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What traits make Swedish dairy cows survive?

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Vilka egenskaper påverkar svenska kors överlevnad?

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Abstract

The ability of dairy cows to survive and the economic importance of this have been increasing in dairy cattle breeding lately. Increased longevity contribute to an increased proportion of cows that produce milk in more productive lactations and reduces the replacement costs together with a good health and fertility. Unfortunately it is often argued that longevity has been decreasing due to a strong selection for production traits in dairy cattle.

The aims of this study were to find correlations between different longevity evaluations and between different estimates on longevity and other traits in the Nordic Total Merit (NTM) breeding value. The aim was also to compare different traits for cows of two different longevity groups.

The data were Predicted Breeding Values (PBV) from Nordic HOL and SR bulls and records from Holstein (HOL) and Swedish Red (SR) cows estimated by the Swedish Dairy Association.

The three Swedish longevity indexes were very highly correlated (>0.89) and the correlations between the Swedish official longevity index and the five Nordic Cattle Genetic Evaluation (NAV) longevity indexes varied between 0.73-0.83.

In the sire evaluation part, the traits most negatively correlated with longevity for HOL were dairyness, protein and fat index. In SR, milk, protein, and fat index only had slightly positive correlations with longevity. The traits most strongly positively correlated with longevity for SR were different fertility traits, udder health, leg and hoof treatments and other diseases. These traits also had high positive correlations to longevity for HOL together with metabolic treatments and different calving and udder traits. Some traits were found to have intermediate optima in the correlation to longevity and the correlations have also been varying during the past 20 years. It was also found that the Swedish official longevity index has been increasing during these 20 years.

In the cow record part all production traits in first lactation were significant positive related to longevity together with udder traits, milking speed and temperament. They should also have posty and parallel legs with a steep foot angle and a fine bone and hock quality. A HOL cow should be shorter, shallower and narrower and have a strong top line, low pins and a coarse dairyness. SR should instead be deeper and more angular. Fertility problems were the most common culling reasons for first lactation cows and udder health traits were the most common culling reason for older cows. Herds decreasing in size had a higher amount of cows that were culled after one lactation than stable or increasing herds. Heifers were also found to live longer in loose housing barns and in organic systems. Heifers born or having their first calf during summer or autumn were more likely to live longer than cows born or having their first calf during winter or spring.

Keywords: dairy cow, longevity, breeding evaluation, production, conformation

Sammanfattning

Mjölkkor som lever längre och den ekonomiska betydelsen av detta har under senare tid haft en allt större betydelse i avelsarbetet. En ökad livslängd bidrar till att fler kor producerar mjölk i senare och mer produktiva laktationer, samt att det minskar rekryteringskostnaderna och främjar en god hälsa och fertilitet hos djuren. Tyvärr påstås det ofta att livslängden hos mjölkkor har minskat till följd av det starka urvalet för produktionsegenskaper.

Syftet med denna studie var att hitta samband mellan olika överlevandetal samt mellan de olika definitionerna av överlevandetal och andra egenskaper i Nordic Total Merit (NTM). Syftet var också att jämföra olika egenskaper hos kor från två olika livslängdsgrupper. Datan bestod av skattade avelsvärden (PBV) från nordiska tjurar av raserna Holstein (HOL) och Svensk Röd Boskap (SR) och från individuella bedömningar hos HOL- och SR-kor som registrerats av Svensk Mjölk.

De tre svenska överlevandetalen var mycket starkt korrelerade med varandra (> 0,89) och sambanden mellan det svenska officiella överlevandetalet och de fem Nordisk Avelsvärderings (NAV)-överlevandetalen varierade mellan 0,73 och 0,83.

Egenskaperna som var mest negativt korrelerade med överlevnad för HOL i tjurdelen var mjölktyp, protein- och fettindex. I SR hade mjölk-, protein- och fettindex bara svagt positiva korrelationer med överlevnad. Egenskaperna som var mest positivt korrelerade med överlevnad hos SR var olika fertilitetsegenskaper, juverhälsa, ben- och klövbehandlingar samt övriga sjukdomar. Dessa egenskaper hade även höga positiva samband med överlevnad hos HOL tillsammans med metaboliska behandlingar och olika kalvnings- och juveregenskaper. Vissa egenskaper visade sig också vara i bäst relation till överlevnad om de höll medel och inte var för höga eller för låga. Korrelationerna mellan olika egenskaper och överlevnad har varierat under de senaste 20 åren och det konstaterades även att det officiella överlevandetalet har ökat under dessa år.

I kodelen var alla produktionsegenskaper I första laktation positivt korrelerade med överlevnad tillsammans med juveregenskaper, mjölkbarhet och temperament. Det visade sig också vara positivt att ha raka och parallella ben med en brant fotvinkel och en fin ben- och haskvalitet. En HOL -ko bör vara lägre, grundare och smalare och ha en stark överlinje, sluttande kors och vara av en grov mjölktyp. SR bör i stället vara djupare och ha en skarpare mjölktyp. Fertilitetsegenskaper visade sig vara den vanligaste utslagsorsaken hos förstakalvare och juverhälsoegenskaper visade sig vara den vanligaste orsaken hos äldre kor. Besättningar som minskar i storlek hade en högre andel utslagna förstakalvare jämfört med besättningar som är konstanta i antal kor eller ökar i storlek. Det visade sig också att kor lever längre i lösdriftssystem och i ekologisk produktion än i uppbundna eller konventionella system. Kvigor som föds eller föder sin första kalv på sommaren eller hösten visade sig leva längre än kvigor som föds eller föder sin första kalv på vintern eller våren.

Nyckelord: mjölkkor, överlevandetal, avelsvärde, produktion, exteriör

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1 Introduction

Longevity is the ability of a dairy cow to survive in certain production conditions and the economic importance of this trait has increased significantly in dairy cattle breeding lately. An increased longevity results in an increased percentage of cows that produce milk in more productive later lactations and it also reduces the replacement costs. A long herd life owing to good health and good fertility also reduce unnecessary treatments. However, in many dairy cattle populations the longevity has been decreasing due to a strong selection for production traits (Vukašinović *et al*., 1995; Essl, 1998; Novaković *et al*., 2009).

A genetic evaluation for longevity is made for all bulls used in Sweden. According to the Nordic Cattle Genetic Evaluation (NAV), the evaluation is estimated from their daughters' ability to survive in the herd. The estimation is based on the proportion of daughters that have been calving four times or more. At less calvings corrections are made because it takes long time for a bull to have a sufficient amount of daughters with the opportunity to start their fourth lactation. This is made by estimating the longevity also for the second and third calving, which therefore gives three evaluations; cows having calved 2 times (Swedish official longevity index), cows having calved 3 times (Swedish longevity index 2) and cows having calved 4 times (Swedish longevity index 3) (NAV, 2010a). The official longevity evaluation in the Nordic Total Merit (NTM) is estimated as the mean value from the Interbull genetic evaluation of Sweden, Denmark and Finland (NAV, 2010b). The proportion of cows that reach their second lactation in Sweden is on average 75%, 50% reach their third and 30% reach a fourth lactation (NAV, 2010a). This can be compared with an investigation by Hare *et al*. (2006) where the average value of survival for 13.8 million dairy cows from five different breeds in USA were 73 % to the second lactation, 50 % to the third, 32 % to the fourth, 19 % to the fifth, 10 % to the sixth, 5 % to the seventh and 2 % to the eighth lactation.

The average culling age for the Swedish dairy cows are 60.2 months. There are no significant difference between the two most common breeds, with 60.4 months for Swedish Red (SR), and 60.5 months for Holstein (HOL). Cows in more high producing herds are found to be culled at an earlier age than cows in low producing herds, but the heifers in low production are instead calving four months later, and are in production six months longer than cows in high production herds. The oldest cow that still is lactating has been calving 15 times (Swedish Dairy Association, 2010a).

An improvement of longevity by direct selection of sires based on their daughters' longevity measures is impractical because of a low heritability and a long generation interval, because all cows must complete their productive lives. As an alternative to direct evaluation for longevity, an indirect prediction from genetically correlated traits can be considered. The knowledge of genetic correlations between longevity and other characteristics may help to improve longevity in dairy cows (Vukašinović *et al*., 1995). There are two definitions of longevity, actual (true) and functional. Actual longevity is defined as the actual time a cow remains in the herd and functional longevity is connected to reasons which determine culling of cows that not are related to milk production (Novaković *et al*., 2009). There are also two different categories of traits that influence longevity, which can cause either voluntary or involuntary culling. Generally, culling because of poor production is called voluntary culling and culling for other reasons (i. e. incidences of diseases, poor reproductive performance or conformation deficiencies) is called involuntary culling. (Essl, 1998; Sewalem *et al*., 2008). It has been suggested that longevity would best be increased by reducing the causes of involuntary culling rather than by improving longevity itself (Essl, 1998). The culling rate of Swedish dairy cows 2009 were 36% and within them the involuntary culling reasons were infertility (25%), mastitis and somatic cells count (SCC) (24%), leg and hoof problem (7%) and other diseases (3%). The voluntary reasons for culling were low production (10%) and high age (1%). The rest are from other reasons like temperament or milkability (Swedish Dairy Association, 2010b).

1.1 Aims

- Estimate the correlations between the different National longevity evaluations and the Official longevity evaluation (SweL1, SweL2, SweL3).
- Estimate the correlations between NAV's new longevity (NAV L1, NAV L2, NAV L3, NAV L4, NAV L5), the Official longevity (SweL1) and the National longevity evaluations (SweL2, SweL3). Calculate correlations between different estimates on longevity and the other traits in the NTM breeding value.

- To compare cows born 2000 – 2001 of the breeds HOL and SR that have calved only once with cows with at least four calvings and find the phenotypic correlations between the two different groups.

2 Literature review

2.1 Definitions of longevity in different countries

Mark (2004) reviewed the status of genetic evaluation systems for functional and production traits as it is carried out in different Interbull member countries. The different definitions for longevity incorporated the number of days from the first calving to culling or the final milk record, the number of days from first calving to culling (uncensored) or to the actual date (right censored data), reappearance in a subsequent lactation or months in milk. Longevity was either defined as true longevity, functional longevity or residual longevity (correction for all other traits measured in the breeding program). Functional longevity was the most common and a variety of different predictors were used to define combined longevity, as selection index or multiple-trait BLUP (Best linear unbiased prediction). These traits included production traits, conformation traits, SCC, maternal calving ease, calving interval minus days to first insemination and milking speed besides direct longevity information. Low correlations were found between comparable longevity traits measured in different countries, which may be a sign of the differences in trait definitions and in culling reasons. Another explanation suggested by the author was that there are problems with estimation of genetic trends in some applications by using time dependent effects. The different definitions and methods for estimating longevity in different countries can be seen in Table 1.

Table 1. Description of National Genetic Evaluation Systems for longevity in dairy cattle as applied in different Interbull member countries (Interbull, 2010)

Country	Trait definition and unit of measurement	Age groups
Australia	The probability to survive from one year to the next.	Up to 7 years after the first calving.
Canada	Predictable differences among daughters.	Survival in the first 3 lactations.
Czech Republic	Functional herd life (number of days between first calving to culling or to actual date – censored data).	All parities.
Denmark	Productive lifespan (the risk of involuntary culling during the lifetime).	All parities.
Finland	Direct longevity (stayability from first calving).	
France	Length of productive life. Functional longevity is computed in a first step and the combined functional longevity is estimated in a second step and published.	Parities 1 to 5.
Germany	Functional herd life (number of days between first calving to culling or between first calving to actual date - censored data).	All parities.
Italy	The risk of involuntary culling during the lifetime.	All parities.
The Netherlands	Productive lifespan (the risk of culling during the lifetime).	All parities.
New Zealand	Survival from the first to the fifth lactation by using a multiple traits model with correlated traits.	Parities 1 – 5.
Spain	Combined functional longevity, which is estimated from direct functional longevity (productive life span) and indirect functional longevity (other traits).	All parities.
Sweden	Survival rate to the second calving. Cows with no culling record 525 days after the first calving is treated as culled.	1 parity (the Swedish official longevity index).
Switzerland	The productive life span of cows.	All parities.
United Kingdom	Lifespan Predicted Transmitting Ability (lactations).	Up to 5 lactations + probability of survival to many lactations.
USA	Productive life (time in the milking herd before removal by voluntary culling, involuntary culling or death). Credits are given for each month in milk and cows get more credit for beginning a new lactation than for continuing in the previous lactation.	All parities included.

2.2 Correlations to longevity

2.2.1 Milk production

It was found in studies from the Netherlands, France, Switzerland, Sweden, Canada and New Zealand that the higher the production of a cow was relative to that of her herd mates (Van Arendonk, 1986; Dekkers *et al.*, 1994; Beaudeau *et al*., 1995; Vukašinović *et al*., 1995; Vollema & Groen, 1998; Dürr *et al*., 1999; Sewalem *et al*., 2005 & Schneider *et al.*, 2007), or cows with an extremely high milk yield (Berry *et al*., 2005), the lower the risk was of that cow being culled. A relation is also found between longevity and a high first lactation milk yield (Miller *et al*., 1967; Essl, 1998), but it was also found that genetic selection for high production (e.g. milk yield, body weight and growth rate) has given negative correlated responses for fitness and longevity traits (Dematawewa & Berger, 1998; Essl, 1998; Novaković *et al*., 2009). The genetic and phenotypic correlations between milk production and longevity from different studies are shown in Table 2. Most studies have found highly positive genetic and phenotypic correlations with milk production and longevity, but there were also them that found a slightly negative correlation.

In an Australian study on 442 HOL cows from the same herd in North Queensland, cows that had a high milk yield (over 30 l per day) in their first lactation had lower lifetime efficiency than cows producing less milk. Cows that instead produced 25 – 30 l per day in their first lactation had the highest lifetime production and longevity (Haworth *et al*., 2008).

2.2.2 Fertility

A study by De Vries *et al*. (2010) on 14 million dairy cows in the eastern USA showed that the hazards of culling were increased for cows that were in herds with shorter days to first insemination and that pregnant cows had 3 to 7 times lower hazards of culling than open cows had. It was also found that cows with more days open had a higher chance to survive if they were in first-parity than if they were older. A suggested reason by the authors for why cows that conceived late in lactation had a shorter herd life could be a higher risk for over-conditioning that led to health problems and therefore an earlier culling. Dematawewa & Berger (1998) also found that open cows were more likely to be culled than pregnant ones and the calving interval were found to have negative genetic correlations with longevity (Pryce & Brotherstone, 1999; Haile-Mariam *et al*., 2003) (Table 2). Sewalem *et al*. (2008) found in a Canadian study that reproduction traits had a high significant relationship with functional longevity in HOL, Ayrshire and Jersey cows. It was found that the relative risk of culling increased as the number of inseminations per series increased. In HOL, cows that required 4 services were 1.14 times more likely to be culled compared with cows requiring two inseminations. It was also found that HOL cows that were first inseminated during the first 90 days after calving were 1.19 times less likely to be culled than cows first inseminated 120 days after calving. In this breed, open cows were found to be 1.15 times more likely to be culled if they were open more than 150 days compared with cows open up to 120 days. It was also found by Schneider *et al.* (2007) on 978 780 Swedish dairy cows that pregnancy status had a distinct effect on culling, where the risk was very low for a pregnant cow whether she was healthy or treated for mastitis.

In a study by Roxström & Strandberg (2002) on 538 783 SR cows it was found that a long interval between calving and first insemination not necessarily had a negative effect on productive life (Table 2). This could be because a cow instead could be more likely to get a chance to conceive, and only get culled if she not becomes pregnant within a realistic time.

2.2.3 Health disorders

3589 French HOL cows from 47 herds were analyzed to find the effects of different disorders on longevity. The disorders included were abortion, calving ease, milk fever, retained placenta, ketosis, metritis, cystic ovaries, locomotor disorders, mastitis, teat injuries and non-traumatic udder disorders. It was found that health disorders that took place during the first lactation had a large effect on longevity but their impacts were still lower than the input of reproductive performances and milk production. Udder disorders (mastitis during the dry period and teat injury) and reproductive disorders (abortion) were found to be the health events that had the highest influence on longevity among the health disorders analyzed (Beaudeau *et al*., 1995).

Calving difficulty

De Vries *et al*. (2010) found that difficult calvings increased the hazard of culling and reduced the longevity in large dairy herds in the eastern USA. Cows with a very difficult calving had up to two times greater hazard of being culled compared with cows that had an easy calving. First-parity cows had a higher risk of being culled than older cows if their calvings were very difficult or needed force. Cows that had twins had a 23 to 46% greater hazard of culling than cows that had single calves and there was also an increase of culling because of twins if it appeared in first-parity cows. It was also found that, except for in the first parity, twin males increased the hazard more than twin females. In the study, a cow that had a single female calf had a 5 to 7% lower hazard of being culled than a cow having a single male calf. Sewalem *et al*. (2008) found in a Canadian study that HOL, Ayrshire and Jersey cows that calved with assisted hard pulls or surgery had a highly increased risk of being culled compared with unassisted cows. HOL that needed surgery were 1.92 times more likely of being culled compared with unassisted calvings. In the three breeds, there also was a greater risk of being culled if the cows gave birth to stillborn calves and there also was a tendency that cows giving birth to calves of an intermediate size had a higher longevity.

Mastitis and somatic cell count

In a study on Danish black and white dairy cattle by Neerhof *et al*. (2000), it was found a negative genetic correlation (- 0.4) between predicted breeding values for mastitis resistance and the risk of being culled. The same results were found in a study by Roxström & Strandberg (2002) on 534 016 SR dairy cows. The correlation between mastitis resistance and culling were – 0.53, which meant that mastitis resistance and productive life were favourably correlated. Samoré *et al*. (2003) found a positive correlation between sire EBV for SCC and for culling rate in an Italian study on 512 221 HOL cows. The result indicated that bulls with poor genetic values for SCC also were associated with poor longevity. Mrode *et al*. (2000) also found a negative genetic correlation between lifespan and SCC in HOL, Ayrshire, Jersey, Guernsey and Shorthorn cattle in the United Kingdom (Table 2). This finding corresponds to the other studies on SCC and longevity correlations in Table 2 and indicates that cows with a high SCC value were at a higher risk of being culled.

Table 2. Correlations between longevity and production-, fertility-, and mastitis traits.[1] Genetic without brackets and phenotypic within brackets

	Trait						
References	MP	DO	CI	CFI	CLI	NINS	SCC
Dematawewa & Berger (1998)[2]	–0.14 (0.10)	–0.13 (0.03)				–0.25 (0.02)	
Haile-Mariam *et al*. (2003)[3]	0.28 (0.16)		-0.33 (0.0)				-0.13 (-0.07)
Harris & Freeman (1992)[4]	0.41 (0.30)						
Mrode *et al*. (2000)[5]							-0.32
Pryce & Brotherstone (1999)[6]			-0.44				-0.27
Roxström & Strandberg (2002)[7]	0.06, 0.09, -0.05			0.25	0.27	0.21	-0.36
Short & Lawlor (1992)[8]	0.08 (0.03)						
Strandberg & Roxström (2000)[9]					0.47		
Vollema *et al*. (2000)[10]				0.14			-0.23
Vukašinović *et al*. (1995)[11]	0.34 (0.02)						

[1] Milk production (MP); Days open (DO); Calving interval (CI); Interval between calving and first insemination in first lactation (CFI); Interval between calving and last insemination in first lactation (CLI); Number of inseminations per series (NINS); Somatic cell count (SCC).

[2] Data from 122 715 lactation records of cows obtained from the Middle USA distributed across 11 374 herd-year-season groups. Across-parity genetic and phenotypic correlations. Model: Linear model.

[3] Data from HOL cows of 1679 sires with 1230 daughters in the first and 1230 daughters in the second parity in Australia. Genetic and phenotypic correlations with survival in the first parity. Correlation with mean milk yield in the MP column and with mean LnSCC in the SCC column. Model: Linear model.

[4] Data from 21 543 records of Guernsey cows in the U.S. at 48 months of age. Genetic and phenotypic correlations with functional herd life. Model: Linear model

[5] Data from 8087 HOL heifers in the United Kingdom. Genetic correlations with life span. Model: Linear model.

[6] Data from HOL in United Kingdom and Ireland. Genetic correlations with life span. Model: Linear model.

[7] Data from 538 783 SR cows. Genetic correlations with length of productive life. MP correlations are from 1st, 2nd and 3rd lactation respectively. Model: Survival analysis.

[8] Data from 125 887 cows after 1677 American HOL sires. Genetic and phenotypic correlations with functional longevity. Model: Linear model.

[9] Data from 534 016 SR cows. Genetic correlations with length of productive life. Model: Survival analysis.

[10] Data from 4 134 499 Dutch cows from 14 158 sires. Genetic correlation with functional longevity. Model: Survival analysis.

[11] Data from 9224 Brown Swiss cows of 274 sires. Genetic and phenotypic correlation with functional productive life 48 months after first calving. Model: Linear model.

2.2.4 Conformation traits

Udder

As can be seen in Table 3, all traits describing udder traits had positive genetic and phenotypic correlations with productive life except from udder depth studied by Vacek *et al*. (2006), that were slightly negative but almost zero. Teats should be placed close together to be favored and be short (Harris & Freeman, 1992; Vollema *et al*., 2000; Mrode *et al*., 2000 and Vacek *et al*., 2006), except from the findings by Vukašinović *et al*. (1995) on Brown Swiss cows. On the other hand, Rogers *et al*. (1991) and Vukašinović *et al*. (1995) found that cows with proper teats and well-shaped and tightly attached qualitative udders remained in the herd longer than other cows even if they had the same production. Such cows were most likely easier to milk and were less susceptible to mastitis and injury, which might had contributed indirectly to a longer productive life according to the authors. Berry *et al*. (2005) found in a study of New Zealand purebred and crossbred HOL and Jersey dairy cattle in commercial herds that udder related traits also had the largest influence on functional longevity among traits other than production. It was also found by Buenger *et al*. (2001) on 234 023 cows from northwest Germany that there were positive correlations between udder shallowness, fore udder length, fore udder attachment (FUA), tightness, rear udder height, suspensory ligament strength, close teat placement and longevity and that a moderate teat length had the highest correlation with longevity.

Zavadilová *et al*. (2009) performed survival analysis on 47 786 Czech Fleckvieh cows that were body conformation scored between day 60 and 180 of the first lactation. They found that fore udder length, rear udder attachment, front teat placement and teat length and width had an intermediate optimum relative longevity. Udder traits that had positive linear relationship to longevity were a strong central ligament and a shallow udder depth. Schneider *et al*. (2003) studied 331 105 records of HOL cows in herds in Quebec, Canada and found that, among different udder traits, cows with strong attached and well defined mammary systems and fine textured udders with a high rear attachment were more expected to have a long functional herd life than cows with the reverse body scores. Further, cows that had a soft udder tissue had higher survival rates than cows with an intermediate phenotype, and cows with coarse and fleshy udders had a 3-fold increased risk of being culled compared with the intermediate. Regarding the front and rear teat placement, the optimal was an intermediate score and cows with extremely widely placed teats were more likely to be culled than cows with more centered placed teats. The intermediate optima on front and rear teat placement were also found by Berry *et al*. (2005).

Table 3. Correlations between longevity and udder traits.[1] Genetic without brackets and phenotypic within brackets

References	UA	UQ/V	UD	SL	TP	TL
Boldman *et al*. (1992)[2]	0.46 (0.06)		0.47 (0.06)	0.22 (0.05)	0.17 (0.05)	
Dekkers *et al*. (1994)[3]	0.27	0.12		0.19		
Harris & Freeman (1992)[4]	0.35 (0.03)		0.04 (0.03)		0.11 (0.01)	-0.57 (-0.04)
Klassen *et al*. (1992)[5]	0.01 (0.08)	0.19 (0.10)		0.05 (0.10)	-0.01 (0.08)	
Mrode *et al*. (2000)[6]	0.28 (0.10)		0.46 (0.09)		0.02 (0.05)	-0.28 (-0.01)
Rogers *et al*. (1991)[7]	0.68 (0.09)		0.60 (0.10)		0.28 (0.06)	
Short & Lawlor (1992)[8]	0.42 (0.12)		0.44 (0.10)		0.28 (0.09)	
Vacek *et al*. (2006)[9]	0.026		-0.021		0.042	-0.058
Vollema *et al*. (2000)[10]			0.38	0.27	0.23	-0.14
Vukašinović *et al*. (1995)[11]	0.53 (0.04)	0.47 (0.05)			0.66 (0.04)	0.59 (0.08)

[1] Udder attachment (UA); Udder Quality/Veining (UQ/V); Udder depth (UD); Suspensory ligament (SL); Teat placement (TP); Teat length (TL).

[2] Data from grade HOL cows in herds in the north and central USA. Genetic and phenotypic correlations with functional herd life. Model: Linear model.

[3] Data from 63 602 Canadian cows. Genetic correlations with functional herd life. Model: Regression of functional herd life on genetic evaluated possibilities.

[4] Data from 4571 records of registered Guernsey cows in the USA at 48 months of age. Genetic and phenotypic correlations with functional herd life. Model: Linear model.

[5] Data from 34 322 Canadian dairy cows. Genetic and phenotypic correlations with number of lactations. Model: Linear model.

[6] Data from 8087 heifers in the United Kingdom. Genetic and phenotypic correlations with lifespan. Model: Linear model.

[7] Data from 9819 Jersey cows in American herds from 158 sires. Genetic and phenotypic correlations with length of productive life after adjustment for milk yield. Model: Linear model..

[8] Data from 125 887 cows after 1677 American HOL sires. Genetic and phenotypic correlations with functional longevity. Model: Linear model.

[9] Data from 41 489 HOL cows in 1685 herds in the Czech Republic. Pearson correlation coefficients between conformation traits and length of productive life. Model: SAS.

[10] Data from 4 134 499 Dutch cows from 14 158 sires. Genetic correlation with functional longevity. Model: Survival analysisSurvival analysis.

[11] Data from 9224 Brown Swiss cows of 274 sires. Genetic and phenotypic correlations with functional productive life 48 months after first calving. Model: Linear model.

Body and legs

The correlations between body and leg traits and longevity were not as consistent as udder traits in different studies, but rather found to be either positive, negative (Table 4) or have an intermediate optima. In a study by Hansen *et al.* (1999) on 397 American HOL cows of two different lines selected for body size, the productive life was longer for cows with a small body size than for cows with a large body size. Wall *et al*. (2007) also found negative relationships between stature, chest width, angularity and body depth throughout the first lactation and longevity (Table 4). Chest width was also found to be negatively related to non-return rate and calving interval, which could have an indirect effect on reduced longevity. Buenger *et al*. (2001) also found negative correlations between stature, chest width, body depth, rump width, sickled rear legs and longevity, but a positive correlation with rump angle, foot angle and longevity. Cows with sickled legs were also at higher risk of being culled in a study by Berry *et al*. (2005). They also found that rump angle and width had optima in-between with an increased risk of culling at the both extremes. Zavadilová *et al*. (2009) found that muscularity, sacrum and wither height, rump length and width had a positive linear phenotypic relationship with culling, which also here indicated that smaller cows had longer productive lives. It was also found that chest girth, rump angle, body depth, rear legs side view and pastern score had the optimum scores intermediate and cows with high or low scores were at higher risks of being culled. Hamoen *et al*. (2009) found that an intermediate score on rump width, chest width, body depth and body condition were highly correlated to longevity. The study was based on data from over 600 000 Dutch cows.

In a Canadian study by Schneider *et al*. (2003) it was by contrast found that a high phenotypic score on frame capacity, rump and feet and legs led to an increased functional herd life than a cow in the intermediate class, which signified that tall and large cows had higher chances to survive. The traits included stature, size, chest width and loin strength. Compared with the other body traits, stature was found to have the strongest effect on functional herd life. Extremely narrow, high or low hips were found to decrease the herd life, whereas wider hips with an intermediate height increased it. Regarding feet and leg traits, cows with a low foot angle were found to have a higher risk of being culled than cows with a steep foot or cows in the intermediate class. The leg straightness of cows was also found to have an intermediate optimum, but the risk of being culled was higher for cows with intensively curved legs than for cows with intensively straight legs. Pérez-

Cabal *et al*. (2006) found that Spanish cows that had high scores for feet and legs and an intermediate score for foot angle and rear legs set had better longevity and production performance (Table 4).

Table 4. Correlations between longevity and body and leg traits.[1] Genetic without brackets and phenotypic within brackets

References	WH/S	BD	C/H	RA	RW	ANG	FA	RL
Boldman *et al*. (1992)[2]	-0.21 (-0.01)	-0.20 (-0.01)			-0.18 (-0.01)		-0.12 (0.03)	0.08 (-0.02)
Dekkers *et al.* (1994)[3]	0.13		0.05		0.0		0.17	0.00
Harris & Freeman (1992)[4]	-0.69 (-0.06)	-0.35 (-0.02)		-0.40 (-0.04)	-0.70 (-0.03)		-0.14 (0.02)	0.16 (-0.01)
Klassen *et al*. (1992)[5]	0.25 (0.07)		0.05 (0.04)	0.44 (0.15)	-0.18 (0.03)		-0.16 (0.04)	-0.06 (0.00)
Mrode *et al*. (2000)[6]			-0.08 (0.01)	-0.04 (-0.03)		0.23 (0.06)	0.47 (0.05)	-0.10 (-0.04)
Pérez-Cabal *et al*. (2006)[7]							0.03	-0,10
Rogers *et al*. (1991)[9]	0.03 (-0.01)		-0.02 (0.01)	-0.10 (-0.01)	0.23 (0.03)		0.36 (0.04)	-0.21 (-0.03)
Short & Lawlor (1992)[10]	0.06 (0.03)	-0.09 (0.01)		0.04 (-0.02)	-0.03 (0.01)		0.11 (0.04)	-0.02 (-0.02)
Vacek *et al*. (2006)[11]	0.06	0.003	0.002	-0.06	0.002	0.13	0.060	-0.075
Vollema *et al*. (2000)[12]			-0.41	0.25			0.34	
Vukašinović *et al*. (1995)[13]	0.02 (0.00)		-0.15 (-0.03)					0.31 (0.03)
Wall *et al*. (2007)[14]	-0.08	-0.27	-0.09			-0.25		

[1] Wither height / stature (WH/S); Body depth (BD); Chest width / heart girth (C/H); Rump angle (RA); Rump width (RW); Angularity / Dairyness (ANG); Foot angle (FA); Rear legs side view (RL).

[2] Data from grade HOL cows in herds in the north and central USA. Genetic and phenotypic correlations with functional herd life. Model: Linear model.

[3] Data from 63 602 Canadian cows. Genetic correlations with functional herd life. Model: Regression of functional herd life on genetic evaluated possibilities.

[4] Data from 4571 records of registered Guernsey cows in USA at 48 months of age. Genetic and phenotypic correlations with functional herd life. Model: Linear model.[5] Data from 34 322 Canadian dairy cows. Genetic and phenotypic correlations with number of lactations. Model: Linear model.

[6] Data from 8087 heifers in the United Kingdom. Genetic and phenotypic correlations with lifespan. Model: Linear model.

[7] Data from 112 166 type scored dairy cows from the Basque and Navarra Autonomous Regions of Spain. Genetic correlation with functional herd life adjusted by production level. Model: Linear model.

[8] Data from HOL in United Kingdom and Ireland. Genetic correlations with life span. Model: Linear model.[9] Data from 9819 Jersey cows in American herds from 158 sires. Genetic and phenotypic correlation with length of productive life after adjustment for milk yield. Model: Linear model.

[10] Data from 125 887 cows after 1677 American HOL sires. Genetic and phenotypic correlations with functional longevity. Model: Linear model.
[11] Data from 41 489 HOL cows in 1685 herds in the Czech Republic. Pearson correlation coefficients between conformation traits and length of productive life. Model: SAS.
[12] Data from 4 134 499 Dutch cows from 14 158 sires. Genetic correlation with functional longevity. Model: Survival analysis.
[13] Data from 9224 Brown Swiss cows of 274 sires. Genetic and phenotypic correlation with functional productive life 48 months after first calving. Model: Linear model.[14] Data from first-lactation HOL cows in the United Kingdom. Genetic correlations with life span. Model: Linear model.

2.2.5 Herd size changes

Sewalem *et al*. (2005) found in a Canadian study on HOL, Ayrshire and Jersey that cows in annually decreasing herds were at a higher risk of being culled compared with cows in stable herds, which had a higher culling risk than cows in annually increasing herds. Samoré *et al*. (2003) found the same results in an Italian study on HOL cows where an annual herd size decrease of 15–50% had a 23% higher culling rate than stable herds. Herds that were increasing 15-50% in size and herds increasing more than 50% in size annually had 8% to 12% decrease in culling rate in comparison to stable herds, respectively.

Dürr *et al*. (1999) got a different result on Canadian HOL cows, where cows in herds increasing in size as well as cows in herds reducing in size were at a higher risk of being culled than cows in stable herds. The changes in herd sizes were however reported to have a small impact on longevity compared with other traits in the two studies.

Schneider *et al*. (2003) instead found that the risk of being culled did not change for HOL cows in Canadian herds that were decreasing or increasing in size.

2.2.6 Housing

Buenger *et al*. (2001) found that cows on short standing tie-stalls with straw bedding or cows in deep boxes with slatted floor and bedding had a significant higher longevity than cows on dung grid tie-stalls with rubber mats or cows in cubicle houses with rubber mats and slatted floor. The tie-stall or free-stall housing system had therefore no importance, but cows on rubber mat surface without bedding had a significant shorter longevity than cows on bedding. The study was made on 43 116 cows from northwest Germany.

Ahlman (2010) found that Swedish cows in organic herds stayed longer and had a lower production, a better fertility and a higher SCC than cows in conventional herds. But, at a given production level the fertility was slightly worse and the SCC was equal as cows in conventional herds. The lower production mostly depends on less energy intake because organically produced feed generally contain less energy than conventionally produced feed and organic feed rations generally have higher proportions of roughage. Fall *et al*. (2008) studied one organic and one conventional group of cows on a Swedish dairy farm and found that there were no differences in health or longevity traits. The only thing that differed was that conventional cows in lactation 3 or more had a longer interval from calving to the first service.

2.2.7 Milking speed and temperament

Berry *et al*. (2005) found that milking speed and temperament had a very weak influence on true longevity in New Zealand purebred and crossbred HOL and Jersey dairy cattle. In an Australian study by Madgwick & Goddard (1989) it was found that temperament had the highest correlation with survival among workability traits. Milking speed was only weakly correlated to longevity, but they were both positive. Visscher & Goddard (1995) also found in their study on Australian HOL and Jersey cows that positive scores for milking speed and temperament had positive genetic correlations with longevity. Furthermore, Cue *et al.* (1996) found positive correlations between milking speed and survival and temperament and survival in HOL, Jerseys and Ayrshires from New Zealand. The genetic correlations were up to 0.38 between temperament and survival and up to 0.52 between milking speed and survival.

2.2.8 Age at first calving (AFC)

It was shown in several studies that cows that were older at their first calving had a higher risk of being culled earlier in life. In an early study by Gill & Allaire (1975) on 933 cows in Ohio, USA, it was found that the correlation between AFC and herd life was slightly negative. A negative correlation was also found by Vollema & Groen (1998) on 256 000 HOL dairy cows from Friesland and by Vollema *et al*. (2000) with data from 4 134 499 Dutch cows from 14 158 sires. Also Wathes *et al.* (2008) concluded in a review that heifers on commercial farms in the United Kingdom that were calving at 22 to 23 months performed best in terms of total milk yield and survival over the first 5 years in comparison to heifers calving later. This was presumably partly due to that good heifer fertility might be associated with better fertility later too. Furthermore, a study by Strandberg & Roxström (2000) on 534 016 SR dairy cows, a study by Schneider *et al.* (2007) on 978 780 Swedish dairy cows, a study by Dürr *et al*. (1999) on 331 147 HOL cows in Quebec (Canada) and a study by Schneider *et al*. (2003) on 331 105 HOL cows in Quebec, found out that the risk of culling did increase with an increasing AFC. These results were also supported by Sewalem *et al*. (2005) on 34 893 HOL sires with daughters in 16 777 herds and 2923 Ayrshire sires with daughters in 1436 herds and 2478 Jersey sires in 847 herds in Canada. The effect was not found to have a large influence on longevity in that study, but a linear relationship showed that the risk of being culled was lower for heifers calving at an age between 24 and 28 months than at an older age.

In an Australian study on 442 HOL cows in the same herd in North Queensland, the life span was significantly shorter for cows that calved at less than two years of age and longer for cows that calved at more than three years of age. However, the animals that were more than 2.5 years old at first calving spent a smaller proportion of their lives lactating than younger cows (Haworth *et al*., 2008).

2.2.9 Season of first calving

It was found in a Turkish study by Tekerli & Koçak (2009) that HOL cows having their first calf during the spring had a higher milk yield and lactation length, but a lower fertility. The length of productive life and herd life were not significant different between the season of first calving, but there was a trend that heifers calving during winter or spring had a longer life than heifers calving during summer or autumn.

2.2.10 Growth rate

In a study by Brotherstone *et al*. (2007) it was found that calves growing faster at weaning were more susceptible to get mastitis when they got older than calves that were growing slower. It was also found that an increased growth rate and weight at weaning and an increased maximum growth rate all were genetically correlated to increased hoof disorders. Further, high milk producing cows were found to have lower breeding value for predicted body weight after calving than lower producing cows. On the other hand, it was also found that heavier cows at calving got fewer fertility problems during the first lactation. The study was made on 21 763 body weight records from birth to 1000 days of age on 625 cows in the United Kingdom.

These findings could indirectly influence longevity because mastitis, hoof disorders, low production and fertility also were found to be negatively correlated with longevity in the studies above.

3 Material and methods

3.1 Sire evaluations

3.1.1 Data

In this study the original data consisted of NAV sire predicted breeding values (PBVs) from 1768 HOL bulls and 918 SR bulls born between 2000 and 2004. The breeding values were estimated by the Swedish Dairy Association with data from the official milk recording system and from field reports of linear scores. Ten longevity evaluations were compared to each other by estimating the correlations between them. These evaluations were:

- Swedish official longevity index (Swe L1) (cows that calved a 2nd time).
- Swedish longevity index 2 (Swe L2) (cows that calved a 3rd time).
- Swedish longevity index 3 (Swe L3) (cows that calved a 4th time).
- The old NAV longevity index (Old NAV) (number of days after first calving, was previously the official longevity index within NAV and Sweden).
- Survival EBV using survival analysis (Surv EBV).
- NAV longevity index 1 (NAV L1) (number of days in 1st lactation).
- NAV longevity index 2 (NAV L2) (number of days in 2nd lactation).
- NAV longevity index 3 (NAV L3) (number of days in 3rd lactation).
- NAV longevity index 4 (NAV L4) (number of days in 4th lactation).
- NAV longevity index 5 (NAV L5) (number of days in 5th lactation).

Only four of these evaluations were used to estimate the correlations to other traits in the sire evaluation. The chosen evaluations were Swe L1, Old NAV, NAV L1 and Surv EBV. These longevity evaluations were chosen because it would have been be too much to use all ten evaluations, but still be possible to compare correlations for the same trait with different longevity evaluations.

To make a regression analysis for longevity and to find out how the correlations have changed over 20 years, a total number of 2185 HOL bulls and 2147 SR bulls born between 1985 and 2004 were used. The evaluation data was scored with a mean of 100 and a standard deviation of 10 (NAV, 2010a). In Appendix 1 the number of bulls, mean values, standard deviations and minimum- and maximum values on each evaluation are found.

3.1.2 Statistical methods

SAS 9.2 Proc Corr was used to estimate the correlations between longevity and other traits in the sire breeding values. Descriptive statistics were estimated by SAS 9.2 Proc Means and a regression analysis was performed by SAS 9.2 Proc Glm (SAS, 2010). To display the results in tables and diagrams, Microsoft Office Excel 2007 was used.

Eight traits that were significant and/or high correlated for at least one breed were further analyzed to find out if the longevity optima were at a low, intermediate or a high breeding value for that trait by SAS 9.2 Proc Means (SAS, 2010). The correlations to longevity for the eight traits were also analyzed to see the change over 20 years, from 1985 to 2004. The years were classified two and two because the class size were otherwise too small. The traits were distributed as one production trait, three health traits and four conformation traits.

3.2 Cow records

3.2.1 Data

The original data set contained 129 322 records on HOL cows and 128 291 records on SR cows born 2000 and 2001 were used in this study. The data were derived from the Swedish Dairy association with data from the official milk recording system and from field reports of linear scores. The characteristics studied were breed, pedigree, production in first lactation (kg of milk, fat, protein) relative the production within herd, days in milk (DIM), NTM, AFC, reasons for culling, herd size (2002 and 2004), housing, organic certificated (KRAV) or not, month of birth, month of first calving and the conformation traits. The cows were divided into two groups; *Group 1* consisted of cows that had been calving one time and then been culled, and *Group 4*$^+$ was cows that had been calving four times or more. The production traits, conformation traits (Table 7) and housing were all records from lactation one for the two groups to make them comparable. With help of birth date and date of first calving, the AFC was calculated. To find different herd size changes, the herds were divided into three groups; *Decreasing* (at least 4 heifers more than the number 2004 calved in that herd 2002), *Stable* (the same number of heifers were calving in that herd 2002 and 2004 with a difference of -3 to 3) and *Increasing* (at least 4 heifers more than the number 2002 calved in that herd 2004).

The NTM index was scored with a mean of 0 and a standard deviation of 6 (NAV, 2010a). Rump height was scored in cm and the rest of the conformation linear scores were recorded at a scale from 1 to 9. The number of cows and mean values on each evaluation are shown in Table 7 for production and conformation traits. For culling reasons, herd size changes, housing, month of birth and first calving, the number of cows are found in the caption to figure 4-8.

3.2.2 Statistical methods

SAS 9.2 Proc Mixed (SAS, 2010) was used to estimate the differences between the two groups of cows for the fixed traits milk, fat, protein, DIM and TMI with *herd* as a random parameter. Conformation scores had the random parameters *herd, sire, judge* and *judgement day* as random parameters. SAS 9.2 Proc Freq (SAS, 2010) was used to estimate the differences between the two groups of cows for AFC, culling reason, herd size changes, housing, month of birth and month of first calving. To display the results in tables and diagrams, Microsoft Office Excel 2007 was used.

4 Results

4.1 Sire evaluations

4.1.1 Correlations between longevity evaluations

Table 5 shows correlations between different longevity evaluations used for the bulls. The correlations between the three Swedish longevity indexes were high (>0.89) as were the correlations between the five NAV longevity indexes (>0.89). The correlations between the old NAV longevity evaluation and the new NAV indexes varied from 0.76 to 0.85. The lowest correlations were between the Swedish official longevity index (SweL1) and Survival EBV (0.68) and between the SweL3 and NAV longevity index 1 (0.69), both for SR.

Table 5. Correlations between different sire evaluations of longevity. HOL above diagonal and SR below diagonal

Correlation	Swe L1[1]	Swe L2[2]	Swe L3[3]	Old NAV[4]	Surv EBV[5]	NAV L1[6]	NAV L2[7]	NAV L3[8]	NAV L4[9]	NAV L5[10]
Swe L1[1]	1.00	0.97	0.95	0.92	0.76	0.76	0.83	0.84	0.83	0.83
Swe L2[2]	0.95	1.00	0.99	0.92	0.80	0.75	0.84	0.86	0.87	0.87
Swe L3[3]	0.89	0.97	1.00	0.91	0.81	0.74	0.84	0.87	0.87	0.88
Old NAV[4]	0.87	0.88	0.87	1.00	0.76	0.76	0.84	0.85	0.85	0.85
Surv EBV[5]	0.68	0.75	0.79	0.79	1.00	0.84	0.91	0.91	0.91	0.91
NAV L1[6]	0.74	0.72	0.69	0.78	0.83	1.00	0.96	0.93	0.91	0.91
NAV L2[7]	0.78	0.79	0.78	0.84	0.89	0.97	1.00	0.99	0.98	0.98
NAV L3[8]	0.76	0.81	0.82	0.85	0.92	0.94	0.99	1.00	1.00	1.00
NAV L4[9]	0.74	0.80	0.83	0.85	0.93	0.90	0.97	0.99	1.00	1.00
NAV L5[10]	0.73	0.80	0.83	0.84	0.93	0.89	0.96	0.99	1.00	1.00

[1] Swedish official longevity index (cows that calved a 2nd time).
[2] Swedish longevity index 2 (cows that calved a 3rd time).
[3] Swedish longevity index 3 (cows that calved a 4th time).
[4] The old NAV longevity index.

[5] Survival EBV.
[6] NAV longevity index 1 (number of days in 1st lactation).
[7] NAV longevity index 2 (number of days in 2nd lactation).
[8] NAV longevity index 3 (number of days in 3rd lactation).
[9] NAV longevity index 4 (number of days in 4th lactation).
[10] NAV longevity index 5 (number of days in 5th lactation).

The number of bulls, mean values, standard deviations and minimum and maximum values of different evaluations are found in Appendix 1.

4.1.2 Correlations between longevity and other breeding value traits in the sire evaluation

Correlations were estimated between four of the longevity evaluations and other traits in the sire evaluation. All the results are shown in Appendix 1 and the traits highest correlated (absolute value above 0.2) to the Swedish official longevity index are shown in Table 6 and 7.

Table 6. Traits that were most strongly correlated to SweL1 (HOL)

Correlation						
-0.4 < - 0.3	- 0.3 < -0.2	0.2 < 0.3	0.3 < 0.4	0.4 < 0.5	0.5 < 0.6	0.6 < 0.7
Dairyness	Protein yield	Heat Sign	Fertility treatments[1]	Number of AI[2]	Calving to first AI[2]	From first to last AI[2]
	Fat yield	Calving Difficulty[3]	Metabolic treatments	Mastitis resistance[4]		Fertility Index
		Stillbirths[5]	Leg and hoof treatments[6]	Udder health		
		Calving Index[7]		Fertility treatments[8]		
		Birth Index		Other diseases		
		Fore Udder Attachment				
		Udder depth				
		Udder				

[1] 1st lactation (15-40 days); [2] cows; [3] heifers (MGS, maternal and directly); [4] 1st lactation (part 1 and 2); [5] cows (MGS, maternal and directly); [6] 1st lactation (15-305 days); [7] MGS; [8] 1st lactation (41-305 days)

Traits that were most strongly correlated to the Swedish official longevity index (SR)

Correlation			
0.2 < 0.3	0.3 < 0.4	0.4 < 0.5	0.5 < 0.6
Non Return, cows	Number of AI[1]	Calving to first AI[1]	From first to last AI[1]
Mastitis resistance[2]	Heat Sign		Fertility Index
Udder health	Mastitis resistance[3]		
Fertility treatments[4]			
Leg and hoof treatments[5]			
Other diseases			

[1] cows; [2] 1st lactation (part 2); [3] 1st lactation (part 1); [4] 1st lactation (41-305 days); [5] 1st lactation (15-305 days)

In Figure 1, eight traits that were important and/or highly correlated to longevity were further analyzed to find out where the optima of the traits were. As can be seen, SweL1becomes higher as production index becomes lower for HOL, but the opposite was found for SR. The higher the fertility index and udder health were and the stronger FUA was, the higher the longevity index was for both breeds. For calving index, the optima tend to be high for HOL, but did not seem to have any relation for SR. For body conformation there tends to be an intermediate to low optimum for SR, and a low optimum for HOL. Udder depth and foot angle do not have any correlation with longevity for SR, but HOL with shallow udders have higher longevity than those with deep udders and HOL with a low to intermediate foot angle also live longer.

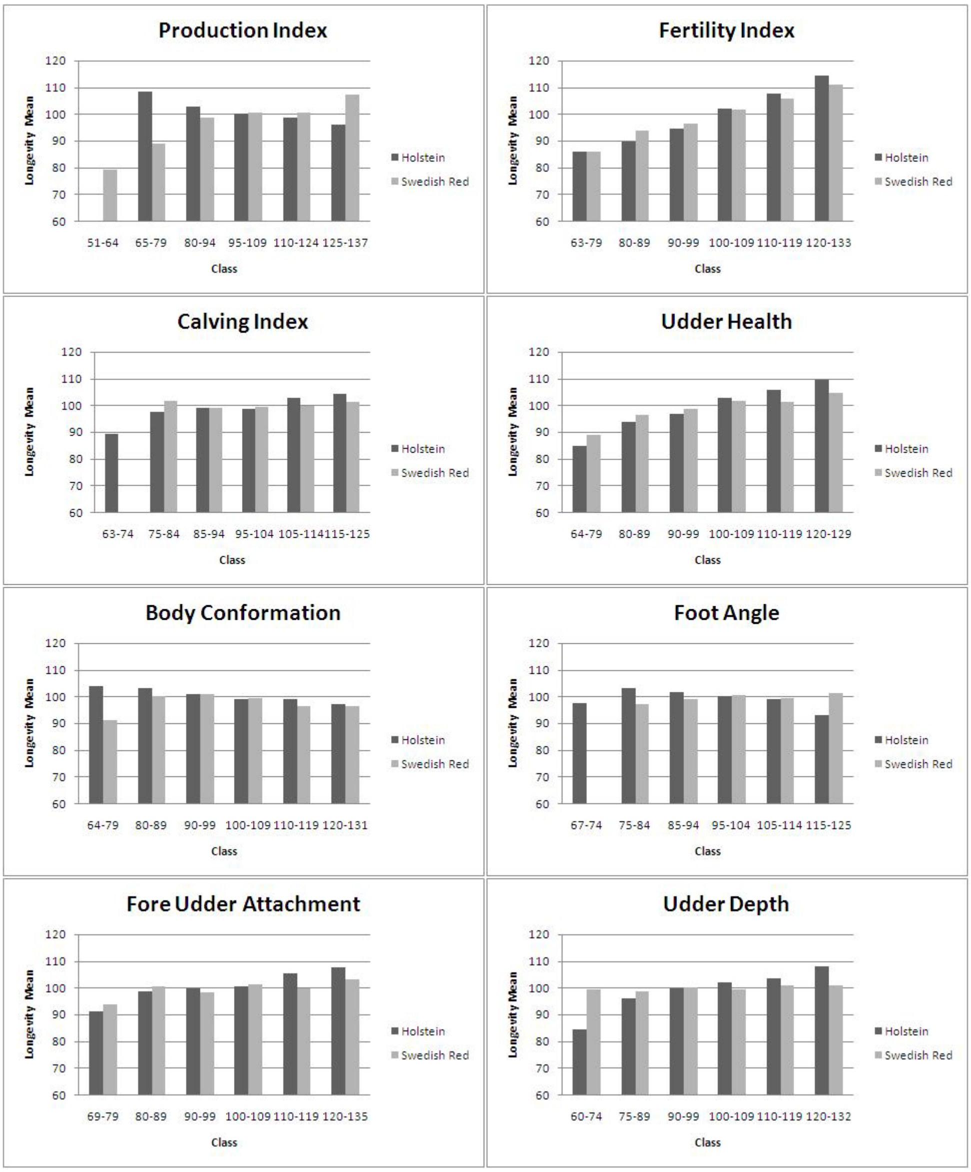

Figure 1. Mean of longevity index in different breeding value classes of other traits.

Figure 2 shows trends on how the correlations between longevity index and the eight other traits described above have changed over 20 years, from 1985 to 2004 based on birth year of sire. The correlation with production index has been quite constant for the breeds with a dip between 1999 and 2002. Udder health has been irregularly correlated with longevity during the years, while the fertility index for HOL has increased markedly from about 0 to 0.6 during the years and for SR it has been rather constant at 0.4-0.5. Calving index has been irregularly correlated to longevity during the years, but higher during the later years for HOL. Body conformation and foot angle were also variably correlated to longevity, but for HOL body conformation has been increasing until 1991-1992 and then been decreasing again. Correlations to FUA and udder depth have been very constant during the years, except for the years 1985-1986 for FUA in SR.

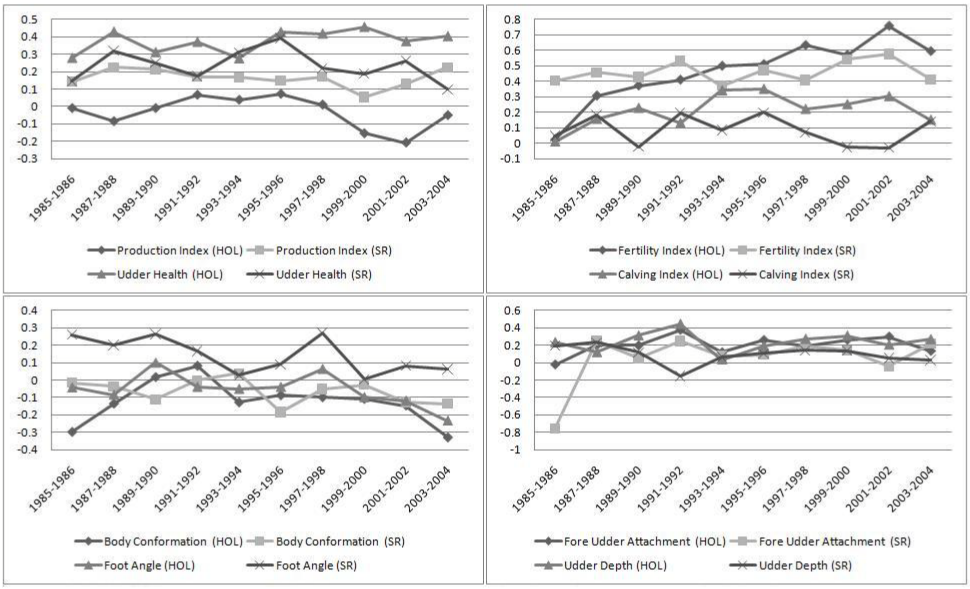

Figure 2. Correlations between the Swedish official longevity index (SweL1) and other traits over time.

A regression analysis for SweL1from 1985 to 2004 can be seen in Figure 3. The index has been increasing significantly ($P< 0.001$) during the years by about 0.29 index units for HOL and about 0.49 index units for SR , but the amount of variation explained was low ($R^2 = 0.0257$ and 0.0694 for HOL and SR respectively).

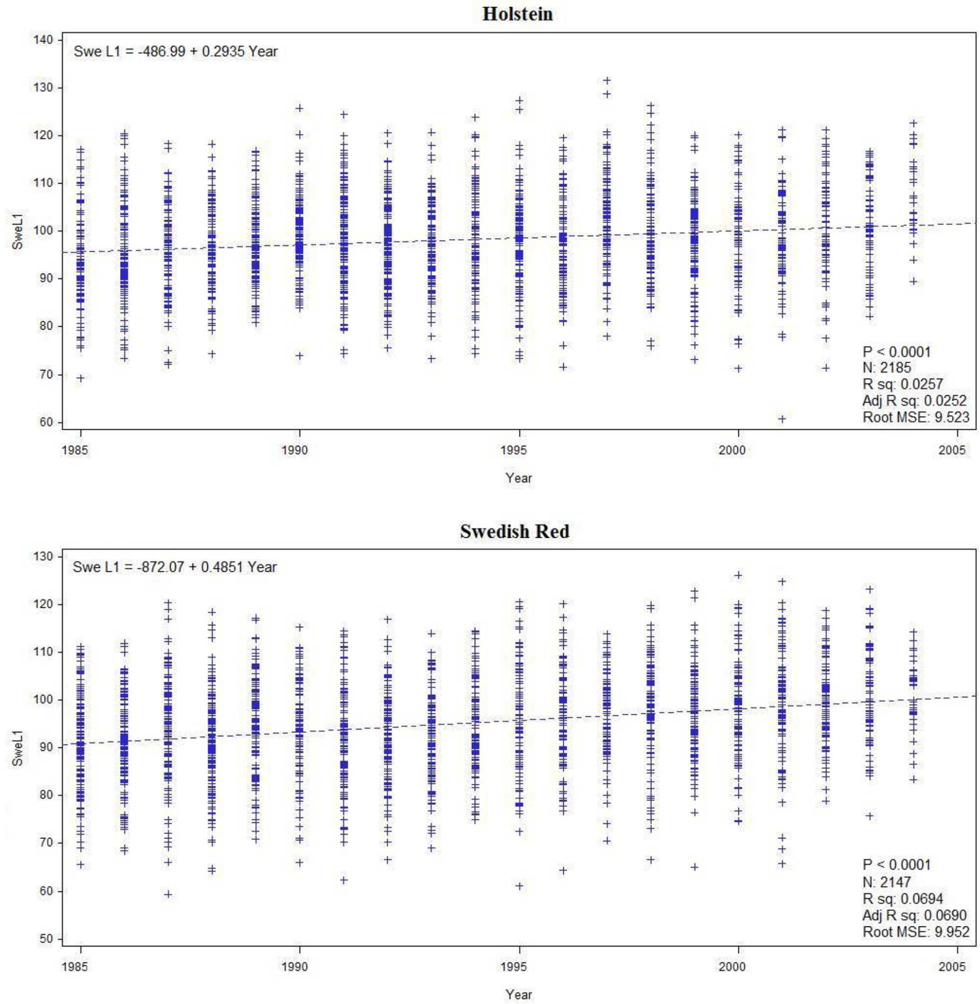

Figure 3. Regression analysis for the Swedish official longevity index over 20 years.

4.2 Cow records

4.2.1 Production and conformation traits

The difference in production and conformation traits based from results only in first lactation, between cows culled after one lactation (Group 1) and cows with at least four lactations (Group 4^+) can be seen in Table 7. The traits were all significanty different between the groups, except for rump angle in SR. As can be seen, cows with a higher milk, fat and protein yield in their first lactation live longer. So were also cows with a higher NTM value, cows with more days in milk and cows with a lower AFC. HOL cows in Group 1 gets were having their first calf 23 days later than Group 4^+, and for SR the difference was 21.4 days.

HOL cows with a smaller body depth score, a lower dairyness score or a higher rear teat placement score were more favourable, while the opposite were found for SR. To continue, all cows were more likely to live longer if they have high scores on top line, rump angle, front teat placement, milking speed, temperament and on all leg and udder traits, except for legs side view. Chest width, rump height, rump width, teat length and teat thickness should instead have low scores to be favourable.

4.2.2 Culling reasons

For cows culled after one lactation, fertility was the most common culling reason followed by udder health, whereas the order was reversed for cows with at least four calvings. In HOL, leg/hoof disorders and other diseases were also common culling reasons for older cows, while low production and teat/udder disorders were more common reasons for young cows. In SR, low production was a common reason for young cows and also for older cows together with milkability and different diseases and disorders.

Table 7. Difference between the groups and breeds of cows for production and conformation traits measured in first lactation

	HOL			SR		
Variable [a]	N	Mean[b]	Difference [c]	N	Mean[b]	Difference [c]
Milk (kg)	47 808[d]	8274	510***	47 652[e]	7570	604***
Fat (kg)	47 808	327.8	14.8***	47 652	326.6	20.1***
Protein (kg)	47 808	274.0	14.5***	47 652	262.6	17.9***
DIM	47 808	283.1	41.8***	47 652	282.0	44.9***
NTM	65 002[f]	-2.30	3.35***	61 062[g]	-7.56	3.38***
AFC (months)	65 002	28.90	-0.75*** (-23.0 days)	61 062	28.70	-0.70*** (-21.4 days)
Rump height (cm)	129 322[h]	144.4	-0.21***	128 291[i]	137.7	-0.12***
Body depth	129 322	6.13	-0.02***	128 291	5.84	0.04***
Chest width	129 322	5.45	-0.01**	128 291	5.31	-0.03***
Dairyness	129 322	5.50	-0.01*	128 291	5.03	0.09***
Top line	129 322	6.60	0.03***	128 291	6.51	0.07***
Rump width	129 322	5.66	-0.06***	128 291	5.00	-0.02***
Rump angle	129 322	4.81	0.02*	128 291	5.27	0.01
Legs side	129 322	4.99	-0.07***	128 291	5.29	-0.11***
Legs rear view	129 322	6.25	0.04***	128 291	6.13	0.06***
Hock quality	129 322	5.87	0.19***	128 291	6.04	0.17***
Bone quality	129 322	6.38	0.12***	128 291	6.20	0.16***
Foot angle	129 322	5.04	0.05***	128 291	5.01	0.04***
FUA	129 322	5.57	0.17***	128 291	5.68	0.18***
Udder width	129 322	5.55	0.08***	128 291	4.93	0.23***
Udder height	129 322	5.64	0.13***	128 291	5.13	0.24***
Suspensory ligament	129 322	5.73	0.17***	128 291	5.53	0.28***
Udder depth	129 322	5.81	0.20***	128 291	5.22	0.28***
Udder balance	129 322	5.77	0.08***	128 291	5.33	0.16***
Teat length	129 322	5.07	-0.03***	128 291	4.73	-0.09***
Teat thickness	129 322	3.96	-0.09***	128 291	3.95	-0.07***
Teat placement front	129 322	5.31	0.12***	128 291	5.11	0.22***
Teat placement rear	129 322	4.91	0.07***	128 291	4.51	-0.25***
Milking speed	129 322	5.35	0.12***	128 291	5.20	0.23***
Temperament	129 322	5.65	0.17***	128 291	5.67	0.22***

*: P < 0.05; **: P < 0.01; ***: P < 0.001

[a] : The variables were all observed in lactation 1 for the two groups.

[b] : Mean of the two groups together.

[c] : Estimation of how many units Group 4^+ differs from Group 1, which is set to 0. (A positive value is positive related to lifespan and vice versa).

[d] : 44.5 % in Group 1.
[e] : 43.7 % in Group 1.
[f] : 53.1 % in Group 1.
[g] : 51.4 % in Group 1.
[h] : 38.6 % in Group 1.
[i] : 37.3 % in Group 1.

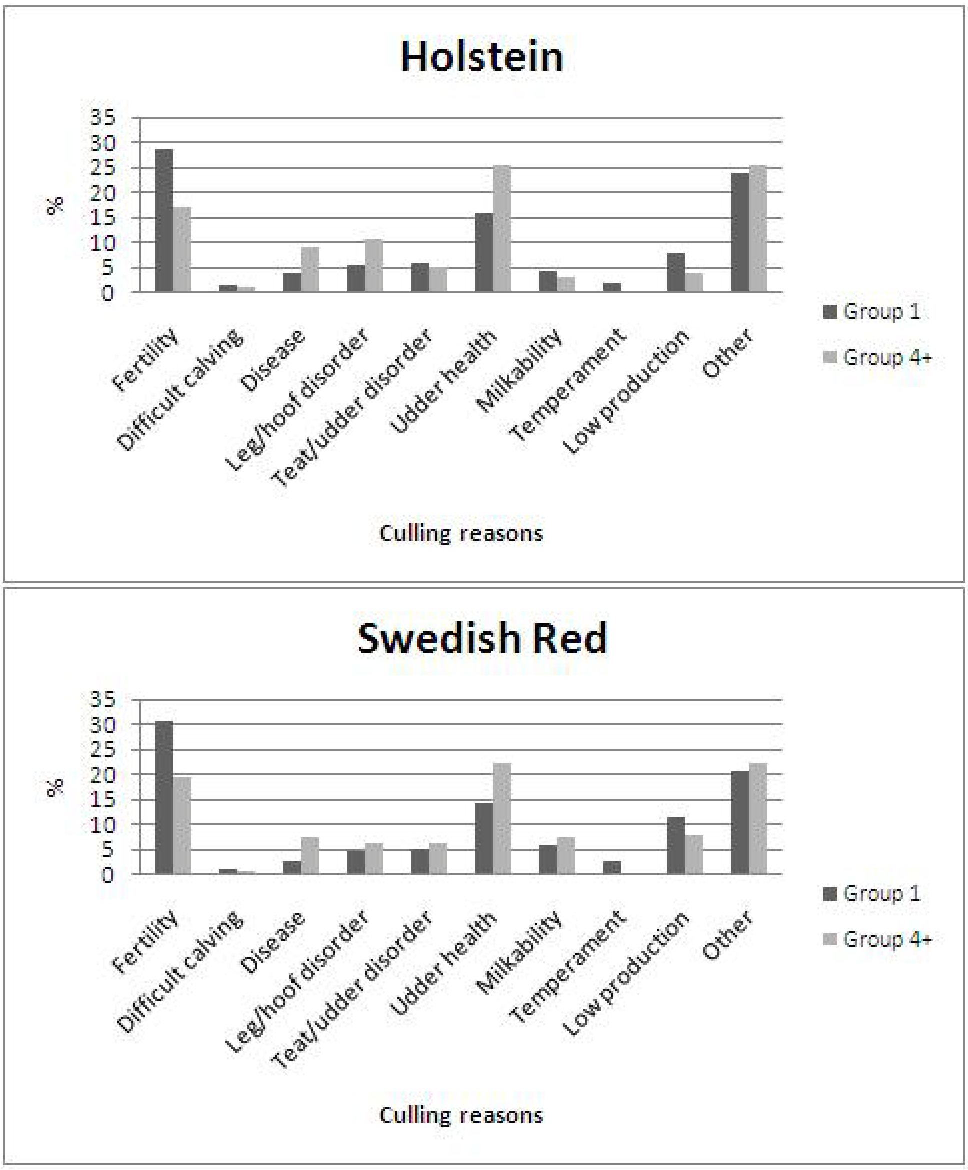

Figure 4. Description of culling reasons for the two groups of cows (Group 1: cows calving only once; Group 4^{+}: Groups calving at least 4 times) for HOL and SR. Fertility: reduced fertility, not pregnant and abortion. Disease: milk fever, acetonemia and other diseases. Udder health: mastitis and high SCC. Other: accident, high age, butchered and other culling reasons. 57 129 HOL cows and 61 062 SR cows.

4.2.3 Herd size and housing

Figure 5 show that dairy herds that were decreasing in number of cows have a higher amount of cows that were culled after one lactation and a lower amount of cows having four lactations or more. It also shows that cows in stable or increasing herds were more likely to live to their fourth lactation or longer.

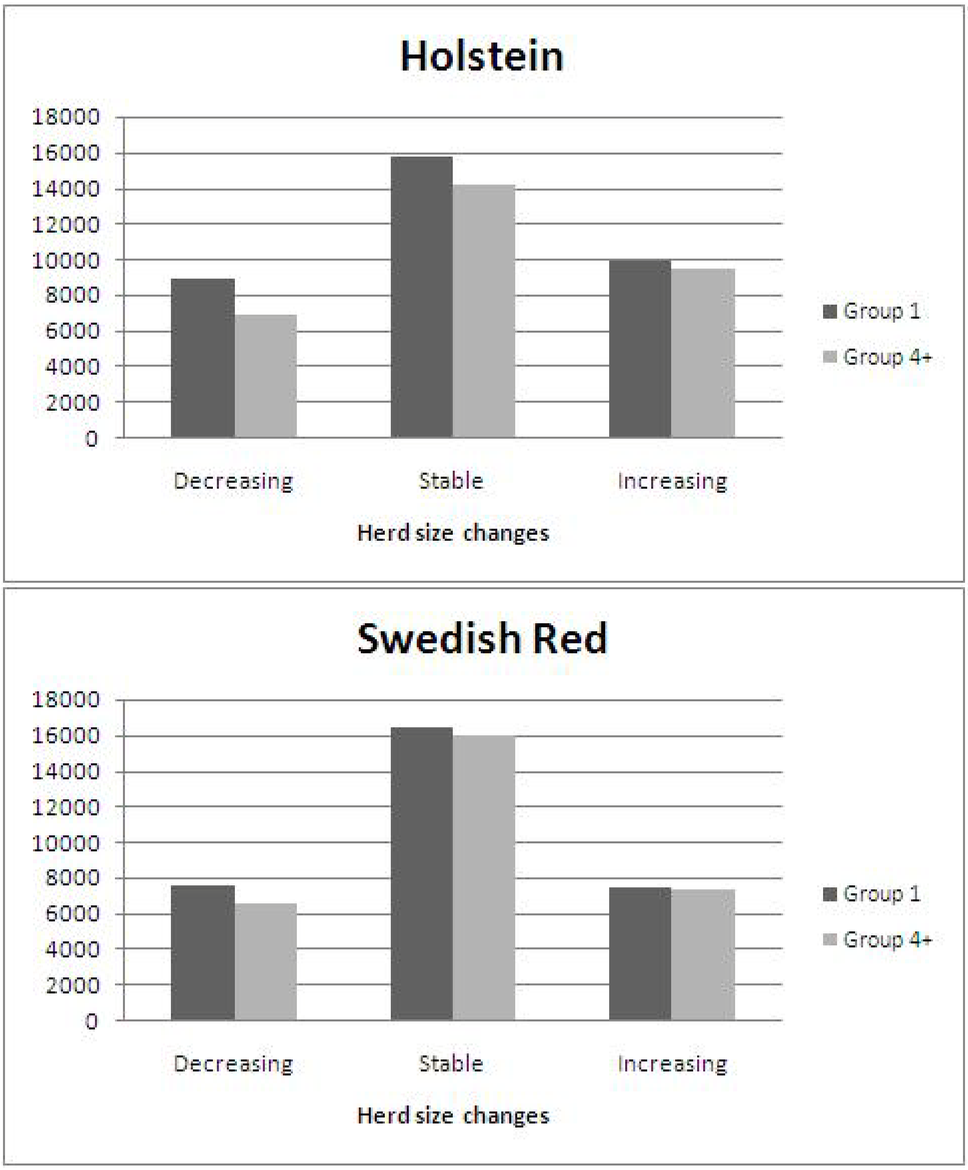

Figure 5. Difference between the two groups and breeds of cows for herd size changes. 65 002 HOL cows and 61 062 SR cows were used in this study.

In Figure 6 it is shown that cows housed in tie stalls were less likely to have four lactations or more, and were instead more likely to be culled after only one lactation. The opposite is found for loose housing. It is also shown in Figure 6 that cows on organic (KRAV) farms have longer lives than cows on conventional farms.

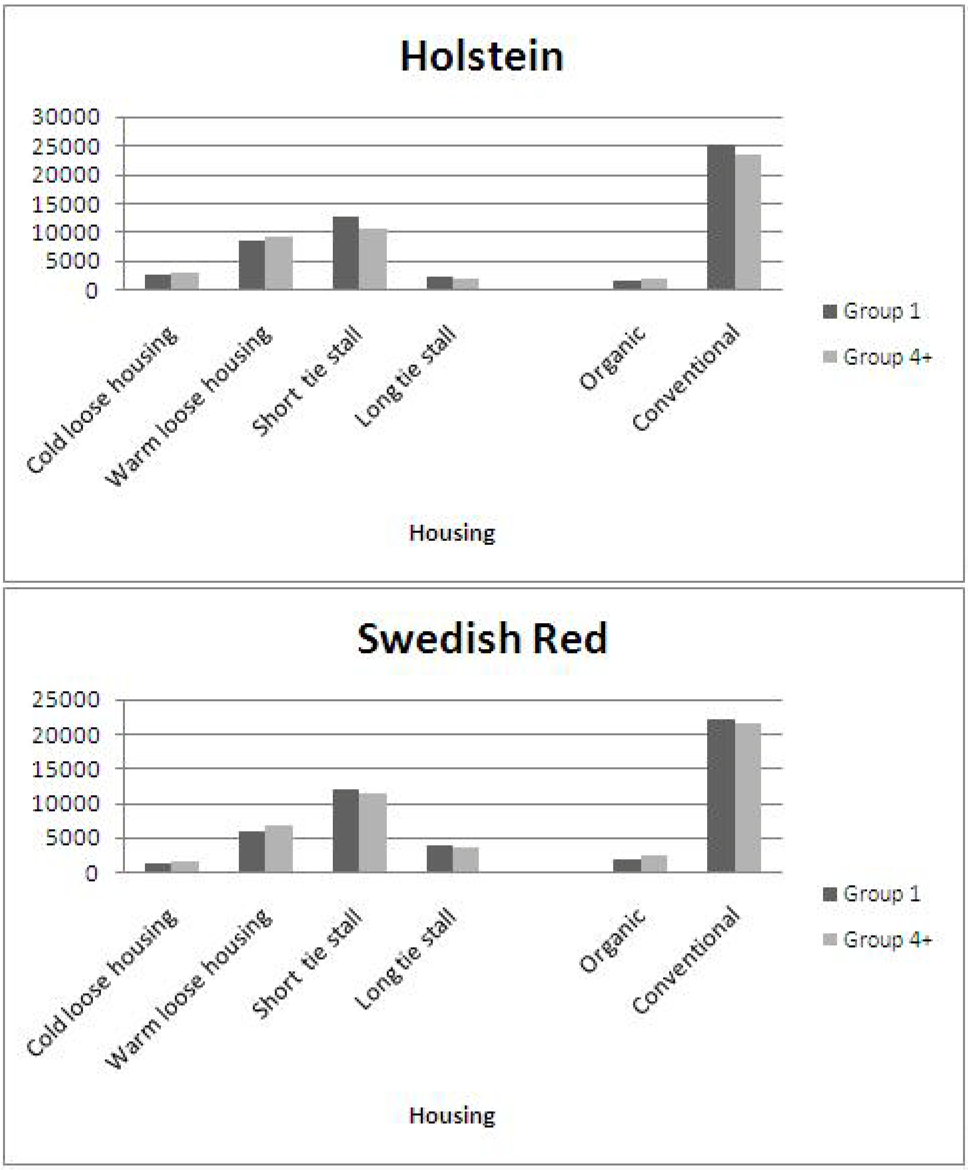

Figure 6. Difference between the two groups and breeds of cows for different housing and organic or conventional systems. 51 607 HOL cows and 47 437 SR cows were used in the housing study and 52 407 HOL cows and 48 355 SR cows were used in the conventional vs organic study.

4.2.4 Month of birth and first calving

Heifers born from November to April were more likely to be culled after one lactation, while heifers born from July to October were more likely to live four lactations or more than be culled after one (Figure 7).

In Figure 8 it is shown that cows having their first calving from November to June were more likely to be culled after one lactation, while cows having their first calf from July to October were more likely to live four lactations or more than be culled after one. This is the same pattern as the month born of the cow itself.

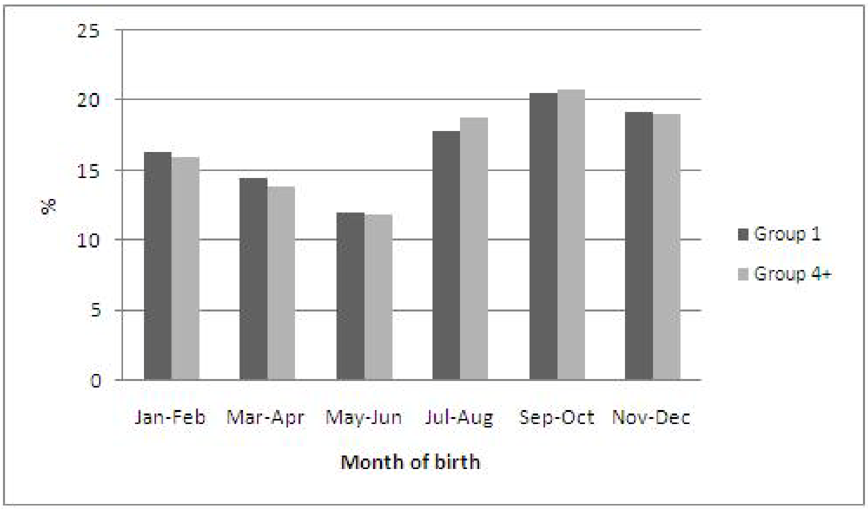

Figure 7. Difference between the two groups of cows for different birth months. The breeds were counted together. 65 002 HOL cows and 61 062 SR cows were used in this study.

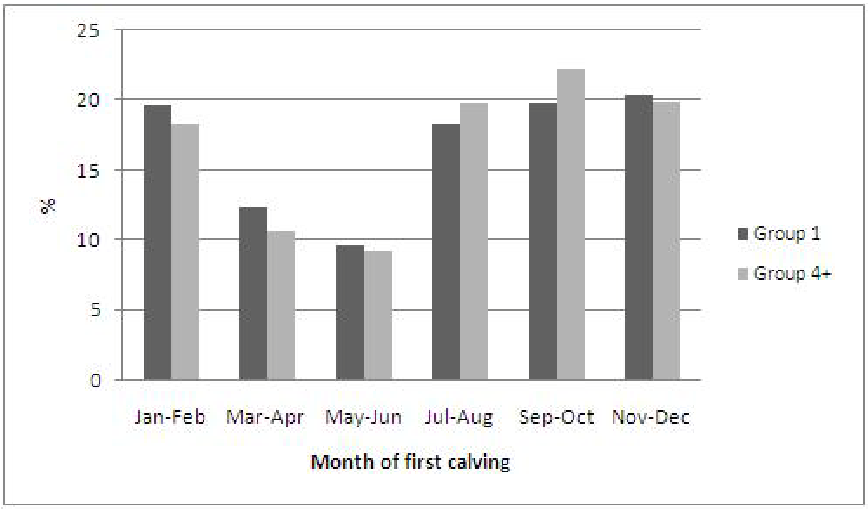

Figure 8. Difference between the two groups of cows for different month of first calving. The breeds were counted together. 65 002 HOL cows and 61 062 SR cows were used in this study.

5 Discussion

5.1 Sire evaluations

5.1.1 Correlations among longevity traits

The different genetic evaluations used for longevity were highly correlated to each other. The three Swedish indexes were similarly defined (NAV, 2010a) and were also very strongly correlated (>0.89 for SR and >0.95 for HOL). The correlations between SweL1 and the five NAV longevity indexes varied between 0.73-0.83 with higher correlations for HOL. The lower correlations than among the Swedish ones might be because the NAV longevity indexes were mean values from three countries (NAV, 2010b) with different definitions of longevity in each country (Interbull, 2010). A little bit higher correlations for HOL than for SR might depend on a different number of bulls in the analysis. This would also explain the low correlations between Swedish longevity index 3 and NAV longevity index 1 (0.69) and between the Swedish official longevity index and Survivle EBV (0.68) for SR.

5.1.2 Correlations with other traits

For HOL, the traits most negatively correlated with longevity (SweL1) were dairyness (cows should be more coarse than angular to live longer), protein and fat index (Table 6). This can be compared with the study by Wall *et al*. (2007) of nationally recorded linear type information in the United Kingdom who found a negative correlation with angularity. For SR there were no strong negative correlations for any trait. Fat and protein index is included in production index and was also somewhat negatively correlated for HOL in this study. Dematawewa & Berger (1998), Essl, (1998), Haworth *et al*. (2008) and Novaković *et al*. (2009) also found a negative correlation with milk production. In contrast, SR had slightly positive longevity correlations to protein and fat index that all were significant (Appendix 1) and in accord with most earlier studies. One important thing to point out is that there are negative weights for body conformation traits in the American Lifetime Profit Index (LPI) and Net Merit $ (NM$) (USDA, 2010-12-22). Body conformation is neither included in NTM, which could have importance in the comparison to earlier studies. The production index relation is also described in Figure 1. A contrast between the breeds could have its reason in that HOL cows have a higher milk production and are more of dairy type cows than SR cows are in general (Swedish Dairy Association, 2010c).

The traits most positively correlated with longevity for SR were fertility index and treatments, AI interval, number of AI, mastitis resistance, udder health, leg- and hoof treatments, other diseases, heat sign, and non-return rate (Table 7). Except for non-return rate, the same traits had high correlations to longevity also for HOL in addition to metabolic treatments, calving difficulty and calving index, stillbirths, birth index, FUA, udder depth and udder score (Table 6). These findings compare well with earlier studies, except for the study by Dematawewa & Berger (1998), where the number of AI per series were found to be negative, and the study by Vacek *et al*. (2006), where a deep udder was found to be more favorable than a shallow one. Heat sign and non-return rate were not included in the literature review, but are also fertility traits.

The high positive correlations with longevity and fertility index, udder health, and for HOL also with calving index, FUA and udder depth are illustrated in Figure 1. HOL is perhaps more selected for calving traits and udder conformation traits than SR, which can explain the differences. Body conformation for SR and foot angle for HOL have their intermediate optima with respect to longevity. This indicates that cows at the both extremes are more likely to being culled earlier. Further, HOL cows with a lower body conformation are favorable, which might indicate that cows that are more of narrow milk-types have shorter lives.

The correlation between longevity and production index has been rather constant during the past 20 years, but always positive for SR. It has been more around zero for HOL in the past and more negative the latest years (- 0.21 the years 2001-2002). This could also have its reason in that more focus has been on other traits than production for HOL the latest years and that the highest milk producers of SR still are the most favorable cows. The correlation between longevity and udder health has been varied in strength during the years, but always been positive. This indicates that udder health is one of the most important traits for a long life. Correlation with fertility index has also been positive during the years for the breeds, but for HOL it has increased a lot, from about 0 to 0.6. This could also have to do with that HOL have had the biggest focus on milk production, which has led to a deteriorated fertility, while SR seems to have had better fertility than HOL on average. Calving index have had a little increase in the correlation to longevity for HOL, but foot angle is in general irregular and do not seem to have had an important impact. The correlation between longevity and body conformation was increasing for HOL until 1991-1992 but then decreased again, probably because cows with a low score were found to be more sustainable, as discussed before. FUA and udder depth seems to always have been important traits for HOL, but of less impact for SR for reasons discussed before. The strong negative correlation 1985-1986 is difficult to explain but may have its reason in that a strong udder were negative correlated to a high milk yield or that the criteria for udder attachment have been changed since then.

The Swedish official longevity index has been increasing during the 20 years in this study for the two breeds. This is probably because more and more weight has been on longevity during the latest years.

5.2 Cow records

For the two breeds, all production traits were significantly different between cows that were culled after one lactation and cows that lived four lactations or more. A long-lived cow should have a high milk, fat, and protein production yield in their first lactation and also a high NTM. These findings on production traits in the first lactation are supported by the literature (Miller *et al*., 1967; Essl, 1998; Roxström & Strandberg, 2002). The reason for this could be that cows with a low production in their first lactation are not profitable and have to make room for better producing cows. These results for HOL are the opposite as were found in the sire evaluation part of this study. This might depend on either that longevity is defined differently in the different studies or the fact that the sire evaluation part is based on genetic correlations and the cow records are based on phenotypic correlations. The conclusions are however that cows with a higher production in first lactation and a lower total production compared to contemporary cows are living longer. This could most possible be due to that very high lactating cows are at more risk of getting disorders and do not become old because of that. SR cows are, as mentioned before, not as distinct milk-type as HOL are, and therefore high producers might be more favourable. Group 1 also had less DIM than group 4^{+}, which most possible is because they are culled before the normal length of the first lactation is over. The NTM were also lower for cows culled early in life, which could have its reason in that they are not as good producers as the cows in Group 4+. The differences were 3.35 units for HOL and 3.38 for SR.

As was also found in the literature (Gill & Allaire, 1975; Vollema & Groen, 1998; Dürr *et al*., 1999; Strandberg & Roxström, 2000; Vollema *et al*., 2000; Schneider *et al*., 2003; Sewalem *et al*., 2005; Schneider *et al.*, 2007 and Wathes *et al.*, 2008), cows with a low AFC are more favorable and live longer than heifers that give birth at an older age. The reason why Haworth *et al*. (2008) found the opposite could be because it was only one herd in the study that could have other conditions than other herds and the heifers calving at an older age had a shorter lactating life anyhow. In the current study AFC was almost one month earlier for Group 4+. The reason why young-calving heifers have a longer life could be due to that early developing heifers might be healthier and have a good milk production and fertility also later in life.

The body conformation traits did not differ much between the groups (between -0.06 to 0.09 units) and therefore it was more likely that there should be intermediate optima as was also found by Hamoen *et al*. (2009), but they were all significant except for rump angle in SR. To summarize the body conformation trait results, a HOL cow should be shorter, shallower and narrower than the average HOL and have a strong top line, low pins and have a coarser dairyness. This is the same result as were found by Boldman *et al*. (1992), Harris & Freeman (1992), Hansen *et al.* (1999), Vollema *et al.* (2000), Buenger *et al*. (2001) and Wall *et al*. (2007). These findings also agree with the sire evaluation part except that some correlations were not significant. SR cows differ from HOL in two traits; they should be deeper and more angular than the breed average. The cow records differ from the sire evaluations in the way that a first lactation SR cow should have a deep body and a strong top line, but the opposite were found in the sire evaluations. The only literature that supports a deeper body is Vacek *et al*. (2006) who found an intermediate optimum in their study. They also found a positive correlation with angularity, as did Mrode *et al*. (2000). The reasons for these results might be, as mentioned before, that HOL are big enough to be good producers and even bigger cows more easily get disorders and diseases. SR are on average not as tall and bigger cows are probably more favourable because of a better production.

To continue with the leg conformation traits, a long-lived cow of any of the two breeds should in her first lactation have straight and parallel legs with a steep foot angle and the bone and hock quality should be more fine than coarse. As was also found in the literature, the legs are more favorable if they are intermediate to posty with a intermediate to steep foot angle (Rogers *et al*., 1991; Short & Lawlor, 1992;

Mrode *et al*., 2000; Vollema *et al*., 2000; Buenger *et al*., 2001; Schneider *et al*., 2003; Berry *et al*., 2005; Pérez-Cabal *et al*., 2006 and Vacek *et al*., 2006).

All udder traits in this study were found to be positively related to longevity. One exception is the slightly negative correlation between longevity and udder depth found by Vacec *et al*. (2006). This could be due to that deeper udders in this study perhaps had positive correlations with positive traits as milk production. The teat traits should on the contrary be short and thin with a close placement in front and rear for HOL. SR should have a wide teat placement in rear but a close front placement. The literature almost agreed completely that teats not should be too long, and the teat placement should have positive values, contrary to the findings on SR in this study. This could most possible be due to that no teat placement data on SR cows were included in the literature part. The exception on teat length were on Brown Swiss cows by Vukašinović *et al*. (1995), which could have its reason in that this breed differs from other breeds in this trait.

Milking speed and temperament do also have count for the longevity, and should as in the literature (Madgwick & Goddard, 1989; Visscher & Goddard, 1995 and Cue *et al.*, 1996) and the sire part be positive. The differences between the groups are bigger for SR, which indicates that these cows might be slower milkers and have a little worse temperament than HOL cows, and therefore these traits might be more important.

Fertility problems were the most common culling reasons for first lactation cows, which indicates that a young cow that does not become pregnant, is more likely to be culled than an older one. For older cows, udder health traits are instead the most common culling reasons. This could be due to that if an older cow has shown other good traits than fertility, she might be allowed to live even if she gets a longer calving interval. It could also be because older cows are more likely to get high SCC and mastitis than younger ones, or that young cows with udder health problems get another chance easier than older cows or a combination of these reasons. In the literature, fertility and udder health have strong positive correlations with longevity (Dematawewa & Berger, 1998; Pryce & Brotherstone, 1999; Haile-Mariam *et al*., 2003; Sewalem *et al*., 2008 and De Vries *et al*., 2010), and so are also udder health traits (Pryce & Brotherstone, 1999; Neerhof *et al*., 2000; Mrode *et al*., 2000; Vollema *et al*., 2000; Roxström & Strandberg, 2002; Haile-Mariam *et al*., 2003 and Samoré *et al*., 2003). The reason why leg and hoof disorders are more common culling reasons in older HOL cows could be because that HOL, and especially older cows, more easily can become lame due to a higher body weight and an older age, probably together with bad leg traits. Older cows might also be culled because of different diseases and other disorders owing to older age. Low production is a common culling reason for young cows of both breeds and could have its reasons the same way as discussed in the first part of this chapter, where first lactation cows with high production are living longer than young cows with lower production. Teat and udder disorders are more common reasons in young HOL and in old SR cows. The reasons for this could be that a young cow with bad teats or udder not is worth to keep and for old SR cows, a pendulous udder might be the prime reason for culling. The relations between culling and different disorders agree with the findings by Beaudeau *et al*. (1995).

Milkability is a more common culling reason in old SR cows, which could have its reason in that udder conformation retrogrades more in older SR cows than in HOL cows or that older SR cows might be less selected for udder traits than HOL as also were found in the sire evaluation part and illustrated in Figure 1. In the literature it was found that milking speed (which is a part of milkability together with udder conformation and the response of the heifer to start being milked) had a weak to strong positive relation to longevity (Madgwick & Goddard, 1989; Visscher & Goddard, 1995; Cue *et al.,* 1996 & Berry *et al*., 2005), which agrees with these results.

The results on herd size changes were not so certain because the real number of cows in the herds were not available, and only an underestimated value from the number of first-calving cows in the herds were used. But still, the results show the same pattern as the studies by Samoré *et al*. (2003) & Sewalem *et al*. (2005) but are partly different from the findings by Dürr *et al*. (1999). In the latter study, cows in increasing herds were at higher risk of being culled. The reason why a larger amount of young culled cows are from decreasing herds than from stable or increasing herds most likely is because these herds have a stronger cow selection, and a lower amount of cows might therefore live four lactations or more in decreasing herds.

One theory why cows have a higher longevity in loose housing could be that it is a better system than tie stalls for animal welfare and management, and therefore the cows are healthier in this system. But it could also be that farms that have changed from a tie stall system to a loose housing system during this period also have been expanding their herd size, and therefore might kept more cows that should have been culled otherwise.

Cows on organic farms might live longer than on conventional farms because of a more natural management that might make them healthier. It is however more likely that it mostly depends on the findings by Ahlman (2010), that lower production and better fertility make organic cows live longer. Fall *et al*. (2008) did not find any difference between conventional and organic farms and does neither agree with the results in this study. Buenger *et al*. (2001) did not find any differences between tie stalls and loose housing, but different management systems (bedding or not) had an impact.

The most dairy heifer calves are found to be born during the second half of the year in Sweden (58 % versus 42 %, Figure 7), which could be due to that farmers want to have dry cows on pasture during the summer that calve on time for the indoor period. The month of birth and month of first calving were also found to be more favourable for longevity if it occurred during summer or autumn, which were different from the findings by Tekerli & Koçak (2009), where there was a trend that heifers calving during winter or spring had a higher longevity. The reason for the results in this study could be that dairy calves are better managed during that part of the year, which could make them strong and healthy, get pregnant early and have their own first calf during the same season.

5.3 Conclusions

The aim of this study was to find correlations between different longevity evaluations and between different estimates on longevity and other traits in the NTM breeding value. The aim was also to compare different traits for cows of two different longevity groups.

The three Swedish longevity indexes were very highly correlated (>0.89) to each other and the correlations between the Swedish official longevity index and the five NAV longevity indexes varied between 0.73-0.83. All longevity correlations were higher for HOL.

In the sire evaluation part, the traits most negatively correlated with longevity for HOL were dairyness, protein and fat index (-0.2 to -0.4). In SR, however, milk, protein, and fat index had slightly positive correlations with longevity (0.13 to 0.18). The traits most strongly positively correlated with longevity for SR (> 0.2) were fertility index and treatments, AI interval, number of AI, mastitis resistance, udder health, leg and hoof treatments, other diseases, heat sign, and non-return. The same traits (except from non-return) had high positive correlations to longevity for HOL (> 0.2) together with metabolic treatments, calving difficulty and - index, stillbirths, birth index, FUA, udder depth and udder score. For some traits that were further analyzed it was found that body conformation for SR and foot angle for HOL had an intermediate optima. During the past 20 years, the correlation between longevity and production index have always been positive for SR. For HOL, this correlation has been around 0 until about 1998 and becoming more and more negative during the later years. The correlation with udder health and fertility index had been positive during the years for the two breeds together with calving index for HOL. FUA and udder depth had always been important traits for HOL, but not for SR. The Swedish official longevity index has been increasing during the 20 years. This might probably be because more and more focus has been on longevity lately.

In the cow record part, all production traits were significant different between the longevity groups, where it was found to be more favourable to have a high milk- fat- and protein production, a high NTM and DIM in the first lactation and a lower AFC, no matter of breed. A HOL cow should be shorter, shallower and narrower and have a strong top line, low pins and a coarse dairyness. SR should instead be deeper and more angular. A cow of any of the two breeds should have posty and parallel legs with a steep foot angle and the bone and hock quality should be more fine than coarse in her first lactation. All udder traits were found to be positively related to longevity together with milking speed and temperament, and the teats should be short and thin. Fertility problems were the most common culling reasons for first lactation cows and udder health traits were the most common culling reason for older cows. Herds decreasing in size had a higher amount of cows that were culled after one lactation and stable or increasing herds had a greater amount of older cows. Cows were also found to live longer in loose housing barns and in organic systems than in tie stall barns and in conventional systems. Cows born or having their first calf from July to October were more likely to live longer than cows born or having their first calf from November to June.

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Appendix 1

Results from the sire evaluation part. Contains number of bulls, mean values, standard deviations, minimum- and maximum values and correlations with different longevity indexes. The longevity indexes are the Swedish official longevity index (Swe L1), NAV longevity index 1 (NAV L1), The old NAV longevity index (Old NAV) and Survival EBV (Surv EBV).

HOL

			Std	Min	Correlations			
Variable	N	Mean	Dev	Max	Swe L1	NAV L1	Old NAV	Surv EBV
Swe L1	346	100.6	10.2	61-123				
Swe L2	346	101.1	11.2	58-128				
Swe L3	346	102.7	10.0	66-127				
Old NAV	323	102.0	9.7	68-128				
Surv EBV	346	96.7	9.9	66-122				
NAV L1	346	98.1	9.0	73-123				
NAV L2	346	96.8	9.7	71-123				
NAV L3	346	96.3	9.9	70-123				
NAV L4	346	96.1	10.1	70-123				
NAV L5	346	96.0	10.1	70-122				
Milk	1281	101.7	12.3	60-138	-0.181***	0.018	-0.250***	0.016
Protein	1281	99.9	13.3	54-138	-0.217***	0.003	-0.278***	-0.042
Fat	1281	98.7	11.2	59-137	-0.213***	-0.086	-0.241***	-0.101
Production Index	1281	98.8	12.4	51-137	**-0.173****	0.051	-0.204***	0.032
Non Return, cows	854	98.1	9.8	60-124	0.115*	0.143**	0.109*	0.151**
Days between calving and first AI, cows	854	106.6	10.3	67-133	0.588***	0.281***	0.555***	0.349***

Days between first and last AI, cows	854	104.9	11.0	55-133	0.655***	0.356***	0.615***	0.465***
# AI, cows	854	101.8	10.2	61-132	0.427***	0.241***	0.405***	0.297***
Heat Sign	675	102.4	10.7	57-136	0.271***	0.051	0.265***	0.138**
Fertility Index	854	104.4	9.9	63-133	**0.666*** **	0.367***	0.632***	0.464***
Stillbirths, heifers MGS	591	67.5	9.2	45-99	0.123*	0.149**	0.236***	0.072
Calving difficulty, heifers MGS	591	104.5	8.9	68-131	0.248***	0.202***	0.272***	0.185***
Stillbirths, cows MGS	591	103.0	8.9	64-127	0.289***	0.238***	0.290***	0.245***
Calving difficulty, cows MGS	591	103.6	8.7	64-129	0.160**	0.105*	0.160**	0.109*
Calving Index, MGS	591	103.8	9.3	68-125	0.294***	0.250***	0.314***	0.252***
Stillbirths, heifers maternal	591	103.2	10.4	61-125	0.253***	0.214***	0.296***	0.221***
Calving difficulty, heifers maternal	591	102.9	9.2	62-124	0.156**	0.120*	0.182***	0.083
Stillbirths, cows maternal	591	102.4	9.7	57-127	0.224***	0.172**	0.217***	0.162**
Calving difficulty, cows maternal	591	102.7	8.9	54-126	0.086	0.038	0.070	0.010
Calving Index	591	103.0	9.9	63-125	0.246***	0.198***	0.271***	0.193***
Stillbirths, heifers directly	591	102.4	8.5	70-125	0.182***	0.186***	0.159**	0.180***
Calving difficulty, heifers directly	961	103.4	9.0	69-126	0.232***	0.201***	0.241***	0.227***
Stillbirths, cows directly	961	101.8	7.8	72-123	0.242***	0.229***	0.262***	0.271
Calving difficulty, cows directly	961	101.8	8.0	68-124	0.149**	0.121*	0.177**	0.170**
Birth Index	961	102.4	8.4	72-126	**0.210*** **	0.204***	0.204***	0.217***
Mastitis 1st lactation part 1	777	103.5	9.2	69-126	0.467***	0.496***	0.527***	0.517***
Mastitis 1st lactation part 2	777	103.3	9.1	65-127	0.408***	0.392***	0.484***	0.462***
Udder health	777	103.5	9.2	64-129	**0.445*** **	0.439***	0.536***	0.516***
Fertility treatments 1st lactation -15-40 days	570	103.8	8.4	68-129	0.385***	0.383***	0.411***	0.368***
Fertility treatments 1st lactation 41-305 days	570	102.7	10.1	70-135	0.474***	0.291***	0.466***	0.378***
Metabolic treatments 1st lactation -15-305 days	570	102.9	9.7	66-126	0.362***	0.390***	0.401***	0.409***

Leg and hoof treatments 1st lactation -15-305 days	570	101.3	9.9	63-126	0.398***	0.438***	0.411***	0.427***
Other diseases	570	102.4	9.0	71-126	0.488***	0.460***	0.510***	0.489***
Growth	947	100.1	10.9	60-146	-0.022	-0.033	-0.120*	-0.096
Classifying	947	99.4	11.8	59-137	0.014	-0.038	-0.085	-0.066
Fat class	947	99.4	10.9	66-136	-0.064	-0.053	0.037	-0.039
Carcass growth	947	100.9	10.7	44-171	-0.062	-0.015	-0.122*	-0.100
Rump height	567	100.4	9.3	67-128	-0.088	-0.050	-0.008	-0.084
Body depth	567	98.7	10.9	54-124	-0.143**	-0.140**	-0.132*	-0.144**
Chest width	567	98.0	9.9	67-124	0.093	0.053	0.112*	-0.009
Dairyness	567	101.1	9.2	75-126	-0.302***	-0.178***	-0.266***	-0.145**
Top line	567	101.2	9.0	71-128	-0.027	0.022	0.001	0.057
Rump width	567	101.1	10.1	60-128	-0.003	-0.025	0.023	-0.057
Rump angle	567	101.1	10.4	63-130	0.033	0.019	0.095	0.057
Body Conformation	567	99.0	10.5	64-131	**-0.175*** **	-0.080	-0.105	-0.057
Legs side	567	99.6	10.6	71-135	-0.092	-0.080	-0.154**	-0.094
Legs rear view	567	98.3	10.4	62-133	-0.113*	-0.086	-0.063	-0.080
Hock quality	567	97.7	11.3	65-129	0.170**	0.179***	0.208***	0.207***
Bone quality	567	97.3	10.8	63-123	0.120*	0.116*	0.137*	0.161**
Foot angle	567	98.0	9.9	67-124	**-0.129***	-0.085	-0.030	-0.099
Legs	567	96.5	10.9	68-133	0.024	0.047	0.110*	0.078
Fore Udder Attach-ment (FUA)	567	101.1	9.2	75-126	**0.213*****	0.228***	0.239***	0.158**
Rear udder width	561	101.2	9.0	71-128	-0.157**	-0.107*	-0.111*	-0.158**
Rear udder height	561	101.6	11.0	65-131	-0.076	0.020	0.005	0.056
Suspensory ligament	567	98.7	10.9	63-134	0.078	0.086	0.138*	0.067
Udder depth	567	101.1	10.1	60-128	**0.282*****	0.323***	0.369***	0.303***
Udder balance	561	100.6	9.1	76-124	0.083	0.126**	0.204***	0.173**
Teat length	567	99.2	9.1	74-125	0.003	-0.012	0.036	-0.002
Teat thickness	567	103.4	10.6	72-139	-0.059	-0.082	-0.064	-0.130*
Teat placement front	561	102.1	9.6	77-128	0.010	0.005	0.046	-0.025
Teat placement rear	567	100.9	9.0	72-127	-0.064	-0.059	-0.043	-0.065
Udder	567	101.1	10.4	63-130	0.272***	0.312***	0.362***	0.281***
Milking speed	567	99.0	10.5	64-131	0.026	0.151**	0.062	0.053
Temperament	567	102.5	9.1	72-131	0.050	0.046	-0.004	-0.010

*: P < 0.05; **: P < 0.01; ***: P < 0.001

SR

Variable	N	Mean	Std Dev	Min Max	Swe L1	NAV L1	Old NAV	Surv EBV
					Correlations			
Swe L1	393	99.7	9.9	66-126				
Swe L2	393	100.6	11.3	55-130				
Swe L3	393	101.4	10.1	63-129				
Old NAV	360	100.5	8.3	69-123				
Surv EBV	393	97.8	8.5	63-120				
NAV L1	393	98.3	8.8	73-121				
NAV L2	393	98.5	8.9	68-120				
NAV L3	393	98.4	8.9	65-119				
NAV L4	393	98.3	8.8	66-119				
NAV L5	393	98.4	8.7	66-119				
Milk	759	99.2	9.7	55-130	0.132**	0.273***	-0.006	0.216***
Protein	759	98.8	11.1	51-134	0.183***	0.309***	0.027	0.223***
Fat	759	98.5	9.6	64-127	0.167***	0.278***	0.055	0.232***
Production Index	759	97.9	10.3	59-129	**0.138****	0.279***	0.022	0.264***
Non Return, cows	586	99.5	9.5	70-127	0.235***	-0.000	0.178***	0.026
Days between calving and first AI, cows	586	100.0	10.3	64-125	0.470***	0.289***	0.423***	0.283***
Days between first and last AI, cows	586	99.6	10.4	67-129	0.550***	0.201***	0.476***	0.239***
# AI, cows	586	99.7	10.3	65-129	0.384***	0.087	0.325***	0.094
Heat Sign	522	100.4	10.7	67-143	0.321***	0.217***	0.244***	0.204***
Fertility Index	586	99.6	10.3	68-127	**0.541*****	0.209***	0.461***	0.237***
Stillbirths, heifers MGS	531	102.3	8.2	67-119	0.134**	0.088	0.125*	0.063
Calving difficulty, heifers MGS	531	102.0	7.6	74-120	0.151**	0.150**	0.140**	0.150**
Stillbirths, cows MGS	531	101.1	8.9	68-126	0.115*	0.120**	0.147**	0.108*
Calving difficulty, cows MGS	531	101.1	8.7	68-121	0.166***	0.175***	0.162**	0.174***

Calving Index, MGS	531	102.1	9.1	64-126	0.144**	0.127*	0.156**	0.111*
Stillbirths, heifers maternal	529	103.1	8.5	73-121	0.020	0.026	0.038	-0.008
Calving difficulty, heifers maternal	529	102.4	7.8	75-123	0.024	0.045	0.039	0.052
Stillbirths, cows maternal	529	102.1	9.5	69-128	0.043	0.106*	0.092	0.093
Calving difficulty, cows maternal	529	101.3	8.9	65-124	0.045	0.079	0.065	0.096
Calving Index	529	102.7	8.9	71-125	**0.035**	0.070	0.069	0.050
Stillbirths, heifers directly	542	100.2	10.2	54-123	0.181***	0.106*	0.142**	0.112*
Calving difficulty, heifers directly	542	100.6	8.1	63-116	0.188***	0.163**	0.151**	0.152**
Stillbirths, cows directly	542	99.5	8.9	70-122	0.146**	0.044	0.123*	0.046
Calving difficulty, cows directly	542	100.5	8.6	64-121	0.197***	0.160**	0.163**	0.134**
Birth Index	542	100.0	10.1	57-123	0.186***	0.103*	0.151**	0.103*
Mastitis 1st lactation part 1	557	101.3	9.2	69-125	0.315***	0.431***	0.350***	0.384***
Mastitis 1st lactation part 2	557	100.8	9.6	72-123	0.213***	0.258***	0.339***	0.371***
Udder health	557	100.9	9.3	70-125	0.231***	0.297***	0.353***	0.387***
Fertility treatments 1st lactation -15-40 days	484	104.5	8.8	65-124	0.175***	0.239***	0.165**	0.218***
Fertility treatments 1st lactation 41-305 days	484	104.1	6.5	80-120	0.298***	0.160**	0.310***	0.204***
Metabolic treatments 1st lactation -15-305 days	484	101.6	9.6	55-120	0.119*	0.252***	0.115*	0.189***
Leg and hoof treatments 1st lactation -15-305 days	484	101.1	9.2	70-126	0.297***	0.362***	0.255***	0.272***
Other diseases	484	102.9	8.5	71-123	0.286***	0.354***	0.290***	0.328***
Growth	628	98.9	10.3	64-130	0.149**	0.064	0.006	-0.011
Classifying	628	100.4	10.7	66-141	0.183***	0.087	0.084	0.019
Fat class	628	99.3	9.0	73-124	-0.049	-0.078	-0.045	-0.035
Carcass growth	628	97.7	10.0	65-129	0.070	0.022	-0.074	-0.037
Rump height	493	99.5	8.8	77-127	-0.095	-0.042	-0.050	-0.037
Body depth	493	96.9	9.8	65-127	-0.144**	-0.136**	-0.210***	-0.229***
Chest width	493	99.2	10.7	64-135	0.000	-0.007	-0.136**	-0.170***
Dairyness	493	99.1	9.3	69-130	-0.089	-0.019	-0.010	0.066

Top line	493	99.9	10.1	55-128	-0.165***	-0.186***	-0.027	-0.055
Rump width	493	101.6	9.6	63-131	-0.062	-0.032	-0.127*	-0.116*
Rump angle	493	101.1	9.8	70-130	-0.015	-0.052	-0.032	-0.032
Body Conformation	493	99.6	9.1	76-124	**-0.130****	-0.067	-0.125*	-0.110*
Legs side	493	102.4	8.9	74-134	-0.062	-0.065	-0.163**	-0.133**
Legs rear view	493	98.7	9.7	69-126	0.054	0.050	0.068	0.037
Hock quality	493	100.6	10.0	74-130	-0.064	-0.051	0.005	0.091
Bone quality	493	100.0	9.7	75-131	-0.020	-0.013	0.069	0.113*
Foot angle	493	98.5	8.2	77-125	**0.054**	0.127*	0.014	0.048
Legs	493	99.1	9.4	73-124	0.029	0.051	0.111*	0.149**
Fore Udder Attachment (FUA)	493	100.1	11.0	69-135	**0.096**	0.206***	0.221***	0.201***
Rear udder width	493	98.9	9.5	77-123	0.041	0.104*	0.109*	0.094
Rear udder height	493	98.6	10.6	69-129	-0.087	0.027	-0.006	0.102*
Suspensory ligament	493	98.9	10.7	62-127	0.059	0.200***	0.124*	0.152**
Udder depth	493	99.6	10.1	73-132	**0.055**	0.178***	0.178***	0.233***
Udder balance	493	99.8	10.2	68-128	-0.031	-0.012	-0.022	-0.035
Teat length	493	100.7	9.7	75-126	-0.153**	-0.097	-0.163**	-0.161**
Teat thickness	493	102.8	10.5	55-131	-0.093	-0.040	-0.164**	-0.104*
Teat placement front	493	98.4	11.5	70-132	-0.004	0.018	0.137**	0.102*
Teat placement rear	493	97.9	11.4	67-137	-0.062	0.026	0.073	0.089
Udder	493	99.8	9.9	68-129	0.059	0.234***	0.203***	0.245***
Milking speed	493	100.0	10.8	66-129	0.057	0.162**	0.022	0.040
Temperament	493	100.0	9.6	60-124	0.194***	0.268***	0.145**	0.122*

*: P < 0.05; **: P < 0.01; ***: P < 0.001