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ABSTRACT

Beyond providing food, livestock species are linked to a wide range of uses and ecosystem services (**ESs**). Based on information reported by 41 countries on 3 361 national breed populations to the Domestic Animal Diversity Information System of the Food and Agriculture Organization of the United Nations, we investigated how factors such as species, region, breed adaptedness, or management system associate with the recognition of provision of a set of 52 ESs. Among species, a greater number of cultural ESs were reported for horses (2.47 for horses vs 0.75 on average across all species), while the major ruminant species (cattle, goats and sheep) were on average associated with more provisioning ESs (2.99 vs 2.39), and more regulating and maintenance ESs (1.86 vs 1.32). Compared to European breeds, African livestock contribute more provisioning ES (3.95 vs 1.88). Native breeds and, to a lesser extent, locally adapted breeds, were linked to more ESs than were exotic breeds (5.97 and 4.10 vs 2.90, respectively), regardless of the ES category considered. The total number of ES reported was greater for breeds primarily kept under Back Yard/Farm Yard and extensive management systems than in other production environments. Different "bundles" of ES were identified in relation to the interdependence among themselves, or according to species or regional specificities. Overall, our results highlight that native and locally adapted breeds, which tend to be raised in less specialized production systems than exotic breeds, are reported to play multiple roles contributing to rural community livelihoods and environmental sustainability of food systems.

Implications

The choice of appropriate animal genetic resources is one of the key factors that influence the sustainability of food systems worldwide. Species, region, and production systems impact the multifunctionality and recognition of the provision of specific ecosystem services. In particular, native and locally adapted breeds are linked to more services than exotic breeds. To make the right choice, the multifunctionality associated with these factors must be carefully evaluated and considered.

Introduction

Beyond their use for food production, livestock are linked to a variety of positive and negative externalities resulting from the complex interactions within their production environments. Livestock also play a variety of socioeconomic roles in the livelihoods of rural communities, particularly in developing regions (Swanepoel et al., 2010). The ecosystem services framework, which considers the benefits people derive from ecosystems, is often used to characterize and classify the various functions and services that livestock systems provide to society (Dumont et al., 2019). These services, which are differentiated into provisioning, cultural, and regulating and maintenance categories (Haines-Young and Potschin-Young, 2018), are very different in nature and can ultimately be difficult to quantify. The provision of individual ecosystem services depends on a variety of social, technical and environmental factors, with potential synergies and antagonisms in ecosystem service provision (Queiroz et al., 2015). The identification and analysis of ecosystem service "bundles", in the sense of a set of ecosystem services that occur together repeatedly in space or time, have been suggested to help identify trade-offs and potential solutions to guide development policies (Raudsepp-Hearne et al., 2010; Dumont et al., 2019). For example, in a study of grasslands in Europe and South Africa, Bengtsson et al. (2019) advocated that these landscapes, in addition to having high biodiversity, provide ecosystem services such as water supply and flow

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regulation, erosion control, cultural values, and carbon storage. Therefore, the authors suggested that stronger and more effective policies should be developed to mitigate their decline and degradation.

Animal genetic resources are an essential component of agricultural biodiversity, playing a crucial role in the provision of ecosystem services (Leroy et al., 2018; Lauvie et al., 2023). Some provisioning services, as for example the provision of milk, eggs and wool, are directly dependent on the species raised. Similarly, depending on its adaptation, productivity or resource base in a given production system, the choice of a given breed or species, as part of management practices, can regulate the provision of specific ecosystem services. For example, in Benin, Houessou et al. (2022) found that herders' choice between zebu and taurine cattle breeds depended on their preference for animals being either more productive or better adapted to pastoral production systems (e.g. walking ability, or resistance to feed shortages). Genetic resources are also sometimes considered as ecosystem services in themselves, given the socio-cultural importance attached to some breeds. In addition, given the antagonistic genetic correlations that exist between certain traits of interest (e.g., production traits and functional traits), the choice of breeds and species bred is likely to be part of the trade-offs in the provision of ecosystem services. In particular, exotic breeds, i.e. those breeds present for a relatively short time in a country different from the one in which they were developed (and not considered as locally adapted to that country), can be compared and contrasted with native and locally adapted breeds, in the sense that the latter have been present long enough to have co-adapted with one or more traditional production systems or environments in the country. Exotic breeds are generally considered to be specialized genetically to be highly productive if kept in more intensive production systems, while native and locally adapted breeds are considered more robust and bred in more extensive systems, and will be seen as more multifunctional, including in terms of providing ecosystem services (Desta et al., 2011; Hoffmann, 2013).

Despite its recognized importance for food system sustainability, livestock multifunctionality has rarely been studied at the global level (Ickowicz et al., 2022). Based on information provided at the national breed population level in the Domestic Animal Diversity Information System (**DAD-IS**) (Food and Agriculture Organization of the United Nations (FAO), 2022), we analyze how region, species, breed adaptedness, and management system impact the recognition of livestock-related ecosystem services provision. We also explore how the aggregation of these services is affected by these factors and discuss implications for livestock policy development.

Material and methods

Data collection

DAD-IS is a database maintained and developed by the Food and Agriculture Organization of the United Nations (FAO), containing information on more than 15 000 national breed populations of 37 livestock species. This information is uploaded by National Coordinators who have been officially nominated by their respective countries. In 2021, FAO was requested by its member countries to include in DAD-IS data fields the ecosystem services associated with national breed populations, thus complementing the existing fields on how these populations are used.

To facilitate the collection of the corresponding information, an *.xlsx* file was sent in 2022 to each National Coordinator, listing their national breed populations in rows, with 52 uses and ecosystem services (hereforth referred to as "ecosystem service (**ES**)" in the manuscript for the sake of convenience) in columns (12 cultural, 30 provisioning, and 10 regulating and maintenance, see Tables 1 and 2). National Coordinators were asked to respond "Yes" for each ES associated with a given breed, which were then considered as binary variables (Yes or empty cell). Forty-one countries provided responses, corresponding to 3 361 national populations of 27 species.

Data analysis

The number of cultural, provisioning, regulating and maintenance ES, as well as the total number of ES reported per national breed population, were used as indicators to approximate multifunctionality. Two statistical analyses were considered, using a generalized linear mixed effects model (R glmer function) with a Poisson distribution. In the first model, region, species, and breed adaptedness class were included as fixed explanatory factors. Given the imbalance in responses (Table 3, Supplementary Fig. S1), three categories of regions were considered: Africa (13 countries), Europe (18 countries), and Other regions (10 countries). Species were grouped into nine categories: cattle, chickens, goats, horses, pigs, rabbits, sheep, other birds (10 species), other mammals (10 species). For adaptedness (see Table 4), the following four categories were considered: native, locally adapted, exotic, and undefined. To account for the potential effects of National Coordinator/Country on responses, country was included in the model as a random effect. Differences in frequencies of national breed populations across factors were eventually tested with χ^2.

National breed populations in DAD-IS can be linked to one or more management systems; however, this information was available for only a limited number of the populations studied. A second model was tested on a subset of 406 national breed populations

Table 1
Provisioning ES reported for the 3 361 livestock national breed populations considered.

ES	Abbrev	N	%
Provisioning			
Meat	Meat	2 228	66.3%
Milk	Milk	632	18.8%
General crossbreeding	GeCr	506	15.1%
Skins hides	SkHi	427	12.7%
Dam line	DaLi	385	11.5%
Eggs	Eggs	380	11.3%
Saving security	SaSe	307	9.1%
Herding	Herd	303	9.0%
Sire line	SiLi	297	8.8%
Production of offspring	PrOf	286	8.5%
Horns	Horn	265	7.9%
Fuel manure	FuMa	247	7.3%
Draught power	DrPo	225	6.7%
Wool	Wool	216	6.4%
Pelt or fur	PeFu	178	5.3%
Feathers	Feat	154	4.6%
Riding work	RiWo	154	4.6%
Transport	Tran	141	4.2%
Interspecies crossing	ISCr	125	3.7%
Hair	Hair	108	3.2%
Lard	Lard	95	2.8%
Carting	Cart	78	2.3%
Guard	Guar	78	2.3%
Pack baggage	PaBa	56	1.7%
Down	Down	49	1.5%
Hunting	Hunt	44	1.3%
Medical	Medi	42	1.2%
Fatty liver	FaLi	37	1.1%
Hair or feathers for fishing lures	HFFL	5	0.1%
Velvet	Velv	1	0.0%

Abbreviations: Abbrev = Abbreviation; ESs = uses and ecosystem services; N = Number of national breed populations reporting.

Table 2
Cultural and regulating and maintenance ES reported for the 3 361 livestock national breed populations considered.

ES	Abbrev	N	%
Cultural			
Hobby	Hobb	590	17.6%
Research	Rese	427	12.7%
Fancy	Fanc	369	11.0%
Cultural and religious ceremonies	CuRC	248	7.4%
Tourist attraction	ToAt	186	5.5%
Riding sport	RiSp	174	5.2%
Sport	Spor	159	4.7%
Dressage	Dress	126	3.7%
Racing	Raci	115	3.4%
Riding by children	RiCh	102	3.0%
Fighting	Figh	14	0.4%
To handle fighting bulls	FiBu	14	0.4%
Regulating and maintenance			
Fertilizer	Fert	786	23.4%
Habitat provision and biodiversity	HaPB	770	22.9%
Vegetation management	VeMa	646	19.2%
Weed control and biomass residue management	WCBM	494	14.7%
Pollination and seed dispersal	PoSD	490	14.6%
Waste recycling of non-human edible feed	WaRe	459	13.7%
Fire protection	FiPr	373	11.1%
Land degradation and erosion prevention	LDEP	249	7.4%
Regulation and control of animal or human diseases	ReCD	141	4.2%
Water quality and flows regulation or purification	WQFR	14	0.4%

Abbreviations: Abbrev = Abbreviation; ESs = uses and ecosystem services; N = Number of national breed populations reporting.

that were explicitly linked to one or more of the following five management systems (see Table 5): Back Yard/Farm Yard, Extensive, Semi-intensive, Intensive, and Not for Production. These management systems were added to the explanatory factors described above as five independent binary fixed effects. The models for cultural ES and regulating and maintenance ES did not include rabbit populations, nor did they include populations with undefined adaptedness for regulating and maintenance ES, as these categories were not associated with such ES in the limited data set, which posed problems for model convergence.

To better understand the relationships between individual ES, tetrachoric correlations, which are inferred Pearson correlations for binary variables, were calculated between ESs (R tetrachoric function). Multivariate factorial analysis was also undertaken (R function MFA), with region, species, and breed adaptedness class included as explanatory factors.

Results

Descriptive results

Across the 3 361 national breed populations considered, an average of 4.46 ESs were reported, including 0.75 for cultural, 2.39 for provisioning, and 1.32 for regulating and maintenance ES. Of the 52 ESs, the six most frequently reported included not only provisioning ES such as provision of meat (66.3% of national breed populations) and milk (18.8%) (Table 1) but also regulating and maintenance ES such as fertilizer (23.4%), habitat provision and biodiversity (22.9%), vegetation management (19.2%), and the cultural ES hobby (17.6%) (Table 2). Some other ESs were reported very infrequently; for example, only 14 national breed populations (buffalo, cattle, chicken) were reported as being used for fighting.

As shown in Table 3, two-thirds of the national breed populations originated from Europe, with significant overrepresentation (χ^2, $P < 0.001$) of rabbits and chickens, and underrepresentation of cattle, compared with the other two regions. In terms of adaptedness (Table 4), 42% of national breed populations were reported as native, 17% as locally adapted, 34% as exotic, with the status undefined for the remaining 7%. The proportion of exotic national breed populations was significantly (χ^2, $P < 0.001$) greater in the "Other regions" group (58%).

When restricting the data set to the 406 national breed populations with management system information, the number of national breed populations linked to a given system ranged from 92 (intensive systems) to 147 (extensive systems) (Table 5), with 252 national breed populations reported as linked to a single management system. Rabbits represented a significantly ($P < 0.001$) larger proportion of national breed populations associated with Back Yard/Farm Yard and "Not for Production systems" than other species. Only 14% of the national populations were rabbits, but they comprised 55% of the populations in Back Yard/Farm Yard systems and 56% of the populations in Not for production systems.

Exotic and locally adapted breeds were predominant among national populations associated with intensive production systems. Exotic breeds represented 46% of such populations, vs only 30% of all populations ($P < 0.001$). Respective percentages for locally adapted breeds were 27 vs 14%.

Statistical analysis of multifunctionality

Table 6 presents the means and estimates of the effects of region, adaptedness, and species category on the number of ES related to national breed populations. Compared to European

Table 3
Livestock national breed populations repartition across regions and species.

Species	Africa (13 countries)		Europe (18 countries)		Other regions (10 countries)		Total
	N	%	N	%	N	%	
Cattle	227	32%	349	49%	140	20%	716
Chicken	87	14%	457	75%	65	11%	609
Goat	119	25%	267	56%	93	19%	479
Horse	38	12%	248	76%	42	13%	328
Pig	81	28%	152	53%	56	19%	289
Rabbit	31	11%	233	85%	10	4%	274
Sheep	37	15%	152	60%	63	25%	252
Other birds (10 species)	32	13%	178	72%	37	15%	247
Other mammals (10 species)	39	23%	104	62%	24	14%	167
Total	691	21%	2 140	64%	530	16%	3 361

Abbreviations: N = number of national breed populations.

Table 4
Livestock national breed populations repartition across breed adaptedness and regions.

	Native		Locally adapted		Exotic		Unknown		
Region	N	%	N	%	N	%	N	%	Total
Africa	264	38%	151	22%	206	30%	70	10%	691
Europe	1 013	47%	337	16%	641	30%	149	7%	2 140
Other regions	128	24%	86	16%	306	58%	10	2%	530
Total	1 405	42%	574	17%	1 153	34%	229	7%	3 361

Abbreviations: N = number of national breed populations.

Table 5
Livestock national breed populations repartition across management systems and factor categories (restricted dataset).

Factor categories	Management systems										Total	
	Back Yard / Farm Yard		Extensive		Semi-Intensive		Intensive		Not for production			
	N	%	N	%	N	%	N	%	N	%	N	%
Region												
Africa	5	5%	15	10%	12	9%	7	8%	0	0%	26	6%
Europe	87	87%	124	84%	99	77%	78	85%	97	99%	347	85%
Other regions	8	8%	8	5%	17	13%	7	8%	1	1%	33	8%
Adaptedness												
Native	77	77%	94	64%	55	43%	24	26%	76	78%	225	55%
Locally adapted	3	3%	24	16%	25	20%	25	27%	0	0%	55	14%
Exotic	20	20%	26	18%	47	37%	42	46%	22	22%	122	30%
Unknown	0	0%	3	2%	1	1%	1	1%	0	0%	4	1%
Species												
Cattle	5	5%	38	26%	33	26%	26	28%	1	1%	81	20%
Goat	4	4%	14	10%	20	16%	12	13%	1	1%	36	9%
Sheep	3	3%	47	32%	33	26%	12	13%	2	2%	79	19%
Pig	2	2%	9	6%	9	7%	26	28%	0	0%	36	9%
Horse	0	0%	10	7%	20	16%	3	3%	10	10%	39	10%
Rabbit	55	55%	0	0%	0	0%	0	0%	55	56%	55	14%
Other mammals	1	1%	8	5%	3	2%	2	2%	0	0%	11	3%
Chicken	19	19%	17	12%	8	6%	8	9%	19	19%	50	12%
Other birds	11	11%	4	3%	2	2%	3	3%	10	10%	19	5%
Total	100		147		128		92		98		406	

Abbreviations: N = number of national breed populations.

Table 6
Averages and estimated effects of region, adaptedness and species groups on the number of ES reported by livestock national breed population.

	Cultural		Provisioning		Regulating and maintenance		Total	
Item	Avg	Est	Avg	Est	Avg	Est	Avg	Est
Intercept		-1.22^{**}		1.06^{***}		-0.99^{NS}		1.39^{***}
Region								
Africa	0.91	0^{a}	3.95	0^{a}	1.64	0^{a}	6.51	0^{a}
Europe	0.71	-0.72^{a}	1.88	-0.56^{b}	1.36	-0.59^{a}	3.96	-0.48^{a}
Other regions	0.68	-0.34^{a}	2.43	-0.11^{ab}	0.7	-1.23^{a}	3.82	-0.17^{a}
Adaptedness								
Native	0.92	0^{a}	3.03	0^{a}	2.02	0^{a}	5.97	0^{a}
Locally adapted	0.62	-0.06^{a}	2.39	-0.13^{b}	1.1	-0.19^{b}	4.1	-0.14^{b}
Exotic	0.69	-0.45^{b}	1.68	-0.41^{c}	0.54	-0.45^{c}	2.9	-0.44^{c}
Unknown	0.38	-0.77^{b}	2.1	-0.42^{c}	1.45	-0.1^{ab}	3.93	-0.38^{c}
Species								
Cattle	0.44	0^{de}	3.35	0^{a}	1.65	0^{a}	5.43	0b
Goat	0.49	0^{de}	2.95	-0.17^{b}	2.24	0.11^{a}	5.68	-0.05^{bc}
Sheep	0.4	-0.4^{e}	2.58	-0.15^{b}	1.96	0.11^{a}	4.93	-0.06^{bc}
Pig	0.45	0.05^{de}	2.18	-0.2^{b}	0.72	-0.37^{b}	3.36	-0.24^{d}
Horse	2.47	1.8^{a}	1.73	-0.44^{c}	1.09	-0.34^{b}	5.3	0.12^{a}
Rabbit	0.87	0.98^{b}	1	-0.69^{d}	0.23	-1.58^{d}	2.1	-0.51^{e}
Other mammals	1.23	0.82^{b}	3.29	-0.15^{b}	1.81	-0.49^{b}	6.34	-0.12^{cd}
Chicken	0.72	0.48^{c}	1.84	-0.53^{cd}	0.65	-0.94^{c}	3.2	-0.5^{e}
Other birds	0.45	-0.18^{cd}	1.66	-0.48^{cd}	0.77	-0.82^{c}	2.87	-0.47^{e}
Total	0.75		2.39		1.32		4.46	

Abbreviations: Avg = Average; ESs = uses and ecosystem services; Est = Estimate; ^{NS}Non-significant; $^{**}P < 0.01$; $^{***}P < 0.001$.
$^{a-e}$ Values within a column group with different superscripts differ significantly at $P < 0.05$ between groups after multiple corrections according to the statistical model used.

breeds, African livestock contributed to a significantly ($P < 0.01$) larger number of provisioning ESs (3.95 vs 1.88), with no significant differences found for other ES categories or for the total number of ES reported. Native and locally adapted breeds were related to significantly ($P < 0.05$) more ESs than exotic breeds, whether for cultural (0.83 vs 0.69), provisioning (2.85 vs 1.68), or regulating and maintenance (1.75 vs 0.54) ES.

Significantly ($P < 0.001$) more cultural ESs were reported for horses (2.47 vs 0.75 on average), while the three main ruminant species (cattle, goat and sheep) were associated with significantly more provisioning ($P < 0.001$) and regulating and maintenance ES (2.99 and 1.86 vs 2.39 and 1.32 on average, respectively).

When using the second statistical model with the restricted dataset, the region, adaptedness, and species factors yielded relatively similar results to the full dataset (Supplementary Table S1) and are therefore not commented further. National breed populations raised in the Back Yard/Farm Yard and Intensive systems were associated with significantly ($P < 0.01$) higher and lower numbers of cultural ES, respectively. No management system had a significant impact on the number of reported provisioning ES. National breed populations raised in "non-production" systems were associated with significantly ($P < 0.01$) fewer regulating and maintenance ES. When considering the total number of ESs reported, a significant ($P < 0.05$) positive impact was found for national breed populations raised in "Back Yard /Farm Yard" and "Extensive" systems.

Correlations among uses and ecosystem services

The tetrachoric correlations between the ESs range from −0.49 to 0.84 with an average around 0.15. Fig. 1 illustrates some trends in correlations among ES. For example, a group ("Equids bundle") of ten transportation and riding ES had high correlations with each other (on average $r = 0.56$), while being negatively correlated with several provisioning ESs such as provision of meat ($r = -0.31$). These results were expected given that the corresponding ESs are either never or only rarely provided by equids (horses and donkeys). While these two species accounted for 11% of the national breed populations in the dataset, they accounted for an average of 79% of those reporting the ten transportation and riding ES.

A second major bundle included 12 ESs that were very heterogeneous in nature, but were nonetheless highly correlated statistically ($r = 0.54$). This group included non-food provisioning ES (hair, horns, hides and skins, fuel and manure, and saving security) and regulating and maintenance ES (fertilizer, habitat and biodiversity, recycling of non-human edible food waste, weed control and biomass residue management, pollination and seed dispersal, vegetation management, fire protection). This second group was named the "Ruminant bundle" because it appears to be largely provided by ruminant (cattle, goats, sheep, and seven other ruminant and camelid (pseudo-ruminant) species in the other mammal group). While these species accounted for 50% of the national breed populations in the dataset, they averaged 77% of those reporting these 12 ESs. Some of these ESs (skin and hides, fuel and manure, saving security) were also particularly correlated with some cultural ESs (cultural and religious ceremonies, research), forming the "African ruminant bundle" ($r = 0.62$), as ruminant national breed populations reported by African countries were particularly overrepresented in this cluster. While African ruminant national breed populations accounted for 12% of the total data set, they represented an average of 57% of those reporting the five ESs of this "African ruminant bundle". Other bundles grouped other similarly

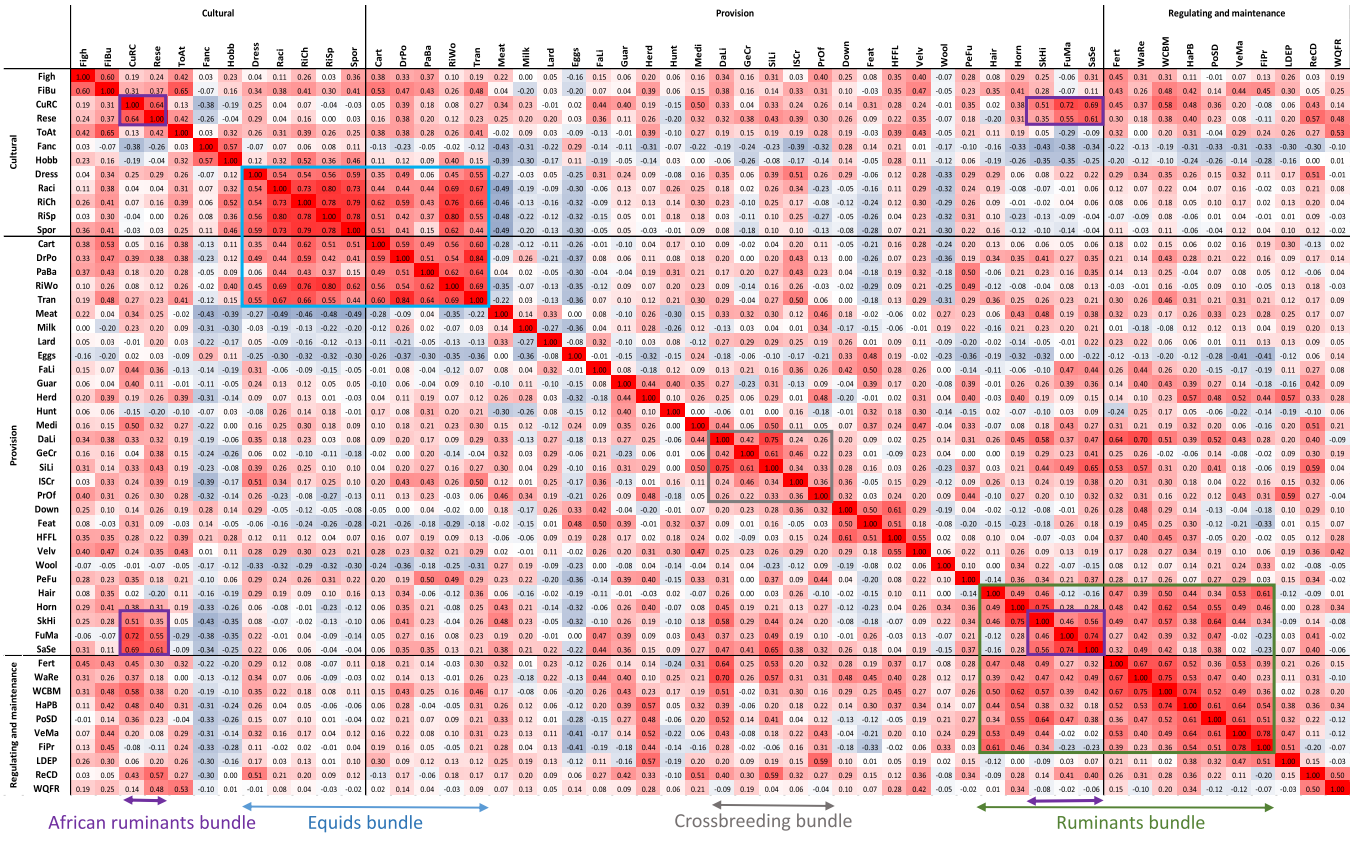

Fig. 1. Tetrachoric correlations matrix of ES reported. Colored frames correspond to various ES bundles identified in the livestock breeds. Abbreviations: ESs = uses and ecosystem services. See Tables 1 and 2 for ES abbreviations.

related ESs more by the nature of ES than by specific species; for example, a set of five ESs related to crossbreeding and offspring production (“Crossbreeding bundle”, r = 0.40).

Multiple factorial analysis

When implementing multiple factor analysis, the first two axes explained 17.4 and 10.5% of the variance of the data set (Fig. 2). The first axis was positively correlated with all regulation and maintenance ES, as well as all provisioning ESs, with the exception of eggs, hunting, and riding for work. The second axis appears to be positively correlated with all cultural ESs and all regulation and maintenance ES. The ES included in the “Ruminant bundle” appeared to be highly correlated with the first axis (see Fig. 1), while those included in the “Equids bundle” were highly correlated with the second axis, with Fancy and Hobby uses also highly correlated with this axis. When considering explanatory factors, the first axis appeared to distinguish cattle, sheep, and goats from rabbits, chicken, and other birds, Africa from Europe and “Other regions”, and native from exotic national breed populations. The second axis primarily distinguished horses and the category “Other mammals” from all other species.

Discussion

Multifunctionality, uses and ecosystem services assessment

Multifunctionality was assessed by the number of ES reported. In terms of their ability to provide a diversity of milk and meat-related food products while interacting with ES, with potential mobility over large distances, ruminant and pseudo-ruminant species were reported to provide a large number of provisioning, regulating and maintenance ES. The larger number of regulating and maintenance ES they provide can be explained by their ability to graze the natural forage of grasslands and rangelands. These habitats are natural and semi-natural habitats that enable the provision of a higher number of these ESs (Burkhard et al., 2012). In terms of cultural ES, horses exhibit the most multifunctionality. This is due in part to the large number of uses related to equestrian activities mentioned above, which increases the number of ES recognized for horse breeds. Regardless of the category considered, the number of reported ES follows a gradient from exotic breeds to locally adapted and native breeds. At the same time, the same gradient could be observed from intensive to semi-intensive and extensive systems, although, according to the statistical analysis, only extensive systems showed a significantly greater association with the total number of ES provided. These results confirm the contrast between specialized and intensive production systems that raise highly productive exotic breeds, as opposed to extensive multipurpose systems that use native breeds, as observed by Rodríguez-Bermúdez et al. (2019) for dairy systems. Our results (see Fig. 2) suggest that locally adapted breeds exhibit intermediate multifunctionality in terms of ES provision. This contrast highlights that livestock policies aimed at supporting the adoption of highly productive breeds by producers may lead to a decrease in the multifunctionality of local livestock production systems.

The ES provided by livestock production systems and practices can be considered as influenced by farmers’ decisions, which include choices in terms of species, breeds, individuals and their combination. Therefore, synergies between pairs of given ESs are expected, either (i) because the two ESs are inherently linked (e.g., fire protection and habitat provision) (Lauvie et al., 2023), or (ii) because the correlation is related to specific production practices or systems (e.g., the use of livestock as an asset for savings and economic security, while at the same time being important for cultural and religious ceremonies, such as in small-scale African production systems), or (iii) because of the species or breeds themselves (e.g., egg and feather production, which are ESs provided only by avian species). Antagonisms may also occur, and for instance, breeds raised for entertainment or hobby are rarely used for meat production. As a result of these synergies and antagonisms, our correlation analysis revealed a set of ES bundles related to animal genetic resources at the global scale. Some of these bundles were predictable given the way the list of uses and ES in the DAD-IS was defined, with, for example, several correlated uses related to horseback riding and transportation by animals, primarily equids. More interestingly, the “ruminant” bundle thus illustrates how some ruminant production systems are known to provide a wide variety of provisioning and regulating and maintenance ESs beyond just food provision. It is noteworthy that the ESs in this set have significantly (P < 0.001) higher correlations with provision of meat (0.28) than with provision of milk (0.07), which may be related to the fact that a significant proportion of national dairy breed populations are raised in production systems less likely to provide such ES. Focusing on specific regions, populations of national breeds of ruminants in Africa appear to be linked to specific ES, such as the cultural and religious ceremonies mentioned above.

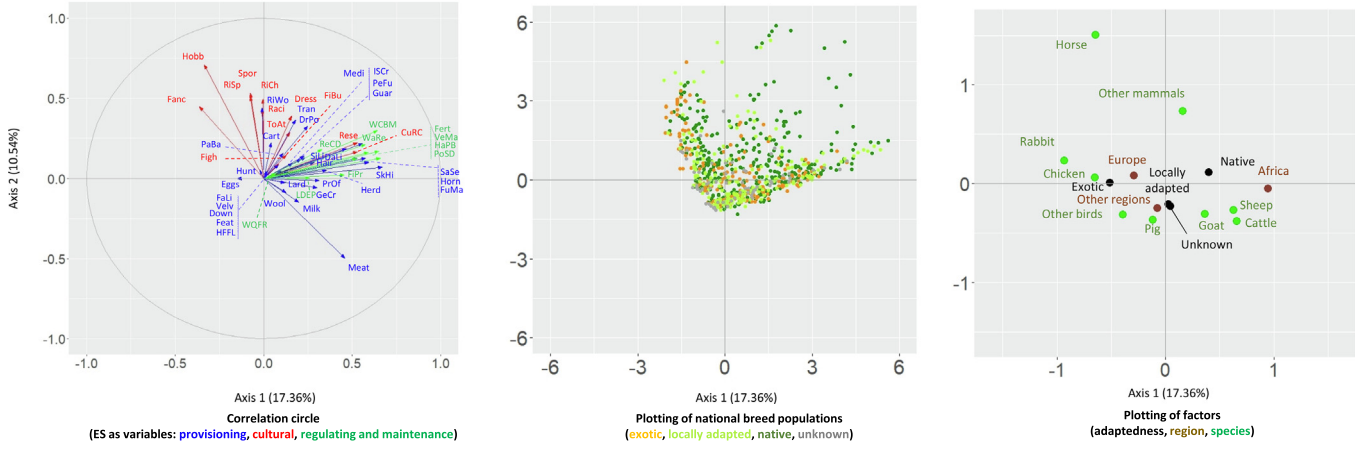

Fig. 2. Projection of ES, national breed populations and explanatory factors on the two first axes of the multiple factorial analysis. (a) Correlation circle of the ES; (b) plotting of the 3 361 livestock national breed populations analyzed; (c) plotting of the three explanatory factors, namely the region, the species and the breed adaptedness groups. Abbreviations: ESs = uses and ecosystem services. See Tables 1 and 2 for ES abbreviations.

The data set did not allow for a general examination of the impact of farming practices on the provision of ES. There are, however, some exceptions to this rule. For example, for ruminant species, "Herding" use was probably understood by the National Coordinators to refer directly to breeds subject to the farming practice of keeping the animals in outdoor herds. Such "herding" usually takes place on natural or semi-natural habitats like rangelands or extensive grasslands which can explain a significant positive correlation (greater than 0.44) with regulating and maintenance ES such as habitat provision and biodiversity, pollination and seed dispersal, vegetation management, fire protection, and (regulation of) land degradation and erosion. This result illustrates the interest in investigating the relationships between breeds and species, farming practices and the ecosystem providing feed resource. In the above case, rangeland is the ecosystem supplying the regulating and maintenance ES. These ESs are mostly studied through an ecosystem lens, for example to compare the relative levels of ES supply across croplands, grasslands, rangelands, wetlands or forests (Burkhard et al., 2012; Van der Biest et al., 2014; Jacobs et al., 2015). They are also commonly assessed through the lens of management focusing directly on the ecosystem, such as the frequency of hay cutting, or amount of nitrogen input in grasslands (Schils et al., 2022), or the use of pesticides in croplands (Power, 2010; Holt et al., 2016). A few recent studies have investigated the links between animal genetic resources and ES provision (Leroy et al., 2018; Velado-Alonso et al., 2021; Lauvie et al., 2023). In agreement with those studies, the above results clearly suggest that the species and breeds, practices and resources cannot be studied in isolation and are interdependent. It illustrates the interest of integrating animal genetic resources in further assessments of regulating and maintenance ES.

Challenges and limits of the study

One of the main challenges in identifying and quantifying ES is related to their different natures and the social dimension in their recognition (Lauvie et al., 2023), as well as the fact that the relationship between them is not always apparent or easy to measure (Rodríguez-Ortega et al., 2014). The use of DAD-IS data, with individual ES reported as binary variables, has allowed for a holistic analysis of how ESs related to livestock are recognized, putting each of these ESs on an equal footing. However, it is important to recognize the limitations of such an approach. The classification into 52 ESs, which represents 43 "uses" historically included in the DAD-IS and 9 ESs added in 2021, is open to improvement. While the vast majority corresponds to ES that match the common international classification of ecosystem services (CICES, Haines-Young and Potschin-Young, 2018), some of these uses and ESs are highly correlated, such as racing, sport riding and children's riding. The fact that ten ESs related to transport and riding were considered gave considerable weight to this theme in the analyses, regardless of its real social or economic importance. Another limiting element concerns the fact that, although the information entered in DAD-IS can be considered as official data, the recognition of a given ES for a given national breed population is related to the way a given National Coordinator collects and interprets the corresponding information, which can often be subjective. Therefore, in the statistical models, countries were considered as random variables. In addition, the structure of the dataset, with only a few transboundary breeds reported more than 20 times, did not allow us to implement a breed-level analysis. Therefore, beyond the species level, our analysis focused on the adaptedness class of national breed populations to understand the extent to which the degree of adaptation of a given breed to a given production environment is related to the ES it provides and its multifunctionality.

In practice, exotic breeds often correspond to transboundary breeds that have been intensively selected for their production characteristics. For example, the transboundary breed Holstein cattle is well known for its high milk production. Most of the national breed populations of Holsteins were reported as exotic (68% of national breed populations with known adaptedness status). On the other hand, for some species such as rabbit, exotic breeds could also be considered as recently imported fancy breeds not used for production (see Table 5). Although exotic breeds appear to constitute the majority of breeds reported in intensive management systems (in contrast to native breeds more present in Back Yard/Farm yard and extensive systems), it has not always been easy to disentangle the relationship between species, region, adaptedness class, and management system. Nevertheless, through the use of explanatory approaches, this study is one of the first to explore how the above factors shape the recognition of livestock multifunctionality and provision of ES globally.

Conclusions

The importance of considering livestock multifunctionality in relation to agricultural livestock development is widely recognized in the literature (Swanepoel et al., 2010; Dumont et al., 2019). At the policy level, the development of agri-environmental programs by Europe in the 2000s was largely influenced by the concept of multifunctionality (Dobbs and Pretty, 2004), with some measures to support the use of traditional and endangered livestock breeds (Baylis et al., 2008). Multifunctionality and ecosystem services have been often considered as two very different approaches, the first one being farm-centered vs the second one more service-oriented, with limited interactions between scientific communities using those approaches (Huang et al., 2015). Yet, as underlined by Barnaud and Couix (2020), ecosystem services as a concept appear as a legitimate analytical tool to investigate multifunctionality, which is largely illustrated by this study.

Our results confirm that certain stakeholders such as National Coordinators are well aware of ES provided by specific breeds and species and recognize differences among populations in the provision of these services. They also illustrate, as above discussed that breeds and species are embedded in specific production systems with a set of practices that shape livestock multifunctionality and provision of ecosystem services (Martin-Collado et al., 2019). In the context of value chain development, any interference of an action with other livestock functions must be carefully assessed (FAO, 2019), taking into account the impact it may have on livelihoods and the environment. The provision of ES should also be taken into consideration when assessing the environmental impact of livestock and individual breeds. For example, in terms of climate change mitigation, "intensity" of emissions of greenhouse gasses is often reported. Intensity is usually measured as the amount of greenhouse gasses emitted per unit of a single commodity (such as kg of milk or meat) produced (Harrison et al., 2021). This approach may penalize species and breeds that provide multiple ESs, relative to specialized populations. An assessment of the ES provided and how they are regulated by current practices, including in terms of the use of animal genetic resources, should be a prerequisite for any livestock development intervention. It requires multidisciplinary participation, as well as broad involvement of stakeholders with a role in related food systems.

Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.animal.2023.101048.

Ethics approval

Not applicable.

Data and model availability statement

DAD-IS data content can be freely accessed in the corresponding website (https://www.fao.org/dad-is). The statistical models were not deposited in an official repository.

Statistic models that support the study findings are available from the authors upon request.

Declaration of Generative AI and AI-assisted technologies in the writing process

The authors did not use any artificial intelligence-assisted technologies in the writing process.

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Declaration of interest

None.

CRediT authorship contribution statement

G. Leroy: Conceptualization, Methodology, Formal analysis, Writing – original draft. **P. Boettcher:** Writing – review & editing, Supervision. **F. Joly:** Methodology, Writing – review & editing. **C. Looft:** Methodology, Writing – review & editing. **R. Baumung:** Conceptualization, Writing – review & editing.

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