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The status and need for characterization of Nordic animal genetic resources

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ABSTRACT

The Nordic countries are committed to conserving farm animal genetic diversity. National reports on phenotypic and genetic characterization point towards a lack of characterization for many Nordic native breeds. Little to no knowledge on the traits of the animals and their derived products leads to potential remaining untapped. The objective of this study was to provide a quantitative assessment of phenotypic and genetic characterization of Nordic native breeds, through a literature search and obtaining census data. Six species and a total of 85 breeds were included. Studies were classified according to six different categories of characterization. Results showed that a large percentage of the breeds are not characterized at all. Moreover, most breeds have extremely low census sizes. A substantial effort to increase population sizes and document characteristics of Nordic native breeds, to promote conservation and sustainable use, is needed.

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Introduction

Animal genetic resources are recognized as fundamental for food security and rural development. Throughout history the human population has been expanding and is currently predicted to grow by 3.2 billion within this century (United Nations 2019). Growth in the Nordic region alone is predicted at 2.2 million people between 2015 and 2030 (Karlsson et al., 2017). This places greater demands on our natural resources which, due to intensification of agriculture (Steinfeld et al., 2006) and rising temperatures, are already stressed (Gubasch et al., 2013; Pacifici et al., 2015). Main commercial breeds, which we base our food supply on might not be able to adapt to the changing conditions fast enough without contribution from the diversity native breeds represents because the commercial breeds are less tolerable towards, e.g. heat stress (Hoffmann 2010).

Intensification of food production threatens the existence of many domestic animal breeds (Scherf 2000) because they are not fit to the intensive production system. Production systems are becoming less diverse because of global trade and exchange of genetic resources of highly productive breeds, requiring similar environmental conditions (Khoury et al., 2014; Macfadyen et al., 2015). Local breeds are replaced and thus, diversity declines, because they are seen as less valuable due to the strong selection of production traits in the highly performing international breeds. This causes a

threat to food security because local breeds may have adapted to different environments and conditions and therefore express valuable traits which may be increasingly important in securing sustainable food production for future generations (Hayes et al., 2013) as unforeseen circumstances must cause the breeds to adapt. Thus, genetic diversity is eroded unless we intervene (Frankham et al., 2002; Oldenbroek 2007; Billionnet 2013) and change the current trend.

The erosion of genetic diversity has been recognized by countries throughout the world. Efforts in conserving animal genetic resources in the Nordic countries, already emerged in the 1950s and 1960s because of worries about hybrid breeding and rapid decreases in the population size of native breeds (Maijala 1970) as a response to the intensification of the livestock sector. Thus, the Nordic countries initiated joint efforts to conserve national breeds, as early as the 1970s and 1980s, primarily due to the similarities in natural conditions, history and culture of the Nordic region (Tapio et al., 2005; Woolliams et al., 2005).

The Global Plan of Action for Animal Genetic Resources (GPA) was negotiated and adopted by FAO member countries in 2007. The framework recommends FAO's member countries, of which the Nordic countries are amongst, to contribute to promoting conservation and sustainable use as well as development of animal genetic resources. One of the main areas of concern is

characterization, involving phenotypic, genetic and historical information on breeds (FAO 2007). In 2015, the Second Report of The State of The World's Animal Genetic Resources for Food and Agriculture was published based on country reports (FAO 2015). The report included an assessment of the level of phenotypic and genetic characterization of animal genetic resources. These scores showed that in the European region coverage was relatively low, highest for phenotypic characterization, lower for quantification of genetic diversity based on pedigree, and lowest for molecular genetic measures of within and between breed diversity (FAO 2015 Figure 3B2).

Characterization of native breeds is necessary for conservation because lacking information hinders decision-making and management plans. Research has shown that the high-output breeds are more dependent on technological potential for adaptation to environmental change than local breeds (Hoffmann 2010). Thus, native breeds might be important for the future adaptation of food production as they possess different traits, such as the ability to utilize pastures that cannot be utilized for other purposes than grazing, which the current main commercial breeds do not have. It is necessary for the Nordic countries to recognize the need for increased characterization of the native breeds to be able to determine conservation priorities and thereby increase the potential of the Nordic region to be able to supply future generations with food. The objective of this study is to provide a quantitative assessment of phenotypic and genetic characterization studies on breeds defined as native to the Nordic countries, which can be used to identify priorities for future characterization activities.

Materials and methods

The study focused on six species of 24 sheep-, 21 cattle-, 14 horse-, 15 chicken-, eight goat-, and three pig breeds native to the Nordic region which can be found in Table 1. The breeds included in this study were those recognized as native breeds, excluding main commercial breeds. The breeds studied were identified by the national coordinator of animal genetic resources from respectively Denmark (including Faroese Islands), Finland (including Åland), Iceland, Norway and Sweden.

Literature search

A literature search focused on peer-reviewed articles, university theses and conference abstracts, was conducted using google scholar. The search was conducted in two rounds, one included information published prior

to 2017 and one included information published between 2017 and spring 2019. The search was based on the breeds' names in English as well as the native language except Icelandic and Faroese. Several breeds do not have an established English name. In those cases, the authors have included a suggested translation to increase the amount of included literature in this study. Search terms, as well as the Icelandic and Faroese breeds' names in their native language, can be found in Table 1.

The identified studies were divided into six categories of characterization. The categories including definitions can be found in Table 2. The first four categories correspond to categories used by FAO, e.g. in the Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture (FAO 2015), whereas the last two categories were formulated in order to include additional aspects of characterization. All studies were divided according to the categories and could thus be included in multiple categories for multiple breeds and species. In what follows, studies will either be referred to as published studies which are studies published in scientific literature, or as scored studies which are published studies addressing one or more categories of characterization and/or one or more breeds. Thus, one published study can be counted as multiple scored studies.

Census data

Census data was obtained from FAO's Domestic Animal Diversity Information System (DAD-IS) in spring 2019. Breeds were evaluated as having available census data if there was an entry under 'Population Min/Max' in DAD-IS. Data was divided into three different groups: the past two years (2017–2018), the past five years (2014–2018) and the past ten years (2009–2018). Data entries for population size in 2019 were not evaluated.

Results

A total of 249 published studies, representing 1029 scored studies, published between 1962 and 2019 were identified. All studies only described one species, except one study, which included both sheep and goats and was thus included as a published study for both species. However, there are large differences in both the number of breeds included in studies as well as the amount of studies per breed or even species. Table 3 contains the aggregated data per species as well as the sum of scored studies per category and species plus the number of published studies per species. On average 4.3 studies have been published

Table 1. Native farm animal breeds that are included in this study.

Breed name in the national language	English name of the breed	Species	Country
Agersø kvæg	Agersøe cattle	cattle	Denmark
Dansk Malkekorthorn	Danish Shorthorn cattle	cattle	Denmark
Jysk Kvæg	Jutland cattle	cattle	Denmark
Rød Dansk Malkerace anno 1970	Danish Red Cattle anno 1970	cattle	Denmark
Sortbroget Dansk Malkekvgæg anno 1965	Danish Black pied dairy cattle, Danish Black and White anno 1965	cattle	Denmark
Itäsuomenkarja	Eastern Finn cattle	cattle	Finland
Länsisuomenkarja	Western Finn cattle	cattle	Finland
Pohjoissuomenkarja	Northern Finn cattle	cattle	Finland
Íslenska kýrin*	Icelandic cattle	cattle	Iceland
Dølafe	Doela cattle	cattle	Norway
Sidet trønderfe og nordlandsfe	Blacksided Troender and Nordland cattle	cattle	Norway
Telemarkfe	Telemark cattle	cattle	Norway
Vestlandsk fjordfe	Western Fjord cattle	cattle	Norway
Vestlandsk raudkolle	Western red polled cattle	cattle	Norway
Østlandsk rødcolle	Eastern Red Polled cattle	cattle	Norway
Bohuskulla	Bohus poll	cattle	Sweden
Fjällko	Swedish mountain cattle	cattle	Sweden
Fjällnära boskap	Fjällnära cattle	cattle	Sweden
Ringamålako	Ringamala	cattle	Sweden
Svensk rödkulla	Swedish red polled	cattle	Sweden
Väneko	Väne	cattle	Sweden
Danske Landhøns	Danish Landrace chicken	chicken	Denmark
Maatiaiskana	Finnish Landrace chicken	chicken	Finland
Landnámshænsn*	Icelandic landrace chicken	chicken	Iceland
Norske jærhøns	Norwegian Jaer hen	chicken	Norway
Bohuslän-dals svarthöna	Bohuslän-dals black hen	chicken	Sweden
Gammalsvensk dvärghöna	Old Swedish dwarf hen	chicken	Sweden
Öländsk dvärghöna	Öländsk dwarf hen	chicken	Sweden
Gotlandshöna	Gotlands hen	chicken	Sweden
Hedemorahöna	Hedemora hen	chicken	Sweden
Kindahöna	Kinda hen	chicken	Sweden
Orusthöna	Orusthen	chicken	Sweden
Skånsk blommehöna	Skaansk blomme hen	chicken	Sweden
Ölandshöna	Ölands hen	chicken	Sweden
Bjurholms höna	Bjurholms hen	chicken	Sweden
Åsbohöna	Aasbo hen	chicken	Sweden
Dansk Landraceged	Danish Landrace goat	goat	Denmark
Suomenvuohi	Finnish goat	goat	Finland
Íslenska geitin*	Icelandic goat	goat	Iceland
Kystgeit	Coastal goat	goat	Norway
Göingeget	Peasantry goats; Göinge goat	goat	Sweden
Jämtget	Jämtland goat	goat	Sweden
Lappget	Lapp goat	goat	Sweden
Svensk lantrasget	Swedish landrace goat	goat	Sweden
Frederiksborghesten	Fredriksborg horse	horse	Denmark
Den Jydske Hest	Jutland horse	horse	Denmark
Knabstrupperhesten	Knabstrupper horse	horse	Denmark
Føroysk ross*	Faroese horse	horse	Faroe Islands
Suomenhevonen	Finnhorse	horse	Finland
Íslenski hesturinn*	Icelandic horse	horse	Iceland
Dølahest	Doela horse	horse	Norway
Norsk fjordhest	Fjord horse	horse	Norway
Nordlandshest/Lyngshest	Northland pony	horse	Norway
Norsk kaldblodstraver	Norwegian Coldblooded Trotter	horse	Norway
Gotlandsruss	Gotlandsruss	horse	Sweden
Svensk kallblodig travare	Swedish Coldblooded Trotter	horse	Sweden
Nordsvensk brukshäst	North-Swedish horse	horse	Sweden
Svensk Ardenner	Swedish Ardenner	horse	Sweden

(Continued)

Table 1. Continued.

Breed name in the national language	English name of the breed	Species	Country
Dansk Landracesvin anno 1970	Danish landrace pig anno 1970	pig	Denmark
Sortbroget Landracesvin	Danish Black pied pig	pig	Denmark
Linderödssvin	Linderöd pig	pig	Sweden
Dansk Landfår	Danish landrace sheep	sheep	Denmark
Hvidhovedet Marskfår	White faced Marsh sheep	sheep	Denmark
Ahvenanmaan lammas	Aaland sheep	sheep	Finland
Kainuun harmas	Kainuu Grey sheep	sheep	Finland
Íslenska sauðkindin*	Icelandic sheep, including the Icelandic leadersheep	sheep	Iceland
Blæset sau	Blaeset sheep	sheep	Norway
Dalasa	Dala sheep	sheep	Norway
Fuglestadbrogete sau	Fuglestadbrogete sheep	sheep	Norway
Gammelnorsk sau, Villsau	Old Norse sheep, Norwegian feral sheep	sheep	Norway
Gammelnorsk Spælsau	Old Spael sheep	sheep	Norway
Grå Trøndersau	Grey Troender sheep	sheep	Norway
Rygjasau	Rygja sheep	sheep	Norway
Steigarsau	Steigar sheep	sheep	Norway
Dala pålsfår	Dala fur sheep	sheep	Sweden
Gestrikefår	Gestrike sheep	sheep	Sweden
Gutefår	Gute sheep	sheep	Sweden
Helsingefår	Helsinge sheep	sheep	Sweden
Klövjsjöfår	Klövsjö sheep	sheep	Sweden
Roslagsfår	Roslag sheep	sheep	Sweden
Ryafår	Swedish Rya sheep	sheep	Sweden
Svenkst finullsfår	Swedish Finewool sheep	sheep	Sweden
Svårdsjöfår	Svårdsjö sheep	sheep	Sweden
Värmlandsfår	Värmland sheep	sheep	Sweden
Åsenfår	Aasen sheep	sheep	Sweden

Unless marked with an asterisk the listed names were used as search terms for a literature search using google scholar.

per year, overall. However, most studies have been published since the beginning of this century with more studies in the most recent years. It is found that the annual average increased from 6.6 studies per year in the 10-year period before to 14.5 in the 10 years following the release of the GPA and 18 studies per year if only counting studies published between 2016 and 2018 which is illustrated by Figure 1.

Sheep

Thirty-three published studies including the different native sheep breeds and characterization categories were found: 16 for Phenotypic characterization, five for Genetic variability and two for Socio-cultural importance and respectively. There were also three concerning Molecular genetic diversity within breed, where one also included Genetic diversity based on pedigree, three for Molecular genetic diversity between breeds and four including both Molecular genetic diversity within and between breeds. The 33 published studies summed overall to 158 scored studies. The aggregated data of the scored studies concerning sheep breeds can be found in Table 4. It is evident that most sheep breeds have only been included in one or two scored studies

Table 2. Definitions of categories for classification of studies, moderated from FAO (2015).

Category	Definition
Phenotypic characterization	Studies identifying distinct populations and describing their morphological and production characteristics within given production environments, including descriptions of production environments and geographical distribution of breeds.
Genetic diversity based on pedigree information	Studies that estimate genetic relationships among individuals based on the probabilities of sharing alleles identical by descent. This includes functions of relationships at breed level, such as average coefficients of inbreeding and/or kinships and their trend over time.
Molecular genetic diversity – within breed	Studies that estimate genetic diversity within breeds based on genotypes of individual or pools of animals. This includes measures of expected and observed heterozygosity, proportion of allele sharing, and measures of inbreeding based on individual loci or haplotypes.
Molecular genetic diversity – between breeds	Studies that evaluate genetic similarity, genetic distance, introgression or other measures of relationships between representative groups of animals from a group of breeds.
Genetic variability	Studies that use phenotypes, pedigree and/or genotypes to estimate genetic variances and covariances, estimates the effects of candidate or marker loci (GWAS) or estimates frequencies and effects of quantitative trait loci.
Socio-economic importance	Studies that describe or estimate economic, cultural, historic and/or eco-system contributions of one or several breeds in one or several production systems or value chains. This includes studies of traditional products based on specific breeds.

in each characterization category. However, on average 35.4% of the breeds have not been included in at least one study across all categories. The percentage of breeds with no studies is illustrated in Figure 2.

The breeds included in most scored studies are the Gute sheep with 16 studies, and with 10 scored studies each, the Old Norse sheep, the Dala sheep and the Aaland sheep. The Gute sheep has been described in relation to, but not limited to, wool isotopic composition (von Holstein & Makarewicz 2016), behaviour (Karlsson 2018), microminerals deficiency (Sundström 2018) coat colour (Rochus et al., 2014) and their socio-cultural importance (Dýrmondsson & Niżnikowski 2010). Likewise, studies on the Old Norse sheep have focused on tickborne infections (Stuen et al., 2011), wool isotopic composition (von Holstein & Makarewicz 2016), antipredator behaviour (Hansen et al., 1998), body weight and blood parameters (Hovstad & Waldeland 2009) as well as microsatellite variation (Tapio et al., 2005; 2010). The Dala sheep, have been included in scored studies focused on yellow fat occurrence (Baker et al., 1985), antipredator behaviour (Hansen et al., 1998), digestive tract anatomy (Stenheim et al., 2003), interaction between genotype and environment in relation to lamb weights (Steinheim et al., 2004), foraging behaviour (Steinheim

et al., 2005) as well as microsatellite variation at 25 loci (Tapio et al., 2005). Most of the scored studies that includes Aaland sheep have used either mitochondrial DNA (Meadows et al., 2005; Lv et al., 2015) or microsatellites (Tapio et al., 2003; 2005) to describe molecular genetic diversity within and/or between breeds.

Several breeds have not been characterized in more than one category or have only been included in one or two different studies. Seven breeds have not been included in any phenotypic studies, 15 breeds have not been included in any studies on genetic variability, one breed has not been included in a study on molecular genetic diversity within breed, all breeds except one have not been included in a study on genetic diversity based on pedigree information and five breeds have not been included in a study on their socio-cultural importance.

All native breeds, except the Icelandic sheep precluding the Icelandic leadersheep, and the Old Spael sheep from Norway are at risk of extinction. The census size of the breeds is in general less than 200 breeding males and between 150 and 1300 breeding females. The Norwegian Steigar sheep have the lowest recorded census size with 40 breeding males and 157 breeding females in 2018. Also, the Dala-fur sheep have a small recorded

Table 3. Number of studies that were scored in each of the six categories per species across all breeds.

Category	Cattle (21)	Sheep (24)	Goat (8)	Horse (14)	Pig (3)	Chicken (15)	SUM of scored studies per category
Phenotypic characterization	49	40	10	69	0	7	174
Genetic diversity based on pedigree information	5	1	1	31	0	1	39
Molecular genetic diversity – within breed	174	42	8	48	2	27	301
Molecular genetic diversity – between breeds	238	45	7	62	5	27	384
Genetic variability	17	11	0	42	1	13	84
Socio-cultural importance	20	19	2	5	1	0	47
SUM of scored studies per species	503	158	28	256	9	75	1029
Number of unique studies per species	60	33	13	118	5	20	249

The number of breeds per species is given in parentheses. Studies can have been scored in multiple categories and multiple times per species if representing several breeds. The sum given in the last column is the total number of scored studies per category across all species. The last row gives the number of published studies found per species and in total.

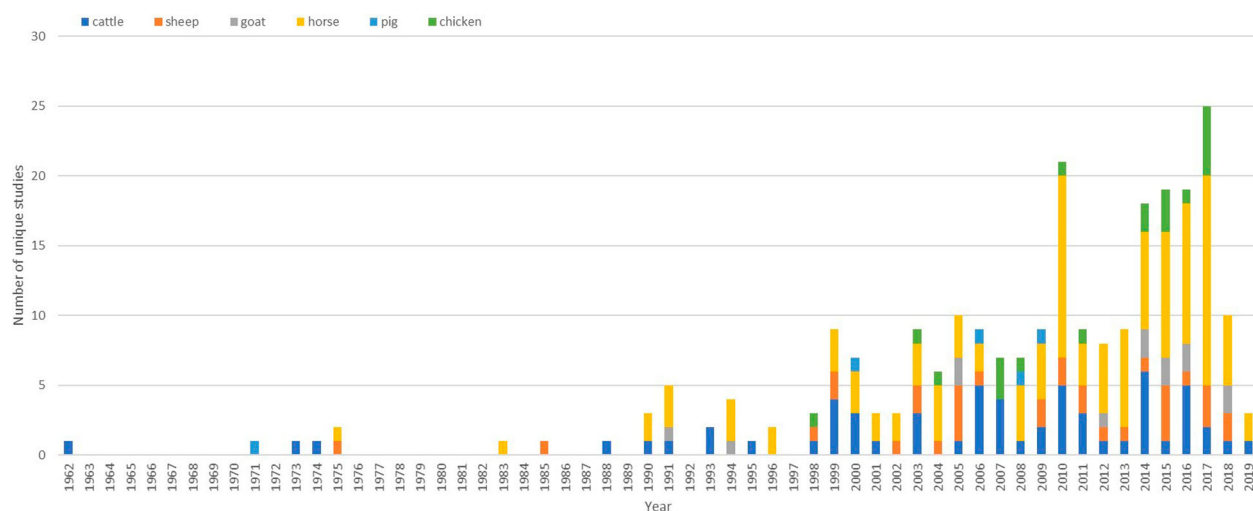


Figure 1. Number of published studies per species per year. One study is included twice in 2005 as it covers both sheep and goats.

size in 2018 with 31 breeding males and 170 breeding females. It is noticeable that there is no record of population size parameters for the Swedish Klövsjö sheep, Rya sheep, Svärdsjö sheep, Värmland sheep, or the Aasen sheep, respectively, since 2015 where there was records of 161, 68, 79, 495 and 175 breeding males,

respectively, and 660, 823, 261, 2632 and 1156 breeding females, respectively. Similarly, the census size of the Finnish Aaland sheep has not been updated since 2010 when there were recorded 100 breeding males and 1000 breeding females, and the Kainuu Grey sheep since 2011 when there was no record of any breeding

Table 4. Number of scored studies per breed and category concerning sheep.

	Phenotypic characterization	Genetic diversity studies based on pedigree information	Molecular genetic diversity studies – within breed	Molecular genetic diversity studies – between breeds	Genetic variability	Socio-cultural importance	Sum
Dansk Landfår			1 ^S : 15	2 ^S : 15,20		1 ^S : 13	4
Hvidhovedet Marskfår			1 ^S : 15	1 ^S : 15			2
Ahvenanmaan lammas (Aaland sheep)			3 ^S : 9,11,15	6 ^S : 9,11,15,17,20,37		1 ^S : 23	10
Kainuun harmas (Kainuu Grey sheep)	4 ^S : 39,41,42,43			2 ^S : 20,37		1 ^S : 23	7
Íslenska sauðkindin (Icelandic sheep)	2 ^S : 38,39		2 ^S : 15,25	3 ^S : 15,20,25	1 ^S : 2	1 ^S : 23	9
Blåset sau			1 ^S : 15	1 ^S : 15			2
Dalasaue	5 ^S : 3,4,8,10,14		1 ^S : 15	1 ^S : 15	2 ^S : 6,7	1 ^S : 13	10
Fuglestadbrogete sau			1 ^S : 15	1 ^S : 15			2
Gammelnorsk sau, Villsau	4 ^S : 4,21,36,39		2 ^S : 15,25	3 ^S : 15,20,25		1 ^S : 23	10
Gammelnorsk Spælsau			1 ^S : 15	2 ^S : 15,20		1 ^S : 23	4
Grå Trøndersau			1 ^S : 15	1 ^S : 15			2
Rygjasau	1 ^S : 3		2 ^S : 15,25	2 ^S : 15,25	1 ^S : 6	1 ^S : 13	7
Steigarsau	2 ^S : 3,4		1 ^S : 15	1 ^S : 15	1 ^S : 6	1 ^S : 13	6
Dala pålsfår	2 ^S : 28,46		3 ^S : 15,28,48	1 ^S : 15		1 ^S : 23	7
Gestrikefår	1 ^S : 28		2 ^S : 15,28	1 ^S : 15		1 ^S : 23	5
Gutefår	4 ^S : 39,44,46,47	1 ^S : 40	4 ^S : 15,25,40,48	4 ^S : 1,15,20,25	2 ^S : 34,35	1 ^S : 23	16
Helsingefår	2 ^S : 28,47		2 ^S : 15,28	1 ^S : 15		1 ^S : 23	6
Klövsjöfår	2 ^S : 28,47		3 ^S : 15,28,48	2 ^S : 1,15	1 ^S : 34		8
Roslagsfår	2 ^S : 28,47		2 ^S : 15,28	2 ^S : 1,15	1 ^S : 34	1 ^S : 23	8
Ryafår	1 ^S : 41		2 ^S : 15,25	3 ^S : 15,20,25		1 ^S : 23	7
Svenskt finullsfår	3 ^S : 41,46,47		1 ^S : 15	1 ^S : 15	1 ^S : 34	1 ^S : 23	7
Svärdsjöfår	1 ^S : 28		2 ^S : 15,28	1 ^S : 15		1 ^S : 23	5
Värmlandsfår	3 ^S : 28,39,47		2 ^S : 15,28	2 ^S : 1,15	1 ^S : 34	1 ^S : 23	9
Åsenfår	1 ^S : 28		2 ^S : 15,28	1 ^S : 15		1 ^S : 23	5
Sum	40	1	42	45	11	19	158

Sheep related references: 1 (Mukiibi et al., 2015), 2 (Adalsteinsson 1975), 3 (Baker et al., 1985), 4 (Hansen et al., 1998), 6 (Tranulis et al., 1999), 7 (Vaage et al., 1999), 8 (Steinheim et al., 2003), 9 (Tapio et al., 2003), 10 (Steinheim et al., 2004), 11 (Meadows et al., 2005), 13 (Shrestha 2005), 14 (Steinheim et al., 2005), 15 (Tapio et al., 2005), 17 (Meadows et al., 2006), 20 (Chessa et al., 2009), 21 (Hovstad & Waldeland 2009), 23 (Dýrmondsson & Niżnikowski 2010), 25 (Tapio et al., 2010), 28 (Dahlberg 2012), 34 (Rochus et al., 2014), 35 (Sunesson 2015), 36 (Stuen et al., 2011), 37 (Lv et al., 2015), 38 (Dýrmondsson 2002), 39 (von Holstein & Makarewicz 2016), 40 (Rochus & Johansson 2017), 41 (Waller 2015), 42 (Väisänen 2013), 43 (Rissanen 2011), 44 (Karlsso 2018), 46 (Sundström 2018), 47 (Rochus et al., 2019), 48 (Rochus 2017).

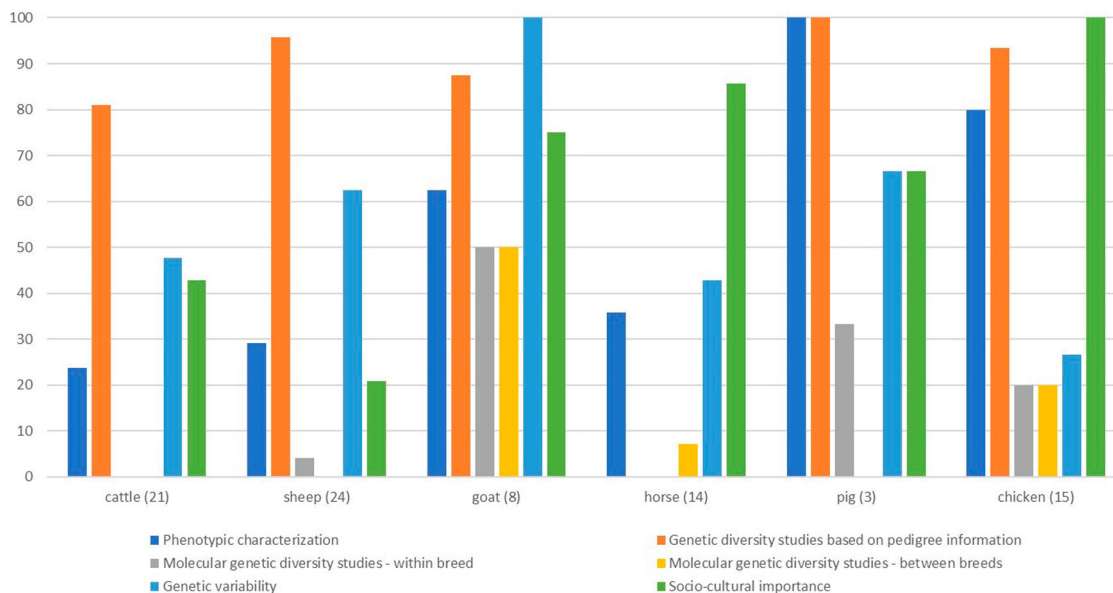


Figure 2. Percentage of breeds per species with no studies in a category.

males and 2943 breeding females. Thus, the current population size of the Finnish breeds may be considered unknown. 37.5% of the Nordic sheep breeds have not had their population size updated in DAD-IS within the past two years and 8.3% of the breeds have not had their population size updated within the past five years. The prevalence of recordings of population size data in DAD-IS is summarized in Figure 3.

Cattle

In the Nordic countries there are 21 native cattle breeds which have been included in this study: five in Denmark, three in Finland, one on Iceland, six in Norway and six in Sweden. Breed names are listed in Table 1. Their history is to a large extent unknown. However, it is known that some of the Nordic breeds have exchanged genetic material through history, e.g. the Eastern Red Polled from Norway, the Red Polled from Sweden, and the Northern Finn cattle from Finland (Blomqvist 1989), as well as the Swedish Mountain cattle and the Northern Finn cattle (Maijala 2011), suggesting that the breeds might be more or less related across borders. Also the Icelandic cattle might be related to other Nordic breeds, as they, according to Kantanen et al. (2000b), were brought to Iceland from Norway 1100–1300 years ago from areas currently populated by Black-sided Troender and Nordland cattle.

There are 60 published studies covering characterization of the native cattle breeds, meaning that 24% of the published studies represent cattle breeds. Most of the published studies includes several breeds and categories. Thus, the 60 published studies sum to 503

scored studies which equals 48.9% of all scored studies. The number of scored studies per cattle breed in each category of characterization is found in Table 5. 81.9% of the scored studies on cattle characterization falls within the two categories of Molecular genetic diversity, and all cattle breeds have been included in at least one study on Molecular genetic diversity within and/or between breeds. These categories are the only categories where all breeds have been included in at least one characterization study, whereas five breeds are not characterized phenotypically, 17 not according to Genetic diversity based on pedigree information, eleven not according to Genetic variability and nine breeds have not been included in studies on the Socio-cultural importance of the breeds. Thus, on average over all categories 32.5% of the breeds have not been characterized as illustrated by Figure 2. The breeds not characterized in the different categories can be found in Table 5.

In general, Icelandic cattle is the breed which is included in most scored studies when summing across all categories for each cattle breed. It is included in respectively 14 and 17 scored studies in the two categories of Molecular genetic diversity. However, it is only included in respectively six studies in the category Phenotypic characterization, one in Genetic diversity based on pedigree information, two in Genetic variability and 0 in Socio-cultural importance. The phenotypic studies concern coat colour (Kantanen et al., 2000a; Klungland et al., 2000), mastitis (Oddgeirsson et al., 1988), production traits (Sigurdsson 1993), prenatal death (Benjaminsson 2007) and the effect of inbreeding on milk, fat and protein yield (Sigurdsson &

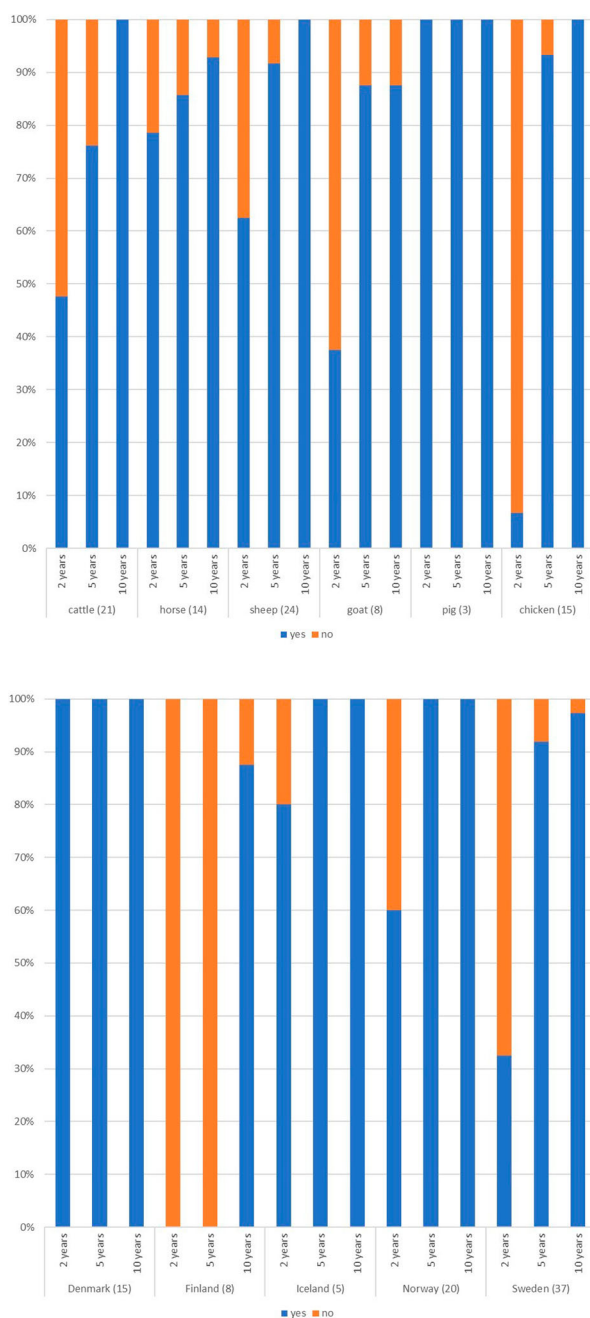


Figure 3. The amount of census data recordings available in DAD-IS for the last 2-, 5- and 10-year period. On top: data is divided by species. The red area of the bars marks unavailable data. On bottom: data is divided by country. The red area of the bars marks unavailable data.

Jonmundsson 1995). The study by Sigurdsson and Jonmundsson (1995) is also the only study, concerning Icelandic cattle, that use pedigree information of the breed to estimate genetic diversity. The other phenotypic scored studies of Kantanen et al., (2000a), Klungland et al., (2000) and Oddgeirsson et al., (1988) also score in several categories as they in addition to phenotypic characterization uses microsatellites to investigate molecular genetic diversity within breed.

Cattle are in general included in most studies on molecular genetic diversity within and between breeds. Western- and Eastern Finncattle are included in the same amount of unique studies on Molecular genetic diversity as the Icelandic cattle. Both of the Finncattle breeds are included in more recent unique studies using SNPs (Li et al., 2006; Edwards et al., 2011; Iso-Touru et al., 2016) and whole genome sequencing (Weldenegodguad et al., 2019). However, most studies use microsatellites, as was found for Icelandic cattle.

The Danish Agerstoe cattle is the only cattle breed included in just one published study scored in both categories of Molecular genetic diversity. The study used 29 microsatellites and 100 amplified fragment length polymorphisms (AFLPs) as well as mitochondrial DNA to describe genetic variation within and between Agerstoe cattle, Jutland cattle and Danish Red anno 1970 (Withen et al., 2011). For the Agerstoe cattle, this is the only study the breed is included in, whereas the Jutland cattle is included in two scored studies on phenotypic characterization, zero scored studies on Genetic diversity based on pedigree information, twelve on Molecular genetic diversity within breed, 15 on Molecular genetic diversity between breeds, one on Genetic variability and, one scored study on Socio-cultural importance, respectively. The Danish Red anno 1970 is included in two scored studies in Phenotypic characterization, one in Genetic diversity based on pedigree information, ten in Molecular genetic diversity within breed, 14 in Molecular genetic diversity between breeds, one in Genetic variability, and two in Socio-cultural importance, respectively. The studies can be found in Table 5.

All Nordic native cattle breeds are at risk, except for the Icelandic cattle. The three breeds from Finland have an unknown status in DAD-IS. The last updated population size record for the Finnish cattle breeds is from 2009 and no information of breeding males were recorded for any of the Finnish breeds. The extinction risk might be most severe for the Danish Agerstoe cattle for which nine breeding males and 98 breeding females were recorded in 2017 and the Swedish Bohus poll for which 19 breeding males and 77 breeding females also recorded in 2017. Väne cattle and Ringamala cattle, which also were among those cattle breeds with fewest scored characterization studies, were recorded to have 31 breeding males and 174 breeding females and 45 breeding males and 146 breeding females, respectively, in 2017. The last record of population size for the Swedish red polled cattle is from 2012 and counts 647 breeding males and 1978 breeding females. Thus, the size of

Table 5. Number of scored studies per breed and category concerning cattle.

	Phenotypic characterization	Genetic diversity studies based on pedigree information	Molecular genetic diversity studies – within breed	Molecular genetic diversity studies – between breeds	Genetic variability	Socio-cultural importance	Sum
Agersø-kvæg			1 ^C : 39	1 ^C : 39			2
Dansk Malkekorthorn	1 ^C : 17	2 ^C : 37,38	3 ^C : 17,18,29	3 ^C : 17,18,29			9
Jysk Kvæg	2 ^C : 17,60		12 ^C : 7,9,17,18,19,26,29,32,35,39,59,60	15 ^C : 3,4,7,9,17,18,19,26,27,29,31,35,39,60,63	1 ^C : 26	1 ^C : 3	31
Rød Dansk Malke race anno 1970	2 ^C : 17,60	1 ^C : 23	10 ^C : 9,16,17,18,19,29,35,39,56,60	14 ^C : 3,4,9,16,17,18,19,27,29,31,35,39,60,63	1 ^C : 57	2 ^C : 3,23	30
Sortbroget Dansk Malkekvæg anno 1965	1 ^C : 17		6 ^C : 7,17,18,29,35,56	8 ^C : 3,4,7,17,18,29,35,39	1 ^C : 57	1 ^C : 3	17
Itäsuomenkarja (Eastern Finn cattle)	4 ^C : 14,17,24,55		14 ^C : 8,15,17,18,19,24,25,26,29,35,53,55,61,88	17 ^C : 3,4,8,12,15,17,18,19,24,25,26,27,29,35,55,63,88	2 ^C : 24,26	4 ^C : 3,50,52, 62	41
Länsisuomenkarja (Western Finn cattle)	6 ^C : 14,17,24,46, 49,55	1 ^C : 86	15 ^C : 8,15,16,17,18,19,24,25,26,29,35,53,55,61,88	16 ^C : 3,4,8,12,15,17,18,19,24,25,26,27,29,35,55,88	2 ^C : 24,26	3 ^C : 3,50,52	43
Pohjoissuomenkarja (Northern Finn cattle)	5 ^C : 14,17,24,51,55		14 ^C : 8,15,17,18,19,24,25,26,29,35,53,55,61,85	15 ^C : 3,4,8,15,17,18,19,24,25,26,27,29,35,55,85	3 ^C : 24,26,45	2 ^C : 3,52	39
Íslenska kýrin (Icelandic cattle)	6 ^C : 17,22,34,64, 65,66	1 ^C : 34	14 ^C : 2,8,16,17,18,19,21,22,28,29,35,58,64,67	17 ^C : 4,6,8,12,16,17,18,19,21,22,27,28,29,31,35,63, 67	2 ^C : 34,65		40
Dølafé	2 ^C : 17,22		11 ^C : 8,16,17,18,19,21,22,26,29,30,35	15 ^C : 3,4,8,16,17,18,19,21,22,26,27,29,30,35,39	1 ^C : 26	1 ^C : 3	30
Sidet trønderfe og nordlandsfe	3 ^C : 17,22,33		11 ^C : 8,16,17,18,19,21,22,28,29,30,35	16 ^C : 4,8,12,16,17,18,19,21,22,27,28,29,30,31,35,63		1 ^C : 33	31
Telemarkfe	2 ^C : 17,22		12 ^C : 8,16,17,18,19,21,22,26,29,30,35,67	18 ^C : 3,4,8,16,17,18,19,21,22,26,27,29,30,31,35,39,63, 67	1 ^C : 26	1 ^C : 3	34
Vestlandsk fjordfe	2 ^C : 17,22		10 ^C : 8,17,18,19,22,28,29,30,35,67	15 ^C : 3,4,8,12,17,18,19,22,27,28,29,30,35,39,67		2 ^C : 3,54	29
Vestlandsk raudkolle	2 ^C : 17,22		8 ^C : 8,17,18,19,22,29,30,35	13 ^C : 4,8,17,18,19,22,27,29,30,31,35,39,63			23
Østlandsk rødkolle	2 ^C : 17,22		7 ^C : 8,17,18,22,29,30,35	12 ^C : 3,4,8,12,17,18,22,27,29,30,31,35		1 ^C : 3	22
Bohuskulla			2 ^C : 19,35	3 ^C : 4,27,35			5
Fjällko	5 ^C : 13,17,48,60, 84		9 ^C : 8,16,17,18,19,26, 29,35,60	12 ^C : 4,8,12,16,17,18,19,26,27,29,35,60	2 ^C : 26,45		28
Fjällnära boskap			3 ^C : 8,19,35	5 ^C : 4,8,19,27,35			8
Ringamålako			2 ^C : 19,35	4 ^C : 4,19,27,35			6
Svensk rödkulla	4 ^C : 17,60,83,84		8 ^C : 8,9,17,18,19,29,35,60	15 ^C : 3,4,8,12,17,18,19,27,29,31,35,39,60,63	1 ^C : 83	1 ^C : 3	29
Väneko			2 ^C : 19,35	4 ^C : 4,19,27,35			6
Sum	49	5	174	238	17	20	503

Cattle related references: 2 (Ásbjarnardóttir et al., 2010), 3 (Beja-Pereira et al., 2003), 4 (Bennewitz et al., 2006), 6 (Blott et al., 2003), 7 (Brüniche-Olsen et al., 2012), 8 (Edwards et al., 2011), 9 (European Cattle Genetic Diversity Consortium* 2006), 12 (Hamilton et al., 2009), 13 (Hessle et al., 2014), 14 (Huuskonen 2014), 15 (Iso-Touru et al., 2016), 16 (Kantanen et al., 1999), 17 (Kantanen et al., 2000a), 18 (Kantanen et al., 2000b), 19 (Kantanen et al. 2009), 21 (Kidd & Cavalli-Sforza 1974), 22 (Klungland et al., 2000), 23 (Lauvie et al., 2008), 24 (Li et al., 2010), 25 (Li et al., 2007), 26 (Li et al., 2006), 27 (Li & Kantanen 2010), 28 (Li et al., 2005), 29 (Lien et al., 1999), 30 (Mejdell et al., 1993), 31 (Negrini et al., 2007), 32 (Pertoldi et al., 2014), 33 (Sæther & Vangen 2001), 34 (Sigurdsson & Jonmundsson 1995), 35 (Tapio et al., 2006), 37 (Trinderup et al., 1999a), 38 (Trinderup et al., 1999b), 39 (Withen et al., 2011), 45 (Venhoranta 2015), 46 (Latvala 2016), 48 (Claesson 2016), 49 (Niemi 2014), 50 (Lilja 2011), 51 (Tuomivaara et al., 2016), 52 (Saine 2013), 53 (Laurén 2010), 54 (Karja & Lilja 2007), 55 (Kantanen et al., 1991), 56 (Bech & Kristiansen 1990), 57 (Christensen et al., 1973), 58 (Braend et al., 1962), 59 (Das et al., 2014), 60 (Rosengaard 2016), 61 (Moisio et al., 1998), 62 (Kinnunen 2010), 63 (Utsunomiya et al., 2014), 64 (Oddgeirsson et al., 1988), 65 (Sigurdsson 1993), 66 (Benjaminsson 2007), 67 (Edwards et al., 2003), 83 (Umeland 2006), 84 (Poulsen et al., 2017), 85 (Pokharel et al., 2018), 86 (Sjöblom 2017), 88 (Weldenogdguad et al., 2019).

the current population is uncertain as is the case for the Finnish breeds.

Horse

Horses are the species with the highest number of published studies. A total of 119 published studies were found, representing multiple breeds and categories per study, these studies summed to 256 scored studies with an average from 0.4 scored studies per breed in the category Socio-cultural importance to 4.9 scored studies per breed in the category of Phenotypic characterization.

Most scored studies are found in the category of Phenotypic characterization. However, still 35.7% of the horse breeds have not been included in any study in this category as illustrated by Figure 2. The variation in breeds being characterized is due to the inclusion of the Icelandic horse in 23 scored studies and the Finnhorse in 22 scored studies of this category. This is in accordance with the overall tendency of the Icelandic horse and the Finnhorse being extensively characterized compared to the rest of the Nordic native breeds. Thus, these two breeds account for 45% of all scored studies for the horse breeds with a broad variation of characterization studies. Table 6 shows the number of scored

Table 6. Number of scored studies per breed and category concerning horses.

	Phenotypic characterization	Genetic diversity studies based on pedigree information	Molecular genetic diversity studies – within breed	Molecular genetic diversity studies – between breeds	Genetic variability	Socio-cultural importance	Sum
Frederiksborghesten		1 ^H : 44	1 ^H : 45	1 ^H : 45			3
Den Jydske Hest		1 ^H : 44	1 ^H : 45	1 ^H : 45			3
Knabstrupperhesten		1 ^H : 44	1 ^H : 45	3 ^H : 36,45,123			5
Føroyssk ross (Faroese Horse)		1 ^H : 108	1 ^H : 94	2 ^H : 36,123			4
Suomenhevonen (Finnhorse)	21 ^H : 41,42,53,59,60,61, 62,64,65,66,67,68,69,71, 72,74,75,78,82,116, 126	3 ^H : 51,54,57	3 ^H : 69,70, 125	3 ^H : 16,70,79	19 ^H : 41,42,43, 53,57, 58,59,60,61,62,64,65, 66,67,68,72,75,76,114	4 ^H : 55,56, 63,73	53
Íslenski hesturinn (Icelandic horse)	23 ^H : 2,3,6,14,19,23,24, 25,29,46,52,71,80,81,83, 88,89,99,100, 101,113, 117,127	2 ^H : 1,93	17 ^H : 1,4,5,6,15, 18,19,24,48,52, 70,81,84,86,87, 88,94	10 ^H : 5,10,11, 12,20, 27,36,49, 70,123	10 ^H : 19,24,25,52,80, 86, 99,100,122, 128		62
Dølahest	3 ^H : 26,39,129	5 ^H : 32,33,34, 47,119	3 ^H : 9,94,125	5 ^H : 9,10,11,12, 36	1 ^H : 39		17
Norsk fjordhest	6 ^H : 14,28,39,92,118,129	4 ^H : 8,34,47,118	4 ^H : 9,70,94,125	12 ^H : 9,10,11, 12,20, 27,36,49, 70,79,123,124	2 ^H : 39,118	1 ^H :28	29
Nordlandshest/ Lyngshest	2 ^H : 39,129	5 ^H : 30,32,33,34,47	3 ^H : 9,94,125	5 ^H : 9,10,11,12, 36	1 ^H : 39		16
Norsk kaldblodstraver	6 ^H : 17,77,101,120, 129,130	2 ^H : 22,35	4 ^H : 103,104,121, 125	5 ^H : 9,10,11,12, 115	4 ^H : 17,31,110,120		21
Gotlandsruss	3 ^H : 96,97,98	1 ^H : 95	2 ^H : 94,95	4 ^H : 16,36,49, 123			10
Svensk kallblodig travare	2 ^H : 81,120	2 ^H : 13,35	4 ^H : 81,94,103,121	4 ^H : 36,112,115, 123	3 ^H : 31,110,120		15
Nordsvensk brukshäst		2 ^H : 13,22	3 ^H : 70,94,121	7 ^H : 27,36,70,79, 115,123,112			12
Svensk Ardenner	2 ^H : 106,107	1 ^H : 107	1 ^H : 94		2 ^H : 105,109		6
Sum	69	31	48	62	43	5	256

Horse related references: 1 (Hreiðarsdóttir et al., 2014), 2 (Hugason 1994), 3 (Hyllmark 2014), 4 (Aberle & Distl 2004), 5 (Aberle et al., 2004), 6 (Andersson et al., 2012), 8 (Bhatnagar et al., 2011), 9 (Bjørnstad et al., 2000), 10 (Bjørnstad et al., 2003), 11 (Bjørnstad & Røed 2001), 12 (Bjørnstad & Røed 2002), 13 (Bohlin & Rönningen 1975), 14 (Brooks et al., 2010), 15 (Campana et al., 2012), 16 (Cothran et al., 2005), 17 (Dolvik & Klemetsdal 1999), 18 (Haase et al., 2015), 19 (Jäderkvist et al., 2015), 20 (Jansen et al., 2002), 22 (Klemetsdal 1999), 23 (Kristjánsson et al., 2013), 24 (Kristjánsson et al., 2014), 25 (Kristjánsson et al., 2016), 26 (Kvale 2010), 27 (Lindgren et al., 2004), 28 (Strøm 2010), 29 (Mejdell & Bøe 2005), 30 (Olsen et al., 2000), 31 (Olsen et al., 2012), 32 (Olsen et al., 2005), 33 (Olsen et al., 2010), 34 (Olsen & Klemetsdal 2010), 35 (Olsen et al., 2013), 36 (Promerová et al., 2014), 39 (Selle 2010), 41 (Suontama et al., 2009), 42 (Suontama et al., 2011), 43 (Suontama et al., 2013), 44 (Thirstrup et al., 2009), 45 (Thirstrup et al., 2008), 46 (Ussing 2004), 47 (Vangen 1983), 48 (Velie et al., 2015), 49 (Vila 2001), 51 (Ettala 2015), 52 (Fegraeus et al., 2017a), 53 (Back 2016), 54 (Tenhunen & Salonpää 2016), 55 (Raento 2016), 56 (Pösö-Sievanen 2015), 57 (Sairanen et al., 2009), 58 (Thuneberg-Selonen et al., 1999), 59 (Schroderus & Ojala 2010), 60 (Ruohoniemi et al., 2003), 61 (Saastamoinen and Nylander 1996a), 62 (Hemmann et al., 2014a), 63 (Schuurman & Nyman 2014), 64 (Sairanen et al., 2011), 65 (Saastamoinen and Ojala 1991a), 66 (Saastamoinen and Nylander 1996b), 67 (Pösö & Ojala 2008), 68 (Suontama et al., 2012), 69 (Hemmann et al., 2014b), 70 (Petersen et al., 2013a), 71 (Hallamaa 2009), 72 (Saastamoinen 1990b), 73 (Pouta et al., 2016), 74 (Saastamoinen & Ojala 1994), 75 (Saastamoinen 1991), 76 (Saastamoinen and Ojala 1991b), 77 (Holm et al., 2000), 78 (Saastamoinen 1990a), 79 (Petersen et al. 2013b), 80 (Árnason & Bjarnason 1994), 81 (Kangas 2013), 82 (Katila et al., 2010), 83 (Keeling et al., 2016), 84 (François et al., 2016), 86 (Eriksson et al., 2015), 87 (Shrestha et al., 2015), 88 (Shrestha 2017), 89 (Jensen et al., 2016), 92 (Eriksen 2010), 94 (Viluma 2012), 95 (Andersson 2010), 96 (Näslund 2016), 97 (Fortini 2015), 98 (Börjesson 2015), 99 (Lindberg 2006), 100 (Eriksson et al., 2008), 101 (Wulfsberg 2010), 103 (Petäjästö 2016), 104 (Revold et al., 2010), 105 (Baird et al., 2010), 106 (Tullberg 2008), 107 (Siekas 2006), 108 (Berg et al., 2013), 109 (Baird et al., 2003), 110 (Fegraeus et al., 2017b), 112 (Fegraeus et al., 2018a), 113 (Janzekovic & Prisenk 2017), 114 (Conn 2017), 115 (Fegraeus et al., 2018b), 116 (Gao 2017), 117 (Reynisson 2017), 118 (Høiseth 2017), 119 (Melheim 2017), 119 (Melheim 2017), 120 (Velie et al., 2018), 121 (Velie et al., 2019), 122 (Johansson et al., 2017), 123 (Staiger et al., 2017), 124 (Tenhunen 2018), 125 (Sild et al., 2019), 126 (Saastamoinen & Särkijärvi 2018), 127 (Sigurðardóttir et al., 2017), 128 (Conn 2019), 129 (Olsen & Klemetsdal 2017), 130 (Jensen 2017).

studies per breed and category for horses. The Icelandic horse has for example been included in Phenotypic scored studies of, but not limited to, responses to cold weather (Mejdell & Bøe 2005), gaits (Andersson et al., 2012; Kristjánsson et al., 2014; Jäderkvist et al., 2015; Reynisson 2017), summer eczema (Lindberg 2006; Hallamaa 2009), temperament (Hyllmark 2014; Sigurðardóttir et al., 2017) and stress hormone in saliva (Janzekovic & Prisenk 2017). Likewise, the breed has been included in 26 scored studies in the categories of Molecular genetic diversity, one fourth of them by use of microsatellites as genetic markers (Bjørnstad & Røed 2001; Bjørnstad & Røed 2002; Bjørnstad et al., 2003; Aberle et al., 2004; Aberle & Distl 2004; Hreiðarsdóttir et al., 2014) and half of them using SNPs, e.g. focusing on the gait keeper

gene (Kangas 2013; Kristjánsson et al., 2014; Promerová et al., 2014; Jäderkvist et al., 2015; Staiger et al., 2017), and studies on Genetic variability focusing on riding ability (Kristjánsson et al. 2016), growth (Árnason & Bjarnason 1994), cryptorchidism (Eriksson et al., 2015), pace (Fegraeus et al. 2017a; Conn 2019) and PMEL which is an eye disorder (Johansson et al., 2017). Whereas, no studies on the Socio-cultural importance is found for the Icelandic horse. The same tendency of distribution of studies is found for the Finnhorse. Thus, a large variation of phenotypic studies are found covering traits of body measures and growth (Saastamoinen 1990a,b; Suontama et al., 2009; Suontama et al., 2011), race performance (Saastamoinen and Nylander 1996a), crib biting (Hemmann et al., 2014a,b), fertility (Katila et al.,

2010; Sairanen et al., 2011), digestibility (Saastamoinen & Särkijärvi 2018) and insulin resistance (Gao 2017). The Finnhorse is only included in six published studies on Molecular genetic diversity; four using SNPs (Petersen et al., 2013a,b; Hemmann et al., 2014a; Fegraeus et al., 2017a), one using microsatellites (Sild et al., 2019) and the last mitochondrial DNA (Cothran et al., 2005), whereas a variety of studies is found for Genetic variability similar to what was found in the category Phenotypic characterization.

On the other end of the scale, breeds such as the Frederiksborg horse, Jutland horse and Faroese horse are found. These breeds have only been included in three, three and four scored studies, respectively. None of them are included in studies in the categories: Phenotypic characterization, Genetic variability or Socio-cultural importance. Thus, limiting the knowledge on the two Danish horse breeds to two studies; a population viability analysis that estimates the vulnerability to extinction and explores management to ensure survival (Thirstrup et al., 2009) and a genetic analysis using twelve microsatellite markers to determine the levels of genetic variability within and between the three Danish breeds (Thirstrup et al., 2008). For the Faroese horse, two of the four scored studies focus on the gait keeper mutation in the DMRT3 gene (Promerová et al., 2014; Staiger et al., 2017) because there is a strong association between the mutation and alternate gaits (Promerová et al., 2014). The last two studies focus on the population status and conservation possibilities, as the Faroese

horse experienced a severe bottleneck in the 1960s where only five individuals were left (Berg et al., 2013), and the correlation between athletic performance and allele frequencies of four specific SNPs in the Myostatin (MSTN) gene (Viluma 2012).

All the Nordic horse breeds are at risk of extinction except the Finnhorse, which is only locally at risk, and the Icelandic horse. However, as the population parameters of the Finnhorse have not been updated since 2009, the current state of the population is uncertain. The population numbers of the Swedish coldblooded trotter were last updated in 2004 with 35 breeding males and 662 breeding females and an unknown risk status. Attempts should be made to update the population numbers and specify the risk status. Of the breeds with known risk status, the Faroese horse express the highest level of risk based on census size. In 2017, the census size was recorded at 81 individuals with no specification of the number of breeding males and females.

Chicken

The breed names of the 15 chicken breeds can be found in Table 1. Between one and 13 scored studies have been identified for the breeds, in total 20 published studies representing 75 scored studies. The number of scored studies per breed and category is found in Table 7. There are no similarities between breeds from the same country being included in more or fewer studies. Thus,

Table 7. Number of scored studies per breed and category concerning chicken.

	Phenotypic characterization	Genetic diversity studies based on pedigree information	Molecular genetic diversity studies – within breed	Molecular genetic diversity studies – between breeds	Genetic variability	Socio-Cultural importance	Sum
Danske Landhøns		1 ^{GH} : 11					1
Maatiaiskana (Finnish Landrace chicken)			2 ^{CH} : 13,14	2 ^{CH} : 13,14	1 ^{CH} : 20		5
Landnámshænsn (Icelandic landrace chicken)			4 ^{CH} : 3,4,10,13				
	4 ^{CH} : 3,9,10,13 1 ^{CH} : 12						
Norske Jærhøns			5 ^{CH} : 3,4,10,13,19	5 ^{CH} : 3,9,10,13,19			10
Bohuslän-dals svarthöna	1 ^{CH} : 1		3 ^{CH} : 1,2,6	3 ^{CH} : 1,2,6	2 ^{CH} : 5,7		9
Gammalsvensk dvärghöna	4 ^{CH} : 15,16,17,18						
Öländsk dvärghöna			2 ^{CH} : 2,6	2 ^{CH} : 2,6	1 ^{CH} : 5		4
Gotlandshöna			2 ^{CH} : 2,6	2 ^{CH} : 2,6	1 ^{CH} : 5		5
Hedemorahöna	2 ^{CH} : 1,8		3 ^{CH} : 1,2,6	3 ^{CH} : 1,2,6	2 ^{CH} : 5,8		10
Kindahöna			1 ^{CH} : 6	1 ^{CH} : 6	1 ^{CH} : 5		3
Orusthöna			1 ^{CH} : 6	1 ^{CH} : 6	1 ^{CH} : 5		3
Skånsk blommehöna			2 ^{CH} : 2,6	2 ^{CH} : 2,6	1 ^{CH} : 5		5
Ölandskhöna			1 ^{CH} : 6	1 ^{CH} : 6	1 ^{CH} : 5		3
Åsbohöna			1 ^{CH} : 6	1 ^{CH} : 6	1 ^{CH} : 5		3
Sum	7	1	27	27	13		75

Chicken related references: 1 (Johansson & Nelson 2015), 2 (Abebe et al., 2015), 3 (Lyimo et al., 2014), 4 (Granevitze et al., 2007), 5 (Karlsson et al., 2016), 6 (Englund et al., 2014), 7 (Dorshorst et al., 2011), 8 (Bergfeldt 2010), 9 (Berthouly et al., 2008), 10 (Twito et al., 2007), 11 (Spalona et al., 2007), 12 (Sundström et al., 2004), 13 (Hillel et al., 2003), 14 (Vanhala et al., 1998), 15 (Olofsson et al., 2015), 16 (Marzal et al., 2016), 17 (Roshier et al., 2017), 18 (Favati et al., 2017), 19 (Brekke 2017), 20 (Fulton et al., 2017).

the Bohuslän-dals black hen from Sweden has been included in 13 scored studies but at the same time the Aasbo hen has only been included in 3. Next to the Bjurholms hen, which has not been included in any characterization studies, the Danish Landrace chicken is least characterized with only one scored study on Genetic diversity based on pedigree (Twito et al., 2007). Similarly, three of the Swedish breeds, the Orust hen, Kinda hen and Aasbo hen, all included in three scored studies, are only characterized by the same two published studies investigating Molecular genetic diversity using dloop mitochondrial DNA (Englund et al., 2014) and Genetic variability of the thyroid stimulating hormone receptor (Karlsson et al., 2016).

Almost all Nordic native chicken breeds are at risk of extinction except the Swedish Aasbo chicken. The risk status of the Icelandic landrace chicken and the Finnish landrace chicken is currently unknown. For both breeds the latest record of population parameters is from 2009. Thus, information on these breeds is crucial, especially as no chicken breed has been characterized in all categories of characterization. For the Danish Landrace chicken, the last record of population size numbers was in 2017. The population size was 2100 individuals. However, number of breeding females and males were not recorded. The smallest population size has been recorded for the Swedish Orust hen and the Norwegian Jaer hen with respectively 88 breeding males and 391 breeding females and 68 breeding males and 333 breeding females, recorded in 2016.

Goat

There are eight different goat breeds, native to the Nordic region. Breed names can be found in Table 1. The Nordic goats are in general longhaired and multicoloured. It is believed that Scandinavian animals where

imported to Iceland more than 1000 years ago constituting the Icelandic breed (Baldursdóttir et al., 2012). It is also known that the Danish landrace goat has been crossed with the German Harz and the Swiss Saanen goat in the beginning of the nineteenth century (Lenstra et al., 2016; Landbrugsstyrelsen 2019).

Overall, there are 13 published studies summing to 28 scored studies with an average of 3.5 scored studies per breed characterizing the goat breeds. This makes overall the goat breeds to the second least characterized of the species considered, next to the pig. However, when considering the distribution of scored characterization studies across breeds, 70.8% of the goat breeds have not been characterized making the goat breeds the least described. The number of scored studies per breed and category can be found in Table 8. Five breeds are not described in the category Phenotypic characterization, seven breeds are not included in a study on Genetic diversity based on pedigree information, and between four to eight breeds, are not included in the remaining categories. The percentage of breeds not being characterized in a category is illustrated in Figure 2. However, there are large differences between breeds. Three breeds; the Swedish Göinge, Jämtland goat and Lapp goat, all from Sweden have not been characterized at all, while the Swedish Landrace goat has been included in four published studies focusing on alpha-casein in relation to milk coagulation (Johansson et al., 2015), alpha S1-casein (Johansson et al., 2014), the effect of milk accumulation interval and milking regime on milk quality (Högberg et al., 2016) and the milk's fatty acid profile (Yurchenko et al., 2018) in the category Phenotypic characterization, but none in the other categories. The Finnish goat and the Norwegian coastal goat have only been included in one published study investigating Molecular genetic diversity within and between breeds using 29 microsatellites (Lenstra et al., 2016).

Table 8. Number of scored studies per breed and category concerning goats.

	Phenotypic characterization	Genetic diversity studies based on pedigree information	Molecular genetic diversity studies – within breed	Molecular genetic diversity studies – between breeds	Genetic variability	Socio-cultural importance	Sum
Dansk Landraceged	2 ^G : 8,9		2 ^G : 1,14	2 ^G : 1,14		1 ^G : 7	7
Suomenvuohi (Finnish Landrace goat)			2 ^G : 1,14	2 ^G : 1,14			4
Íslenska geitin (Icelandic Landrace goat)	4 ^G : 4,5,11,12	1 ^G : 5	3 ^G : 1,5,14	2 ^G : 1,14		1 ^G : 8	11
Kystgeit			1 ^G : 1	1 ^G : 1			2
Göingeget							
Jämtget							
Lappget							
Svensk Lantrasget	4 ^G : 2,3,10,15						4
Sum	10	1	8	7		2	28

Goat related references: 1 (Lenstra et al., 2016), 2 (Johansson et al., 2015), 3 (Johansson et al., 2014), 4 (Ævarsdóttir 2014), 5 (Baldursdóttir et al., 2012), 7 (Shrestha 2005), 8 (Kiani et al., 2015), 9 (Mbassa & Poulsen 1991), 10 (Högberg et al., 2016), 11 (Sveinsdóttir & Dýrmondsson 1994), 12 (Dýrmondsson 2005), 14 (Cardoso et al., 2018), 15 (Yurchenko et al., 2018).

The Icelandic goat is the goat breed included in most scored characterization studies; four studies in the category of Phenotypic characterization focusing on activity, group structure and plant selection (Ævarsdóttir 2014), coat colour (Sveinsdóttir & Dýrmundsson 1994; Dýrmundsson 2005; Baldursdóttir et al., 2012) as well as milk yield and birth weight (Sveinsdóttir & Dýrmundsson 1994; Dýrmundsson 2005), one study in Genetic diversity based on pedigree information using the pedigree of 2240 animals for estimating the rate of inbreeding as 3% per year and an effective population size of 5.1 individuals (Baldursdóttir et al., 2012), two studies in Molecular genetic diversity within breed using 29 microsatellites (Lenstra et al., 2016) and 15 microsatellites plus dloop mitochondrial DNA (Baldursdóttir et al., 2012), respectively. The study by Lenstra et al. (2016) also investigated between breed molecular genetic diversity. The Icelandic goat was in addition included in one study in Socio-cultural importance investigating the breed's origin (Kiani et al., 2015). Thus, the Icelandic goat has not been described according to Genetic variability.

The Danish landrace has been included in one scored study for each of the categories Molecular genetic diversity within- and between breeds using 29 microsatellites (Lenstra et al., 2016), as well as one study on composite origins (Shrestha 2005) of Socio-cultural importance, and two scored studies of endocrine and metabolic adaptations (Kiani et al., 2015) and haematological profiles (Mbassa & Poulsen 1991) in Phenotypic characterization. Thus, the Danish landrace has not been characterized according to either Genetic diversity based on pedigree nor Genetic variability.

All the native goat breeds of the Nordic region are at risk of extinction except the Finnish goat whose status is currently unknown. The population parameters of the Finnish goat have not been updated since 2008 at which point 5500 males and 6000 females were recorded.

The three Swedish breeds that have not been characterized are all small populations. In 2015, 101 breeding males and 323 breeding females were recorded for the Swedish Göinge. Similarly, the Jämtland goat was in

2014 recorded with 106 breeding males and 392 breeding females and the Lapp goat was in 2015 recorded with 63 breeding males and 196 breeding females. The Norwegian Coastal goat is an even smaller population with only 15 recorded breeding males and 204 breeding females in 2017.

Pig

In the Nordic region three breeds are recognized as native: the Linderöd pig from Sweden, and the Danish Black pied pig as well as the Landrace pig anno 1970 from Denmark. Table 9 sums up scored studies per breed and category. None of the pig breeds are included in studies in the categories Phenotypic characterization and Genetic diversity based on pedigree information. The Linderöd pig has been included in one published study, specific to the breed, using microsatellites and AFLPs to describe within- and between breed molecular genetic diversity (Ollivier 2009). Likewise, the Danish Black Pied pig has been included in a published study using microsatellite markers to describe both within and between breed molecular genetic diversity (Laval et al., 2000). All three breeds have in addition been included in one study, using microsatellites to describe between breed molecular genetic diversity (SanCristobal et al., 2006). It is only the Danish Landrace pig anno 1970 which has been included in a study on Genetic variability measuring inbreeding and heritabilities (Jonsson 1971) and the Linderöd pig which has been included in a study on Socio-cultural importance collecting information on how to keep the breed as well as documenting the prevalence of the breed (Hansson 2008).

Overall, the few studies of characterization of Nordic pigs makes them the least described species with on average 61% of the breeds not being described in a category. In addition, it is only in the category of Molecular genetic diversity between breeds where one study including more than one breed is found.

The Danish breeds, Danish Landrace pig anno 1970 and Danish Black pied pig, are very small populations with seven and 42 breeding males and 17 and 105

Table 9. Number of scored studies per breed and category concerning pigs.

	Phenotypic characterization	Genetic diversity studies based on pedigree information	Molecular genetic diversity studies – within breed	Molecular genetic diversity studies – between breeds	Genetic variability	Socio-Cultural importance	Sum
Dansk Landracesvin anno 1970				1 ^P : 3	1 ^P : 5		2
Sortbroget Landracesvin			1 ^P : 2	2 ^P : 2,3			3
Linderödssvin			1 ^P : 1	2 ^P : 1,3	1 ^P : 4		4
Sum			2	5	2		9

Pig related references: 1 (Ollivier 2009), 2 (Laval et al., 2000), 3 (SanCristobal et al., 2006), 4 (Hansson 2008), 5 (Jonsson 1971)

breeding females, respectively, recorded in 2017. The population of the Swedish Linderöd pig is larger with 173 breeding males and 414 breeding females in 2017.

Discussion

National strategies/action plans only have the breeds' names in their native language specified. Some breeds have been identified by several English names, e.g. Dola/Doela/Dole horse or Gotlandsruss/Gotland pony. Thus, we cannot guarantee that we have identified all published studies. However, we have not identified references to studies not included in this paper, indicating that the studies identified represents an almost complete coverage of published studies.

We have focused on characterizing studies identified by Google Scholar. Other material that can be classified in one or more of the characterization categories very likely exists. However, this is mainly in sources that are difficult to access, e.g. annual agricultural reports, or difficult to validate. Results reported here, strongly supports the need to make this hidden information available for a more thorough characterization of the species considered here.

A major finding was the unequal representation of the six categories of characterization (Table 2). Most studies were found in the two categories Molecular genetic diversity within and between breeds. The least studied categories were Socio-cultural importance and Genetic diversity based on pedigree information, with an exception for horses. The focus on molecular genetic characterization might reflect the rapid development of genotyping technologies and analytical tools. This likely promotes scientific interest as well as funding being more accessible in a developing scientific field. A thorough characterization in all categories of characterization are important to fulfil the ambitions set out in the Global Plan of Action (FAO 2007).

Across species it was found that a few breeds are included in several studies, whereas many breeds are included in only a few or no studies. More specifically many breeds across species are not characterized in several of the six characterization categories. The exception are especially horse and cattle breeds involved in several studies. For molecular genetic characterization this is likely due to the availability of samples. There are several examples of the same samples being used in several studies. Horses and cattle stood out, not only by having well studied breeds but also by being the species with most scored studies.

An increasing number of studies is observed post 2007, when the GPA was developed. But despite this the ambitions for characterization of animal genetic

resources are far from fulfilled. Most breeds are poorly characterized, being included in relatively few studies and more generally not being covered by studies addressing all the characterization categories. On average 70.8% of goat, 61.1% of pig, 51.4% of chicken, 35.4% of sheep, 32.5% of cattle and 28.6% of the horse breeds have not been characterized across all categories.

Census sizes showed that most breeds considered are endangered. More surprisingly, census sizes as reported in DAD-IS were not updated for many breeds. This is the more surprising since all Nordic countries have support schemes based on reproducing purebred animals, and thus the data should be available.

Conclusion

Nearly all Nordic native farm animal breeds are at risk of extinction. Most of them with critically low population sizes and thus, in need of structured conservation breeding programmes to increase the effective sizes of the populations. In addition, most of the breeds have not been thoroughly characterized. On average 47.5%, ranging from 28.6% to 70.8%, of all breeds across all characterization categories have not been characterized. In general, studies in the categories of Genetic diversity based on pedigree, Socio-cultural importance and Genetic variability are least frequent. Thus, there is a need for increased focus on characterization of animal genetic resources to promote informed decisions on conservation and sustainable use.

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