timed artificial insemination (TAI) after an oestrus synchronisation protocol. The use of TAI reduces the need for farmer observation in order to detect oestrus (Dutil et al., 1999; Lamb et al., 2010). However, studies to determine optimal time of AI relative to naturally occurring oestrus in beef cows are limited (Fields et al., 1975; Robbins et al., 1978).

Oestrus synchronisation and timed artificial insemination

Oestrus synchronisation in beef cattle can be used to increase the proportion of AI and to shorten calving season in a herd (Larson et al., 2006). Different TAI protocols have been developed that eliminate the need for oestrus detection (Larson et al., 2006). Currently, in Norway, prostaglandins (Estrumat vet. and Dinolytic vet.), progestin (Relmont vet.) and the gonadotropin releasing hormone (GnRH) analogue buserelin (Receptal vet.) are commercially available for the regulation of oestrus in cattle and TAI (Anonymous, 2016b). In a US study in which more than 2500 suckled beef cows from 7 different states were oestrus synchronized and different TAI protocols were compared, the achieved proportion of pregnancy was found to range between 37% and 67% (Larson et al., 2006).

Perhaps the single most commonly used protocol in Norway is single or double injection of prostaglandin F2α, which is well-studied for its efficient, luteolytic property (Lauderdale, 2001). GnRH regulates the blood concentrations of luteinizing hormone and follicle stimulating hormone (Anonymous, 2016b). Additionally, GnRH can be used to shorten postnatal anoestrus in beef cows (Stevenson, 2001). Progestins are progesterone analogues that supress the release of GnRH and luteinizing hormone (Anonymous, 2016b). Progestins can additionally be used to facilitate the induction of puberty in prepubertal or peripubertal heifers (Patterson et al., 2013). Several protocols for the regulation of oestrus have been evaluated and found useful (Bridges et al., 2014; Patterson et al., 2013; Sales et al., 2011). However, during the development of Norwegian Red production, where emphasis has been on good reproductive performance (Geno, 2016), the demand for regulation of oestrus has been low. Therefore, the practices of oestrus synchronisation and TAI are limited in Norway. Moreover, TAI is restricted in organic cattle production according to the regulations for organic farming (EC No. 1804/1999), and there is little social acceptance of routine use of hormone treatments among European consumers (Opsomer et al., 2006). Despite the promising results found in studies of TAI (Bridges et al., 2014; Patterson et al., 2013; Sales et al., 2011), blanket use of oestrus synchronisation or TAI currently seems unlikely to be implemented in Norwegian beef herds.

Stock bulls vs. artificial insemination

There are advantages and disadvantages of using AI over natural mating in a herd. The cost of keeping a bull, compared to the cost and income of an additional female, in terms of feed and special housing facilities is an important factor to consider when comparing natural service to AI. However, the economic calculations are highly herd-dependent.

The bulls selected for semen collection within the AI industry have been found to have a superior genetic merit and overall reliability. AI provides access to elite genetics for most sucker cow herds (French et al., 2013). This can be utilized to increase the rate of genetic improvement, and it is possible to increase genetic diversity in the population with fewer bulls in total (Nicholas, 1996). The semen collected from these bulls can be distributed to many cows anywhere in the world, and frozen semen can be stored for many years. Despite the fact that AI bulls in general undergo rigorous disease and genetic testing to avoid spread, the impact of spread might be large due to easy distribution of semen and long shelf life (Wentink et al., 2000). However, it is an advantage to use AI instead of natural mating to avoid spreading diseases and unfavourable genetic aberrations, even though genetic defects have been spread through AI bulls in the past (Gentile et al., 2006). The time needed to detect oestrus before AI is another disadvantage of that method.

Natural mating is easy for management purposes, and the presence of a herd bull has been found to have a positive effect on fertility in bio-stimulations (Burns et al., 1992; Fiol et al., 2016; Landaeta-Hernández et al., 2004; Landaeta-Hernández et al., 2013). A major disadvantage of stock bulls is that they might fail to serve the herd, which has large negative economic consequences if many cows are left open undetected until pregnancy check. It is estimated that almost 25% of bulls are subfertile (Kennedy et al., 2002), and bull fertility is often best in the first part of the breeding season (Larson et al., 2016). Even though these studies were performed in the US, where different bull nutrition might affect testicular function (Kastelic, 2014), bull fertility should also be examined under Norwegian conditions. Natural mating could potentially be hazardous for the bull. Should injuries or infections occur, these might permanently or temporarily impair semen quality or reduce libido, and consequently negatively affect the probability of pregnancy or skew calving distribution within the calving period in the herd (Ellis et al., 2005; Kennedy et al., 2002). Additionally, the hazards of having a bull in the herd should also be considered, as eight fatal accidents involving humans, mostly caused by bulls, were registered in Norwegian suckler herds in the period 1997 to 2008 (Anonymous, 2010).

Sexed semen

The use of sexed semen has the potential to be beneficial in beef cattle herds (Seidel, 2014b). Example scenarios include when heifers are replaced by their female calf, or when all cows have terminal-cross bull calves for fattening to utilize the heterotic effect (Roughsedge et al., 2001; Seidel, 2014a). The proportion of sexed semen is increasing in the AI doses used in Norwegian beef cattle. When used, separated female (x) semen provides over 90% heifer calves, whilst separated male (y) semen provides about 80% bull calves (Anonymous, 2016a). When using sexed semen, it has been recommended in the US that AI at expressed oestrus should be preferred over TAI, and that females have expressed oestrus previously to the oestrus where AI is performed (Hall et al., 2013).

Diagnostic properties of oestrus detection

In herds where AI is performed, correctly identifying oestrus is of key importance for reproductive efficiency, and sensitivity (Se) and specificity (Sp) of detection of oestrus are important factors for success (Rorie et al., 2002). Se and Sp are based on a binary or binomial classification test where the options in the case of oestrus detection might be defined as ‘outcome’ or ‘no outcome’. Se is the probability that a test will correctly detect and classify ‘outcome’ among all tested truly with outcome, and Sp is the probability that a test will correctly classify ‘no outcome’ among all tested truly without outcome. Positive predictive value (PPV) is the proportion of all tests classified with ‘outcome’ that truly had outcome, and the negative predictive value (NPV) is the proportion classified ‘no outcome’ that truly had none. The relationship between Se, Sp, PPV and NPV is illustrated in Fig. 2.

		True status		
		Outcome	No outcome	
Test Status	Classified ‘outcome’	a	b	a/(a + b) = PPV
	Classified ‘no outcome’	c	d	d/(c + d) = NPV
		a/(a + c) = Se	d/(b + d) = Sp	

Green = test classification in compliance with truth.

Red = test classification not in compliance with truth.

Figure 2. Performance of a binominal classification test to find sensitivity (Se), specificity (Sp), positive predictive value (PPV) and negative predictive value (NPV) relative to the true status (Figure drawn by ST Nelson).

When female cattle stand to be mounted, a high PPV, but low Se, is reported for visual observation (Kiddy, 1977; Roelofs et al., 2010). The main reason for low Se is that oestrous activity can be expressed at any time, and not necessarily at the times herdspersons are present (Roelofs et al., 2010). Additionally, not all females in a herd stand for mounting, and some may only stand for a few mounts when no herdsperson is present, which makes their oestrus less likely to be visually detected (Hurnik et al., 1987; Roelofs et al., 2010). The amount of mounting behaviour during an oestrous period is also affected by many factors, e.g. lameness, herd size, season, and housing (Roelofs et al., 2010). The number of herd mates in pre-oestrus and oestrus at the same time is reported to affect oestrous behaviour in dairy cattle (Hurnik et al., 1975). Hence, aids to continuous herd monitoring with high Se for detection of oestrus are likely to be beneficial in suckler herds in which AI is performed.

Numerous reviews have been published on oestrus detection aids for dairy cattle, but few for beef cattle (Diskin et al., 2000; Rao et al., 2013; Roelofs et al., 2015). However, for beef cattle it was found that automatic systems for detection of oestrus had higher Se than, but equal Sp to, visual observation (Landaeta-Hernández et al., 2002). Five desired requirements are stated for an oestrus detection aid: 1) 24/7 surveillance, 2) automatic detection, 3) endurance of the system, 4) low labour requirements, and 5) high Se that correlates with ovulation (Senger, 1994). There are many aids for the detection of oestrus on the market today, and 31 of them were reviewed in 2013 (Rao et al., 2013). However, several of these oestrus detection methods are not relevant for Norwegian herds or in conflict with Norwegian legislation, e.g. the use of androgenized cows or surgery to prevent penile intromission (Anonymous, 2006; 2009). Of the aids reviewed, those most likely to become implemented in Norway are the technical devices. Objective monitoring of animals can become very helpful in the future to assist herd management, and technical monitoring aids have shown to perform better than or equal to timed AI programs in dairy herds (Neves et al., 2015; Neves et al., 2012). Even though higher Se is reported for technical monitoring devices than for visual detection of oestrus (Landaeta-Hernández et al., 2002), the need for improved Sp and PPV values has also been reported (Hockey et al., 2010). Additional monitoring of changes in rumination activity at oestrus has shown promising results in a recently performed study (Reith et al., 2014). One study reported that a mounting detection device gave lower pregnancy rates than visual detection for heifers, but the authors suggested that a reason for this result could be that they did not take into account the differences in time to ovulation between the device used and visual detection (Rae et al., 1999). Examples of aids that might be useful and applicable in suckler herds are activity meters, mount detectors and continuous temperature measurements.

Activity meters

Activity meters, including pedometers, are movement recorders attached to an animal's neck or leg by a collar. These meters sense and report the animal's level of activity, which might exceed three times its basic level of activity during oestrus (Kiddy, 1977; Reimers et al., 1985). A system reporting activity continuously or in blocks to a central unit able to visualize, notify or somehow inform about an individual animal's current and historical activity, is defined as an automatic activity monitoring system (AAMS) (Aungier et al., 2015). The Se and PPV of such systems vary between studies, but Se has been reported as being between 59% and 90% and PPV between 67% and 94% (Roelofs et al., 2015). New technology makes it possible to take rumination into consideration as well, which further increases the accuracy of oestrus prediction and detection of silent oestrus (Kamphuis et al., 2012; Reith et al., 2014). The use of neck collars is already established in Norwegian cattle herds for other purposes, such as for animal identification or for automatic concentrate feeder tags, and thus neck collars are generally accepted by the stockpersons and tolerated by the cows. The possibility of using neck collars for multiple purposes and the disadvantages of leg-attached pedometers in straw bedding favour neck-attached pedometers in beef suckler herds. A general disadvantage of activity meter and pedometer systems is the high cost of investment.

Mount detectors

Mount detectors are pressure sensitive devices for detecting oestrus attached to the sacrum of the cow to register specific sexual behaviour. When a female stands for mounting, the mount detector is activated. Non-electronic variants are common and utilize colourful paint either on the tail or sacral area (Diskin et al., 2014). Detectors functioning as 'scratch cards' when attached to the female sacrum are also available (Holman et al., 2011). An advantage of these aids is low investment cost. Disadvantages include increased handling of animals if the females are not handled for other reasons, e.g. reproductive examination, and the fact that the detectors can be rubbed off or activated without mounting when cattle are housed indoors (Diskin et al., 2014; Holman et al., 2011). Additionally, lower Se has been found for the scratch card type detectors compared to other methods of detecting oestrus (Holman et al., 2011).

Temperature measurements

During oestrous periods, the female experiences a progesterone-associated drop in body temperature, but with a peak of elevated temperature coinciding with standing to be mounted behaviour (Boehmer, 2012; Kyle et al., 1998). The decline in progesterone blood concentration is suggested to be the cause of the drop in body temperature (Kyle et al., 1998; Wrenn et al., 1958). The standing oestrus temperature increase is suggested to be caused by elevated activity level, which is found to be greater among loose housed cattle than among tethered cattle (Suthar et al., 2011). Radio-telemetered monitoring of vaginal or ear skin temperature has been studied, and vaginal temperature had 81% Se and 69% PPV for detection of oestrus (Redden et al., 1993; Roelofs et al., 2010). This system can also be used in tie stalls because animals with restricted movement also have elevated temperature during the standing to be mounted phase (Suthar et al., 2011). Automatic temperature registration can be useful for monitoring other conditions that affect body temperature as well (Johnson et al., 2016). However, vaginal or ear tag temperature measures are more invasive than the other detection methods described.

Visual and auditory monitoring

To standardize visual observation and to diminish subjectivity, a 24-hour cumulative scoring scale for visual evaluation of oestrous behaviour has been developed, shown in Table 3 (Van Eerdenburg et al., 1996). However, visual detection is time-consuming and has disadvantages such as lack of efficiency and accuracy (Diskin et al., 2014; 2016).

An existing, and common, method for monitoring suckler cows is by security camera, which can also be used for detection of oestrous behaviour such as mounting activity or increased oestrous activity. Because vocalisation is found to alter at oestrus, in addition to being a potentially useful indicator of cattle physiological and psychological functioning, the possibility of recording and transferring sounds from the herd might make the camera an even better tool for oestrus detection in beef herds of the size typically found in Norway (Manteuffel et al., 2004; Schön et al., 2007). Nevertheless, cameras are often installed to monitor calving. It is important not to compromise on monitoring of calving for oestrus detection. Dystocia is a critical event, and early intervention is important for several reasons including animal welfare, production efficiency and producer emotions.

Table 3. Standardized visual observation scoring scale of oestrous behaviour (Van Eerdenburg et al., 1996).

Behaviour	Scoring scale
Mucous vaginal discharge	3
Cajoling	3
Restlessness	5
Being mounted, but not standing	10
Sniffing the vulva of other cow	10
Resting with chin on other cow	15
Mounting (or attempting) other cows	35
Mounting head side of other cow	45
Standing heat	100

Dystocia in suckler cow herds

Dystocia is defined as difficult birth, but the diagnosis is applied with a high degree of subjectivity (Noakes, 2009). Both cow and calf might suffer from stress and diseases following dystocia (Dobson et al., 2001; Larson et al., 2005; Lombard et al., 2007), and in severe cases it can be fatal for one or both of the animals involved. Hence, dystocia has a large negative impact on animal welfare and production in the herd. Dystocia affects reproduction (Diskin et al., 2014) and has been shown to significantly affect longevity and consequently lifetime calf production of beef cows (Rogers et al., 2004; Szabó et al., 2009). Dystocia also directly causes losses in production, and in 2012, dystocia was reported as the main reason for emergency slaughtering of 470 heifers and young cows nationally (Animalia, 2015a). The most common cause of dystocia is foetal-maternal disproportion (Bellows, 1993; Bellows et al., 2000; King et al., 1993; Nix et al., 1998). That means either the maternal delivery channel is too small, or the foetus is too large or has an adverse conformation, making it impossible to pass the maternal birth channel. A combination of both maternal and foetal causes is especially a concern in calvings by females still in growth (Funnell et al., 2016; Laster et al., 1973). In dairy cattle, the calf weight to cow weight ratio at birth had a mean ratio of 6.9% (SD 1.2%), and the ratio of 7.2% gave the highest perinatal calf survival rates (Johanson et al., 2003).

The production losses caused by dystocia include increased calf and/or dam mortality, reduced reproductive performance in terms of delayed return to cyclicity and delayed onset of luteal activity of the dam, decreased lifetime calf production, and increased incidence of disease among the progeny (Lombard et al., 2007; Nix et al., 1998; Toombs et al., 1994; Wittum et al., 1995; Zaborski et al., 2009).

Factors affecting birth weight

In the annual NBCRS report from 2014, the proportion of beef calf births reported to have some or severe dystocia were 4.2% and 2.4%, respectively. There are several reasons why producers may desire a heavy calf at birth. One reason is that birth weight is positively correlated with growth traits, weaning, yearling and mature weight (Morrison et al., 1986).

Small calves might lack vigour and tolerance to cold stress and be unable to adapt to extra-uterine life and its challenges (Carstens et al., 1987; Holland et al., 1992). Therefore, it is desirable for calves to be large enough to be healthy and robust (Holland et al., 1992). Birth weight depends on both genetic and environmental factors (Colburn et al., 1997; Holland et al., 1992; Price et al., 1978). Environmental factors that might affect birth weight were reviewed by Holland and Odde, 1992, and are presented in Table 4 (Holland et al., 1992; Mee, 2008). However, the optimal birth size of a calf depends on maternal breed and parity, and it is reported that the cause of dystocia is not birth weight per se, but the calf to cow weight ratio (Berger et al., 1992; Johanson et al., 2003). Birth weight can be predicted by expected progeny differences (EPD), which provide estimates of the genetic value of an animal as a parent (Greiner, 2009; Sanderson, 2005). EPDs are calculated using complex statistical equations and models, and depend on the heritability of the trait, correlations with other traits included in the evaluation, number of records, relationships among animals with records, and distribution of information across herds (Cundiff, 2010). An EPD is a prediction, based on available data, of one-half the breeding value of an animal, which is what the animal is expected to transmit to its future offspring (Cundiff, 2010). EPDs are used to compare animals, and the difference in EPDs between two bulls of the same breed is a prediction of the difference between the future performances of their progeny (Cundiff, 2010; Holland et al., 1992). The sum of the EPDs, weighted by their economic values, might be used to rank bulls using the best linear unbiased predictor of economic merit (BLUP) (Cundiff, 2010).

Table 4. Factors affecting beef calf birth weight (Holland et al., 1992)

Genetic effects	Environmental effects	
Sire and dam	Maternal body weight/size	Gestation length
Breed	Dam age	Dam nutrition
Heterosis	Maternal ability	Environmental temperature
Inbreeding	Pregnancy site	Season
Sex of calf	Lactation status	Altitude
Genetically anomaly and malformation	Foetal number	Geographic location

Average maternal size within a breed is predictive of calf size. In general, dams of large breeds give birth to calves that are heavier than calves born to dams of smaller breeds (Andersen et al., 1965). In the US, the difference in birth weight between male and female calves has been reported to be relatively constant between breeds at 5% to 8% (Holland et al., 1992). These estimates are based on older studies, but guidelines for uniform beef improvement programs currently use a standard difference between male and female calves at birth in adjustment formulas of 2.3 kilos in favour of the male calf (Cundiff, 2010; Holland et al., 1992). Birth weight had been found to be a more important variable for dystocia than sex of the calf in US and Canadian studies (Bellows, 1993; McDermott et al., 1992). However, a Swedish study including birth weights of Charolais and Hereford calves found 1.4 times higher dystocia in male calves than females (Eriksson et al., 2004).

Calves born in colder climates are heavier than calves born in warmer climates (Colburn et al., 1997; Deutscher, 1999; Holland et al., 1992; Soren, 2012; Young, 1975). Cold stress seems to affect cattle most in the autumn before the animals have adapted to a colder environment (Gonyou et al., 1979), which likely coincides with the second trimester in a large proportion of Norwegian beef cattle parities (Ruud et al., 2013). Environmental factors are complex and interact with each other. Such interactions can be seen for nutrition and temperature, which both affect growth hormone balance in cattle still in growth and therefore indirectly affect foetal growth through blood thyroid hormone concentrations (Christopherson et al., 1979; Johnson et al., 2015). Additionally, cold-stressed ruminants have increased blood concentrations of fatty acids, amino acids and glucose (Soren, 2012). Hence, altered heifer growth hormone balance and elevated nutrient concentrations in the bloodstream might affect the foetuses of cold-stressed dams, compared to foetuses of dams within their thermoneutral zone (Soren, 2012).

Spring calving beef heifers that are housed for their last trimester are found to give heavier calves than the heifers not housed (Andreoli et al., 1988). Additionally, periods of undernutrition or large changes in the energy content of the feed are found to give heavier calves at birth than steady feeding (Clanton et al., 1983; Micke et al., 2010b).
In nutrient-restricted pregnant cattle, cotyledon size and placentome number and surface increased (Taylor, 2015). Large nutritional and temperature changes might be experienced by

cattle moved from poor late autumn pasture and challenging weather conditions to sheltered housing and high quality fodder.

Heifers are especially likely to be affected by undernutrition, as they are still growing (Arango et al., 2002b). Additionally, compensatory growth (Ryan et al., 1993; Yambayamba et al., 1996) or an altered ratio of calf birth weight to heifer body weight might influence foetal growth (Berry et al., 2007). Therefore, heifer rearing is one of the most important factors influencing subsequent calving (Johnson et al., 2013; Norman et al., 2007). Moreover, to avoid dystocia, the evaluation of reproductive soundness of heifers based on weight, reproductive tract score, and pelvic area is very important (Larson et al., 2007). To achieve desired heifer weight at breeding and birth in beef suckler cow herds it is important to monitor and evaluate heifer growth by weighing the heifers, at approximately 200, 365, and 550 days of age. Because most Norwegian beef suckler herds calve in the spring, peaking in March (Animalia, 2013; 2015a; 2016), weighing at these ages can help monitor performance of the heifers from birth until weaning, post weaning and during their first pasturing period weaned. When sufficient weighing is performed in the herd, the gathered data can be evaluated for improvements, and eventual corrections might subsequently be implemented.

Knowledge gaps

Specialized beef production is a relatively new enterprise in Norway, and those involved in this enterprise, including specialized beef producers, their veterinarians and advisors, have limited experience with this form of production. Additionally, during the past few years, it has become clear that factors affecting productivity in beef production in Norway are not fully understood. Lifetime calf production of beef females is known to be an important factor for net income in beef suckler herds, but factors influencing lifetime calf production in Norwegian beef herds are not sufficiently known. Calf birth weights are reported to affect both rate of dystocia and lifetime calf production, but little is known of factors affecting calf birth weights in Norwegian suckler herds. Calf birth weights have high heritability and can be altered by AI. In addition, AI can enhance overall genetic merit in the rapidly expanding beef cattle population because live animal import is undesirable. However, as labour costs in Norway are high, efficient ways of monitoring oestrus in beef herds and knowledge of when to perform AI have to be found. It is known from the dairy industry that AAMS increases the probability of pregnancy by AI, but knowledge about the efficiency of such systems in beef herds, in terms of Se, Sp, PPV and NPV, is lacking. Furthermore, there is little scientific consensus on when to perform AI relative to detection of oestrus by either AAMS or visual observation in housed beef herds. Beef production yields marginal profits, and the proof of the usefulness of AAMS is important in order to justify investment costs.

Aim of the Study

The overall aim of this thesis was to identify factors affecting productivity in Norwegian suckler herds, with emphasis on detection of oestrus to increase the use of AI, calf birth weight for optimal performance of both dam and calf, and lifetime calf production for increased production. The overall aim was approached by pursuing the following specific objectives:

- Evaluate the usefulness of an automatic activity monitoring system in a beef herd through a diagnostic test evaluation (Paper I)
- Estimate the time from oestrus to ovulation for both AAMS and visual detection in a Hereford beef herd (Paper I)
- Describe birth weights and factors affecting birth weights of Norwegian beef calves through available register data (Paper II)
- Describe the lifetime calf production and factors affecting the lifetime calf production of Norwegian beef suckler cows in terms of total number of calves born (Paper III)

Material and Methods

Study design and data recording

The data investigated in this project were obtained from a field study (Paper I) and from the NBCRS (Paper II and Paper III). The study samples, source, study types and statistical method for each objective are summarized and presented in Table 6.

Field study (Paper I)

A field study was performed at Götala Beef and Lamb Research Centre, Sweden, during five weeks in June and July, 2015. The study population consisted of 40 Hereford suckler females, of which 24 had a calf at foot and 15 were heifers. The prospective cohort study performed was based on thrice-daily standardized visual detection of oestrus and continuous AAMS recorded activity. The AAMS continuously recorded the activity of each female in the herd, and the level of activity was calculated using a proprietary matrix every second hour. Figure 3 shows an example of an activity curve and a rumination curve for a cow, obtained from AAMS software. An almost simultaneous increase in activity and decrease in rumination on two occasions indicate two oestrous periods for this particular cow. When a female was classified as in oestrus by visual or AAMS detection, transrectal ultrasound scanning was performed every 8 hours until ovulation, defined as the disappearance of the dominant follicle. During the study period, a total of 15 blood samples were taken from each female and analysed for serum progesterone concentrations (n = 570). A diagnostic test approach was used to evaluate the ability of AAMS and visual assessment to detect oestrus (Dohoo, 2009b). Individual serum progesterone concentrations defined the gold standard of ovulatory and non-ovulatory phases (Fig. 3). The relationship between visual or AAMS detection of oestrus and ovulation was explored using survival analysis.

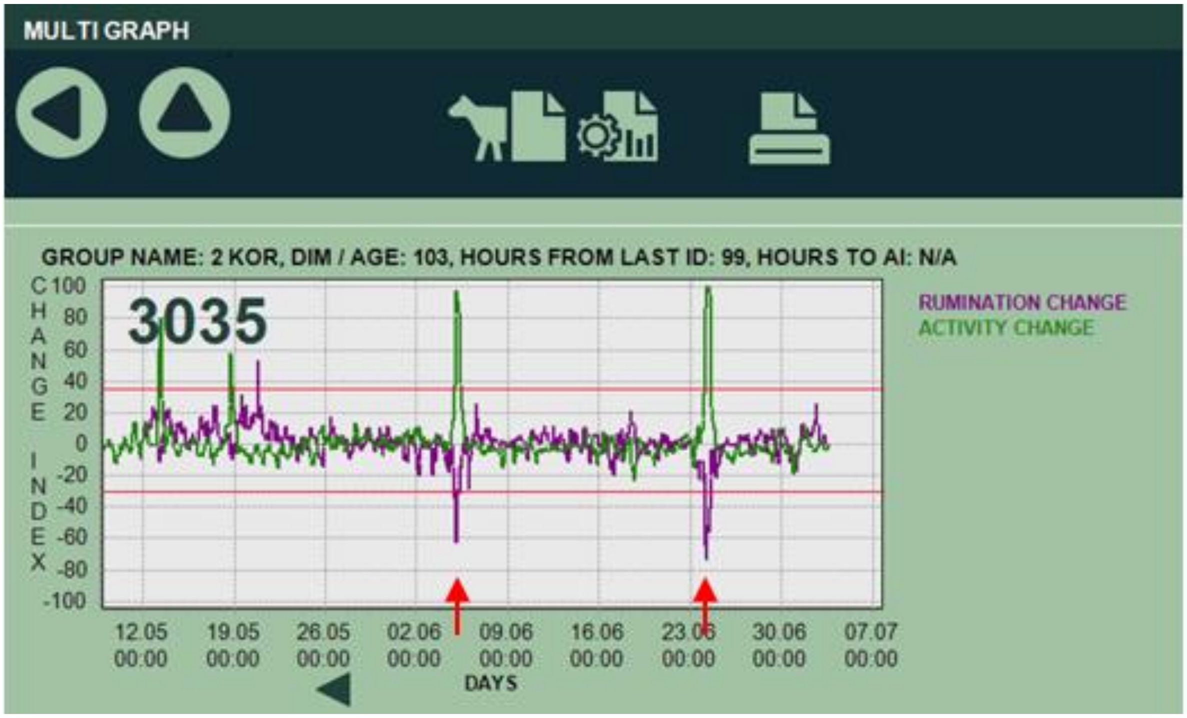

Figure 3. Example of an activity curve for a cow monitored with an AAMS (screenshot from Heatime®), where two oestrous periods are indicated with red arrow (Figure made by ST Nelson).

Dataset, Paper I

<u>a) Evaluation of diagnostic properties of AAMS and visual observation of oestrus:</u> For the test evaluation, the study sample consisted of 38 Hereford females, including 14 heifers and 24 multiparous cows. One cow was excluded due to calving at study start and a heifer was excluded because of freemartin syndrome. No primiparous females were present in the herd.

<u>b) Time from onset of oestrus to ovulation:</u> The survival analysis comparing time from onset of oestrus to ovulation for heifers and cows was performed on a subsample of 29 females, including 10 heifers and 19 multiparous cows. Those females excluded from the subsample did not express signs of oestrus during the study, and it was not possible to assess the time from oestrus to ovulation in these cows. The females included in the subsample expressed a total of 49 oestrous periods. Oestrous periods confirmed with both ovulation and low serum progesterone were included in the estimations.

Sampling and laboratory examinations

Fifteen serum samples were taken from each animal for progesterone analysis by competitive ELISA (enzyme-linked immunosorbent assay) (Voller et al., 1978). The degree of colouring of the sample was read by an absorbance plate reader along with a set of standards for quantification. The standards and samples were run in duplicate. Intra-assay precision (coefficient of variation) was 9.6% and the inter-assay coefficient of variation was 6.6%, according to the producer (Ridgeway Science, Gloucester, UK).

Statistical analysis

For the diagnostic test evaluation, the Se, Sp, PPV and NPV of two methods for detection of oestrus were calculated against the gold standard layout (Dohoo, 2009b). Gold standard was defined by temporal patterns of serum progesterone concentration. The relationship between time of ovulation and oestrus was explored using survival analysis. Ovulation was defined as the ‘event’, and the time from either AAMS alarm or visual observation of oestrus to event was set as ‘survival time’. Overall survival time to ovulation was estimated for each test using the Kaplan–Meier method (Dohoo, 2009b).

Database studies (Paper II and Paper III)

Data for Paper II and Paper III were extracted from the NBCRS. Data were obtained on all cows slaughtered between 2010 and 2013, along with all available data on their progeny. Information on 20,541 cows and 62,813 calves was initially retrieved.

The cows and their progeny are uniquely identified in the system through both a unique database ID number and a 12-digit ID number which consists of eight digits for herd (composed of numbers for county, municipality and herd), and a four-digit individual number within the herd. Descriptive statistics were performed as background information for the statistical inference.

Dataset, Paper II

The study sample consisted of 29,294 calves registered with the outcome variable birth weight. These calves were born to 9,903 dams. Of the calves, 8,738 were registered as a firstborn calf to a heifer. Explanatory variables are shown in Table 5.

Table 5. List of variables in the NBCRS extracted for the raw dataset used in the database studies.

Maternal variables	Progeny variables
Cow unique ID in database	Progeny unique ID in database
Herd number	Herd of birth
Individual number in herd	Individual number in herd
Cow date of birth	Sex
Cow date of slaughter	Birth date
Calving number	Weight at birth
Cow breed	Weight at 200 days of age
Cow weight at slaughter	Twinning
	Calving difficulties (diagnosis)
	Calving difficulties (degree of)
	Breed of progeny

Dataset, Paper III

The study sample consisted of 16,917 cows (1858 herds), which gave birth to 50,578 calves in total, of which 1076 were twins. Only cows recorded to be between 1.5 and 3.5 years old at first calving were included. The outcome variable was total number of calves born to each cow, and explanatory variables were region, herd size, breed, age at first calving, calving ease, calving interval, and twinning.

Model building strategy, Paper II and Paper III

The model building strategy was similar for both database studies. A linear (Paper II) and a Poisson (Paper III) regression were used to test univariable relationships between each of the explanatory variables and the outcome. Variables associated with the outcome with a P-value < 0.2 were selected for the multivariable regression models. Two multilevel regression models were built for each paper, one of which included all cows in the study. For each paper, a second model was included: a) in Paper II, a model exclusively for first calvers, and b) in Paper III, a model encompassing calving intervals for multiparous cows.

Herd and cow random effect(s) were used to account for lack of independence between offspring within cows and cows within herds in Paper II, and for the effect of herd in Paper III. Biologically plausible interaction effects between statistically significant explanatory variables were tested by adding interaction terms to the main effects model.

For the linear regression (Paper II), the assumption of normally distributed residuals was investigated using a normal quantile plot of standardized residuals at all levels of the model in question. The final model raw and standardized residuals were plotted against predicted values at all levels of the model in question to check for heteroscedasticity, as well as for potential outliers. The amount of variation present at each level in the hierarchical models (calving/cow/herd) was calculated.

In Paper III, incidence rate ratio (IRR) was calculated for all combinations of breed and region of Norway based on results from the multivariable model including the interaction term. The amount of unexplained variance at herd and cow level was calculated for all combinations of predictor variables using the exact formula described by Dohoo et al. (Dohoo, 2009a).

Table 6. Source of data, study sample, outcome variable and statistical methods for each objective of the thesis.

Objective (Paper)	Source	Subject	n	Type of study	Outcome variable	Statistical method
1 (I)	Field trial	Cows: Oestrous periods	38 52	Diagnostic test evaluation	Oestrus +/-	'Gold standard' layout
2 (I)	Field trial	Cows: Ovulations:	29 52	Prospective cohort	Ovulation +/-	Survival analysis
3 (II)	NBCRS*	Cows: Calves:	9,903 29,294	Cross-sectional	Birth weight	Linear regression
4 (III)	NBCRS*	Cows: Calves:	17,863 54,415	Retrospective cohort	n of calves	Poisson regression

* Norwegian beef cattle recording system

Main Results

Field study (Paper I)

Among the 38 eligible females, 111 ovarian phases were identified by analysing the temporal pattern of serum progesterone concentrations over the study period, of which 48 were defined as ovulatory. Transrectal ultrasonography indicated ovulation on 52 occasions. Of these, two oestrous periods were omitted from the estimations because the disappearance of the ovulatory follicle was not clearly identified, despite the temporal pattern of progesterone concentrations indicating that ovulation had occurred.

Oestrus detection

Systematic visual observation detected 36 and AAMS detected 43 oestrus periods. The disappearance of an ovulatory follicle coincided with 49 detected oestrous periods, 39 of these after visual detection and 49 after AAMS detection of oestrus. Evaluated separately, thrice-daily visual detection of oestrus had a sensitivity of 77% (95% confidence interval [CI] 62% to 88%) and a specificity of 89% (95% CI 79% to 95%), whereas the AAMS had a sensitivity of 90% (95% CI 77% to 97%) and a specificity of 100% (95% CI 94% to 100%) for identifying oestrus. No incorrect reports of oestrus were made by the AAMS. Hence, the PPV for the AAMS was 100% (NPV 93%). However, some oestrous periods were recorded in non-ovulatory cows based on standardized visual detection, which gave a PPV of 84% (NPV 84%). Combining both thrice-daily visual observation and AAMS, the sensitivity was 96% (95% CI 86% to 99%) and the specificity was 90% (95% CI 80% to 96%) for identifying oestrus, while the PPV and NPV were 88% and 97%, respectively.

Time to ovulation

Calculation of time from oestrus to ovulation was based on 40 visual observations and 50 AAMS-detected oestrus events. However, one oestrus period not correctly followed up was censored 17 hours into the investigation.

The median time to ovulation from detection of oestrus was 21 hours for standardized visual detection, 28 hours (IQR 13 to 29 hours) for heifers and 21 hours (IQR 13 to 29 hours) for cows. For AAMS alarm, time to ovulation from detection of oestrus was 23 hours (25 hours for heifers and 23 hours for cows, with an IQR from 11 to 29 hours and 19 to 25 hours, respectively). The log-rank test indicated the oestrus to ovulation interval did not vary between heifers and cows (visually detected P = 0.89; AAMS detected P = 0.68).

Database studies (Paper II and Paper III)

Birth weights (Paper II)

The descriptive investigation of available birth weight data showed that the mean birth weight of calves born to slaughtered cows was 43.5 kg, but, depending on breed, ranged from 40.4 kg for Aberdeen Angus to 45.6 kg for both Charolais and Simmental. The female calves were on average 2.3 kg (P < 0.001) lighter at birth than male calves. Calves born of first-calf heifers were estimated to be 0.4, 0.6 and 0.3 kg heavier than calves born to 2^{nd}, 3^{rd} and 4^{th} parities, respectively (P < 0.001). Calves born in the autumn were on average 0.5 kg (P < 0.001) lighter than spring-born calves. A significant interaction term was found between breed and age at first calving. Heifers calving for the first time before 2.5 years of age gave birth to heavier calves than heifers calving older than 2.5 years of age, but the effect differed by breed, and for NRF, weights were the same regardless of calving age. Furthermore, a significant interaction term was found between breed and region of Norway, which means the effect of cow breed on calf birth weights was dependent on the geographical location. Calves born in central Norway (‘Midt-Norge’) were the heaviest, while calves born in western Norway were lighter than equivalent calves born in all other regions. Charolais had the heaviest calves in all regions except western Norway, where the calves born to Hereford dams were the heaviest. Of the unexplained variation in birth weights, 40% was found at herd level while 11% was found at cow level. In a model including heifers only, the herd random effect accounted for 37% of the unexplained variation in birth weights.

Lifetime calf production (Paper III)

In the study sample, mean and median herd size were 24 and 19 suckler cows (IQR 12 to 31), respectively. The median cow age at slaughter was 3.8 years (min 1.5, max 17). The British breeds Hereford and Angus both had a mean lifetime calf production of three calves/cow, but overall median lifetime calf production across breeds was two calves/cow. Approximately 55% of the cows produced fewer than three calves, and if severe dystocia at first calving was experienced, the lifetime calf production was decreased by 30%, incidence rate ratio (IRR) 0.70 (95% CI 0.66-0.75). Heifers calving for the first time at a younger age than 2.5 years had an odds ratio of 2.0 for dystocia in the univariate analyses of Paper III, but no significant difference was found for lifetime calf production in the multivariate analyses. A significant interaction term was present between breed and region of Norway, i.e. the effect of cow breed on lifetime calf production was dependent on the geographical location. Lifetime calf production per cow was highest in coastal parts of eastern Norway for all breeds except Simmental. Limousin cows had the lowest lifetime calf production, irrespective of region, whereas Charolais cows had the second lowest in all areas except the costal southeast region. Both Limousin and Charolais had particularly low production in the northern and western regions. Cows that had lived in herds larger than 30 cows produced 11% more calves in their lifetime compared to cows in smaller herds ($P < 0.001$). For lifetime calf production, the herd random effect was highly significant and the amount of unexplained variation at the herd level in small herds (≤ 30 cows) ranged from 23% for Limousin in northern Norway to 29% for Charolais in the inland southeast. For large herds (> 30 cows), the amount of unexplained herd-level variation ranged from 51% for Limousin in northern Norway to 58% for Charolais in the inland southeast.

Discussion

Field study (Paper I)

Oestrus detection

The Se and Sp for both the AAMS and standardized visual detection in Paper I were similar to or higher than those found in equivalent studies in both beef and dairy cattle (Rae, 2002; Roelofs et al., 2015; Rorie et al., 2002; Wojcik et al., 2015). The improved oestrus detection in the present study compared to previous studies in dairy cattle might also be due to a tight calving pattern in our experimental herd. A tight calving pattern results in more females being in oestrus at the same time, which increases the expression of oestrus as sexually active groups form (Roelofs et al., 2005a). Additionally, the number of females in anoestrus in the current study might have slightly inflated the Sp and PPV for both visual detection and AAMS, although slightly lower Sp and PPV would not be considered to be a major threat to the usefulness of the AAMS. Similar conditions to those in the investigated herd would commonly be found in other beef herds as well. Another reason for the improved results in this study compared to studies performed with dairy cattle might be that the expression of oestrus has been weaker in dairy cattle in recent decades due to factors such as genetics and metabolic stress (Dobson et al., 2008).

Based on the presented results, it can be concluded that the AAMS was very useful for detecting oestrus in the studied Hereford herd. The AAMS detected more oestrous periods and had a higher PPV compared to visual detection. Therefore, under Norwegian conditions, producers should consider investing in such a system if they intend to use AI in beef suckler herds. By combining both methods, Se was enhanced compared to either method alone, but Sp was decreased compared to AAMS only. In the practical life of the producer, an improved Se is more important than a decrease in Sp, because most animals are checked again at AI and rejected if not in oestrus. A combination of both methods might be useful during the first weeks of the breeding season to increase the number of cows inseminated by AI in this period. However, it is important of consider that the quality of visual detection of oestrus performed in the study probably was higher than what is achievable under commercial conditions, as the procedure was carried out systematically at regular intervals by trained personnel. This might be the reason why the reported disadvantages of visual oestrus detection, such as low Se and low PPV (Diskin et al., 2014; 2016), were minimized in this study.

A limitation of the performed study (Paper I) is the lack of primiparous animals in the herd, because their postpartum return to luteal activity and postpartum expression of oestrus differs compared to multiparous animals (Larson et al., 2016; Reith et al., 2014). Thus, it remains unknown whether primiparous females could have affected Se and Sp in the herd during the study period. Additionally, when comparing present and earlier studies, it is important to consider that technology and software have been under continuous development, which might account for improved efficiency and accuracy in current AAMS as compared to studies performed only a decade ago.

Furthermore, the AAMS had a high Sp (100%) and NPV (93%), and can effectively be used to identify anoestrus cows (Fig. 3). When identified, these females can then be clinically examined and potentially treated to prevent premature culling due to reproductive failure, or culled if necessary. The results obtained in the performed study indicate that the usefulness of an AAMS in beef cattle is at similar level as for dairy cattle. Sufficient detection of females actually in oestrus and few incorrect detections of those not in oestrus are important for user satisfaction. The good performance of the AAMS means that it can potentially be employed to increase the use of AI in beef production and thus increase overall productivity in the herds (Bennett et al., 1996). In the investigated herd, the results indicate that AAMS might perform at a level beneficial for herd lifetime production as it could help the producer achieve a restricted breeding season and front-end loading (Larson et al., 2016). However, the level of success would depend, among other things, on adequate birth weight of the calves to avoid delayed onset of luteal activity.

Time to ovulation

In the current study, no statistically significant difference was found between heifers and cows for time from detection of oestrus to ovulation, either with AAMS or with standardized visual detection. However, the time from oestrus detection to ovulation observed in this study is in contrast to other studies of beef cows, where mean time from onset of oestrus to ovulation is approximately 31 hours (White et al., 2002; Yelich et al., 1995). However, these studies were performed under different conditions than the current study, and with genetically different animals, and their estimations might also be correct under their specific conditions. Additionally, when comparing studies of the interval between oestrus detection and ovulation in cattle, it is important to be aware that there is a variety of different strategies for detection of oestrus, which might complicate comparisons of these studies (Roelofs et al., 2010). In the performed study, the interval between AAMS detection of oestrus and ovulation is based on oestrous activity above a defined threshold value, which causes the interval between detection of oestrus and ovulation to appear shorter than in studies presenting results from onset of oestrus to ovulation. However, time from standardized visual detection of oestrus to ovulation was also shorter for this Hereford herd than what has been found for dairy cattle (Roelofs et al., 2005b).

According to the results in the performed study, the optimum interval for AI to be performed in Hereford cattle after detection of oestrus by AAMS or standardized visual detection of oestrus might be shorter than the 12 hours commonly used ('AM-PM' rule) (Diskin et al., 2016). Therefore, the present findings indicate that it is reasonable to question whether this rule is applicable to beef cattle rearing under similar conditions as in the studied Herford herd. A definite recommendation of the optimum time for AI in Hereford cattle under the conditions of the current study should therefore perhaps not be made without first conducting a study of confirmed pregnancy by AI at differing time intervals relative to oestrus and ovulation. Unfortunately, performing AI and confirming pregnancy was not possible within the timeframe of the current study.

The investment costs of installing an AAMS requires acceptable pregnancy results when performing AI in beef herds to provide an economic return. The new information found in this study might increase the success of performing AI in Hereford cattle, and possibly in other beef breeds, after detection of oestrus using a standardized visual approach or by AAMS. Initially, it might be necessary to make adjustments to the timing of AI after AAMS detection in individual herds according to the results. Large variations in both birth weight (Paper II) and lifetime production (Paper III) were found at the herd level, which includes paternal genetics. Therefore, the results of this project might be important for improving herd efficiency, which includes a restricted breeding season and the use of AI.

Database studies (Paper II and Paper III)

Birth weights (Paper II)

The descriptive results of the investigation of birth weight were in agreement with other studies, even though mean birth weight across breeds was found to be in the upper range of commonly reported birth weights for beef calves (Cundiff et al., 1993; Eriksson et al., 2004; Hampel, 2014; Johanson et al., 2003; Olson et al., 1991). The high birth weights might be an effect of these cows residing in colder regions rather than in more temperate zones, which has previously been reported to increase calf birth weights (Colburn et al., 1997; Deutscher, 1999; Holland et al., 1992; Soren, 2012; Young, 1975). Similarly, in the US, birth weights of calves of comparable genotype have been found to be lighter in warmer conditions in the south than in the colder conditions in the north (Burns et al., 1979; Olson et al., 1991). In the current study, the lightest birth weights are found in the mildest region and the heaviest birth weights in the region with the most challenging weather.

The difference between male and female calves was found to be consistent with previously reported values from beef cattle in Sweden (Eriksson et al., 2004) and in the US (Bourdon et al., 1982; Holland et al., 1992). Moreover, most studies of seasonal effects on birth weight are in agreement with the current study that spring calves are heavier (Cundiff, 2010; Johanson et al., 2003), although contradictory findings have been reported (Durunna et al., 2014; Holland et al., 1992). However, the high birth weight of calves born to heifers contrasts with the findings of most other studies, where calf birth weights are reported to increase with increasing parity (Colburn et al., 1997; Cundiff, 2010; Cundiff et al., 1992; Holland et al., 1992; Johanson et al., 2003).

Both productivity of suckler cow production and animal welfare are known to be substantially affected by calf birth weight, as high birth weight increases the incidence of dystocia (Bellows, 1993; Berger et al., 1992; Johanson et al., 2003; Rogers et al., 2004; Szabó et al., 2009). The relationship between birth weight and lifetime production is linked through dystocia, and an effect of dystocia on lifetime production described in the literature was found in the current study (Paper III). The relationship between birth weight and dystocia is well described in the literature, and further investigation of the effect of birth weight on dystocia was beyond the scope of this study.

The large herd effect found for birth weight might involve paternal genetics, which have been found to potentially cause large variances in birth weight in cattle (Holland et al., 1992). If one bull is used for the herd, the bull might not have the desired traits to suit both the heifers and the cows regarding EPD for birth weight. Therefore, an alternative to an additional bull in these herds might be to use AI performed after visual detection of oestrus (Paper I) or TAI for single females or groups. This alternative might be more cost efficient than acquiring and keeping an additional bull, and might also prevent decreased production (Paper III).

Another management decision might be the length of autumn pasturing where the additional energy-demanding decrease in temperature, elevated precipitation and frosty conditions might cause the animals to experience cold stress, which has the potential to affect both heifer growth and the foetuses of heifers (Christopherson et al., 1979; Gonyou et al., 1979:Johnson, 2015 #850; Soren, 2012). Cold stress in the late autumn and winter seasons might increase the birth weight of calves born in the spring. Furthermore, sudden and large changes in nutrition should be avoided (Andreoli et al., 1988). These typically occur when the cattle are moved from late autumn pasture to nutrient-rich fodder and supplements (Micke et al., 2010a). Moreover, replacement heifers should be weighed throughout the production stages to monitor growth and eventually identify hazards during the heifer rearing period.

Lifetime calf production (Paper III)

The mean herd size in the investigated herds was larger than the mean of the suckler herds in Norway in general, which was 15.4 suckler cows/herd in the beginning of 2016 (Statistics Norway, 2016). This might mean that hobby herds and less production-focused herds are not members of the NBCRS. These herds are not likely to play an important role in the future of Norwegian beef production.

Furthermore, the current study found that the productivity at cow level in suckler cow production is probably suboptimal. Many cows are slaughtered after having one or two calves, but the reasons for early culling remain unclear. One reason might be dystocia among heifers, because heifers experiencing dystocia had lower lifetime calf production compared to heifers recorded without dystocia. Dystocia is suspected to be substantially underreported in the NBCRS, and this might be supported by the current study where overall lifetime calf production of heifers experiencing dystocia was decreased to a higher degree than in comparable studies performed in the US and Europe (Brinks et al., 1973; Meijering, 1984; Zaborski et al., 2009). Hence, the threshold for culling heifers experiencing dystocia is lower compared to other populations. Another reason for early culling of females might be insufficient quality of heifer rearing, e.g. undernutrition in marginal pasture or late autumn pasturing, or lack of parasite control, causing impairment of heifer growth and consequently delayed start of breeding. If heifers do not calve early in the calving season or experience dystocia, they might experience difficulties rebreeding compared to multiparous animals (Larson et al., 2016). Females that conceive late or fail to be rebred within the breeding season are found to be at greater risk of culling (Arthur et al., 1993).

Overall, the early-maturing British breeds had higher lifetime performance than the later-maturing continental breeds. This might reflect the breeds' different ability to adapt to Norwegian conditions. However, similar effects of breed on lifetime calf production is also found in Hungarian studies (Dakay et al., 2006; Szabó et al., 2009), and might indicate a difference in breed longevity independent of conditions in Norway. Another explanation might be differences in handling of extensive breeds compared to intensive breeds, which might be confirmed by the higher proportion of AI in intensive breeds compared to extensive ones in Norway (Animalia, 2015a).

Herd, breed and regional effects

Herd effects

In the investigated data material, large herd random effects were found for both birth weight and lifetime calf production. The random herd effect represents all unmeasured factors at herd level affecting the outcome. The large herd random effects mean that interventions at herd level would be more efficient than intervention at cow level to improve overall calf production efficiency. For birth weight (Paper II), the herd random effect was found to be large (37% to 40%), while the random effect at cow level (11%) was within expected values (Bourdon et al., 1982; Eriksson et al., 2004; Simm, 1998a). The herd effect for lifetime calf production varied between herd sizes (23% for Limousin in northern Norway to 29% for Charolais in the inland southeast, and from 51% for Limousin in northern Norway to 58% for Charolais in the inland southeast) (Paper III).

The effect of herd size on increased lifetime calf production found in the current study, where females in larger herds produced more calves than females in smaller herds, has not been reported for Norwegian suckler cows. However, the effect of herd size has previously been linked to improved reproduction management within the Norwegian dairy industry (Simensen et al., 2010). A reason for the effect of herd size might be that producers with smaller suckler cow herds are likely to get a larger proportion of their income from sources other than their herd, and thus their priorities might be divided between other income sources, resulting in less intense or focused herd management. Another reason might be the Norwegian subsidy regimen relevant to the investigated beef cattle population. Subsidies for up to 25 females in a herd were substantially higher compared to subsidies given for additional cows exceeding this number (Ruud et al., 2013). Therefore, producers with herds larger than 25 cows might have been more focused on efficiency than those with smaller herds. Hence, a revision of the Norwegian subsidy regimen might be beneficial for increasing the efficiency of Norwegian suckler cow production.

The Norwegian beef cattle population is expanding, but the number of beef suckler herds is static (Statistics Norway, 2016). Because not all herds are expanding, this means that the effect of herd size found in the current study might be caused by herds in expansion, which are keeping cows on the farm longer than their counterparts not in expansion (Martin, 2015; Roberts et al., 2015). Alternatively, the more favorable climate and topography for grass and cattle production in the area (eastern Norway) where the larger herds are located might have an effect (Paper II).

Furthermore, the effect of herd size is interesting information that might be important for the implementation of the results from the field study (Paper I). The investigated herd was in the larger size category, and the investigators found it to be well managed. Therefore, the results of the investigation might be in the upper segment of what can be expected with an AAMS. A factor for lifetime production specific to Norway might be the current subsidy regimen, which rewards the existence of females in the herds while paying less attention to production (Åby et al., 2012).

Breed and regional effects

This study found considerable inter-breed differences in mean birth weight. Whilst these effects have been documented for decades, the effect of breed should not be overlooked. The similarity of the inter-breed differences found in this study to those found in previous studies in part validates the findings reported in this thesis. The interaction term between age at first calving and breed found for birth weights of heifer-born calves was most pronounced for the late maturing Limousin breed, where calves born to heifers older than 2.5 years were found to be born lighter than calves born to heifers younger than 2.5 years. The interaction might be an effect of the different age at which lighter and heavier breeds reach mature weight, where compensatory growth or altered ratio heifer body weight to foetal weight might affect the later-maturing breeds more than the early-maturing breeds when bred at the same age (Berry et al., 2007; Ryan et al., 1993; Yambayamba et al., 1996). Therefore, Limousin cattle might benefit from being bred later than the other investigated breeds to avoid an increase in the proportion of dystocia caused by a large calf to heifer weight ratio, and a decrease in lifetime calf production.

The lower overall lifetime calf production found for the French breeds in the investigated data material compared to the British breeds has previously been reported in studies from other countries (Dakay et al., 2006; Szabó et al., 2009). However, the highly significant breed-region interaction found for both lifetime calf production and birth weight has, to our knowledge, not previously been reported in Norway. The above-mentioned French breeds had the lowest lifetime calf production in the more challenging regions, i.e. northern Norway and the fjords of western Norway. This might indicate that these breeds do not adapt well to Norwegian conditions and that a more adaptable breed could increase lifetime calf production (Arango et al., 2002a). Steep or marginal pastures, which are common in both regions, suit light British breeds better than large continental breeds (Hampel, 2014; Ruud et al., 2013). One reason for the regional interaction for beef cattle birth weight might be a negative linear relationship between calf birth weight and environmental temperature, e.g. higher birth weights at colder temperatures (Deutscher, 1999). Therefore, some of the effects found for birth weight and lifetime calf production might be a consequence of different climatic conditions in different regions (Colburn et al., 1997; Deutscher, 1999; Holland et al., 1992; Soren, 2012; Young, 1975).

The large herd effect seen in the performed studies (Paper II and Paper III) indicate that advisory services at herd level might be effective in increasing production output in suckler herds. Additionally, the breed-region interaction found in the performed studies (Paper II and Paper III) provides valuable insight, and suggests that the region of herd location should influence choice of breed to increase lifetime calf production and to keep the birth weight of the calves within the desired weight interval.

Methodological considerations

Laboratory methods

Serum progesterone, as used in Paper I, is well established as the gold standard for oestrus detection. Even though the term ‘gold standard’ has been debated (Claassen, 2005), progesterone has been used for many years to observe the different stages of the bovine oestrous cycle (Dobson et al., 1975). Temporal pattern of progesterone concentration display intervals of low serum progesterone (< 1 ng/mL) at oestrus and elevated serum progesterone (> 1 ng/mL) in the luteal phase (Colazo et al., 2008; Wiltbank et al., 2011). The concentration of progesterone relative to time of ovulation has been studied in dairy cattle, but not, to our knowledge, in beef cattle (Roelofs et al., 2006b). The competitive ELISA was used to determine serum progesterone concentrations, where analytic Se is related to limit of detection and midpoint of the curve (Armbruster et al., 2008). Analytic Sp was based on cross-reactivity (Wiederschain, 2009). There is no reason to believe that beef cattle would either affect the analytic curve for progesterone or contribute to an increase in cross-reactivity differently than dairy cattle. Therefore, the results for progesterone used in this study were considered reliable.

Study design

The studies presented in Paper I and Paper III were both cohort studies, which means a group of subjects was followed through time. One of the cohort studies was prospective (Paper I), the other retrospective or historical (Paper III). Typical advantages of cohort studies are that they can differentiate cause and effect, and that a single study can examine various outcome variables (Mann, 2003). A typical disadvantage of cohort studies is selection bias due to changes in the cohort over time (Dohoo, 2009b). This might have been the case in the retrospective cohort, where bias through an age-period-cohort effect is possible. The number of animals in the NBCRS database increased from 63% to 78% of the suckler cow population during the study period. The inclusion criterion for this study was dams from member herds in the NBCRS database that were slaughtered between 2010 and 2013. Therefore, more primiparous animals became eligible for inclusion during the study period. The study resulting in Paper II was a cross-sectional study. In general, cross-sectional studies are observational studies with a straightforward basic structure and fewer concerns about design relative to cohort and case-control studies. Such studies have the disadvantage of not being suitable for inferring causality because exposure and outcome are measured simultaneously (Dohoo, 2009b).

Prospective cohort study, Paper I

The prospective cohort study was performed in a purebred Hereford herd consisting of 40 cows and heifers. The herd was commercially run in facilities that were typical of those on the Scandinavian Peninsula, both important factors when choosing a herd to make the results of the trial more applicable. A larger number of subjects would have been desirable for the project to increase study precision. Still, by extending the study period, more than one oestrous period for many females in the herd was covered to increase the precision of the study.

The oestrus detection system developed by Van Eerdeburg et al. (Van Eerdenburg et al., 1996) in the Netherlands on Holstein dairy cattle was modified in the study. In the original system, animals had to total 100 points in a 24-hour period to be identified as being in oestrus. In the field study, the animals needed to reach the 100-point threshold in a single 20-minute observation period. The adaption was thought to make the study more applicable to Norwegian suckler production systems and took into account the differing breed and housing conditions between the study suckler herd and the Dutch dairy production system.

The subjects stayed in their herd under well-organized herd management and familiar handling conditions (all animals were used to being weighed), and stress behaviour was, in the opinion of the researchers, almost non-existent. The study results are likely valid for other similarly managed Hereford suckler herds. However, the results are based on only one herd, and large herd effects on productivity are found in other studies in this project (Paper II and Paper III).

Database studies, Paper II and Paper III

The study population for Paper II and Paper III was based on a data extraction from the NBCRS database on suckler cows slaughtered from 2010 to 2013. The study population consisted of almost 20,000 cows and their progeny.

The years for data extraction were selected for several reasons, among others that there were no major changes in category definitions during the selected period. During the study period the definition of a breed was constant. A ‘pure’ animal had at least 15/16 of its ancestors of the same breed during the study period. Additionally, the proportion of calves that were weighed differs between the breeds. For some breeds, less than half of the calves born were weighed, and thus, some degree of selection bias might be present. The Hereford was the breed of the five major investigated breeds with the lowest proportion of weighing in the NBCRS in 2012, 38% (n = 1890). Limousin had the largest proportion of calves weighed with 79% (n = 1849) (Animalia, 2013), followed by Charolais 66% (n = 3442). A Swedish study has investigated genetic parameters for calving difficulty in Charolais and Hereford cattle (Eriksson et al., 2004). The birth weights for Charolais were similar to the ones found in the current study (Paper II), but large differences in the birth weights of Hereford calves between the two nations was present, especially for the heifers (36.9 kg in Sweden vs. 43.3 kg in Norway). This might indicate that a selection bias has occurred among the 38% of the weighed calves in the NBCRS data used for the current study, e.g. that more of the heavy calves have been weighed compared to the lighter ones. Additionally, because heifers are often more stressed around birth, only calves of heifers that have already been handled due to dystocia are weighed, and the weight of calves from unassisted heifer births is guesstimated or not recorded to avoid further stress for the dam. Hence, a registration bias might occur where the heavier calves typically found at assisted births are overrepresented.

The NBCRS is a voluntary database, which means that data being reported, e.g. birth weight, might be different for production-focused compared to subsidy-focused producers, and these data might introduce bias. Variables analysed for the lifetime calf production (Paper III) are largely based on mandatory data and data that form the basis of the herd subsidy incomes and are therefore considered more reliable than voluntarily recordings such as birth weight. Data quality is important when using secondary data (Emanuelson et al., 2014) and it is recognized that the database has not been validated for use in research, as is the case for the Norwegian dairy herd recording system (Espetvedt et al., 2013). However, the herds represented all regions of the Norwegian mainland and included 57% of suckler beef herds and 78% of suckler cows (Animalia, 2013). It is therefore reasonable to assume that the study sample represents the commercial part of the Norwegian beef suckler population well.

Ethical considerations

The project was designed to have no foreseeable ethical conflicts. The whole project was largely observational. The intervention performed in the prospective cohort study (Paper I) was authorized by the Gothenburg Research Animal Ethics Committee, and given the approval number ‘Dnr.Etisk: 187-2014’. In the database studies (Paper II and Paper III), all producers agreed in advance that anonymized data on their herds might be used for research purposes. All producers were anonymized throughout the whole study by the use of only numbers at all stages of the data handling. Individual identification of the farms in the study is not possible from the published data to preserve producer confidentiality.

Key findings and implications

- In the studied Hereford herd, an AAMS was found to be very useful for monitoring oestrous activity. The system had both a higher Se (90%) and Sp (100%) than structured thrice-daily visual detection of oestrus (77% and 89%, respectively).
- The time from detection of oestrus to ovulation indicates that ovulation occurs sooner than expected in Hereford cattle. To increase chances of pregnancy, it might be appropriate to inseminate Hereford suckler cows sooner after detection of oestrus than is recommended for Norwegian dairy cows ('AM-PM rule').
- Birth weights of beef calves in the NBCRS were influenced by calf sex, breed of dam, parity, age at first calving, calving season, and region. Herd and cow random effects accounted for 40% and 11% of the remaining variation, respectively. The heifers delivered heavier calves than cows, and the third parity cows yielded the lightest calves. Heifers calving for the first time before 2.5 years of age were recorded as having heavier calves than those first calving older than 2.5 years. Calves were, on average, heavier at birth when born in the spring than when born in the autumn. Choosing the right breed for different regions and conditions will be one of several management choices to consider in order to achieve optimal birth weights.
- The lifetime calf production of beef suckler cows was influenced by region, breed, calving ease at first calving, twinning events, calving interval, and herd. As for birth weights, choosing the right breed for different regions and conditions will be one of several management choices to consider to optimize lifetime calf production. Larger herds had larger lifetime calf production than smaller herds, but the reason for this remains unclear.
- The herd random effect was highly significant for both birth weight and lifetime calf production. The herd effect encompasses all unmeasured management factors, among which are genetics, nutrition and disease control. Hence, knowledge gain among producers, advisors and veterinarians, and knowledge and experience exchange between the professions and between the herds, would benefit beef production in general. A part of this improvement is the implementation of weighing of the animals at key points in the production cycle.

Future perspectives

The performed studies have found several factors affecting productivity in Norwegian suckler herds. However, the findings have also raised questions for further research. Management appears to be very important for suckler herds to be productive. Efficient tools are available to support producers in achieving good reproductive management in their herds, and additional tools for use in beef herds are expected in the future. However, such tools are not better than the producer using them, and overall management control for the producer is important. The following questions should be pursued further:

- The unexpected results of heavy calves born to heifers have to be further investigated to clarify their causes and whether the finding is real or caused by biased sampling. Initially, it would benefit many aspects of beef production if a validation study of the NBCRS, similar to the one performed for the cattle database (Espetvedt et al., 2013), was performed. Formal validation of the NBCRS database would improve the confidence in the presented results and other studies based upon it.
- The use of AAMS has provided an objective and effective method for detecting oestrus, which can be used for a standardization of research on time to ovulation. The other common beef breeds still have to be investigated. Increased knowledge is very important in order to facilitate herd management and to utilize the potential in genetics offered by AI.
- Further investigation into reasons why animals are culled after only one calf is required if production efficiency is to be improved.
- Large differences are seen between comparable herds, which can reveal factors for efficient production in other stages of the production than those investigated in this body of work. Breaking down the 'herd effect' could be an important task for optimizing productivity.

Most important for further research and improvements in the herds is reliable data registration. For the beef industry as whole, knowledge transfer and collaboration seem to be key for future professional production.

Reference List

Agthe, O. and Kolm, H.P., 1975. Oestrogen and progesterone levels in the blood plasma of cows with normal parturition or with a retained placenta. J Reprod Fertil 43(1): 163-166.

Allrich, R.D., 1994. Endocrine and neural control of estrus in dairy cows. J Dairy Sci 77(9): 2738-2744.

Andersen, H. and Plum, M., 1965. Gestation length and birth weight in cattle and buffaloes: A review. J Dairy Sci 48(9): 1224-1235.

Andreoli, K.M., Minton, J.E., Spire, M.F. and Schalles, R.R., 1988. Influence of prepartum exposure of beef heifers to winter weather on concentrations of plasma energy-yielding substrates, serum hormones and birth weight of calves. Theriogenology 29(3): 631-642.

Animalia, 2013. Animalia - Årsmelding Storfekjøttkontrollen 2012 (English: "Norwegian beef cattle recording system - Annual report 2012"). Oslo; Animalia - Norwegian Meat and Poultry Research Centre.

Animalia, 2015a. Animalia - Årsmelding Storfekjøttkontrollen 2014 (English: "Norwegian beef cattle recording system - Annual report 2014"). Oslo; Animalia - Norwegian Meat and Poultry Research Centre.

Animalia, 2015b. Kjøttets tilstand (English: "Norwegian meat and egg production - Annual report 2015"). Oslo; Animalia - Norwegian Meat and Poultry Research Centre.

Animalia, 2016. Animalia - Årsmelding Storfekjøttkontrollen 2015 (English: "Norwegian beef cattle recording system - Annual report 2015"). Oslo; Animalia - Norwegian Meat and Poultry Research Centre.

Anonymous, 2006. Regulation on the welfare of farmed animals, §11. Oslo; Ministry of Agriculture and Food.

Anonymous, 2009. Law on animal welfare, §9. Oslo; Ministry of Agriculture and Food.

Anonymous, 2010. Arbeidsskadedødsfall i landbruket – Utviklingstrekk (English: "Work related deaths within agriculture - trends"). Oslo; Norwegian Labour Inspection Authority.

Anonymous, 2016a. Bruk av kjønnsseparert sæd (English: "The use of sexed semen"). Retrieved 15.05, 2016, From: http://www.tyr.no/Avl-stambok/Kjøttfesemin/Kjønnsseparert-sæd.

Anonymous, 2016b. Veterinærkatalogen (English: "The Norwegian veterinary pharmaceutical product compendium". Retrieved 15.05, 2016, From: http://www.felleskatalogen.no/medisin-vet.

Arango, J. and Van Vleck, L.D., 2002a. Size of beef cows: early ideas, new developments. Genet Mol Res 1(1): 51-63.

Arango, J.A., Cundiff, L.V. and Van Vleck, L.D., 2002b. Breed comparisons of Angus, Charolais, Hereford, Jersey, Limousin, Simmental, and South Devon for weight, weight adjusted for body condition score, height, and body condition score of cows. J Anim Sci 80(12): 3123-3132.

Armbruster, D.A. and Pry, T., 2008. Limit of blank, limit of detection and limit of quantitation. Clin Biochem Rev 29(s1): 49-52.

Arnoldussen, A.H., Forbord, M., Grønlund, A., Hillestad, M.E., Mittenzwei, K., Pettersen, I. and Tufte, T., 2014. Økt matproduksjon på norske arealer (English "Increased food production of arable land"). Oslo; AgriAnalyse AS.

Arthur, P.F., Makarechian, M., Berg, R.T. and Weingardt, R., 1993. Longevity and lifetime productivity of cows in a purebred Hereford and two multibreed synthetic groups under range conditions. J Anim Sci 71(5): 1142-1147.

Aungier, S.P.M., Roche, J.F., Duffy, P., Scully, S. and Crowe, M.A., 2015. The relationship between activity clusters detected by an automatic activity monitor and endocrine changes during the periestrous period in lactating dairy cows. J Dairy Sci 98(3): 1666-1684.

Azzam, S.M., Werth, L.A., Kinder, J.E. and Nielsen, M.K., 1991. Distribution of time to first postpartum estrus in beef cattle. J Anim Sci 69(6): 2563-2570.

Bellows, R.A., 1993. Factors affecting calving difficulty. Proceedings, range beef cow symposium XII, Chyenne, WY: 17.

Bellows, R.A. and Lammoglia, M.A., 2000. Effects of severity of dystocia on cold tolerance and serum concentrations of glucose and cortisol in neonatal beef calves. Theriogenology 53(3): 803-813.

Bennett, G.L. and Gregory, K.E., 1996. Genetic (co) variances among birth weight, 200-day weight, and postweaning gain in composites and parental breeds of beef cattle. J Anim Sci 74(11): 2598-2611.

Berger, P.J., Cubas, A.C., Koehler, K.J. and Healey, M.H., 1992. Factors affecting dystocia and early calf mortality in Angus cows and heifers. J Anim Sci 70(6): 1775-1786.

Berry, D.P., Lee, J.M., Macdonald, K.A. and Roche, J.R., 2007. Body condition score and body weight effects on dystocia and stillbirths and consequent effects on postcalving performance. J Dairy Sci 90(9): 4201-4211.

Boehmer, B.H., 2012. Ruminal temperature for identification and prediction of estrus in beef cows, Oklahoma State University. Stillwater, OK. Master of science.

Bourdon, R.M. and Brinks, J.S., 1982. Genetic, environmental and phenotypic relationships among gestation length, birth weight, growth traits and age at first calving in beef cattle. J Anim Sci 55(3): 543-553.

Bridges, G.A., Lake, S.L., Kruse, S.G., Bird, S.L., Funnell, B.J., Arias, R., Walker, J.A., Grant, J.K. and Perry, G.A., 2014. Comparison of three CIDR-based fixed-time AI protocols in beef heifers. J Anim Sci 92(7): 3127-3133.

Brinks, J.S., Olson, J.E. and Carroll, E.J., 1973. Calving difficulty and its association with subsequent productivity in Herefords. J Anim Sci 36(1): 11-17.

Burns, P.D. and Spitzer, J.C., 1992. Influence of biostimulation on reproduction in postpartum beef cows. J Anim Sci 70(2): 358-362.

Burns, W.C., Koger, M., Butts, W.T., Pahnish, O.F. and Blackwell, R.L., 1979. Genotype by environment interaction in Hereford cattle: Birth and weaning traits. J Anim Sci 49(2): 403-409.

Caldow, G., Lowman, B. and Riddell, I., 2005. Veterinary intervention in the reproductive management of beef cow herds. In Pract 27(8): 406-411.

Carstens, G.E., Johnson, D., Holland, M. and Odde, K.G., 1987. Effects of prepartum protein nutrition and birth weight on basal metabolism in bovine neonates. J Anim Sci 65(3): 745-751.

Chagas, L.M., Bass, J.J., Blache, D., Burke, C.R., Kay, J.K., Lindsay, D.R., Lucy, M.C., Martin, G.B., Meier, S., Rhodes, F.M., Roche, J.R., Thatcher, W.W. and Webb, R., 2007. Invited review: New perspectives on the roles of nutrition and metabolic priorities in the subfertility of high-producing dairy cows. J Dairy Sci 90(9): 4022-4032.

Chenoweth, P.J., 2005a. Assisted reproduction. In: Chenoweth, P.J. and Sanderson, M.W. (Eds.), Beef practice: Cow-calf production medicine. 175-191. Ames, IA; Blackwell Publishing Professional.

Chenoweth, P.J., 2005b. Cow-calf production principles. In: Chenoweth, P.J. and Sanderson, M.W. (Eds.), Beef practice: Cow-calf production medicine. 9-27. Ames, IA; Blackwell Publishing Professional.

Christopherson, R.J., Gonyou, H.W. and Thompson, J.R., 1979. Effects of temperature and feed intake on plasma concentration of thyroid hormones in beef cattle. Can J Anim Sci 59(4): 655-661.

Ciccioli, N.H., Wettemann, R.P., Spicer, L.J., Lents, C.A., White, F.J. and Keisler, D.H., 2003. Influence of body condition at calving and postpartum nutrition on endocrine function and reproductive performance of primiparous beef cows. J Anim Sci 81(12): 3107-3120.

Claassen, J.A.H.R., 2005. The gold standard: Not a golden standard. BMJ 330(7500): 1121.

Clanton, D.C., Jones, L.E. and England, M.E., 1983. Effect of rate and time of gain after weaning on the development of replacement beef heifers. J Anim Sci 56(2): 280-285.

Clark, R.T., Creighton, K.W., Patterson, H.H. and Barrett, T.N., 2005. Symposium paper: Economic and tax implications for managing beef replacement heifers. Prof Anim Sci 21(3): 164-173.

Colazo, M.G., Ambrose, D.J., Kastelic, J.P. and Small, J.A., 2008. Comparison of 2 enzyme immunoassays and a radioimmunoassay for measurement of progesterone concentrations in bovine plasma, skim milk, and whole milk. Can J Vet Res 72(1): 32-36.

Colburn, D.J., Deutscher, G.H., Nielsen, M.K. and Adams, D.C., 1997. Effects of sire, dam traits, calf traits, and environment on dystocia and subsequent reproduction of two-year-old heifers. J Anim Sci 75(6): 1452-1460.

Corah, L.R., Quealy, A.P., Dunn, T.G. and Kaltenbach, C.C., 1974. Prepartum and postpartum levels of progesterone and estradiol in beef heifers fed two levels of energy. J Anim Sci 39(2): 380-385.

Cozzi, G., Gottardo, F., Brscic, M., Contiero, B., Irrgang, N., Knierim, U., Pentelescu, O., Windig, J.J., Mirabito, L., Kling Eveillard, F., Dockes, A.C., Veissier, I., Velarde, A., Fuentes, C., Dalmau, A. and Winckler, C., 2015. Dehorning of cattle in the EU Member States: A quantitative survey of the current practices. Livest Sci 179: 4-11.

Crowe, M.A., Diskin, M.G. and Williams, E.J., 2014. Parturition to resumption of ovarian cyclicity: Comparative aspects of beef and dairy cows. Animal 8(s1): 40-53.

Cundiff, L.V., 2010. Guidelines for uniform beef improvement programs. Cundiff, L.V., Van Vleck, L.D. and Hohenboken, W.D. (Eds.). Raleigh, NC; North Carolina State University.

Cundiff, L.V., Nunez-Dominguez, R., Dickerson, G.E., Gregory, K.E. and Koch, R.M., 1992. Heterosis for lifetime production in Hereford, Angus, Shorthorn, and crossbred cows. J Anim Sci 70(8): 2397-2410.

Cundiff, L.V., Szabo, F., Gregory, K.E., Koch, R.M., Dikeman, M.E. and Crouse, J.D., 1993. Breed comparisons in the germplasm evaluation program at MARC. Beef improvement federation 25th annual research symposium and annual meeting proceedings, Asheville, NC: 124-136.

Cushman, R.A., Kill, L.K., Funston, R.N., Mousel, E.M. and Perry, G.A., 2013. Heifer calving date positively influences calf weaning weights through six parturitions. J Anim Sci 91(9): 4486-4491.

Dakay, I., Marton, D., Bene, S., Kiss, B., Zsuppan, Z. and Szabo, F., 2006. The age at first calving and the longevity of beef cows in Hungary. Arch Tierz 49(5): 417-425.

Deutscher, G.H., 1999. Climate affects calf birth weights and calving difficulty. Nebr Beef Cattle Rep (1999): 6-9.

Deutscher, G.H., Stotts, J.A. and Nielsen, M.K., 1991. Effects of breeding season length and calving season on range beef cow productivity. J Anim Sci 69(9): 3453-3460.

Diskin, M.G. and Kenny, D.A., 2014. Optimising reproductive performance of beef cows and replacement heifers. Animal 8(s1): 27-39.

Diskin, M.G. and Kenny, D.A., 2016. Managing the reproductive performance of beef cows. Theriogenology 86(1): 379-387.

Diskin, M.G. and Sreenan, J.M., 2000. Expression and detection of oestrus in cattle. Reprod Nutr Dev 40(5): 481-491.

Dobson, H., Ghuman, S., Prabhakar, S. and Smith, R., 2003. A conceptual model of the influence of stress on female reproduction. Reproduction 125(2): 151-163.

Dobson, H., Midmer, S.E. and Fitzpatrick, R.J., 1975. Relationship between progesterone concentrations in milk and plasma during the bovine oestrous cycle. Vet Rec 96(10): 222-223.

Dobson, H., Tebble, J.E., Smith, R.F. and Ward, W.R., 2001. Is stress really all that important? Theriogenology 55(1): 65-73.

Dobson, H., Walker, S.L., Morris, M.J., Routly, J.E. and Smith, R.F., 2008. Why is it getting more difficult to successfully artificially inseminate dairy cows? Animal 2(8): 1104-1111.

Dohoo, I., 2009a. Mixed models for discrete data. In: Dohoo, I., Stryhn, H. and Martin, W. (Eds.), Veterinary epidemiologic research. 2nd ed., 579-606. Charlottetown; VER Inc.

Dohoo, I., 2009b. Screening and diagnostic tests. In: Dohoo, I., Stryhn, H. and Martin, W. (Eds.), Veterinary epidemiologic research. 2nd ed., 91-134. Charlottetown; VER Inc.

Dorsey, B.R., Kasimanickam, R., Whittier, W.D., Nebel, R.L., Wahlberg, M.L. and Hall, J.B., 2011. Effect of time from estrus to AI on pregnancy rates in estrous synchronized beef heifers. Anim Reprod Sci 127(1–2): 1-6.

Dransfield, M.B.G., Nebel, R.L., Pearson, R.E. and Warnick, L.D., 1998. Timing of insemination for dairy cows identified in estrus by a radiotelemetric estrus detection system. J Dairy Sci 81(7): 1874-1882.

Dufey, P.A., 2002. Fleischrinderrassen im Vergleich. (RAP-aktuell, 6). Mangold, G. (Ed.). Posieux, CH; Eidg. Forschungsanstalt für Nutztiere (RAP).

Durunna, O.N., Girardin, L.C., Scott, S.L., Robins, C., Block, H.C., Iwaasa, A.D., Khakbazan, M. and Lardner, H.A., 2014. The effects of spring versus summer calving on beef cattle reproductive and growth performance in western Canada. Can J Anim Sci 94(2): 259-271.

Dutil, L., Fecteau, G., Bouchard, E., Dutremblay, D. and Pare, J., 1999. A questionnaire on the health, management, and performance of cow-calf herds in Québec. Can Vet J 40(9): 649-655.

EC No. 1804/1999, Council regulation (EC) No 1804/1999 of 19th July 1999 supplementing Regulation (EEC) No 2092/91 on organic production of agricultural products and indications reffering thereto on agricultural products and foodstuffs to include livestock production.

Ellis, R.W., Rupp, G.P., Chenoweth, P.J., Cundiff, L.V. and Lunstra, D.D., 2005. Fertility of yearling beef bulls during mating. Theriogenology 64(3): 657-678.

Emanuelson, U. and Egenvall, A., 2014. The data–sources and validation. Prev Vet Med 113(3): 298-303.

Eriksson, S., Naisholm, A., Johansson, K. and Philipsson, J., 2004. Genetic parameters for calving difficulty, stillbirth, and birth weight for Hereford and Charolais at first and later parities. J Anim Sci 82(2): 375-383.

Espetvedt, M.N., Reksen, O., Rintakoski, S. and Østerås, O., 2013. Data quality in the Norwegian dairy herd recording system: Agreement between the national database and disease recording on farm. J Dairy Sci 96(4): 2271-2282.

Ferrell, C.L., 1982. Effects of postweaning rate of gain on onset of puberty and productive performance of heifers of different breeds. J Anim Sci 55(6): 1272-1283.

Fields, M.J., Warnick, A.C., Wise, T., Bass, J. and Koger, M., 1975. A re-evaluation of artificial insemination in beef cattle. J Anim Sci 41(1): 352.

Fiol, C. and Ungerfeld, R., 2016. Positive effects of biostimulation on luteinizing hormone concentration and follicular development in anestrous beef heifers. J Anim Sci 94(3): 971-977.

Floyd, L.N., Lents, C.A., White, F.J. and Wettemann, R.P., 2009. Effect of number of cows in estrus and confinement area on estrous behavior of beef cows. J Anim Sci 87(6): 1998-2004.

French, J.T., Ahola, J.K., Whittier, J.C., Frasier, W.M., Enns, R.M. and Peel, R.K., 2013. Differences in lifetime productivity of beef heifers that conceived to first-service artificial insemination (AI) or a clean-up bull via natural service (NS) as a yearling and among females that were offspring of an AI or NS mating. Prof Anim Sci 29(1): 57-63.

Funnell, B.J. and Hilton, W.M., 2016. Management and prevention of dystocia. Vet Clin North Am Food Anim Pract 32(2): 511-522.

Funston, R.N. and Deutscher, G.H., 2004. Comparison of target breeding weight and breeding date for replacement beef heifers and effects on subsequent reproduction and calf performance. J Anim Sci 82(10): 3094-3099.

Garcia-Winder, M., Imakawa, K., Day, M.L., Zalesky, D.D., Kittok, R.J. and Kinder, J.E., 1984. Effect of suckling and ovariectomy on the control of luteinizing hormone secretion during the postpartum period in beef cows. Biol Reprod 31(4): 771-778.

Geno, 2015a. Inseminering (English: "Insemination"). Retrieved 16.02, 2016, From: http://www.geno.no/Start/Brunst/SEMINTJENESTE1/Inseminering/.

Geno, 2015b. Årsberetning og regnskap Geno SA 2014 (English: "Annually report Geno SA 2014"). Retrieved 11.05, 2015, From: http://viewer.zmags.com/publication/f1a8d1f8#/f1a8d1f8/42.

Geno, 2016. Norwegian Red; Historical breeding program. Retrieved 11.05, 2016, From: http://www.genoglobal.com/Start/Norwegian-Red/about-norwegian-red/Norwegian-red-breeding-program/.

Gentile, A. and Testoni, S., 2006. Inherited disorders of cattle: A selected review. Slov Vet Res 43(1): 17-29.

Ginther, O.J., 1974. Internal regulation of physiological processes through local venoarterial pathways: A review. J Anim Sci 39(3): 550-564.

Gonyou, H.W., Christopherson, R.J. and Young, B.A., 1979. Effects of cold temperature and winter conditions on some aspects of behaviour of feedlot cattle. Appl Anim Ethol 5(2): 113-124.

Graves, W.M., Dowlen, H.H., Lamar, K.C., Johnson, D.L., Saxton, A.M. and Montgomery, M.J., 1997. The effect of artificial insemination once versus twice per day. J Dairy Sci 80(11): 3068-3071.

Greiner, S.P., 2009. Understanding expected progeny differences. Retrieved 02.05, 2016, From: https://pubs.ext.vt.edu/400/400-804/400-804_pdf.pdf.

Hall, J.B. and Glaze, J.B., 2013. How can sexed semen be used in commercial beef herds? Proceedings, range beef cow symposium XXIII, Rapid City, SD; University of Nebraska, Lincoln: 60-70.

Hall, J.G., Branton, C. and Stone, E.J., 1959. Estrus, estrous cycles, ovulation time, time of service, and fertility of dairy cattle in Louisiana. J Dairy Sci 42(6): 1086-1094.

Hampel, G., 2014. Die Rassen (English: "The breeds"). In: Hampel, G. (Ed.), Fleischrinderzucht und Mutterkuhhaltung (English: "Beef cattle breeding and the keeping of beef suckler cows"). 5th ed., 20-53. Stuttgart; Ulmer.

Heringstad, B. and Larsgard, A.G., 2010. Correlated selection responses for female fertility after selection for high protein yield or low mastitis frequency in Norwegian Red cows. J Dairy Sci 93(12): 5970-5976.

Hockey, C.D., Morton, J.M., Norman, S.T. and McGowan, M.R., 2010. Evaluation of a neck mounted 2-hourly activity meter system for detecting cows about to ovulate in two paddock‐based Australian dairy herds. Reprod Domest Anim 45(5): e107-e117.

Holland, M.D. and Odde, K.G., 1992. Factors affecting calf birth weight: A review. Theriogenology 38(5): 769-798.

Holman, A., Thompson, J., Routly, J.E., Cameron, J., Jones, D.N., Grove-White, D., Smith, R.F. and Dobson, H., 2011. Comparison of oestrus detection methods in dairy cattle. Vet Rec 169(47): 7.

Howard, W.H. and Cranfield, J., 1995. Ontario beef producers' attitudes about artificial insemination. Can J Agric Econ 43(2): 305-314.

Hume, D.A., Whitelaw, C.B.A. and Archibald, A.L., 2011. The future of animal production: improving productivity and sustainability. J Agric Sci 149(s1): 9-16.

Hurnik, J.F. and King, G.J., 1987. Estrous behavior in confined beef cows. J Anim Sci 65(2): 431-438.

Hurnik, J.F., King, G.J. and Robertson, H.A., 1975. Estrous and related behaviour in postpartum Holstein cows. Appl Anim Ethol 2(1): 55-68.

Jaiswal, R.S., Singh, J., Marshall, L. and Adams, G.P., 2009. Repeatability of 2-wave and 3-wave patterns of ovarian follicular development during the bovine estrous cycle. Theriogenology 72(1): 81-90.

Johanson, J.M. and Berger, P.J., 2003. Birth weight as a predictor of calving ease and perinatal mortality in Holstein cattle. J Dairy Sci 86(11): 3745-3755.

Johnson, D.M., Uhland, S.A., Abhishek, R., Krivacic, R.T. and Sheridan, M., 2016. Implantable estrus detection devices, systems, and methods; US Patent 20,160,030,010.

Johnson, J.S., Abuajamieh, M., Fernandez, M.V.S., Seibert, J.T., Stoakes, S.K., Nteeba, J., Keating, A.F., Ross, J.W., Rhoads, R.P. and Baumgard, L., 2015. Thermal stress alters postabsorptive metabolism during pre-and postnatal development. Climate change impact on livestock: Adaptation and mitigation. 61-79. Heidelberg; Springer.

Johnson, S.K. and Funston, R.N., 2013. Postbreeding heifer management. Vet Clin North Am Food Anim Pract 29(3): 627-641.

Kamphuis, C., DelaRue, B., Burke, C.R. and Jago, J., 2012. Field evaluation of 2 collar-mounted activity meters for detecting cows in estrus on a large pasture-grazed dairy farm. J Dairy Sci 95(6): 3045-3056.

Kastelic, J.P., 2014. Understanding and evaluating bovine testes. Theriogenology 81(1): 18-23.

Kennedy, S.P., Spitzer, J.C., Hopkins, F.M., Higdon, H.L. and Bridges, W.C., 2002. Breeding soundness evaluations of 3648 yearling beef bulls using the 1993 Society for Theriogenology guidelines. Theriogenology 58(5): 947-961.

Kiddy, C.A., 1977. Variation in physical activity as an indication of estrus in dairy cows. J Dairy Sci 60(2): 235-243.

Kiddy, C.A., Mitchell, D.S. and Hawk, H.W., 1984. Estrus-related odors in body fluids of dairy cows. J Dairy Sci 67(2): 388-391.

King, B.D., Cohen, R.D.H., McCormac, S. and Guenther, C.L., 1993. Maternal factors and the prediction of dystocia in beef heifers. Can J Anim Sci 73(2): 431-435.

Kirkland, R.M., Patterson, D.C., Keady, T.W.J., Moss, B.W. and Steen, R.W.J., 2007. Beef production potential of Norwegian Red and Holstein-Friesian bulls slaughtered at two ages. Animal 1(10): 1506-1514.

Knickerbocker, J.J., Wiltbank, M.C. and Niswender, G.D., 1988. Mechanisms of luteolysis in domestic livestock. Domest Anim Endocrin 5(2): 91-107.

Kyle, B.L., Kennedy, A.D. and Small, J.A., 1998. Measurement of vaginal temperature by radiotelemetry for the prediction of estrus in beef cows. Theriogenology 49(8): 1437-1449.

Lamb, G.C., Dahlen, C.R., Larson, J.E., Marquezini, G. and Stevenson, J.S., 2010. Control of the estrous cycle to improve fertility for fixed-time artificial insemination in beef cattle: A review. J Anim Sci 88(13): e181-e192.

Landaeta-Hernández, A.J., Giangreco, M., Meléndez, P., Bartolomé, J., Bennet, F., Rae, D.O., Hernández, J. and Archbald, L.F., 2004. Effect of biostimulation on uterine involution, early ovarian activity and first postpartum estrous cycle in beef cows. Theriogenology 61(7): 1521-1532.

Landaeta-Hernández, A.J., Meléndez, P., Bartolomé, J., Rae, D.O. and Archbald, L.F., 2013. Effect of biostimulation and social organization on the interval from calving to resumption of ovarian cyclicity in postpartum Angus cows. Theriogenology 79(7): 1041-1044.

Landaeta-Hernández, A.J., Yelich, J.V., Lemaster, J.W., Fields, M.J., Tran, T., Chase, C.C., Rae, D.O. and Chenoweth, P.J., 2002. Environmental, genetic and social factors affecting the expression of estrus in beef cows. Theriogenology 57(4): 1357-1370.

Larson, J.E., Lamb, G.C., Stevenson, J.S., Johnson, S.K., Day, M.L., Geary, T.W., Kesler, D.J., DeJarnette, J.M., Schrick, F.N., DiCostanzo, A. and Arseneau, J.D., 2006. Synchronization of estrus in suckled beef cows for detected estrus and artificial insemination and timed artificial insemination using gonadotropin-releasing hormone, prostaglandin F2α, and progesterone. J Anim Sci 84(2): 332-342.

Larson, R.L., 2005. Replacement heifers. In: Chenoweth, P.J. and Sanderson, M.W. (Eds.), Beef practice: Cow-calf production medicine. 127-150. Ames, IA; Blackwell Publishing Professional.

Larson, R.L. and Randle, R.F., 2007. Heifer development: Nutrition, health, and reproduction. In: Youngquist, R.S. and Threlfall, W.R. (Eds.), Current therapy in large animal theriogenology. 2nd ed., 457-463. Saint Louis; W.B. Saunders.

Larson, R.L. and Tyler, J.W., 2005. Reducing calf losses in beef herds. Vet Clin North Am Food Anim Pract 21(2): 569-584.

Larson, R.L. and White, B.J., 2016. Reproductive systems for North American beef cattle herds. Vet Clin North Am Food Anim Pract 32(2): 249-266.

Laster, D.B., Glimp, H.A., Cundiff, L.V. and Gregory, K.E., 1973. Factors affecting dystocia and the effects of dystocia on subsequent reproduction in beef cattle. J Anim Sci 36(4): 695-705.

Lauderdale, J.W., 2001. Use of prostaglandin F2a in cattle breeding. In: Fields, M.J. (Ed.), Factors affecting calf crop Biotechnology of reproduction. 23-34. Boca Raton, FL; CRC Press.

LaVoie, V., Han, D.K., Foster, D.B. and Moody, E.L., 1981. Suckling effect on Eetrus and blood plasma progesterone in postpartum beef cows. J Anim Sci 52(4): 802-812.

Le Danvic, C., Gérard, O., Sellem, E., Ponsart, C., Chemineau, P., Humblot, P. and Nagnan-Le Meillour, P., 2015. Enhancing bull sexual behavior using estrus-specific molecules identified in cow urine. Theriogenology 83(9): 1381-1388.

Lesniewski, R.R., Kirsch, J.D., Mrozinski, L.E., Hellwig, D.H., Kotwica, J. and Williams, G.L., 1985. In vitro metabolism of ovarian steroids by bovine whole blood and plasma. Domest Anim Endocrin 2(3): 141-150.

Lombard, J.E., Garry, F.B., Tomlinson, S.M. and Garber, L.P., 2007. Impacts of dystocia on health and survival of dairy calves. J Dairy Sci 90(4): 1751-1760.

Lyimo, Z.C., Nielen, M., Ouweltjes, W., Kruip, T.A.M. and Van Eerdenburg, F.J.C.M., 2000. Relationship among estradiol, cortisol and intensity of estrous behavior in dairy cattle. Theriogenology 53(9): 1783-1795.

MacNeil, M.D., Dearborn, D.D., Cundiff, L.V., Dinkel, C.A. and Gregory, K.E., 1989. Effects of inbreeding and heterosis in Hereford females on fertility, calf survival and preweaning growth. J Anim Sci 67(4): 895-901.

Mann, C.J., 2003. Observational research methods. Research design II: cohort, cross sectional, and case-control studies. Emerg Med J 20(1): 54-60.

Manteuffel, G., Puppe, B. and Schön, P.C., 2004. Vocalization of farm animals as a measure of welfare. Appl Anim Behav Sci 88(1): 163-182.

Martin, A.D., 2015. Surveillance of reproductive performance in Norwegian cattle farming, Norwegian University of Life Sciences (NMBU). Oslo. PhD Thesis.

Martin, L.C., Brinks, J.S., Bourdon, R.M. and Cundiff, L.V., 1992. Genetic effects on beef heifer puberty and subsequent reproduction. J Anim Sci 70(12): 4006-4017.

Matre, T., 2010. Beite - en viktig ressurs (English: "Pasture - an important resource"). Charolaisnytt. Hamar. 2: 8-9.

Mc Parland, S., Kearney, J.F., MacHugh, D.E. and Berry, D.P., 2008. Inbreeding effects on postweaning production traits, conformation, and calving performance in Irish beef cattle. J Anim Sci 86(12): 3338-3347.

McDermott, J.J., Allen, O.B., Martin, S.W. and Alves, D.M., 1992. Patterns of stillbirth and dystocia in Ontario cow-calf herds. Canadian Journal of Veterinary Research 56(1): 47-55.

Mee, J.F., 2008. Prevalence and risk factors for dystocia in dairy cattle: A review. Vet J 176(1): 93-101.

Meijering, A., 1984. Dystocia and stillbirth in cattle - A review of causes, relations and implications. Livest Prod Sci 11(2): 143-177.

Mialon, M.-M., Renand, G., Krauss, D. and Ménissier, F., 2000. Genetic variability of the length of postpartum anoestrus in Charolais cows and its relationship with age at puberty. Genet Select Evol 32(4): 1-12.

Micke, G.C., Sullivan, T.M., Rolls, P.J., Hasell, B., Greer, R.M., Norman, S.T. and Perry, V.E.A., 2010a. Dystocia in 3-year-old beef heifers; Relationship to maternal nutrient intake during early- and mid-gestation, pelvic area and hormonal indicators of placental function. Anim Reprod Sci 118(2–4): 163-170.

Micke, G.C., Sullivan, T.M., Soares Magalhaes, R.J., Rolls, P.J., Norman, S.T. and Perry, V.E.A., 2010b. Heifer nutrition during early- and mid-pregnancy alters fetal growth trajectory and birth weight. Anim Reprod Sci 117(1–2): 1-10.

Miller, V. and Ungerfeld, R., 2008. Weekly bull exchange shortens postpartum anestrus in suckled beef cows. Theriogenology 69(8): 913-917.

Ministry of Agriculture and Food, 2004. Forskrift om hold av storfe (English: "Legislative regulation - keeping of cattle"). Oslo; Ministry of Agriculture and Food.

Morris, C.A., 1980. A review of relationships between aspects of reproduction in beef heifers and their lifetime production. Associations with fertility in the first joining season and with age at first joining. Anim Breed Abstr 48(10): 655-676

Morris, M.J., Kaneko, K., Walker, S.L., Jones, D.N., Routly, J.E., Smith, R.F. and Dobson, H., 2011. Influence of lameness on follicular growth, ovulation, reproductive hormone concentrations and estrus behavior in dairy cows. Theriogenology 76(4): 658-668.

Morrison, D.G., Williamson, W.D. and Humes, P.E., 1986. Estimates of heritabilities and correlations of traits associated with pelvic area in beef cattle. J Anim Sci 63(2): 432-437.

Murphy, M.G., Boland, M.P. and Roche, J.F., 1990. Pattern of follicular growth and resumption of ovarian activity in post-partum beef suckler cows. J Reprod Fertil 90(2): 523-533.

Neves, R.C. and LeBlanc, S.J., 2015. Reproductive management practices and performance of Canadian dairy herds using automated activity-monitoring systems. J Dairy Sci 98(4): 2801-2811.

Neves, R.C., Leslie, K.E., Walton, J.S. and LeBlanc, S.J., 2012. Reproductive performance with an automated activity monitoring system versus a synchronized breeding program. J Dairy Sci 95(10): 5683-5693.

Nicholas, F.W., 1996. Animal reproduction: Research and practice: Genetic improvement through reproductive technology. Anim Reprod Sci 42(1): 205-214.

Nix, J.M., Spitzer, J.C., Grimes, L.W., Burns, G.L. and Plyler, B.B., 1998. A retrospective analysis of factors contributing to calf mortality and dystocia in beef cattle. Theriogenology 49(8): 1515-1523.

Noakes, D.E., 2009. General considerations. In: Noakes, D.E., Parkinson, T.J. and England, G.C.W. (Eds.), Veterinary reproduction and obstetrics. 9th ed., 209-222. Edinburgh; Elsevier Health Sciences.

Norman, S. and Youngquist, R.S., 2007. Parturition and dystocia. In: Youngquist, R.S. and Threlfall, W.R. (Eds.), Current therapy in large animal theriogenology. 2nd ed., 310-335. Saint Louis; W.B. Saunders.

Nortura SA, 2012. Grunnlagsdokument storfe, sau/lam og egg - høst 2012 (English: "Basis document cattle, sheep/lamb and egg - autumn 2012"). Oslo; Notura SA.

Nortura SA, 2015. Grunnlagsdokument storfe, sau/lam, og egg - høst 2015 (English: "Basis document, cattle, sheep/lamb and egg, autumn 2015"). Oslo; Nortura SA.

Nortura SA, 2016. Grunnlagsdokument storfe, sau/lam, og egg - vår 2016 (English: "Basis document, cattle, sheep/lamb and egg, spring 2016"). Oslo; Nortura SA.

Nunez-Dominguez, R., Cundiff, L.V., Dickerson, G.E., Gregory, K.E. and Koch, R.M., 1991. Lifetime production of beef heifers calving first at two vs. three years of age. J Anim Sci 69(9): 3467-3479.

Odde, K.G., Ward, H.S., Kiracofe, G.H., McKee, R.M. and Kittok, R.J., 1980. Short estrous cycles and associated serum progesterone levels in beef cows. Theriogenology 14(2): 105-112.

Olson, T.A., Euclides Filho, K., Cundiff, L.V., Koger, M., Butts, W.T. and Gregory, K.E., 1991. Effects of breed group by location interaction on crossbred cattle in Nebraska and Florida. J Anim Sci 69(1): 104-114.

Opsomer, G., Leroy, J., Vanholder, T., Bossaert, P. and de Kruif, A., 2006. Optimizing dairy cow reproductive performances besides the use of hormones. 24th World buiatrics congress, Nice: 484-492.

Orihuela, A., 2000. Some factors affecting the behavioural manifestation of oestrus in cattle: A review. Appl Anim Behav Sci 70(1): 1-16.

Parish, J., 2010. Beef production strategies; Mississippi State University.

Parkinson, T.J., 1996. Artificial insemination. In: Arthur, G.H., Noakes, D.E., Pearson, H. and Parkinson, T.J. (Eds.), Veterinary reproduction and obstetrics. 7th ed., 751-778. London; WB Saunders.

Patterson, D.J., Thomas, J.M., Martin, N.T., Nash, J.M. and Smith, M.F., 2013. Control of estrus and ovulation in beef heifers. Vet Clin North Am Food Anim Pract 29(3): 591-617.

Perry, R.C., Corah, L.R., Kiracofe, G.H., Stevenson, J.S. and Beal, W.E., 1991. Endocrine changes and ultrasonography of ovaries in suckled beef cows during resumption of postpartum estrous cycles. J Anim Sci 69(6): 2548-2555.

Peter, A.T., Levine, H., Drost, M. and Bergfelt, D.R., 2009. Compilation of classical and contemporary terminology used to describe morphological aspects of ovarian dynamics in cattle. Theriogenology 71(9): 1343-1357.

Peters, A.R., 1984. Reproductive activity of the cow in the post-partum period: Factors affecting the length of the post-partum acyclic period. Br Vet J 140(1): 76-84.

Price, T.D. and Wiltbank, J.N., 1978. Dystocia in cattle: A review and implications. Theriogenology 9(3): 195-219.

Prince, D.K., Mickelsen, W.D. and Prince, E.G., 1987. The economics of reproductive beef management. Bovine Pract 22: 92-97.

Rae, D.O., 2002. Bovine estrus: Tools for detecting and understanding. In: Fields, M.J. (Ed.), Factors affecting calf crop Biotechnology of reproduction. 7-21. Boca Raton, FL; CRC Press.

Rae, D.O., Chenoweth, P.J., Giangreco, M.A., Dixon, P.W. and Bennett, F.L., 1999. Assessment of estrus detection by visual observation and electronic detection methods and characterization of factors associated with estrus and pregnancy in beef heifers. Theriogenology 51(6): 1121-1132.

Rao, N.K.T.K.S., Kumar, P., Chaurasia, S. and Patel, N.B., 2013. Heat detection techniques in cattle and buffalo. Vet World 6(6): 363-369.

Redden, K.D., Kennedy, A.D., Ingalls, J.R. and Gilson, T.L., 1993. Detection of estrus by radiotelemetric monitoring of vaginal and ear skin temperature and pedometer measurements of activity. J Dairy Sci 76(3): 713-721.

Reimers, T.J., Smith, R.D. and Newman, S.K., 1985. Management factors affecting reproductive performance of dairy cows in the Northeastern United States. J Dairy Sci 68(4): 963-972.

Reith, S., Brandt, H. and Hoy, S., 2014. Simultaneous analysis of activity and rumination time, based on collar-mounted sensor technology, of dairy cows over the peri-estrus period. Livest Sci 170: 219-227.

Robbins, R.K., Sullivan, J.J., Pace, M.M., Elliott, F.I., Bartlett, D.E., Press, P.J. and Grace, W.R., 1978. Timing the insemination of beef cattle. Theriogenology 10(2–3): 247-255.

Roberts, A.J., Petersen, M.K. and Funston, R.N., 2015. Beef species symposium: Can we build the cowherd by increasing longevity of females? J Anim Sci 93(9): 4235-4243.

Roelofs, J., López-Gatius, F., Hunter, R.H.F., Van Eerdenburg, F.J.C.M. and Hanzen, C., 2010. When is a cow in estrus? Clinical and practical aspects. Theriogenology 74(3): 327-344.

Roelofs, J.B., Bouwman, E.G., Dieleman, S.J., Van Eerdenburg, F.J.C.M., Kaal-Lansbergen, L.M.T.E., Soede, N.M. and Kemp, B., 2004. Influence of repeated rectal ultrasound examinations on hormone profiles and behaviour around oestrus and ovulation in dairy cattle. Theriogenology 62(7): 1337-1352.

Roelofs, J.B., Graat, E.A.M., Mullaart, E., Soede, N.M., Voskamp-Harkema, W. and Kemp, B., 2006a. Effects of insemination–ovulation interval on fertilization rates and embryo characteristics in dairy cattle. Theriogenology 66(9): 2173-2181.

Roelofs, J.B., van Eerdenburg, F.J., Soede, N.M. and Kemp, B., 2005a. Pedometer readings for estrous detection and as predictor for time of ovulation in dairy cattle. Theriogenology 64(8): 1690-1703.

Roelofs, J.B., van Eerdenburg, F.J., Soede, N.M. and Kemp, B., 2005b. Various behavioral signs of estrous and their relationship with time of ovulation in dairy cattle. Theriogenology 63(5): 1366-1377.

Roelofs, J.B., Van Eerdenburg, F.J.C.M., Hazeleger, W., Soede, N.M. and Kemp, B., 2006b. Relationship between progesterone concentrations in milk and blood and time of ovulation in dairy cattle. Anim Reprod Sci 91(3–4): 337-343.

Roelofs, J.B. and Van Erp-van der Kooij, E., 2015. Estrus detection tools and their applicability in cattle: recent and perspectival situation. Anim Reprod 12(3): 498-504.

Rogers, P.L., Gaskins, C.T., Johnson, K.A. and MacNeil, M.D., 2004. Evaluating longevity of composite beef females using survival analysis techniques. J Anim Sci 82(3): 860-866.

Rorie, R.W., Bilby, T.R. and Lester, T.D., 2002. Application of electronic estrus detection technologies to reproductive management of cattle. Theriogenology 57(1): 137-148.

Roughsedge, T., Thompson, R., Villanueva, B. and Simm, G., 2001. Synthesis of direct and maternal genetic components of economically important traits from beef breed-cross evaluations. J Anim Sci 79(9): 2307-2319.

Rutter, L.M. and Randel, R.D., 1986. Nonpuberal estrus in beef heifers. J Anim Sci 63(4): 1049-1053.

Ruud, T.A., Wittusen, H.T., Juul-Hansen, O.B., Mellby, J.O., Røhnebæk, E., Aass, L., Rustad, L.J., Flittie Anderssen, Å.M. and Nafstad, O., 2013. Økt storfekjøttproduksjon i Norge - rapport fra ekspertgruppen (English: "Increased beef production in Norway"). Oslo; Animalia - Norwegian Meat and Poultry Research Centre.

Ryan, W.J., Williams, I.H. and Moir, R.J., 1993. Compensatory growth in sheep and cattle: Growth pattern and feed intake. Aust J Agric Res 44(7): 1609-1621.

Saacke, R.G., Dalton, J.C., Nadir, S., Nebel, R.L. and Bame, J.H., 2000. Relationship of seminal traits and insemination time to fertilization rate and embryo quality. Anim Reprod Sci 60-61: 663-677.

Sales, J.N.S., Neves, K.A.L., Souza, A.H., Crepaldi, G.A., Sala, R.V., Fosado, M., Campos Filho, E.P., De Faria, M., Sá Filho, M.F. and Baruselli, P.S., 2011. Timing of insemination and fertility in dairy and beef cattle receiving timed artificial insemination using sex-sorted sperm. Theriogenology 76(3): 427-435.

Sanderson, M.W., 2005. Calving and calf management in beef herds. In: Chenoweth, P.J. (Ed.), Beef practice: Cow-Calf production medicine. 193-213. Ames, IA; Blackwell Publishing Professional.

Schallenberger, E., Schams, D. and Zottmeier, K., 1978. Response of lutropin (LH) and follitropin (FSH) to the administration of gonadoliberin (GnRH) in pregnant and post-partum cattle including experiments with prolactin suppression. Theriogenology 10(1): 35-53.

Schön, P.C., Hämel, K., Puppe, B., Tuchscherer, A., Kanitz, W. and Manteuffel, G., 2007. Altered vocalization rate during the estrous cycle in dairy cattle. J Dairy Sci 90(1): 202-206.

Seehusen, T., 2016. Fagnotat til rapporten "Landbruk og klimaendringer" (English: "Memorandum to the report "Agriculture and climate changes""). Ås; NIBIO.

Seidel, G.E., 2014a. Beef cattle in the year 2050. In: Lamb, C.l.G. and DiLorenzo, N. (Eds.), Current and future reproductive technologies and world food production. Vol. 752, 239-244. New York, NY; Springer.

Seidel, G.E., 2014b. Update on sexed semen technology in cattle. Animal 8(s1): 160-164.

Senger, P.L., 1994. The estrus detection problem: New concepts, technologies, and possibilities. J Dairy Sci 77(9): 2745-2753.

Simensen, E., Østerås, O., Bø, K.E., Kielland, C., Ruud, L.E. and Næss, G., 2010. Housing system and herd size interactions in Norwegian dairy herds; associations with performance and disease incidence. Acta Vet Scand 52(14): 1-9.

Simm, G., 1998a. Beef cattle breeding. In: Simm, G. (Ed.), Genetic improvement of cattle and sheep. 253-299. Ipswich; Farming Press,.

Simm, G., 1998b. Strategies for genetic improvement. In: Simm, G. (Ed.), Genetic improvement of cattle and sheep. 64-106. Ipswich; Farming Press,.

Soren, N.M., 2012. Nutritional manipulations to optimize productivity during environmental stresses in livestock. In: Sejian, V., Naqvi, S.M.K., Ezeji, T., Lakritz, J. and Lal, R. (Eds.), Environmental stress and amelioration in livestock production. 181-218. Berlin; Springer.

Stabenfeldt, G.H., Ewing, L.L. and McDonald, L.E., 1969. Peripheral plasma progesterone levels during the bovine oestrous cycle. J Reprod Fertil 19(3): 433-442.

Stabenfeldt, G.H., Osburn, B.I. and Ewing, L.L., 1970. Peripheral plasma progesterone levels in the cow during pregnancy and parturition. Am J Physiol 218: 571-575.

Statistics Norway, 2016. Statistics Norway. From: http://www.ssb.no/en/.

Stevenson, J.S., 2001. Use of GnRH to synchronize estrus and/or ovulation in beef cows without timed insemination. In: Fields, M.J. (Ed.), Factors affecting calf crop Biotechnology of reproduction. 43-56. Boca Raton, FL; CRC Press.

Suthar, V.S., Burfeind, O., Patel, J.S., Dhami, A.J. and Heuwieser, W., 2011. Body temperature around induced estrus in dairy cows. J Dairy Sci 94(5): 2368-2373.

Szabó, F. and Dákay, I., 2009. Estimation of some productive and reproductive effects on longevity of beef cows using survival analysis. Livest Sci 122(2–3): 271-275.

Taylor, R.E., 2015. Effects of maternal nutrient restiction during early or medgestation on bovine fetal growth, placentomes, and miRNA expression, Clemson University. Clemson, SC. MS Thesis.

Toombs, R.E., Wikse, S.E. and Kasari, T.R., 1994. The incidence, causes, and financial impact of perinatal mortality in North American beef herds. Vet Clin North Am Food Anim Pract 10(1): 137-146.

Tozer, P.R. and Heinrichs, A.J., 2001. What affects the costs of raising replacement dairy heifers: A multiple-component analysis. J Dairy Sci 84(8): 1836-1844.

Troxel, T.R. and Barham, B.L., 2009. The impact of reducing the length of the calving season. Arkansas agricultural experiment station reseach series. Fayetteville, AR. 574: 75-76.

Van Eerdenburg, F.J.C.M., Loeffler, H.S.H. and Van Vliet, J.H., 1996. Detection of oestrus in dairy cows: a new approach to an old problem. Vet Q 18(2): 52-54.

Vishwanath, R., 2003. Artificial insemination: the state of the art. Theriogenology 59(2): 571-584.

Voller, A., Bartlett, A. and Bidwell, D.E., 1978. Enzyme immunoassays with special reference to ELISA techniques. J Clin Pathol 31(6): 507-520.

Walker, W.L., Nebel, R.L. and McGilliard, M.L., 1996. Time of ovulation relative to mounting activity in dairy cattle. J Dairy Sci 79(9): 1555-1561.

Wathes, D.C., Pollott, G.E., Johnson, K.F., Richardson, H. and Cooke, J.S., 2014. Heifer fertility and carry over consequences for life time production in dairy and beef cattle. Animal 8(s1): 91-104.

Wentink, G.H., Frankena, K., Bosch, J.C., Vandehoek, J.E.D. and van den Berg, T., 2000. Prevention of disease transmission by semen in cattle. Livest Prod Sci 62(3): 207-220.

White, F.J., Wettemann, R.P., Looper, M.L., Prado, T.M. and Morgan, G.L., 2002. Seasonal effects on estrous behavior and time of ovulation in nonlactating beef cows. J Anim Sci 80(12): 3053-3059.

Wiederschain, G.Y., 2009. The ELISA guidebook. Biochemistry (Mosc) 74(9): 1058.

Wiltbank, J.N., Shumway, R.P., Parker, W.R. and Zimmerman, D.R., 1967. Duration of estrus, time of ovulation and fertilization rate in beef heifers synchronized with dihydroxyprogesterone acetophenide. J Anim Sci 26(4): 764-767.

Wiltbank, M.C., Souza, H., Carvalho, P., Bender, R.W. and Nascimento, A.B., 2011. Improving fertility to timed artificial insemination by manipulation of circulating progesterone concentrations in lactating dairy cattle. Reprod Fertil Dev 24(1): 238-243.

Wittum, T.E. and Perino, L.J., 1995. Passive immune status at postpartum hour 24 and long-term health and performance of calves. Am J Vet Res 56(9): 1149-1154.

Wojcik, P. and Olszewski, A., 2015. Use of pedometers to analyse 24-hour activity and fertility of Limousin cows. Folia Pomeranae Univ Technol Stetin Agric Aliment Pisc Zootechn 322(36/4): 119-124.

Wrenn, T.R., Bitman, J. and Sykes, J.F., 1958. Body temperature variations in dairy cattle during the estrous cycle and pregnancy. J Dairy Sci 41(8): 1071-1076.

Yambayamba, E.S., Price, M.A. and Foxcroft, G.R., 1996. Hormonal status, metabolic changes, and resting metabolic rate in beef heifers undergoing compensatory growth. J Anim Sci 74(1): 57-69.

Yavas, Y. and Walton, J.S., 2000. Postpartum acyclicity in suckled beef cows: A review. Theriogenology 54(1): 25-55.

Yelich, J.V., Holland, M.D., Schutz, D.N. and Odde, K.G., 1995. Synchronization of estrus in suckled postpartum beef cows with melengestrol acetate, 48-hour calf removal and PGF2α. Theriogenology 43(2): 401-410.

Young, B.A., 1975. Temperature-induced changes in metabolism and body weight of cattle (*Bos taurus*). Can J Physiol Pharm 53(5): 947-953.

Zaborski, D., Grzesiak, W., Szatkowska, I., Dybus, A., Muszynska, M. and Jedrzejczak, M., 2009. Factors affecting dystocia in cattle. Reprod Domest Anim 44(3): 540-551.

Østerås, O., Solbu, H., Refsdal, A.O., Roalkvam, T., Filseth, O. and Minsaas, A., 2007. Results and evaluation of thirty years of health recordings in the Norwegian dairy cattle population. J Dairy Sci 90(9): 4483-4497.

Åby, B.A., Aass, L., Sehested, E. and Vangen, O., 2012. A bio-economic model for calculating economic values of traits for intensive and extensive beef cattle breeds. Livest Sci 143(2–3): 259-269.

Papers I - III

I

Theriogenology 87 (2017) 205–211

Contents lists available at ScienceDirect

Theriogenology

journal homepage: www.theriojournal.com

Automated activity monitoring and visual observation of estrus in a herd of loose housed Hereford cattle: Diagnostic accuracy and time to ovulation

S.T. Nelson [a], C.S. Haadem [a], A. Nødtvedt [a], A. Hessle [b], A.D. Martin [a,*]

[a] Department of Production Animal Clinical Sciences, Norwegian University of Life Sciences, Oslo, Norway
[b] Division of Production Systems, Department of Animal Environment and Health, Swedish University of Agricultural Sciences, Skara, Sweden

ARTICLE INFO

Article history:
Received 1 July 2016
Received in revised form 15 August 2016
Accepted 25 August 2016

Keywords:
Activity monitoring system
Beef
Cattle
Estrus
Hereford
Ovulation

ABSTRACT

A prospective cohort study was performed in the purebred Hereford herd at Götala Beef and Lamb Research Centre, Sweden. The study's first objective was to assess the ability of an automatic activity monitoring system (AAMS) to detect estrus in beef suckler cows, and its second objective was to estimate the time from estrus to ovulation. The study sample ($n = 38$) consisted of 14 Hereford heifers and 24 Hereford cows. Standardized visual observation of estrus was performed for 20 minutes thrice daily, and animal activity was recorded with an AAMS system, Heatime (SCR Engineers Ltd., Israel). Cows in estrus underwent transrectal ultrasonography every 8 hours, to estimate the time of ovulation. Blood samples for progesterone analysis were collected thrice weekly throughout the study period. A cutoff value of 1-ng progesterone/mL of serum was used to define luteal activity. The AAMS had a 90% (95% confidence interval [CI] 77%–97%) sensitivity and 100% specificity (95% CI 94%–100%), and visual detection of estrus had a 77% sensitivity (95% CI 62%–88%) and a 89% specificity (95% CI 79%–95%) for identifying estrus when compared to the gold standard defined by temporal pattern of serum progesterone concentration. When both methods were used in parallel, the sensitivity increased to 96% (95% CI 86%–99%), and the specificity increased to 90% (95% CI 80%–96%). The time of ovulation after estrus was determined on 50 occasions. The median estrus (AAMS detected) to ovulation interval was 25 hours for heifers and 23 hours for cows (interquartile range 11–29 hours and 19–25 hours, respectively). The median estrus (visually detected) to ovulation interval was 28 hours for heifers and 21 hours for cows (interquartile range 13–29 hours for both categories). In conclusion, the AAMS had both a higher sensitivity and specificity for estrus detection than thrice-daily visual observation. The time from detection of estrus to ovulation observed in this study indicates that reproductive performance might be improved if Hereford cattle are inseminated sooner after detection of estrus than is currently recommended.

1. Introduction

The duration of bovine estrus is between 11 and 21 hours, in an estrous cycle which lasts between 18 and 24 days [1–4]. Typically, ovulation occurs 12 hours after the end of estrus, and it is recommended that artificial insemination (AI) is performed 6 to 24 hours before ovulation [5]. Studies investigating estrus, ovulation, and timing of AI have almost exclusively been performed on dairy cows. There is evidence that patterns of estrus expression, e.g., a decrease in the primary sign of estrus "standing to be mounted," in dairy cows have changed in the past half century [6]. Concurrent with this altered

* Corresponding author. Tel.: +47 67 23 00 00; fax: + 47 22 59 70 83.
E-mail address: adam.martin@nmbu.no (A.D. Martin).

0093-691X/$ – see front matter © 2016 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.theriogenology.2016.08.025

expression of estrus, there have been considerable production increases and intense genetic selection for traits such as milk yield [7] which may have altered the relationship between estrus behavior and ovulation in dairy cows. The selection for productivity has been different in beef populations, and it is not known how, and if beef cows estrous behavior and its relationship to the time of ovulation, has changed over time.

Despite the clear benefits of AI, less than 15% of Norwegian beef cows are artificially inseminated [8]. This is low compared to the Norwegian dairy population in which 85% of cattle are bred to AI [9]. Reasons AI is not used include the following: difficulties in the detection of estrus, time constraints, and inconvenience [10]. Various automatic activity monitoring systems (AAMSs) have been developed for the detection of estrus which negates a number of arguments against performing AI in beef cattle [11], but studies evaluating AAMS in beef herds are scarce [12]. Instead, research on the use of AI in beef herds has focused on estrus synchronization and timed AI protocols [13,14]. These protocols have been so successful that these programs are believed to be the main reason for increases in AI use among beef cattle producers in many parts of the world [15]. However, in Europe, there is a resistance to the use of hormones to treat cattle [16], and studies determining the optimal AI time in unsynchronized beef cows are limited [17]. Therefore, knowledge about the optimal time to perform AI in unsynchronized beef cows is important for beef production in Europe and other areas.

There is little reason to assume the duration of estrus and estrous behaviors are identical between beef and dairy cows given the considerably different genetic selection and production demands placed on them [7]. Particularly, when there is evidence from the dairy population that breed affects estrous behavior [18]. A better understanding of temporal relationships of estrus and ovulation in beef cows is important if AI is to be successful in beef herds. The primary objective of this applied study was to evaluate the ability of an AAMS and visual observation to detect estrus in beef suckler cows, both compared to a gold standard for estrus defined by serum progesterone levels. The secondary objective was to determine the time from AAMS or visual detection of estrus to ovulation in beef suckler cows, comparing nulliparous to multiparous females.

2. Materials and methods

The study was authorized by the Gothenburg Research Animal Ethics Committee (Dnr. Etisk: 187-2014).

2.1. Study population

This prospective cohort study was performed in a purebred Hereford herd at Götala Beef and Lamb Research Centre, Sweden, from the 31st of May to the 4th of July 2015. The herd is a research herd but managed following the principals of a commercial herd. The herd consisted of 40 purebred female Hereford beef cattle over 13 months old, 24 of which had suckling calves, and a bull. The cows that were eligible calved 1 to 70 days before the start of the study, except for two cows which last calved in 2014. The study population was kept in two groups. One group consisted of 15 nulliparous heifers aged between 13 and 16 months, and the other group consisted of 25 multiparous cows. There were no primiparous cows present in the herd during the study period. Both objectives of this study were investigated using the same study population, although different inclusion criteria and unit of observation mean that the number of observations used for each analysis differs.

The heifers and cows were loose housed in separate rectangular pens measuring 105 m^2 and 315 m^2, respectively. The pens were adjacent to each other in an uninsulated barn with deep straw bedding and scraped alleys with solid concrete floors in front of the feed bunks. A young bull was located in a pen at a short end of the rectangular cow pen. The herd was fed ad libitum first cut *Festulolium* grass silage supplemented with 100 g of mineral mix per head as recommended [19] once daily at 6:30 AM, and all animals had free access to water and sodium chloride salt licks. The body condition score (BCS) of all females in the study was assessed on a nine-point scale (1 = emaciated, 9 = obese) [20], by the same member of the staff on the first and final day of the study.

2.2. Detection of estrus

No hormonal treatments were administered to heifers or cows. Consequently, all estrous periods were spontaneous.

2.2.1. Standardized visual detection

Standardized visual observation of estrus was performed by one of three experienced veterinarians (S.T.N., C.S.H., and A.D.M.) in each group of cows for 20 minutes thrice daily at 6 AM, 2 PM, and 10 PM. When a behavior associated with estrus was observed, a score was assigned to that female as outlined in Table 1 [21]. After each observation period, the scores for estrus behaviors were summated for each female. Estrus was defined as starting the first time a female scored 100 points or more in a 20-minute observation period.

2.2.2. Automated activity monitoring system

The neck collars of a commercially available AAMS (Heatime HR System, SCR Engineers Ltd., Israel) were fitted to the females 1 month before the study commenced. The

Table 1
Standardized scoring scale for visually observed estrous behavior.

Estrus sign	Scoring scale
Other signs	
Mucous vaginal discharge	5
Bellowing	5
Restlessness	5
Sniffing the vulva of other cow	10
Resting with chin on other cow	15
Mounting signs	
Mounted by other cow, but not standing	10
Mounting (or attempting) other cows	35
Mounting head side of other cow	45
Standing heat	100

Modified version of [21].

activity of the herd was measured at the individual cow level using a proprietary movement sensor included in the neck collar, which is reported to record all cow movement and activity intensity (www.scrdairy.com/cow-intelligence/technology.html), continuously throughout the study period. These data were transferred from the neck collar to the central computer in 2-hour blocks by radio transmission. Activity measurements recorded in the central computer were used to establish the threshold of estrus activity according to the manufacturer's guidelines (SCR Engineers Ltd.). Estrus was defined as beginning at the time of the AAMS alarm.

2.3. Ultrasonography

Transrectal ultrasonography (Easi-Scan, BCF Technology Ltd., Scotland) of the reproductive tract was performed in both heifers and cows by one of three experienced veterinarians (S.T.N., C.S.H., and A.D.M.) after initial detection of estrus (visual or AAMS alarm). The first transrectal examination was performed directly after the visual estrus observation period was completed, and every 8 hours thereafter, to determine time of ovulation. Examinations stopped immediately after ovulation was confirmed as having occurred by disappearance of the dominant follicle, or after the sixth transrectal examination (48 hours).

2.4. Blood sampling and analysis

Blood samples were collected from the medial coccygeal vein of all heifers and cows included in the study sample thrice weekly (Monday, Wednesday, and Friday) throughout the study period. Samples were collected with a Vacutainer system (Venoject 0.9 × 40 mm, Terumo Europe N.V., Leuven, Belgium) into a 4-mL Vacuette, Z serum cloth activator (Greiner Bio-One International GmbH, Kremsmünster, Austria). The blood samples were stored at room temperature for 1 hour before being centrifuged at 3000 × *g* for 10 minutes at 20 °C. The serum was transferred to a Vacuette, 2 mL, Z No Additive (Greiner Bio-One International GmbH) with a single-use pipette before being stored at −20 °C. The samples were thawed before progesterone concentration was determined by commercial ELISA (Ridgeway Research Ltd., UK). The laboratory reported the intra-assay coefficient of variation to be 9.6%, and the interassay coefficient variation to 6.6%.

2.5. Statistical analyses

Data management and statistical analysis were performed using Stata (Stata SE/12, Stata Corp., USA). In all analyses, statistical significance was defined by a P-value below 0.05.

2.5.1. Diagnostic test evaluation

Thrice-weekly (Monday, Wednesday, and Friday) serum progesterone measurements were used to define the "gold standard" for the calculation of sensitivity and specificity of each estrus detection method [22]. The phase of ovarian activity was defined as either ovulatory (the follicular phase of females that had commenced luteal activity by the time the study started) or nonovulatory (females that were in the luteal phase of the estrous cycle or were in anestrous). The heifers and cows were defined as being in a nonovulatory phase if their serum progesterone concentrations were greater than 1 ng/mL, and in an ovulatory phase if less than 1 ng/mL for less than five consecutive blood samples, as illustrated by Figure 1. One physiologically normal reproductive cycle for a healthy cow consisted of one ovulatory and one nonovulatory phase and would be expected to last between 18 and 24 days. Heifers and cows in which the serum progesterone concentrations never exceeded 1 ng/mL were defined as being in anestrous and in a nonovulatory phase throughout the study. Females with an observed estrus event (AAMS or visual) in the ovulatory phase were regarded as being in "true estrus" if she made a transition to a nonovulatory phase within 8 days. If the study period ended before this transition, that estrus was not included in the sensitivity and specificity calculations as it was not confirmed.

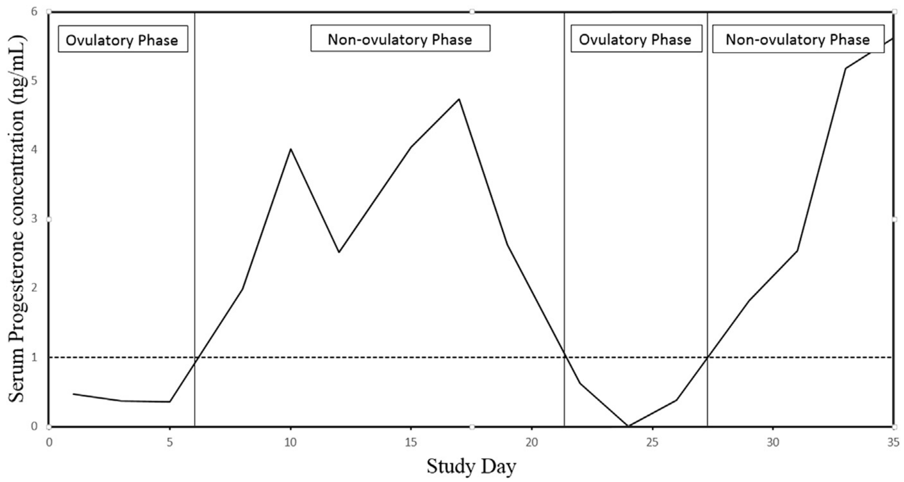

Fig. 1. An example, heifer "118," of an individually typical thrice-weekly serum progesterone profile, used to define the "gold standard" for heifers and cows in estrus by the definition of the two phases "ovulatory" and "nonovulatory."

2.5.2. Time to ovulation

The interval (in hours) from estrus to the visual disappearance of the ovulatory follicle by transrectal ultrasonography was recorded. Because ultrasound was only performed every 8 hours, the midpoint between the examination including the last visualization of the ovulatory follicle and first examination with no detectable ovulatory follicle was used to estimate time of ovulation. Survival analysis was performed to estimate the interval from estrus to ovulation for visual- and AAMS-detected estrus. In these analyses, "ovulation" was defined as the "event," and the time from AAMS alarm or visually observed estrus to event constituted "survival time."

Descriptive statistics for time at risk, and median, 25th, and 75th percentiles of survival time were calculated separately for both methods used for the detection of estrus across both age groups and separately for heifers and cows (Table 2). Overall survival time was estimated using the Kaplan–Meier method, and a log-rank test was performed to test for differences in time to ovulation between heifers and cows.

3. Results

3.1. Study sample

Two animals from the study population ($n = 40$) were not included in the study sample ($n = 38$). This is because one cow had calved the day before the study start and one heifer was a freemartin. All of the 38 females (14 heifers and 24 cows) in the study sample contributed data to the diagnostic test evaluation (primary objective). The animals in the study sample had a mean and median BCS of 6 (range 4–8) when estimated at both the start and the end of the study. None of the animals experienced a BCS change exceeding one unit. The minimum time from calving until study start for females in the study sample was 22 days.

Nine of the 38 females in the study sample did not express estrus. The temporal pattern of progesterone concentration indicated that in the study period, eight of these animals were in anestrous. The remaining 30 animals were classified as having a normal temporal pattern of progesterone concentration [23]. One animal had a silent estrus. Consequently, data from 29 females (10 heifers and 19 cows) were included in the estimation of estrus to ovulation interval (secondary objective).

3.2. Diagnostic test evaluation

A total of 111 ovarian phases were identified by analyzing the temporal pattern of serum progesterone concentration among the 38 eligible females over the study period. Of these, 48 were defined as ovulatory. Systematic visual observation and AAMS detected 36 and 43 of these as "estrus," respectively. The observations are summarized in Table 2. Overall, thrice-daily visual detection of estrus was 77% (95% confidence interval [CI] 62%–88%) sensitive and 89% specific (95% CI 79%–95%), whereas the AAMS was 90% (95% CI 77%–97%) sensitive and 100% specific (95% CI 94%–100%) at identifying estrus. If both thrice-daily visual observation and AAMS were used in parallel to detect estrus, with detection of estrus by either method being classified as positive, the sensitivity for detection of estrus was 96% (95% CI 86%–99%) and the specificity was 90% (95% CI 80%–96%).

3.3. Ultrasonography

Transrectal ultrasonography of the female reproductive tract to attempt to identify the disappearance of an ovulatory follicle, indicating an ovulation had occurred, commenced on 52 occasions. There were two occasions for which disappearance of the ovulatory follicle was not clearly identified, despite the temporal pattern of progesterone concentrations

Table 2
Number of ovulatory and nonovulatory phases used for the test evaluation of a standardized visual observation, an automatic activity monitoring system and when combining both methods, performed for detection of estrus in a Hereford herd.

Estrus detected	Ovarian phase		Total	Predictive values
	Ovulatory	Nonovulatory		
Visual-observed estrus				
Yes	36	6	42	PPV[a] = 84 (69–93)
No	11	57	68	NPV[b] = 84 (73–92)
Total	47	63	110	
	Se[c] = 77 (62–88)	Sp[d] = 89 (79–95)		
AAMS-alarmed estrus				
Yes	43	0	43	PPV[a] = 100 (92–100)
No	5	63	68	NPV[b] = 93 (84–98)
Total	48	63	111	
	Se[c] = 90 (77–97)	Sp[d] = 100 (94–100)		
Visual-observed or AAMS-alarmed estrus				
Yes	46	6	52	PPV[a] = 88 (77–96)
No	2	57	59	NPV[b] = 97 (88–100)
Total	48	63	111	
	Se[c] = 96 (86–99)	Sp[d] = 90 (80–96)		

Abbreviations: AAMS, automatic activity monitoring system; CI, confidence interval.
[a] Positive predictive value % (95% CI).
[b] Negative predictive value % (95% CI).
[c] Sensitivity % (95% CI).
[d] Specificity % (95% CI).

indicating that ovulation had occurred. Both these estrous periods were omitted from the estimations of the estrus to ovulation interval. Calculation of time from estrus to ovulation was, therefore, based on 50 AAMS-detected estrus events and 40 visual observations. One estrus period was censored at 17 hours after detection of estrus (both AAMS and visual) due to loss to follow-up. In total, the disappearance of an ovulatory follicle was therefore identified in 49 estrous periods, 39 of these after visual detection of estrus and 49 after AAMS detection of estrus (Table 3).

3.4. Estrus to ovulation interval

For estrous periods detected by systematic visual observation, the median estrus to ovulation interval was 28 hours (interquartile range [IQR] 13–29 hours) for heifers and 21 hours (IQR 13–29 hours) for cows. The median time from AAMS-detected estrus to ovulation interval was 25 hours for heifers and 23 hours for cows, with an IQR from 11 to 29 hours and 19 to 25 hours, respectively. These estimates are given in Table 3. The log-rank test indicated the estrus to ovulation interval did not vary between heifers and cows (visually detected $P = 0.89$; AAMS detected $P = 0.68$).

4. Discussion

This study was performed to evaluate the ability of an AAMS to detect estrus in beef cattle and to estimate time from AAMS alarm or standardized visual detection of estrus to ovulation. The AAMS out-performed structured thrice-daily visual detection of estrus, and females with an AAMS-detected estrus were very likely to actually be in heat as seen by the positive predictive value of 100 (95% CI 92–100). The estrus to ovulation interval found in this study was shorter than previously described in other classes of cattle. This indicates that better results may be achieved if AI in housed Hereford cattle is performed closer to detection of estrus than is currently recommended for Norwegian cattle in general (www.geno.no).

4.1. Diagnostic test evaluation

The sensitivity of detection of estrus was high, and the specificity was very high for the AAMS in the studied Hereford herd. The diagnostic properties for the detection of estrus were higher for the AAMS than for standardized visual detection of estrus, although the visual detection of estrus performed better in this study than has been previously reported [24,25]. These findings concur with similar studies that have been performed in dairy herds and shown AAMS to outperform visual detection of estrus [25–28]. If both the thrice-daily visual observation and AAMS were used in parallel to detect estrus, the sensitivity was improved compared to each method separately.

In practice, the sensitivity of detection of estrus is more important than its specificity because an examination and reconfirmation of estrus is performed before AI. Consequently, any false positives, animals not in estrus, can be rejected before AI is performed. A low positive predictive value is of course also undesirable for practical and economic reasons. On the other hand, undetected estrous periods are difficult to manage and are likely to increase costs due to animals having an increased number of days open. This means that the system used for detection of estrus requires a high negative predictive value (NPV) if AI is to be used successfully in commercial suckler herds. Unfortunately, the first ovulation postpartum in cattle is often reported to be silent [29]. Therefore, the NPV for detection of estrus will be expected to increase for both visual detection and AAMS after the first ovulation has occurred. In the present study, a parallel interpretation of the results of systematic visual observation and AAMS yielded the highest sensitivity, and consequently NPV.

Full compliance with the systematic visual detection regimen used in this study is unlikely to be achieved in a commercial operation. Reasons for this include different observer experience, reduced levels of objectivity, and often suboptimal observation facilities compared to the present study in which three highly motivated and experienced large animal veterinarians performed the observations as part of the study protocol. The AAMS is, however, objective, independent of observation facilities and time efficient, although it requires a considerable financial investment.

Animals in anestrus were responsible for most of the visually falsely identified estrous periods, and the likelihood of correctly identifying Herefords in estrus by visual detection would be increased if all females have commenced luteal activity before the beginning of the breeding period. This emphasizes the importance of well-organized herd management, such as nutritional management and planned calving and voluntary waiting period, which potentially increases the importance of advisory services on these farms [7,30]. Furthermore, checking the ovarian status of females at the start of the breeding season could be a useful exercise to exclude prepubertal heifers, reveal cows in anestrus, or with ovarian or uterine

Table 3
Survival statistics for 50 estrous periods for both visual detection of estrus and automatic activity monitoring system (AAMS)–alarmed estrus to ovulation in a Hereford herd.

Detection method	Category	Time at risk, h	Females	Estrous periods[a]	Survival time, h		
					Median	25%	75%
Visual observation	Total	924	24	40	21	13	29
	Heifers	387	9	16	28	13	29
	Cows	537	15	24	21	13	29
AAMS alarm	Total	1076	28	50	23	19	27
	Heifers	383	9	18	25	11	29
	Cows	693	19	32	23	19	25

[a] One estrous period in a cow was censored at 17 h of follow-up in both the visual and AAMS groups.

disorders, hence securing a concentrated calving pattern. It is also important to be aware of the fact that female cattle might exhibit estrous behavior also after conception [31].

4.2. Estrus to ovulation interval

The median estrus to ovulation interval was shorter in this study than the 27 to 31 hours and 26 to 30 hours reported in similar studies performed in beef and dairy herds [28,32–36], irrespective of the method used in this study to detect estrus. The differences found between the studied herd and dairy cattle may be due to genetics, presence of progeny with dam, or less metabolic stress in beef cattle [7,37,38].

In this study, 50% of the ovulations (IQR) occurred within 19 to 27 hours after detection of estrus with AAMS and 21 to 29 hours after detection of estrus visually. Optimal timing of AI relative to estrus is important to maximize reproductive success. It is a trade-off between low fertilization rate and high embryo quality when inseminated early, and high fertilization rate and low embryo quality when inseminated late [39–41]. Optimal time for AI has been reported to be 6 to 24 hours before ovulation [5], 5 to 17 hours after increase in activity, and 2 to 14 hours after the commencement of standing to be mounted [42]. A study of beef cattle found optimal time of AI to be 20 to 21 hours after detection of estrus [17]. The current recommendation for performing AI in Norwegian cattle is 9 to 24 hours after start of increased activity [9]. However, the time from detection of estrus to ovulation seen in the present study would indicate that AI should be performed approximately 6 hours after detection of estrus to maximize reproductive performance.

In dairy cattle, it is reported that heifers ovulate a little earlier after the onset of estrus than cows [31,43]. Studies performed in beef cattle have shown similar trends reporting an interval of 27 and 31 hours from onset of estrous activity to ovulation for heifers and cows, respectively [4,44]. However, the estimated estrus to ovulation interval in this study did not differ between heifers and cows, which is in accordance with some earlier studies [45].

If visual detection of estrus was to occur less frequently than thrice daily, it is likely that the time from detection to ovulation would be shorter and that fewer estrous periods would be detected. This might mean that reproductive performance could be maximized if AI was performed immediately after the detection of estrus, particularly if estrus was detected at night when waiting means delaying insemination to the day after. In Norway, most inseminations are performed by veterinary surgeons (65%) or technicians (32%) [46], and for an insemination to be performed the same day orders must be placed before 10 AM. In practice, this means that many beef heifers and cows would have already ovulated at the time of AI. Therefore, producer AI or timed AI after estrus synchronization might be necessary to achieve acceptable results from AI in Norwegian commercial cow–calf operations.

4.3. Methodological considerations

The results from this observational study have a high internal validity as the study population included all eligible females in the herd, and detailed, standardized, observations were performed by the same researchers throughout the study. Previous studies have found that stress can delay ovulation, and repeated transrectal examinations could have been stressful for some, or all, of the animals involved [47]. However, the study was observational in nature, and the herd stayed in their familiar environment and were handled as they were accustomed during the study. Therefore, it is unlikely the timing of ovulation was affected by stress.

The activity level and temperament of Hereford cattle differs from other breeds [48], which might influence the estrus to ovulation period. The number of females in estrus at the same time is also important for the expression of estrus, hence the size of the groups has to be taken into consideration [1]. Furthermore, flooring facilities [49] or general high incidence of lameness in the herd [7,50] are examples of factors that may alter general activity, expression of estrus, and time to ovulation relative to estrus [51]. The results are likely to be valid for other Hereford cows in similar production systems. However, extrapolation to other beef breeds in other production systems should be performed with caution.

4.4. Conclusions

In the studied Hereford herd, the AAMS identified more estrous periods than structured thrice-daily detection of estrus. The AAMS did not detect all females in estrus, but those with an AAMS-detected estrus were very likely to actually be in heat. The time from detection of estrus to ovulation found in this study indicates that inseminations of Hereford suckler cows might result in a higher risk of pregnancy if performed closer to estrus, approximately 6 hours after detection, than is currently recommended for Norwegian dairy cattle although further research is required to investigate this.

Acknowledgments

Animalia (the Norwegian Meat and Poultry Research Center), Nortura SA, Tyr (Norwegian Beef breeders Association), Geno, the Foundation for Research Levy on Agricultural Products/Agricultural Agreement Research Fund, grant no. 233683/E50 “Optibeef—Increased meat production from beef cattle herds,” and the Section for Herd Health and Field Service, Norwegian University of Life Sciences, Oslo, Norway, are acknowledged for providing financial support for this study. The authors are grateful to the Götala staff for their contribution to this project.

References

[1] Floyd L, Lents C, White F, Wettemann R. Effect of number of cows in estrus and confinement area on estrous behavior of beef cows. J Anim Sci 2009;87:1998–2004.
[2] Hurnik JF, King GJ. Estrous behavior in confined beef cows. J Anim Sci 1987;65:431–8.
[3] Jaiswal RS, Singh J, Marshall L, Adams GP. Repeatability of 2-wave and 3-wave patterns of ovarian follicular development during the bovine estrous cycle. Theriogenology 2009;72:81–90.

[4] White FJ, Wettemann RP, Looper ML, Prado TM, Morgan GL. Seasonal effects on estrous behavior and time of ovulation in nonlactating beef cows. J Anim Sci 2002;80:3053–9.
[5] Arthur GH, Noakes DE, Pearson H, Parkinson TJ. Veterinary reproduction and obstetrics. Seventh edition. London: WB Saunders; 1996.
[6] Dobson H, Walker SL, Morris MJ, Routly JE, Smith RF. Why is it getting more difficult to successfully artificially inseminate dairy cows? Animal 2008;2:1104–11.
[7] Crowe MA. Resumption of ovarian cyclicity in post-partum beef and dairy cows. Reprod Domest Anim 2008;43:20–8.
[8] Animalia. Kjøttets tilstand, 2013, (English: "Norwegian Meat and Egg Production—Annual report 2013"). Oslo: Norwegian Meat and Poultry Research Centre; 2014.
[9] GENO. Geno SA, Annual report 2013 (Geno SA, The breeding organization of the cattle breed Norwegian Red. Norwegian: "Geno—Årsberetning og regnskap 2013") 2013. p. 1–56. Hamar, Norway.
[10] Howard WH, Cranfield J. Ontario beef producers' attitudes about artificial insemination. Can J Agric Econ 1995;43:305–14.
[11] Roelofs JB, van Erp-van der Kooij E. Estrus detection tools and their applicability in cattle: recent and perspectival situation. Anim Reprod 2015;12:498–504.
[12] Kamphuis C, DelaRue B, Burke CR, Jago J. Field evaluation of 2 collar-mounted activity meters for detecting cows in estrus on a large pasture-grazed dairy farm. J Dairy Sci 2012;95:3045–56.
[13] Lamb GC, Mercadante VR. Synchronization and artificial insemination strategies in beef cattle. Vet Clin North Am Food Anim Pract 2016;32:335–47.
[14] Dutil L, Fecteau G, Bouchard E, Dutremblay D, Pare J. A questionnaire on the health, management, and performance of cow-calf herds in Québec. Can Vet J 1999;40:649–55.
[15] Lamb GCM, Mercadante VRG, Henry DD, Fontes PLP, Dahlen CR, Larson JE, et al. Invited review: advantages of current and future reproductive technologies for beef cattle production. Prof Anim Sci 2016;32:162–71.
[16] Opsomer G, Leroy J, Vanholder T, Bossaert P, de Kruif A. Optimizing dairy cow reproductive performances besides the use of hormones. 24th World Buiatrics Congress. Nice 2006. p. 484–492.
[17] Robbins RK, Sullivan JJ, Pace MM, Elliott FI, Bartlett DE, Press PJ, et al. Timing the insemination of beef cattle. Theriogenology 1978;10:247–55.
[18] Xu Z, McKnight D, Vishwanath R, Pitt C, Burton L. Estrus detection using radiotelemetry or visual observation and tail painting for dairy cows on pasture. J Dairy Sci 1998;81:2890–6.
[19] Spörndly R. Fodertabeller för idisslare 2003 (In English: "Feed tables for ruminants, 2003"). Sixth edition. Uppsala, Sweden: Swedish University of Agricultural Sciences, Department of Animal Nutrition and Management; 2003.
[20] Herd DB, Sprott LR. Body condition, nutrition and reproduction of beef cows. Texas Agricultural Extension Service, 1998, Texas A&M Univerisy system, College Station, Texas.
[21] Van Eerdenburg FJCM, Loeffler HSH, Van Vliet JH. Detection of oestrus in dairy cows: a new approach to an old problem. Vet Q 1996;18:52–4.
[22] Dohoo I, Stryhn H, Martin W. Veterinary epidemiologic research. Second edition. Charlottetown: VER Inc.; 2009.
[23] Martin AD, Lystad ML, Reksen O, Ropstad E, Waldmann A, Nafstad O, et al. Assessment of progesterone profiles and postpartum onset of luteal activity in spring calving Hereford beef suckler cattle. Acta Vet Scand 2010;52:42–50.
[24] Rorie R, Bilby T, Lester T. Application of electronic estrus detection technologies to reproductive management of cattle. Theriogenology 2002;57:137–48.
[25] Van Vliet JH, Van Eerdenburg FJCM. Sexual activities and oestrus detection in lactating Holstein cows. Appl Anim Behav Sci 1996;50:57–69.
[26] Aungier SPM, Roche JF, Sheehy M, Crowe MA. Effects of management and health on the use of activity monitoring for estrus detection in dairy cows. J Dairy Sci 2012;95:2452–66.
[27] Chanvallon A, Coyral-Castel S, Gatien J, Lamy J-M, Ribaud D, Allain C, et al. Comparison of three devices for the automated detection of estrus in dairy cows. Theriogenology 2014;82:734–41.
[28] Valenza A, Giordano JO, Lopes G, Vincenti L, Amundson MC, Fricke PM. Assessment of an accelerometer system for detection of estrus and treatment with gonadotropin-releasing hormone at the time of insemination in lactating dairy cows. J Dairy Sci 2012;95:7115–27.
[29] Murphy MG, Boland MP, Roche JF. Pattern of follicular growth and resumption of ovarian activity in post-partum beef suckler cows. J Reprod Fertil 1990;90:523–33.
[30] Bossis I, Wettemann RP, Welty SD, Vizcarra J, Spicer LJ. Nutritionally induced anovulation in beef heifers: ovarian and endocrine function during realimentation and resumption of ovulation. Biol Reprod 2000;62:1436–44.
[31] Hall J, Branton C, Stone E. Estrus, estrous cycles, ovulation time, time of service, and fertility of dairy cattle in Louisiana. J Dairy Sci 1959;42:1086–94.
[32] Hockey CD, Morton JM, Norman ST, McGowan MR. Evaluation of a neck mounted 2-hourly activity meter system for detecting cows about to ovulate in two paddock-based Australian dairy herds. Reprod Domest Anim 2010;45:e107–17.
[33] Roelofs JB, van Eerdenburg FJ, Soede NM, Kemp B. Various behavioral signs of estrous and their relationship with time of ovulation in dairy cattle. Theriogenology 2005;63:1366–77.
[34] Roelofs JB, van Eerdenburg FJ, Soede NM, Kemp B. Pedometer readings for estrous detection and as predictor for time of ovulation in dairy cattle. Theriogenology 2005;64:1690–703.
[35] Stevenson JS, Hill SL, Nebel RL, DeJarnette JM. Ovulation timing and conception risk after automated activity monitoring in lactating dairy cows. J Dairy Sci 2014;97:4296–308.
[36] Walker WL, Nebel RL, McGilliard ML. Time of ovulation relative to mounting activity in dairy cattle. J Dairy Sci 1996;79:1555–61.
[37] Stagg K, Diskin MG, Sreenan JM, Roche JF. Follicular development in long-term anoestrous suckler beef cows fed two levels of energy postpartum. Anim Reprod Sci 1995;38:49–61.
[38] Stagg K, Spicer L, Sreenan J, Roche J, Diskin M. Effect of calf isolation on follicular wave dynamics, gonadotropin and metabolic hormone changes, and interval to first ovulation in beef cows fed either of two energy levels postpartum. Biol Reprod 1998;59:777–83.
[39] Dalton J, Nadir S, Bame J, Noftsinger M, Nebel R, Saacke R. Effect of time of insemination on number of accessory sperm, fertilization rate, and embryo quality in nonlactating dairy cattle. J Dairy Sci 2001;84:2413–8.
[40] Saacke R, Dalton J, Nadir S, Nebel R, Bame J. Relationship of seminal traits and insemination time to fertilization rate and embryo quality. Anim Reprod Sci 2000;60:663–77.
[41] Sales J, Neves K, Souza A, Crepaldi G, Sala R, Fosado M, et al. Timing of insemination and fertility in dairy and beef cattle receiving timed artificial insemination using sex-sorted sperm. Theriogenology 2011;76:427–35.
[42] Roelofs JB, Graat EAM, Mullaart E, Soede NM, Voskamp-Harkema W, Kemp B. Effects of insemination–ovulation interval on fertilization rates and embryo characteristics in dairy cattle. Theriogenology 2006;66:2173–81.
[43] Noakes DE, Parkinson TJ, England GC. Veterinary reproduction and obstetrics. Ninth edition. Edinburgh: Elsevier Health Sciences; 2009.
[44] Lynch CO, Kenny DA, Childs S, Diskin MG. The relationship between periovulatory endocrine and follicular activity on corpus luteum size, function, and subsequent embryo survival. Theriogenology 2010;73:190–8.
[45] Orihuela A. Some factors affecting the behavioural manifestation of oestrus in cattle: a review. Appl Anim Behav Sci 2000;70:1–16.
[46] GENO. Inseminering (English: "Insemination"). Geno SA; 2015. http://www.geno.no/Start/Brunst/SEMINTJENESTE1/Inseminering/ [accessed 22.09.16].
[47] Morris MJ. Stress and subfertility in dairy cows [Ph.D Diss.]. Liverpool: University of Liverpool; 2008.
[48] Morris CA, Cullen NG, Kilgour R, Bremner KJ. Some genetic factors affecting temperament in Bos taurus cattle. N Z J Agric Res 1994;37:167–75.
[49] Lopez H, Shipka MP. Association of flooring surface to estrous behavior in lactating dairy cows as determined by radiotelemetric estrous detection. 5th International Dairy Housing Conference for 2003. Fort North, Texas: American Society of Agricultural and Biological Engineers; 2003. p. 296–302.
[50] Sood P, Nanda AS. Effect of lameness on estrous behavior in crossbred cows. Theriogenology 2006;66:1375–80.
[51] Morris M, Kaneko K, Walker S, Jones D, Routly J, Smith R, et al. Influence of lameness on follicular growth, ovulation, reproductive hormone concentrations and estrus behavior in dairy cows. Theriogenology 2011;76:658–68.

II

Preventive Veterinary Medicine 125 (2016) 59–65

Contents lists available at ScienceDirect

Preventive Veterinary Medicine

journal homepage: www.elsevier.com/locate/prevetmed

A cross-sectional study of factors associated with birth weights of Norwegian beef calves

Sindre T. Nelson*, Adam D. Martin, Ingrid H. Holmøy, Knut Karlberg, Ane Nødtvedt

Department of Production Animal Clinical Sciences, Faculty of Veterinary Medicine and Biosciences, Norwegian University of Life Sciences, Oslo, Norway

ARTICLE INFO

Article history:
Received 30 September 2015
Received in revised form 4 January 2016
Accepted 6 January 2016

Keywords:
Bovine
Cattle
Management
Recording system
Suckler cows
Offspring

ABSTRACT

A cross-sectional study was performed to evaluate factors which influence birth weights of beef suckler calves in Norway. Data were from a national beef cattle registry, and lifetime production data of cows slaughtered between January 2010 and January 2013 were included in the study population. The study population consisted of 20,541 cows and 53,819 calves. The analysis was performed on the subset of singleton calvings from which birth weights were recorded. The study sample consisted of 9903 cows with birth weights available for 29,294 calves. The mean birth weight was 43.47 kg (95% CI 43.40; 43.53). Two multilevel linear regression models were built; the first was for all calves and included parity of dam as one of the explanatory variables (with herd and cow as random effects), the second model was for calves born to primiparous dams only where age of first calving was included as an explanatory variable (with a random herd effect). The multilevel regression models estimated that female calves were 2.3 kg lighter than males (95% CI 2.2–2.4, $P < 0.001$), that calves of Norwegian Red, Charolais, Aberdeen Angus and "Other" born in the western part of Norway were lighter than from all other regions, and that calving in the autumn yielded lighter offspring than calving other parts of the year. Furthermore, calves born from primiparous cows were heavier than calves from older cows. Herd explained a large proportion of the variation in birth weights (40% and 37%, in the full and heifer models, respectively), and both the herd and cow random effects were highly significant. In conclusion, birth weights of beef calves in the Norwegian Beef Cattle Recording System were influenced by sex of the calf, breed of the dam, parity, age at first calving, calving season, cow, herd and region.

1. Introduction

There is no tradition for specialized beef production in Norway, where milk and meat for the domestic market have traditionally been produced by dual purpose Norwegian Red cattle. Over the past two decades, improvements in the breeding and management of Norwegian dairy cows have resulted in considerably higher milk yields per cow leading to a decrease in the size of the national dairy population, but still filling the nationally regulated milk quota (Kumbhakar et al., 2008). Beef is a by-product of the dairy industry and the reduction in the national dairy herd has led to a reduction in beef production in Norway. Concurrently the human population has increased and beef consumption has increased. Consequently, in 2012 more than 22% of the annual consumption of beef was imported into Norway (Animalia, 2013a). If domestically produced beef is to meet consumer demand, which is a political goal, the number of beef cattle must increase substantially over the next decade and their productivity must be improved (Ruud et al., 2013). Norwegian beef producers, as well as their veterinarians and advisors, therefore need information regarding factors affecting productivity in the national beef herd in order to increase the output in a sustainable manner.

In specialized beef production the successful rearing of calves for slaughter and replacement of breeding stock is a key factor determining herd profitability. Economic studies of the functional traits of beef production showed that fertility was the most important trait for sustainable suckler cow operations (Prince et al., 1987; Diskin and Kenny, 2014).

The optimal size of a calf will vary depending on the breed and parity of the dam, and there must be a balance between being large enough to be healthy and robust and not being so large as to cause dystocia. Birth weight is reported to be the single most important risk-factor for occurrence of dystocia (Nix et al., 1998; Bellows and Lammoglia, 2000), and dystocia can affect both the cow and calf

* Corresponding author at: Department of Production Animal Clinical Sciences, Faculty of Veterinary Medicine and Biosciences, Norwegian University of Life Sciences, P.O. Box 8146 Dep., N-0033 Oslo, Norway. Fax: +47 22597083.
E-mail address: sindre.nelson@nmbu.no (S.T. Nelson).

http://dx.doi.org/10.1016/j.prevetmed.2016.01.011
0167-5877/

Table 1
Generation of the study sample in a cross-sectional study of birth weights among Norwegian beef calves based on the Norwegian Beef Cattle Recording System (NBCRS) database.

Herds (*n*)	Cows (*n*)	Calves (*n*)	Explanation
2176	20,541	62,813	Study population, extracted animals from the NBCRS
	−55	−234	Excluded: obvious recording errors
		−1459	Excluded: twin calves
	−661	−2245	Excluded: age at first calving below 1.5 or over 3.6 years
	−1875	−5056	Excluded: first calving missing in NBCRS
	17,950	53,819	
		−24,525	Birth weight missing
1192	9903	29,294	Study sample

negatively and in severe cases lead to loss of both. Dystocia is further known to negatively impact fertility in the post-partum period leading to increased occurrence of uterine disease, delays in onset of luteal activity and extended calving intervals (Zaborski et al., 2009). Calf birth weight has also been shown to influence days open in Norwegian Hereford herds (Martin et al., 2010). The factors influencing birth weights of beef calves are not fully known, but both genetic and environmental factors are involved (Holland and Odde, 1992). Important factors influencing birth weights include: parity, fetal sex, sire and dam breed, maternal nutrition and climate during last trimester (Mee, 2008). Furthermore, differences between the geographical regions of Norway might potentially influence birth weights through differences in management, climate and/or nutrition. Understanding the variability in birth weights in Norwegian beef suckler herds, and the mechanisms behind this variability, can be a means to optimizing the production. The aim of this study was therefore to document the distribution of birth weights among beef suckler calves in Norway, and to evaluate factors associated with birth weights at the individual calf level. The factors of interest were sex of the calf, breed, region, damís age at first calving, calving season, parity, cow and herd.

2. Materials and methods

2.1. Study population

The data used in this study were extracted from the Norwegian Beef Cattle Recording System (NBCRS). Producer membership in the NBCRS is voluntary, but more than 78% (n = 66,584) of Norwegian beef suckler cows, representing 57% (n = 2428) of the Norwegian beef herds, were enrolled at the end of 2012 (Animalia, 2013b). In the NBCRS animals are identified by a unique 12-digit number, where 8 digits identify the location of farm of origin and 4 digits identify the individual, and all the cattle must be ear-tagged with this number in accordance to EU-legislation EF 1760/2000. The database further includes individual animal information regarding date of birth, sex, breed, herd (current and of origin), ancestry, slaughter date and slaughter quality. Producers are encouraged to record weights at certain ages, e.g., at birth and 200 days of age, calving difficulties and animal losses other than slaughter.

Data on all adult cows slaughtered between 1st of January 2010 and 23rd of January 2013 were extracted from the NBCRS (Table 1). Only cows registered with a least one progeny were kept in the initial extraction along with all data of their offspring, including those born before herd membership in the NBCRS. The data set was screened for illogical observations, obvious typing errors and duplicates, and when found these were omitted. If only one obvious error occurred in the records of a cow with many parities the single offspring was removed. However, if errors occurred more than once, all the registrations concerning the cow and her progeny were deleted. Data from cows with age at first calving below 1.5 years and cows with age at first calving over 3.6 years of age where excluded from the analyses.

2.2. Outcome and explanatory variables

The outcome variable of interest was the birth weight of each calf and the explanatory variables included were cow identity, sex of the calf, breed of the dam, region, age of dam at first calving, season of calving, parity of the cow and herd of birth. The breed of each animal was defined as purebred if the animal was registered genetically as 15/16 parts (or more) of the same breed, calculated from the breed composition of parents, grand- and great grandparents. If less than 15/16 parts purebred, animals were coded as crossbreed. The breed variable was retained for the most important breeds; Norwegian Red, Hereford, Charolais, Aberdeen Angus, Limousin and Simmental, while the less numerous breeds were merged into a pooled category; "Other". The Other category consisted of the breeds Jersey, Sided Troender/Northland cattle, Telemark cattle, Doela cattle, Old Norwegian Red Polled, Norwegian South- and Western cattle, Norwegian Western Fjord cattle, Holstein, Danish Red, Blond d'Aquitaine, Highland Cattle, Tiroler Gray, Dexter, Piemontese, Galloway and cross-breeds. The herds' locations were grouped into five geographical regions of Norway which are also used for the regulation of movements of cattle livestock; Costal Southeast, Inland Southeast, Western, Mid- and, Northern Norway, respectively. Age at first calving was defined by subtracting birth date from first calving date. Parity was defined by the sequence of calvings for each cow in the dataset. For twin calvings, the birth weights of both twins were excluded from the analysis but the calving still gave rise to an increase in parity. Parity was coded individually for the first 6 parities, while subsequent parities were pooled as greater than 6th due to the low number of observations in this group. Season of calving was dichotomized based on month of partum. "Spring calving" was defined as births between first of February and the end of July while the "Autumn calving" season was set to the first of August to the end of January. The unit of observation was the calving, and because several sequential offspring could be registered from each cow these observations were not independent of each other, which needed to be taken into account during analysis. Cows were further clustered within herds, which were located within regions.

2.3. Statistical methods

The generation of the initial database from the NBCRS was performed using SAS 9.2 (SAS Institute Inc., Cary, NC, USA). Further data management and statistical analysis was performed using Stata SE/12 (Stata Corp., College Station, TX, USA).

The mean birth weights, with standard errors and 95% confidence intervals (CI), for offspring were calculated overall and for sub-groups defined by sex, breed, region, age at first calving, season of calving and parity. Two multilevel linear regression models were built; one for all animals (with herd and cow as random effects) which included parity as an explanatory variable, and a second model for first calvings only where age of (first) calving was included as an explanatory variable and with a herd random effect. The command *xtmixed* in Stata was used, assuming equal correlations between animals within a herd and hence applying a *compound symmetry* correlation structure. Variables were tested in the multilevel linear regression models with a manual backward stepwise regression strategy until all included variables were significant at a P-value of $\leq$0.01. Potential confounding variables were identified a priori through the construction of a causal diagram. Variables considered potential confounders were tested running the model with and without the variables in question and changes in estimates were explored. Overall significance of groups of categorical variables, e.g., breed and region, were tested using likelihood ratio tests. The amount of variation present at each level in the hierarchical models (calving/cow/herd) was calculated. Biologically plausible interaction effects between statistically significant explanatory variables were tested by adding interaction terms to the main-effects model. The cut-off for keeping an interaction term in the model was set to $P < 0.01$. When significant interactions were present, the effects were estimated and compared for subgroups defined by combinations of different levels of the interacting variables.

The linearity of the association between outcome and explanatory variables was assessed through a locally weighted scatterplot smoother. After the regression process, the assumption of normally distributed residuals was assessed through a normal quantile plot of standardized residuals at all levels of the models in question. The final model raw and standardized residuals were plotted against predicted values at all levels of the model in question to check for heteroscedasticity as well as for potential outliers. Assessment of multicollinearity was based on variance inflation factors provided by a regression analysis including all predictors of the final models.

3. Results

3.1. Study population

Table 1 states the number of animals and herds originally available for inclusion from the NBCRS (cows: $n = 20{,}541$ and calves: $n = 62{,}813$), the numbers that were excluded in order to obtain the study sample of 9903 cows and 29,294 calves, as well as brief descriptions of the reasons for exclusion. The study sample included 29,294 calves with a recorded birth weight, which was 54.4% of the calves in the study population. The number of observations per group and the mean birth weights by sex, breed, region, age at first calving, birth season and parity are presented in Table 2 (for all calves) and Table 3 (for calves of primiparous dams only). The mean birth weight of the calves was 43.47 kg (95% CI 43.40; 43.53).

3.2. Model including all animals

Results from the multivariable model including all animals are given in Table 4. The regression model estimated that female calves were 2.3 kg lighter than males ($P < 0.001$) and that calvings in the autumn yielded 0.5 kg lighter offspring than spring calvings ($P < 0.001$). Furthermore, calves born from primiparous animals were heavier than calves from older animals ($P < 0.001$).

Table 2
A descriptive presentation of the Norwegian Beef Cattle Recording System study population, all calves included. The number (n), mean birth weight of calves (kg) and 95% confidence interval (CI) are presented for the subgroups sex, dam breed, region of birth, the dams age at calving, birth season, and dam parity. The table includes 29,294 calves with birthweights, born to 9903 dams from 1192 herds.

Variable	Level	n	Mean	95% CI
Sex	Male	14,641	44.6	44.5; 44.7
	Female	14,653	42.3	42.2; 42.4
Dam breed	Norwegian Red	2386	43.9	43.7; 44.2
	Hereford	7507	42.9	42.7; 43.0
	Charolais	7682	45.6	45.5; 45.8
	Aberdeen Angus	4428	40.4	40.3; 40.6
	Limousin	3911	43.3	43.2; 43.5
	Simmental	1649	45.6	45.3; 45.8
	Other[a]	1731	42.0	41.7; 42.4
Region of Norway	Costal Southeast	8753	43.4	43.3; 43.5
	Inland Southeast	8375	43.7	43.6; 43.8
	Western	3594	42.1	41.9; 42.3
	Mid	6529	44.0	43.8; 44.1
	North	2043	43.5	43.3; 43.8
Age of dam at first calving	≤2.5 years	27,632	43.5	43.4; 43.6
	>2.5 years	1662	42.9	42.6; 43.1
Birth season	February–July	24,124	43.5	43.4; 43.6
	August–January	5170	43.3	43.1; 43.4
Parity of dam	1st	8738	43.9	43.7; 44.0
	2nd	6085	43.4	43.3; 43.6
	3rd	4362	43.1	43.0; 43.3
	4th	3192	43.4	43.2; 43.6
	5th	2301	43.3	43.1; 43.6
	6th	1648	43.2	42.9; 43.5
	>6th	2968	43.3	43.1; 43.5

[a] Includes crossbreds, unknown breeds, Dexter, Galloway, Blonde d'Aquitaine, Highland cattle and various local breeds.

Table 3
A descriptive presentation of the Norwegian Beef Cattle Recording System study population, calves of primiparous dams only. The number (n), mean birth weight of calves (kg) and 95% confidence interval (CI) are presented for the subgroups sex, dam breed, region of birth, the dams age at calving, birth season, and dam parity. The table includes 17,950 calves with birthweights, born to 8738 dams from 1098 herds.

Variable	Level	n	Mean	95% CI
Sex	Male	4295	45.0	44.9; 45.2
	Female	4443	42.7	42.6; 42.9
Dam breed	Norwegian Red	739	43.8	43.4; 44.3
	Hereford	2058	43.3	43.1; 43.5
	Charolais	2470	45.6	45.4; 45.8
	Aberdeen Angus	1199	41.2	40.9; 41.5
	Limousin	1256	43.7	43.4; 44.0
	Simmental	483	45.8	45.2; 46.3
	Other[a]	533	42.5	41.9; 43.1
Region of Norway	Costal Southeast	2336	43.7	43.4; 43.9
	Inland Southeast	2599	44.0	43.8; 44.3
	Western	1112	42.7	42.4; 43.1
	Mid	2026	44.3	44.1; 44.6
	North	665	44.2	43.8; 44.7
Age of dam at first calving	≤2.5 years	7076	44.1	43.9; 44.2
	>2.5 years	1662	42.9	42.6; 43.1
Birth season	February–July	7059	43.9	43.8; 44.0
	August–January	1679	43.6	43.3; 43.9

[a] Includes crossbreds, unknown breeds, Dexter, Galloway, Blonde d'Aquitaine, Highland cattle and various local breeds.

There was an interaction between breed and region, i.e., the effect of breed of dam was dependent on which region of Norway the calf was born in, and vice versa. Based on results from the multivariable model including the interaction, estimated birth weights were calculated for all combinations of breed and region of Norway,

Table 4
Variables significantly associated with birth weights of Norwegian beef calves. Multivariable estimates, 95% confidence intervals (CI) and *P*-values from a multilevel linear regression model. Herd and cow random effects were applied to account for intra-herd and intra-cow correlation. The analysis included 29,294 calves born from 9903 cows in 1192 Norwegian beef herds.

Variable	Levels	Estimates	95% CI	*P*
	Intercept	44.9	44.1; 45.6	<0.001
Sex	Male	Baseline		
	Female	−2.3	−2.4; −2.2	<0.001
Region of Norway[b]	Costal Southeast	Baseline		
	Inland Southeast	0.0	−1.0; 0.9	0.931
	Western	−0.6	−1.7; 0.6	0.326
	Mid	0.7	−0.2; 1.7	0.139
	North	−0.5	−1.9; 0.9	0.502
Dam breed[c]	Norwegian Red	Baseline		
	Hereford	−0.2	−0.9; 0.4	0.462
	Charolais	0.2	−0.4; 0.9	0.536
	Aberdeen Angus	−1.0	−1.8; −0.2	0.014
	Limousin	0.0	−0.7; 0.7	0.977
	Simmental	−0.3	−1.3; 0.8	0.634
	Other[a]	−0.9	−1.7; −0.1	0.035
Dam breed × Region[d]	Hereford × Costal S.	Baseline		
	Hereford × Inland S.	0.0	−0.9; 0.9	1
	Hereford × Western	1.0	−0.1; 2.2	0.085
	Hereford × Mid	−0.2	−1.1; 0.7	0.641
	Hereford × North	0.8	−0.5; 2.1	0.204
	Charolais × Costal S.	Baseline		
	Charolais × Inland S.	−0.2	−1.1; 0.7	0.733
	Charolais × Western	0.0	−1.1; 1.2	0.941
	Charolais × Mid	0.1	−0.8; 1.0	0.898
	Charolais × North	1.4	0.0; 2.8	0.057
	A. Angus × Costal S.	Baseline		
	A. Angus × Inland S.	1.0	−0.1; 2.0	0.079
	A. Angus × Western	−1.3	−2.6; −0.1	0.04
	A. Angus × Mid	0.1	−1.0; 1.2	0.863
	A. Angus × North	0.7	−0.9; 2.2	0.401
	Limousin × Costal S	Baseline		
	Limousin × Inland S.	−0.2	−1.2; 0.8	0.658
	Limousin × Western	0.6	−0.6; 1.9	0.322
	Limousin × Mid	−0.5	−1.6; 0.6	0.384
	Limousin × North	0.0	−1.8; 1.9	0.982
	Simmental × Costal S.	Baseline		
	Simmental × Inland S.	0.6	−0.8; 1.9	0.4
	Simmental × Western	0.8	−1.2; 2.9	0.418
	Simmental × Mid	0.0	−1.4; 1.4	0.999
	Simmental × North	−0.3	−2.6; 2.0	0.809
	Other[a] × Costal S.	Baseline		
	Other[a] × Inland S.	−0.3	−1.4; 0.9	0.654
	Other[a] × Western	−0.1	−1.5; 1.3	0.881
	Other[a] × Mid	0.3	−0.8; 1.5	0.58
	Other[a] × North	1.4	−0.4; 3.2	0.139
Birth season	February–July	Baseline		
	August–January	−0.5	−0.7; −0.4	<0.001
Parity of dam[e]	1st	Baseline		
	2nd	−0.4	−0.5; −0.2	<0.001
	3rd	−0.6	−0.8; −0.5	<0.001
	4th	−0.3	−0.5; −0.1	<0.001
	5th	−0.3	−0.5; −0.1	0.009
	6th	−0.4	−0.6; −0.1	0.002
	>6th	0.1	−0.1; 0.3	0.5
Variance herd		14.2	12.6; 15.8	
Variance cow		3.8	3.5; 4.1	
Variance residual		17.4	17.4; 17.0	

[a] Includes crossbreds, unknown breeds, Dexter, Galloway, Blonde d'Aquitaine, Highland cattle and various local breeds.
[b] LRT = $P < 0.01$.
[c] LRT = $P < 0.001$.
[d] LRT = $P < 0.001$.
[e] LRT = $P < 0.001$.

shown in Fig. 1. Calves of Norwegian Red, Charolais, Aberdeen Angus and "Other" born in the western part of Norway were lighter than equivalent calves from all other regions—this effect was most pronounced for Aberdeen Angus calves. Calves from Charolais dams

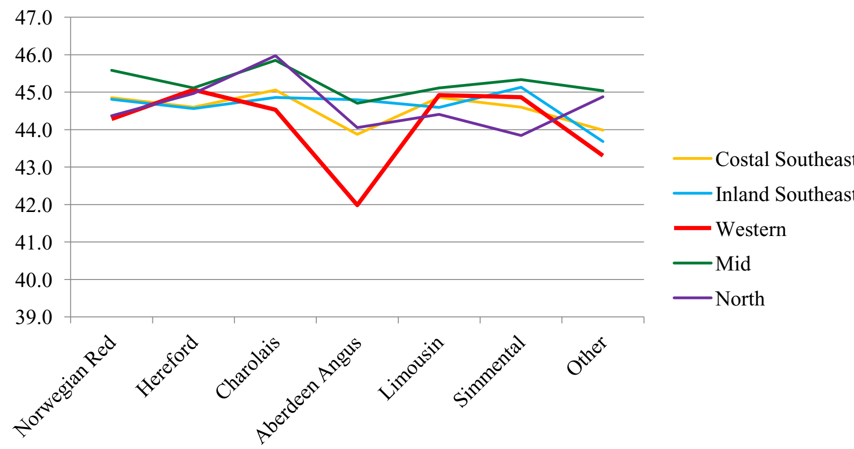

Fig. 1. Estimated birth weights (kg) of spring-born male calves born to first parity cows for combinations of breed and region. Estimated birth weights were based on the multivariable adjusted estimates from the mixed-effects linear regression model in Table 3 ($n = 9903$).

were heaviest, except those born in Western Norway where Hereford calves were heaviest. Both the herd and cow random effects were highly significant. Herd explained 40% of the variation in birth weights, whereas 11% of the variation was explained by the cow level.

3.3. *Model including first calving only*

Results from the multivariable model including birth weights for calves born to first parity dams are given in Table 5. The heifer model was comparable to the full model in that it estimated that female calves were 2.3 kg lighter than males ($P < 0.001$) and that calvings in the autumn yielded 0.5 kg lighter offspring ($P < 0.001$). Calves born to beef breeds were lighter when born to heifers aged ≥2.5 years at calving compared to heifers aged <2.5 years at calving. Other factors significantly influencing birth weights from first parity animals were breed of dam, age at first calving and region. A significant interaction term between age at first calving and breed was present i.e., the effect of age at first calving was dependent on the breed of the dam. Across all breeds the calves were heavier when age at first calving was less than (or equal to) 2.5 years of age, however, the magnitude of the effect differed by breed. Based on results from the multivariable model, estimated birth weights were calculated for all combinations of age at first calving and dam breed (Table 6). The herd random effect was highly significant and explained 37% of the variation in birth weights.

4. Discussion

The difference in mean birth weight between male and female calves was found to be 2.3 kg in this study, which concurs with other studies (Andersen and Plum, 1965; Holland and Odde, 1992; Cundiff et al., 2010). The differences between the breeds regarding birth weight of calves in this study is also well known and described (Cundiff et al., 1993). Earlier studies have shown that the weights of dam and sire are positively correlated with the birth weight of their offspring (Bennett and Gregory, 1996). This study showed an interaction between breed and region which might indicate that certain breeds are better adapted to the climate and geography of specific regions. This interaction could be further explored for the purpose of providing better management advice to producers, such as choosing the best suited breed for each region.

The results show that birth weights of the calves from primiparous animals were higher than birth weights by multiparous cows. These results contradict the findings of most other studies which have reported that birth weights of calves born to primiparous dams are lighter than to those born to multiparous dams (Cundiff et al., 1992, 2010; Holland and Odde, 1992; Colburn et al., 1997; Johanson and Berger, 2003). Birth weights are related, among other factors, to gestation length and heifers normally have shorter gestation lengths than cows (Andersen and Plum, 1965; Johanson and Berger, 2003). Gestation length data were unavailable in the studied dataset and this association could not be explored further. It is possible that the retrospective method in which cows were included in this study has introduced some bias because of an age-period-cohort effect. The number of animals in the NBCRS database increased considerably during the study period from 63% to 78% of the suckler cow population (Animalia, 2013a) primarily due to legislative changes in Norway. Inclusion criteria for this study was that the dam had been slaughtered between January 2010 and January 2013, and that the cow came from a herd in the NBCRS database. Therefore, more primiparous animals became eligible for inclusion during the study period. Higher calf birth weight is a known risk factor for dystocia in heifers and adult cows (Nix et al., 1998; Berry et al., 2007) and the risk of slaughter in heifers is higher after dystocia (Rogers et al., 2004; Szabó et al., 2009). Consequently, the observed higher birthweights of calves born from the slaughtered heifers might be an effect of the expanding NBCRS-membership across the study-period and an over-representation of primiparous animals being culled following dystocia due to high birthweights. In order to try to account for this potential bias the variable of 'slaughter in parity X' was added to the multivariable model. However, the tendency for heavier calves being born to animals calving for the first time was still seen (analysis not shown).

In this study, calves born in the spring were heavier than those born in the autumn. This is consistent with earlier studies, where autumn born calves were lighter than the spring born calves in temperate zones (Johanson and Berger, 2003; Cundiff et al., 2010). However, other studies have reported that autumn born calves are the heaviest (Andersen and Plum, 1965; Holland and Odde, 1992). Researchers in Nebraska reported that calves born in colder climates were heavier than calves born in warmer climates (Colburn et al., 1997; Deutscher et al., 1999). The highest mean birth weights in this study were seen in the regions with the coldest climate, but this effect could also be mediated through regional differences in herd management factors such as feeding strategies and time of housing the herd for the winter.

Generally, this study found that the lowest birth weights were found in Western Norway and the highest in Mid-Norway. The Norwegian regions are naturally divided by geography, and the climate,

Table 5
Variables significantly associated with birth weights of Norwegian beef calves born to primiparous animals. Multivariable estimates, 95% confidence intervals (CI) and *P*-values from a multilevel linear regression model. A herd random effect was applied to account for intra-herd correlation. The analysis included calves born from 8738 heifers from 1098 Norwegian beef herds.

Variable	Levels	Estimates	95% CI	*P*
	Intercept	44.8	44.2; 45.5	<0.001
Sex	Male	Baseline		
	Female	−2.3	−2.5; −2.1	<0.001
Region of Norway[b]	Costal Southeast	Baseline		
	Inland Southeast	0.1	−0.6; 0.8	0.771
	Western	−0.8	−1.6; 0.0	0.048
	Mid	0.8	−0.1; 1.5	0.028
	North	0.4	−0.6; 1.4	0.405
Dam breed[c]	Norwegian Red	Baseline		
	Hereford	0.1	−0.4; 0.6	0.635
	Charolais	0.8	0.3; 1.3	0.003
	Aberdeen Angus	−0.8	−1.4; −0.2	0.008
	Limousin	0.6	0.1; 1.2	0.033
	Simmental	0.5	−0.3; 1.3	0.229
	Other[a]	−0.2	−0.8; 0.5	0.634
Age of dam at first calving	≤2.5 years	Baseline		
	>2.5 years	−0.5	−1.4; 0,4	0.263
Dam breed × age at first calving[d]	Hereford × >2.5 years	−0.8	−1.9; 0.3	0.147
	Charolais × >2.5 years	−0.3	−1.3; 0.7	0.555
	A. Angus × >2.5 years	−0.1	−1.3; 1.1	0.870
	Limousin × >2.5 years	−1.7	−2,8; −0.7	0.002
	Simmental × >2.5 years	−0.8	−2.2; 0.7	0.311
	Other[a] × >2.5 years	−1.6	−2.9; −0.2	0.021
Birth season	February–July	Baseline		
	August–January	−0.5	−0.8; −0.3	<0.001
Variance herd		12.4	10.8; 14.3	
Variance residual		21.5	20.1; 22.2	

[a] Includes crossbreds, unknown breeds, Dexter, Galloway, Blonde d'Aquitaine, Highland cattle and various local breeds.
[b] LRT: $P < 0.001$.
[c] LRT: $P < 0.005$.
[d] LRT: $P < 0.001$.

Table 6
Estimated birth weights (kg) of spring-born male calves for combinations of age at first calving and breed. Estimated birth weights were based on the multivariable estimates from the mixed-effects linear regression model in Table 5 ($n = 8738$).

Age at calving	Breed						
	Norwegian Red	Hereford	Charolais	Aberdeen Angus	Limousin	Simmental	Other[a]
≤2.5 years	44.3	43.9	44.6	43.0	44.4	44.3	43.7
>2.5 years	43.8	43.1	44.3	42.9	42.7	43.5	42.1

[a] Includes crossbreds, unknown breeds, Dexter, Galloway, Blonde d'Aquitaine, Highland cattle and various local breeds.

pasture use, and the soil mineral content differs between regions. Western Norway has the mildest climate with smaller temperature differences between the seasons, temperatures rarely drop below 0 °C and the levels of precipitation are high. The Mid-Norway region has greater differences in seasonal temperature, similar to those in eastern Norway, but higher precipitation and windier conditions are found here than in eastern Norway during the autumn (Anon., 2015). The effect of cold stress elevates the levels of the nutritional substances in the blood due to increased metabolism (Young, 1975), and increases the demand for energy. This might be particularly relevant if pregnant cattle are still in growth (Arango et al., 2002) and could potentially contribute to the differences in birth weights between breeds in different regions because the heavier breeds are expected to reach mature weight later. The observed interaction between breed and age at first calving might also be an effect of the different age at which lighter and heavier breeds reach mature weight. Regional differences in macro- and trace mineral concentration in pasture plants (Sivertsen et al., 2015) might also contribute to regional differences in calf birth weights.

The herd effect was large in this study, and could be influenced both by genetics and environment. The prevalence of use of artificial insemination (AI) in Norwegian beef cattle management is low, with less than 20% of cows receiving AI across all breed categories (Animalia, 2013a). Widespread use of local bulls might lead to a higher degree of shared genetic material within a beef suckler operation than what is common in Norwegian dairy herds, where AI use is almost 85% (Geno, 2013). Differences in management, including AI use, are hence likely to be important drivers behind the large herd effect observed. The direct heritability of birth weight is estimated to be between 30 and 50% (Simm, 1998; Eriksson et al., 2004). In this study, the paternal effect is included in the herd effect because the extensive use of on-farm bulls made it impossible to investigate the effect of sire and herd separately. The full model estimated that 11% of the variation in birth weights could be attributed to the effect of dam, controlling for breed, region, season, parity and sex (Table 4). The maternal heritability of birth weights is estimated to be 8–15% (Eriksson et al., 2004). Thus, the importance of choosing good breeding animals in beef suckler operations, and keeping good records of cow (and offspring) performance is a valuable tool for the herd in the animal selection process.

It can be assumed the study sample represents the Norwegian beef suckler population reasonably well. The database included 78% of beef suckler cows and 57% of the beef herds. Herds were located throughout Norway which makes the results relevant for the national beef cattle population. The results might also apply to small-scale beef suckler herds in other temperate areas. Membership in the NBCRS is voluntary and members might typically have a greater focus on production goal improvement compared to non-member producers. Thus, our sample of herds might be biased towards including farms that were more focused on production targets than the 'average' producer. However, non-members are probably less likely to be in the target group when herd advisors seek to implement changes in management based on new knowledge gained from investigations based on the NBCRS database.

Data quality is essential when using secondary data, such as this registry. Only about 50% of calvings were recorded with a birth weight in the NBCRS database, and it is not known if the values are missing at random or if systematic lack of reporting is causing bias. The extent of weighing in beef herds might be linked to the level of "professionalism" of the herd because the recording of birth weights is done on a volunteer basis. It is also possible that farmers will report weights from only the best (heaviest) calves, especially if they plan on selling these animals. If the practice of selecting the "best" calves for weighing occurs more commonly in heifers, this might provide a potential explanation for the contradictory finding of primiparous animals producing heavier offspring than older cows. Even though the sex differences in birth weights are consistent with other studies, which increases the plausibility of the data, it is important to appreciate that the database has not been validated for use in research in the same way as the Norwegian Dairy Herd Recording System (Espetvedt et al., 2013). Formal validation of the NBCRS database would improve the certainty of the results of this, and other studies based upon it.

5. Conclusion

A large proportion of the variation in beef suckler birth weights was attributed to the herd and cow random effects. Further, birth weights of beef calves in the NBCRS were influenced by sex of the calf, breed of dam, parity, age at first calving, season and region. The choice of the right breed for the different regions and conditions will be one of several management choices to considerer in order important consideration to achieve optimal birth weights.

Acknowledgments

Access to the data was provided by the Norwegian Meat and Poultry Research Centre according to agreement number 1/2013 of 29th October 2013. The project was financed by The Foundation for Research Levy on Agricultural Products/Agricultural Agreement Research Fund, grant no. 233683/E50 "Optibeef-Increased meat production from beef cattle herds", Animalia, Nortura SA, KLF Meat and Poultry Association, The Norwegian Beef Breeders Association (TYR) and Geno Breeding and AI Association. The Norwegian University of Life Sciences is also acknowledged for providing financial support for the PhD student. The authors are grateful to Frøydis Hardeng for her initial preparation of the dataset.

References

Andersen, H., Plum, M., 1965. Gestation length and birth weight in cattle and buffaloes: a review. J. Dairy Sci. 48, 1224–1235.
Animalia, 2013a. Norwegian Beef Cattle Recording System—Annual Report 2012 (Norwegian: Årsmelding Storfekjøttkontrollen 2012). Norwegian Meat and Poultry Research Centre, Oslo.
Animalia, 2013b. Norwegian Meat and Egg Production—Annual Report 2013, (Norwegian: Kjøttets tilstand, 2013). Norwegian Meat and Poultry Research Centre, Oslo.
Anon., 2015. Norwegian Meteorological Institute (Norwegian: Meteorologisk Institutt). http://met.no.
Arango, J.A., Cundiff, L.V., Van Vleck, L.D., 2002. Breed comparisons of Angus, Charolais, Hereford, Jersey, Limousin, Simmental, and South Devon for weight, weight adjusted for body condition score, height, and body condition score of cows. J. Anim. Sci. 80, 3123–3132.
Bellows, R.A., Lammoglia, M.A., 2000. Effects of severity of dystocia on cold tolerance and serum concentrations of glucose and cortisol in neonatal beef calves. Theriogenology 53, 803–813.
Bennett, G.L., Gregory, K.E., 1996. Genetic (co) variances among birth weight, 200-day weight, and postweaning gain in composites and parental breeds of beef cattle. J. Anim. Sci. 74, 2598–2611.
Berry, D.P., Lee, J.M., Macdonald, K.A., Roche, J.R., 2007. Bodycondition score and body weight effects on dystocia and stillbirths and consequent effects on postcalving performance. J. Dairy Sci. 90, 4201–4211.
Colburn, D.J., Deutscher, G.H., Nielsen, M.K., Adams, D.C., 1997. Effects of sire, dam traits, calf traits, and environment on dystocia and subsequent reproduction of two-year-old heifers. J. Anim. Sci. 75, 1452–1460.
Cundiff, L.V., Nunez-Dominguez, R., Dickerson, G.E., Gregory, K.E., Koch, R.M., 1992. Heterosis for lifetime production in Hereford, Angus, shorthorn, and crossbred cows. J. Anim. Sci. 70, 2397–2410.
Cundiff, L.V., Szabo, F., Gregory, K.E., Koch, R.M., Dikeman, M.E., Crouse, J.D., 1993. Breed comparisons in the germplasm evaluation program at MARC. In: Proceedings, Beef Improvement Federation: Research Symposium and Annual Meeting, Asheville, NC, pp. 124–136.
Cundiff, L.V., Van Vleck, L.D., Hohenboken, W.D., 2010. Guidelines for Uniform Beef Improvement Programs, 9th ed. Beef Improvement Federation, Raleigh, NC.
Deutscher, G.H., Colburn, D.J., Davis, R., 1999. Climate affects calf birth weights and calving difficulty. Nebraska Beef Cattle Report. Paper 400.
Diskin, M.G., Kenny, D.A., 2014. Optimising reproductive performance of beef cows and replacement heifers. Animal 8, 27–39.
Eriksson, S., Näsholm, A., Johansson, K., Philipsson, J., 2004. Genetic parameters for calving difficulty, stillbirth, and birth weight for Hereford and Charolais at first and later parities. J. Anim. Sci. 82, 375–383.
Espetvedt, M., Reksen, O., Rintakoski, S., Østerås, O., 2013. Data quality in the Norwegian dairy herd recording system: agreement between the national database and disease recording on farm. J. Dairy Sci. 96, 2271–2282.
Geno, 2013. Geno SA, Annual report 2013 (Geno SA, the breeding organization of the cattle breed Norwegian Red. Norwegian: Geno—Årsberetning og regnskap 2013). Hamar, Norway.
Holland, M.D., Odde, K.G., 1992. Factors affecting calf birth weight: a review. Theriogenology 38, 769–798.
Johanson, J.M., Berger, P.J., 2003. Birth weight as a predictor of calving ease and perinatal mortality in Holstein cattle. J. Dairy Sci. 86, 3745–3755.
Kumbhakar, S.C., Lien, G., Flaten, O., Tveterås, R., 2008. Impacts of Norwegian milk quotas on output growth: a modified distance function approach. J. Agric. Econ. 59, 350–369.
Martin, A.D., Lystad, M.L., Reksen, O., Ropstad, E., Waldmann, A., Nafstad, O., Karlberg, K., 2010. Research assessment of progesterone profiles and postpartum onset of luteal activity in spring calving Hereford beef suckler cattle. Acta Vet. Scand. 52, 42.
Mee, J.F., 2008. Prevalence and risk factors for dystocia in dairy cattle: a review. Vet. J. 176, 93–101.
Nix, J.M., Spitzer, J.C., Grimes, L.W., Burns, G.L., Plyler, B.B., 1998. A retrospective analysis of factors contributing to calf mortality and dystocia in beef cattle. Theriogenology 49, 1515–1523.
Prince, D.K., Mickelsen, W.D., Prince, E.G., 1987. The economics of reproductive beef management. Bovine Pract. 22, 92–97.
Rogers, P., Gaskins, C., Johnson, K., MacNeil, M., 2004. Evaluating longevity of composite beef females using survival analysis techniques. J. Anim. Sci. 82, 860–866.
Ruud T.A., Wittusen H.T., Juul-Hansen O.B., Mellby J.O., Røhnebæk E., Aass L., Rustad L.J., Flittie Anderssen Å.M., Nafstad O., 2013. Increased beef production in Norway (Norwegian: Økt storfekjøttproduksjon i Norge—rapport fra ekspertgruppen), 1–54.
Simm, G., 1998. Genetic Improvement of Cattle and Sheep. Farming Press, Ipswich.
Sivertsen, T., Garmo, T.H., Lierhagen, S., Bernhoft, A., Steinnes, E., 2015. Geographical and botanical variation in concentrations of copper molybdenum, sulphur and iron in sheep pasture plants in Norway. Acta Agric. Scand. A 64, 188–197.
Szabó, F., Dákay, I., Márton, D., Benedek, Z., Török, M., Lengyel, Z., 2009. Age at first calving and the logevity of beef cows. Livest. Sci. 122, 271–275.
Young, B.A., 1975. Temperature-induced changes in metabolism and body weight of cattle (*Bos taurus*). Can. J. Physiol. Pharm. 53, 947–953.
Zaborski, D., Grzesiak, W., Szatkowska, I., Dybus, A., Muszynska, M., Jedrzejczak, M., 2009. Factors affecting dystocia in cattle. Reprod. Domest. Anim. 44, 540–551.

III

Factors associated with the lifetime calf production of Norwegian beef suckler cows

Ingrid H. Holmøy*, Sindre T. Nelson, Adam D. Martin, Ane Nødtvedt

Department of Production Animal Clinical Sciences, Faculty of Veterinary Medicine and Biosciences, Norwegian University of Life Sciences, Oslo, Norway

*Corresponding author: Department of Production Animal Clinical Sciences, Faculty of Veterinary Medicine and Biosciences, Norwegian University of Life Sciences, P.O Box 8146 Dep. N-0033 Oslo, Norway Tel.: +47 67232133; fax: +47 22597083

Email address: ingrid.hunter.holmoy@nmbu.no

ABSTRACT

A retrospective cohort study was performed to evaluate factors associated with lifetime calf production in Norwegian beef suckler herds. Production data from 20,541 cows in 2210 herds slaughtered over a three-year period (1st of January 2010 to 23rd of January 2013) were extracted from the national beef cattle registry. This study's inclusion criteria were met for 16,917 cows (1858 herds) which gave birth to 50,578 calves. The median number of calves born per cow was 2 (min 1, max 18). The early maturing breeds (Hereford and Aberdeen Angus) had a higher lifetime calf production than the late maturing breeds (Charolais and Limousin). Two multilevel Poisson regression models with herd random effects showed that early maturing breeds had higher lifetime calf production than late maturing breeds in all areas of Norway. A significant breed-region interaction indicated that the coastal South East region of Norway (which has a relatively long growing season and gentle topography) yielded the highest lifetime production for all but one breed (Simmental). Cows that needed assistance or experienced dystocia at their first calving had a lower lifetime calf production than those that did not: incidence rate ratio 0.87 (0.84-0.91) for assistance and 0.70 (0.66-0.75) for dystocia, respectively. Cows in larger herds (>30 cows) produced 11% more calves in their lifetime compared to cows in smaller herds (≤30 cows) ($P<0.001$). The study found large inter-herd variation indicating systematic differences in herd level factors influencing lifetime calf production. The herd random effects were large and highly significant, suggesting that unmeasured factors at the herd level were responsible for a high amount of the unexplained variation in the number of calves born. In conclusion, appropriate breed selection for a farm's environment affects lifetime calf production in Norwegian suckler herds.

Keywords:
Bovine
Calves
Recording system
Offspring
Beef
Cattle

1. Introduction

Specialized beef production is a relatively new enterprise in Norway, because the dual-purpose Norwegian Red breed has historically produced meat for the domestic market. However, increasing milk yields per cow have resulted in a reduction in the Norwegian dairy cow population which led to a net import of 22,000 tons of beef (29% of consumption) in 2015 (Animalia, 2016a). Self-sufficiency in beef production is considered desirable by the government of Norway, for food security reasons as well as to distribute employment-opportunities throughout the country (Animalia, 2013a). Consequently, considerable economic support is provided to Norwegian beef producers (Åby et al., 2012a). The financial support and changing market place have created a specialized, but immature, beef industry in Norway that functions parallel to the combined, established, milk and beef production that has dominated Norwegian agriculture for decades (Martin, 2015). Between 1990 and 2015 the number of herds with specialized beef production increased from 1841 to 4851 (Statistics Norway, 2015). The herds are typically small, family-run farms and the average herd size in 2012 was 13 cows (Statistics Norway, 2015). The four most numerous beef breeds in Norway are Charolais, Hereford, Limousin and Aberdeen Angus (Animalia, 2013b). The majority of animals are finished for slaughter on the farm of their birth, although a handful of rearing and finishing herds do exist. Average slaughter age and weight of young bulls is 16.4 months and 322 Kg, respectively (Animalia, 2016b). The corresponding averages for heifers are 16.6 months and 237 Kg (Animalia, 2016a).

Production efficiency in all cow-calf operations is dependent on the successful rearing of calves for both slaughter and replacement of breeding stock, each cow’s lifetime production, and efficient use of resources. A cow’s lifetime calf production depends on, amongst other things, her longevity and reproductive performance. Lifetime production can be defined as a cow's output in terms of number of calves born, number of calves weaned or total calf weaning weight (Arthur et al., 1993). Each of these lifetime production-parameters are important when trying to understand how production can be increased and made more efficient.

A Norwegian study of functional and production traits of beef suckler cows found that longevity was the most important economic trait in beef suckler production (Åby et al., 2012b). The importance of longevity in beef suckler production is supported by other studies (Perry and Cushman, 2013; Diskin and Kenny, 2014). However, without production, longevity is a poor measure of success. Good reproductive performance is essential for a suckler cow operation to be economically viable (Diskin and Kenny, 2014). Total lifetime calf production is the result of longevity and reproductive performance, which makes it interesting to study. Increasing total lifetime calf production has been shown to increase efficiency and decrease the environmental impact of beef suckler farming (Ogino et al., 2007).

Age at first calving is a key performance indicator in beef production systems. At calving, animals should be of sufficient size and maturity to be able to calve without difficulty, suckle their calf, and gain weight whilst returning rapidly to estrus after parturition. There is some debate as to the optimal time to calve beef heifers. Chapman et al. (1978) reported no differences in lifetime production in purebred Hereford cows calving at two or three years of age. Meanwhile, Núñez-Dominguez et al. (1991) reported that crossbred beef cows calving at two years of age for the first time gave birth to 1.1 more calves and weaned 138 kg more in their lifetime compared to those that calved for the first time at three years of age. Typically, economic efficiency calculations favor calving at two instead of three years of age (Núñez-Dominguez et al., 1991).

Inadequate maternal size at first calving is a risk factor for dystocia (Turner et al., 1992), which again is a risk factor for death of both the dam and her progeny (Rogers et al., 2004). If heifer growth rates are to be such that heifers reach adequate size when calving at two years of age poor quality forage must be supplemented with more expensive and more concentrated forms of energy (wheat, barley, compounded concentrates). The climatic conditions, and so quality of roughage, vary considerably between the different regions of Norway. A recent Norwegian study showed that there was a significant effect of breed and region regarding calf birth weight (Nelson et al. 2016). Late maturing, 'intensive', breeds require a greater nutritional input to reach optimal size at first calving than the early maturing, ‘extensive’, breeds. Calving at two years of age might not be beneficial in for all breeds in all the regions of Norway when the consequences calving undersized heifers, e.g. increased dystocia, increased calf mortality, increased culling, and reduced reproductive performance, are accounted for (Nix et al., 1998; Zaborski et al., 2009). Thus limited resources, insufficient quality of roughage available to obtain adequate weight for calving at two-years of age, in combination with suboptimal choice of breed for the given conditions, could be a limiting factor for longevity and production in Norwegian beef suckler herds.

Beef suckler production is an immature, rapidly expanding sector in Norwegian agriculture. Currently little is known about the impact of factors associated with Norwegian beef production. This knowledge is essential if the efficiency and production of Norwegian beef suckler herds is to increase. The aims of this study were to estimate the lifetime calf production of Norwegian beef suckler cows and evaluate factors influencing lifetime calf production. The factors investigated were region, breed of the dam, age at first calving, calving ease at first calving, twinning and mean calving interval.

2. Materials and methods

2.1 Data source

Data were extracted from the Norwegian Beef Cattle Recording System (NBCRS). Membership in the NBCRS is voluntary. In 2012, 57% (2428 herds) of Norwegian beef suckler herds were enrolled, comprising 78% of the Norwegian beef suckler cow population (Animalia, 2013a). The database included individual animal information such as a unique identification number, date of birth, pedigree, breed, sex, calving ease, date of slaughter or death for other reasons, and when slaughtered, information on carcass weight and quality.

2.2. Study design and study sample

A retrospective cohort study was performed using data from the NCBRS on all adult cows slaughtered in a three year period (1st of January 2010 to 23rd of January 2013), including data on their offspring. The data were screened for obvious typing errors and duplicates, and when found, these were omitted. Heifers calving under 18 months old or those over 42 months old that calved for the first time were excluded from the study as they were considered atypical. Cows exhibiting one or several calving intervals <300 days were also excluded. Cows from herds in which herd size could not be retrieved were excluded.

2.3. Outcome and explanatory variables

The outcome variable in this study was the total number of calves born to beef suckler cows in their lifetime. A variable identifying county was derived from the herd identification number, which contains the county number. The 19 counties of Norway were grouped into five regions as shown in Fig.1 – North Norway, Mid Norway West Norway, Inland Southeast Norway and Costal Southeast Norway. The original breed variable was retained for the most numerous breeds; Norwegian Red, Hereford, Charolais, Aberdeen Angus, Limousin and Simmental, while the less numerous purebred and crossbred animals were merged into a pooled category. Age at first calving was defined by subtracting date of birth from first calving date. Calving interval was defined by subtracting the date of a calving from the subsequent date of calving, and mean calving interval across the cow's lifetime was calculated. The number of twin events indicates the number of twin sets born to each cow in her lifetime. Calving ease is recorded in the NBCRS as either ‘‘normal’’, ‘‘assisted’’, ‘‘dystocia’’ or “unknown”.

2.4. Statistical methods

2.4.1 Data handling and univariable analysis

Generation of the initial dataset from the NBCRS was performed using SAS 9.2 (SAS Institute Inc., Cary, NC, USA). Further data management and statistical analysis was performed using Stata (Stata SE/14, Stata Corp., College Station, TX, USA). Region, breed and calving ease were treated as categorical variables in the analysis, using Coastal Southeast Norway, Hereford and “normal”, respectively, as reference groups. Herd size was initially grouped into six equally sized groups and treated as a categorical variable. Age at first calving was dichotomised at 2.5 years. The variable indicating the number of twin births was grouped into 0, 1, 2 and >2. Mean calving interval was treated as a continuous variable.

A Poisson model was used for testing univariable relationships between each of these explanatory variables and the outcome. The effect-measure was the incidence rate ratio (IRR). Variables associated with the outcome with a *P*-value <0.2 were tested in a multivariable Poisson model. Cows within a herd were not expected to be independent of each other and therefore a herd random effect, assuming a compound symmetry correlation matrix, i.e. constant correlation between cows within a herd, was applied.

2.4.2. Multivariable analysis

Two multilevel Poisson regression models (*mepoisson*) were built, both with herd random effects; one model including all cows and a second model using only the subset of multiparous cows. In the latter model, mean calving interval was included as an explanatory variable. Variables were tested in the multilevel Poisson models with a manual backwards stepwise regression strategy until all included variables were significant at a P-value of <0.01. Potential confounding variables were identified *a priori* through the construction of a causal diagram. Variables considered to be potential confounders were tested by running the model with and without the variables in question while changes in estimates were explored. Overall significance of groups of categorical variables, e.g. breed and region, were tested using likelihood-ratio tests. Biologically plausible interaction effects between statistically significant explanatory variables were tested by adding interaction terms to the main-effects model. The cut-off for keeping an interaction term in the model was set to $P<0.01$. A random effects negative binomial model allows for extra-Poisson variation and was applied given the distribution of the outcome. However, the overdispersion parameter (α) was close to zero, thus the Poisson model was considered more appropriate.

Post regression, the predicted number of events was calculated. The final model was rerun in a generalized linear mixed model to obtain standardized residuals at cow and herd level. Standardized residuals were plotted against the predicted number of events at all levels of the model in question to check for potential outliers. The amount of unexplained variance at herd- and cow-level was calculated for all combinations of predictor variables using the exact formula given by Dohoo et al. (2009).

3. Results

3.1. Source population and study sample

The source population consisted of 20,541 cows slaughtered between 2010 and 2013, and their 62,813 offspring. Fig.2 shows the number of calvings, beef suckler cows and herds that were excluded from the initial data file to obtain the study population, and gives brief descriptions of the reasons for exclusion. This study's inclusion criteria were met for 16,917 cows that gave rise to 50,578 calving events in total, out of which 1076 calvings produced twins and 5 yielded triplets.

3.2. Descriptive findings

The distribution of the number of calves born to each cow in her lifetime (the outcome variable) is shown in Fig.3. The median number of calves born to each cow was 2 (min 1, max 18) calves. Age at first calving is shown in Fig.4. The median age of cows at slaughter was 3.8 (min 1.5, max 17). The herds were located throughout the country. The mean herd size was 24 cows (median 19, interquartile range 12 to 31), whereas the mean number of slaughtered adult cows per herd during the three-year period was 9 (median 6, interquartile range 3 to 12). Distribution of cows included in the study by various characteristics and the median and maximum number of calves born to each cow within each category are shown in Table 1.

3.3 Multivariable models

Results from the multivariable model including all cows are given in Table 2. A significant interaction term between breed and region of Norway was present, i.e. the effect of breed of cow on the number of calves born to each cow was dependent on the cow's location. Based on results from the multivariable model including the interaction term, incidence rate ratios (IRR) were calculated for all combinations of breed and region of Norway (Fig.5). The number of calves born to each cow was highest in coastal parts of Eastern Norway for all breeds, except Simmental. Limousin cows had the lowest number of calves born irrespective of region, whereas Charolais cows had the second lowest in all areas except the Costal Southeast region. Both Limousin and Charolais had particularly low production in the North and West regions.

The model estimated that a single twin event resulted in 76% more calves born, while more than one twin event resulted in 234% more calves born (P<0.001). Cows assisted or experiencing dystocia at their first calving had a lower number of calves born: IRR (95% CI) 0.87 (0.84-0.91) and 0.70 (0.66-0.75) respectively, compared to cows without. Cows that belonged to herds larger than 30 cows gave birth to 11% more calves in their lifetime compared to cows in smaller herds (P<0.001). Whether cows were under or over 2.5 years old at first calving did not affect the number of calves born when herd random effects were included. The herd random effect was highly significant, and the amount of unexplained variation at the herd level in small herds (≤30 cows) ranged from 23% for Limousin in Northern Norway to 29% for Charolais in the Southeast Inland. For large herds (>30 cows), the amount of unexplained herd-level variation ranged from 51% for Limousin in Northern Norway to 58% for Charolais in Inland Southeast.

To estimate of the effect of mean calving interval on the number of calves born, a model including only multiparous cows was built. The model included the same explanatory variables as the model shown in Table 2, however an additional variable accounting for the mean calving interval across lifetime was added (Table 3). The range of mean calving interval across the interquartile range was 359 to 410 days, and the estimated IRRs at the 25th percentile and 75th percentile were 0.81 and 0.78, respectively.

4. Discussion

Region and breed were both found to have a significant effect on a cow's lifetime calf production and have previously been found to effect other performance traits in Norwegian beef cattle (Nelson et al.,2016). The two early-maturing breeds (Hereford and Aberdeen Angus) had the highest lifetime calf production (median 3) compared to the other breeds in this study (median 2). Furthermore, a significant region-breed interaction was found in the multivariable Poisson model indicating that breed differences in performance will vary by region. However, when regional and breed differences were accounted for the late-maturing Limousin had the lowest lifetime calf production in all regions of Norway. Charolais cows produced the second lowest number of calves throughout their lifetime in the three regions which topographically (North and West characterized by steep hilly/mountainous pastures with meagre levels of top soil), and climatically (Inland Eastern Norway with a short growing season) pose challenges to cattle production. The ability of heavy, late-maturing breeds to adapt to Norwegian conditions appears to be lower than for lighter, earlier maturing breeds.

The Norwegian climate and topography leads to a grazing season that is short compared to many parts of the world. This means that suckler cow production in Norway is heavily dependent on conserved forage, which can be of variable quality because of the changeable nature of the weather and short harvesting season. This study has shown that the successful suckler breeds in Norway are the smaller, early-maturing breeds. The early-maturing breeds have lower maintenance energy requirements, and require less energy to improve body condition in the pre-breeding and breeding season, which means their reproductive performance, as measured by lifetime calf production, is likely to be better than for the heavier breeds (Arango et al., 2002; Richards et al., 1986). Aberdeen Angus and Hereford cattle also have a relatively high voluntary feed intake capacity and a good capacity to efficiently maintain weight when energy intake is restricted compared to Limousin and Charolais cattle (Taylor et al., 1986). The variable quality of Norwegian forage make these traits important. Calf production is the first step in the production chain and although it is important, this study does not provide enough evidence to recommend that Norwegian suckler production should rely exclusively upon the extensive breeds. However, this study shows that early-maturing breeds of cattle produce more calves in their lifetime than late-maturing breeds under Norwegian conditions.

More than half of all suckler cows in this study produced two or fewer calves in their lifetime. Whilst there is debate as to the optimal method of producing suckled beef (Lowman and Vickers, 2015; Seidel and Whittier, 2015) traditional cow-calf systems require suckler cows to have produced between 3 and 5 calves before they have repaid their rearing costs (Patterson et al., 1992). Thus, the performance of the animals in this study is suboptimal. The modal average for number of calves born in the lifetime of a Norwegian suckler cow was one. Dystocia is major cause of early culling of animals either directly, as emergency slaughter or euthanasia during parturition, or indirectly, caused by inadequate post-partum reproductive performance (Nix et al., 1998; Zaborski et al., 2009). These problems are closely related to poor nutrition both before and after service of nulliparous heifers.

In this study, moderate or severe dystocia at first calving reduced lifetime calf production by 13% and 30%, respectively. Fetal maternal disproportion is the most common cause of dystocia in calving beef heifers (Johnson et al., 1988; King, 1993). There are two primary causes of feto-maternal disproportion; i) a relatively oversized calf, ii) a relatively undersized heifer. Incorrect bull selection is a likely cause of calving problems in heifers in small herds using natural service, as the bull used is likely to be used to serve both multiparous cows and nulliparous heifers. Inadequate heifer growth prior to service results in increased incidence of feto-maternal disproportion. The climate and topography of Norway means that the forage fed to nulliparous heifers before service may be inadequate for them to achieve target weights (65% of mature body weight) at service aged 14-15 months (planned first calving at 24 months). Therefore, it might have been expected that older, larger, animals experienced less dystocia at first calving and therefore had a longer productive life in the herd than younger, smaller animals (Hickson, 2010). Univariable analysis performed, but not reported, in this study showed that animals calving below 2.5 years were twice as likely to experience dystocia than older animals (OR 2.1, $p<0.001$). However, the multivariate model showed that once factors other than age were accounted for, age at first calving was not related to lifetime calf production.

Subsidies account for over 60% of a Norwegian beef farmer’s income (Åby et al., 2012a) the majority of these subsidies are not linked to production (Åby et al., 2012b; Animalia, 2013a). The current subsidy payments combined with the the fact that animals slaughtered as *young cows* recieve a premium compared to older cows in Norway means that the finacial incentive to address inefficiencies, and increase lifetime calf poduction, on an individual farm might not exist.

It is unclear why cows in larger herds had a higher lifetime calf production compared to cows in smaller herds in this study. Previous studies in the Norwegian dairy sector have shown herd size to be positively correlated with reproductive performance and suggested that improved management practices are the reason for this relationship (Simensen et al., 2010). An alternative explanation might be that larger herds have been in a period of expansion and have kept cows on the farm longer than their counterparts that have not expanded (Roberts et al., 2015). It is possible that larger herds are located in areas with a climate and topography more favorable to grass-, and therefore cattle-production, or simply that those with larger herds are more experienced, better, stockmen.

Unsurprising findings of this study were that mean calving interval and occurrence of multiple births (twins and triplets) affected lifetime calf production. The median lifetime calf production found in this study was low (two calves) meaning that a multiple birth would have at least matched the population median level of production. Additionally, incidence of multiple births increases with parity such that the older cows (which had produced more calves) would be more likely to have experienced twinning (Rutledge, 1975). Shortened or extended calving intervals were found to negatively affect lifetime calf production. Presumably as calving intervals below 365 days are likely to be associated with fetal loss, a risk factor for culling. Also, extended calving intervals are likely to be related to management deficiencies not consistent with efficient production.

In line with other studies that have used the NBHRS database (Nelson et al., 2016) this study found that the effect of herd was large. The herd effect will encompass all unmeasured herd-level management factors including heifer rearing, genetic effects and management strategy. Furthermore, the change that the Norwegian beef industry is undergoing (Martin, 2015) increases the likely differences between herds, as some farmers look to expand their businesses while others aim to keep going until they quit production at, or before, retirement age. Currently, there is a paucity of information available regarding Norwegian beef suckler farming systems, and this knowledge gap should be addressed by future studies. The large herd effect also indicates that there is likely to be a need for improving skill levels of producers and their advisors if increased productivity among beef suckler herds in Norway is to be achieved.

The NBHRS is a voluntary recording scheme run for the beef industry by the industry funded body Animalia (www.animalia.no). The database included 78% of beef suckler cows and 57% of the beef herds in Norway. Herds were located throughout the country, which should provide acceptable external validity. However, farmers owning the herds enrolled in the recording system might have a greater focus on production goals compared to non-member farmers. Thus, our sample of herds might tend to be biased by including farms that were, on average, somewhat better managed than the average national herd. The variables analyzed in this study are largely required to be recorded by law, e.g. date of birth, date of death, location, and should therefore be considered reasonably reliable. An exception is the variable “calving ease” which included in total 14% missing values. Calving ease is classified by the farmer as ‘‘normal’’, ‘‘assisted’’, ‘‘dystocia’’ and “unknown”. The same classification is also used for breeding and management purposes at the herd level, which means that the farmers are familiar with both its use and value, and consequently the recorded values were considered reasonably reliable. Ideally, a validation of the data-quality should be performed before using a secondary database for research purposes, in order to evaluate the ability of the recording system to capture events in the population (Emanuelson and Egenvall, 2014). It is likely that the principal findings of this study are applicable to beef production systems in other temperate areas, although applying direct results should be performed with caution.

Acknowledgements

Access to the data was provided by the Norwegian Meat and Poultry Research Centre according to agreement number 1/2013 of 29th October 2013. The project was financed by The Foundation for Research Levy on Agricultural Products/Agricultural Agreement Research Fund, grant no.

233683/E50 “Optibeef- Increased meat production from beef cattle herds”, Animalia, Nortura SA, KLF Meat and Poultry Association, The Norwegian Beef Breeders Association (TYR) and Geno Breeding and AI Association. The Norwegian University of Life Sciences is also acknowledged for providing financial support for the PhD student. The authors are grateful to Frøydis Hardeng for her initial preparation of the dataset.

References

Animalia, 2013a. Økt storfekjøttproduksjon i Norge. Oslo. (In Norwegian).

Animalia, 2013b. Storfekjøttkontrollen Årsmelding 2012. Oslo. (In Norwegian).

Animalia, 2016a. Kjøttets tilstand - 2015. Oslo. (In Norwegian).

Animalia, 2016b. Storfekjøttkontrollen Årsmelding 2015. Oslo. (In Norwegian).

Arango, J.A., Cundiff, L.V., Van Vleck, L.D., 2002. Breed comparisons of Angus, Charolais, Hereford, Jersey, Limousin, Simmental, and South Devon for weight, weight adjusted for body condition score, height, and body condition score of cows. J. Anim. Sci. 80, 3123-3132.

Arthur, P.F., Makarechian, M., Berg, R.T., Weingardt, R., 1993. Longevity and lifetime productivity of cows in a purebred Hereford and two multibreed synthetic groups under range conditions. J. Anim. Sci. 71, 1142-1147.

Chapman, H.D., Young, J.M., Morrison, E.G., Edwards, N.C., 1978. Differences in lifetime productivity of Herefords calving first at 2 and 3 years of age. J. Anim. Sci. 46, 1159-1162.

Diskin, M.G., Kenny, D.A., 2014. Optimising reproductive performance of beef cows and replacement heifers. Animal 8, suppl. s1, 27-39.

Dohoo, I., Martin, W., Stryhn, H., 2009. Mixed models for discrete data. In: Veterinary Epidemiologic Research. 2nd ed. VER Inc., Charlottetown, Prince Edward Island, Canada, p 579-606.

Emanuelson, U., Egenvall, A., 2014. The data – Sources and validation. Prev. Vet. Med. 113, 298-303.

Hickson, R.E., Lopez-Villalobos N., Kenyon P.R., Ridler B.J., Morris S.T., 2010. Profitability of calving heifers at 2 compared with 3 years of age and the effect of incidence of assistance at parturition on profitability. Anim. Prod. Sci. 50, 354-358.

Johnson, S.K., Deutscher, G.H., Parkhurst, A., 1988. Relationships of pelvic structure, body measurements, pelvic area and calving difficulty. J. Anim. Sci. 66, 1081-1088.

King, B.D., Choen., R.D.H., McCormac, S., Guenther, C.L., 1993. Maternal factors and the prediction of dystocia in beef heifers. Can. J. Anim. Sci. 73, 431 - 435.

Lowman, B., Vickers, M., 2015. Once-bred heifers from the suckler herd. http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2015/10/BRP-once-bred-heifers.pdf. [Accessed March 15, 2016]

Martin, A.D., 2015. Surveillance of reproductive performance in Norwegian cattle farming. Norwegian University of Life Sciences, Oslo. Ph.D. thesis.

Nelson, S.T., Martin, A.D., Holmøy, I.H., Karlberg, K., Nødtvedt, A., 2016. A cross-sectional study of factors associated with birth weights of Norwegian beef calves. Prev. Vet. Med. 125, 59-65.

Nix, J.M., Spitzer, J.C., Grimes, L.W., Burns, G.L., Plyler, B.B., 1998. A retrospective analysis of factors contributing to calf mortality and dystocia in beef cattle. Theriogenology 49, 1515-1523.

Núñez-Dominguez, R., Cundiff, L.V., Dickerson, G.E., Gregory, K.E., Koch, R.M., 1991. Lifetime production of beef heifers calving first at two vs three years of age. J. Anim. Sci. 69, 3467-3479.

Ogino, A., Orito, H., Shimada, K., Hirooka, H., 2007. Evaluating environmental impacts of the Japanese beef cow–calf system by the life cycle assessment method. Anim. Sci. J. 78, 424-432.

Patterson, D.J., Perry, R.C., Kiracofe, G.H., Bellows, R.A., Staigmiller, R.B., Corah, L.R., 1992. Management considerations in heifer development and puberty. J. Anim. Sci. 70, 4018-4035.

Richards, M.W., Spitzer, J.C., Warner, M.B., 1986. Effect of varying levels of postpartum nutrition and body condition at calving on subsequent reproductive performance in beef cattle. J. Anim. Sci. 62, 300-306.

Roberts, A.J., Petersen, M.K., Funston, R.N., 2015. Beef species symposium: Can we build the cowherd by increasing longevity of females? J. Anim. Sci. 93, 4235-4243.

Rogers, P.L., Gaskins, C.T., Johnson, K.A., MacNeil, M.D., 2004. Evaluating longevity of composite beef females using survival analysis techniques. J. Anim. Sci. 82, 860-866.

Rutledge, J.J., 1975. Twinning in cattle. J. Anim. Sci. 40, 803-815.

Seidel, G.E., Whittier, J.C., 2015. Beef species symposium: Beef production without mature cows. J. Anim. Sci. 93, 4244-4251.

Simensen, E., Østerås, O., Bøe, K.E., Kielland, C., Ruud, L.E., Næss, G., 2010. Housing system and herd size interactions in Norwegian dairy herds; associations with performance and disease incidence. Acta Vet. Scand. 52, 14.

Statistics Norway, 2015. Jordbruksbedrifter med husdyr per 1. januar, etter husdyrslag. Oslo. (In Norwegian) https://www.ssb.no/statistikkbanken. [Accessed December 7, 2015]

Taylor, S.C.S., Moore, A.J., Thiessen, R.B., 1986. Voluntary food intake in relation to body weight among British breeds of cattle. Anim. Sci. 42, 11-18.

Turner, H.A., McInnis, M.L., Angell, R.F., Weber, D.W., 1992. Factors associated with dystocia in beef cattle. Prof. Anim. Sci. 8, 43-47.

Zaborski, D., Grzesiak, W., Szatkowska, I., Dybus, A., Muszynska, M., Jedrzejczak, M., 2009. Factors affecting dystocia in cattle. Reprod. Domest. Anim. 44, 540-551.

Åby, B.A., Aass, L., Sehested, E., Vangen, O., 2012a. A bio-economic model for calculating economic values of traits for intensive and extensive beef cattle breeds. Livest. Sci. 143, 259-269.

Åby, B.A., Aass, L., Sehested, E., Vangen, O., 2012b. Effects of changes in external production conditions on economic values of traits in Continental and British beef cattle breeds. Livest. Sci.150, 80-93.

Table 1

Distribution of the 16,917 beef suckler cows, belonging to 1,858 herds, slaughtered between January 2010 and January 2013 by various characteristics. The median and maximum number of calves born to each cow is given for each variable level.

Variable	Level	N (%) of cows	Median (max) number of calves
Region of Norway	Costal Southeast	2,842 (17)	3 (15)
	Inland Southeast	6,383 (38)	2 (15)
	Western	2,740 (16)	2 (18)
	Mid	3,738 (22)	2 (14)
	North	1,214 (7)	2 (14)
Breed	Hereford	3,816 (23)	3 (15)
	Norwegian Red	2,716 (16)	2 (13)
	Charolais	3,886 (23)	2 (15)
	Aberdeen Angus	2,080 (12)	3 (18)
	Limousin	1,922 (11)	2 (14)
	Simmental	824 (5)	2 (15)
	Other	1,673 (10)	2 (14)
Age at first calving (yr)	<2.5	12,815 (76)	2 (18)
	>2.5	4,102 (24)	2 (14)
Calving ease at first calving	Normal	11,895 (80)	2 (18)
	Assisted	1,250 (8)	2 (13)
	Dystocia	545 (4)	1 (13)
	Not known	1,172 (8)	3 (12)
	missing	2,055	
No. of twin births	None	15,980 (94)	2 (15)
	1	814 (5)	5 (15)
	2	105 (0.6)	8 (13)
	>2	19 (0.1)	11 (18)
Mean calving interval (days)	300-364	3,929 (36)	3 (15)
	365-545	6,423 (58)	4 (18)
	546-3304	684 (6)	3 (9)
	missing[3]	5,881	

[1] Includes crossbreds, unknown breeds, Dexter, Galloway, Blonde d’Aquitaine, Highland cattle and various local breeds.

[2] Percentage distribution does not include missing values.

[3] Cows having only one calf in lifetime.

Table 2

Variables significantly associated with the total number of calves born to Norwegian beef suckler cows in lifetime. Multivariable incidence rate ratios (IRR), 95% confidence intervals (CI) and *P*-values from a multilevel Poisson regression model. Herd random effect was applied to account for intra-herd correlation. The analysis included 14,862 beef suckler cows in 1,802 Norwegian beef herds.

Variable	Level	IRR	95% CI of IRR		*P*-value[3]
Intercept		2.68	2.54	2.84	
Region x Breed	Inland Southeast x Hereford	ref.[1]			<0.0001
	Inland Southeast x Norwegian Red	0.99	0.93	1.06	
	Inland Southeast x Charolais	0.84	0.79	0.89	
	Inland Southeast x A Angus	0.94	0.88	1.01	
	Inland Southeast x Limousin	0.82	0.76	0.88	
	Inland Southeast x Simmental	1.02	0.93	1.12	
	Inland Southeast x Other[2]	0.96	0.89	1.03	
	Costal Southeast x Hereford	1.16	1.06	1.27	
	Costal Southeast x Norwegian Red	1.08	0.97	1.19	
	Costal Southeast x Charolais	1.05	0.96	1.16	
	Costal Southeast x A Angus	0.98	0.87	1.10	
	Costal Southeast x Limousin	0.94	0.84	1.05	
	Costal Southeast x Simmental	0.96	0.79	1.16	
	Costal Southeast x Other[2]	0.96	0.86	1.08	
	Western x Hereford	0.83	0.75	0.92	
	Western x Norwegian Red	0.84	0.77	0.92	
	Western x Charolais	0.77	0.69	0.86	
	Western x A Angus	0.94	0.85	1.04	
	Western x Limousin	0.63	0.55	0.72	
	Western x Simmental	0.87	0.73	1.04	
	Western x Other[2]	0.81	0.73	0.90	
	Mid x Hereford	0.87	0.80	0.95	
	Mid x Norwegian Red	0.94	0.86	1.03	
	Mid x Charolais	0.83	0.76	0.90	
	Mid x A Angus	0.87	0.78	0.97	
	Mid x Limousin	0.79	0.70	0.88	
	Mid x Simmental	0.83	0.73	0.95	
	Mid x Other[2]	0.83	0.74	0.92	
	North x Hereford	0.87	0.77	0.99	

	North x Norwegian Red	0.81	0.70	0.94	
	North x Charolais	0.74	0.63	0.86	
	North x A Angus	0.86	0.74	1.00	
	North x Limousin	0.60	0.48	0.76	
	North x Simmental	1.01	0.78	1.31	
	North x Other[2]	0.82	0.70	0.97	
Calving ease at first calving	Normal	ref. [1]			<0.0001
	Assistance	0.87	0.84	0.91	
	Dystocia	0.70	0.66	0.75	
	Not known	1.20	1.14	1.25	
No of twin births	None	ref. [1]			<0.0001
	1	1.76	1.70	1.83	
	≥2	2.34	2.18	2.52	
Herd size	≤30	ref. [1]			<0.0001
	>30	1.11	1.06	1.16	
Random effect variances	Herd	0.14	0.13	0.16	

[1]Reference category

[2]Includes crossbreds, unknown breeds, Dexter, Galloway, Blonde d'Aquitaine, Highland cattle and various local breeds.

[3] Significance level (Likelihood ratio test) of main effects or combined effects.

Table 3

Variables significantly associated with the total number of calves born to multiparous Norwegian beef suckler cows in lifetime. Multivariable Incidence rate ratios (IRR), 95% confidence intervals (CI) and *P*-values from a multilevel Poisson regression model. Herd random effect was applied to account for intra-herd correlation. The analysis included 9,617 beef suckler cows in 1,524 Norwegian beef herds.

Variable	Level	IRR	95% CI		*P*-value[3]
Intercept		4.67	4.37	5.00	
Region x Breed	Inland Southeast x Hereford	ref. [1]			<0.0001
	Inland Southeast x Norwegian Red	0.99	0.93	1.06	
	Inland Southeast x Charolais	0.93	0.88	0.99	
	Inland Southeast x A Angus	0.97	0.91	1.05	
	Inland Southeast x Limousin	0.93	0.86	1.01	
	Inland Southeast x Simmental	1.03	0.94	1.13	
	Inland Southeast x Other[2]	0.98	0.90	1.05	
	Costal Southeast x Hereford	1.11	1.03	1.20	
	Costal Southeast x Norwegian Red	1.12	1.02	1.24	
	Costal Southeast x Charolais	1.09	1.01	1.18	
	Costal Southeast x A Angus	1.02	0.91	1.14	
	Costal Southeast x Limousin	1.06	0.96	1.17	
	Costal Southeast x Simmental	0.87	0.72	1.05	
	Costal Southeast x Other[2]	1.06	0.95	1.17	
	Western x Hereford	0.92	0.84	1.02	
	Western x Norwegian Red	0.86	0.79	0.94	
	Western x Charolais	0.88	0.79	0.98	
	Western x A Angus	1.05	0.96	1.14	
	Western x Limousin	0.75	0.66	0.86	
	Western x Simmental	0.90	0.76	1.06	
	Western x Other[2]	0.89	0.80	0.98	
	Mid x Hereford	0.90	0.83	0.98	
	Mid x Norwegian Red	0.90	0.83	0.98	
	Mid x Charolais	0.89	0.82	0.96	
	Mid x A Angus	0.93	0.84	1.02	
	Mid x Limousin	0.89	0.80	0.99	
	Mid x Simmental	0.86	0.76	0.98	
	Mid x Other[2]	0.87	0.78	0.96	
	North x Hereford	0.94	0.84	1.05	

	North x Norwegian Red	0.93	0.81	1.07	
	North x Charolais	0.90	0.78	1.05	
	North x A Angus	0.91	0.79	1.04	
	North x Limousin	0.72	0.56	0.92	
	North x Simmental	1.00	0.76	1.31	
	North x Other[2]	0.87	0.74	1.04	
Calving ease at first calving	Normal	ref. [1]			<0.0001
	Assistance	0.94	0.90	0.98	
	Dystocia	0.95	0.88	1.02	
	Not known	1.09	1.04	1.14	
No. of twin births	None	ref. [1]			<0.0001
	1	1.46	1.40	1.51	
	2	1.94	1.80	2.08	
Herd size	<30	ref. [1]			
	>30	0.99	0.99	0.99	<0.0001
Mean calving interval		1.07	1.03	1.12	<0.0001

[1]Reference category

[2]Includes crossbreds, unknown breeds, Dexter, Galloway, Blonde d’Aquitaine, Highland cattle and various local breeds.

[3] Significance level (Likelihood ratio test) of main effects or combined effects.

Figure captions:

Fig. 1. Regions of Norway

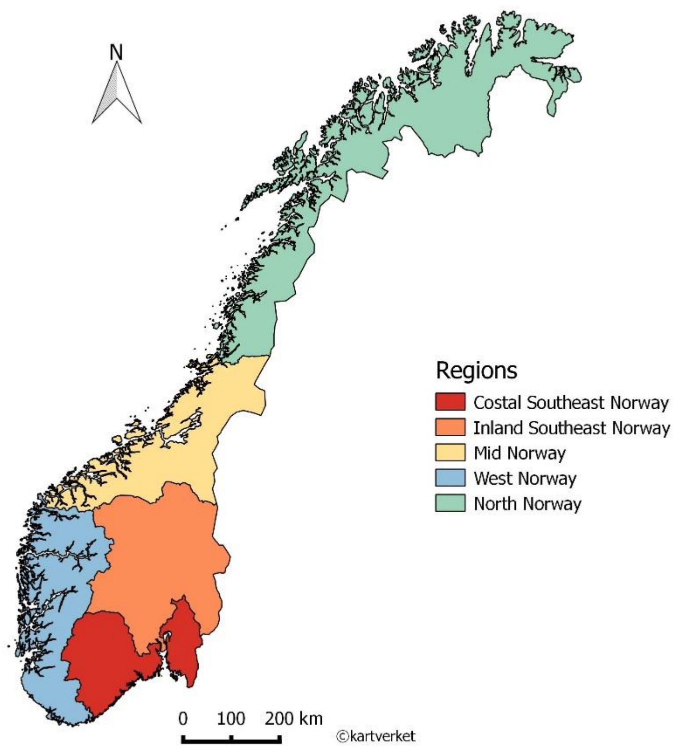

Fig. 2. Selection of study sample

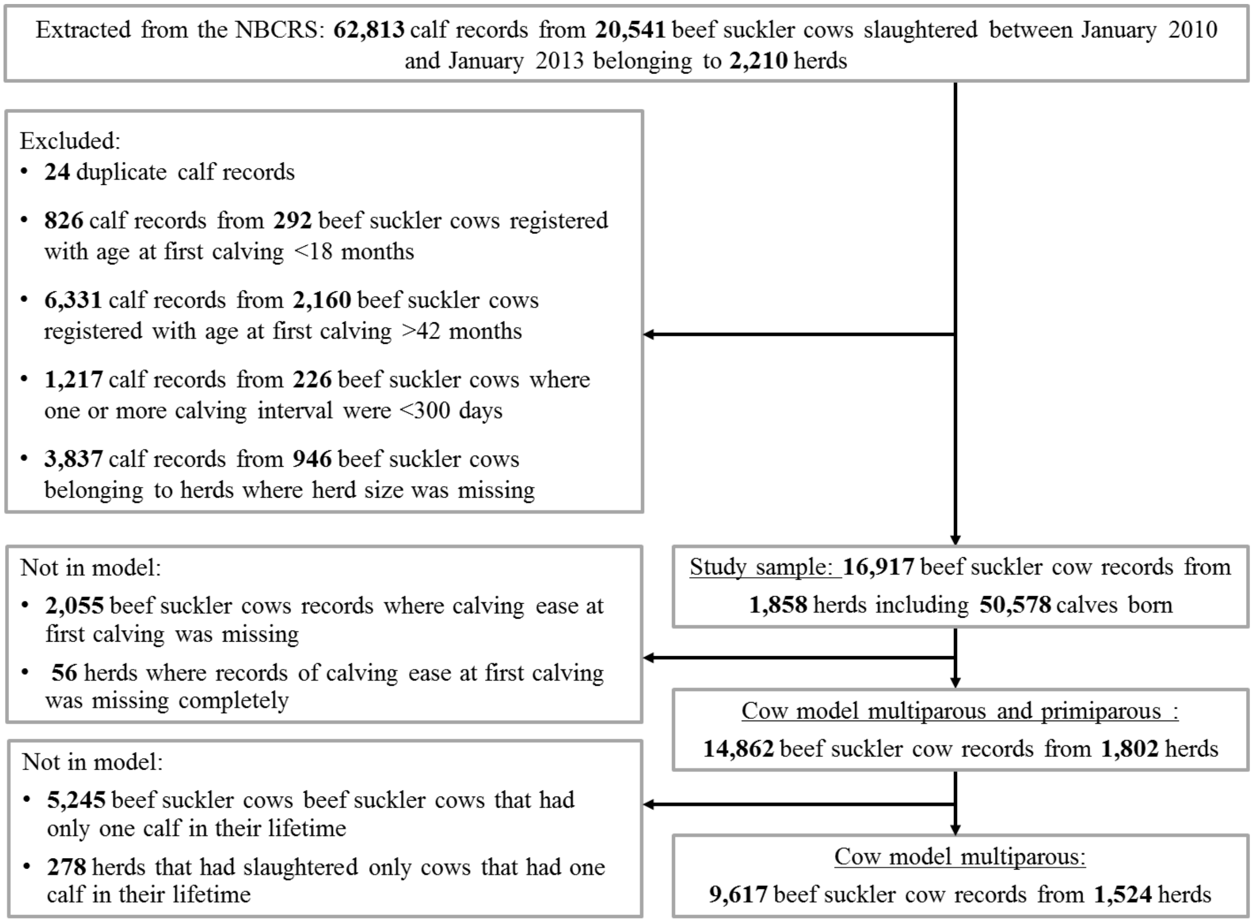

Fig. 3. Distribution of 17.863 beef suckler cows in Norway by lifetime production (total number of calves born to each cow)

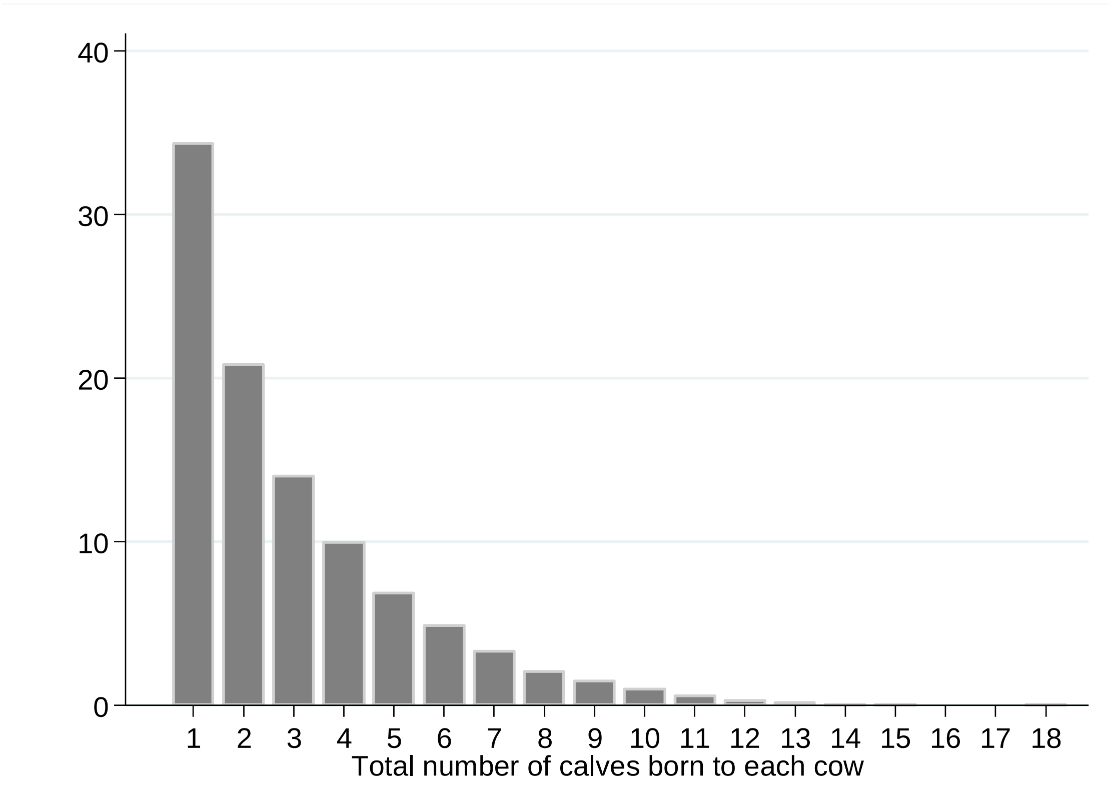

Fig. 4. Age at first calving (years)

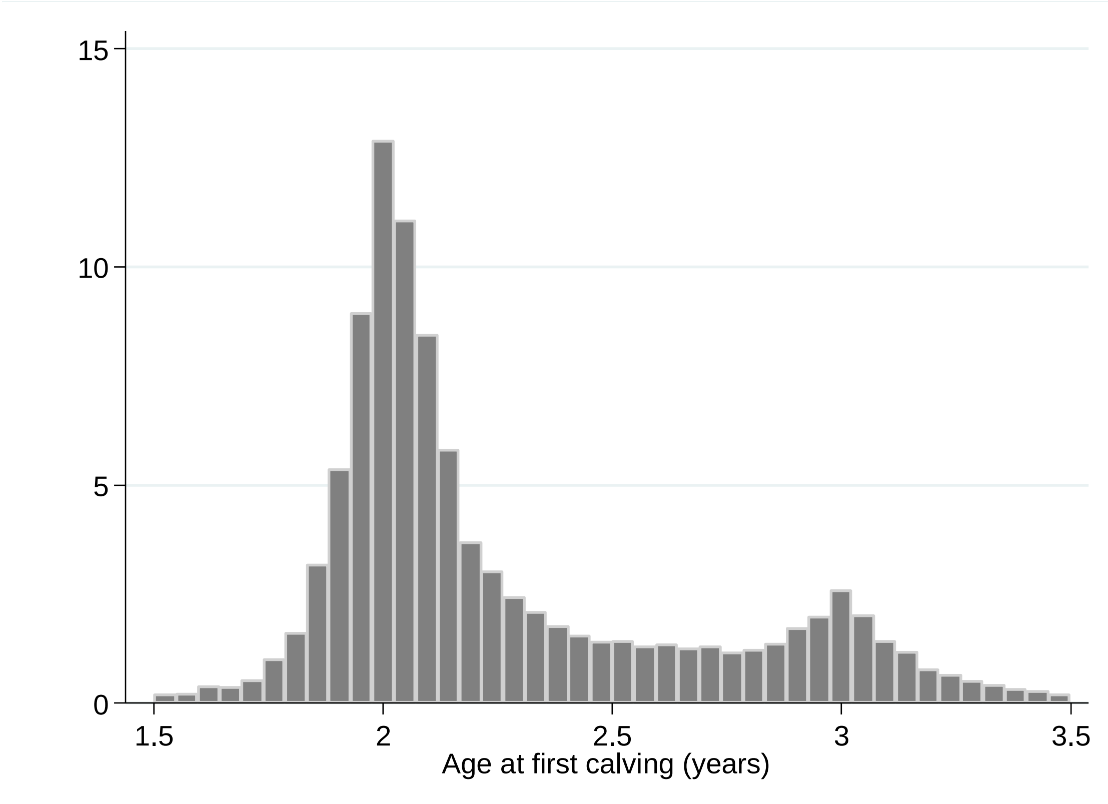

Fig. 5. Estimated lifetime production of cows that belonged to herds≤30 cows, had a normal first calving and no twins in lifetime for the combinations of breed and region. Estimated lifetime production were based on the multivariable estimates from the mixed-effects Poisson model in Table 2 (n=14.862)