Swedish University of Agricultural Sciences
Faculty of Veterinary Medicine and Animal Science
Department of Animal Breeding and Genetics

Genetic Variation in Local Swedish Sheep Breeds

Linnea Dahlberg

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Linnea Dahlberg

Supervisor: Anna Johansson, Department for Animal Breeding and Genetics
Assistant supervisor: Anna Näslund, Department for Animal Breeding and Genetics

Examiner: Lotta Rydhmer, Department for Animal Breeding and Genetics

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ABSTRACT

Sheep have played a very important part in rural history. In Sweden there were many kinds of small native breeds, kept for their meat and fleece. Women cared for the flock that often had very little to feed on during the cold and sometimes harsh winter months. This meant that these sheep over time acquired special phenotypic properties depending on the environment they lived in, and easily fed compared to modern breeds kept for meat. Most of these sheep have since become extinct. Since the rediscovery of the 9 breeds we have today, a lot of work has been done to preserve the biological diversity of them. It is a certainty that sheep are inbred within each breed, since there were very few individuals to start off with. It is however not known how closely related the breeds are. Each breed has been named by the area it has been rediscovered in and, if more than one group of individuals has been found, their phenotypic similarities have decided which breed they belong to.

The aim of this study was to determine kinship by genetic variability between the breeds using 18 microsatellites as genetic markers. Blood samples were collected from at least 2 different flocks and at least 15 individuals of each breed (with the exception of Fjällnäs and Gestrike sheep). Individuals closely related to founder parents were preferably chosen, as well as individuals from different families.

The results of this study showed a rather surprising genetic diversity between each breed, involving at least one unique allele in all breeds. Though the sample range is questionable with it being small and many individuals being closely related, there is also a variability of alleles within each breed therefore acknowledging that all these breeds should if possible be kept from interbreeding.

SAMMANFATTNING

Får har haft en mycket stor roll i agrarhistoria. I Sverige har det en gång funnits många små lantraser som hölls för kött och ull. Kvinnan i hushållet ansvarade för fåren utöver sina många övriga sysslor. Fåren hade ofta dålig tillgång på föda under de bistra vintermånaderna. Det här innebar att djuren under tidens gång utvecklade särskilda fenotypiska egenskaper beroende på den omgivning de levde i. De var även mycket lättfödda jämfört med dagens köttraser. Idag är de flesta av dessa raser utrotade, men sedan återupptäckten av de 9 raser vi idag kallar allmogefår har det lagts ner väldigt mycket tid och energi på att bevara den biologiska mångfalden hos dem. Det man vet är att inavelsgraden är mycket hög, eftersom avelsmaterialet är så litet. Hur nära besläktade raserna är vet man däremot inte. Varje ras har namngivits efter det område de återupptäckts i. I de fall det finns flera grupper av djur har deras fenotypiska likheter klassificerat dem som samma eller olika raser.

Studiens syfte var att kartlägga släktskapet mellan raserna genom att använda 18 olika mikrosatelliter som genetiska markörer. Blodprover samlades från minst 2 olika flockar och åtminstone 15 olika individer av varje ras (undantaget Fjällnäsfåren och Gestrikefåren). Individer nära besläktade med founderdjur valdes, liksom individer från olika föräldradjur.

Resultaten visade på en förvånande genetisk diversitet mellan varje ras, där minst en allel är unik för var ras. Trots att urvalet av proverna kan ifrågasättas, få antal prover och många individer är nära besläktade, finns en klar variation av alleler inom varje ras. Dessa resultat pekar på att varje ras bör om så är möjligt hållas som en egen och därmed inte korsas med övriga.

INTRODUCTION

The native Swedish breeds of sheep were in the beginning of the 1990's very near extinction. Nils Dahlbeck set out to find sheep he remembered from his youth. He was looking for coloured sheep and horned rams, which he didn't see in production sheep at this time. He received information about small coloured sheep and rams with horns from different places in Sweden. He categorized them as Rya sheep, Skogs sheep and Dala Päls sheep. Dahlbeck wrote that Rya sheep, originally known as Swedish Native Breed, bred in the 1920's from Dala Päls sheep in Skattungbyn and the Norwegian Spelsau. Skogs sheep were the remainder of the Swedish Native Breed that used to be spread over the whole north of Sweden with characteristics very close to the Spelsau with a short tail and wool free face and legs. Dala Päls sheep could be distinguished from the Skogs sheep by their shorter curlier fleece (Dahlbeck, 1993). In 1995, shortly after Dahlbeck's publication, the association of Swedish local sheep breeds (Föreningen Svenska Allmogefår, FSA) was founded. Only three of the local breeds were known then. Today there are nine, some of which are acutely threatened with extinction (FSA homepage).

How closely related these sheep are is, however, unknown. There is a study made in 2005 by Tapio *et al*, comparing alleles using microsatellite markers between different breeds of sheep, including some of the native Swedish breeds. This study doesn't include all of the local sheep, and most of them (with the exception of Roslags sheep) are bundled together in one single group of sheep named "Skogs sheep", as Dahlbeck (1993) had categorized them. The study made in 2009 by Lasagna *et al* also uses microsatellites, as microsatellites are preferred to mithochondrial DNA because of the possibility to determine genetic diversities and genetic relationships in and between breeds (Goldstein and Schlötterer, 1999). The study by Lasagna *et al* was carried out on Italian breeds of sheep. A spatial distribution of the samples, according to Correspondence Analysis, showed well defined clusters of each breed, therefore confirming genetic identity.

HISTORY

Domestication of sheep

Sheep evolved 2.5 million years ago in Eurasia. There aren't many remains to follow the precise evolutionary sequence, but it is known that sheep were as large as oxen before the ice ages. True sheep would replace the large giant sheep by the end of the ice ages, and spread throughout Europe and Asia. They would follow the retreating ice, most probably due to their wool that would keep them warm and let them adapt to different environments, and their very efficient feeding regime due to rumination (Ryder, 1983).

Animals first domesticated by man were more slender than today's domesticated sheep. The tail was short, and horns very prominent. The horns were used as weapons while fighting other individuals. Wild sheep have a hairy outer coat covering a finer, wooly undercoat. The whole coat is shed each spring, which isn't usually the case in domestic breeds. Domestic breeds have mainly kept the finer undercoat of wool and replaced the coarse outer coat with

another layer of finer wool (Ryder, 1983). In many of the local native breeds, however, this type of coat was very important so that sheep could be kept outside without getting wet. Many of the local native breeds also carry large, majestic horns (Hallander, 1989).

Sweden's commitment to biological diversity

In 1992 Sweden signed United Nation's Convention on Biological Diversity (CBD) which entered into force in 1993. The convention's three main objectives are the conservation of biological diversity, the sustainable use of the components of biological diversity and the fair equitable sharing of the benefits arising out of the utilization of genetic resources. This means that Sweden has a responsibility to maintain it's biological and therefore genetic diversity in, among others, the local Swedish breeds.

According to the Action Plan for the long-term sustainable management of Swedish animal genetic resources 2010-2020 it is important that we prevent genes and species from dying out, and to preserve traditional native breeds. An example of a lost Swedish breed is Ölänningen, a small horse that used to be native to the island of Öland outside the south-east coast of Sweden's mainland. A mare named Kajsa was the last of these little horses, and she died as late as the 1920's, leaving the breed extinct (Hallander, 1989).

THE LOCAL BREEDS

In this study I have used Hallander's (1989) definition of *native breeds,* which is: domesticated breeds that are native to an area and have adapted to their environment with relatively little interference from humans.

With *local breeds* I'm referring to the Swedish word "allmogefår" which is a name used to describe native breeds that usually are rare and originate from a small flock or area.

Dala Päls sheep

In 1976 the Dala Päls sheep were found in Dalarna by a passionate woman. A pair of brothers had kept them, and she remembered the same kind of sheep from her youth. When the brothers no longer could keep their sheep they were distributed between a couple of flocks. Yet another group of Dala Päls were found in 1996, not far from the where the first flock was discovered. Dala Päls sheep are so called because the skin was used in Dalarna's traditional costumes (FSA homepage; Dahlbeck, 1993). The wool had to be just the right quality, very curly and finer than that of most other Swedish sheep. Traditionally the lambs were slaughtered at 2 months and 10 days of age to be used for the costumes (Dahlbeck, 1993). Because of this use, the white fleece was preferred to fleece of other colours, and still today most Dala Päls are white.

Dala Päls males have large circular horns that are triangular in cross-section with a flattened tip (Dahlbeck, 1993). Males weigh about 50 kilos, the females 30-35 kilos and usually have 1-2 lambs a year (FSA homepage).

In 2010 the FSA had a total of 467 (57 males) Dala Päls sheep registered in 37 flocks.

Fjällnäs sheep

Fjällnäs are the latest addition to the allmoge family. They were accepted by the FSA as a breed in early 2011. Fjällnäs sheep were unknown until recently (approximately 2006), discovered on a small farm near Fjällnäs in the north of Sweden. A couple of sheep were retrieved from this flock and have since then been kept in Älvsbyn in northern Sweden. Their shepherd says their fleece reminds him greatly of old sheep skins with their yellowish colour and the quality of the fleece. Some lambs are born fawn but grow lighter with time (FSA). Furthermore the size, short tail and small ears are a sign of a breed being of old origin (Ryder, 1983).
Because of the lack of rams in the new flock, trials have been made to mate Fjällnäs females with a Dala Päls male. However the offspring were phenotypically too different from the parental Fjällnäs sheep (FSA).

Females do not bare horns, while some males have small brittle horns. Males weigh about 30-50 kilos, the females 25-40 kilos and usually have 1-2 lambs (FSA).

2011 the FSA had a total of 10 completely purebred individuals (7 males) of Fjällnäs sheep registered in one single flock.

Gestrike sheep

This breed of sheep stems from the county of Gästrikland. It is a very old breed that has kept its diversity of colours and markings. In 1994 the founder flock was slaughtered, and only 7 ewes and a ram were sold to an enthusiast. All sheep of this breed today are descendents of these individuals (FSA homepage).

Both males and females can bare horns. Gestrike males weigh 60-70 kilos, females about 45 kilos and usually have twins, but triplets or quadruplets aren't rare (FSA homepage).

In 2010 the FSA had a total of 401 (46 males) Gestrike sheep registered in 28 flocks.

Helsinge sheep

In the county of Helsingland and neighboring county of Medelpad two goups of sheep have been kept since times past. These flocks have rams with large circular horns and a diversity in colours and markings. In the group from Medelpad some individuals have wattles under their chin (FSA homepage). Hallander (1989) describes that Swedish

Figure 1. Ewe of the breed Helsinge sheep with wattles

sheep in the 19th century could bare wattles (Figure 1). In the other flock of Helsinge sheep a male of the breed Åsen sheep was used for mating during one season (FSA homepage).

Males can have majestic horns or not carry any at all. Females do not have horns. Males weigh 45-55 kilos, females weigh around 35-50 kilos and usually have 1-2 lambs, but triplets aren't unusual (FSA homepage).

In 2010 the FSA had a total of 775 (139 males) Helsinge sheep registered in 69 flocks.

Klövsjö sheep

All Klövsjö sheep derive from a couple of flocks surrounding Klövsjö, a small village in the county of Jämtland. The first flock known to the FSA was kept by an elderly lady who had inherited them from her father. He was given the sheep as a wedding gift from his mother. Klövsjö sheep are usually white or black with white markings, but brown and even mottled sheep are known. The sheep have a rather wide stature with a low stance, a silky and shiny fleece and often live to be 15 years of age (FSA homepage).

This breed doesn't usually have horns, but males can sometimes grow small brittle horns. Males weigh 60-70 kilos, females weigh around 40-60 kilos and usually have twins or triplets, and every so often even quadruplets (FSA homepage).

In 2010 the FSA had a total of 283 (62 males) Klövsjö sheep registered in 34 flocks.

Roslags sheep

In 1992 Nils Dahlbeck received a tip from someone on the island Raggarön in Roslagen, in the county of Uppland. On this island there were sheep with rams that bore great horns. According to the owners, these sheep had always been on the island. To avoid inbreeding all the lamb rams were kept during the mating season, allowing the flock to mate freely, and then all rams were slaughtered in the autumn (Dahlbeck, 1993). This particular flock of sheep are mentioned in the farms documents dating back to the 18th century. These sheep are small and were very important on the farms in the Roslagen area. Their long thick wool was essential for making the clothes needed, and was even used for making sails. When it was possible to commercially buy the gloves and socks needed, the breed's importance diminished, and only one flock remained on Raggarö (FSA homepage).

Roslags sheep are commonly white or black with white markings, but individuals can also be mottled. Some lambs are born brown but fade to creamy white. Males have large majestic circular horns while females don't carry any. Males weigh about 50 kilos and females 30-40 kilos Ewes usually have just one lamb a year, but twins aren't uncommon (FSA homepage).

In 2010 the FSA had a total of 895 (131 males) Roslags sheep registered in 67 flocks.

Svärdsjö sheep

Close to Falun in Dalarna county, there is a small community called Svärdsjö. On a farm there Svärdsjö sheep have been kept by the family since the 1600's. Until the 1950's every farm in the village and in the neighboring village kept the same kind of sheep. Ewes were every so often exchanged between farms, whilst the farm kept its own rams. The sheep are small, with very tight, fine and curly soft fleece. The wool and skin were readily used for clothing (FSA homepage).

Most Svärdsjö sheep are white, traditionally coloured sheep and rams with horns would be slaughtered. Today there are white as well as black sheep with white markings, and males can bare small horns, or none at all. Females do not have horns. Males weigh about 50 kilos, females 35-45 kilos and usually have one or two lambs a year, triplets are rare (FSA homepage).

In 2010 the FSA had a total of 257 (42 males) Svärdjö sheep registered in 20 flocks.

Värmlands sheep

All Värmlands sheep derive from a large flock in Värmland. This flock consisted of sheep the owner had acquired from his parent's farm, as well as sheep he found around Värmland county that in appearance were very similar to his own. Some of these sheep were distributed to new flocks, and during Dahlbeck's (1993) travels through Sweden in search of rams with horns, a few more typical rams were found in the counties Hälsingland and Dalarna.

Most Värmlands sheep are gray, but there are also blackish-gray, brown and white sheep and some are even known to be mottled. They are rather small in size, rams may or may not have horns while ewes do not. The wool is usually fine, varies in quality but is easy to felt. Males weigh 60-70 kilos, females 40-65 kilos and usually have twin lambs (FSA homepage).

In 2010 the FSA had a total of 2399 (198 males) Värmlands sheep registered in 154 flocks.

Åsen sheep

Three farms close to Åsen in the county of Dalarna used to let their flocks graze together during the summers until 1990. They left the ram lambs in the flocks until they brought them all home late in the summer when all rams were slaughtered. After 1990 these flocks were dispersed and moved to new owners (FSA homepage).

The wool is of varying quality both within the breed and on the same individual, it is easily spun and easy to work with. Lambs are often born dark and then grow lighter with age. Åsen sheep can have every colour of gray, from white to black and some individuals have a little brown tint. Rams may have large majestic circular horns, or sometimes none at all. Ewes usually don't bare horns, but can have a small hard structure. The wool, usually fine, varies in

quality but is easy to felt. Males weigh 45-55 kilos, females 35-45 kilos and usually have one or two lambs (FSA homepage).

In 2010 the FSA had a total of 1149 (165 males) Åsen sheep registered in 111 flocks.

SAMPLES AND METHODS

Sample range

For the results to be considered significant, samples from at least 15 individuals are needed, preferably from 3 different flocks within each breed.

The contact with the flocks was initiated by talking to the persons responsible for the gene bank for each breed in the association of Swedish local sheep breeds (FSA). The FSA were very helpful, and all sheep owners asked were pleased to include their sheep in the study.

Because of the time limit of the study and the geographical distances, the optimum number of samples could not be collected. Blood samples were obtained from 1-3 different flocks of each of the 9 breeds (a total of 218 individuals, see Table 1), the number of samples analyzed are also shown in the last row in the table below. The limited funds for this study meant that not all samples taken could be analyzed.

Table 1: Blood samples and measurements were taken from the number of animals listed below. Not all individuals were tried for the microsatellite markers. The number of animals included are listed in the last row

Breed	Da	Fj	Ge	He	Kl	Ro	Sv	Vä	Ås	Total
Number of flocks	2	1	1	2	3	2	2	2	2	**17**
Number of sheep	20	10	29	18	41	27	30	30	18	**223**
Included in study	17	10	18	17	36	20	30	23	17	**188**

All individuals sampled are 12 months of age or older. There is only one flock of Fjällnäs sheep with 10 individuals over 12 months of age in Sweden. Gestrike sheep all derive from the one flock which is sampled. All sampled animals are registered in the Allmoge association's gene bank (FSA).

Methods

A total of 2 batches with 94 samples each were used in the study, in addition to two negative controls in each batch. The samples were kept chilled or, if more than 10 days before being analyzed, frozen.

All samples were analyzed for alleles with 18 microsatellite markers (BM1818, BM1824, BM6506, BM8125, CSRD247, CSSM66, ETH10, ETH225, ILSTS11, INRA006, INRA35, INRA63, MAF65, OarFCB20, SPS115, TGLA53, TGLA122, TGLA126) in accordance with the two first capillary runs in the study by Lasagna *et al* (2009).

All markers underwent a multiplex PCR amplification as following: denaturation 5 min 94^{o}C, 35 cycles of 30 sec at 95^{o}C, 45 sec at 65^{o}C, 30 sec at 72^{o}C and finally an extension of 15 min at 72^{o}C. After this the samples were subjected to the capillary machine.

The software program GeneMapper was used to determine the different alleles. The results were then analyzed using Genepop 4.0.10 on the web.

Measurements for body size were taken from all sampled individuals (with the exception of one Klövsjö flock, since these samples were taken by a practicing veterinarian visiting the flock for other purposes), see table in appendix.

RESULTS

Markers BM1818, BM6506, INRA63 and OarFCB20 did not amplify in any of the samples.

Table 2. Markers diverging (P < 0.05) from Hardy-Weinberg equilibrium within each breed

Breed	Markers
Dala Päls	
Fjällnäs	
Gestrike	CSSM66, TGLA112, TGLA126
Helsinge	CSSM66, ETH225, MAF65, TGLA112
Klövsjö	CSSM66, ETH225, TGLA112
Roslags	
Svärdsjö	INRA006, TGLA112
Värmlands	CSSM66, INRA006, TGLA112
Åsen	TGLA53, TGLA112, TGLA126

The Hardy-Weinberg principle (Hardy, 1908; Weinberg, 1908) assumes that alleles and gene frequencies are constant in a population, meaning that no alleles will be added or leave the population and the frequency is kept at the same level, thus defining a population to be in equilibrium. When testing the Hardy-Weinberg principle, one has to assume that the population is infinite in size, that random mating occurs and that the population isn't isolated. Since the exact opposite is the case in most of the local breeds, it was expected that most markers would not be in equilibrium. Astonishingly, most markers in each breed are in equilibrium according to the Hardy-Weinberg principle. Marker CSSM66 showed a divergence ($P < 0.05$) in Gestrike, Helsinge, Klövsjö and Värmlands sheep. ETH225 in Helsinge and Klövsjö sheep. INRA006 in Svärdsjö and Värmlands sheep. MAF65 in Helsinge sheep. TGLA53 in Åsen sheep. TGLA112 in Gestrike, Helsinge, Klövsjö, Svärdsjö, Värmlands and Åsen sheep. TGLA126 in Gestrike and Åsen sheep. This is shown in table 2. All other markers were shown to be close to equilibrium.

The mean number of alleles in each breed ranged from 2.14 in Roslags sheep to 4.75 in Värmlands sheep. The total numbers of alleles in each marker ranged from 2 in ETH10 to 15 in TGLA126. The mean number of alleles over all markers was 8. The diversity of alleles are illustrated below in table 3. Marker ETH10 is very monomorphic, only Klövsjö sheep have two alleles of this marker.

Table 3. Number of alleles of each marker in the different breeds – Dala Päls (Da), Fjällnäs (Fj), Gestrike (Ge), Helsinge (He), Klövsjö (Kl), Roslags (Ro), Svärdsjö (Sv), Värmlands (Vä), Åsen (Ås)

	Breed									
Marker	Da	Fj	Ge	He	Kl	Ro	Sv	Vä	Ås	**Total**
BM1824	-	3	3	2	4	3	2	-	-	**5**
BM8125	4	4	3	5	3	2	3	3	2	**6**
CSRD247	5	4	6	4	4	2	4	5	4	**9**
CSSM66	3	3	3	4	3	2	3	6	3	**7**
ETH10	1	1	1	1	2	1	1	1	1	**2**
ETH225	3	2	3	3	4	2	3	5	1	**6**
ILSTS11	-	3	5	3	5	2	3	-	-	**6**
INRA006	4	2	2	5	4	2	4	4	4	**9**
INRA35	3	2	3	3	4	3	3	4	3	**7**
MAF65	3	4	5	4	5	2	3	6	3	**7**
SPS115	5	4	6	4	4	2	4	5	4	**9**
TGLA53	4	2	4	6	6	2	4	8	4	**11**
TGLA122	2	4	5	5	7	3	3	6	4	**13**
TGLA126	5	2	5	6	6	2	3	4	4	**15**
Mean no. of alleles	**3.50**	**2.86**	**3.86**	**3.93**	**4.36**	**2.14**	**3.07**	**4.75**	**3.08**	**8.00**

The proportion of variance in individuals, the inbreeding coefficient ($F_{IS} = 1 - H_O/H_E$, H_O is observed heterozygosity and H_E the expected heterozygosity), in each breed is shown in table 4. The *IS* means that the individual (*I*) is compared to the subpopulation (*S*), in this study, each breed is defined as a subpopulation. Most breeds have an F_{IS} ranging from -0.18 to 0.14. A negative value indicates a higher proportion of heterozygotes than expected. Fjällnäs and Klövsjö sheep have 0.17 and 0.20 respectively indicating a slightly higher level of inbreeding than the other breeds. F_{IS} over all markers was estimated at 0.07 and over all breeds 0.06.

The observed heterozygosity within individuals, $1\text{-}Q_{INTRA}$, is also shown in table 4. Q being the observed homozygosity, INTRA indicating a mean within individuals, therefore $1\text{-}Q_{INTRA}$ is an indication of gene diversity. The mean $1\text{-}Q_{INTRA}$ in each breed ranges from 0.36 in

Table 4. Mean diversity (heterozygosity, 1-Q_{INTRA}) and inbreeding coefficient (F_{IS}).

Breed	1-Q_{INTRA}	F_{IS}
Dala Päls	0.50	0.03
Fjällnäs	0.43	0.17
Gestrike	0.46	0.12
Helsinge	0.61	0.02
Klövsjö	0.46	0.20
Roslags	0.36	-0.18
Svärdsjö	0.47	-0.02
Värmlands	0.60	0.04
Åsen	0.45	0.14
Mean	0.48	0.06

Roslags sheep to 0.61 in Helsinge sheep. The higher the value, the higher the heterozygosity and, most probably, also gene diversity. The 1-Q_{INTRA} over all breeds in this study was 0.48.

The F_{ST} value is the proportion of genetic variance in one breed, or subpopulation (*S*), compared to the total population (*T*). A higher value indicates a higher proportion of variance. The F_{ST} over all breeds was estimated at 0.28. Table 5 illustrates the pairwise values for F_{ST} over all combinations of breeds according to Weir and Cockerham (1984). The F_{ST} values range from 0.13 to 0.47 indicating how much the breeds differ from one another. Värmlands and Helsinge sheep have a value of 0.13 indicating a higher genetic similarity than between Åsen and Klövsjö sheep with a pairwise F_{ST} value of 0.30. The highest F_{ST} value is found between Dala Päls and Roslags sheep (0.47), meaning that these breeds differ most genetically. Roslags sheep and Åsen have a value of 0.45, while Dala Päls and Åsen that both differ so much from Roslags sheep, gives a lower value of 0.15 meaning that they are rather similar genetically.

Table 5. Pairwise F_{ST}-values over combinations of breeds - Dala Päls (Da), Fjällnäs (Fj), Gestrike (Ge), Helsinge (He), Klövsjö (Kl), Roslags (Ro), Svärdsjö (Sv), Värmlands (Vä), Åsen (Ås)

	Da	Fj	Ge	He	Kl	Ro	Sv	Vä
Fj	0.30							
Ge	0.32	0.28						
He	0.23	0.18	0.17					
Kl	0.33	0.27	0.19	0.19				
Ro	0.47	0.42	0.34	0.38	0.25			
Sv	0.38	0.33	0.28	0.27	0.31	0.45		
Vä	0.27	0.19	0.15	0.13	0.21	0.30	0.26	
Ås	0.15	0.27	0.28	0.19	0.30	0.45	0.38	0.24

DISCUSSION

As all breeds derive from small flocks (FSA; Dahlbeck, 1993) and therefore all individuals within a breed have a few common ancestors. Because of this we know that each breed is interbred. As an example we can use the newly acknowledged Fjällnäs sheep. There are today a total of approximately ten individuals known, and all come from the same group of animals.

It is stated in literature (Dahlbeck, 1993; Hallander, 1989) that some breeds have been described to have interbred at times, and even other breeds than the local ones are supposed to have been crossed into pure bred flocks. For this reason it would have been interesting to

compare other breeds such as Norwegian Spelsau, Gotlands sheep and Rya sheep with the other breeds included in this study.

The mean inbreeding coefficient (F_{IS}) in this study was 0.06 over all breeds and 0.07 over all markers. Comparing this study with one by Tapio *et al* (2005), a larger study with a larger amount of animals from different countries included, we have very similar results. In the Tapio study the mean F_{IS} over all breeds as well as all markers were 0.07. This is a relatively low inbreeding coefficient when compared to a Spanish study (Lasagna *et al*, 2009) where the F_{IS} values over the breeds ranged from 0.048 to 0.118. These results state that the overall inbreeding coefficient over the Swedish breeds is no higher than the inbreeding coefficient over breeds from different areas and countries.

Even in this rather small study there is a clear genetic diversity between all breeds sampled. Even alleles can be unique to one breed. For example, the allele 207 in marker ETH10 which only exists in Klövsjö sheep, the marker in all other breeds being monomorphic, but is present in all three flocks sampled, even though the individuals are not all from the same family. This specific marker is known to have an influence on growth and size in growing cattle (DeAtley *et al*, 2009), but it is not known if there is a similarity in sheep. According to the measurements taken during this project, there is no evidence that the sheep carrying the unique allele have a different size than other sheep. Klövsjö sheep are one of the largest of the local breeds, but not the largest.

According to a study by B-Rao (2001) the sample size has to be 4-5 times the amount of alleles at a specific locus to be accurate. In this study, the sample size is sufficient in some markers, but not in others. When an allele is more uncommon than another within the same locus, the sample size has to be even larger.

CONCLUSION

Individuals were tested from only 1-3 different groups of animals, which means that many of the individuals used in the study are closely related and even close family. This together with the rather low number of individuals used in the study render our results not quite conclusive. In the Hardy Weinberg tests only a few markers in some breeds diverged from equilibrium. This could be dependent on the small sample range. A larger sample range would be more accurate.

While using the computer software GeneMapper one might find faults in the subjectivity of the interpretation of the resulting alleles, since the person working on the computer has to decide which peaks really are alleles and which are just nonsense.

Not all microsatellites amplified, of course I would have liked to compare more than the maximum of 14 markers I had to make the study even more accurate, but because of the time limit of this study these could not be re-done. The reason for the loss in amplification can be a

small mistake in mixing the primers, something wrong in the machine or any other of a number of reasons. Even a small mistake will show up as a marker not amplifying.

Taking all the results as well as doubts into consideration, this study does show a genetic diversity between these breeds that is important to preserve. However, because of the small sample range, the results can not be held quite conclusive. A larger study is needed to come to an accurate conclusion.

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APPENDIX

All sheep sampled were also measured, with the exception of one flock of Klövsjö sheep. Using FSA's form for inventory of local Swedish sheep breeds as a guideline, not all measurements were taken due to the time limit of the study.

Measurements that were taken were:

- Muzzle – from the root of the nose to the middle of the muzzle.
- Between ears – from the base of one ear over the top of the head to the base of the other ear.
- Horns – if any, just a hard area (residue), a small elevated area (button), small horns (length) or large horns (circumference at base and length of outside of left horn)
- Chest – circumference of chest
- Length – length of back from withers to last vertebrate of back
- Tail – length from first vertebrate to last vertebrate of tail
- Height – height at withers

Measurements of Dala Päls sheep in cm

Mean	Female	Male	All
Muzzle	12.9	-	12.9
Ears	13.0	-	13.0
Chest	88.3	-	88.3
Length	59.4	-	59.4
Tail	16.6	-	16.6
Height	60.6	-	60.6

Horns in females - 4 rudiments, 3 button, 2 small

Measurements of Fjällnäs sheep in cm

Mean	Female	Male	All
Muzzle	12.2	13.1	12.9
Ears	10.0	14.1	12.9
Chest	83.5	89.6	87.8
Length	49.5	55.6	53.8
Tail	10.8	12.1	11.8
Height	57.3	64.3	62.2

Horns in males - 3 rudiments, 3 small, 1 large

Measurements of Gestrike sheep in cm

Mean	Female	Male	All
Muzzle	14.8	15.3	14.9
Ears	12.2	16.2	13.3
Chest	87.1	88.6	87.5
Length	62.6	64.8	63.2
Tail	17.3	18.6	17.7
Height	64.6	68.9	65.8

Horns in females - 7 large
Horns in males - all large

Measurements of Helsinge sheep in cm

Mean	Female	Male	All
Muzzle	14.9	16.0	14.9
Ears	13.9	18.0	14.1
Chest	87.3	107.0	88.4
Length	62.9	69.0	63.3
Tail	16.9	18.0	16.9
Height	63.5	74.0	64.1

Horns in females - 1 rudiment, [1]4 wattles
Horns in males - rudiments

Measurements of Klövsjö sheep in cm

Mean	Female	Male	All
Muzzle	14.1	17.0	14.2
Ears	12.2	20.0	12.4
Chest	90.9	102.5	91.3
Length	65.0	68.0	65.1
Tail	15.4	15.0	15.4
Height	65.1	66.0	65.2

Horns in females - 4 rudiments
Horns in males - buttons

Measurements of Roslags sheep in cm

Mean	Female	Male	All
Muzzle	15.0	12.5	14.9
Ears	11.2	15.0	11.5
Chest	78.0	80.0	78.1
Length	56.8	54.0	56.6
Tail	15.9	16.3	15.9
Height	57.6	57.5	57.6

Horns in females - 1 rudiment, 1 button
Horns in males - large

[1] Wattles are common in goats and were found in sheep in 19th century (Hallander, 1989), see page 5

Measurements of Svärdsjö sheep in cm

Mean	Female	Male	All
Muzzle	12.5	13.8	12.7
Ears	10.6	14.7	11.4
Chest	73.6	78.2	74.5
Length	57.0	53.3	56.3
Tail	14.3	13.5	14.1
Height	59.6	62.8	60.3

Horns in males - rudiments

Measurements of Värmlands sheep in cm

Mean	Female	Male	All
Muzzle	14.6	16.3	15.0
Ears	14.6	16.2	14.9
Chest	97.6	106.1	99.3
Length	65.5	69.8	66.3
Tail	16.0	15.5	15.9
Height	67.8	71.7	68.6

Horns in females - 4 rudiments
Horns in males - 2 rudiments, 1 small, 3 large

Measurements of Åsen sheep in cm

Mean	Female	Male	All
Muzzle	13.9	14.5	14.0
Ears	13.1	14.5	13.2
Chest	88.8	86.5	88.7
Length	58.1	57.0	58.1
Tail	17.4	23.0	17.7
Height	61.6	63.0	61.7

Horns in males - large