

SECTION XX: ROLES, USES AND VALUES OF ANIMAL GENETIC RESOURCES

1. Introduction

Over the past decade, the roles, uses, and values of livestock have been widely examined, particularly in relation to their potential synergies, trade-offs, and complex interlinkages—both positive and negative—with the Sustainable Development Goals (SDG) (FAO, 2018). A key conclusion from these discussions is that achieving the SDG will require profound structural transformations within the livestock sector to ensure its sustainability. Animal genetic resources (AnGR) represent a foundational pillar of this transformation. As the raw material for both natural evolutionary processes and human-directed genetic improvement programs, AnGR diversity is essential for adapting livestock systems to changing environmental and socio-economic conditions. It offers one of the most powerful levers for driving sustainable development in the sector.

The ecosystem services framework, which considers the benefits people derive from ecosystems, allows to capture most functions and services that livestock systems provide to society (Dumont *et al.*, 2019). Those services are commonly differentiated into provisioning, cultural, and regulating and maintenance categories (Haines-Young, 2023). Since 2021, DAD-IS allows countries to link national breed populations to a list of 50¹ different ecosystem services (Tables 1D1, 1D3, 1D4), combining a list of uses already entered in DAD-IS with additional ecosystem services identified as particularly relevant for livestock species and breeds (Hoffmann *et al.*, 2014).

As of August 2025, associations with at least one ecosystem service had been made for 9,675 of the 15,715 national breed populations entered in DAD-IS.

This section considers first the roles, uses and values related to AnGR under the ecosystem service classification framework. As this framework misses some functions of paramount importance for livestock such as the sector's contribution to food security, poverty alleviation and livelihood development, those topics are investigated in the subsequent subsection part. Finally, we will investigate more in detail how the choices made in the AnGR to be utilized may regulate and impact the delivery of those roles, uses and values within agroecosystems.

2. Ecosystem services related to Animal Genetic Resources

2.1 Provisioning services

Provisioning services are defined as products obtained from agroecosystems, including food, fiber or energy. They also encompass other functions, such as the use of animals for reproductive purpose, workforce or as a form of saving and insurance. As illustrated in Table 1D1, food production was the most important type of provisioning service, with meat, milk and eggs occupying three of the four most frequently reported services associated with national breed populations, along with general crossbreeding. Among these, meat was unsurprisingly the most important (6,045 instances), given that

¹ 'Riding (sport)' and 'Riding (by children)', previously treated as distinct ecosystem services in DAD-IS, were recently merged due to their strong similarities, while 'Production of offspring for slaughter as young animals' was merged into 'Meat' service.

39 all livestock animals are composed of edible muscle and fat. This was followed by milk and eggs (1,933
40 and 990 instances, respectively).

41 **Table 1D1. Provisioning ecosystem services reported**

Ecosystem services	N
Meat	6,045
Milk	1,933
General crossbreeding	1,284
Eggs	990
Skin/hides	920
Wool	791
Fuel (manure)	702
Saving and security	648
Dam line	639
Draught power	621
Sire line	525
Herding	383
Horns	341
Pelt or fur	278
Riding (work)	268
Hair	237
Transport	234
Lard	212
Carting	195
Feathers	173
Interspecies crossing	151
Pack/baggage	135
Guard	103
Hunting	83
Medical	58
Fatty liver	48
Downs	24
Velvet	17
Hair or feathers for fishing lures	11

42 *N: number of national breed populations associated with the services*

43 *Source: DAD-IS (accessed August 2025).*

44

45 2.1.1 Livestock and food production

46 Since 2013, the global production of food of animal origin has continued to grow significantly
47 (Table 1D2), although trends vary across species and product types. For instance, chicken meat
48 production increased by 30 percent between 2013 and 2023, becoming the most plentiful meat product
49 in production, while for pig meat (second most abundant meat), the increase was only of 9 percent. For
50 some species, the production has dramatically decreased, for instance for rabbit (-47 percent) and
51 donkey meat (-61 percent). Both of these cases have been driven by a change in the consumption and
52 use pattern especially in Asia. The data in Table 1D2 highlight the high reliance of animal husbandry
53 on a small number of species. The main five species (chicken, pig, cattle, sheep, goat) contribute
54 93 percent of the total meat production, and this increases to 99 percent if buffalo, duck, goose and
55 turkey are included. For other products that are species specific, such as milk and eggs, the contribution

56 is even more concentrated, with for instance chicken contributing to 99.7 percent of global eggs
57 production in volume.

58 Production data in FAOSTAT are not disaggregated below the species level—that is, by breed or breed
59 category. However, complementary data suggest that a small number of mainstream breeds contribute
60 disproportionately to overall food production. For example, according to estimates submitted by 81
61 countries to DAD-IS, the global population of the Holstein (black and white) breed exceeds 52 million
62 individuals. This accounts for approximately 9.3 percent of the total number of purebred cattle recorded
63 in DAD-IS, around 3.3 percent of the global cattle population including crossbred animals (FAOSTAT,
64 2025), and about 7 percent of the global dairy cattle herd (FAO, 2022). According to DAD-IS, the
65 average milk yield is 7,200 kg for Holstein (black and white) cattle, compared to an overall average of
66 2,850 kg across all cattle breeds. Based on these figures, it can be roughly estimated that Holstein cattle
67 contribute at least 17 percent of the global production of cattle milk.

68 **Table 1D2. Global output of animal-source foods (2013 and 2023)**

Category	Product	2013	2023	Change
		tonnes		%
Meat	Chicken meat	97,579,707	126,530,271	30
	Pig meat	114,124,165	124,667,863	9
	Cattle meat	63,021,529	69,462,203	10
	Sheep meat	9,079,086	11,532,801	27
	Goat meat	5,747,418	7,463,593	30
	Buffalo meat	6,234,265	7,098,608	14
	Duck meat	4,349,383	7,055,620	62
	Goose meat	2,673,081	5,213,921	95
	Turkey meat	5,535,639	5,204,656	-6
	Horse meat	687,861	810,960	18
	Rabbit meat	1,297,698	681,996	-47
	Camel meat	499,594	612,448	23
	Donkey meat	210,574	81,303	-61
Milk	Cattle milk	635,267,192	782,901,752	23
	Buffalo milk	107,001,831	150,341,734	41
	Goat milk	15,987,281	20,857,812	30
	Sheep milk	9,672,033	10,017,335	4
	Camel milk	3,665,561	4,095,972	12
Eggs	Hen eggs	1,354,079,337	1,815,640,487	34
	Eggs of other birds	5,435,915	6,284,195	16
Honey	Natural honey	1,688,386	1,893,805	12

69 *Source: FAOSTAT (accessed August 2025).*

70

71 Food production encompasses a wide variety of products, each with distinct nutritional, health, and
72 sensory qualities. Beyond the influence of animal feeding and food processing methods—such as those
73 used in dairy production—, genetic variation at the species, breed, and individual levels plays an
74 important role in determining the nutritional properties and overall quality of terrestrial animal-source
75 foods (FAO, 2023). For example, the smaller diameter of fat globules in goat’s milk contributes to the
76 softer texture of its cheese as compared with cheese from cow’s milk (Martini *et al.*, 2016). Similarly,
77 the high milk fat content of the Jersey cattle breed—averaging 5.1 percent compared to the general
78 average of 4.3 percent in cattle milk reported in DAD-IS—enhances key characteristics such as texture,
79 flavor, and color, which are particularly important for butter production. As regards egg quality

80 parameters and yolk nutritional composition, noticeable differences have been reported between
81 indigenous breeds of laying hens and selected high-yielding commercial strains (Romero *et al.*, 2024).
82 Also in this sense, the physico-chemical and antioxidant properties of honey have been found to be
83 affected by bee species (Nidhi *et al.*, 2025). Accordingly, in European countries the products originating
84 from rustic and locally well-adapted livestock breeds are of renowned organoleptic quality and are often
85 protected by differentiated food quality seals, such as Designations of Origin. Moreover, recent studies
86 highlight that consumers are increasingly demanding animal-source foods generated by heritage breeds
87 in non-industrial systems (Menger and Hamm, 2021; Tampaki *et al.*, 2022).

88

89 2.1.2 Other provisioning services

90 As illustrated by Table 1D1, the role of livestock in provisioning services goes far beyond the sole
91 provision of food. Some of those services are particularly crucial in mixed and/or pastoral systems
92 (Leroy *et al.*, 2018).

93 Animal genetic resources contribute significantly to the production of fiber, hides, and skins, which are
94 essential raw materials for textiles, leather goods, and traditional crafts. Between 2013 and 2023 (latest
95 available year), while global shorn wool production has continued to decline, decreasing from 2.05 to
96 1.75 million tonnes (-15 percent), the production of raw hides and skins has conversely increased from
97 11.89 to 13.79 million tonnes (+16 percent) (FAOSTAT, 2025). In DAD-IS, 920 and 791 national breed
98 populations are reported to be associated with the production of skin/hides and wool, respectively.
99 Species and breeds vary in the quality and characteristics of these products. Some examples illustrate
100 the extremes: such as, the exceptional softness of alpaca fiber, the remarkable durability of buffalo hides,
101 or the fine wool produced by Merino sheep (see Box 1D1). These materials not only support local
102 economies and cultural heritage but also play a role in global trade and sustainable material sourcing.

103 In many agroecosystems, especially in low-input or remote settings, livestock continues to serve vital
104 roles in transport and draught power. There are no recent data allowing to assess the number of animals
105 involved in such activity; however, in many countries transport and draught power are still the main
106 reason for keeping horses, donkeys and mules (Allan, 2021). Over the last two decades, mechanization
107 is widely recognized as a key factor accounting for the decline in the population sizes of species and
108 breeds traditionally used as working animals in many Asian countries. In contrast, in several African
109 countries, population growth of these equid species may be linked to increased demand for
110 transportation and labor, rising fuel prices, or the growing market for donkey hides (Allan, 2021;
111 Asteraye *et al.*, 2024). Other species are also used in transport and for draught power but to a lesser
112 extent; for instance, some cattle breeds are prioritized for their draught power (Traoré *et al.*, 2017).

113 Manure and urine are important by-products of livestock production, providing valuable services in crop
114 fertilization (please see next section on regulating and maintenance services) and as source of energy—
115 including their use for cooking, heating, thermal wall insulation and biogas generation. Germany and
116 China have currently the highest annual biogas production with 87 and 81 TWh per year, respectively
117 (Gustafsson *et al.*, 2024).

118 The chemical composition of manure and its influence on soil fertility and biodiversity are known to be
119 highly dependent on livestock species (Köninger *et al.*, 2021). For example, Yang *et al.* (2019) reported
120 that both poultry litter and cattle manure enhanced soil microbial biodiversity. In contrast, Sun *et al.*
121 (2016) observed that pig manure, when applied alongside mineral fertilizers, promoted greater
122 diversification of the fungal community compared to cow manure.
123 Dung cakes are also still largely used as solid cooking fuels in rural developing regions, despite their
124 recognized negative impact in terms of greenhouse gas emission and human health (Bharadwaj *et al.*,
125 2025). On one hand, poor management of livestock manure can lead to serious environmental issues,
126 including water pollution, soil degradation, and greenhouse gas emissions, as well as health risks
127 resulting from pathogens, antibiotic residues, and harmful gases such as ammonia and methane. On the
128 other hand, proper manure management can support circular bioeconomy models and can contribute

129 significantly to climate-smart agriculture by enhancing nutrient recycling, reducing reliance on synthetic
130 inputs, and improving overall sustainability.

131 The use of animals to breed, maintain or establish populations is considered as a provisioning service,
132 and is reported for many national breed populations with the denomination of “general crossbreeding”.
133 Countries report this service for 1,284 national breed populations, either as dam line (639 cases) or sire
134 line (525). Those uses cover very different practices and strategies (Leroy *et al.*, 2016a), from the use
135 of complementary breeds (e.g. sire lines with meat qualities crossed with dam lines with desired
136 maternal traits) to the production of interspecies crosses such as mules or Mulard ducks.

137 Livestock often serves as a form of savings or financial security, particularly in pastoral and smallholder
138 systems (Camara *et al.*, 2019). This function was reported for nearly 650 national breed populations.
139 Other functions are related to specialized working roles such as herding, hunting and guarding,
140 especially in dogs. Additionally, some breeds or species are valued for the medicinal properties of their
141 products—such as camel milk in traditional medicine—or for cultural and ceremonial purposes (please
142 see next section on cultural services). These uses reflect the deep socio-economic and cultural
143 importance of AnGR beyond their direct material outputs.

144

145 **Box 1D1. Cultural importance of Merino fleece**

146 The Merino sheep breed originated in the southwestern part of the Iberian Peninsula during the Middle
147 Ages. Since then, wool from Merino sheep has been very valued by the textile industry because of the
148 softness of the clothing made with it. With an average diameter smaller than 24 μm , fibers of the Merino
149 wool are flexible and bend easily when getting in contact with the skin and therefore do not prick it.
150 Commonly, Merino fleeces consist of fibers whose diameter ranges from 18 to 22 μm but superfine
151 Merino wool can also be found, in which case the fiber diameter goes down to 15-17 μm . In summary,
152 the smaller the fiber diameter, the softer the wool feels to the touch. An indirect way of assessing fiber
153 fineness consists in measuring the number of ripples per cm. Indeed, the fiber fineness and the number
154 of ripples are strongly correlated in wool. The finer the wool is, the higher the number of ripples. On the
155 contrary, coarse wool from other sheep breeds (fiber diameter up to 45 μm in some cases) has usually
156 been discarded in garment making and has been rather used for manufacturing carpets because thick
157 fibers (diameter above 26 μm) are less flexible and hence do not bend easily against the skin. The latter
158 explains why coarse wool pricks the skin and feels scratchy. On balance, the very thin fibers of Merino
159 wool make this material unique and ideal for next-to-skin wear.

160

161 Consequently, Merino wool was for centuries a highly profitable commodity for the Spanish kingdom
162 and Merino breed turned out to be the “crown jewel” of the Spanish livestock sector. Accordingly, Spain
163 endeavored to keep the monopoly on this prized sheep breed and succeeded in it for centuries (from the
164 Middle Ages until the 18th century). Exiting the country with Merino sheep was banned and was even
165 punishable by death. In 1273, King Alfonso X created the Council of the Mesta, an association of Merino
166 breeders that became very powerful over the centuries because the Spanish Kings successively granted
167 many privileges to this association. Indeed, the Council of the Mesta is deemed the most powerful
168 livestock breeder association in the history of humanity. Drove roads, called “cañadas” in Spanish, were
169 set up all throughout the country (in total, 125,000 km in length) to facilitate the seasonal movements
170 of huge flocks of Merino sheep in search of pastures (to the North in summertime and back to the South
171 in wintertime). The privileges conceded to the Merino breeders and the transhumance ensured the
172 availability of grasslands to feed the sheep during the whole year. Even nowadays, these sheep-walks
173 are considered public domain and are legally protected from being built on. The drove roads are not just
174 routes used to move herds through the Iberian Peninsula. They are very valuable for many other reasons.
175 These pathways constitute very biodiverse ecological corridors, along which sheep and other livestock

176 species spread seeds, they enable the connectivity between natural protected areas and they serve as
 177 routes for migrating wild species. Moreover, the transhumance connected distant human populations,
 178 that otherwise would have never come into contact in past centuries, and made possible cultural linkages
 179 that resulted in the transfer of words between different Spanish dialects and in the exchange of musical
 180 instruments. Besides, the transhumant shepherds created poems, songs and proverbs that have survived
 181 to the present day and are now considered a cultural heritage.

182
 183 The Spanish monopoly on the Merino breed ended with the arrival of a new dynasty to the Spanish
 184 throne (the French dynasty of the Bourbons) and with the independence of the American provinces
 185 (Spaniards had carried Merino sheep to the territories that later became Argentina and Uruguay). Merino
 186 sheep were so coveted by the northern European governments that the new sovereigns in Spain gifted
 187 Merino sheep to other courts, including France, Sweden, The Netherlands and Prussia, to seal alliances.
 188 For instance, the Merino sheep offered in 1786 by King Carlos III of Spain to King Louis XVI of France
 189 gave rise to the Rambouillet Merino. Eventually, the Spanish Merino breed reached distant countries
 190 such as South Africa, Australia and New Zealand.

191
 192
 193 *Provided by Carlos Romero*

194

195

196 2.2 Regulating and maintenance services

197 Regulating and maintenance services mediate or moderate ecosystem processes and environmental
 198 conditions that affect human health, safety, or comfort. In comparison to provisioning services, they are
 199 more difficult to quantify and appraise, especially considering their indirect use or non-use values (Leroy
 200 *et al.*, 2018). Depending on the circumstances, impact of livestock on ecosystem processes can be either
 201 positive (services) or negative (disservices). As illustrated by Table 1D3, substantial number of national
 202 breed populations in DAD-IS have been reported to be associated with services and functions such as
 203 fertilization (1,447 national breed populations), vegetation management (1,157) and contributions to
 204 habitat provision and the maintenance or enhancement of biodiversity (1,125) (see Box 1D2).

205 **Table 1D3. Regulating and maintenance ecosystem services reported**

Ecosystem services	N
Fertilizer	1,447
Vegetation management	1,157
Habitat provision and biodiversity	1,125
Weed control and biomass residue management	889
Waste recycling of non-human edible feed	599
Pollination and seed dispersal	576
Land degradation and erosion prevention	550
Fire prevention	506
Regulation and control of animal/human diseases	234
Water quality and flows regulation/purification	43

206 *N: number of national breed populations associated with the services*
 207 *Source: DAD-IS (accessed August 2025).*

208

209

210 Box 1D2. Ecosystem services of extensive livestock systems: safeguarding habitats and species

211 The ecosystem services provided by the livestock species reared under extensive conditions encompass
212 soil fertilization, seed dispersal, waste recycling, fire prevention by browsing on shrub biomass and
213 provision of habitats for wildlife, to name but a few. As regards habitat provision, recent research studies
214 have evinced that the abundance of numerous wild bird species relies on the grazing management of
215 grasslands, since livestock grazing enables the maintenance of suitable habitats for wildlife. Broad
216 evidence has shown that in Mediterranean countries threatened birds like the Dupont's lark
217 (*Chersophilus duponti*) and the little bustard (*Tetrax tetrax*) inhabit steppe areas that have been long-
218 term grazed by sheep with moderate intensity (Traba and Pérez-Granados, 2022). Accordingly, the
219 alarming continuous decline of the populations of these bird species noted over the last thirty years in
220 Western Europe has been found to be directly linked with the decline in sheep stocks and the consequent
221 abandonment of pastures. Likewise, the presence of livestock has shown to benefit the aquatic warbler
222 (*Acrocephalus paludicola*), the rarest passerine bird in Europe (Fundación Global Nature, 2021). It has
223 been observed that when cattle have disappeared from wetlands, and thus have stopped to graze, these
224 habitats have become unsuitable for the aquatic warbler due to the overgrowth of vegetation which
225 makes marshlands become denser. The return of cattle to fens reduces the density of reeds and other
226 plants and thereby, transforms these wetlands into the open habitat warblers require. Even if sometimes
227 the relationship does not seem obvious, these examples demonstrate that livestock grazing can be crucial
228 for the conservation of threatened wild birds.
229



230

231 *Photo credit: Carlos Romero.*232 *Provided by Carlos Romero.*

233 Detailed analysis of DAD-IS data reveals that ruminants are more frequently associated with regulating
234 and maintenance ecosystem services than are pigs, rabbits, chickens and other avian species (Leroy *et*
235 *al.*, 2024). Differences in grazing behavior across species influence vegetation dynamics and,
236 consequently, factors such as plant biodiversity and fire risk (Francksen *et al.*, 2022). Owing to their
237 nimbleness and browsing behavior, goats have proven to be more effective than cows and sheep,
238 especially in steep areas, in consuming shrubby biomass and hence, in reducing the fuel load and the
239 fire risk (Mancilla Leytón and Martín Vicente, 2012; Lovreglio *et al.*, 2014; Grupenhoff and Molinari,
240 2021). While some studies suggest that the impact of livestock breed on grassland biodiversity is
241 minimal as compared with management practices like grazing intensity (Wallis de Vries *et al.*, 2007),

242 others highlight breed-specific differences in foraging behavior among cattle breeds (Cibils *et al.*, 2023;
243 Pauler *et al.*, 2020), which may affect the provision of related ecosystem services. Overall, the literature
244 emphasizes that the ecological outcomes of grazing—whether beneficial or detrimental—are highly
245 context-dependent, with genetic resources representing just one of many influencing factors (Primi *et*
246 *al.*, 2025) (Box 1D3). Nonetheless, the diversity of the breeds themselves may be considered an
247 outstanding component of agrobiodiversity, contributing to the richness and resilience of the
248 ecosystems.

249 **Box 1D3. The feral cattle population of Amsterdam Island: genetic adaptation and island**
250 **management issues**

251 The feral cattle population of the Amsterdam island was completely eradicated in 2010 although it
252 represented a unique genetic resource and a remarkable case study of the successful establishment of a
253 population of large mammals in a seemingly hostile environment by just five founders. Introduced in
254 1871 to this small, isolated sub-Antarctic island of the Indian Ocean (part of the Terres Australes et
255 Antarctiques Françaises), these animals expanded rapidly after an intense but brief initial bottleneck,
256 reaching nearly 2,000 heads living in complete autonomy. Recent genomic analysis of a few individuals
257 revealed that approximately 75% of their ancestry came from European taurine close to Jersey cattle
258 and 25% from Indian Ocean zebu cattle (Gautier *et al.* 2024). The initial success of the herd's
259 establishment may have resulted from the predicted pre-adaptation of their European taurine ancestors.
260 The climatic conditions on Amsterdam Island were indeed relatively similar to those on the island of
261 Jersey, which reduced the bioclimatic challenge faced by the animals. Contrary to some theories, their
262 small size was not the result of rapid insular dwarfism, but was more likely inherited from their ancestral
263 breeds. Adaptation to life in the wild, or feralisation, also left genomic footprints, particularly in genes
264 involved in the development and function of the nervous system, which is consistent with the emergence
265 of complex social organisation and untamed behaviour, characteristic of wild animals.
266



267

268 *Photo credit: François Colas.*

269 The history of the herd illustrates the complexities and resulting tensions involved in the conservation
270 of island territories. On the one hand, cattle were considered a significant threat to endemic species,
271 such as *Phylica arborea* and the Amsterdam albatross, due to trampling and overgrazing. Control
272 measures implemented from 1988 onwards, such as reducing the herd size and confining the cattle to a
273 fenced area away from these endemic species, effectively mitigated most of these ecological damages.
274 On the other hand, the ecological services provided by the cattle, such as clearing brush and maintaining
275 a firebreak around the Martin de Viviès scientific base, were not taken into account when the decision

276 was made to eradicate them. The importance of these services was highlighted by the fire in early 2025,
 277 which destroyed nearly half of the island. This included around 90% of the *Phyllica* woods and their
 278 nursery, effectively wiping out years of replanting efforts.

279
 280 Hasty eradication of animals without fully assessing the consequences has led to the loss of a unique
 281 genetic resource and potentially exacerbated environmental risks that could have been mitigated through
 282 regulated herd management.

283
 284 *Provided by Laurence Flori, François Colas, Thierry Micol, Tom Druet et Mathieu Gautier.*

285

286 2.3 Cultural services

287 Cultural ecosystem services correspond to benefits people obtain from ecosystems through spiritual and
 288 intellectual enrichment, cognitive development, reflection, recreation, and aesthetic experiences. As
 289 non-material benefits, cultural services tend also to be quite complex to quantify and appraise. Animal
 290 genetic resources nevertheless play an important cultural role that goes beyond the livestock keepers
 291 themselves (Box 1D1, Leroy *et al.*, 2018). Recent studies have defined breeds both as eco-cultural
 292 entities (Velado-Alonso *et al.*, 2021) and as indicators of cultural ecosystem services (Marsoner *et al.*,
 293 2018). In DAD-IS, national breed populations have been most frequently reported to have key roles and
 294 uses in research (1,030 national breed populations), hobbies (922), sport (706), for their “fancy”
 295 phenotypes (598) and cultural and religious ceremonies (569) (Table 1D4).

296 **Table 1D4. Cultural ecosystem services reported**

Ecosystem services	N
Research	1,030
Hobby	922
Sport	706
Fancy	598
Cultural and religious ceremonies	569
Tourist attraction	447
Riding	379
Dressage	285
Racing	259
Fighting	61
To handle fighting bulls	23

297 *N: number of national breed populations associated with the services*

298 *Source: DAD-IS (accessed August 2025).*

299 As illustrated above, livestock species and breeds are broadly recognized as valuable resources for
 300 research, going beyond the sole use as experimental lines. For many breeds defined as “fancy”, the act
 301 of breeding itself has become a cultural hobby. Among the data collected in DAD-IS, the role in cultural
 302 and religious ceremonies was often associated with other non-cultural services, such as provision of fuel
 303 and manure, saving and security, or weed control and biomass residue management (Leroy *et al.*, 2024).
 304 This was particularly evident in African cattle breeds, highlighting a close relationship between specific
 305 breeds and a diverse bundle of services of very different nature.

306

307 3. Contributions to food security, poverty reduction and livelihood 308 development

309 Beyond their association with a wide range of ecosystem services, AnGR also contribute significantly
310 to the achievement of several SDG. In this subsection, we will focus on SDG 2 (Zero Hunger) and SDG
311 1 (No Poverty), where livestock diversity plays a key role by enhancing food security, improving
312 livelihoods, and supporting resilient agricultural systems—particularly in marginal environments with
313 harsh conditions and among vulnerable populations.

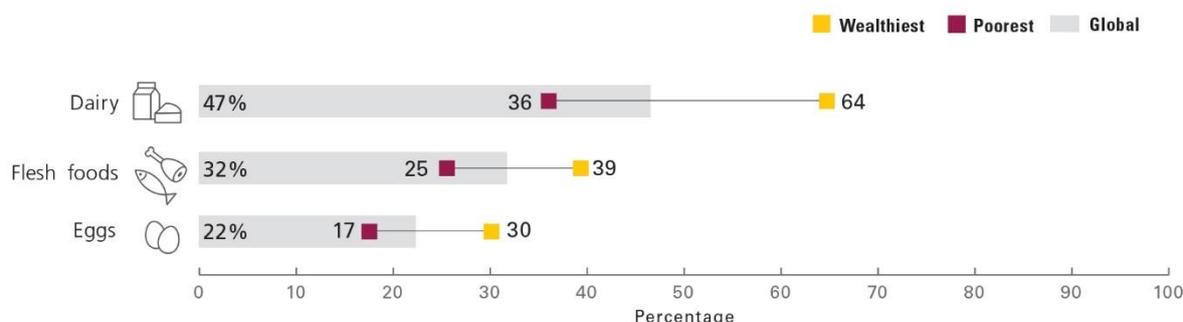
314

315 3.1 Food security

316 The relationship between AnGR and food security is primarily rooted in their role in food production.
317 There is a well-established link between poverty, food insecurity, and limited access to animal source
318 foods (Figure 1D1). These foods are rich in essential nutrients—such as Vitamin A, Vitamin B12,
319 calcium, iron, zinc, and high-quality proteins—that are critical for health, particularly during key life
320 stages (FAO, 2023). In some societies, such as pastoralist communities, this role is particularly
321 exacerbated because in these cases animal-source foods make up a big portion of the basic diet and
322 provide essential micronutrients, while access to other-source foods is limited.

323 Restricting access to animal-source foods can intensify malnutrition and is likely to increase the risk of
324 various health issues. For example, in young children, deficiencies in zinc and iron are associated with
325 stunting, increased susceptibility to diarrheal diseases, higher mortality rates, and impaired cognitive,
326 linguistic, and socio-emotional development (FAO, 2023).

327 **Figure 1D1. Percentage of children between 6 and 23 months consuming animal source food, by**
328 **poorest and wealthiest quintile relative to the global average**



329

330 *Note: “Flesh foods” in the figure refers to meat, fish, poultry and organ meats. Data from UNICEF global databases, 2021,*
331 *based on multiple indicator cluster survey (MICS), demographic and health surveys (DHS) and other nationally*
332 *representative sources. Source: Adapted from UNICEF (2021).*

333

334 There is a notable lack of studies assessing specifically the global contribution of locally adapted breeds
335 (i.e. breeds adapted to traditional production systems in a country) to food security (Leroy *et al.*, 2018).
336 As a result, their role in delivering this important ecosystem service must be mostly inferred indirectly,
337 such as through their association with specific production systems. For instance, international
338 transboundary breeds—typically selected for high performance in a single trait such as milk, meat, or
339 egg production—are predominantly raised in high-input, intensive industrial systems. In contrast,
340 locally adapted breeds are more commonly found in low-external-input mixed or grassland-based
341 systems, where they often provide multiple products and services. These different production systems
342 contribute unequally to global food supply. According to Mottet *et al.* (2017), 43 percent of livestock

343 products from cattle, buffaloes, small ruminants, poultry, and pigs originate from industrial pig and
344 poultry systems and ruminant feedlots; 34 percent come from intermediate-intensity systems involving
345 pigs, chickens, and mixed ruminants; 16 percent from grazing ruminant systems; and 7 percent from
346 backyard pig and poultry systems.

347 In more intensive systems non-limited by resources, intensively selected breeds show strong potential
348 for efficient animal-source food production, particularly due to their superior feed conversion ratios.
349 Within these systems, genetic variability—both within and between breeds—is a strategic lever to
350 enhance production efficiency through breeding programs. Conversely, in extensive, resource-driven
351 systems, locally adapted breeds often possess unique traits (e.g., salt tolerance, resistance or tolerance
352 to endemic parasites) that enable them to survive and perform under harsh environmental conditions and
353 on poor-quality feed resources, typically in areas unsuitable for crop cultivation. Although these breeds
354 are generally less productive, they are consistently associated with greater multifunctionality (Leroy *et al.*,
355 2024), and their resilience and adaptability are often crucial in providing food security, especially in
356 vulnerable or marginal regions with poor access to other food sources. In these geographical regions
357 with adverse climatic, hydrological and topographical conditions that high-demanding selected animals
358 would not withstand, the locally adapted livestock breeds constitute thus the only viable option for food
359 production and hence, represent the sole farming system enabling a livelihood for local human
360 populations.

361

362

363 3.2 Roles in poverty alleviation and livelihood development

364 A wide range of ecosystem services beyond food and product provision contribute to poverty alleviation
365 and livelihood development. These include functions such as savings and insurance, employment
366 opportunities, transport, draught power, and crop fertilization, all of which support human, social, and
367 physical capital. Livestock plays a catalytic role in helping rural households achieve their livelihood
368 goals and serves as an important buffer against external shocks. Simultaneously, livestock production
369 stimulates economic growth both along the supply chain (vertical effects) and across local communities
370 (horizontal effects) and thereby creates jobs and income at every stage of production, processing, and
371 trade (FAO, 2018). Given the sector's rapid growth and its central role in rural economies, the
372 contribution of livestock to poverty reduction and resilience building remains both significant and often
373 underappreciated.

374 A breeding strategy may be a powerful source of leverage in that extent. In Tanzania, Kitole and Sesabo
375 (2022) showed that the adoption of improved beef and dairy breeds significantly reduced poverty
376 compared to traditional breeds. On the other hand, it has also been demonstrated that livestock
377 diversification (Ngigi *et al.*, 2021), and transition to more resilient species (e.g. from cattle to camel,
378 Volpato and King, 2019) or breeds (Kabote *et al.*, 2024) were part of the strategies to cope with
379 economic and environmental uncertainties. Also, Birhanu *et al.* (2024) observed that lack of sustained
380 supply of an integrated technology package, low support in capacity development and inadequate access
381 to markets were important factors in the abandonment of improved specialized chicken breeds in Africa
382 in favor of local breeds requiring less inputs. Ultimately, the choice of AnGR involves trade-offs within
383 specific production systems, as traits linked to productivity and resilience are often negatively correlated
384 across breeds and species.

385

386 4. Challenges in understanding how the diversity of animal genetic 387 resources shapes livestock roles, uses and values within 388 agroecosystems

389 Animal genetic resources are intrinsically linked to a diverse array of roles, uses, and values. As
390 highlighted by Marsoner *et al.* (2018) and Velado-Alonso *et al.* (2021), AnGR can be viewed as goods,
391 final services, mediators and regulators, or even indicators within the ecosystem services framework—
392 underscoring their multifaceted nature. This complexity makes their positioning within the framework
393 both rich and challenging. Nevertheless, unlocking the full potential of AnGR to drive a sustainable
394 transformation of the livestock sector requires overcoming a range of interconnected challenges.

395 First, as previously underlined, many ecosystem services associated with livestock breeds and species,
396 especially those involving cultural or regulating and maintenance roles, are difficult to quantify due to
397 their non-material nature (Lauvie *et al.*, 2023). Moreover, the values of AnGR can be considered to
398 extend beyond those associated with their current use and associated services. Option value refers to the
399 value that arises when the continued existence of a resource increases the capacity to respond to
400 unpredictable future events, such as climate change. Quantifying the values of AnGR is therefore a
401 complex task that involves the use of a range of tools and adequate frameworks in order to provide
402 stakeholders with the right incentives that will lead them to change their practices towards a more
403 sustainable use of their breeds and species.

404 A key challenge in identifying the links between ecosystem services and AnGR lies in accurately
405 determining their role in the delivery of these services. This is complicated by the fact that the actual
406 "delivery unit" is the agroecosystem in which AnGR are embedded, rather than the genetic resources
407 themselves (Martin-Collado *et al.*, 2019). For example, the impact on grassland biodiversity within a
408 given agroecosystem—whether positive or negative—depends on a combination of management
409 practices, such as stocking density, the use of continuous versus rotational grazing, and ultimately, the
410 type of animals involved. Therefore, it is essential to disentangle the specific contribution of AnGR from
411 other influencing factors to better understand their role in ecosystem service delivery.

412 Then, relationships between AnGR and ecosystem services need to be considered at different scales,
413 from individual to breed and species. Typically, some traits related to growth, meat and milk production
414 directly regulate the delivery of some provisioning services and are often integrated into breeding
415 programs. In some cases, certain phenotypes with well-characterized expression and inheritance are
416 directly linked to the cultural identity of a given breed, such as the belted coat pattern in the Lakenvelder
417 (Dutch belted) cattle or gait locomotion in Icelandic horse breed (Leroy *et al.*, 2016b). On the other
418 hand, particularly in the context of non-material ecosystem services, the relationship between
419 phenotypic traits and ecosystem services is often indirect (e.g. adaptedness and habitat provision).
420 Moreover, the genetic variation that potentially affects the delivery of a specific ecosystem service may
421 be significant at the species level, but negligible at the breed level or below. While emerging approaches
422 like landscape genomics offer promising avenues for identifying genomic variants linked to traits such
423 as adaptation, substantial development is still needed. In particular, disentangling the complex
424 relationships between genetic variation across hierarchical levels (species, breed, individual) and the
425 mediation of specific ecosystem services remains a key challenge.

426 Finally, one of the major challenges lies with the complex interlinkages, positive and negative, among
427 ecosystem services, but also among related genetic traits. It has been suggested to analyze ecosystem
428 services as "bundles", in the sense of a set of ecosystem services that occur together repeatedly in space
429 or time to help identify trade-offs and find win-win options in development policies (Raudsepp-Hearne
430 *et al.*, 2010). Analysis of DAD-IS data underlined also positive and negative associations across
431 ecosystem services associated with national breed populations, revealing similar bundle patterns. Those
432 bundles may either relate to the intrinsic relationship between ecosystem services or to biological
433 associations among phenotypes. Examples on relationships among ecosystem services include the

434 positive association between vegetation management and fire prevention and the use of local cattle
435 breeds both for cultural and religious ceremonies and for saving and financial security in African
436 production systems. Biological associations between traits at species level can include both
437 commonalities, such as provision of eggs and feathers by avian species, or mutually exclusive cases like
438 provision of eggs and wool (Leroy *et al.*, 2024). Biological associations may also include favorable or
439 antagonistic genetic correlations between certain traits of interest within a given breed. For example,
440 many production parameters and functional traits are negatively correlated genetically, and this may
441 mediate the delivery of the related ecosystem services by a specific breed.

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445 5. Conclusions and research priorities

446 A priority for future research should be systematic quantification and deeper understanding of the
447 synergies, trade-offs, and intricate interlinkages among ecosystem services and the genetic traits of
448 AnGR within specific agroecosystems. Gaining such insights is essential to fully leverage the potential
449 of AnGR in advancing the sustainable transformation of the livestock sector. This requires a holistic
450 approach that integrates ecological, genetic, and socio-economic dimensions.

451 We must acknowledge that livestock keepers operate in highly diverse contexts and may follow
452 development pathways, shaped by their specific individual-level factors. These factors may comprise
453 attitudes toward risk and prioritization of food security, livelihood enhancement, or economic and
454 environmental resilience. Additionally, agroecosystem-level factors—including access to markets,
455 inputs and services, exposure to environmental risks, and prevailing cultural norms—play a critical role
456 in shaping these preferences (Bettridge *et al.*, 2018).

457 Therefore, future research should not only focus on generating technical knowledge—such as the
458 quantification of ecosystem services and the characterization of how genetic variability at different
459 levels influences these services—but should also consider the broader socio-cultural and economic
460 contexts in which livestock keepers operate. Understanding these realities is essential to ensure that
461 innovations are not only scientifically sound but also practically applicable, socially acceptable, and
462 equitably beneficial.

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