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Effects of changes in the breeding goal on genetic improvement for maternal traits in Landrace pigs

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Abstract

Maternal ability is becoming increasingly more important in today's breeding practices, as it increases the animal welfare, as well as, decreases the economic cost related to the loss of animals. Because of the complexity of traits associated with maternal ability, selecting for these traits with traditional breeding methods have showed difficulties, and it is unknown how selection has affected traits related to maternal ability. The Norwegian pig breeding organisation Norsvin have six traits included in their breeding related to maternal ability. The traits investigated in this thesis are total born, stillborn, mortality at 3 weeks, weight at 3 weeks, shoulder sore (SS) and body condition score (BCS). As well as, variance at 3 weeks which is not included in the breeding goal, but is monitored.

Genetic changes from 1990 to today, in the seven traits in Norwegian Landrace has been calculated with DMU based on breeding values, including genetic correlations. Total born was first introduced in 1992, at the same time BLUP breeding values became the basis for selection. In 2003, was weight at 3 weeks (adjusted for litter size) included, and mortality at 3 weeks was introduced in 2007. Stillborn, SS and BCS was introduced in 2010. Stillborn and total born is both defined under litter size. The economic weights for litter size has changed from 18 to 28% throughout the period, mortality have changed from 10 to 14%, weight changed from 13 to 2%, SS from 4 to 0% and BCS from 0 to 6%. Genetic trends were calculated based on 395 000 records in the first traits, down to 147 000 records for the last introduced traits. The pedigree file includes 936 000 animals, of which 40 000 were genotyped. The genetic trend for total born have increased within the period, while weight at 3 weeks have had the greatest increase. Mortality increased until 2009, while variance had its peak in 2012. With SS and BCS included, the genetic trends changed from negative to positive. Detailed results will be given on all traits, however the results show that it is possible to obtain sustainable improvements in all maternal traits when reliable records are available and the traits are given relevant economic weighting in the selection program for a maternal line.

This thesis is investigating the changes in phenotypic and genetic trends of the seven traits related to maternal ability of Norwegian Landrace pigs, utilising data provided by Norsvin from 1990 to today. Furthermore, investigating the effect the changes in the breeding goal have had on the maternal ability of the sows. Enquiring an overview of the changes on maternal traits is beneficial for a sustainable future breeding practice, which includes both ethical and economic aspects.

Sammendrag

Moregenskaper blir mer og mer viktig i dagens avl, dette fordi det øker dyrevelferden, i tillegg til at det senker økonomiske tap relatert til tap av dyr. På grunn av kompleksiteten av egenskaper assosiert med moregenskap, seleksjon for disse egenskapene har vært vanskelig med de tradisjonelle avlsmetodene, og det har vært usikkert hvordan seleksjon har påvirket egenskapene relatert til moregenskap. Den norske svineavlsorganisasjonen Norsvin har i dag seks egenskaper inkludert i avlsmålet som påvirker moregenskapen. Egenskapene undersøkt i denne oppgaven er totalfødt, dødfødt, dødelighet ved 3 uker, vekt ved 3 uker, skuldersår (SS) og hold ved avvenning (BCS). I tillegg til variansen i vekt ved 3 uker, som ikke er inkludert i avlsmålet, men som har blitt overvåket.

Genetiske endringer fra 1990 til i dag, på de syv egenskapene i Norsk Landsvin har blitt kalkulert med DMU basert på avlsverdiene, og genetiske korrelasjoner. Totalfødt var først introdusert i 1992, samme tidspunkt som BLUP avlsverdier ble basis for seleksjonen. I 2003, ble vekt ved 3 uker (justert for kullstørrelse) inkludert, og dødelighet ved 3 uker ble inkludert i 2007. Dødfødt, SS og BCS ble inkludert i 2010. Dødfødt og totalfødt er begge definert under kullstørrelse. Den økonomiske vekten for kullstørrelse har endret seg fra 18 til 28% i perioden, dødelighet har endret seg fra 10 til 14%, vekt har endret seg fra 13 til 2%, SS fra 4 til 0% og BCS fra 0 til 6%. Genetiske trendene var kalkulert basert på 395 000 observasjoner for den første egenskapen, ned til 147 000 observasjoner for egenskapen som var senest inkludert. Slektskapsfila inkluderer 936 000 dyr, av de 40 000 var hadde genotype. Den genetiske trenden for totalfødt har økt innen perioden, men vekt ved 3 uker har hatt den største økningen. Dødelighet ved 3 uker økte inntil 2009, mens variansen ved 3 uker hadde sin topp i 2012. Med SS og BCS inkludert, endret de genetiske trendene seg fra negative til positive. Detaljerte resultater er presentert for alle egenskapene, men resultatene viser at det er mulig å oppnå bærekraftig forbedringer i alle moregenskapene når pålitelige observasjoner er tilgjengelig og egenskapene er tildelt relevant økonomisk vekt i et seleksjonsprogram for morlinjer.

Denne oppgaven undersøker endringene fenotypiske og genetiske trender for de syv egenskapene relatert til moregenskaper på Norsk Landsvin, med bruk av data fra Norsvin fra 1990 til i dag. Videre undersøke effekten endringene av avlsmålet har hatt på moregenskapene. Å oppnå en oversikt over endringene på moregenskapene er positivt for å kunne ha et fremtidig bærekraftig avlsprogram, som inkluderer både etiske og økonomiske aspekter.

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1. Introduction

During the development of a breeding goal, it is important to consider a broad spectrum of traits, and be aware of correlations that may exist between the traits. Furthermore, the weighting of traits is a challenge, as one wants to see improvements, but still be precautious in regard to existing correlations and correlations that may be undiscovered. In addition, the consequences of the weightings allocated may not be possible to observe until years later, as breeding goals changes happens regularly there might be changes in traits that are difficult to determine the background of. Previously, the breeding of animals has been based on the phenotypes of the animals, and further utilising offspring recordings to estimate future performances. As time went on, the use of indexes and statistical analysis was established, Best Linear Unbiased Prediction (BLUP) utilising a mixed linear model was introduced to more accurately estimate breeding values, and was found to work successfully in regard to traits that are easily recorded and have moderate to high heritabilities. However, required great investments for traits with lower heritabilities.

As technology has advanced, breeding companies have moved on from offspring recording to genomic selection. By utilising genomic information, the generation interval gets smaller, while the selection intensity and accuracy is increasing, leading to a greater genetic gain per generation. Due to more advanced technology and methods it is now possible to more accurately select for traits with lower heritabilities. Reproduction traits have been included in breeding goals for years, however definition and weighting of the traits have differed throughout the years and between breeding organisations. Maternal ability is becoming increasingly more important in today's breeding practices, as it increases the animal welfare, as well as, decreases the economic cost related to the loss of animals. Because of the complexity of traits associated with maternal ability, selecting for these traits with traditional breeding methods have showed difficulties, and it is unknown how selection has affected traits related to maternal ability.

Research on maternal behaviours of sows intensified in the early 1900s. It is important to differentiate between maternal behaviour and maternal traits, as behaviour is not a trait in itself, but rather a factor influencing the traits. Because behaviour is not measured linearly or is seen as an objective trait, the inclusion of behaviour in breeding goals is not common practice. However, it is still important to consider the effect of animal behaviour on maternal traits. Furthermore, some of the other factors influencing the maternal traits are age, parity, longevity and the production environment.

Through selective breeding there has historically been a high pressure on increasing the litter size, in order to increase the profit. However, one of the consequences was a lower survival rate, therefore, leading to a change in breeding goals to try to achieve a greater balance between the different traits. Selective breeding has successfully been used to limit stillbirths. However, high litter mortality still remains a challenge across the industry that needs to be addressed by pig breeders. Recent research has made it evident that some variations in piglet mortality across individual sows may be attributed to innate differences in maternal ability. However, finding the most appropriate traits for describing ideal maternal skills is not an easy task. Different authors have put forth different traits to describe maternal ability in pigs. Therefore, defining maternal ability with just a few traits is difficult, considering the current lack of consensus related to the most profitable and effective maternal traits.

However, some important traits have been identified and have been applied successfully in pig breeding programs. The Norwegian pig breeding organisation Norsvin established in 1958, have a long tradition for considering a wide range of traits in their breeding goal, including traits for greater maternal ability. In addition, they have recorded traits they believed might be important, even if not directly included in the breeding goal until later on. This have proven to be beneficial in regard to breeding for maternal ability, as when traits have been considered to be allocated a weighting there is sufficient number of recordings available. Today, Norsvin have six traits included in their breeding goal which is either directly or indirectly a measure of maternal ability, as well as an additional trait that is recorded to supervise the development. The traits included are total born, stillborn, mortality at 3 weeks, weight at 3 weeks, shoulder sore and body condition score. Furthermore, the variance in weight at 3 weeks is monitored to prevent the variance drastically increasing. This thesis is investigating the changes in phenotypic and genetic trends of the seven traits related to maternal ability of Norwegian Landrace pigs, utilising data provided by Norsvin from 1990 to today. Furthermore, investigating the effect the changes in the breeding goal have had on the maternal ability of the sows. Enquiring an overview of the changes on maternal traits is beneficial for a sustainable future breeding practice, which includes both animal welfare and economic aspects.

2. Literature Review

The traits selected for through animal breeding is either production, health- or reproductive traits. Breeding for production traits such as leanness and increased growth rate is extremely important in today's livestock production. However, approximately 30% of the culling in the pig industry is due to reproductive problems (Onteru *et al.*, 2012). Fertility issues leads to a substantial loss in efficiency and affects the cost of production (Varona *et al.*, 2001).

Maternal ability is vital in many species for survival and growth of offspring. A proportion of the variation in reproductive traits are genetic, and therefore provides the opportunity to improve the genetic gain by utilising genomic selection (Zak *et al*., 2017). Reproductive traits are complex and is often quantitative, meaning that the trait is affected by multiple genes (Onteru *et al.*, 2012). Reproductive traits are dictated by two routes of gene expression, the direct animal effect and the maternal effect. The maternal effect consists of the intrauterine conditions, milk production and the mothering ability. These effects are influenced by both genetics and the environment (Dube *et al*., 2014). Selection for reproduction traits, such as increase of litter size has been included in the breeding goal for several years, as a consequence it is increasingly putting more pressure on the maternal abilities of the sows (Grandinson, 2005).

Maternal ability is important in both intensive and extensive production systems. In extensive production systems, the level of human intervention is limited and it is therefore crucial that the sow can successfully rear her piglets on her own without human interaction. The common trend in today's livestock, as the demand is increasing, is that the production systems are getting larger and a common consequence is that the stockperson gets less time supervising individual animals (Grandinson, 2005). There has been an increase in litter size, both at birth and weaning, however, as the litter size increases the survival rate decreases if not considered in breeding programs (Grandinson *et al*., 2003). According to literature, the most common cause of death in piglets before weaning is crushing by the sow, at around 45%, while an additional 20% is due to inadequate nutrition supply (Grandinson *et al*., 2003). To reduce the occurrence of crushing farrowing crates was introduced to limit the movement in the farrowing pen (Grandinson, 2005). However, even though this is practiced many places in the world, the

Norwegian animal welfare regulations states that both sow stalls and farrowing crates are banned (Lovdata, 2017). The farrowing pen have certain space requirements that ensures the welfare of both the sow and litter during farrowing. Confinement of using a farrowing crate is only allowed for a maximum of one week, if sows show significant restlessness or aggression (Ocepek *et al*., 2017). However, research indicates that the use of farrowing crates has reduced the natural selection pressure regarding maternal behaviour (Appell *et al.,* 2016). As welfare considerations are becoming increasingly more important both in the livestock sector and the society in general, it is to believe that the legislations regarding the use of farrowing crates will become stricter around the world. Hence, the importance of maternal abilities, both behavioural and more objective traits, are becoming increasingly more important in animal breeding (Grandinson, 2005). Behavioural traits are used throughout literature to indicate the maternal ability of the sow, however, even though multiple tests have been conducted in the pursuit of characterising maternal behaviour, the genetic variances and heritabilities are generally low (Appell *et al*., 2016).

2.1 The Role of the Maternal Traits

The primary purpose of pig production in modern times is the production of high quality meat at a low cost. Efficient farming depends on several factors including high reproductive rate and rapid growth rate. Present consumer demands for requirement of low fat have led to selection for increasing lean meat production (Rydhmer and Canario, 2014). The number of piglets per sow and number of litters per year are economically the most important reproductive traits required by pig producers and are often found to be the only reproductive trait included in multiple breeding programs (Palmo 2009).

Although in most cases, increase in litter size at weaning is the goal desired by pig producers, the number of piglets born alive is the most widely chosen selection trait. However, the process of selection on the basis of litter size has associated problems such as increased mortality of piglets. According to a study by Tribout *et al.* (2013), after selection for 14 generations, the selected breed line had significantly larger size of litters, but also suffered with high rate of stillbirth and high mortality rate before weaning. In addition, Lund *et al.* (2012) found significant negative association between birth litter size and survival of piglets from birth to weaning. Therefore, given the negative genetic correlations identified in terms of high piglet mortality, selection on basis of litter size at birth by itself, seems to be unprofitable. Improving survival of piglets is therefore greatly motivated from both economical and ethical standpoints.

In response to these concerns, there currently seems to be increasing interest in possibilities of improving maternal abilities in breed lines. For example, international breeding company TOPIGS has been selecting a sire line based on the innate capacity of piglets to survive (Knol and Leenhouwers, 2012). Similarly, Norsvin has been recording various traits that are associated with maternal ability since the 1990s (Norsvin, 2013).

Based on literature, maternal behaviour is recognised as playing a major role as a determent of good maternal ability (Rutherford *et al*., 2013). In recent years, various behavioural traits have been researched and some also been successfully applied by pig breeders. Fraser (2015) found that maternal behaviour varies largely between individual sows and that this difference is caused partly by genetics as well as environmental factors. If large genetic variation exists within the behaviour traits associated with maternal ability, then selection based on improved behaviour can be a useful means of improving piglet survival. Engelsma *et al.* (2011) strengthened this theory in their study that assessed certain behaviour traits on pig survival rates. The result was increased piglet survival rate after 14 generations.

2.2 Factors That Determine Maternal Ability of Sows

A number of factors determine how successfully the sow weans a piglet. For example, litter size during birth is influenced by embryo survival and ovulation rate and the farrowing length influences the number of piglets born alive. Figure 1 puts forth various aspects that can affect and be used to measure maternal ability in sows, which include litter size, piglet weight variations, birth weight, early growth, sow behaviour and piglet survival. Even though behaviour is included in the figure because of its influence, it is important to remember that it affects the maternal ability differently than traits that can objectively be measured and recorded, and should therefore be considered separately. Furthermore, while behaviour is an aspect which affects all the traits, the remaining traits are considered economical traits as they have a direct impact on the cost and profit of the production. Therefore, not including behaviour would be limiting to the investigation of maternal ability.

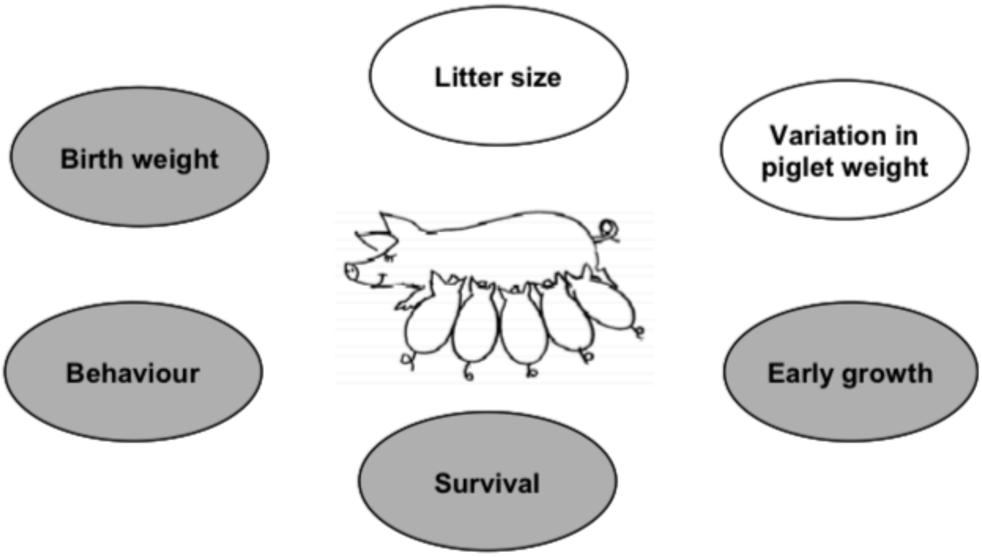


Figure 1 Aspects affecting the maternal ability of the sow (Grandinson et al., 2005)

Research suggests that the behaviour of sows in particular is one of the components of maternal ability that plays a major role in determining survival of piglets (Canario *et al.*, 2014). It is often a challenging task for the sow to ensure survival of her offspring. This task gets more complicated with larger litter sizes and the considerable size difference between sow and offspring. For this reason, careful behaviour by the sow is vital for minimizing risk of piglet crushing. Furthermore, considering that new born piglets have very low energy reserves, they depend largely on the sow's milk for survival immediately after birth. Therefore, nursing behaviour and milk production is extremely important requirements for increasing piglet survival rates (English and Smith, 2005).

Different researchers have evaluated maternal ability using different approaches. While there is consensus that maternal ability refers to the ability of sows to efficiently raise litters until weaning, the approaches to assess its effects, advantages and effectiveness have been different. Hanenberg *et al*. (2001) used the percentage of piglets weaned out of the total number of piglets nursed, including cross-fostering, to be able to estimate the combination of real mothering ability and piglet vitality. While Knol *et al*. (2002) estimated maternal ability based on number of overall stillborn and percentage of stillborn on litter level. Multiple studies have conducted research based on fear associated with humans (Janczak *et al.*, 2003), and the sow's reaction when separated from offspring, and towards stockman handling (Gäde *et al.*, 2008). In addition to this, personality characteristics have been utilised for an estimate of maternal ability for several years (Hemsworth, 1981; Hemsworth, 1989; Pedersen and Kongsted, 2001), however, when utilising personality characteristics, it is important to be able to objectively record the traits, to get as much uniformity and accuracy as possible. Stratz *et al*. (2016) therefore separated behavioural traits into group behaviour, such as aggression and tail-biting, and farrowing and nursing behaviour. In addition to this, Stratz *et al*. (2016) utilised as well as piglet weaning weight and survival rate, and the balance of the litter, more physiological traits such as oestrus behaviour. Further behavioural studies include Gäde *et al*., (2008), which defined five behavioural traits that can be utilised when estimating maternal ability. This includes group behaviour, attitude towards people, crushing of piglets and savaging of piglets.

Maternal ability has been assessed in multiple different manners, some researchers evaluated maternal ability in terms of behaviour of sows in both free-range conditions and in more intensive environments, while others assessed maternal ability in terms of piglet mortality and the ability of sows to protect and provide (milk) to the young ones. Furthermore, specific traits that are more easily recorded in greater quantities have been defined by breeding organisations such as Norsvin. Because of the wide range of definitions and recording methods in regard to maternal ability, the different aspects have therefore been discussed.

2.4 Selection on Maternal Ability based on behaviour

Measuring piglet mortality between birth and weaning is seen as a good indication for maternal ability. Piglet mortality is inherently very high in swine farming. Most of the mortality occurs within the first 2 days of birth. Piglets with lower birth weight are more vulnerable to mortality and even more so if they are born in larger litters (Edwards *et al.*, 2016). Recent research indicates that stillbirth, crushing by the sow and starvation are the three most common causes of mortality (Dyck and Swiersta 2017). It is often highly difficult to identify the actual cause of death. In most cases, crushed piglets may initially be weakened due to malnutrition. Therefore, two of the two causes of mortality among live born piglets – starvation and crushing are not completely independent (Wechsler and Haggling, 1997).

Therefore, while the crushing of viable and healthy piglets may be attributed to behaviour and maternal ability of the sow, and the response of a sow to the distress call of the piglets, crushing of piglets that are already weak or injured should not be directly correlated with maternal ability (Wechsler and Hegglin, 1997). Additionally, piglets born with lower weight tend to remain closer to the sow, as compared to normal weight piglets for better access to teats, thereby increasing their chances of being crushed (Weary *et al.*, 2016). Therefore, inability to procure adequate quantities of food can be a result of several reasons. Some of which are related to the piglet's own ability to succeed in competing with other littermates and some are sow related maternal traits such as insufficient functional teats and low milk production.

However, some behavioural maternal traits that's exclusive to sows have also been identified. Hutson *et al*. (2011) found some major individual differences between sows in terms of behaviours following farrowing, suggesting that some sows show increased likelihood of putting their little ones at risk of starvation and crushing as compared to others. Few identified behavioural maternal traits include pre-parturient behaviour; crushing related behaviours; and aggression and fear related behaviours.

The long-term aim of breeding and selection for improved maternal behaviour would be to minimize piglet losses before weaning or put in other words, increase survival rate of piglets until weaning. This would result in improved animal welfare and also increased economic gain. With these aims in mind, Gade *et al.* (2008) procured data from 32 multiplier and nucleus herds in Germany for estimating breeding values and variance components for four important behaviour traits in sows. A total of 31,000 farrowing was recorded between December 2003 and July 2005. Estimates were performed univariate by using the animal threshold model. The four maternal behaviour traits they studied included group behaviour, attitude to people, crushing of piglets and savaging of piglets and heritabilities coefficients observed were 0.03, 0.01, 0.02 and 0.06 respectively. They identified low heritability and poor genetic correlation to litter size during birth, suggesting that it would be difficult to improve maternal ability using selection and breeding techniques. This also suggests that selection for improved maternal ability is not necessarily associated with reduced litter size.

2.4.1 Selection Based on Maternal Behaviour of Free Range Sows as Determinants of Maternal Ability

In farrowing pens, sows are prevented from performing most of the behaviour patterns seen among sows grown in free-range conditions. However, according to Gustafsson *et al*. (2009), motivation to perform these behavioural patterns remains largely unchanged across both intensive and extensive production systems. Fraser *et al.* (2015) also put forth similar findings by showing that the sow's motivation to perform certain behaviour patterns in free-range conditions can be similar even in intensive commercial housing systems. Therefore, with today's increased inclination towards intensive farming, it is essential to assess sow behaviour in unrestricted environments in order to better understand successful maternal ability in intensive systems. The initial approach for determining maternal ability was to assess how sows would succeed in bringing up their young ones in free-range conditions. This would help in understanding how they would do in intensive farming conditions. Few of the aspects considered were nest building, nest occupation period and integration of litter with family group.

Feral pigs and wild boars tend to live in small groups of closely related females such as sisters and daughters. Shortly prior to farrowing, the sow leaves the group and travels to find a suitable place for building a nest. The nest is usually built in a period of 24 hours prior to farrowing. Sows usually travel more than 6 km in search of a nest site during which investigative behaviour such as rooting and sniffing is actively performed. Subsequently, sows pick well-protected places for nests such as under a tree. Such location of nests at a distance from family groups protects them from being trampled by adults and also prevents unrelated piglets from stealing milk from the mother (Jensen *et al.*, 1993). The ability of sows to efficiently arrange for a farrowing nest in free-range conditions is considered as a determinant of good maternal ability even in intensive conditions.

Subsequently, after arranging for the nest and farrowing, the ideal sow doesn't leave the nest while farrowing. Sows are considered to have good maternal abilities if they stand up once in a while to turn around and sniff the piglets. During this process, the sow removes piglets and moves them away from herself so that she doesn't lie down on them. This behaviour suggests that sows would be more careful to not lie over their piglets even under intensive farming conditions (Jensen *et al.*, 1993).

Sows stay away from the family group until the piglets are at least 10 days old. In the first 2 days of farrowing, both piglets and the sow remain within the nest. On the third day, the sow leaves the nest for foraging nearby and the piglets follow her on short excursions in the vicinity of the nest. Subsequently, the piglets learn to respond to acoustic signals in the last part of the nesting period. According to Jensen *et al.* (1993), the better the communication between the piglet and the sow, the lower the number of piglets abandoning the sow, and the lower the piglet mortality; the better would the considerations of maternal ability be. After abandoning the nest, the sow leads the litter back to the family group. The new litter is gradually integrated into the group as the mother picks new places to rest closer to the family.

2.4.2 Pre-parturient behaviour

As described earlier, sows are involved in high levels of activity in the last 24 hours prior to farrowing among free-range sows. Similarly, sows housed in intensive farming settings also exhibit nest-building behaviours in the form of pawing the floor and rooting even when no forms of nest building material are available (Haskell and Huston, 2016). Thodberg *et al.* (2012) found that sows that were provided with nesting material such as sawdust, sand and straw were more active before the process of farrowing, but became passive after the farrowing started. This reduced movement decreased the risk of crushing piglets at the time of parturition. Additionally, such provision of building materials was found to be associated with lesser stillborn piglets, increased responsiveness to distress calls of piglets, shorter times of parturition, reduced number of terminations of suckling sessions by the sow and increased suckling duration (Herskin *et al.*, 2009). Herskin *et al.* (2009) also recorded greater survival rate between birth and weaning among sows that were given opportunities to build nests. These studies suggest that providing an environment closer to the free-range conditions of pigs can help enhance the maternal ability.

2.4.3 Crushing Related Behaviours

Crushing by the sow have according to literature been deemed one of the most common causes of piglet mortality. Improving maternal ability of pigs by reducing the number of crushed piglets can help reduce piglet mortality to a great extent. When investigating maternal traits such as group behaviour, attitude towards people, crushing of piglets and savaging of piglets; the greatest genetic correlation found to be between crushing of piglets and maternal ability (Gäde *et al.*, 2008). Crushing risk mostly occurs when a sow changes its position, for instance from sitting to lying or standing to lying (Fraser 2015). Valros *et al.* (2010) put forth three aspects of the behaviour of a sow that influence the crushing possibility. These include the general restlessness of the sow while being in vicinity of her litter, her behaviour while lying down and the sow's reaction to the screaming piglet. Grandinson *et al.* (2005) further concluded that alertness of the sow to piglet screams is associated genetically to increased piglet survival. Few other investigated traits were aggression towards stockperson, crushing of piglets, nursing behaviour and savaging of piglets (Haskell and Huston, 2016).

Two different movement patterns that lead to either ventral crushing or posterior crushing have been identified. Ventral crushing may occur when the sow lies down from the sitting position leading to crushing of piglets under the thorax. Posterior crushing occurs when the sow lies down from standing position leading to trapping of piglets under hindquarters. Ventral crushing is more common in intensive housing conditions (Fraser 2015). Researchers have identified differences between individual sows with respect to behaviour while changing position and crushing behaviour in general. This suggests differences in behavioural patterns which contribute to the overall maternal ability within sows of the same breed and living in similar environmental conditions. This also suggests that selection on the basis of fewer or no crushed piglets would be beneficial in producing lines with better maternal abilities. On the other hand, few sows within the same breed were found to be more careful while lying down than others (Wechsler and Hegglin, 1997). In addition, McGlone and Morrow-Tesch (2010) found that time spent in sitting position was correlated positively to number of crushed piglets. Furthermore, Sows that did not show sitting behaviour crushed significantly lower number of piglets than those that showed sitting behaviour. Subsequently, McGlone *et al.* (2011) put forth that if selection was performed based on sitting behaviour, mortality due to crushing would decrease greatly. Moreover, they also found heritability of 0.4 among slaughter pigs for sitting frequency, suggesting that successful selection for this trait could be performed. The proposal of McGlone *et al.* (2011) however has not been put to the test and no further evidence exists to prove that piglet crushing would reduce if maternal ability was improved in terms of number of sitting hours.

Rolling movements of the sows, wherein they move from lying on the side to lying on the udder and vice versa also put piglets at risk of crushing. This risk in turn is related to the manner and speed in which it occurs rather than its frequency (Weary *et al.*, 2016). Also, Wechsler and Hegglin (1997) found that crushing occurs most often when a sow lies down suddenly from standing position. They also put forth that sows that never 'flopped straight down' had lowest number of crushed piglets. Therefore, considering that these traits are specific to individual sows and not inherent within breeds, selection based on these traits have been believed to improve overall maternal ability and resultantly reduce piglet mortality before weaning.

Another trait that has been associated with reduction in number of crushed piglets is the responsiveness of sows to the piglets' distress calls. Considering that piglets and sows are confined to small spaces in intensive settings during lactation period, there are obvious chances that even careful sows will lie down on piglets. If this happens, there is a possibility for piglets to survive if sows respond to the tactile and vocal stimuli of the piglet. According to Weary *et al.* (2016), the chances of piglet mortality increase with the duration of time a piglet remains trapped under the body of the sow. Hutson *et al.* (2011) found major individual differences in how sows react to vocal stimuli of piglets. Some sows were found to be totally unaffected while lying upon a screaming piglet, while other sows very alertly reacted by standing. Despite the availability of evidence suggesting that selection based on responsiveness of sows to crushed piglet stimuli, none of the genetic studies performed till date have successfully proven this association (Hemsworth and Coleman, 2014).

Hellbrügge *et al*. (2008) also put forth similar results for maternal crushing, as they estimated low heritability of 0.03 for the parental crushing behavioural trait based on data from 1500 litters by applying a threshold model. The researchers treated every piglet as repeated observations of the sow and resultantly assessed heritabilities. Similarly, Grandinson *et al.* (2005) also found low heritability of just 0.06 for the crushing trait. Therefore, evidence seems to be inclined to the fact that crushing is largely inherent within individual sows and has no genetic heritability.

2.4.4 Fear and Aggression Related Behaviours

Like other production animals, pigs are frequently exposed to the stockperson. Sometimes such interactions are positive in nature such as a gentle stroke; alternatively, they can also be negative like hitting or pushing. Regular interaction may have significant positive or negative effects on physiology, behaviour and production of the animal (Hemsworth and Coleman, 2014). Lambe *et al.* (2001) reported that higher levels of fear were found to be associated with higher rates of stillbirth. However, very few studies have presented a positive correlation between maternal success and fear related behaviour. On the other hand, sows and gilts that showed aggressive behaviours towards the stockperson were also found to be associated with high levels of maternal protectiveness, suggesting good maternal abilities.

In today's pig livestock system, sows are faced with repeated regroupings throughout their lives at various stages of production. Less aggressive sows have been reported to increase the overall welfare of group sows (Andersen *et al.*,2005), as well as, Lovendahl *et al.,* (2005) indicated that less aggressive sows also exhibits better maternal abilities. Based on this, it seems feasible to be able to select for group behaviour to improve maternal ability in sows. It has been a common belief that the more aggressive sows are better mothers. However, no association have been found between aggression towards stockpersons and increased piglet survival (Forde 2002). Among farmers, it is argued whether or not sows that show more aggressive behaviour towards the stockperson is more successful mothers, however, this has not been supported by sufficient research. Løvendahl *et al*. (2005) stated that less aggressive sows, however not stated if in regard to stockman ship or other pigs, showed a greater responsiveness when piglets were handled by the stockmanship. However, Hellbrügge *et al*. (2008) found a positive genetic correlation between the first separation test of sow and piglet, and aggressive behaviour in group settings. Furthermore, as Grandinson *et al*. (2003), found that aggression has a genetic background it is possible to select against this, however, no results indicate that selecting against aggression would affect the piglet mortality, but however, make them easier to handle. Furthermore, the scream test performed and the display of avoidance towards humans seems to be genetically correlated with piglet survival rate. As avoidance of stockmen may be a result of stress and fear, selection against fearfulness is believed to increase the animal welfare. When deciding traits for selection it is important to consider the possible gain in piglet survival rate, while not compromising the animal welfare in this case in regard to avoidance. Appel *et al*. (2016) stated that it is possible to select for both reduced aggression and greater maternal ability simultaneously, and therefore suggests that the inclusion of these traits in pig breeding would be a step in the right direction.

2.5 Litter size

Litter size at weaning is a complex trait because litter size includes number of piglets born, survival throughout farrowing, and pre-weaning survival, which again includes multiple aspects (Zak *et al.*, 2017). The survival rate of piglets is further discussed later on. Litter size is often used as an indicator of the sow's fertility, and the number of weaned piglets is seen as the major factor for increasing the productivity, therefore, litter size has been an extremely important trait during the last decade (Nielsen *et al.*, 2016). In addition, to increasing the litter size, the reduction of piglet mortality has been included as it increases the animal welfare and secures the full potential of the litter size, and is the major determinant for litter size (Nielsen *et al*., 2016). Litter size is composed of several aspects, e.g. uterine capacity, ovulation – and survival rate. Even though the ovulation rate determines the maximum number of piglets born, the litter size does only minimally increase when selecting using an index based on the ovulation rate and prenatal survival (Rosendo *et al*., 2007). Research have shown that embryonic – and fetal losses that can occur in every stage of the pregnancy plays an essential role on the final litter size (Spötter and Distl, 2006). It is possible to improve the litter size by minimising losses during the pregnancy, however, it is affected by multiple aspect, as well as genetics, management, husbandry and nutrition affects the prenatal losses.

The uterine capacity highly affects the placental development, sows with a greater uterine capacity does therefore have better predispositions for being able to nurture a greater litter size. It is possible to increase the litter size, however on the expense of the mean birth weight (Spötter and Distl, 2006). On the other hand, research have stated that a high enough birth weight is extremely important for the survival rate. However, this has not been proven through genetic analyses, rather a negative correlation between birth weight and survival rate. Directly selecting for piglet survival would rather affect the body composition than the birth weight (Spötter and Distl, 2006). Furthermore, it was speculated that if it is not the birth weight that affects the survival rate, but the variation of weight within the litter (Knol *et al*., 2002). Direct selection on piglet survival would increase the placental efficiency, carcass fat percentage, and the maturity of piglets at birth, but on the other hand, decrease the mean birth weight, the placenta weight and variation within (Leenhouwers *et al*., 2002). The maturity of piglets at birth improves the piglets' predisposition to handle stressful situations, and may also be able to cope better with a lesser maternal ability. Selecting for lean tissue growth leads to heavier piglets, however, less mature. Furthermore, selecting for survival rate and litter size might ultimately result in piglets that are more similar to more genetically obese line, e.g. Meishan (Spötter and Distl, 2006). Zak *et al*. (2017) suggested that rather than selecting for the ability of a foetus to adapt to limited space in a uterus, the selection should rather be focused on the size of the uterus and the uterus' ability to adapt for larger litters, which may then lead to increased litter weight, more uniformity within the litter and then also increase the litter survival rate until weaning.

It is important to keep in mind the average birth weight within a breed, and to maintain the optimal range, and rather focusing on decreasing the within litter variation. Furthermore, the genes associated with litter size, total number born, have been found to differ based on the environment. This further confirms the importance of defining the production environment, to be able to successfully breed for desired traits. The selection for individual complex traits are not recommended as they often have undesirable genetic correlations, for example the fact that larger litter sizes is associated with higher mortality rate (Zak *et al*., 2017). It is expected that the response will be erratic for each generation, however, responses close to the estimated based on heritability should occur.

2.6 Survival rate

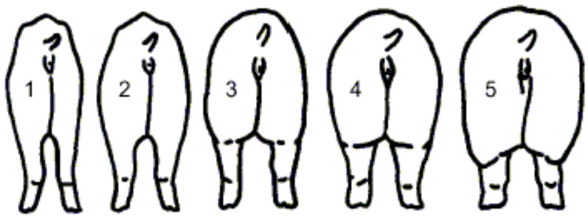
The piglet survival until weaning is influenced by numerous factors such as management routines, environment, piglet viability and maternal behaviour (Ocepek *et al*., 2017). It has been found simple qualitative relationships between maternal behaviour, such as responsiveness and nest building, and the piglet survival rate (Ocepek and Andersen, 2017). To be able to benefit from the genetic gain regarding higher growth rate and litter size, the breeding goal needs to be balanced with traits for maternal ability and behaviour to be able to provide the piglets with a sufficient environment (Grandinson *et al*., 2003). The most obvious way is to directly select for survival and early growth, however, even though relatively easy to record, these traits may difficult to integrate into breeding schemes. It is difficult to rank animals on their genetic merit in regard to survival, as this is defined as a categorical trait, with low heritability (Grandinson, 2005). The growth and survival in the pre-weaning period is influenced by both direct and maternal effects, which have been found to have a negative correlation (Vangen *et al*., 2002). Therefore, ignoring the maternal effect results in an overestimate of the direct heritability (Dube *et al.*, 2014). Furthermore, statistical analysis has been applied as an estimate to increase piglet survival rate, even though, the heritability is relatively low, there are significant genetic differences. Knol *et al.,* (2002) stated that if utilising this tool, then the sire-model including litter effect will produce an underestimate as the sire model lacks the inclusion of the sow's genetic contribution. However, a direct-maternal model, with the higher contribution from the maternal effect would give a more accurate result. Nevertheless, when trying to increase piglet survival rate modelling the survival rate with direct, maternal and nurse sow effect was not found to be successful, and to achieve the most consistent estimates, the sire line and sow line should be calculated in two different data sets (Knol *et al.,* 2002). Breeding for higher piglet survival rate have shown difficulties because of the low heritability and the fact that it is influenced by multiple environmental factors. In addition, it is extremely difficult to correctly consider the effect of cross-fostering. So, when breeding for maternal abilities, it ensures a higher survival rate, as well as, overall welfare of piglet. Reliable estimates of the genetic contributing parameters, including their genetic correlations, are needed to be able to conduct successful and accurate selection.

2.7 Body Conformation

Body conformation is important for the overall health and welfare of the sow. Throughout the years, the conformation of pigs in commercial livestock production have changed in regard to size, weight and composition of the animal e.g. the fat:muscle ratio. However, it is crucial to always monitor and be aware of the consequences when selecting for trait that may change the conformation of an animal. Two traits that have been successfully integrated into breeding programs in regard to body conformation is body condition score and shoulder sore. These traits are also related to the maternal ability of the sow (Norsvin, 2013).

2.7.1 Body Condition Score

Body Condition Score (BCS) is used worldwide and is developed to be able to easily assess the animal (Figure 2). The most common assessment method is done by hand and finger pressure as well as visually ranking the animal. This may cause inaccuracy as it is dependent on the skill of the person assessing, as well as, if the same person is conducting the assessment within the same herd it is recorded that some deviations of the optimal score may be ignored unintentionally (Maes *et al.*, 2004). Through the reproductive cycle the requirement for nutrition changes, and it is therefore important to monitor the changes to be able to evaluate if sufficient amount and nutrient requirements are achieved. As all of the phases in the reproductive cycle is related, deviations in BCS in one of the phases may compromise the performance in another phase, furthermore, the effects of underfeeding may not be detectable until later parities or months after the occurrence (Maes *et al.*, 2004). BCS is important in regard to the size of the litter the sow is able to bring forward through gestation, as well as, an indication if the sow is able to provide enough nutrients for her young throughout farrowing.



Score	Condition	Detection of ribs, backbone, "H" bones, and "pin" bones
1	Emaciated	Obvious
2	Thin	Easily detected with pressure
3	Ideal	Barely felt with firm pressure
4	Fat	None
5	Overly fat	None

Figure 2 Body Condition Score of Sows (The Pig Site, 2000)

A poor BCS is known to be related to reproductive problems, therefore, to be able to be the most successful, it is a necessity to monitor the condition of the sow. Furthermore, one of the most common causes for culling is reproductive problems (Engblom *et al.*, 2007). As the selection for bigger litter sizes is progressing, it becomes a greater burden on the sow, and have been found to result in a lower BCS at weaning (Lundgren *et al*., 2014). For each kg of piglet body weight, an additional 4 kg of maternal milk is needed, putting more pressure of the BC of the animal (Lundeheim *et al.*, 2014). Literature indicates that a lower BCS is genetically associated with heavier litters, on the other hand, research have shown that sows with a genetic potential of good BCS at the weaning of the 1st litter are more likely to produce a larger 2nd litter (Lundgren *et al*., 2014). One of the biggest challenges in today's breeding programs, especially in regard to Norwegian Landrace pigs is maintaining the BCS throughout multiple parities (Martinsen *et al.,* 2016).

2.7.2 Shoulder Sore

Shoulder sores are caused by continual pressure on the spine of the scapula (Figure 3). This occurs when the sow lies on her side as the majority of her weight is then concentrated on this specific point as it sticks out the farthest. This pressure over time results in restriction of the blood supply, causing the tissue to die. Because of the direction of the pressure, most of the damage have already occurred before an actual shoulder sore have been developed (Reese *et al.*, 2005).

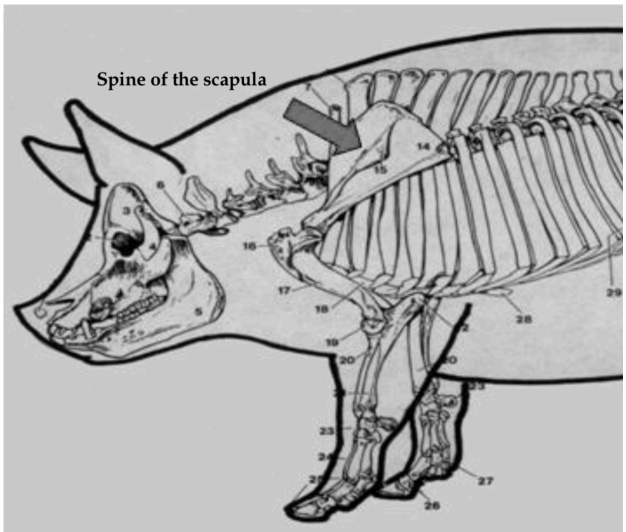


Figure 3 Anatomy of shoulder of sow (Reese et al., 2005)

The avoidance of shoulder sores is important both for ethical and economic reasons. There is a considerable cost in regard to treatment and loss of carcass value and the involuntary culling commonly occurs (Lundgren *et al*., 2014). The occurrence of shoulder sores is related to low BCS as the bones become more prevalent due to the limited amount of fat. Environmental factors such as flooring, pen size, humidity, feeding routines, temperature affect the prevalence (Lundgren *et al*., 2009). Furthermore, the level of activity during parturition and lactation also plays a role (Bonde *et al.*, 2004). According to literature shoulder sore is genetically correlated to BCS and should therefore be considered when developing breeding goals (Lundgren *et al.*, 2012).

2.8 Selection for maternal traits

Multiple aspects affect the maternal ability of the sow, as mentioned previously, research have often focused on the behaviour of the sow when measuring the maternal ability. However, aspects such as age and parity number also needs to be considered. Breeding across species have often been focused on the earlier parities, and achieving the greatest outcome early in the sows' reproductive life. Reproductive traits are complex and quantitative traits, meaning it is affected by multiple genes, different genes have been found to be active dependent on the parity of the sow (Onteru *et al.*, 2012). In regard to parity number, research have indicated that it did not affect the sow's response to piglet vocal stimuli when handled (Vangen *et al*., 2005). However, it was recently documented that the carefulness and communication; such as sniffing, grunting and nudging, of the sow decreased with parity number. Research conducted by Ocepek *et al.* (2017) concluded that this is a result of breeding for a greater maternal investment early in their reproductive life. Thus, recommended selecting for maternal behaviour throughout the sow's life, rather than focusing on earlier parities, as this may compromise the longevity (Ocepek *et al*., 2017). Furthermore, the parity number affects the heritability of number of stillborn which have shown to increase from 0.02 to 0.04 from first to later parity sows (Knol *et al*., 2002).

Selecting for maternal ability in sows is a complex area, with little consensus across literature on what maternal ability entails and the most optimum way to select for it. A considerable amount of research is focused on the maternal behaviour of the sow, and even with this approach, different behaviours are utilised by different researchers. With such a wide range of traits that can be utilised in breeding programs it is necessary to evaluate the suitability and convenience for both producers and organisations. Over all, traits that are objective and easily measured is often preferred when incorporating traits into breeding programs. By doing so, it is a greater chance of high number of record will be reported, as well as, the measurements won't be at risk of extensive human perception or misperceptions. The overall economic goal of pig production is to obtain the greatest number of weaned piglets, as well as, a sufficient weight of the piglets. However, with still maintaining the integrity of the animal. Therefore, as Norsvin have defined seven traits for improving the maternal ability of the sow, including both economical as well as, health related traits, it is interesting and beneficial for future breeding to investigated the changes of breeding goal have affected both the phenotypic and genetic development of the traits.

3. Norsvin

Norsvin, established in 1958, is the only pig breeding organisation in Norway, and is owned by Norwegian pig producers. Norsvin is owned by approximately 1500 pig farmers, and organises all pig breeding in Norway. They are working around the three main principles "progress for all", "inclusion of new research in breeding practices" and "farmer participation in breeding decisions". As Norsvin has developed breeding programs regarding pedigree breeding, cross-breeding and artificial insemination, the aim has always been to ensure healthy, robust and efficient pigs adapted to different environments. In addition, the focus is on ensuring a high-quality end-product, and maintain an ethical and sustainable production (Borgen and Aarset, 2016). The members of Norsvin provide recordings of their herds, which includes the sow control, as well as, supplying animals for boar testing, aiding the future research at Norsvin. In 2014 Norsvin went into collaboration with Topigs and established the company Topigs Norsvin that is characterising themselves as the most innovating swine genetic companies in the world (Topigs Norsvin, 2018).

3.1 History

Naturally there have been multiple changes in the breeding goal throughout the years as the knowledge has improved, and the inclusion of more traits have become more prevalent. Breeding plan one and two are not documented. In 1969 the 3rd breeding plan for Norsvin was established. There were a limited number of traits included to achieve a greater selection pressure for the traits viewed as more important such as meat quality. Still in 1969 fertility and maternal ability was included and had a relative weight of 10%. It was originally set to 16%, however, when taking into account that natural selection also works in the favour of larger litters, as more piglets would be available for selection.

The 4th breeding plan was published in 1977, fertility and maternal ability had a steady weighting of 10% as the previous breeding plan. Fertility and maternal ability was defined as number of pigs weaned in regard to the input of feed, buildings and labour required. This included number of pigs born alive, losses from birth to weaning, age at first parity, and the interval in between parities. During this period, it was suggested to include litter size at three weeks old by utilising the information of both grandfathers' daughters, however, this was not completed. The weighting was decided by economic value, breeding value and correlations. Selection for fertility was conducted separately from other traits that were recorded at the testing station, because of the way the system was built it was not possible to include fertility in the selection indexes. It was speculated that pigs born in relatively small litters had a benefit when selecting for greater growth rate and feed efficiency, and therefore contributing to a negative selection for litter size. Furthermore, there is the possibility that sows born in a large litter size, show tendencies to often produce small litters.

In 1987 the 5th breeding plan was published and for the first time did they separate sow and boar fertility. The sow fertility was defined as the number of weaned piglets; however, the recording of litter size was conducted at 3 weeks. The economic value was calculated based on saved feed, buildings and labour required by increased litter size. The boar fertility was included in the breeding goal and consisted of the quality of semen. There was more routine testing introduced to be able to more accurately estimate the breeding values. Furthermore, they were still relying on the natural selection pressure that sows with larger litter sizes will naturally will be more genetically represented in the next generation. In the period between 1975-1985 the litter size, phenotypically speaking, remained stable at around 10.4-10.5.

Even though, in theory fertility and maternal ability was stated to have an economic weighting in the older breeding plans, it is not believed that it was actually selected for due to lack of recordings.

3.2 Today's breeding goal

The development of the breeding goal of Norsvin Landrace is presented in Figure 4. As seen there have been multiple changes in regard to weighting placed on the different traits. In the earliest stages, it was exclusively selected for the production traits carcass quality, meat percentage, food conversion rate and average daily gain. Selecting for few traits allows for a greater progress, however, is not very sustainable. Throughout the years additional traits have been included, and as the Norsvin Landrace have developed to be a maternal line, the traits in focus have also shifted.

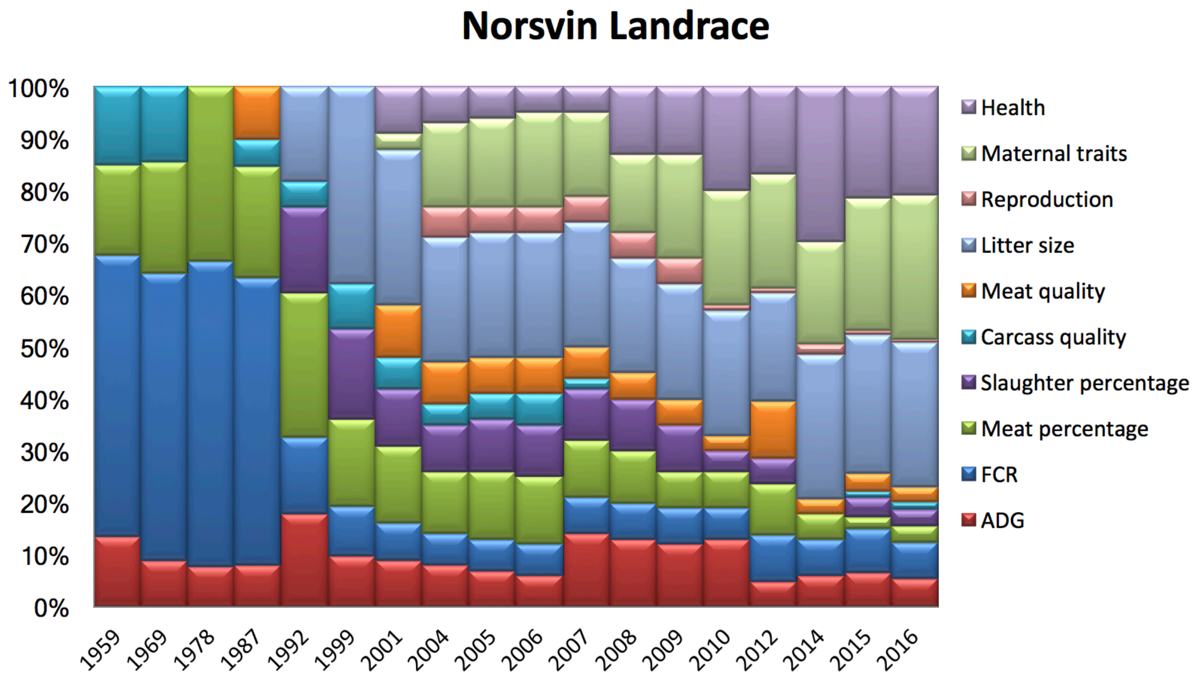


Figure 4 Breeding goal of Norsvin Landrace from 1959 to 2016 (Dan Olsen, pers. com., 2018)

In today's breeding goal, 7 traits are recorded in relation to maternal ability, these include: total born, stillborn, mortality at 3 weeks, litter weight at 3 weeks, variation within the litter weight at 3 weeks, shoulder sore and body condition score. Total born and stillborn are both included in the trait "litter size", mortality and weight at 3 weeks are included in maternal traits, shoulder sore and body condition score is included in health, while variance within the litter weight at 3 weeks is not included in the breeding goal, but is however recorded to be able to monitor changes. In 1992, BLUP was introduced to more accurately estimate breeding values, for the first-time litter size was included in the breeding goal, with a weighting of 18%. Previously the Norwegian Landrace had been selected for production traits using phenotypic recording. In 1999, the weighting on litter size increased to 38%, however, has then decreased and is today weighted with 27.9% (Figure 5). Weight at 3 weeks old was included as a trait in 2003, when a sufficient number of recordings had been collected. However, the actual weighting of the trait from 2003 to 2007 is unknown. Furthermore, in 2007 mortality from birth to 3 weeks old was included. The last traits were included in 2010, shoulder sore (SS) and body condition score (BCS) respectively.

The weighting of traits that's defined as maternal ability throughout the years are displayed below (Figure 5 and 6). Maternal ability was first weighted in 1999, while the biggest increase can be seen from 2001 at 3% to 2004 at 16%. From 2004 to 2006 the weighting occurred linearly with 1%, although follows a decrease to 15% in 2008. The graph shows similar trends throughout the years from 2008 with small dips, although not going lower than previous values. The highest weightings are observed in 2016 and 2017 at 28%. In regard to litter size, it only included stillborn from 2010, previously the only trait considered was total born. When Norsvin initially started weighting litter size there was a massive increase and reached its peak in 1999 with 38%, following there was a decrease trying thereafter stabilises at 24% from 2004 to 2007. The following years, there were minor changes made to the weighting before being weighted the same as maternal traits in 2016 at 28%. Even though litter size is considered a contributing trait to the maternal ability, in the breeding goal, litter size and maternal traits are divided into separate groups, and allocated separate weightings as displayed in figure 5.

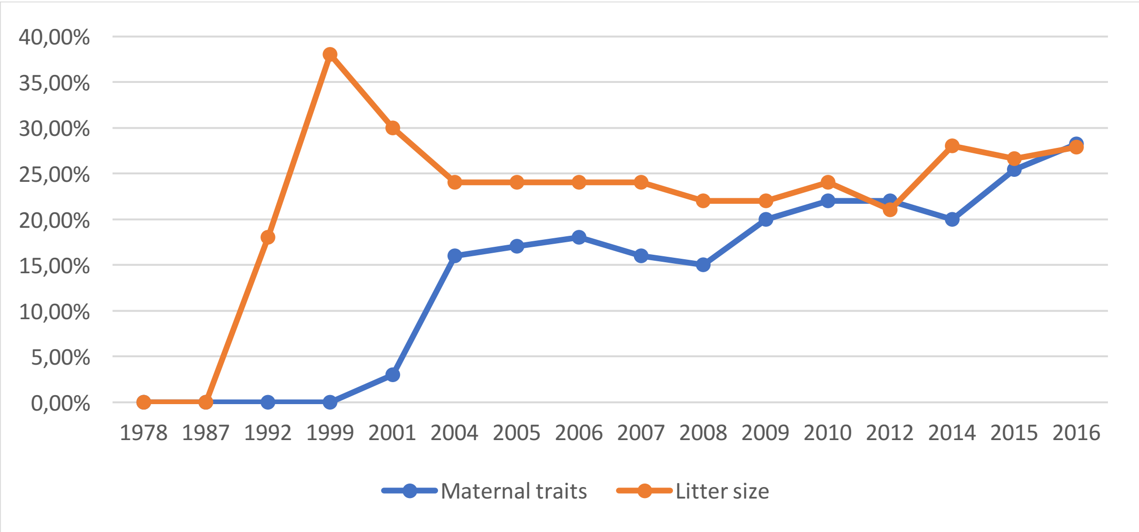


Figure 5 The weighting of litter size and maternal traits from 1978 to 2016 (Dan Olsen, pers.com., 2018)

A more detailed overview on the exact weighting of the traits, from 2007 to 2016, that are included in this thesis is found in Figure 6. Within the whole of the breeding goal, the traits are allocated within different categories. With total born and stillborn within litter size, weight and mortality at 3 weeks within maternal traits, and shoulder sore and BCS within health. As seen in Figure 6, the weighting of total born have decreased from 2007 (24%) to 2012 (14%), before increasing towards 2016 (21%). Weight at 3 weeks was not weighted in 2012 and 2014, hence the disappearance of the line in those years. The weighting on mortality at 3 weeks proceeded that of total born in 2012 with a weighting of 16%. Stillborn was included in 2010, with a stable weighting of 7% to 2012, and increased to 11% in 2014 before a slight decrease towards 2016. The weighting on shoulder sore was at its highest in 2010, when it was included, at 4%, but have however since then been the trait with the lowest weighting. When BCS was included in 2010 it did not have any weighting, but did then decrease to 8% in 2014, with a following decrease to 6% in 2016.

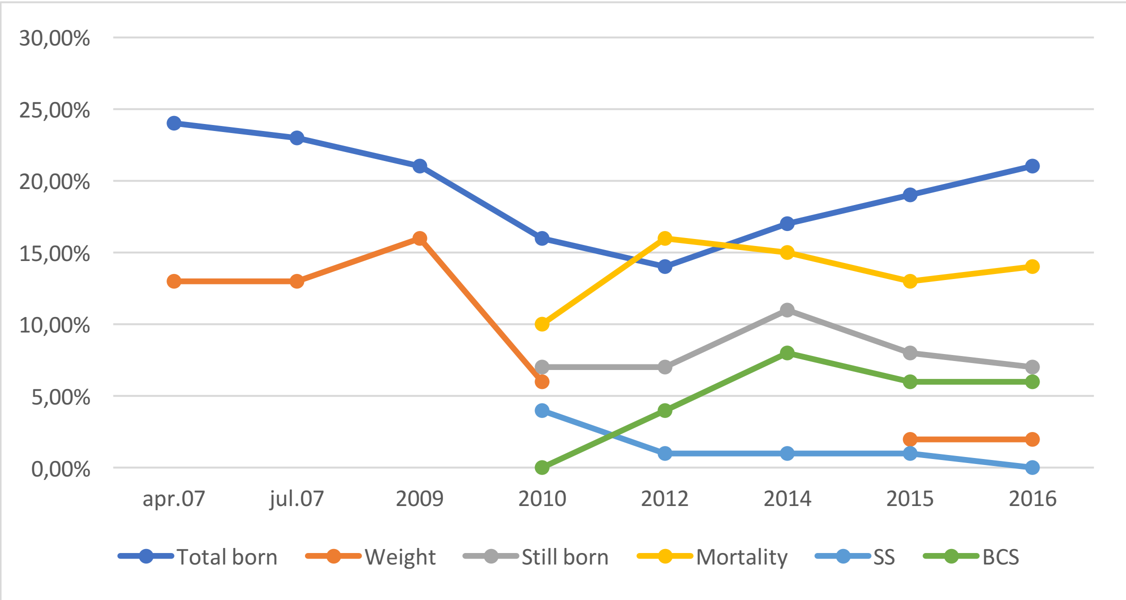


Figure 6 The weighting of maternal traits from 2007 to 2016 (Dan Olsen, pers. com., 2018)

The current weighting of traits is displayed below (Figure 7). As both litter size, and maternal traits are completely related to maternal ability, in comparison to health which includes multiple other traits, in today's breeding goal there are 56.1% (+ SS and BCS from health) weighting on improving the maternal ability of the Norwegian Landrace.

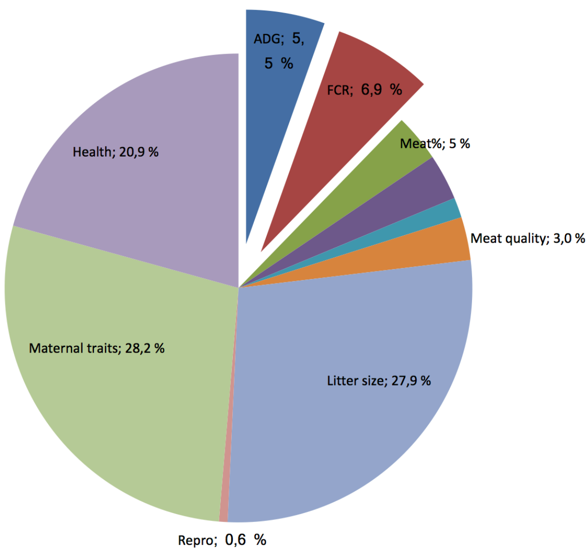


Figure 7 Current weighting of traits in Norsvin (Dan Olsen, pers. com., 2018)

3.3 Recording system

Norsvin relies on the Norwegian pig producers for recording and reporting the results to their database. The sow management system utilised is called Ingris, and is made for all production forms, this includes weaner production, finisher production, as well as combined production. It is easy to register data for every aspect of the herd, which includes the artificial insemination (AI), farrowing and weaning. In addition, Ingris also requires health registrations, feed consumption and costs related to the production. With the purchase of a breeding animal from a breeding herd, then they are able to dismiss the animal from their herd, that way they will automatically get transferred to the new owners' section in Ingris, then only need to supply them with an identification number. Over 800 Norwegian swine producers utilise Ingrid, which means approximately 65% of the breeding sows in Norway, as well as, 24% of the finishers. In addition, there are international users based on the export market of Norsvin (Animalia, 2016).

Ingris is also provides the farmer, or farm staff, with the opportunity to easily report the results of the different traits. During the establishment of the sow management system only total born was required to report. Later on, weight at 3 weeks was included in Ingris, however some challenges were faced when introducing more recordings, especially recordings that were more time consuming for the producer. Therefore, Norsvin started to require that piglets needed either a weight recording, or an out-date. For circumstances where neither is provided, the mortality of the litter is not estimated, and therefore loss of information for the entire litter. By doing this, producers lost possible income as their litter was not included in the future breeding, therefore, encouraging producers to report as they would possibly benefit in the future. By introducing requirements for the producers to report a number of traits, even if not yet included, it makes sure that if the trait is ever considered important, Norsvin already have sufficient data to include the trait directly, rather than having to postpone the changes to breeding goal.

4. Materials and Methods

4.1 Data description

The data provided will be utilised to produce an overview of the phenotypic and genetic development of the seven traits and investigate the effect of the changes in the breeding goal have had on the traits. The data analysed has been collected by Norsvin since 1990 and is based on the producers own recordings to the sow management system Ingris. The seven traits analysed were defined as follows:

Total born = number of piglets born
Stillborn = number of piglets born that were dead
Mortality at 3 weeks = number of piglets dead at 3 weeks, the biological mother
Weight at 3 weeks = weight of piglet at 3 weeks old (kg), the sow the piglet is currently with, if spent a minimum of 60% of time with current sow. The piglets are weighed between 17-25 days old which are then corrected to 3 weeks, sum of individual weights is defined as the litter weight
Variance at 3 weeks = variance in weight at 3 weeks old (kg), the biological mother.
Shoulder sore = occurrence of shoulder sore, measured as 1-4 (1=no SS)
Body condition score = ranking of body condition at weaning, measured as 1-5 with half points (Figure 2). The analyses require whole numbers, and the scale was therefore changed to fit the requirements (Table 1).

Table 1 The BCS ranking in the analysis and the actual score

Analysis	Actual score
1	1
2	1.5
3	2
4	2.5
5	3
6	3.5
7	4
8	4.5
9	5

Data from 1990 and 2018 were excluded from the genetic development due to the low number of records. Number of observations analysed is presented in table 1. The traits total born and stillborn have more recordings as expected due to that they have been either been included in the breeding goal for more years, or for stillborn have been monitored for additional years compared to the other traits.

Table 2 Presenting the number of observations for each trait

Trait	No. of observations
Total born	395 217
Stillborn	395 239
Mortality at 3 weeks	149 394
Weight at 3 weeks	221 038
Variance at 3 weeks	210 907
Shoulder sore	149 717
BCS	147 015

The pedigree information contained 936 000 animals, where 40 000 of the animals were genotyped.

4.2 Analyses

Firstly, the data were analysed using the statistical program SAS (SAS Institute Inc, 2011). This was done to be able to test for outliers, non-logical numbers. Further, the data was analysed with the DMU program (Madsen and Jensen, 2012) utilising the model regularly used by Norsvin for their genetic analyse and breeding value estimation. Breeding values was the basis for calculating the genetic trends over the years.

The full overview of variables utilised in the analysis is displayed below (Table 3). The model consists of eight fixed effects, the litter number of mother, litter number of offspring, herd/year, season, breed/year, weighed, weighed_b and weaning. There are three random effects; litter, individual as the animal effect, and individual effect as a permanent environment effect. Furthermore, six effects are utilised as fixed regression. These are age of litter, age of litter squared, age at weaning, age at weaning squared, age of mother at the litter number and age of mother at the litter number squared.

Table 3 Overview of all the variables utilised in the analysis

Variable	Description
Individ	Random effect, individual, utilised twice – once as animal effect and once as a permanent environment effect
Kull	Random effect, litter
M_kullnr	Fixed effect, litter number of mother
Kullnr	Fixed effect, litter number of offspring
Hy	Fixed effect, herd + year
Ses	Fixed effect, season
Raseaar	Fixed effect, breed + year
Veide	Fixed effect, number of weighed piglets between 17-25 days of age
Avv	Fixed effect, weaning
Veide_b	Fixed effect, number weighed piglets regardless of age
Alderk	Fixed regression, age of litter
Alderk2	Fixed regression, age of litter^2
Alderm	Fixed regression, age of mother
Alderm2	Fixed regression, age of mother
Aldera	Fixed regression, age at weaning
Aldera2	Fixed regression, age at weaning^2

For analysing the traits total born, stillborn and mortality at 3 weeks, the following model was used:

$$Y = m\_kullnr + kullnr + hy + ses + raseaar + kull + individ_a + individ_{pe} + alderm(kullnr) + alderm^2\,(kullnr) + e$$

Where:

Y = trait

$individ_a$ = random animal effect

$individ_{pe}$ = permanent environmental effect of the animal

The remaining variable descriptions are found in Table 3

For the traits weight at 3 weeks, variance in weight at 3 weeks, shoulder sore and body condition score at weaning additional effects were included. The full overview of the fixed and fixed regressions utilised for each trait is displayed below (Table 4).

Table 4 The different fixed effects that are included in the model for each trait

	Litter no. mother	Litter no.	Herd/year	Season	Breed/year	Weighed	Weighed_b	Weaning	Age weaning	Age weaning^2	Age_m	Age_m^2
Total born	X	X	X	X	X						X	X
Still born	X	X	X	X	X						X	X
Mort 3w	X	X	X	X	X						X	X
Weight 3w	X	X	X	X	X	X					X	X
Var 3w	X	X	X	X	X		X				X	X
BCS	X	X	X	X	X			X	X	X	X	X
SS	X	X	X	X	X			X	X	X	X	X

The DMU analysis results also provided the estimated variance components needed to calculate the heritability for each of the traits. The estimated variance components were produced utilising the model regularly used by Norsvin.

The heritability (h^2) was calculated using the following formula:

$$h^2 = \frac{\sigma_A^2}{\sigma_A^2 + \sigma_e^2}$$

Where:
σ_A^2 = Additive genetic variance
σ_e^2 = Residual error variance

The variance connected to random effects was not included, as if the variance between other genetic effects is big, it would produce an apparent low heritability, which is not necessarily true to the real heritability of the trait.

The phenotypic results show some differences in time spans, due to lack of data for the respective years. Total born and stillborn both had sufficient number of records from 1990 to 2016. Mortality, weight and variance at 3 weeks all had sufficient number of records from 1990 to 2015. While shoulder sore and BCS had sufficient number of records from 1991 to 2015. The y-axis for both the phenotypic and genetic development are corresponding to the definitions of the traits (p. 33).

B-values are presented for the genotypic trends to get a better understanding of the rate of increase and decrease in the changes. The number of linear regression lines for each of the traits varied depending on the nature of the curve. This is done to obtain more accurate b-values for the years of which there was a substantial change. By doing this, being able to better compare the changes in the breeding goal to the changes in the genetic development. The b-values are presented in the result section.

5. Results

5.1 Phenotypic trends

5.1.1 Total born

The phenotypic trends for total born for litter 1 to 5 from 1990 to 2016 are displayed below (Figure 8). Each of the number of litters follows similar trends throughout the years, indicating that the major differences are between the litters. It is obvious that litter number one have the overall lowest number of total born throughout the years. Further litter number two also show lower trends compared to the three latter litters. Litter number three and four have the most similar results over the years, with litter number four having slightly greater average than number three throughout the years. In addition, litter number four shows the greatest number of total born throughout the years in 2000 with 15.5 total born. Litter number 5 shows more independent results not following similar trends as previous litters, this may also be caused by the fact that with increase of litter number, the decrease of observations. From 2013 all of the litters show similar decrease to 2016, however, differences are seen in the rate of decrease for the different litter numbers.

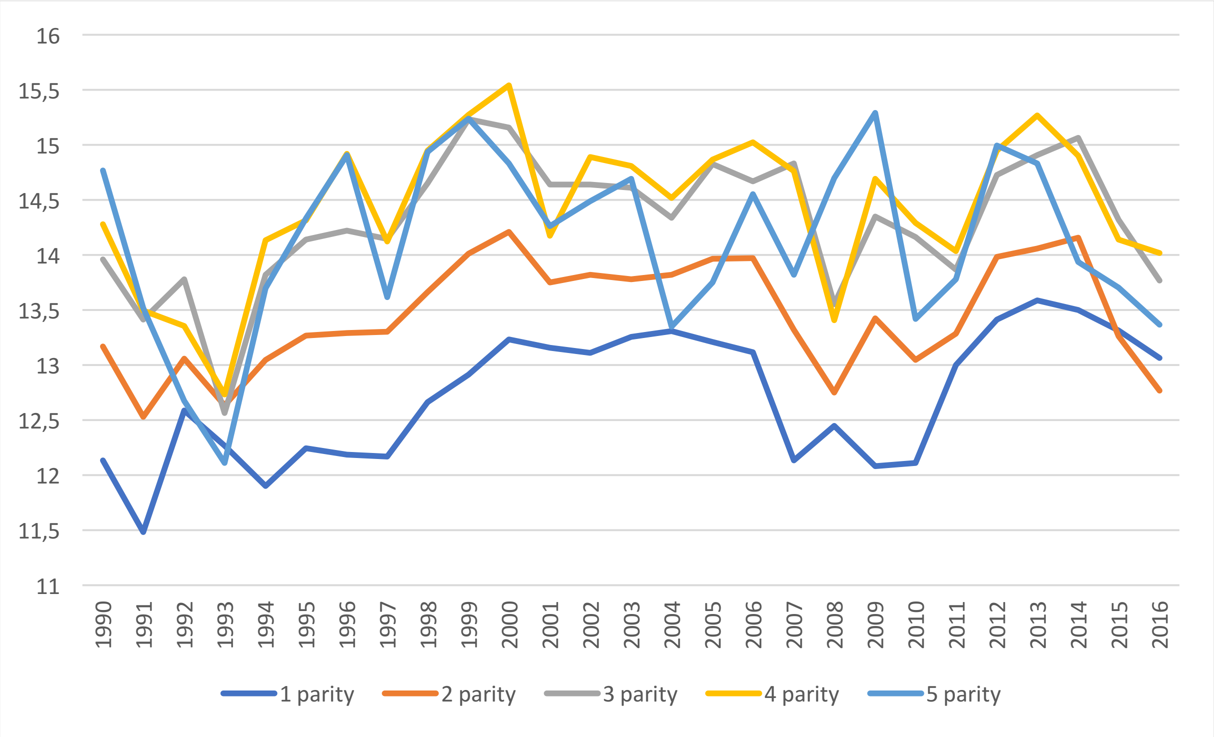


Figure 8 The phenotypic development of the trait Total Born in regard to litter number from 1990 to 2016

5.2.2 Stillborn

The phenotypic trends for stillborn for litter 1 to 5 from 1990 to 2016 are displayed below (Figure 9). Litters number one and two shows very similar results throughout the years. The number of stillborn increases with litter three, and then further increases with litter number four. Litter number five shows a more sporadic development compared to the earlier litters, this may also be caused by the lower number of observations available. The number of stillborn was highest in 1998 at 2.25 in litter 5. For all the litters, great differences can be observed between years, and all the litters show tendencies to similarly increase and decrease for the respective years. In 2016 the number of total born was between 0.9 and 1.1 for all litter numbers. In 2015, both litter 4 and litter 5 experienced a massive decrease in number of stillborn.

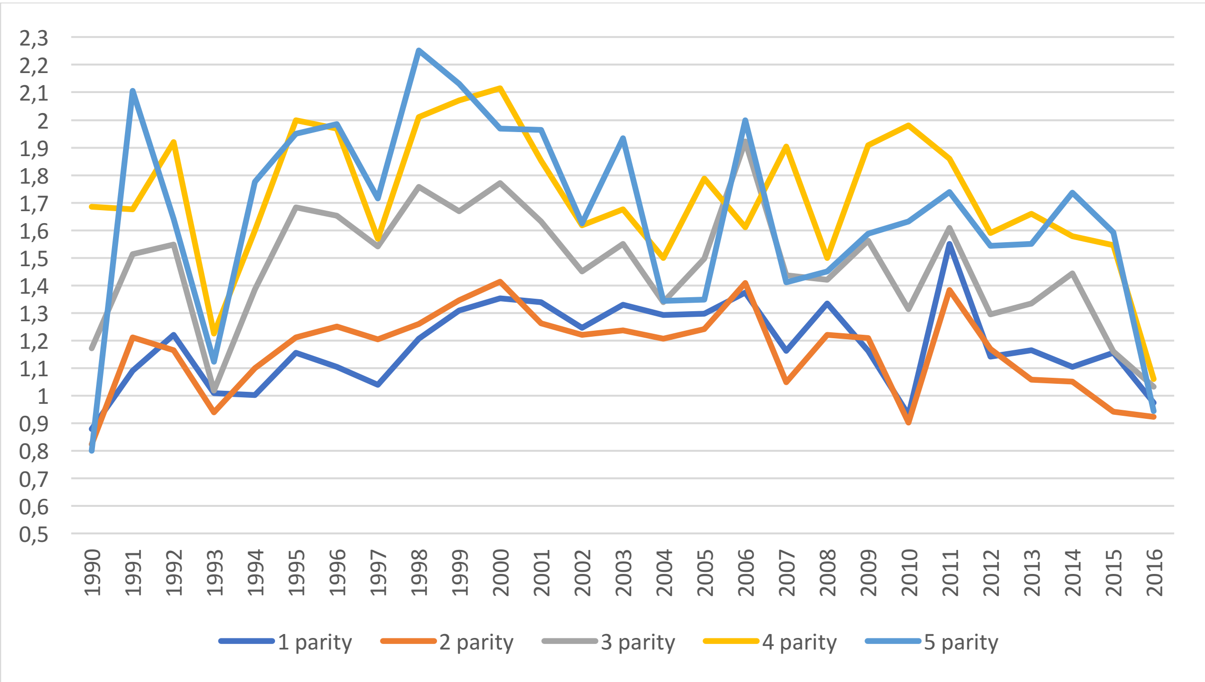


Figure 9 The phenotypic development of the trait Stillborn from 1990 to 2016

5.2.3 Mortality at 3 weeks

The phenotypic trends for mortality at 3 weeks for litter 1 to 5 from 1990 to 2015 are displayed below (Figure 10). Litter number one and two follow similar trends throughout the years. Further, it can be observed a drop in 1994 with the mortality dropping from between 1 and 1.5 to keeping steady at around 0.5, before having a massive increase in 1998 reaching 1.55 in 1999. Litter number three is a mediate throughout the years between the earlier and later litters, although showing a peak in 2007 at 2.48 followed with a considerable decrease to 2010 with value of 1.12. Litter four have from 1993 to 2006 had the overall highest mortality rate at 3 weeks old. Both litter four and litter five displayed the same pattern from 2007 to 2011 with rapid peaks and falls, with both being at zero in just two years apart. From 2014, litter one and two have remained relatively stable, as litter three and four both had a decrease in mortality and showing more similar results to the earlier litters. On the other hand, litter number five showed a rapid increase in 2013 reaching the highest number of mortality in week 3 at 3.4.

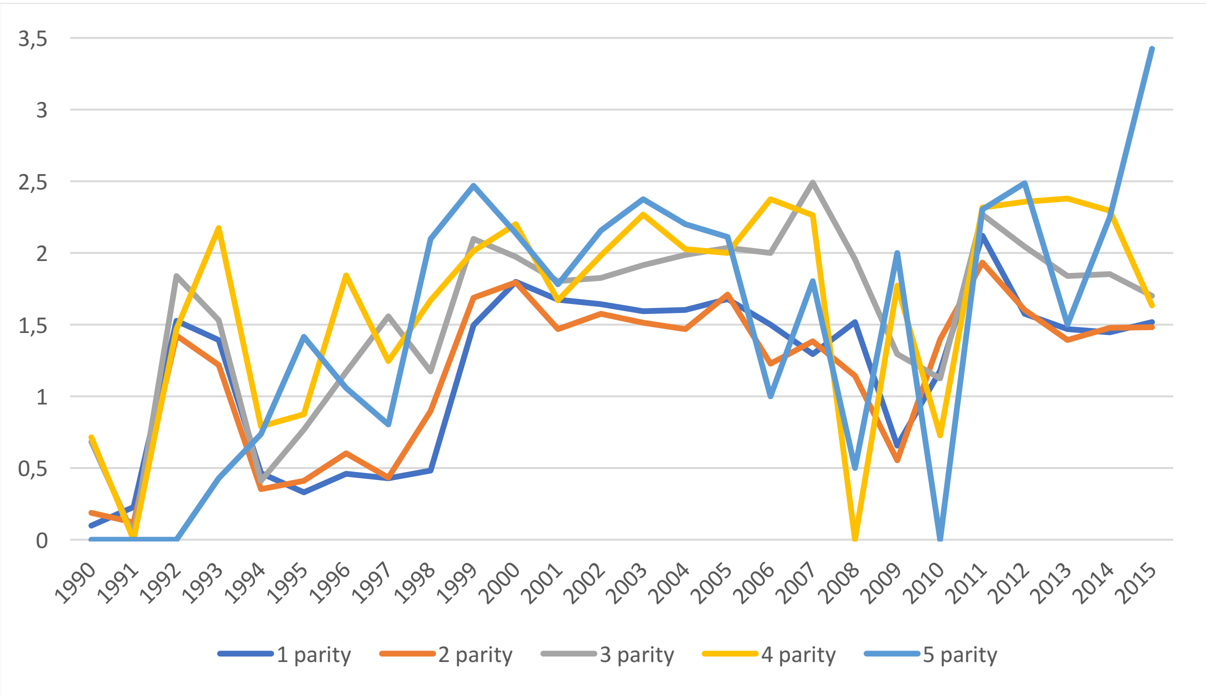


Figure 10 The phenotypic development of the trait Mortality at 3 weeks from 1990 to 2015

5.2.4 Weight at 3 weeks

The phenotypic trends for weight at 3 weeks for litter 1 to 5 from 1990 to 2015 are displayed below (Figure 11). Overall, litter number one have the lowest weight at 3 weeks throughout the years. Whereas for previous traits, litter one and two have had quite similar trends for weight litter two shows one of the highest weight recordings throughout the years. Litter two and three are observed to have the highest weight from 1990 to 2015. Furthermore, litter number four shows intermediate weight recordings, and litter five have been shown more sporadic weight recordings with greater differences between the years. In 2010 there was a major decrease for all five litters, with values ranging from 48kg for litter one to 62kg for litter number three in 2011. Following this decrease there was a massive increase to 2013 with all litters showing higher weight recordings than previous years for the respective litter, ranging from 74kg for litter number one to 87kg for litter number two. From 2013 to 2015 the development slowed down, with some differences between the litters, although all litters having a steadier development. The weight at three weeks in 2015 was 75kg for litter one, 79kg for litter five, 82kg for litter four, 85kg for litter three and 88kg for litter number two showing the highest three-week weight of all time.

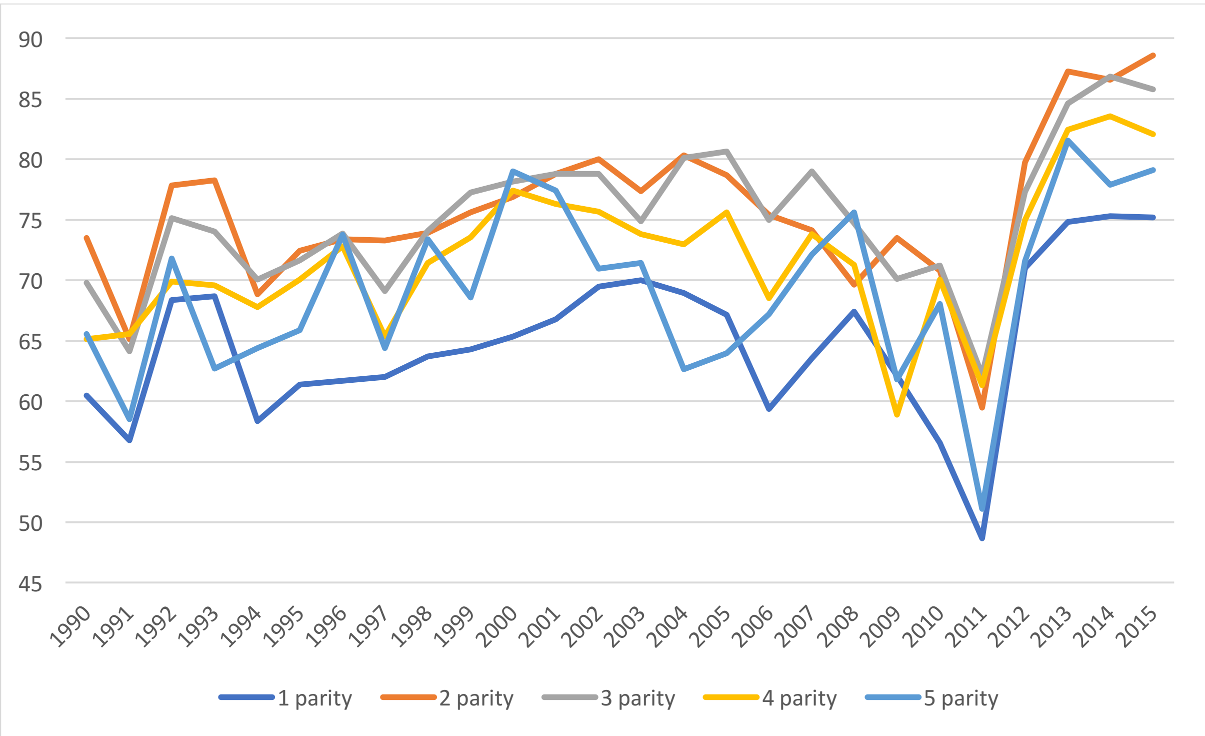


Figure 11 The phenotypic development of the trait Weight 3 weeks from 1990 to 2015

5.2.5 Variance 3 weeks

The phenotypic trends for variance at 3 weeks for litter 1 to 5 from 1990 to 2015 are displayed below (Figure 12). Litter one has the lowest variance in weight at three weeks old throughout the years, being completely separated from the other litters not exceeding any of the values of the other litters. Furthermore, litter number two follows similar trends as for litter number one although considerably higher variance compared to litter one. Overall, litter two is observed to have quite an intermediate difference compared to the other litters. Litter three and four have similar recordings, although, litter four showing slightly higher values throughout. In addition, litter four shows the highest value recorded from 1990 to 2015 at 1.56kg in 2007. Litter number five shows more a sporadic development with more variation from year to year. After some quite steep peaks in 2007 and 2009 for all litters, a considerable decrease occurred in 2010 for all the five litters. In 2011 the values ranged from 0.8kg for litter one to 1.1kg for litter number four. Following this decrease, there was an increase in variance in 2012, although all litters showing lower results than earlier years. From 2013 to 2015 the different litters have displayed different trends. Litter one is maintaining a steady development, litter number three have had a slight decrease, litter number two and four is increasing, however none changed at the same rate as litter number five which displays a major increase.

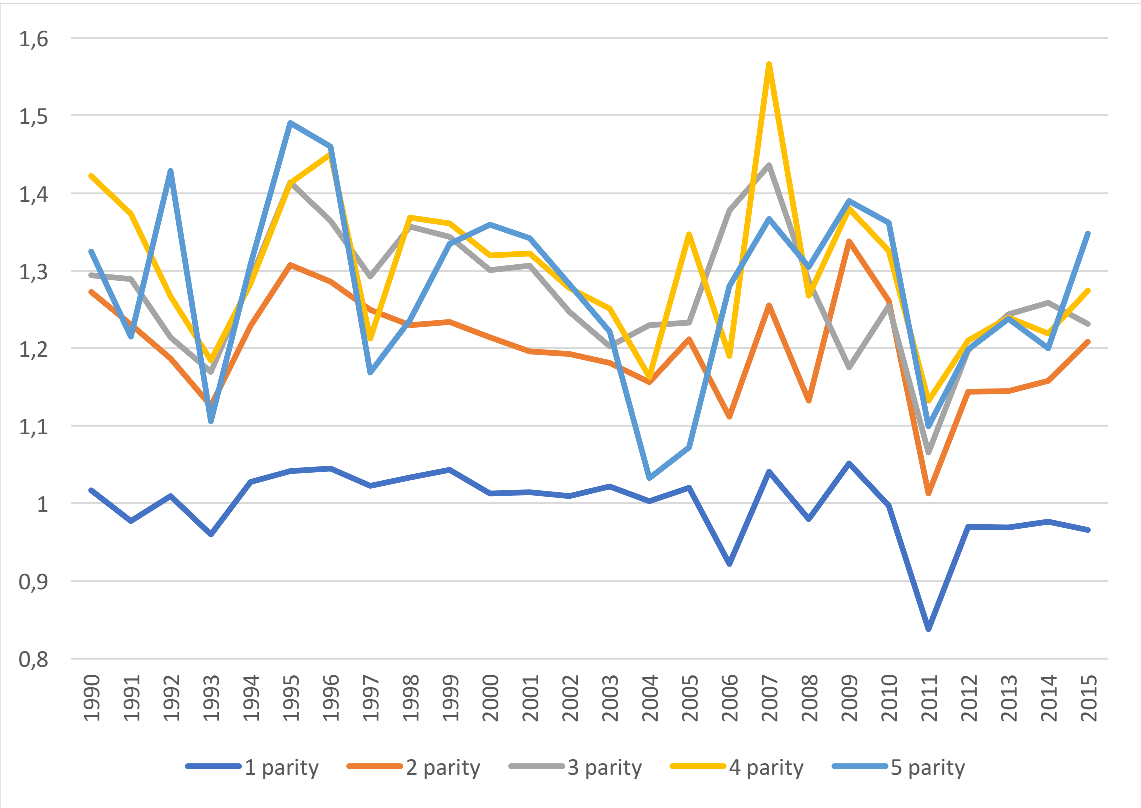


Figure 12 The phenotypic development of the trait Variance 3 weeks from 1990 to 2015

5.2.6 Shoulder sore

The phenotypic trends for shoulder sore for litter 1 to 5 from 1990 to 2015 are displayed below (Figure 13). The scale for shoulder sore is from 1 to 4. The occurrence of shoulder sore is lowest in litter one, with some more shallow changes throughout the years, although never exceeding 0.4. Litter number two have a considerably higher occurrence of shoulder sores compared to the first litter, and have scores that are in the higher range. The peak in litter two can be observed in 2010 with 0.8. Litter number three had quite similar results to litter two in the earlier years, although later experiencing more rapid changes. In 2009 litter three had the highest score recorded throughout the years for all litters, at 1.6. Litter number four have shown more rapid changes, although showing more intermediate recordings in the earlier years. In 2006 there was a peak in the score at 0.8, before decreasing again in 2007 down to 0.18. There were no recordings for litter four in 2008, however in 2009, the score was the highest for litter four at 1. The following year in 2010 the score was at its lowest for litter four at 0. However, the score increased again in 2011 to 0.6. Litter five have shown the greatest changes in scores between the years, with a score of 0 in both 1994 and 2006, and its highest score in 2009 with 1. Similar to litter four, there were no recordings in 2008, prior to the increase in scoring. From 2012 the development was steadier, litter one has barely changed to 2015, while litter two have had a slight decrease. As for litter three, four and five an increase in the scoring can be observed.

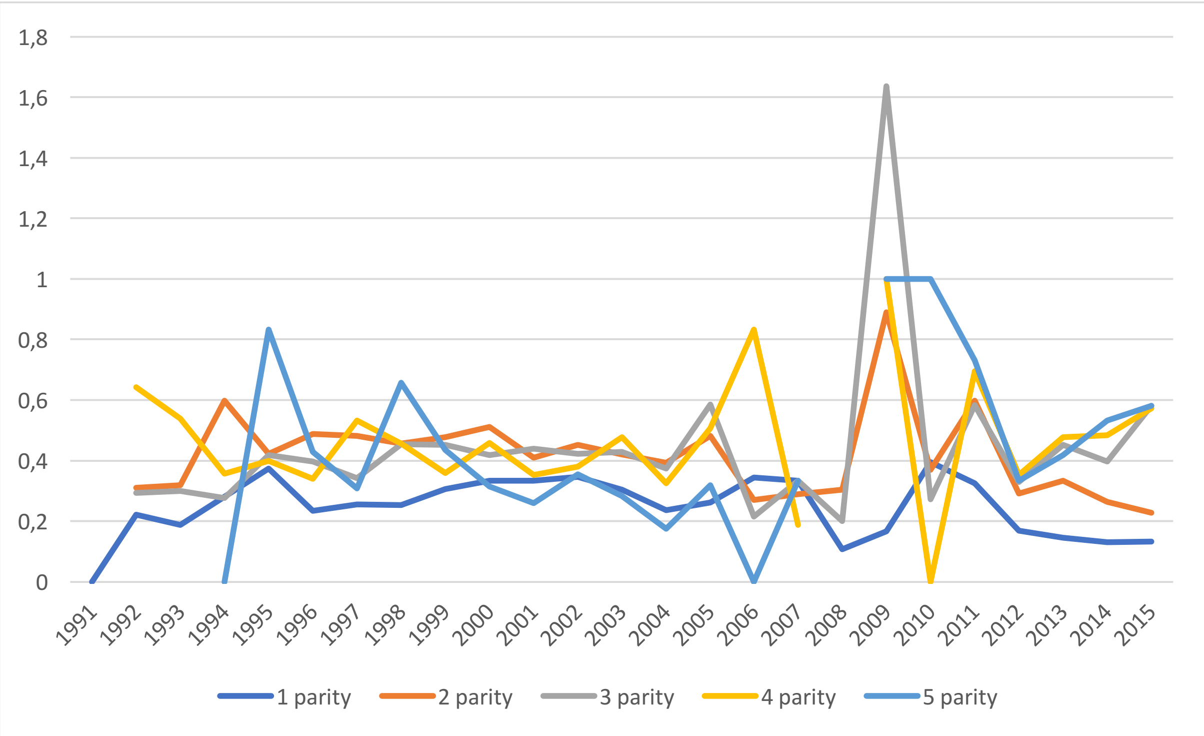


Figure 13 The phenotypic development of the trait Shoulder Sore from 1991 to 2015

5.2.7 Body condition score

The phenotypic trends for shoulder sore for litter 1 to 5 from 1990 to 2015 are displayed below (Figure 14). The scale for shoulder sore ranges from 1 to 5, with half-points. However, in the analysis the range was changed to 1-9. Therefore, it is important to keep in mind that the values displayed from the analysis differs from the actual values in real life, the conversions are displayed in the definition of the traits (Table 1).

Litter one has overall maintained lower scores throughout the years, having its highest score in 1991 with a score of 5 (3), which is seen as the ideal BCS. Further, there were some rapid peaks from 2005 to 2009. Litter number two have had similar recordings to litter number one, although having slightly higher scores throughout the years. Further, having more rapid changes from 2005 to 2011. From 1992 to 2005 litter three had a greater score than the previous litters, the later years until 2009, litter three obtained a lower BCS than both litter one and two, displaying the lowest score recorded for any litter in any year, in 2007 with a score of 3.8. For litter four the recordings have been overall higher than the three previous litters, with the exception of in 2006 with value of 4.1. There were no observations of BCS for litter four in 2008, before reaching its peak in 2011 with the score of 5. The observations for litter number five were first recorded in 1994 with the highest overall score for all litter throughout the years, at 5.6. However, the score drastically decreased in 1995, and was down to 4. Further, the BCS for litter five have overall had the highest score results compared to the other litters, although recordings missing from 2007 to 2011. From 2011 to 2015 litters one to four have gradually become closer to each other, small exception with litter number 2 with a minor decrease, however, litter number five is increasing. Overall, the development has occurred between 4 and 5, meaning actual score of 2.5 to 3. A score of 3 is seen as the ideal BCS, meaning the todays phenotype is considered a bit on the lower side, however, is still satisfactory.

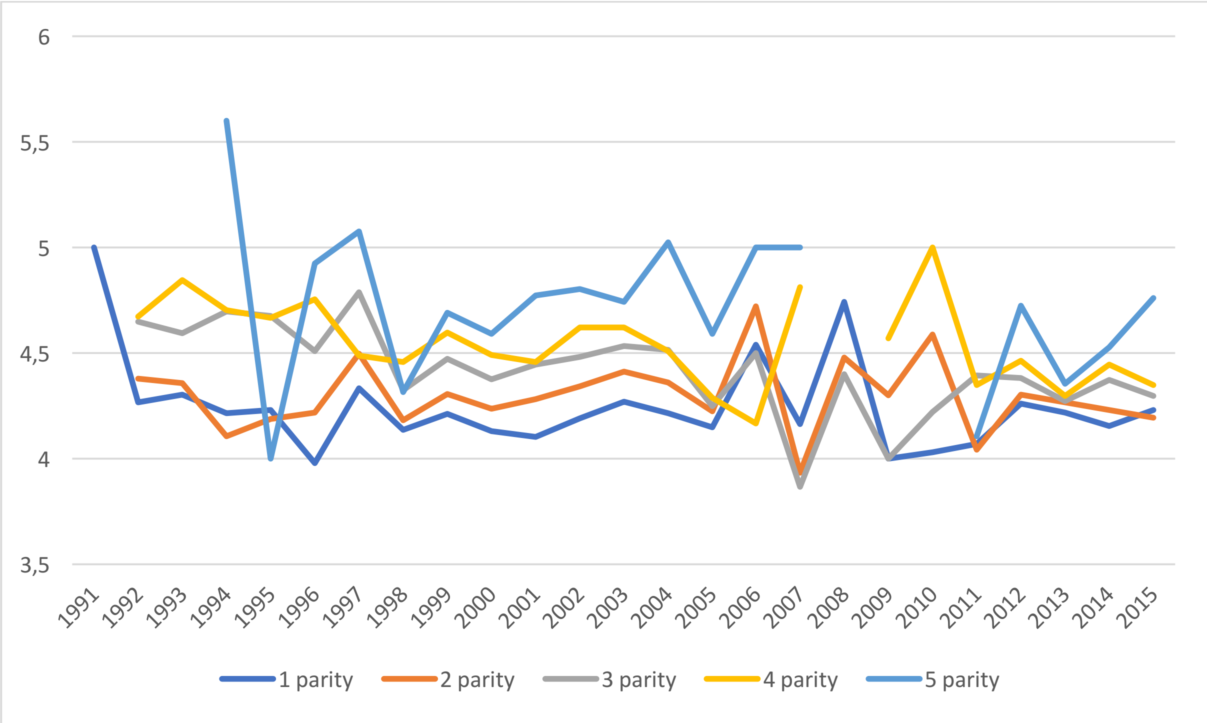


Figure 14 The phenotypic development of the trait BCS from 1991 to 2015

5.2 Genetic parameters

5.2.1 Variance components and heritabilities

The variance components and the heritabilities for each trait is presented below (Table 6). Low to moderate heritabilities were found for all traits. The lowest heritability being for mortality at 3 weeks with 0.06. While the highest heritabilities was found to be for weight at 3 weeks (0.14), shoulder sore (0.14) and BCS (0.13), however is considered moderate heritability. With high additive genetic variance, also follows a high residual error. Therefore, a relative high genetic variance does not necessarily result in high heritabilities.

Table 5 The variance components for the additive genetic variance (σ_A^2), the residual error (σ_e^2), and the heritability (h^2)for the traits

Trait	σ_A^2	σ_e^2	h^2
Total born	0.89	9.29	0.09
Stillborn	0.18	2.35	0.07
Mortality at 3 weeks	0.19	3.03	0.06
Weight at 3 weeks	12.58	79.08	0.14
Variance at 3 weeks	0.01	0.14	0.07
SS	0.06	0.36	0.14
BCS	0.08	0.52	0.13

5.2.2 Correlations

The genetic correlations between the seven traits investigated is displayed below (Table 5). Total born, have highest positive correlation with mortality at 3 weeks, which is also the highest correlation between any of the traits. Further, total born and stillborn also have a high genetic correlation compared to the other traits. Stillborn have a high positive correlation with total born, while the traits that displays a negative correlation with total born is weight at 3 weeks, shoulder sore and BCS at weaning. Stillborn have its highest positive correlation being with total born, and variance at 3 weeks, and the highest negative correlation with body condition score at weaning. The trait mortality at 3 weeks, have the highest negative correlation with the trait weight at 3 weeks and highest positive correlation with total born. Variance at 3 weeks only have one negative correlation, with that being body condition score at weaning. Shoulder sore have the highest negative with BCS, and the highest positive correlation with stillborn. Furthermore, BCS have the highest negative correlation with shoulder sore, and the only positive correlation with mortality at 3 weeks.

Table 6 The genetic correlation between the traits

	Total born	**Still born**	**Mort 3w**	**Weight 3w**	**Var 3w**	**SS**	**BCS**
Totalborn	1						
Stillborn	0.46	1					
Mort3w	0.66	0.26	1				
Weight3w	-0.34	-0.004	-0.48	1			
Var3w	0.06	0.30	0.12	0.48	1		
SS	-0.05	0.22	-0.03	0.04	0.18	1	
BCS	-0.17	-0.24	0.06	-0.25	-0.26	-0.58	1

5.3 Genotypic trends

5.3.1 Total Born

The genetic development of the trait total born is displayed in Figure (15). The first considerable change in the genetic trend is observed from 1993 to 1999, where it drops from -0.006 in 1993 to -0,212 in 1996, before it reaches approximately the same level again in 1999 at 0,052. From 1996 there is a rapid increase throughout the years until it reaches a small holt at 1.048/1.041 from 2006 to 2007 respectively. Afterwards it again has approximately the same rate of increase as previously for two years, before the development slows down until 2012 at 1.267, where the development again experiences a drop down to 1.134 in 2014. From 2015 to 2017 the development has been the most consistent and steepest trend line, and reaches the overall highest result throughout the years at 1.451.

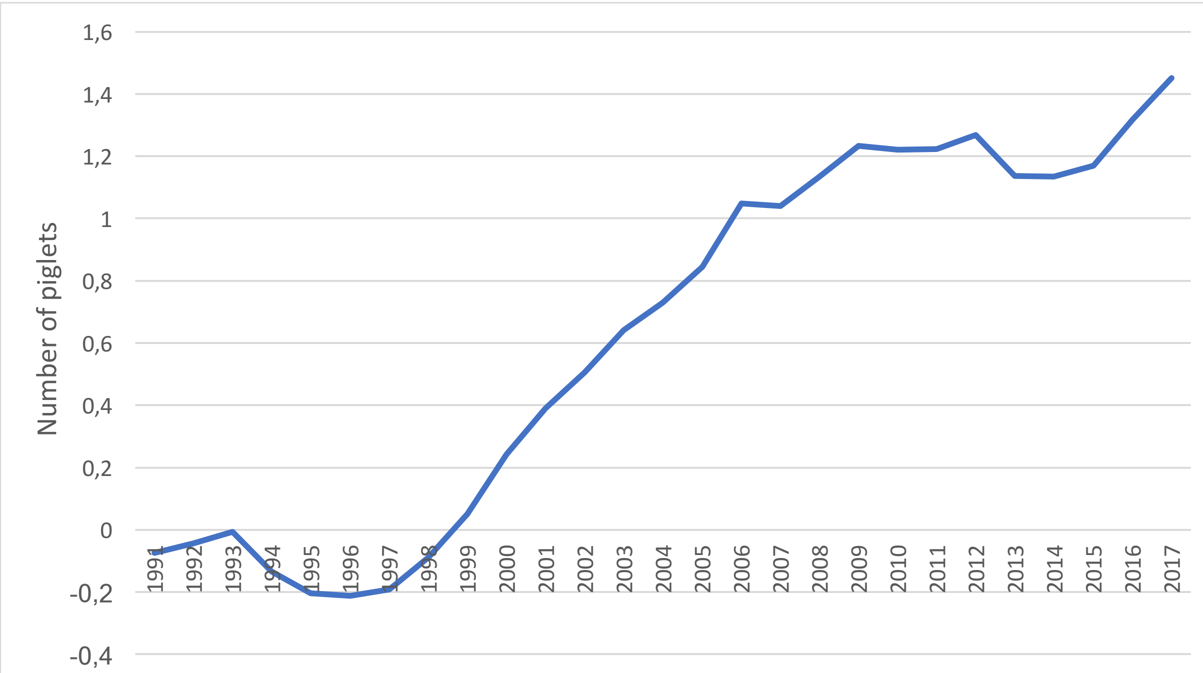


Figure 15 The genetic development of the trait Total born from 1991 to 2017

The b-values for Figure 15 is presented in the table below (Table 7)

Table 7 B-values for different time periods for the trait total born

Year	B-value for different time periods
1993-1996	-0.07
1996-2009	0.12
2015-2017	0.14

5.3.2 Stillborn

The genetic development of the trait stillborn is displayed in Figure (16). From 1991 the rate of stillborn increased steadily from 0.010 to 0.038 in 1993. From 1993 there is a considerable drop until 1996 and 1997 where it stabilises at -0,04 and -0,038 respectively. Further, the rate of stillborn increases, although a bit crooked, until 2003 where it reaches its highest point throughout at 0.095. The rate continues to decrease, although some stagnations in the years 2007 and 2008 with values of 0.075 and 0.071 respectively. Further the rate decreases, exception of a marginally increase in 2012, however leads to a steeper decrease rate until 2015 at -0.172 and at its all-time low at -0.206 in 2017.

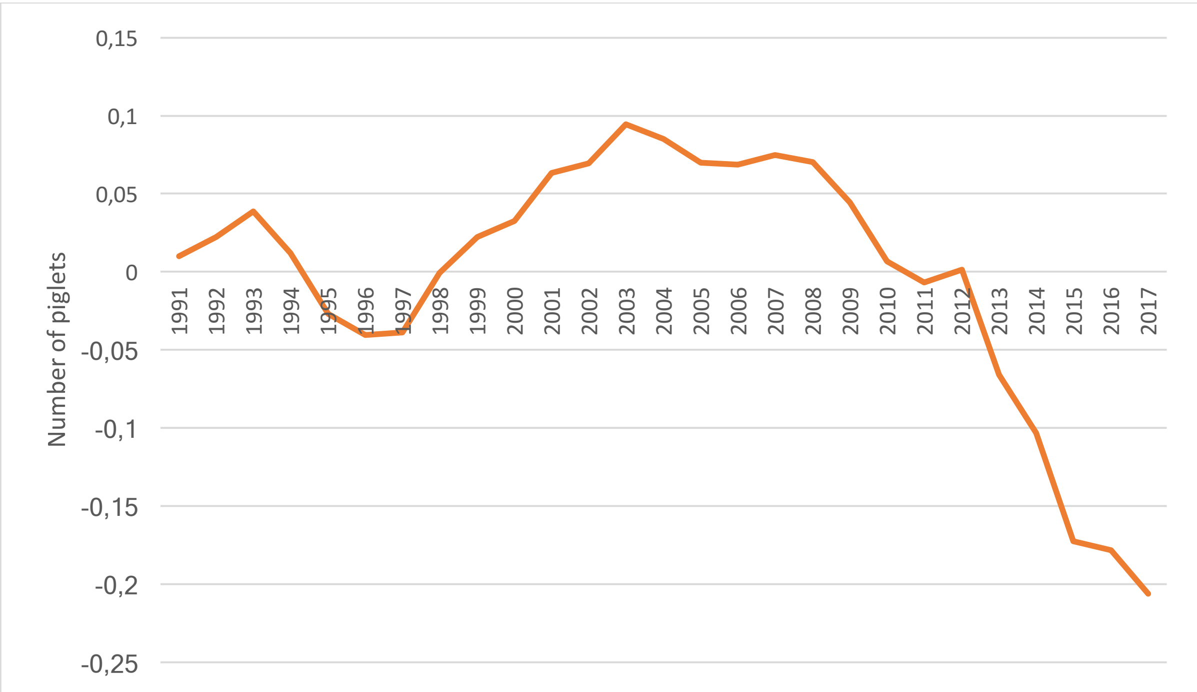


Figure 16 The genetic development of the trait Stillborn from 1991 to 2017

The b-values for Figure 16 is presented in the table below (Table 8)

Table 8 B-values for different time periods for the trait stillborn

Year	B-value for different time periods
1993-1996	-0.03
1996-2003	0.02
2003-2012	-0.01
2012-2017	-0.04

5.3.3 Mortality at 3 weeks

The genetic development of the trait mortality at 3 weeks is displayed in Figure (17). The mortality has increased with a relative steady growth, with the exception of some irregularities in the trend seen in the years 1993 to 1996, with 0.037 and 0.051 respectively, as well as, at 2001 with 0.3. Furthermore, from 2006 to 2007, there is a short plateau with values of 0.524 and 0.527 respectively. The mortality rate at 3 weeks reaches an all-time high in 2009 with 0.574. Further it follows a rapid decrease, however with a slight plateau in 2011 and 2012 with 0.467 and 0.468 respectively, the decrease continues although a slightly shallower slope from 2015 to 2017.

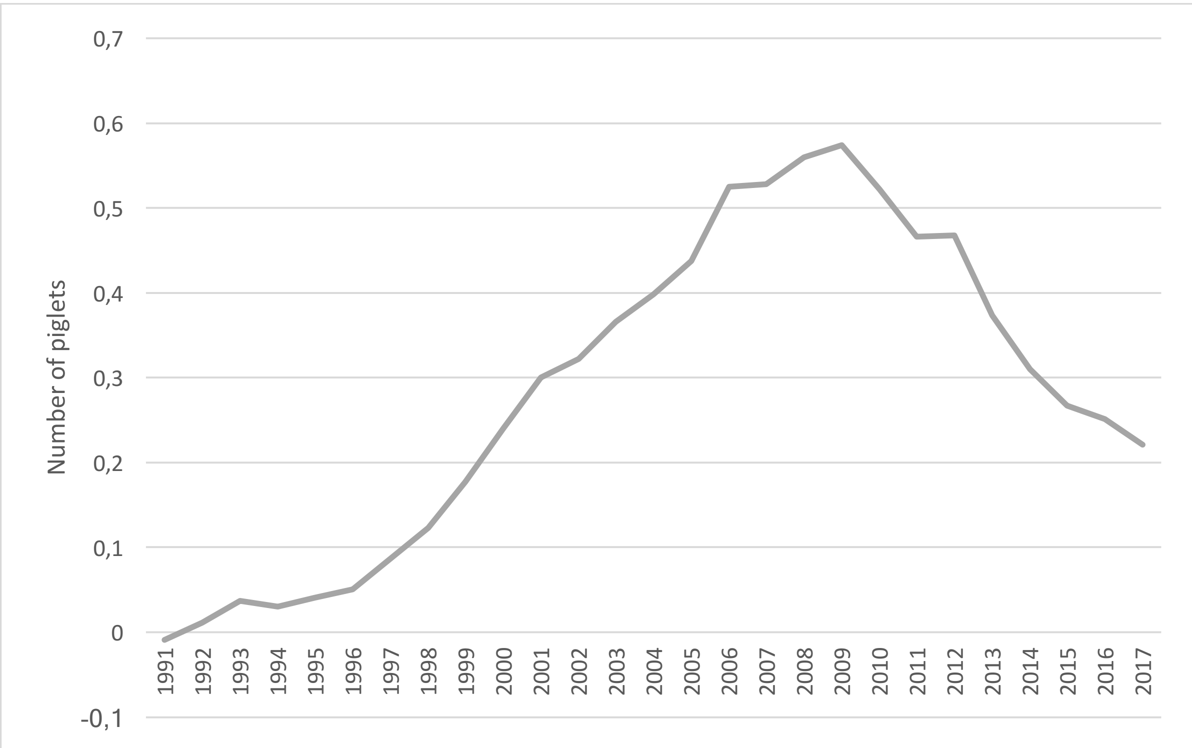


Figure 17 The genetic development of the trait Mortality at 3 weeks from 1991 to 2017

The b-values for Figure 17 is presented in the table below (Table 9)

Table 9 B-values for different time periods for the trait Mortality at 3 weeks

Year	B-value for different time periods
1994-2009	0.04
2009-2017	-0.05

5.3.4 Weight 3 weeks

The genetic development of the trait weight at 3 weeks is displayed below (Figure 18). The figure shows a slight decrease in weight from 1991 to 1996, where it displays a sudden drop from -0.246 in 1996 to -0.584 in 1997. The greatest decrease is seen from 1998 with -0.491 to the all-time lowest in 2000 at -0.984. From 2000 there is a continuous increase, however with plateaus from 2003 to 2004 with the values -0.545 and -0.548, and 2005 and 2006 with -0.054 and -0.06 respectively. Thereafter, there is a steady increase to 2009 where it intensifies until 2011 with the value of 2.642. The development reaches its peak in 2014 with 3.163, before a steady decrease until 2.422 in 2017.

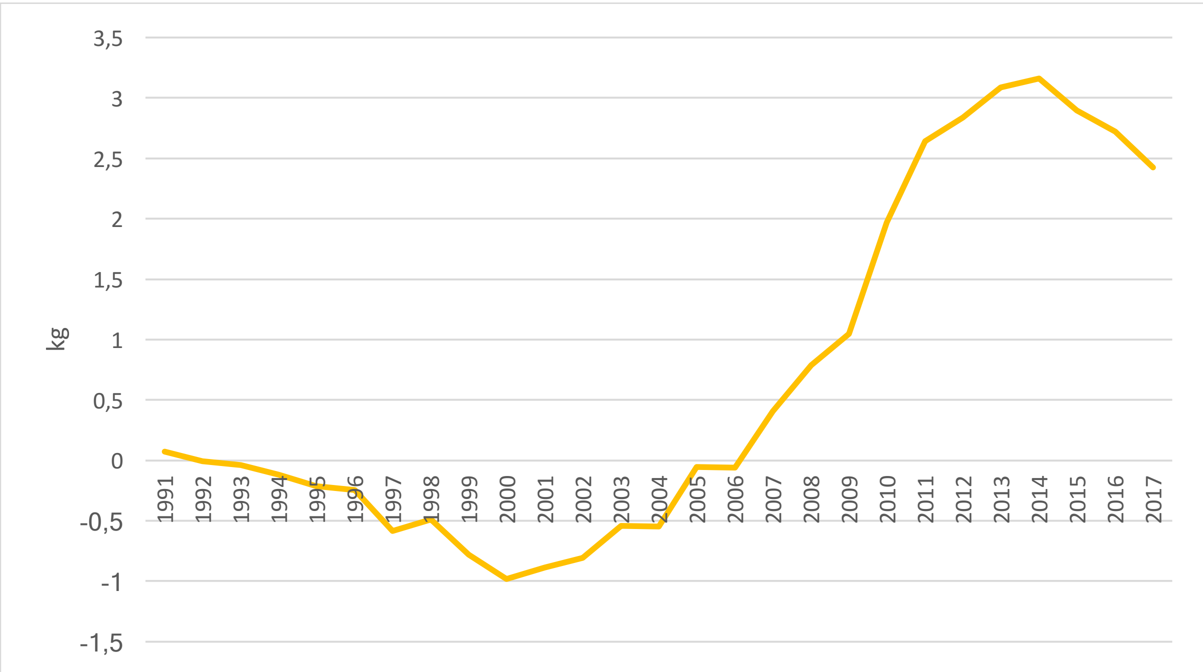


Figure 18 The genetic development of the trait Weight at 3 weeks from 1991 to 2017

The b-values for Figure 18 is presented in the table below (Table 10)

Table 10 B-values for different time periods for the trait Weight at 3 weeks

Year	B-value for different time periods
1991-2000	-0.11
2000-2007	0.19
2007-2014	0.44
2014-2017	-0.24

5.3.5 Variance 3 weeks

The genetic development of the trait variance at 3 weeks is displayed below (Figure 19). From 1991 there has been a gradual increase in the variance, although more rapid increase from 1997 at 0.022 to 1998 at 0.032, and after the plateau to 2000, there is an increase again from 0.032 to 0.046 in 2001. The years following there is a crooked increase, with a sudden drop in 2008 and 2009 with values of 0.068, before it reaches its peak in 2012 with the value of 0.083. After 2000 there is a rapid decrease until 2015 at 0.049 before it continues with the rapid decrease in 2016 to 2017 with the values 0.047 and 0.033.

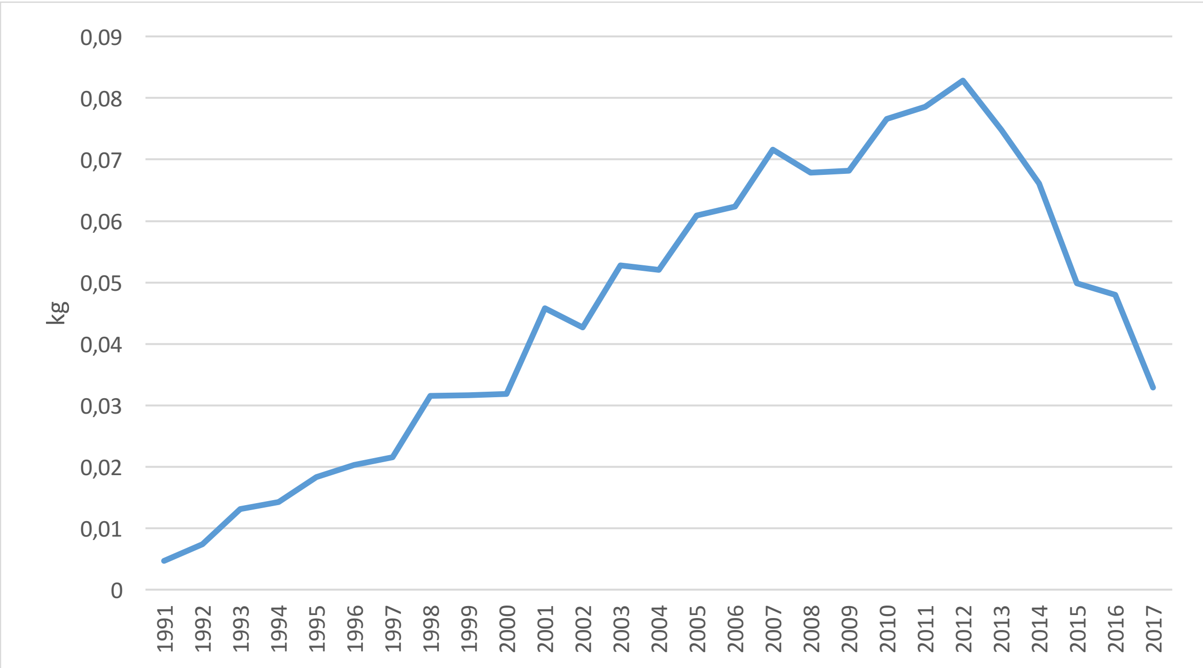


Figure 19 The genetic development of the trait Variance at 3 weeks from 1991 to 2017

The b-values for Figure 19 is presented in the table below (Table 11)

Table 11 B-values for different time periods for the trait Variance at 3 weeks

Year	B-value for different time periods
1991-2012	0.004
2012-2017	-0.019

5.3.6 Shoulder Sore

Overall, the development of shoulder sores has a shallow curving with a steady increase before a shallow decrease, until the development more rapidly decreases (Figure 20). The results show the genotypic changes, according to the shoulder sore scale. However, some irregularities can be observed in 2004 with the highest observed value of 0.126 before a drop in 2005 and 2006 at 0.11 and 0.10 respectively. From 2010 with the value of 0.065 there is a more drastic decrease until 2017 with the lowest observed values at -0.167.

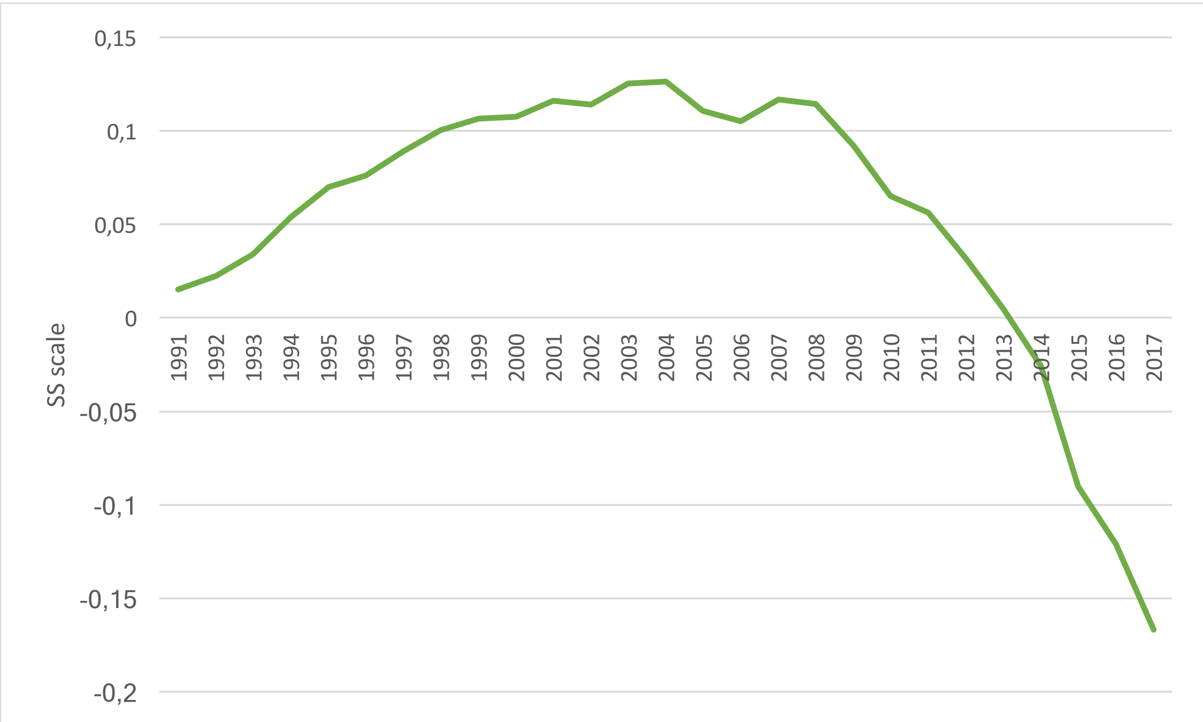


Figure 20 The genetic development of the trait Shoulder Sore from 1991 to 2017

The b-values for Figure 20 is presented in the table below (Table 12).

Table 12 B-values for different time periods for the trait shoulder sore

Year	B-value for different time periods
1991-2003	0.009
2003-2011	-0.008
2011-2017	-0.038

5.3.7 Body Condition Score at Weaning

The genetic development of the trait BCS is displayed below (Figure 21). The results show the genetic changes according to the BCS scale. There are little changes in the years 1991 to 1997, where there is a massive decrease from -0.01 in 1997 to -0.22 in 2011. However, some years' worth noticing are 2003 with the value of -0.11, 2006 at -0.15 and 2009 at -0.17. From 2011 there is a rapid increase, with the exception of a slight holt from 2015 at -0.094 to 2016 at -0.086 before a drastic increase to 2017 at the value of -0.04.

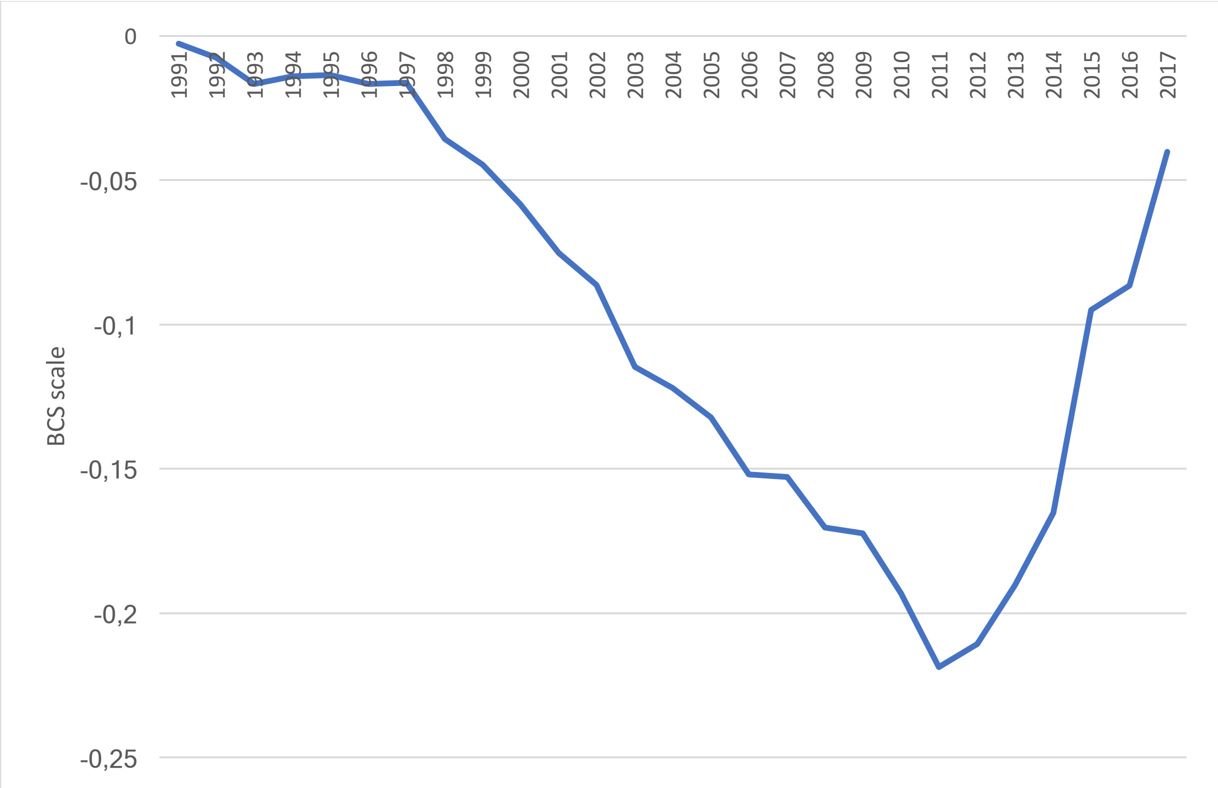


Figure 21 The genetic development of the trait BCS from 1991 to 2017

The b-values for Figure 21 is presented in the table below (Table 13).

Table 13 B-values for different time periods for the trait body condition score at weaning

Year	B-value for different time periods
1991-1997	-0.002
1997-2011	-0.012
2011-2017	0.0314

6. Discussion

In this thesis, the development from 1990 to today of seven traits related to maternal ability was investigated. Both the phenotypic and genetic trends were mapped to be able to compare the changes observed to the changes done in the breeding goal. To be able to get a better understanding of the changes and the connection to the other traits, the genetic trends are summarised in figure 22. Because of the differences in units, the traits that are comparable are collected in one graph.

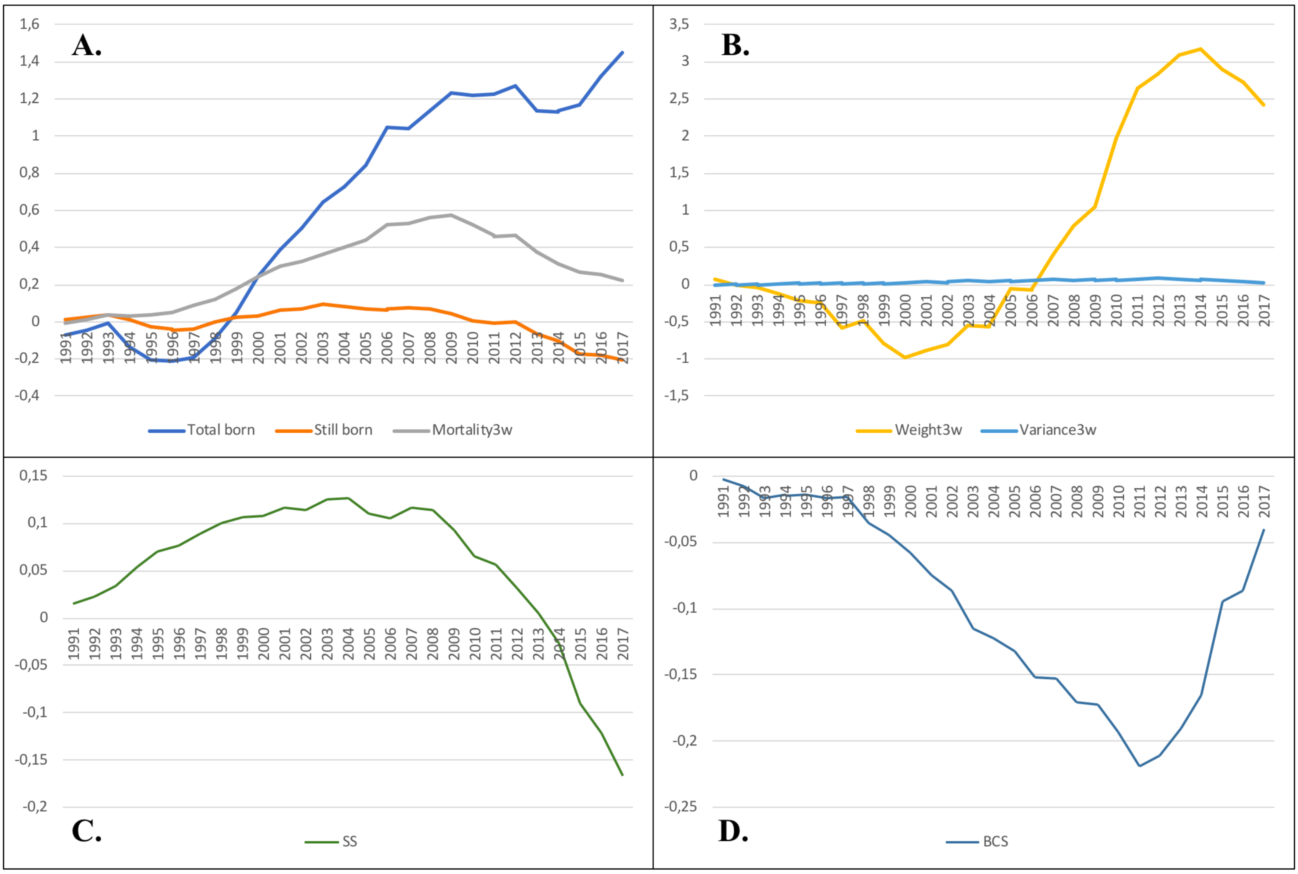


*Figure 22 Comparing the genetic changes in the traits with the same units: **A**. Total born, stillborn and mortality at 3 weeks (number of piglets) **B**. Weight and variance at 3 weeks (kg) **C**. Shoulder sore (specified scale) **D**. Body condition score (specified scale)*

Presented in section A is the genetic trends for total born, stillborn and mortality at 3 weeks. As seen previously, the number of total born have increased over the years, and have considerable higher values than stillborn and mortality. Number of total born exceeded both stillborn and mortality in 2000. Both stillborn and mortality show similar trends throughout the years, however mortality at 3 weeks showing a higher number of piglets throughout. In section B, weight and variance at 3 weeks are presented. Compared to each other, because of the substantially greater increase in weight, the development of variance seems minimal. However, it can be seen an increase in variance in 2012, at the same time the weight at 3 weeks is at its highest. The genetic development for shoulder sore is presented in section C, while BCS is presented in section D. Even though the units are not comparable, the trends are. As seen, shoulder sore and BCS can be viewed as counterparts, meaning an increase in SS results in a decrease in BCS. The major change in these traits occurred in 2011 with the decrease in shoulder sores and increase in BCS. The two traits surpassed each other in 2015, and is showing continuous trends.

Because of the existing correlations, all the traits affect each other as well as the constant influence of the environment on both performance and the genetics. This discussion will look closer into each of the seven traits, comparing the phenotypic and genetic results to the changes in the breeding goal. The overall economic goal of pig production is to obtain the greatest number of weaned piglets, as well as, a sufficient weight of the piglets. However, with still maintaining the integrity of the animal, therefore, it is also necessary to look into the ethics regarding animal production.

6.1 The traits

6.1.1 Total born

Total born, more commonly used in literature as litter size, is often considered one of the most important traits in pig production. Especially in regard to maternal lines. As mentioned the optimal goal is to increase the number of weaned piglets at a satisfactory weight, the increase in number of total born is of course necessary to reach this goal. By including the other traits, raising the chances of being able to produce larger litter sizes until weaning, while maintaining good animal welfare.

In regard to the genetic trends the first and only considerable decrease is found in 1993 to 1996 with the b-value of -0.0688. However, according to the breeding goal, total born was only included in 1992 with a weighting of 18%. Therefore, one would expect that the number of total born would increase instead of decrease in the following years. Other changes made in 1992 was the massive weight reduction on feed efficiency from 55% in 1987 and 15% in 1992.

The reason for no immediate response in total born may have been the addition of more traits, as well as, multiple drastic changes in weightings. Furthermore, the weighting of litter size was at 18%, which may show that if one is desiring a more rapid increase in number of total born, more weight is required. However, with no further changes of weighting the total born did increase at approximately the same rate as the decrease from 1996 to 1998. In 1999 the weighting on total born increased to 38%, the response is visualised in Figure 22.

The rate of increase on total born responded to the increase of weighting and the development curve got steeper. As the number of total born continued to increase in the years to follow, the weighting decreased and stabilised at 24% from 2004 to 2007. It is important to remember that there is rarely an immediate response, and changes that have been made can affect the trait in years to follow. The total increase from 1996 to 2009 occurred with a b-value of 0.1202. The trait stillborn was included in 2010, however it did not affect the total born in any major direction. In 2012 there was a small decrease in number of total born as reflected from the decrease in weight to 21%. However, this change was quickly corrected with a weighting of 28% in 2014, from 2015 to 2017 the rate of increase was faster, b-value of 0.1404, than previously, even though the weighting was lower than in 1999.

Large litters are often associated with a high number of stillborn, as well as, a higher mortality rate. Number of total born have positive correlations with both stillborn and mortality at three weeks, with 0.46 and 0.65 respectively. It is important to remember that a positive correlation doesn't necessarily mean favourable. Therefore, if stillborn or mortality was not included in the breeding goal, these traits would increase. Furthermore, as the litter size increases the weight of the piglets decreases, this study displayed a genetic correlation of -0.34. In addition, with larger litters there is also often observed greater variance of weight within the litter. Both the weight and variance in weight is associated with greater mortality. The traits will be discussed in more detail in the following sections.

6.1.2 Stillborn

Stillborn is seen as a problem across the animal industry, as even though one can increase the genetic potential of increasing total born, it is of no benefit if the number of piglets born alive remains the same. The occurrence of still births is reliant on the fetal development, especially at the end of the gestation the piglets experience an increase in growth rate, as well as, finalizing physiological aspects. Still births occur due to implications in the stillborn itself or inadequate environment in the uterus. However, these aspects are also more often than not intertwined. This may occur with litter sizes increasing, that the uterine environment is simply not equipped to nurture the development and growth of that number of fetuses. Furthermore, the space requirement of the litter may exceed that of which the uterus is capable of. This may lead to partial or entire underdevelopments of the piglet, if haven been born would decrease the survival rate. Either suffering from birth defects or being more susceptible to diseases.

Previous to the inclusion of the trait in 2010 there were still changes in the trait due to correlations. As total born was included in 1992 with 18% it is fair to assume the number of stillborn would increase, however, it decreased with the b-value of -0.0275 from 1993 to 1996. However, as seen the number of total born also decreased in this period, even though the breeding goal would indicate differently. From 1996 to 2003 there was an increase in still births with b-value of 0.0201. The weighting on total born was 38% and 30% in 1999 and 2001 respectively, and was not adjusted until 2004. This was the same period where the number of total born was increasing, so as expected if total born increases so will stillborn if not included in breeding goal. As a consequence of the weight reduction of total born in 2004 to 24% the rate of still births slightly decreased in the following years. In 2010, stillborn was first included in the breeding goal with a weighting of 7%, there was a slight decrease following this change, however at a lower rate than before. In 2012 the weighting on stillborn remained stable, but the weight on total born decreased which may have aided the more steeper decrease. The weight on stillborn increased from 7% to 11% in 2014. The greatest decrease in number of stillborn was from 2012 to 2017 with b-value of -0.0412. However even with the additional weight on total born from 2014 the stillborn kept decreasing even though the direct weighting on stillborn decreased slightly.

The genetic development is supported with the findings in the phenotypic trends with the same litter numbers also having the greatest number of stillborn. With the exception of litter number one and two, where the number of stillborn are extremely similar. As the number of stillborn is increasing considerably with the number of litter, it is necessary to evaluate the cost of culling and the profit of the additional litters. Further, even with the additional stillborn, the total number of piglets born are still exceeding that of earlier litters.

6.1.3 Mortality at 3 weeks

As mentioned previously, the overall goal of pig production is to get the maximum of healthy pigs to survive until weaning. Therefore, mortality at 3 weeks may be seen as one of the most important traits to achieve this goal. However, mortality is also one of the traits that are most and dependent on other variables. The weight of the piglet is a crucial factor to its survival, which is further dependent on the maternal ability and behaviour of the sow. There are both economical and ethical aspects that needs to be considered when evaluating the cost of mortality. In ethics as for any subject, different views on the problem can be presented. Some may argue that the loss of an animal is never justified, while others may argue that the objective and way of death matters. From an economical point of view, the loss of animal is always seen as a cost. A death within the three first weeks is a bigger cost than that of a stillborn.

The mortality at 3 weeks steadily increased from 1991 to 2009 with b-value of 0.0409. However, it follows similar trends as total born and stillborn with a minor dip from 1993 to 1996. With fewer piglets born, the less are also the potential of mortality in week 3. The major increase in total born was in 2009 and can also be seen in the highest peak in mortality being in 2009. Therefore, it is feasible to say because of the high number of total born, a lot more piglets died within the first 3 weeks. Hence, just increasing total born is not economical beneficial because of the cost of the loss of piglets, including all the resources utilised within the three weeks. The following decrease from 2009 to 2011 was with b-value of -0.0464. Mortality at 3 weeks was included as a trait in 2010 with a weighting of 10%, however Figure 22 show no immediate changes in the mortality. Further, in 2012 the weighting of mortality was increased to 16%, as well as total born was decreased to 21%, and the decrease in mortality at three weeks continues. According to the phenotypic trends litter numbers one to four are now developing closer towards each other between 1.5 and 2 for number of piglets that dies before the 3-week period. However, litter number five is showing alarming results by increasing faster than previous years.

High mortality rate is often associated with the increase of litter size, however, the correlation between the two traits was found to be 0.65. Therefore, as the correlation is less than 1, only interpreting it genetically, means that the two traits are not always accompanied by each other. On the contrary, Sundrum 2011, reported a higher average of mortality for litters with a lower litter sizes. This is supported by the findings in this study, showing that the litter number three and four had the highest total born, while litter five showed the highest mortality at 3 weeks. Regardless of an increase in litter size being associated with high mortality rate, if the increase ultimately leads to an increase of weaned piglets, it is considered beneficial for the production system.

6.1.4 Weight at 3 weeks

The weight of the piglets is extremely important for the survival until weaning. The weight is considerably affected by the sow's physiology and behavior. Physiology as some sows have a better predisposition to be able to bring forth and provide sufficient nutrition to the total number of piglets. Furthermore, the quality of the teats is crucial for the piglets to be able to access the milk. Some of the more common problems with teats are dysfunctional ones, as well as, inverted teats. The behavior of the sow in relation to the weight is dependent on the feeding behavior. If the sow is laying down enough for the piglets to get enough time to suckle, further, the position of the sow is important for the piglets to be able to access the teats. Throughout the years, it has been selected for increase in body weight, as well as average daily gain. Therefore, the weight at 3 weeks have increased, but it is important to look at when the increasing and decreasing have occurred, and why.

Weight at 3 weeks is the trait that have experienced the greatest changes in the period from 1991 to 2017. From 1991 to 2000 there was a decrease in weight with b-value of -0.1128. The lowest value of weight was in 2000, this is the same year as the weighting on total born was at its highest at 38%. Because of the higher weighting on total born, it is as expected that the weight of individual piglets is decreasing as a result of the total weight being distributed on more individuals. From 2000 to 2007 there was in increase in weight with b-value of 0.1921. The trait litter weight was included in 2004, the weighting of the trait from 2004 to 2007 is unknown, therefore it is not possible to pin point the exact reason for the increase in this time period. However, in 2006 the weighting on total born had stabilised at 24%, therefore not putting more pressure on the weight, as well as, that it had recently been included in the breeding goal. The greatest increase in weight was from 2007 to 2014 with b-value of 0.4388. The weighting on the trait remained stable at around 13-16% in 2007, however did in 2010 decrease to 6%. However, the weight continued to increase, 2010 was also the year mortality was included in the breeding goal. Mortality and weight are closely related, as weight is extremely important for the survival of piglets and makes piglets more resistant to stressors. In 2012 and 2014 the trait was not weighted at all in the breeding goal, however, total born was weighted as 14% and 19% respectively, as well as, mortality being weighted more compared to previous years. Because of this the weight continued to increase from 2012 to 2014, although not with the same rate as before. From 2014 the weight at 3 weeks started decreasing with b-value of -0.24. This decrease can be due to the fact that weight had no direct weighting from the two previous years. In 2015 and 2016 it was again weighted, but only with 2%, this small change made the decrease shallower. With the massive increase in weight from previous years, it is obviously putting more pressure on the sow, and might therefore compromise the animal welfare. Hence the decrease in weight that is observed can be viewed as an ethical choice, as well as an economical. Ethical as with bigger piglets requires more output of the mother, as well as, economical changes, the BCS of mother in one stage of the reproductive cycle may compromise the performance in another stage.

Number of total born, is associated with the weight of litter with a genetic correlation of -0.34. Meaning as the number of total born is increasing, the weight is decreasing as a result of the weight being distributed among more piglets. Furthermore, weight and mortality is often linked together. According to the phenotypes, litter number two have the highest weight recordings, while litter number one followed by litter number five displayed the lowest values. Further, litter number five is displaying the highest mortality, however, litter number one have some of the lowest recorded mortality rate. Mortality and weight have a negative correlation of -0.48, meaning that the lower the weight, the higher is the mortality rate. However, as the phenotypes show different trends, there are additional factors that contributes to the mortality rate, as e.g. litter number one with relatively low weight does not have a considerable high mortality. On the other hand, there are additional aspects that affects the mortality, other than simply the weight, however, a low weight may be a contributing factor making the piglet more vulnerable for other risks that are not directly genetically linked. As previously mentioned, the most common causes of piglet mortality after birth are crushing, starvation or hypothermia (Edwards, 2002). All of these scenarios become more likely with a lower birth weight. Piglets with lower weight are often predisposed to lose competition against litter mates for teats, therefore, not being able to get the adequate nutrition, ending up weaker more vulnerable for crushing and hypothermia. Furthermore, the consequences of low weight are associated with long-term negative effects on both behaviour and physiology, e.g. higher stress, which is an obvious welfare issue (Rutherford *et al*., 2011). However, because of the competition within litters, it might be the variance in weight that have a higher effect on the mortality rate of piglets, rather than just the weight itself. Furthermore, the low weight does not only heighten the probability of mortality, but also may result in a lower profit for the farmer. It is important to remember that the overall goal of pig production is to produce the highest number of healthy piglets, and to therefore achieve the greatest possible profit.

6.1.5 Variance at 3 weeks

The variance in weight is seen as one of the biggest determents for the survival of the piglets until weaning. The competition for nutrition throughout the farrowing period can be tough, and if the variance within the litter is too high there is a high probability that the piglets on the lower side won't survive until weaning. This is problematic both economically and ethically, as previously discussed. The mortality rate in litters with high variance is often found to be higher, this is due to competition for teats, as well as the sow's behaviour, as piglets that does not manage to get sufficient nutrition is often weaker, and therefore have a higher predisposition for both crushing and diseases.

Variance at 3 weeks have never been included in the breeding goal, however, because of correlations have also had changes throughout the years. Variance at 3 weeks have been recorded for several years because of its importance related to survival. By recording the trait Norsvin is able to monitor changes and be aware of correlations that exists. From 1991 to 2012 there was an increase in variance in weight at 3 weeks with b-value of 0.0039. This increase is simultaneous with the increase of total born and mortality. Further, it is noticeable how similar the trends for mortality and variance at 3 weeks are. The variance within litter has a great impact on the survival rate of the litter, as with bigger litters follows greater competition for resources which then results in higher mortality for individuals which are on the lower side of the scale. From 2012 to 2017 there was a decrease in the variance with b-value of -0.0099. There are a few reasons why this might have occurred, however, it is caused by correlating traits as variance at 3 weeks have never been included in breeding goal. In 2010 there was four new traits included in the breeding goal related to maternal ability; stillborn, mortality, shoulder sore and BCS. The addition of new traits may have had an effect on the following changes in variance. In 2012 the weighting on total born was decreased to 21%, with lower weight, then as a consequence, less piglets would lead to less variance between individuals. However, the weighting on total born is again increased to 28% in 2014. Mortality was weighted from 10% in 2010 to 16% in 2012, which may have been one of the reason for the decrease in variance, even though the relative low genetic correlation of 0.12. According to the phenotypes litter number two have relatively high weight recording, as well as, scoring low for the variance within the litter. In addition, litter number two have a low mortality rate, but also one of the lower number of total born recordings. As previously discussed, lower number of total born is often associated with low weight recordings, however, in this case the results show differently. These results do however, support the theory of having a low variance in weight within litter decreases the mortality rate.

The current study reported a positive correlation between stillborn and variance, at 0.3, meaning a greater variance in weight at 3 weeks is correlated with higher proportion of still births. It is also important to consider the impact of heavier piglets, and the effect this has on the sow. With larger pigs, it is seen as a greater burden on the mother both during gestation and at labour, which then affect the occurrence of shoulder sores, worsen the BCS, as well as, reducing the longevity of the sow.

6.1.6 Shoulder sore

Shoulder sores occur due to continuous pressure on the spine of the scapula. As all the other traits affect the physiology and composition of the sow, it also affects the occurrence of shoulder sores. The number of total born and the weight of piglets are the traits that mostly affect the trait shoulder sore, as these are the traits which affect the weight of the sow to the greatest degree. There is little additive genetic variance (0.06), therefore the development of the trait is highly dependent on the other correlating traits, as well as the environment.

The trait shoulder sore has had a rather shallow curve throughout the years, although becoming steeper when it was included in 2010. The increase in occurrence of shoulder sore from 1991 to 2003 occurred with b-value of 0.0094. At this time, there was increasingly more pressure on number total born, which is reflected in the greater occurrence of shoulder sore. With larger litters, more pressure is put on the mother. The sow becomes heavier as litters are becoming heavier to carry as well as the additional nutrient requirements expected to be met by the mother to nurture the additional piglets. As the body weight increases so does the pressure on the spine of the scapula where shoulder sores occur.

From 2003 to 2011 there was a steadier development, although a minor decrease of -0.0081. In 2004, the peak in occurrence of shoulder sores, there were changes to the breeding goal which might have caused the following decrease. There was a decrease in weighting on litter size from 30% in 2001 to 24% in 2004. Therefore, not putting increasing pressure on the sow. In addition, this is further supported with the fact that there was a steeper decrease in shoulder sores from 2008, when again the litter size decreased to 22%. Furthermore, the weight on health traits increased from 3% in 2001 to 16% in 2004. Even though shoulder sore was not included in the breeding goal until 2010, it is plausible that the increasing weight on health would improve the sow's predisposition to not develop shoulder sores. After the inclusion of shoulder sore in 2010, even with a relatively low weighting of 4% and decreasing to 1% in later years, the decrease in shoulder sore became steeper from 2011 to 2017 with b-value -0.0382. According to the phenotypes, litter number two, three and four showed a higher shoulder sore score in 2011, while litter number one and five showed lower scores than before. For litter number two, three and four there was an immediate decrease in 2012. 2011 was the first year BCS was allocated a weighting in the breeding goal. As a consequence, with better BCS, the less is the occurrence of shoulder sores. Furthermore, health traits had a weighting of 30% in 2014, which may have affected shoulder sore, as better health results in better body condition score.

The genetic correlation between shoulder sore and BCS have been found to be -0.5752. Norsvin is breeding for the reduction of shoulder sores, and it is important to remember that the BCS of what is ideal is bell-formed, meaning that the middle of the scale is seen as optimal. So therefore, if breeding only for reducing the occurrence of shoulder sore then the BCS will eventually become worse as the sows become fatter. However, the Norsvin Landrace was and still is slightly under the ideal BCS of 3. Therefore, when shoulder sore was included in the breeding goal, it gave a positive consequence on the BCS. But, this is also why it is important to have BCS included in the breeding goal to avoid the increase in scoring. As the fat tissue provides cushioning for the spine of the scapula, only breeding for avoidance of shoulder sores would result in obese sows.

6.1.7 Body Condition Score at Weaning

Through the reproductive cycle the requirement for nutrition changes, and it is therefore important to monitor the changes to be able to evaluate if sufficient amount and nutrient requirements are achieved. As all of the phases in the reproductive cycle is related, deviations in BCS in one of the phases may compromise the performance in another phase, furthermore, the effects of underfeeding may not be detectable until later parities or months after the occurrence (Maes *et al.*, 2004). BCS is important in regard to the size of the litter the sow is able to bring forward through gestation, as well as, an indication if the sow is able to provide enough nutrients for her young throughout farrowing.

During 1991 to 1997 there was no major development in regard to body condition score. After 1997 there was a massive decrease in BCS, the same year there was a considerable increase in total born and stillborn. Because of the additional pressure on the sow that follows with increasing litter size, the BCS would then decrease because of the extra resources required to care for the additional piglets. From 1997 to 2011 there was a continuous decrease with b-value of -0.0137. Multiple changes occurred in the breeding goal during this time, the weighting on total born decreased from 38% in 1999 to 24% in 2010. However, even though the weighting decreased, the development in number of total born did increase. The increase in BCS from 2011 to 2017 with b-value of 0.0314 occurred at a faster rate than the decrease the years prior. In 2010, BCS was included in the breeding goal alongside other traits such as shoulder sore, stillborn and mortality. However, BCS did not have any weighting until 2012. The increase in BCS can have been influenced by multiple traits, but it is to believe that the inclusion of mortality and shoulder sore have played a massive role. As shoulder sore have decreased, the trends show that the BCS have increased. Further, it is to believe that better BCS would decrease the mortality of piglets, as the sow would have a better opportunity for supplying the necessary nutrients.

Maintaining a good BCS is essential for achieving the best possible results for any of the traits. There are observed negative correlation between BCS and all the other traits investigated in this thesis, except for mortality at 3 weeks. However, it is important to remember that negative correlations do not necessarily mean unfavourable. As the number of total born increases, the BCS gets worse as more of the sow is expected to provide for more piglets, and it also therefore requires a greater body weight, leading a higher BCS. There is a relatively low correlation between the two traits, at -0.168. However, as it is BCS at weaning that is bred for at Norsvin the extra weight the sow puts one during gestation, may be sufficiently lost during the weaning period.

6.2 Economic considerations

In any livestock production system, there needs to be a considerable profit of the production. There's many cost factors in livestock production ranging from housing and feed, to veterinary cost. An overall goal in any production system is minimising the cost, while at the same time maximising the profit.

6.2.1 Longevity

As seen in the phenotypic trends, for the traits total born and stillborn, litter number five does not stand out in particular way. However, for mortality at 3 weeks litter number five is showing alarming trends and is increasing at a fast rate, while the other traits are beginning to stabilise at 1.5. According to the phenotypes, litter number two have the highest weight recordings, while litter number one followed by litter number five displayed the lowest values. However, as litter number five is displaying alarming mortality trend, while litter number one have some of the lowest recorded mortality rate it is important to notice that low weight does not always mean high mortality. Furthermore, the variance at 3 weeks for litter number five is increasing at a higher rate than the previous litters. As well as, for both shoulder sore and BCS litter number five is showing higher results than previous litters. As for BCS, this is not necessarily negative as it is closer to the middle of the scale, which is seen as more ideal for the sow. However, over all litter number five is showing worse results than the previous litters.

Earlier in the breeding programs for Norsvin, traits such as litter size and weight was split with different weightings on the first, second and third litter. Therefore, it may be an answer that litters up to number five never really have been included in the breeding goal, and therefore showing more sporadic results, not displaying similar trends to earlier litters. There are no traits that acts directly on longevity in today's breeding goal on Norsvin's Landrace, however, other breeding companies have included a separate trait for longevity (DanBred, 2018). This may be an obvious solution in ensuring successful parities of the sow, however, DanBred have some of the highest piglet mortality in the world (Politiken, 2011). Therefore, simply including another trait without adjustments of existing traits have proven to not be sufficient enough. Longevity of the sow have been shown to be highly influenced by the litter size (Serenius and Stalder, 2007; Hoge and Bates, 2011), therefore, the increase in litter size reduces the reproductive life span of the sow often due to the physical impact of increasing the litter size. Some of the most common reasons for culling have been found to be age, reproductive problems or problems related to the udder (Stalder *et al*., 2004; Engblom *et al*., 2007). Hence, the shortening of the sows' life span as the litter size increases might be inevitable, unless specific measures are included, not just longevity, but also including better health and traits such as body condition score of the sow. Furthermore, from an economic standpoint, litter number five produce on average 9 piglets to weaning, while litter four and three is at 12 and the two previous litters are at around 11. Of course, there is a cost in losing piglets, but on the other hand, if the sow has proven to show good maternal behaviour it might be more beneficial than relying on a new mother. This evaluation needs to be looked more closely into, as well as considering the ethical point of view, if it is acceptable to cull an animal if they are not producing as many piglets as is wanted. As the number of stillborn is increasing considerably with the number of litter, it is necessary to evaluate the cost of culling and the profit of the additional litters.

6.2.2 Animal size

The weight at 3 weeks is the trait which have increased the most throughout the years. The selection for higher piglet weight, greater litter sizes as well as the selection for growth rate means the size of the animals is also increasing. When the animals are increasing in size, the management practices also need to be examined. For example, the housing of the animals may need to be examined if the weight and size continuous to increase. This goes for both the farrowing pen as well as the sow housing system. Furthermore, as the litter sizes are continuing to increase, it is obvious that the so will the sow. The size of the sow would increase as the litter requires more space in the uterus, as well as the sow preparing for supplying nutrients for the piglets after birth. Therefore, sows carrying forth larger litters is often larger and that putting more pressure on the health of the sow. Larger sows have a greater predisposition of becoming lame, and experiencing leg problems. Furthermore, because of the excess weight there is a greater chance of developing shoulder sores, however, the excess fat tissue may provide sufficient cushioning to prevent this. An ill animal is an obvious cost, and as for management procedures the animals may need more supervision to prevent the damage to get out of hand. Furthermore, the cost of veterinary help and possible culling also needs to be considered. The nutrition requirements for sows carrying larger litters also increases, and it is necessary to be aware of which requirements that needs to be met. A poor BCS is known to be related to reproductive problems, therefore, to be able to be the most successful, it is a necessity to monitor the condition of the sow. Through the reproductive cycle the requirement for nutrition changes, and it is therefore important to monitor the changes to be able to evaluate if sufficient amount and nutrient requirements are achieved. As all of the phases in the reproductive cycle is related, deviations in BCS in one of the phases may compromise the performance in another phase, furthermore, the effects of underfeeding may not be detectable until later parities or months after the occurrence (Maes *et al.*, 2004).

6.3 Ethical considerations

In any livestock production, it is necessary to consider the ethical dilemmas that will follow. There are different sections of the industry that have different requirements and views, that being for example the farmer, producer or the consumer. All of which is important to maintain.

6.3.1 Increasing litter size

As mentioned, an overall goal of pig production is as many piglets as possible to survive until weaning. Larger litters are seen as a greater burden on the sow. The increased pressure may lead to health and welfare implications, if the management is lacking in some areas, however the extent of the welfare implications is unknown. Larger litter sizes are associated with longer farrowing period which may be more painful for the sow. With larger litters, also follows a higher number of stillborn, it is speculated that sows experience greater pain with the passing of stillborn piglets (Rutherford *et al*., 2011). Furthermore, in the case of larger litter sizes the sow may not be able to provide sufficient nutrition to every piglet. In scenarios like this, cross-fostering is often utilised, where the piglets are moved to another sow. This is done to improve the weight of the piglets, therefore decreasing the pre-weaning mortality. However, there are also welfare implication associated with this, as well as the stress the piglets are exposed to. In addition, the time of the cross-fostering is important as it may affect the immunity of piglet

(Baxter *et al*., 2013). In regard to cross-fostering a major ethical question is if it is acceptable to make sows produce more piglets than they are able to foster.

Furthermore, an increased litter size is associated with a lower birth weight which makes the piglets more vulnerable to environment. This also is applicable for litters with a greater weight variance within litters. With low birth weight and a high variance within litters there are often found a greater mortality rate. This due to the three main causes of piglet mortality as crushing, starvation or hypothermia (Edwards, 2002). The smaller piglets have a higher risk of starvation due to competition of the teats, in addition, if they do get access to a productive teat, the drinking would statistically be less efficient because of the lack of strength, therefore not being able to suckle properly. Furthermore, with the lack of benefiting from the early lactation, including the colostrum, may follow a lack in their immune system causing them to be more susceptible to diseases. Furthermore, as the thermoregulation of weaker piglets are considered poorer than that of more fit litter mates, this have also been connected to less activity of the piglet, which may cause them to be less responsive to the sow's movements. Therefore, having a higher risk of getting crushed by the sow. In addition, piglets with a low birth weight have been observed to spend greater time closer to the udder of the mother, further putting themselves at higher risk situations (Weary *et al*., 1996). However, it is important to remember that it is not only the piglets on the lower weight of the scale variance within litter may not be beneficial for. A high birth weight has been recorded from other studies to have an unfavourable genetic correlation with the proportion of still births (Damgaard *et al*., 2003).

Furthermore, as mentioned in the economic considerations, the maintenance of BCS is important also for the animal welfare. With a better BCS, the better the sow is better prepared to deal with stressors such as changes in environment. Overall, the BCS for the Norsvin landrace is good, and is continuing to increase to reach the middle of the scale. However, too high BCS is not beneficial either, therefore it is important to monitor the changes to make sure the score doesn't exceed the midpoint by too much which may implicate the animal welfare.

6.3.2 Welfare implications of death

The death of an animal brings forth ethical questions of animal welfare and the sentience of piglets. Is it seen as bad animal welfare to die, and is the circumstances around the death related to the answer, whether the animal was intended to die or if it was a consequence of achieving another goal. It is overall consensus in society that the event of dying is seen as negative, but also that the circumstances around the death affects this immensely. However, there are different approaches regarding how to evaluate how negative the death is. Yeates (2010) utilised the definition that dying is as bad as the deprivation of potential future animal welfare. Therefore, indicating that the younger the individual at the time, the worse is the death. Another approach to evaluate the negativity dying is known as Time Relative Interest Account (McMahan, 2002). This approach is based on the desire of the individual to continue their life, this is related to the thoughts and expectations of their future. Therefore, indicating that the loss of an older individual with stronger psychological connections to their future would be considered a more negative death compared to infants with limited psychological connections to their future. Furthermore, in regard to animals it is an ongoing debate on how or if they are capable of conceiving the future (Suddendorf and Corballis, 2007; Mendl and Paul, 2008; Clayton *et al*., 2009). However, if the experience at the time of death is conceived in the same manner regardless of age, the future welfare it is deprived of or connection to the future may be surplus in evaluating the compromise on welfare in that exact moment. On the other hand, the circumstances around the death occurs should therefore be more in focus and if the individual is deprived of future pain. When discussing still births it is important to consider the consciousness and sentience of the animal, there are a lot of support towards the theory that humans and animals are first considered conscious when the complex nervous system have developed to a specific point, not occurring before 24 weeks of age as the cortical region of the brain is then first developed which are needed to be able to become conscious and experience pain (RCOG, 2010). Furthermore, research have suggested that a fetus does not become fully conscious until after the birth (Mellor, 2010). A study conducted on lambs suggest that 95% of fetal lambs are in a state of unconsciousness, for the remaining 5% of the time it was concluded that because the lambs never showed coordinated movements or opened their eyes, they were not conscious (Mellor *et al.*, 2005; Rigatto *et al.*, 1986). On the other hand, with the utilisation of of ultrasound, Coombs et al (2010) was able to visualise coordinated tongue and mouth movements, as well as, flexing of neck and head.

There is an overall consensus in society that death within the first 3 weeks of life is considered worse than the event of a still birth. So why does these deaths occur, and which measures can be taken to avoid these deaths. The high mortality of piglets is often considered one of biggest animal welfare impacts in today's pig production system. The most common causes of piglet mortality after birth are crushing, starvation or hypothermia (Edwards, 2002). The majority of death occur within the first 72 hours after the birth, however deaths after this period also occur, but then more often related to diseases (Rutherford *et al*., 2011). The evaluation of the welfare depends on the capacity of the animal to experience pain. Legislations from multiple countries, e.g. Norway, Denmark and the United Kingdom, are supporting the argument of less developed animals experience less pain (Lovdata, 2003; Retsinformation, 2016; Welfare of Farmed Animals, 2003). All of the countries states in their legislation that mutilations such as teeth clipping, castration and tail docking needing to be undertaken before 7 days of age. This is based on various aspects, one of them being that the central nervous system is not yet fully developed, and therefore, the pain is not experienced in the same manner as more mature animals (Fitzergald, 2005). Another cause may be due to that humans are not able to consciously remember painful event that occurred early in life, however, research have concluded with that individuals can in fact experience pain early in life (Bellieni and Buonocore, 2008). In addition, pain experiences early in life may lead to long-term effects regarding pain responses (LaPrairie and Murphy, 2010). These findings imply that pain experiences in immature animals is a welfare issue, regardless of the animal being sentient at the time of occurrence. Further, possible being more detrimental than previously thought as inhibition systems may be developed after the pain occurrence, leading to further welfare issues in the future (Fitzergald, 2005).

It is important to remember that the society and the consumers plays a major role in regard to what is deemed acceptable in the livestock production. A few years ago, there were multiple news articles in Denmark regarding the number of piglets passing away (DR, 2010; Politiken, 2011). Denmark have a high occurrence of mortality before weaning because of the intense selection for larger litters. The news displayed headlines like "Denmark having the world records in piglet moralities" and "25 000 piglets dies every day". These headlines obviously created a lot of reactions, and both breeders and consumers did not agree in the production system. However, even though with the pressure from the society, the breeding goal for the Danish breeding company does not display any major changes made to aid the situation (DanBred, 2018). The only trait included in the breeding goal for DanBred Landrace focused on reducing the mortality is living pigs in the litter five days after farrowing. This suggests that even though highlighting problems to the public, does not necessarily lead to changes. This can be due to the pressure being too low, and as multiple have studies have showed before, consumers’ attitudes often differ from their actions.

7. Conclusion

Based on the data provided by Norsvin the genetic and phenotypic development of maternal traits from 1991 to 2017 was calculated. All the traits showed changes throughout the years. The traits total born, weight at 3 weeks and BCS all showed increasing genetic trends, while stillborn, mortality at 3 weeks, variance at 3 weeks and shoulder sores all have decreased since 1991. These all show desirable developments for each of the traits. The results show that higher weighting doesn't necessarily mean a greater improvement for the trait, e.g. total born. Weight at 3 weeks have shown the greatest genetic development of all the traits. Variance at 3 weeks have had the smallest development, although as expected, as this is the only trait not included in the breeding goal. However, the variance has still decreased in the later years, the variance is not that high that it is needed to include the trait as of yet. A majority of the literature related to maternal ability is focused around maternal behaviour. This thesis further confirm that it is successful to define objective traits to be included in the breeding goal to improve the maternal ability. The overall economic goal of pig production is to obtain the greatest number of weaned piglets, as well as, a sufficient weight of the piglets. However, with still maintaining the integrity of the animal. Norsvin is working on achieving this by having included the traits discussed in this thesis, they have achieved a lot, although there's always room for improvements. When examining the phenotypic trends, it is obvious that litter number five often is displaying worse trends than the previous litters. Therefore, it might be beneficial to have a higher selection on longevity. However, in this case it is not known how the selection on longevity will affect the performance of earlier litters. Therefore, there is a need to evaluate the profit of litter number five compared to that of culling of the animal both economically and ethically. Overall, the changes in the breeding goal throughout the years have had a positive influence on the genetic trends of the seven traits. Total born, weight at 3 weeks and BCS have all increased. While stillborn, mortality at 3 weeks, variance at 3 weeks and shoulder sore have decreased. Therefore, the breeding conducted by Norsvin for maternal traits in Norwegian Landrace have improved the overall economical and ethical picture.

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