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Characterization and conservation
of indigenous sheep genetic resources:
A practical framework for developing
countries

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Characterization and conservation of indigenous sheep genetic resources: A practical framework for developing countries

Solomon Gizaw,[1] H. Komen,[2] O. Hanotte,[3] J.A.M. van Arendonk,[2] S. Kemp,[3] Aynalem Haile,[4] O. Mwai[3] and Tadelle Dessie[4]

1. Debre Birhan Agricultural Research Center, P.O. Box 112, Debre Birhan, Ethiopia
2. Animal Breeding and Genomics Centre, Animal Sciences Group, Wageningen University, P.O. Box 338, 6700 AH, Wageningen, The Netherlands
3. International Livestock Research Institute (ILRI), P.O. Box 30709, Nairobi, Kenya
4. ILRI, P.O. Box 5689, Addis Ababa, Ethiopia

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Executive summary

Livestock characterization projects in developing regions are characterized by a mere physical description of traditionally recognized populations or a purely academic genetic description of populations. However, characterization of livestock resources is meant to serve the purpose of developing conservation and utilization programs. A national characterization project should be geared to the specific national livestock production objectives. Thus there is a need to adopt a more practical characterization approach to assist in the development of national conservation and utilization strategies. This report provides a practical methodological framework suited for characterization and conservation of sheep resources in developing regions. The report highlights current approaches and tools for characterization and conservation of sheep resources and presents a model approach synthesising results of a study on characterization and conservation of sheep resources of Ethiopia. The study is a collaborative project between Wageningen University and the International Livestock Research Institute. The methodological framework can be applied elsewhere in developing countries with similar characterization and conservation objectives.

Characterization of Farm Animal Genetic Resources (FAGR) encompasses all activities associated with the identification, quantitative and qualitative description, and documentation of breed populations and the natural habitats and production systems to which they are or are not adapted. The initial step in characterization is identification of distinct populations using information on their geographic and ecological isolation, traditional nomenclatures (traditionally recognized populations), phenotypic distinctness and the level of genetic differentiation among the populations. Identification of genetically distinct breeds is commonly based on molecular data which is considered as the state-of-the-art technique. However, identification of distinct populations or groups could be done using tools ranging from simple significant morphological characters to molecular data. Data collected on Ethiopian sheep resources showed that there is a high congruence between classifications of the sheep resources into major breed groups using significant morphological characters (tail type and shape), multivariate analysis using several morphological characters, and microsatellite allele frequency data. However, even multivariate analysis could not discriminate between populations within the major groups. For such detailed characterization, molecular genetic tools are required. A parallel morphological characterization of genetically identified breeds is mostly missing from characterization projects. Besides to their role in classification, morphological characters, together with geographic distributions, are also required to physically identify, describe, and recognize a genetically distinct animal or plant population.

Assessment of the population characteristics of identified breeds is also an important component of livestock characterization. This includes estimates of population sizes, flock structure, and assessment of the level of indiscriminate or irrational crossbreeding which are indicators of threat to the survival of the adapted indigenous genetic resources. Furthermore, information on the current merits of the breeds regarding their contribution to the socio-economic wellbeing of the communities maintaining them need to be collected, and their relative contributions to the total genetic diversity need to be assessed. All the above information can be combined to set conservation and utilization priorities. Commonly, conservation priorities of breeds are set based on their contribution to the genetic diversity conserved. However, conservation priorities in developing regions should be set based on the overall merit of each breed. Study on sheep resources of Ethiopia showed that ranking of breeds for conservation changes as the criteria for conservation change. Furthermore, conservation strategies should not exclude utilization of the resources to the benefit of the communities keeping the breed including improvement of the breeds. However, genetic improvement of traditional breeds should not be at the expense of conservation. To this end, conservation-based breeding programs considering breeding objectives of communities, adaptive merits of breeds, and full involvement of the community in the design and implementation of breeding programs are required.

A literature review of characterization approaches showed that some of the characterization activities are resource and time intensive and cannot be applied in developing regions. For instance, extensive nationwide production system surveys, long-term characterization approaches such as performance evaluation of breeds under experimental conditions, and continuous monitoring of farmers flocks are not feasible and the information collected may not deserve the time and resource spent. An array of complicated molecular characterization tools is also used. Experiences from characterization of Ethiopian sheep resources indicate that a simpler practical approach needs to be adopted.

This report largely dwelt on the technical aspects of sheep genetic resource characterization and conservation in developing regions. Operational aspects of setting up national programs for characterization and conservation action may be country specific. However, some general aspects such as institutional setups and breeding policy and strategy formulation could be similar across countries. A proposed scheme for setting up a national livestock characterization and conservation program is presented, taking Ethiopia as a case study.

1   Introduction

Characterization of Farm Animal Genetic Resources (FAGR) encompasses all activities associated with the identification, quantitative and qualitative description, and documentation of breed populations and the natural habitats and production systems to which they are or are not adapted. The aim is to obtain better knowledge of FAGR, of their present and potential future uses for food and agriculture in defined environments, and their current state as distinct breed populations (Rege and Lipner 1992). National-level characterization comprises the identification of the country's FAGR, understanding their status, trends and the associated risks that these resources are exposed to. The process also includes the systematic documentation of the indigenous knowledge around them as well as the information gathered so as to allow easy access and sustainable management (FAO 2007).

Livestock characterization projects in developing regions are often characterized by mere physical descriptions of traditionally recognized populations or a purely academic genetic description of populations. However, characterization of livestock resources is meant to inform development of conservation and utilization strategies and programs. To achieve this, there is a need to adopt a more practical and in-depth characterization approaches.

The objective of this report is to highlight the available characterization and conservation tools and provide a practical framework that could suit developing countries situations. Characterization tools range from simple descriptions of traditional livestock populations to a highly sophisticated molecular genetics tools. This report provides a practical methodological framework suited for characterization and conservation of sheep genetic resources in developing regions. The report highlights current approaches and tools used for characterizing and conserving sheep resources. By synthesising results of a study on characterization and conservation of sheep resources of Ethiopia, it presents a replicable model for countries with similar situations. The report is on a study and project that was undertaken by the International Livestock Research Institute (ILRI) in collaboration with Wageningen University, and that was funded by the Netherlands Foundation for the Advancement of Tropical Research (WOTRO) grants number WB 82-280.

2 Characterization of sheep resources

2.1 Overview of characterization approaches

2.1.1 Production system and environment description

Characterization of the production system and environment in which a breed is kept and used is an essential component of characterization of FAGR. Description of the production system is particularly relevant in developing regions where farm animals are kept under diverse production systems and for multiple uses. When characterizing a livestock population and production system in order to inform sustainable utilization of the livestock resources, emphasis should be given to farmers' and pastoralists' indigenous knowledge that relate to the management of the genetic resources in question. Besides, the value of the genetic resource in terms of tangible (economic) and intangible benefits (cultural, social and environmental) it provides to the community, as well as farmers preferences and opinions need to be assessed. Such information is essential in informing the design of an effective and sustainable community-based utilization and conservation schemes. A detailed livestock systems research manual has been developed by the International Livestock Research Institute (ILCA 1990) and a comprehensive list of animal and environment descriptors to serve as a guide for standardized characterization activities at various levels has been developed by FAO (FAO 1986).

Description of the production environment is highly valuable for understanding the comparative adaptive fitness of a specific animal genetic resource, which is the case in developing regions where the production environment is mostly marginal and thus adaptive traits are important merits of the breeds. Production environment descriptors for animal genetic resource study have been devised (FAO 1998).

Information on production system and production environment is collected through surveys. Surveying of production systems *per se*, not in the context of breed characterization, has been a major research undertaking in developing regions. The main objectives of these surveys are to describe the production system and environment and identify constraints to increase livestock productivity. Such surveys targeted administrative zones rather than breed populations, and as such largely fail to address the objectives of breed characterization. Therefore, surveying needs to be undertaken systematically after breeds or breed groups have been identified or simultaneously with breed identification surveys (section 2.1.2.1). Nevertheless, information collected from lower administrative levels or zones can be collated, aggregated and analysed to give breed-level description of production systems and environments.

2.1.2 Phenotypic characterization

2.1.2.1 Breed identification and description

Physical characteristics of livestock could be associated with various productive and adaptive characteristics of the same. Neutral genetic markers are commonly used in genetic characterization of livestock species. However, contrary to characterization using adaptive physical characters, neutral markers do not reflect the diversity in production and adaptive traits. Therefore, in addition to neutral marker information, physical characteristics such as described in FAO descriptor list (FAO 1986) could thus be used to separate genetically distinct populations and identify those that are suitable for specific production environments.

In developing regions, populations of livestock of the same species, especially if they are geographically isolated and recognized by ethnic owners as being distinct from others around them, are traditionally recognized/considered as distinct eco-types or breeds. Preliminary identification of breeds involves phenotypic characterization of the local populations using purposive sampling strategy for targeting traditionally recognized populations. If such traditionally classified populations do not exist, purposive sampling based on traditional nomenclatures could be complemented by systematic sampling strategy. Systematic sampling could consider geographical isolation, ecological isolation and evident phenotypic distinctness of populations. Systematic sampling could also help identify traditionally unrecognized, but distinct populations.

Qualitative and quantitative physical measurements of animals required for identifying and describing distinct populations or breeds or breed groups are collected through surveys. For this purpose, a comprehensive list of animal descriptors has been developed by FAO (see FAO 1986). Besides, images of typical adult males and females under their natural habitat need to be taken.

2.1.2.2 On-station performance evaluation

On-station phenotypic performance evaluations of breeds are also essential component of FAGR characterization in a broader sense. Information on the value of a breed in terms of its performance provides a basis for conservation and utilization decisions. Performance evaluations have dominated national livestock programs in developing regions (see national reports in Rege and Lipner 1992) including Ethiopia (Biniam 1992; Abegaz and Duguma 2000; Solomon 2002).

Performance evaluation mainly encompasses maintaining nucleus flocks in government ranches and research stations and collection of performance data and their use to describe

performance characteristics of a local breed. The activity could also be a comparative evaluation involving more than one local breed and/or local and crossbred populations.

2.1.2.3 On-farm monitoring

On-station performance evaluation (see section 2.1.2.2) provides a more accurate performance characteristic of a breed as it is carried out under well designed and controlled experimental conditions. On the other hand, on-farm performance evaluation gives a more representative performance level of the breed since it is undertaken under the natural production environment of the breed.

On-farm monitoring involves monitoring the productive and reproductive performance of a breed on selected representative village flocks or herds. For a detailed description of the methodology, reference is made of a manual by the International Livestock Centre for Africa (ILCA 1990). Periodic monitoring of the population dynamics and flock structures of a breed is also suggested for the purpose of assessing the risk status of a breed (FAO 2007).

2.1.3   Genetic characterization

2.1.3.1 Genetic parameter estimation

Genetic evaluation is best carried out under a controlled on-station condition. Genetic evaluation could be carried out as a comparative study regarding the additive genetic merits of two or more breeds for certain genetic traits. It could also be a genetic description of a breed population in terms of additive genetic variance in certain selected performance and adaptive traits within the population (i.e. estimation of genetic parameters). A fairly detailed guideline for establishing on-station flocks for the purpose of estimating genetic parameters is provided in Rege and Lipner (1992).

2.1.3.2 Molecular genetic characterization

Outcomes of morphological characterization (see section 2.1.2.1) need to be complemented by genetic characterization (FAO 2007). Genetic characterization involves the description of breeds in terms of the relative allelic frequencies, degree of polymorphism using a set of neutral reference markers and classifying livestock breeds using genetic distances between populations/breeds (Cavalli-Sforza and Edwards 1967; Nei 1972; Nei et al. 1983).

A while ago, genetic characterization tools included biochemical (protein) polymorphisms and molecular polymorphisms. However, biochemical markers lack the power to resolve differences between closely related populations because of low polymorphism (Meghen et al. 1994). Polymorphic molecular genetic markers include microsatellites, single nucleotide

polymorphisms (SNPs), restriction fragment length polymorphisms (RFLPs), randomly amplified polymorphic DNA (RAPDs), mitochondrial DNA markers, Y-specific alleles and amplified fragment length polymorphisms (AFLPs). In recent past,, microsatellites have become markers of choice for diversity study (Ruane 1999; Sunnucks 2001) because of their co-dominant nature, ease of amplification and hypervariability. Microsatellites are also recommended markers for characterizing FAGR (FAO 2005). However, it should be emphasized that microsatellites are more useful for measuring short range diversity. For a thorough diversity assessment, in addition to marker types, molecular characterization need to take into consideration the number of markers required and their diversity scope.

2.2   A practical characterization approach for developing regions

Most of the characterization and conservation tools available in the literature are largely relevant to the developed country situations, and are ill-suited to the developing country settings. Breed characterization approaches that suit developing region situations need to be developed (see section 2.1 above). The relevance of animal genetic resource characterization tools to developing regions are discussed and a practicable approach is presented. This is a synthesis of the experiences of a study on sheep resources of Ethiopia into a methodological approach.

2.2.1   Practical considerations

2.2.1.1 Planning and implementation

Survey of sheep resources of Ethiopia encompassed phenotypic descriptions, molecular genetic characterization, and description of the production systems and production environments of the sheep breeds. This involved office, field and laboratory activities. It is important to plan well for such a country-wide survey. Extensive literature study on sheep resources of Ethiopia as well as the study of political, ecological and route maps of Ethiopia facilitated planning of the field work. It is also important to plan with regional, zonal and district level agricultural development offices that have the means to facilitate the field work.

Field work implementation needs to be coordinated (see Workneh and Rowlands 2004). In the current survey the major activities were blood sample collection, phenotypic observation and measurement, and characterization of the production systems and environments. It is important that the different survey activities be conducted first in one population so that experiences could be used for characterizing the subsequent populations. Surveying of the Ethiopian sheep was undertaken on a sheep population basis (i.e. all the activities were completed during one field visit to each sheep population). For survey of each population, the regional and zonal agricultural development offices were contacted for a brief discussion

on traditionally recognized sheep types and their distribution in the region and selection of sample districts. The district level development workers were consulted to select sample villages (peasant associations, PAs), and PA development workers to select flocks or households. As an indication for similar works, the whole survey work was undertaken by one researcher, one field assistant-driver, and hired labourers in each locality for sheep handling. The field work took a six-month intensive work and the laboratory analysis took another six months.

2.2.1.2 Sampling strategy

A general sampling strategy for characterizing livestock resources is discussed under section 2.1.2.1. In the case of sheep resources in Ethiopia, mainly a purposive sampling was followed since there are traditionally well recognized sheep populations. Thus we primarily targeted sheep populations traditionally recognized by ethnic and/or geographic nomenclatures. Phenotypically similar, ecologically and geographically proximate populations may have different names, or could each consist of distinct subpopulations. Thus traditionally recognized, phenotypically distinct, and/or geographically/ecologically isolated populations were surveyed. There are quite many ecological subzones in Ethiopia, but only the major ecological zones were sampled. The sampling sites and the ecological zones are shown in Figure 1 and summarized in the footnote of Figure 1.

Once a population to be sampled is identified, sampling of individual flocks or animals within population needs consideration. For molecular genetic analysis unrelated animals need to be sampled. For each population, 48 animals comprising 1–2 animals per flock randomly selected from each village, the latter of which were randomly selected from the selected districts were sampled across different districts within the breeding tract of the population were sampled and blood samples collected for genetic analysis. Morphological data should be collected from animals of similar sex and age. Thus morphological measurements were made on full-mouth adult ewes only. Depending on the trait, 18–40 ewes from each population were measured. Blood samples and morphological measurements were collected on the same set of animals.

2.2.2   Phenotypic characterization

2.2.2.1 Physical and performance characteristics

A physical descriptor list (FAO 1986) was adopted for characterizing sheep resources of Ethiopia. Qualitative traits observed included: coat colour, fibre type, face profile, ear form, presence of horn, tail type and tail shape. Quantitative and morphometric characteristics measured were: body weight, withers height, body length, heart girth, substernal height,

ear length, tail length, tail width at the middle of the tail, and hair length. Means for each quantitative measurement were calculated to describe the size and shape of each population sampled.

I Suba lpine zone

II Humid lowland zone

III Wet highland zone

IV Arid lowland zone
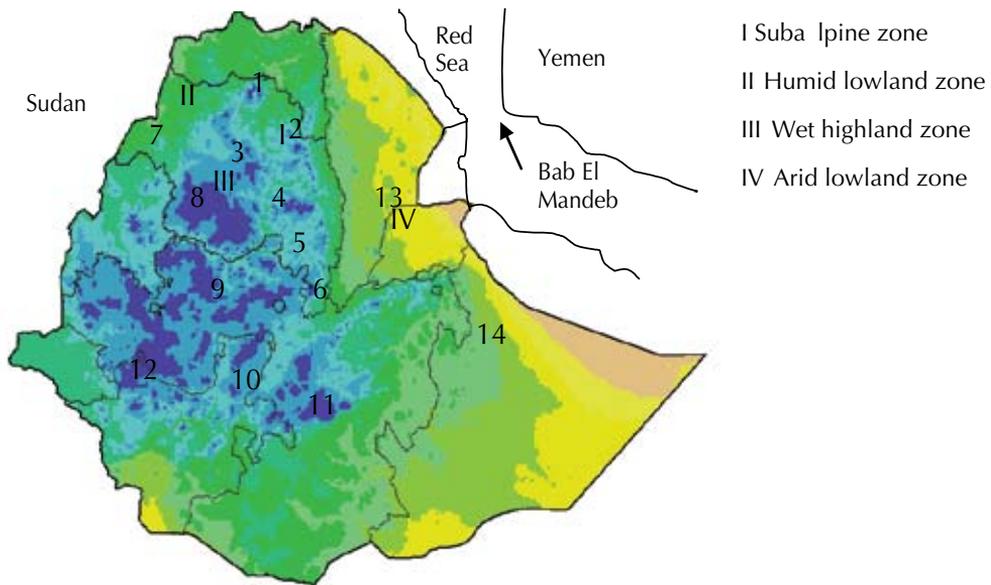
Source: Based on MOA (1998).

Figure 1. *Map of Ethiopia showing location of sampled sheep population and a sketch of the Red Sea area showing Bab-el-Mandeb, route of fat-tailed sheep introduction into Africa.*

Traditional sheep populations sampled: 1. Simien, 2. Sekota, 3. Farta, 4. Tikur, 5. Wollo, 6. Menz, 7. Gumz, 8. Washera, 9. Horro, 10. Adilo, 11. Arsi, 12. Bonga, 13. Afar, 14. Black head Somali.

Ecological zones: I. Subalpine: cool to very cold submoist/dry alpine mountains and plateaus, low vegetation cover, with average altitude of 3008 masl, with 1102 mm rainfall, maximum 22.1ºC and minimum 7.6ºC temperature; II. Humid lowland: hot subhumid lowland plain, high vegetation cover, with average altitude of 637 masl, 894 mm rainfall, maximum 37.7ºC and minimum 20.1ºC temperature; III. Wet highland: tepid to cool wet highlands, very high vegetation cover, with average altitude of 2091 masl, 1437 mm rain, maximum 24.8ºC and minimum 10.1ºC temperature; and IV. Arid lowland: hot arid lowland plain, very low vegetation cover, with average altitude of 894 masl, 404.5 mm rainfall, maximum 33.2ºC and minimum 17.4ºC temperature.

The 14 sheep populations identified were, based on the traditionally recognized ethnic or geographic names, local keepers, geographic and ecological distributions "distinctly" distinguishable by their different physical features. Information collected need to be compiled in a format (Table 1) that can facilitate the documentation of the populations in global databanks (DAD-IS of FAO and DAGRIS of ILRI).

Table 1. *Sheep types and their ecology, geographic distribution, distinguishing physical features, performance levels and population sizes*

Sheep types	Other names	Ecology	Geographic distribution	Important physical features* and performance levels	Population (000)
Subalpine short-fat-tailed group			9.1 –14.5°N and 36.3–39.8°E	Litter size range: 1.0 ± 0.01 to 1.09 ± 0.05	
Menz	Legegora, Shoa, Abyssinian, Ethiopian highland sheep	Submoist/ dry, subalpine highlands (2500 and 3200 masl);	North Shoa zone of Amhara state	Short fat tail turned-up at end; small body size; short-legged; long fleece with coarse wool; commonly black with white patches, white, brown, white with brown patches; straight-faced; horned males; short semi-pendulous ears with 12% rudimentary ears in the population. Kept by Amhara community	971.4
Sekota	Tigray highland, Abergelle	Cool, dry/ submoist highlands (2000 masl); semi-arid river valley	Wag Himra zone of Amhara State and Tigray State	Short fat tail turned-up at end and fused with main part; medium-sized; predominantly brown or white coat, few black with brown belly; white animals have finer hair or woolly undercoat; semi-pendulous or rudimentary ears in Wag Himra and Tigray, predominantly rudimentary in Tekeze valley. Reared by Agew, Tigray and Amhara communities	732.3
Semien		Alpine mountains (3000–4000 masl) including Semien wildlife park	North Gondar zone of Amhara state (Debark, Dabat, Janamora, Wegera)	Short fat tail; well developed woolly undercoat; plain brown, plain white, brown/white with white/brown patches, plain black and black with brown belly; unique long laterally spiral horn in males and short horns in most females; largest of the highland woollen sheep. Reared by Amhara community	347.6
Tikur		Subalpine highlands (3000 masl)	North Wollo zone of Amhara state	Short fat tail; woolly undercoat; predominantly black (60%) coat; small body size; majority short semipendulous ears, 24% rudimentary ears. Reared by Amhara communities	525.3

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Table 1. *continued*

Sheep types	Other names	Ecology	Geographic distribution	Important physical features* and performance levels	Population (000)
Subalpine short-fat-tailed group				Litter size range: 1.0 ± 0.01 to 1.09 ± 0.05	
Wollo		Cool highland (2000–3200 masl)	South Wollo zone of Amhara state	Short-fat-tail with short twisted/coiled end, occasionally turned up at end; Small size; well developed woolly undercoat; predominantly black, white or brown, either plain or with patches of white, black or brown; long hair with woolly undercoat; horned males. Reared by Amhara communities	
Farta		Submoist highland (2000–2500 masl)	South Gondar zone; Gondar zuria, Belesa, Dembia districts	Short fat tail; medium size; woolly undercoat; commonly white (37.5%), brown (27.5%) and black with brown belly (15%), white/brown with brown/white patches; males are horned. Reared by Amhara communities	555.6
Washera	Agew, Dangilla	Wet, warmer mid-highlands (1600–2000 masl)	West and East Gojam and Agew Awi zones of Amhara state; Dangur, Madura and Alefa Takusa districts	Short fat tail; large body size; short-haired; predominantly brown; both males and females are polled. Reared by Amhara and Agew communities	1227.7
Highland long-fat-tailed group				Litter size range 1.29 ± 0.06 to 1.55 ± 0.12	
Adilo	Wolaita	Wet, warmer mid-highland (1800–2000 masl)	North Omo, Derashie, Gedio and Amaro zones of Southern state; some northern Borana districts (1300–2400 masl)	Long fat tail reaching the hocks, broad at the base and upper third with long tapering end; large size; short-haired; males are short-horned and 18.4% of ewes are horned; predominantly brown (43%), brown with white patches (32%), black (16%), and black with brown patch (9%). Reared by Southern nationalities	407.7

9.1 –14.5°N and 36.3–39.8°E

10.4–5.8°N and 34.5–40.3°E

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Table 1._continued_

Sheep types	Other names	Ecology	Geographic distribution	Important physical features* and performance levels	Population (000)
Arsi-Bale		Mainly wet, cool and warmer highlands (2000–3300); submoist lowlands	Arsi, Bale, East Shoa, West Hararghe zones, some districts in Borana zones of Oromia; Hadya, Gurage, Kembata and Sidama zones	Long fat tail with twisted end in some animals; medium size; hairy fibre, especially in adult ewes, males have minor wool growth in some parts of body; males and most females (52%) are horned; large size; coat colours are brown (35.1%), brown with white patches (24.3%), black, white, and combinations of above colours. Reared by Oromo communities	6345.1
Horro		Cool, wet highlands (2991 masl) to humid mid-highlands (1600 masl)	East Welega, West Welega, Illubabor, Jimma and West Shoa zones of Oromia, and some bordering Gambella and Benishangul districts	Long fat tail extending below hock, either straight (51.4%) or coiled/twisted (48.6%) at the tapering end; prominent fat tail in males; large, leggy and prolific; dominant colours are brown and fawn, belly is lighter especially in adult ewes, less frequent are black, white, brown with white patches; both sexes are polled. Reared by Oromo, Benishangul and Gambella communities	3409.3
Bonga	Gesha, Menit	Humid mid-highland (1200–2500)	Keffa, Sheka and Bench zones of Southern State	Long fat tail with straight tapering end (98.4%); hair sheep; large size; predominantly plain brown (57.9%) or with black (0.9%) or white (5.3%) shade, plain white (10.5%) or with brown patches (10.5%), and black (2.6%); both sexes are polled. Reared by Keffa, Sheka and Bench communities	517.5
Lowland fat-rumped group					
Afar	Adal, Danakil	Mainly arid lowland (<1000 masl); mid-highland (1200–1900 masl)	Afar state; bordering Tigray, Amhara; East and West Hararghe and East Shoa of Oromia	Wide fat tail, in some large fat tail reaching below the hock; hair fibre; medium size; characteristically uniform creamy white/beige coat; rudimentary ear; polled; dewlap. Reared by Afar, Amhara, Tigray communities	681.9

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Table 1.*continued*

Sheep types	Other names	Ecology	Geographic distribution	Important physical features* and performance levels	Population (000)
BHS	Wanke, Ogaden, Berbera black head	Mainly arid lowlands (215–900 masl); highlands (up to 2000 masl)	Somali state; lowlands of Bale, Borana and south Omo zones; part of East Hararghe	Short fat rump with a stumpy appendage; uniform white body and black head and neck; polled; convex face, especially in males; short, outward forward drooping ear; well developed dewlap. Reared by Somali and Oromo, Konso and south Omo communities	906.2
Lowland thin-tailed group				Litter size 1.28 ± 0.06	
Gumz		Moist lowlands (< 1000 masl)	Benishangul-Gumz state; lowlands of North Gondar	Long thin tail; somewhat dwarf; convex face profile; long pendulous ear; commonly plain brown or with patch (39.4%), white with brown or black patch (21%), black (15.8%), white, black with white patch, brown with black patch; polled. Reared by Gumz and Amhara communities	50.9

* Coat colours are in order of frequency in the population.

Detailed and accurate performance characteristics can only be assessed on few selected breeds maintained on-station or monitored on-farm (see sections 2.1.2.2 and 2.1.2.3). Nonetheless, even in a nation-wide breed survey, involving single-visits, key individual and flock level performance can still be assessed. This was the case in this survey. Body weights of full-mouth adult ewes (Table 4) were taken/assesed using sling balance and their reproduction performance (flock or for selected animals) data (Table1) were collected using farmer recall method.

2.2.2.2 Bio-geographical mapping of the resources

Description of geographical and ecological distribution as well as estimates of population sizes of animal genetic resources is also an essential component of characterization effort. Geographical distribution of animal genetic resources can be accurately mapped using geographic information system (GIS) tools. A simplified approach as used to map sheep resources of Ethiopia can also be adopted (Figure 2).
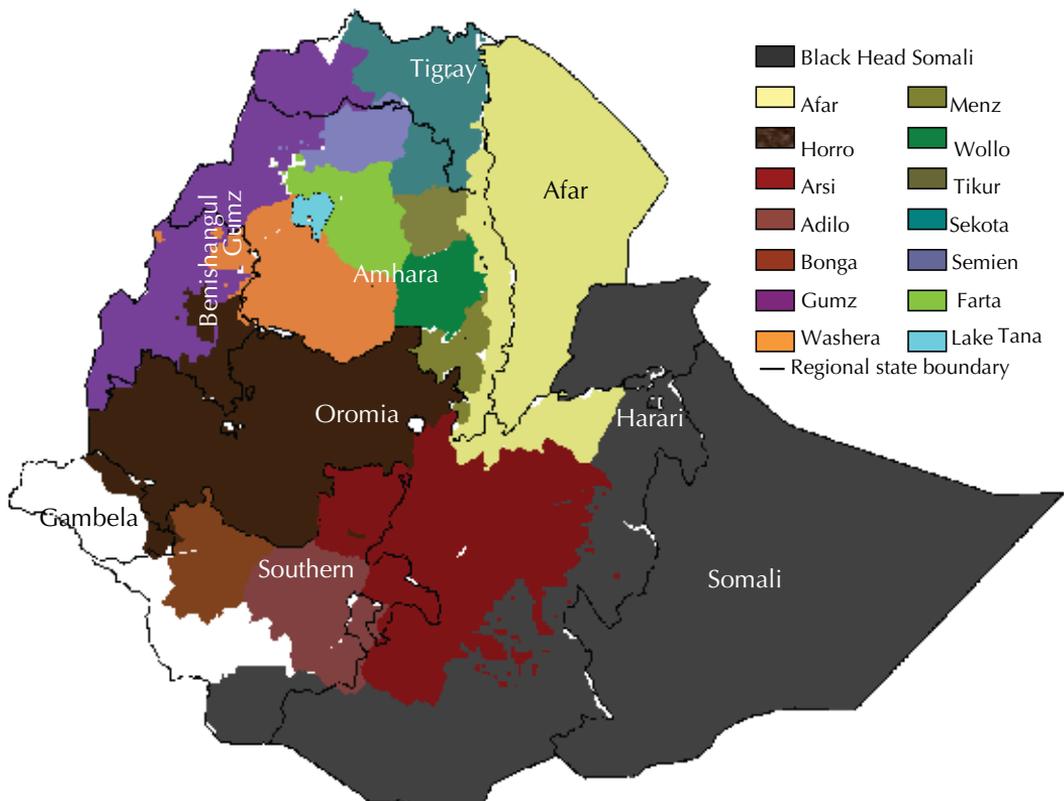
Source: Solomon et al. (2008a).
Figure 2. *Geographic distribution of sheep types.*

Here we consulted farmers and development agents on the distribution of the sheep populations and made extensive field observation which was virtually a transect walk across

the country. Distribution of each population was appraised by district level, and a district-based digital mapping resource (Collins et al. 2001) was used to map the resources. Figure 1 shows ecological distributions of the populations.

Breed-level population data is required to monitor risk status of populations and design conservation and improvement programs. However, breed-level livestock population data are not available in developing regions. Livestock population censuses are commonly taken by geographical location (district, zone or region) of populations. We used the national livestock estimate of sheep population (CSA 2005) to derive breed-level population estimate for sheep breeds in Ethiopia (Table 1). Breed-level population estimates were extracted based on geographic distribution of the breeds.

Population sizes as such may not show the risk status of breeds. A direct indicator of the population characteristics is the effective population size, which can be calculated from the rate of inbreeding in the population. Rate of inbreeding is also an indicator of the level of within-population genetic diversity. Rate of inbreeding can be calculated using molecular data. However, in situations where acquisition of molecular data is not practicable, as is the case in most developing countries, information on flock structure can be used to calculate the rate of inbreeding using the formula:

$$\Delta F = 1/4N_m + 1/4N_f$$

where N_m and N_f, are the number of breeding males and females in the flock, and effective population sizes using the formula:

$$N_e = 1/2\Delta F$$

Thus a detailed description of breed-level average flock sizes and compositions by sex and age is essential (see Solomon et al. 2008).

2.2.3   Production system description

Description of production systems has abounded the literature on livestock studies in developing regions. Most of the studies are too detailed and the information contained may not worth the time and resources spent. Detailed studies are not feasible, particularly when breed-level description of production systems at national level is required. In recognition of the high resource requirements for extensive surveys, particularly in developing regions, a simplified recording of production system variables has been suggested (FAO/UNEP 2000; see Appendix 1).

A brief description using major indicators of production systems and environments may give a fair picture of a breed's niche. Such an approach was adopted for characterizing the production systems and environments in which sheep breeds of Ethiopia are raised and adapted (Table 2). It is important to assess the whole range of production systems and environments where a particular breed is raised. Such information gives an indication of the range of productive and adaptive potential of a breed. It should be noted from Table 2 that a particular breed could be raised in more than one production system and environment (e.g. BHS is primarily adapted to arid lowlands but it seems that its adaptive fitness has extended through time to higher altitudes).

Table 2. *Sheep types and major sheep production systems in Ethiopia*

Production systems	Characteristic features of production systems			Sheep breeds
	Environment	Main products	Scale of production and management	
Subalpine sheep–barley system	Subalpine (> 3000 masl)	Meat, fibre, manure, skin; unreliable, long-season barley	Medium-scale sheep production; semi-intensive,[†] low-input	Simien,[1] Tikur,[1] Menz,[1] Wollo,[1] Farta,[2] Arsi-Bale,[3] Horro[3]
Highland cereal–livestock system	Highlands (1500–3000 masl)	Mainly cereal cropping; meat, manure, skin	Small-scale sheep production; semi-intensive, low-input	Washera,[1] Sekota,[1] Horro,[2] Arsi-Bale,[2] Wollo,[3] Farta,[1] BHS[3]
Highland perennial crop system	Highlands (1500–2000 masl)	Mainly perennial cash crops (coffee, inset, khat); meat, skin	Minor sheep production; semi-intensive, low-input; some practice tethering	Bonga,[1] Adilo,[1] Horro,[2] Arsi-Bale[2]
Lowland crop–livestock system	Wet lowland (up to 1000 masl)	Cereals, sesame, cotton; meat, skin	High level of livestock keeping; semi-intensive, low-input	Gumz,[1] Afar,[3] Arsi-Bale,[3] BHS[3]
Pastoral/ agro-pastoral system	Semi-arid/ arid (up to 1000 masl)	Meat, milk, skin; minimal or no cropping	Rangeland-based large-scale sheep production; extensive, low-input	Afar,[1] BHS[1]

[†] Based on feeding, veterinary care, and housing.

1. Major portion of or the whole sheep population is managed under the system.

2. Significant portion of the sheep population is managed under the system.

3. Minor portion of the sheep population is managed under the system.

Other important characteristics of sheep production systems in Ethiopia collected include breed-level flock structure and farmers' assessment of their breed in terms of productive and adaptive traits. The information was collected in a single-visit simple participatory survey tool, Rapid Rural Appraisal (see Solomon et al. 2008a). A detailed analysis of the production

systems in which a breed is used may be needed for a breed(s) chosen for technological interventions. Information to be collected may include farmers' socio-economic conditions, preferences, and breeding, production and marketing objectives. Such information could be collected in a single-visit survey (e.g. see Solomon (2008) for Menz and BHS breeds) or as part of a multi-visit on-farm monitoring activity (see section 2.1.2.3).

2.2.4 Molecular genetic characterization

2.2.4.1 Genotyping

Molecular genetic characterization of populations broadly involves analysis of the genetic diversity within- and between-populations. Arrays of molecular genetic markers are used to describe the molecular genetic characteristics of livestock populations. Microsatellite allele frequency is commonly used. This was also used to estimate within-population genetic diversity and genetic distances between sheep populations in Ethiopia. A strategy that was used for blood sampling and for genotyping is described in section 2.2.1.2. All animals sampled were genotyped using 17 microsatellite genetic markers: OARVH72, TGLA53, MCM42, OARFCB20, ILSTS005, ILSTS011, BM8125, ILSTS44, DYMS1, MAF209, MAF214, MCM527, OARFCB11, OARCB226, OARFCB304, OARJMP29, and SRCRSP9 as recommended by FAO (2005). DNA extraction, amplification and analysis were done following standard procedures (see Solomon 2008 for details).

2.2.4.2 Within-population genetic diversity

Study of the genetic variation within a population gives indications as to the potential of a population to adapt to a changing environment. Study of within-breed diversity may also provide information on the potential response of a population to within-breed selective genetic improvement. However, markers currently in use for genetic characterization are neutral markers and thus there is a need to characterize populations based on variation at quantitative trait loci coding for productive and adaptive functions. Generally, within-population diversity is important to measure as it is one major criterion to set conservation priorities.

Most genetic characterization studies list a range of measures of genetic diversity within populations. In the study of sheep resources of Ethiopia, we selected two parameters to estimate genetic diversity (allelic richness and expected heterozygosity). We observed a high degree of within-breed genetic diversity compared to between-breed diversity. This is a characteristic of large traditional populations that have not been under strong selection (Lauvergne et al. 2000). This is a strong indication to the need to conserve traditional populations.

2.2.4.3 Between-population genetic diversity

Another measure of genetic diversity is genetic distances between populations. Genetic differentiation can be measured as overall genetic differentiation among sheep populations and differentiation between pairs of populations. Genetic differentiation of sheep populations in Ethiopia was estimated by F-statistic (FST) and genetic distances between populations were measured by Nei's (1972) genetic distance, DA.

An important characteristic to note in genetic diversity in livestock populations is that the variation within a population is much larger than that between the populations. This is well exemplified in the study of Ethiopian sheep where the diversity between Ethiopian sheep populations accounted for only 4.6% of the overall genetic diversity (global FST value = 0.046 ± 0.004), the rest being accounted for by within-population variation. It is also important to note that the relative small contribution of between-breed diversity to total diversity does not necessarily imply small differences between populations; FST values between pairs of Ethiopian sheep populations indicated that most populations are genetically distinct.

2.2.5   Approaches to classification

Classification determines methods for organizing the diversity of livestock populations. Phenotypic and genetic description of surveyed livestock populations should not be the final output of a characterization effort. Most characterization efforts culminate in providing the phenotypic and molecular genetic characteristics of the surveyed populations. However, such information should be further utilized to classify the traditional populations into phenotypically and genetically distinct management units termed as 'breeds' in conventional animal breeding nomenclature.

Different 'levels of classification' can be considered depending on the resources available to generate data on the phenotypic and genetic characteristics of populations. Populations could be broadly categorized based on few morphological characters which are believed or known to have evolutionary significance in differentiation of populations. If resources allow, populations could be classified based on detailed morphological characters employing advanced multivariate morphometric analysis. Further, genetically distinct breeds could be identified using molecular genetic tools.

2.2.5.1 Significant morphological characters

The first attempt to categorize African sheep based on few significant phenotypic characters such as tail and hair type was by Epstein (1971). In this section, classification of Ethiopian sheep into major groups based on significant phenotypic characters is described.

The 14 sheep types were categorized based on tail type and tail form/shape (short vs. long), as well as their ecological and geographical distribution as presented below. Tail type is a significant morphological character used to classify African sheep as it is related to evolutionary history of founder sheep populations from Asia. A careful examination of morphological characters and eco-regional distributions can result in a more refined categorization of populations. For instance, earlier studies used tail type (MOA 1975) and eco-regional distribution (Sisay 2002) to describe some of the sheep types. Inclusion of tail form/shape as a criterion in the current study enabled identification of two groups of fat-tailed sheep (short-fat-tailed and long-fat-tailed) which were grouped together previously as fat-tailed sheep. In the current study four major groups were identified: subalpine short-fat-tailed, highland long-fat-tailed, lowland fat-rumped, lowland thin-tailed. Each group inhabits an adjacent geographic and ecological region and the four groups differ in other morphological characteristics and certain performance parameters (Table 1).

2.2.5.2 Multivariate analysis

As discussed above, detailed phenotypic data can be used for classification purpose if time and resources allow. Quantitative and qualitative characters as described in section 2.1.2.1 were used for the multivariate analysis. The quantitative measurements were made size-free by allometric transformation. This was done to transform the quantitative size measurements to measures of body shape which is an important adaptive character. Multivariate analysis using continuous quantitative and discrete qualitative variables together could pose a problem as most software for multivariate analysis have no provision for such combined analysis. This problem was overcome in the current analysis by scoring qualitative characters on a quantitative binary scale using dummy variables. See Appendix 2 for description of the characters and character states. Hierarchical cluster analysis and discriminant function analysis were used to depict morphological clustering patterns (see Solomon et al. 2007 for a detailed method).

Setting the break point for Euclidean distance at 10 (Figure 3), the 14 populations clustered into four groups which corresponded to the four groups classified based on tail form and shape alone (see section 2.2.5.1). The exception was Washera sheep which was separated from the short-fat-tailed group. Washera sheep is an out-group. Though it has a short fat tail, it does not resemble the other populations in the group: it is a hair sheep, large-sized and prolific (litter size = 1.8). Hair coat is found in several East African fat-tailed sheep that have interbred with hairy thin-tailed sheep (Epstein 1971).

The question arises whether multivariate analysis which requires collection of data on a multiple of phenotypic descriptors is worthwhile. Comparison of the two phenotypic approaches for classification discussed in sections 2.2.5.1 and 2.2.5.2 reveals that there is a

high congruence between visual classification based on few morphological characters and multivariate analysis. The added advantage of multivariate analysis in discriminating Washera sheep may not deserve the extra time and resource spent to collect data on a multiple of phenotypic traits. Nevertheless, data on a multiple of phenotypic descriptors need to be collected in order to describe the populations adequately (see Table 1).
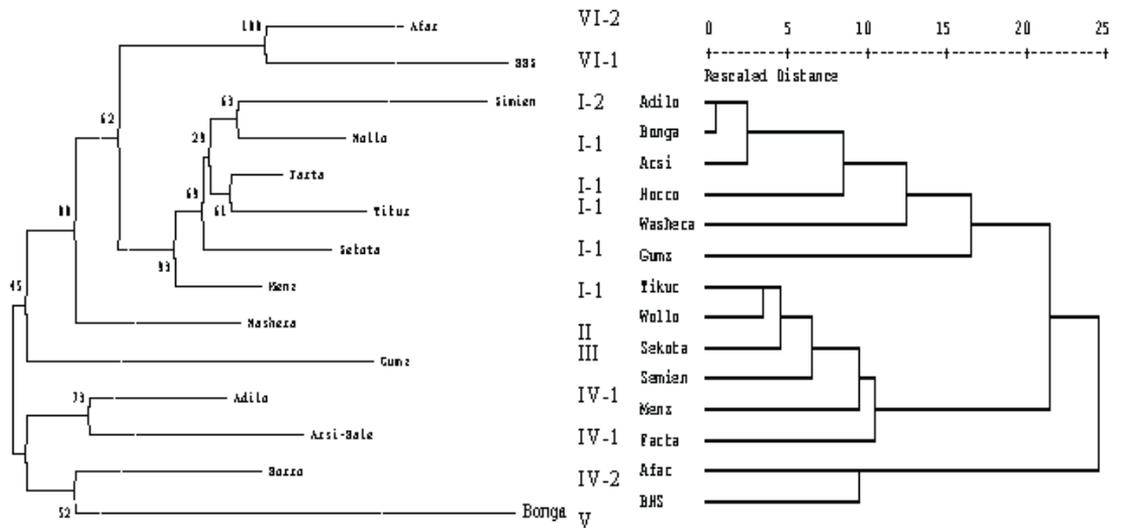
Figure 3. *Neighbour-joining dendrogram.*

These are constructed from Nei's genetic distances (left), and UPGMA dendrogram constructed using between-population Euclidean distances derived from morphological variables (right). Roman numbers indicate breed groups, and within breed group; Arabic numbers indicate breeds.

2.2.5.3 Should phenotypic classification suffice?

Phenotypic descriptors are the oldest tools for taxonomic studies. In fact the 'Tree of Life' is constructed based on observation of morphological traits. The value of morphological classification can be evaluated by assessing the congruence between morphological and genetic data obtained on the same sample population. From the study on sheep resources of Ethiopia, it can be seen that there is a fair congruence between the dendrograms constructed based on Euclidean distances and molecular genetic distances (Figure 3). Populations in the five morphological clusters (section 2.2.5.2) also clustered together in the genetic tree. Furthermore, populations in the four major groups classified using significant morphological characters (section 2.2.5.1) also clustered together in the genetic tree.

From the discussion above, it should be fairly safe to conclude that morphological characterization is an important tool in characterization of sheep resources, and that morphological variation could be used to classify populations into genetically distinct

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major groups. Besides, morphological characterization could be used as a sole tool where resources are limiting, which is the case in most developing regions. However, even multivariate analysis could not discriminate between populations within the major groups. For such detailed characterization, molecular genetic tools are required. A further drawback of morphological tools is that they cannot distinguish between populations that are under similar adaptive evolutionary processes but under different forces of neutral selection (e.g. Horro and Bonga sheep).

2.2.5.4 Molecular classification

Two molecular genetics tools were used to classify sheep resources of Ethiopia. The first is based on the 14 predefined populations using Nei (1972) genetic distance, *DA*. Five distinct clusters (Figure 3) can be discerned based on Nei genetic distances: (1) Menz, Sekota, Tikur, Farta, Wollo, and Simien; (2) Adilo, Arsi-Bale, Horro and Bonga; (3) Afar and BHS; (4) Gumz; and (5) Washera.

The above tree-based method could not discriminate populations within each cluster. Further, the approach could not tell if there are genetically distinct subpopulations within a population. Therefore, a Bayesian method without a priori knowledge on populations (i.e. taking the 14 populations as a single population) was used to refine the classification (Table 3). The Bayesian analysis refined the classification by discriminating Bonga sheep from the long-fat-tail group. The analysis further gave the level of admixture within each inferred population. The information on the level of admixture is particularly important as to why Washera sheep clustered separately in the tree-based analysis.

Table 3. *Proportion of membership of each of the 14 predefined populations in each of the 5 inferred populations obtained from Bayesian analysis*

Predefined populations	Inferred populations				
	1	2	3	4	5
Simien	0.043	0.027	0.079	0.799	0.053
Sekota	0.074	0.059	0.090	0.569	0.207
Farta	0.094	0.072	0.106	0.582	0.146
Tikur	0.052	0.065	0.143	0.642	0.099
Wollo	0.101	0.069	0.132	0.574	0.124
Menz	0.094	0.091	0.090	0.507	0.217
Gumz	0.073	0.038	0.828	0.031	0.030
Washera	0.319	0.054	0.323	0.204	0.099
Horro	0.624	0.143	0.116	0.048	0.068
Adilo	0.669	0.112	0.079	0.060	0.081
Arsi-Bale	0.674	0.051	0.097	0.059	0.119
Bonga	0.025	0.892	0.033	0.018	0.032
Afar	0.097	0.062	0.106	0.113	0.621
BHS	0.075	0.035	0.043	0.044	0.803

Classification of genetic resources should be based on a combined consideration of genetic differentiation, phenotypic distinctness and ecological distribution of populations. Besides to their value as a classification tool, phenotypic or morphological characters help in describing the genetically distinct populations. Furthermore, ecological and morphological variations are indicative of adaptive variation among populations. We made use of the different molecular analytical tools to arrive at a thorough classification of sheep resources of Ethiopia. Based on Bayesian method, six breed groups were identified. Within each breed group, we considered the DA distance between populations and identified in total nine breeds (Table 4).

Table 4. *Proposed classification of Ethiopian sheep into major breed groups and breeds*

Breed group	Breed	Population	Tail type/shape	Fibre type	Body weight[1] (kg)
I. Short-fat-tailed	Simien	Simien	Fatty and short	Fleece	26.9
	Short-fat-tailed	Sekota, Farta, Tikur, Wollo, Menz	Fatty and short	Fleece	25.4
II. Washera	Washera	Washera	Fatty and short	Hair	32.8
III. Thin-tailed sheep	Gumz	Gumz	Thin and long	Hair	31.0
IV. Long-fat-tailed	Horro	Horro	Fatty and long	Hair	35.4
	Arsi	Arsi-Bale, Adilo	Fatty and long	Hair	28.6
V. Bonga	Bonga	Bonga	Fatty and long	Hair	34.2
VI. Fat-rumped sheep	Afar	Afar	Fat rump with fat tail	Hair	31.0
	BHS	BHS	Fat rump/tiny tail	Hair	27.9

1. Average adult body weight for a given breed.

2.2.6 Causes of divergence

Knowledge on the degree of genetic and morphological diversity of a genetic resource and the classification of the diversity into management groups should be supplemented with information on the factors contributing to diversification of the genetic resource. This helps to design a successful program for the management of the resources. To this end, information on the historical pattern of diversification of populations under study, the role of the communities maintaining the populations through breeding management practices, and adaptive variation among populations including the factors contributing to adaptive variation need to be assessed.

Current population structure in African sheep populations is believed to correspond to the historical pattern of introduction of sheep into Africa. Sheep were introduced to Africa via three routes of migration and identified as fat-tailed, thin-tailed and fat-rumped sheep (Epstein 1971). However, further diversification after initial introduction of the three precursor

populations is to be expected. This is best exemplified by the case in the study of Ethiopian sheep where a careful observation of the sheep populations revealed further diversification in significant morphological characters. Such diversification could be due to adaptive fitness or selective breeding by the communities maintaining the resources. An approach for analysing the association between the hypothesized causal factors and the observed genetic and morphological variation based on Manly (1991) is presented in Solomon et al. (2007). For example, the analysis of population structure in Ethiopian sheep indicated that morphological variation was found to be adaptive and significantly related with ecological distribution of the populations. On the contrary, further genetic differentiation after initial introduction was explained by Isolation-by-distance model (Wright 1943), and was not related with variation in ecology or breeding management of the different communities maintaining the resources.

3 Conservation of sheep resources

The goal of characterizing livestock genetic resources is to gather information on the diversity and genetic merits of the resources that can be used to develop conservation and genetic improvement programs. The interface between conservation and genetic improvement programs or utilization does not seem very clear in the literature when the concept of conservation is applied to farm animals which are a major source of livelihoods in many parts of the world. The main question to answer regarding conservation of farm animals is whether conservation and genetic improvement are competitive or complementary.

Conservation of livestock resources should ideally be undertaken at global level because of the existence of cross-country breeds. However, specific local interests, such as conservation with the objectives of improving local communities, are better served by national conservation programs. Furthermore, breed information collected for local or regional conservation purposes can as well be used for designing global conservation schemes. The first and primary activity in designing a national livestock conservation program is to set conservation priorities at species and breed levels.

3.1 Strategies for setting conservation priorities

Resources are always limited to conserve all the available livestock genetic resources, particularly at the national level in most developing regions. Besides, all the breeds may not be at risk or endangered, or may not contribute equally to the total genetic diversity or to the socio-economic livelihood of the communities maintaining the breeds to warrant conservation efforts. Thus there is always a need for setting priorities to conserve, develop and utilize among the available genetic resources.

Strategies for setting conservation priorities for livestock populations depend on the objectives or arguments for conservation. Insurance arguments promote preserving the available genetic diversity for the uncertain future. Another argument is conservation for sustainable utilization of the resources currently and for posterity.

In this section, a methodological approach to select breeds for conservation is illustrated, adopting strategies identified by Bennewitz et al. (2007) for setting conservation priorities. Information gathered for characterizing and conserving sheep resources in Ethiopia is used for the illustration. The illustration focuses on how the ranking of breeds changes as the objectives for conservation effort changes. Relevance of the strategies for conserving livestock genetic resources in the context of developing regions is discussed.

3.1.1 Risk strategy

Risk strategy is defined as the choice of breeds for conservation based on their risk status. Risk status of breeds has been considered as a primary criterion for setting conservation priorities. Risk categories for livestock breeds (safe, endangered, critical) have been defined by FAO. Risk status or degree of endangerment of a breed is inferred from various criteria: population size, population dynamics, number of breeding males and females, rate of inbreeding, level of indiscriminate crossbreeding, ongoing conservation activities, and risk of natural and human disaster. Crossbreeding may increase overall genetic diversity as it introduces new genes in the population and new genotypes (e.g. synthetic breeds). However, the major culprit threatening the survival of the adapted indigenous breeds in Africa is indiscriminate or irrational crossbreeding. Crossbreeding can be considered as 'a necessary evil' as it delivers the much desired fast growth in livestock productivity and at the same time threatens the indigenous breeds through breed replacement.

Risk or threat status of sheep breeds in Ethiopia was established using five indicators. In order to derive a unique risk criterion, the five indicators were combined to a single value of extinction probability (see Solomon et al. 2008b for description of the indicators and deriving extinction probabilities). Most of the breeds with high threat status (Table 5) do not contribute to the sheep genetic diversity in Ethiopia. Contribution of a breed to the total genetic diversity of a species depends on whether there are other breeds which are closely related with it. If risk strategy were to be adopted for setting conservation priorities for Ethiopian sheep, then most of the genetic diversity would be lost. Therefore, risk strategy could fall short of addressing a major objective of conservation efforts, conserving the maximum genetic diversity for the uncertain future. The strategy also does not consider contribution of breeds to the livelihood of the communities keeping the animals, which should be a major objective in developing regions.

3.1.2 Maximum-diversity-strategy

3.1.2.1 Measures of contribution to diversity

The strategy targets conservation of the maximum of the genetic diversity in a population for the uncertain future (insurance objective of conservation). Breeds for conservation are selected solely based on their contribution to genetic diversity. Two alternative methods have been suggested in the literature to assess contribution of livestock breeds to the total genetic diversity conserved. The first (Weitzman method) is based on between-breed genetic diversity (Weitzman 1992), and the second (core set method) accounts for both between- and within-breed genetic diversity (Eding et al. 2002; Caballero and Torro 2002).

Table 5. *Relative conservation priorities for Ethiopian sheep breeds based on contributions to Eding core set diversity, extinction probability and overall breed merits*

Breed	Contribution to diversity	Extinction probability[1]	Average breed merit[2]	Total utility	Conservation priority
Farta	0.0000	0.50	0.27	0.27	10
Menz	0.0000	0.40	0.40	0.40	4
Sekota	0.0000	0.10	0.23	0.23	13
Simien	0.4355	0.30	0.33	0.60	1
Tikur	0.0000	0.30	0.33	0.33	8
Wollo	0.0000	0.50	0.33	0.33	7
Afar	0.1291	0.05	0.40	0.41	3
BHS	0.0000	0.10	0.40	0.40	5
Adilo	0.0000	0.40	0.17	0.17	14
Arsi-Bale	0.0000	0.10	0.27	0.27	12
Horro	0.0000	0.20	0.27	0.27	11
Bonga	0.1774	0.40	0.20	0.34	6
Gumz	0.1170	0.90	0.23	0.44	2
Washera	0.0696	0.10	0.27	0.28	9

1. Extinction probabilities were calculated based on indicators of threat status (see section 3.1.1).

2. Average breed merits were calculated as average of economic, ecological and socio-cultural merits.

The two methods were compared using microsatellite data collected on Ethiopian sheep breeds (Solomon 2008). The core set method appears to be more appropriate for selecting breeds for conservation as it favours breeds with high between- as well as within-breed variation, while the Weitzman method favours the conservation of genetically distance but inbred breeds. This argument has been supported by other findings (Caballero and Torro 2002; Eding et al. 2002; Tapio et al. 2006).

However, the core set method involves maintaining an interbreeding population composed of individuals selected from the breeds contributing to the core set. This may not suit conservation strategies (such as community-based management of genetic resources in developing regions) that aim to maintain individual breeds that have affinities with specific communities. Yet, the core set method can still be used to rank breeds based on their relative contributions to the core set and maintain the breeds separately (see Solomon et al. 2007 for such application).

3.1.2.2 Relevance to developing regions

The maximum-diversity-strategy may be most appropriate in the context of wildlife conservation and avoiding extinction of rare livestock breeds at the brink of extinction,

particularly in the developed regions. The primary objective of livestock conservation for developing regions is sustainable utilization with the view of improving the livelihood of the communities maintaining the genetic resources. The maximum-diversity-strategy does not meet this objective. For instance in the study of sheep resources of Ethiopia, most of the breeds with high current breed merits would have been excluded if conservation priorities were to be set based on their contributions to genetic diversity alone (Table 5).

3.1.3   Maximum-utility-strategy

3.1.3.1 Setting conservation priorities

To meet conservation objectives of developing regions, an approach combining threat status of breeds, their contributions to genetic diversity, and to farm livelihoods (i.e. current breed merit, which includes economic or production, ecological and socio-cultural values of breeds) is needed. Such an approach (maximum-utility-strategy) is applied for setting conservation priorities among Ethiopian sheep breeds (Solomon et al. 2008b). The relative conservation priorities of the breeds changed when they were ranked based on their contribution to genetic diversity alone or on their total utility (Table 5). The five breeds that contributed to the total genetic diversity in Ethiopian sheep constitute the top priority group for conservation. However, among the five breeds, Bonga and Washera are excluded when breeds are ranked based on their total utility. The two breeds (Menz and BHS) that replace Bonga and Washera have higher average breed merit values although they do not contribute to the total genetic diversity conserved. Conservation of the five breeds with highest total utility would still conserve 73.4% of the genetic diversity in Ethiopian sheep. Total genetic diversity conserved could be increased to 92.5% if the sixth highest ranking breed (Bonga) is also included in the conservation list. Consideration of current breed merits besides to their contribution to neutral genetic diversity enables to balance the trade-offs between conserving diversity as insurance against future uncertainties and for current sustainable utilization of Ethiopian sheep breeds.

3.1.3.2 A simplified approach to ...

A broad conservation objective needs to target sustainable contributions of breeds to current farm livelihoods and insurance against uncertain future. There has been very limited research on optimally combining measures of neutral diversity and breed merits in order to rank breeds on their total utility. A conceptual framework for a maximum utility through a weighted summation of measures of neutral diversity and breed merits has been suggested by Simianer et al. (2003). The limitation to apply such a framework is that currently there is no obvious way of obtaining weights such as relative economic values of neutral diversity.

A simplified approach to rank breeds on their total utility as used in Solomon et al. (2008b) can be adopted to provide a working ranking of breeds. Total utility of breed i (u_i) can be estimated as:

$$u_i = 2(z_i * D_i) + W_i$$

where z_i is extinction probability, D_i is partial contribution of breed i to Eding core set (the loss of diversity caused by the extinction of breed i). W_i is current merit of breed i. The 'conservation potential' $(z_i * D_i)$ is the possible increase in expected diversity if an endangered breed i was made completely safe.

3.2   Conservation methods

There are two broad conservation approaches: *in vitro* and *in vivo*. *In vitro* method is cryopreservation of genetic materials. It is too early to make use of cryopreservation in many developing countries. In the mean time, there are more feasible conservation methods at hand under the current circumstances including *in vivo* conservation. *In vivo* conservation includes *in situ* and *ex situ* methods. *Ex situ in vivo* conservation is the maintenance of pure-bred nucleus flocks in organized government farms or research farms which can form a repository of the pure breed. However, maintenance of *ex situ* flocks needs to be linked to farmer livelihoods in order to be feasible, for instance through closed or open nucleus breed improvement schemes. *In situ* conservation is the maintenance of livestock breeds in their natural breeding tract through their sustainable utilization by the communities keeping them. *In situ* approach is the method of choice for conservation of farm animal genetic resources, particularly where farm animal genetic resources are the best available livelihood option for farmers.

3.3   Conservation through utilization
3.3.1 Communities are the vanguards of genetic resources

Unlike modern breeds of livestock, traditional breeds have been developed and maintained by communities through generations of breeding. Communities have in the process developed indigenous knowledge of managing their breeds. It is thus important that communities be involved and spearhead conservation of traditional breeds. Animal genetic resources could be considered as national and global public goods and their utilization be guided by national strategies. However, such national strategies should fully consider communities' interests and economic needs as livestock are the major means of livelihoods for farmers and pastoralists.

3.3.2 Genetic improvement-based conservation

3.3.2.1 Conservation vs. definition of breeding objectives

Sustainable animal breeding enhances conservation of genetic resources. Sustainable animal breeding strategies require a broad definition of breeding objectives that emphasize biodiversity in addition to increased genetic progress. Such a conservation-based breeding program should be based on a broader breeding objective (than conventionally defined narrower objective) that incorporates the needs and perceptions of the community and maintenance of the genetic diversity such as adaptation traits. Involvement of the farmers in the design and implementation of the breeding program is in line with the principles of *in situ* conservation of genetic resources.

An example of a conceptual framework for a farmer-participatory conservation-based breeding strategy is presented in Solomon (2008) for sheep breeds in Ethiopia. In the framework, it is argued that adaptive traits are as important as production traits in subsistence farming in marginal areas. It is also argued that sustainable livestock production requires a trade-off between increased productivity and adaptation. The argument is substantiated in the analysis of alternative breeding objectives (production vs. production + adaptation traits, Table 6), which shows that a sacrifice of 25.0 – 58.0% in genetic gain of production traits was required in order to balance genetic progress and conservation of adaptive potential (FEC) of Menz sheep.

Table 6. *Genetic gains attained from selection indexes constructed using production (YW) and production and adaptation (FEC) traits based on farmers preferences of traits*

Selection index	Breeding-objective traits[‡]						
	YW	MW	ADG	CG	NLW	GFW	FEC
Production traits	0.64	0.50	0.012	0.85	0.009	0.017	−3.8
Production + adaptation traits	0.32	0.21	0.009	0.43	0.009	0.010	−13.7

[‡] YW, yearling weight; MW, mature weight; ADG, daily gain during finishing; CG, chest girth; NLW, number of lambs weaned; GFW, greasy fleece weight; FEC, faecal worm egg count.

3.3.2.2 Conservation vs. breeding programs

Livestock breeding programs can be broadly categorized into hierarchical and village-based breeding programs. Hierarchical breeding programs involve commonly tiers where genetic improvement is created in a station nucleus flock and genetic gain is disseminated to village flocks. The down side of hierarchical breeding programs is their inconsideration to the preferences of the end-user communities for genetic improvement of their breeds. On the other hand, village or community-based breeding programs involve a one-tier breeding scheme where both genetic improvement and production are carried out in village flocks.

In situ conservation of livestock breeds is primarily the active breeding of animal populations and their continued use as part of an ongoing livelihood strategy (Woolliams et al. 1998; Gibson et al. 2006). In such a context, community- or village-based breeding programs can be viewed as part and parcel of a comprehensive conservation plan, and not as a separate genetic improvement activity that entails significant additional costs.

Village-based breed improvement programs are complementary to *in situ* livestock conservation objectives. However, consideration should be given to maintaining the genetic diversity while aiming for maximum genetic progress. Studies on conservation-based optimal design of village breeding schemes under smallholder conditions in developing regions are very limited in the literature. Optimizing breeding schemes requires consideration of both short-term (high rate of genetic gain) and long-term (maintenance of genetic variance and avoidance of inbreeding depression) effects of selection decisions. Study on the designing of conservation-based village selection scheme for Ethiopian Menz sheep (Solomon 2008) showed that the design should compromise the genetic gain achieved and the rate of inbreeding which is a measure of within-breed genetic diversity. Important factors to consider when designing the breeding scheme are the intensity of selection (Figure 4) and the flock size or effective population size which can be increased by increasing the number of villages cooperating in the scheme (Figure 5).
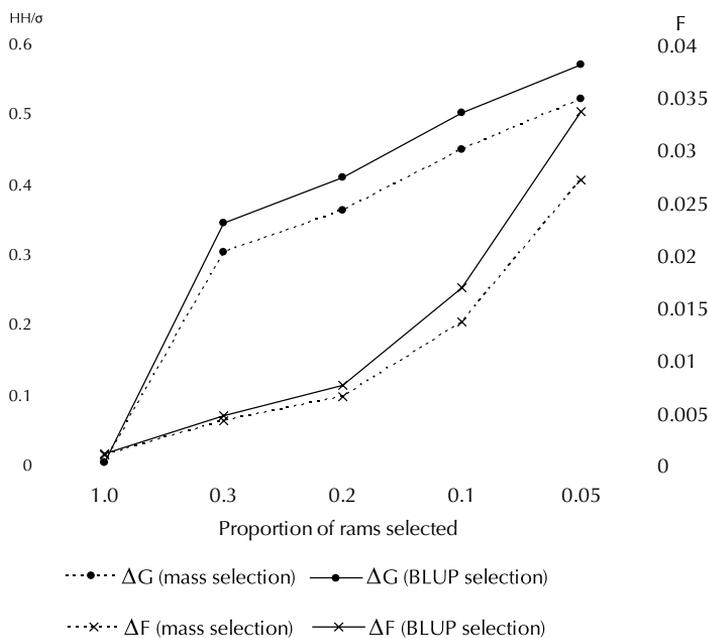
Figure 4. *Aggregate response as proportion of genetic standard deviation of the aggregate genotype (H/σH) and rate of inbreeding (ΔF) with decreasing proportion of rams selected.*
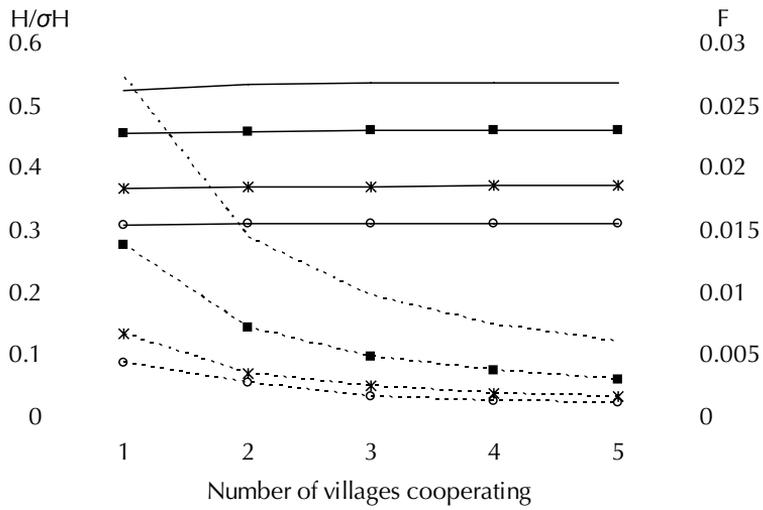
**Figure 5.** *Aggregate response as proportion of genetic standard deviation of the aggregate genotype (H/σH) and rate of inbreeding (ΔF) with increasing number of villages cooperating and different proportions of rams selected (P).*

4 Concluding remarks—Operational aspects of characterization and conservation

This report presented the technical aspects of sheep genetic resource characterization and conservation in developing regions. Operational aspects of setting up national program for characterization and conservation action may be country specific. However, some general aspects such as institutional setups and breeding policy and strategy formulation could be similar across countries. The *ad hoc* conservation programs and institutions set up in some developing countries are largely non-functional and efforts are uncoordinated. In some cases, there is an overlapping mission of institutions regarding conservation of livestock species which further aggravates the coordination effort. There is thus a need for institutional analysis to identify an apex body to coordinate national characterization and conservation programs and collaborating institutions that have the means to carry out the activities. Research, development and documentation activities in national livestock characterization and conservation programs also need to be identified. Figure 6 shows such a scheme for a national livestock characterization and conservation program, taking Ethiopia as a case study.
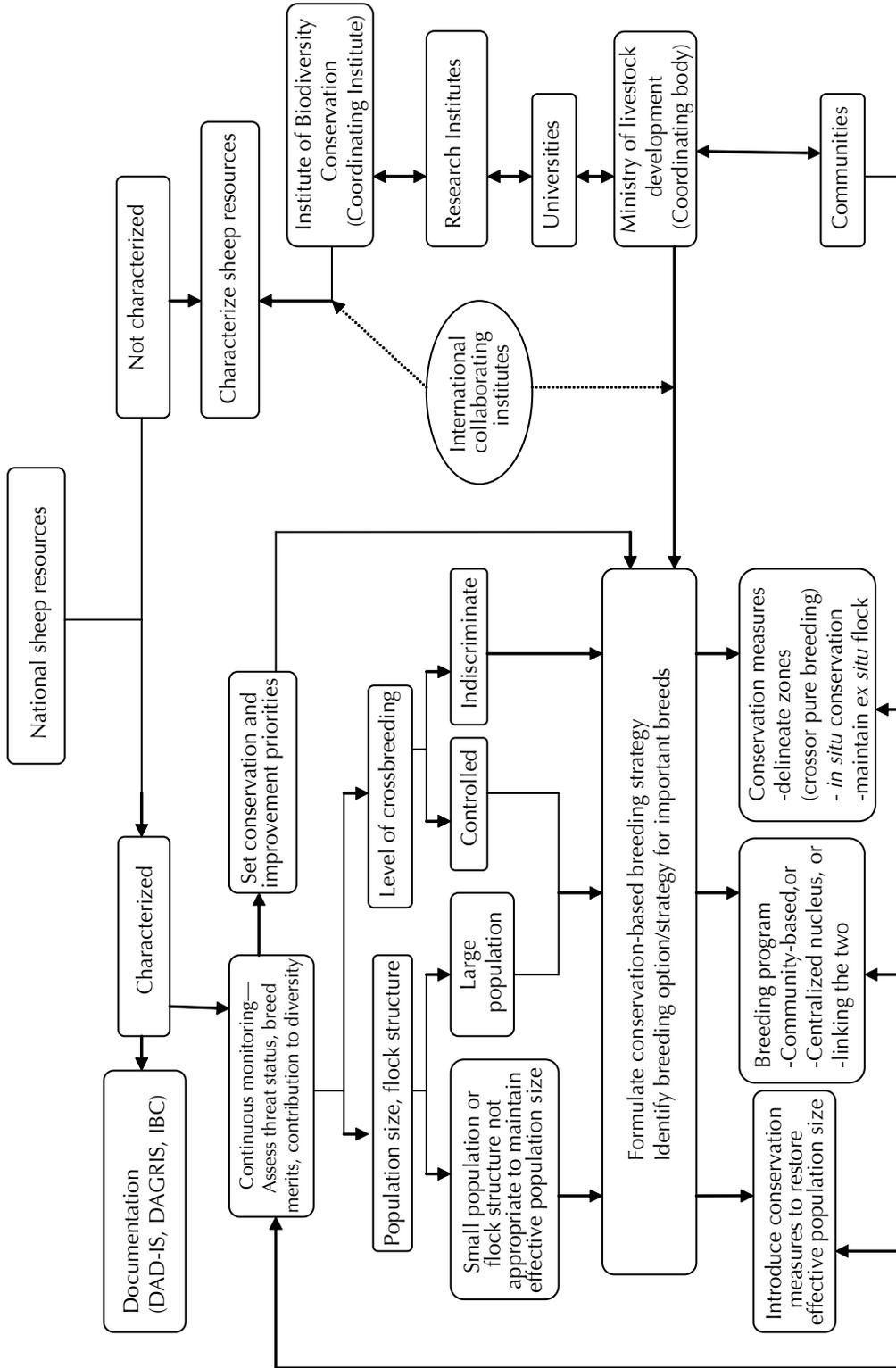
Figure 6. *Research, development and documentation activities and institutions in national animal genetic resource characterization and conservation program.*

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Appendix 1. Information recorded for mammalian species in the Global Databank for Animal Genetic Resources

General information

Species

Breed name (most common name and other local names)

Distribution

• Population data: Basic population information

Year of data collection

Total population size (range or exact figure)

Reliability of population data

Population trend (increasing, stable, decreasing)

Population figures (based on census/survey at species/breed level or estimate)

Advanced population information:

Number of breeding females and males

Percentage of females bred to males of the same breed and percentage of males used for breeding

Number of females registered in herd book/register

Artificial insemination usage and storage of semen and embryos

Number of herds and average herd size

• Main uses (listed in order of importance)

• Origin and development

Current domestication status (domestic/wild/feral)

Taxonomic classification (breed/variety/strain/line)

Origin (description and year)

Import

Year of herd book establishment

Organization monitoring breed (address)

• Morphology

Adult height and weight

Number and shape/size of horns

Colour

Specific visible traits

Hair and/or wool type

Special qualities

Specific quality of products

Specific health characteristics

Adaptability to specific environment

Special reproductive characteristics

Other special qualities

• Management conditions/management system

Mobility

Feeding of adults

Housing period

Specific management conditions

• *In situ* conservation

Description of *in situ* conservation programs

• *Ex situ* conservation

Semen stored and number of sires represented

Embryos stored and number of dams and sires represented in embryos

Description of *ex situ* conservation programs

• Performance

Birth weight

Age at sexual maturity

Average age of breeding males

Age at first parturition and parturition interval

Length of productive life

Milk yield and lactation length (mammals)

Milk fat

Lean meat

Daily gain

Carcass weight

Dressing percentage

Management conditions under which performance was measured

Source: FAO/UNEP (2000).

Appendix 2. Summary of variable definition for morphological characters

Character	Variable	Description
	Continuous variables	
Withers height	Withers height	Height from ground to withers, cm
Chest girth	Chest girth	Circumference of the chest, cm
Body length	Body length	Distance between shoulder and pin bone
Substernal height	Substernal	Height from ground to sternum, cm
Ear length	Ear length	Length of ear, cm
Tail length	Tail length	Length of tail, cm
Tail width	Tail width	Width of tail at the widest point, cm
	Dummy variables**	
Fibre type	1*	Animal has short-haired coat
	2	Animal has long coarse-wool coat
Coat colour	1	Plain black
	2	Plain white
	3	Plain brown
	4	Plain beige
	5	Black with white patches
	6	Brown with white patches
	7	Brown with black belly (Tazma)
	8	Black with brown on belly and head (Woyni)
	9	Black body and white patch on head (Boqa)
	10	White body and black head
	11	Brown body and white head
	12	White body and brown head
Horn presence	1	Animal has horn
	2*	Animal has no horn
Tail form	1	Triangular, straight long tapering end
	2	Triangular, coiled/twisted long tapering end
	3	Cylindrical, short, straight
	4	Cylindrical, short, twisted
	5	Cylindrical, short, turned-up
	6	Tubular, long, straight
	7	Bi-lobbed, turned-up
	8*	Rudimentary, tiny appendage
Tail type	1	Animal is fat-tailed
	2	Animal is thin-tailed
	3*	Animal is fat-rumped

* Reference categories excluded from analysis. ** Dummy variables took values 0 or 1 to indicate the absence or presence of the characteristics described for the character state (dummy variable).

Appendix 3. Pair-wise FST (above diagonal) and Nei's genetic distances, DA (below diagonal) between 14 sheep population in Ethiopia

Population	Simien	Sekota	Farta	Tikur	Wollo	Menz	Gumz	Washera	Horro	Adilo	Arsi	Bonga	Afar	BHS
Simien		0.0312	0.0195	0.0294	0.0271	0.0275	0.0703	0.0449	0.0847	0.0713	0.0916	0.1074	0.0558	0.0848
Sekota	0.0791		0.0072 NS	0.0158	0.0136	0.0078	0.0541	0.0223	0.0587	0.0481	0.0656	0.0740	0.0277	0.0476
Farta	0.0654	0.0394		0.0001 NS	0.0048 NS	0.0035 NS	0.039	0.0183	0.0422	0.0322	0.0503	0.0607	0.0279	0.0481
Tikur	0.0838	0.0556	0.0368		0.0112	0.0005 NS	0.0378	0.0251	0.0456	0.0302	0.0505	0.0654	0.0292	0.0540
Wollo	0.0694	0.0538	0.0425	0.0595		0.0089	0.0393	0.0231	0.0480	0.0351	0.0520	0.0590	0.0381	0.0522
Menz	0.0807	0.0511	0.0377	0.0486	0.0507		0.0503	0.0229	0.0467	0.0351	0.0592	0.0680	0.0265	0.0537
Gumz	0.1647	0.1346	0.1170	0.1279	0.1109	0.1292		0.0357	0.0482	0.0496	0.0587	0.0585	0.0494	0.0741
Washera	0.1082	0.0843	0.0736	0.0931	0.0689	0.0692	0.1115		0.0317	0.0287	0.0457	0.0623	0.0436	0.0626
Horro	0.1645	0.1183	0.0994	0.1220	0.1101	0.0958	0.1235	0.0828		0.0287	0.0573	0.0660	0.0561	0.0874
Adilo	0.1551	0.1124	0.0949	0.1133	0.0915	0.0983	0.1241	0.0859	0.0711		0.0246	0.0597	0.0414	0.0706
Arsi	0.1593	0.1161	0.1078	0.1336	0.1065	0.1147	0.1317	0.1075	0.1044	0.0681		0.0979	0.0430	0.0542
Bonga	0.2235	0.1716	0.1531	0.1614	0.1489	0.1506	0.1509	0.1449	0.1220	0.1239	0.1729		0.0748	0.1069
Afar	0.1375	0.0830	0.0884	0.1086	0.0988	0.0749	0.1389	0.1062	0.1151	0.1145	0.1133	0.1623		0.0222
BHS	0.1628	0.1064	0.1117	0.1344	0.1155	0.1011	0.1619	0.1232	0.1447	0.1290	0.1163	0.1864	0.0747	

Except those marked NS, all FST values were significantly different from zero at 0.1% level of significance based on 91,000 permutations.