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Factors and determinants of animal genetic resources management activities across the world

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ABSTRACT

This paper investigates the factors affecting the implementation of various management activities related to the characterization, use and conservation of animal genetic resources (AnGR) across countries. The 128 official country reports provided for *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture* were analysed based on a multivariate approach. These reports investigated topics related the national level of AnGR diversity, the extent of characterization activities, use and breeding programmes and conservation activities, as well as capacities in AnGR management and the use of biotechnologies related to livestock breeding. A large part of the variability (34.7%) of the dataset could be explained by one synthetic variable, which could be interpreted as the general extent of AnGR related activities, and indicate that country efforts on AnGR are directed relatively homogenously towards the various activities and species considered. This variable differentiated mainly OECD and BRICS countries from less developed ones. OECD and BRICS countries also appeared to be differentiated with respect to the use of some specific biotechnologies such as cloning, genetic modification and transplantation of gonadal tissues. With regards to economic and development indicators, the first synthetic variable showed large correlation with the number of researchers in agricultural sciences per inhabitant ($r=0.643$) and national GDP ($r=0.516$). Capacities in research therefore appeared to be one of the main enabling forces for activities related to AnGR and the implementation of the Global Plan of Action (GPA) for AnGR.

1. Introduction

Animal genetic resources (AnGR), corresponding to domestic livestock and poultry species, have an essential role in the maintenance and development of livestock production systems over the world. They are critical for insuring long-term food security and poverty alleviation, as the number of poor livestock keepers around the world is estimated around 750 million (FAO, 2012a).

In 1992, the Convention on Biological Diversity (CBD, 1992) established the responsibilities of countries with respect to the conservation of their genetic diversity, including its domesticated component. In 2007, the report on *The State of the World's Animal Genetic Resources for Food and Agriculture* (SoW) constituted a first global assessment of the status and trends of AnGR and their management (FAO, 2007a). Through the Interlaken Declaration, countries confirmed their common and individual responsibility for the conservation, sustainable use and development of AnGR (FAO, 2007b). They adopted, in response to the gaps and needs identified in the first SoW, the Global Plan of Action for Animal Genetic Resources (GPA), a framework featuring 23 Strategic Priorities (SP) grouped into four Strategic Priority Areas (SPA): Characterization, Inventory and Monitoring of Trends and Associated Risks (SPA 1); Sustainable Use and Development (SPA 2); Conservation (SPA 3); and Policies, Institutions and Capacity-building (SPA 4). The GPA includes lists of actions for each SP.

The SoW, which was based on information provided by 169 countries, showed large discrepancies between countries in terms of the state and management of AnGR: breeds and species are not equally present across all regions; breeding activities (animal identification, genetic evaluation, etc.), as well as the use of reproductive and molecular biotechnologies (artificial insemination, genetic modification, etc.), are not implemented at the same level; similarly, characterization and conservation activities differ greatly between countries. These differences may be explained by a range of factors, including the general level of economic and agricultural development, or have sociocultural causes.

In order to assess the changes in the general state of capacities in AnGR management since the publication of the SoW (FAO,

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Table 1
Variables used from the Country Reports received for the Second Report on the State of the World's Animal Genetic Resources, grouped by topic and respective section.

Topic	Section[1]	Variables	By species	Number of variables
Diversity	II	Number of breeds reported by countries (by species) ratio of number of exotic breeds to total number of breeds	yes	9
Characterization	II	Extent of characterization activities, based on proportion of breeds with activities implemented, estimated or approximated (by species)	yes	56
	IV	Level of progress in GPA strategic priorities relative to Strategic Priority Area (SPA) 1 (characterization) of the Global Plan of Action for Animal Genetic Resources	no	2
Use and breeding	II	Proportion of breeds with specific activities undertaken (by species)	yes	56
	IV	Level of progress in GPA strategic priorities relative to SPA2 (sustainable use)	no	4
Conservation	II	Extent of coverage of in situ, *ex situ* in vivo, *ex situ* in vitro conservation activities areas (n/a, none, low, medium, high) (by species)	yes	21
	IV	Level of progress in GPA strategic priorities relative to SPA3 (conservation)	no	3
Capacities	II	Extent of country capacity and provisions estimated in different areas of animal genetic resources (none, low, medium, high)	no	10
	IV	Level of progress in GPA strategic priorities relative to SPA4 (Policies, Institutions and Capacity-building)	no	5
Biotechnologies	II	Level of availability of reproductive and molecular biotechnologies (none, low, medium, high) (by species)	yes	63

[1]Section II. Data on AnGR and activities for their management (FAO, 2007); Section IV. Status in the implementation of the Global Plan of Action for Animal Genetic Resources – 2007–2013.

2007a) and the adoption of the GPA in 2007, FAO recently prepared *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture* (SoW2). To collect the information necessary for this assessment, FAO, in 2013, invited all countries worldwide to submit country reports, using a standardized questionnaire.

In general, the information provided in the country reports was either quantitative (count data or subjective ordinal ratings) or qualitative (narrative descriptions or explanations). In total, 128 official country reports (66% of countries) were received, the reduction in comparison to first SoW being related, among other things, 30 from OECD countries and 98 from non-OECD countries, including the 5 BRICS (Brazil, the Russian Federation, India, China and South Africa). The analysis of the country reports revealed wide variation across countries in terms of AnGR management (FAO, 2015a) and in terms of the level of implementation of the Global Plan of Action (FAO, 2014). Despite considerable achievements in policy development, technical developments such as the characterization, use and conservation of the world's AnGR remain far from complete, especially in developing countries. Limited financial resources, lack of policy/legal framework implementation, and lack of institutional and human capacity were frequently listed in the country reports as important constraints to progress in AnGR management and GPA implementation. These findings are in agreement with existing literature (Zonabend et al., 2013; Chagunda et al., 2015).

Country response rate to United Nations global assessments is usually low (United Nations Statistics Division, 2007; WHO, 2008; Lesnikowski et al., 2013). The high return of country reports for the two global AnGR assessments is, in itself, a measure of success and an indication of high interest and engagement in the topic. This may be because a diverse portfolio of livestock breeds is vital to food security and enables food systems to adapt to changing conditions and country decision-makers are increasingly concerned about the sustainability of their national agriculture and food systems. The maintenance of breed diversity is not only a goal of the GPA, but also of the Convention on Biological Diversity's Aichi Target 13 and of Sustainable Development Goal (SDG) Target 2.5.

The information provided in the country reports, for example all Likert-scale answers, is partially subjective, as it reflects the judgement of the national coordinators and advisory committees who completed the questionnaires. To our knowledge, such “soft” information provided in country reports for a United Nation consultation process has so far mostly been analysed descriptively, and only “hard” statistical data used for statistical analysis.

In this study, we performed a quantitative analysis of the country report data, using multivariate approaches. Among others things, we sought to find patterns of differentiation among countries in terms of the current state of AnGR and actions improving their management. Another aim of the study was to answer various questions on the factors associated with the degree of implementation of AnGR management activities, such as (i) how the economic situation determines the extent of AnGR activities, (ii) whether efforts in AnGR management are directed toward all species and activities equally and (iii) whether all available technologies are used in AnGR management..

2. Material and methods

2.1. Material studied

Data were extracted from the 128 country reports, specifically from quantitative responses provided in Sections II and IV of the reports (the two other sections provided an executive summary and information contributing to another global assessment). The questionnaires included explanations and definitions for all terms to ensure that responses were as consistent as possible (for access to questionnaires, see http://www.fao.org/3/a-i4787e/i4787e01.htm). Section II addressed the state of AnGR within each country and the state of programmes and capacity for their management. Section IV provided information specifically on national implementation of various aspects of the GPA. The Section II questions selected for analysis (Table 1) addressed the following six topics: 1) AnGR diversity; 2) characterization; 3) breeding programmes; 4) conservation programmes; 5) capacities in AnGR management; and 6) use of biotechnologies.

The country report questions on AnGR diversity included those seeking information on the numbers of breeds reported for the “big five” species: cattle (separately for dairy cattle, beef cattle and multipurpose cattle), sheep, goats, pigs and chickens; the number of breeds reported for other species; and the ratio between the number of exotic breeds and the total number of breeds reported for all species. The questions related to characterization addressed the extent of characterization activities such as baseline surveys, regular monitoring, phenotypic characterization, and pedigree or molecular genetic diversity studies. Questions on breeding programmes sought information on the proportions of breeds (among all breeds of the respective species) for which breeding-related activities such as animal identification, performance recording or genetic evaluation are undertaken. On conservation, countries were asked to report on levels of coverage of in situ, *ex situ in vivo* and *ex situ in vitro* conservation programmes. Questions on capacities addressed the extent of country capacities and provisions in fields such as education, research, infrastructure, and policies and laws and their implementation. Finally, countries were requested to report on the availability of different reproductive and molecular biotechnologies such as artificial insemination, embryo transfer, cloning and genetic modification.

For some questions, countries were asked to provide the number of breeds, for a given species, for which a specific activity (e.g. artificial insemination) is implemented; this number was then divided by the total number of breeds reported to calculate the level of implementation of that activity. For other questions, countries were asked to subjectively assess, in ordinal categories, the extent to which a given activity is practised or a technology used (none, low, medium or high); the estimates were then transformed into a 0–3 scale. As indicated in Table 1, most of the questions requested independent responses for each of the major livestock species groups (i.e. dairy cattle, beef cattle, multipurpose cattle, sheep, goats, pigs and chickens).

As described above, Section IV of the country reports dealt specifically with the progress made in the implementation of the GPA between 2007 and 2013. FAO (2014) had previously developed a method for summarizing the responses to these questions as quantitative "process" indicators of GPA implementation, and these derived indicators were used as input data in the present study (see also Scherf and Baumung, 2015). Each of these indicators is associated with a specific SP (and corresponding SPA) and falls on a continuous scale ranging from 0 (indicating that no action has been taken) to 2 (all actions covered by the indicator have been implemented fully). As shown in Table 1, the SPAs correspond to four topics addressed in Section II (characterization, use and breeding, conservation, capacities) and were grouped accordingly in further analysis. Not all of the 23 SPs were considered in the analysis, because some of the SPs address AnGR-related activities at regional and global levels rather than at national level.

The overall dataset included 229 variables, i.e. answers related to subcomponents of a question (for instance, the level of implementation of a specific activity for a given species). These are described in more detail in Supplementary Table 1.

2.2. Statistical analyses

As data were missing for 23.7% of the cells (for instance if the question was not answered due to absence of a given species), missing data were imputed through iterative Principal Component Analysis (PCA) (Josse and Husson, 2013). Variables were weighted to give equal importance to each of the six topics described in Table 1. Within each topic, variables were given the same weight.

Pearson correlation coefficients and PCA analysis (variables scaled to unit variance) were undertaken for the 229 variables individually, resulting in 26,106 correlation coefficients. Correlations were therefore grouped by topic and section, by species, or by capacities reported in different areas. Average values were computed and compared within and among groups (Tables 2–4 and Supplementary Table 2). Differences in average correlations were assessed through Mann-Whitney *U* test. PCA was also undertaken separately on subsets consisting of data from the 35 OECD and BRICS countries (BRICS countries being considered as intermediate in terms of economic development) and the 93 countries belonging neither to the OECD or to BRICS (hereafter

Table 2
Average correlations between responses to questions from the Country Reports for the *Second Report on the State of the World's Animal Genetic Resources*, grouped by topic and respective section (in bracket standard deviation).

Issue and activities	Abbrev.	AnGR div	Charac	SPA1	Breeding	SPA2	Conserv	SPA3	Capac	SPA4	Biotech	Total	PCA axis 1	PCA axis 2
AnGr diversity	AnGR div	**0.32 (0.26)**	0.22 (0.18)	0.3 (0.12)	0.17 (0.14)	0.26 (0.13)	0.2 (0.19)	0.27 (0.14)	0.25 (0.15)	0.25 (0.14)	0.24 (0.16)	0.22 (0.17)	0.41 (0.23)	0.14 (0.12)
Characterization	Charac		**0.43 (0.18)**	**0.49 (0.14)**	**0.32 (0.14)**	**0.34 (0.15)**	**0.35 (0.15)**	**0.39 (0.13)**	**0.38 (0.12)**	**0.34 (0.14)**	0.29 (0.17)	**0.34 (0.17)**	0.61 (0.16)	−0.06 (0.17)
	SPA1			**0.69 (0)**	**0.41 (0.13)**	**0.55 (0.13)**	**0.43 (0.12)**	**0.64 (0.06)**	**0.53 (0.07)**	**0.55 (0.1)**	**0.36 (0.14)**	**0.43 (0.15)**	0.78 (0.01)	−0.11 (0.07)
Use and Breeding programmes	Breeding				**0.39 (0.17)**	0.28 (0.15)	0.26 (0.13)	0.32 (0.12)	0.32 (0.13)	0.28 (0.13)	0.25 (0.15)	0.3 (0.16)	0.52 (0.16)	−0.1 (0.14)
	SPA2					**0.58 (0.06)**	**0.35 (0.1)**	**0.53 (0.09)**	**0.4 (0.11)**	**0.51 (0.13)**	**0.26 (0.14)**	**0.32 (0.15)**	0.6 (0.15)	−0.1 (0.03)
Conservation	Conserv						**0.45 (0.16)**	**0.44 (0.11)**	**0.38 (0.11)**	**0.37 (0.12)**	0.27 (0.15)	**0.31 (0.16)**	0.58 (0.14)	−0.02 (0.11)
	SPA3							**0.64 (0.05)**	**0.48 (0.05)**	**0.54 (0.1)**	0.26 (0.12)	**0.35 (0.15)**	0.67 (0.04)	−0.19 (0.11)
Capacities	Capac								**0.6 (0.09)**	**0.47 (0.09)**	0.29 (0.13)	**0.35 (0.14)**	0.68 (0.05)	−0.19 (0.1)
	SPA4									**0.53 (0.11)**	0.27 (0.14)	**0.32 (0.15)**	0.62 (0.13)	−0.14 (0.07)
Reproductive and molecular biotechnologies	Biotech										**0.42 (0.17)**	0.29 (0.16)	0.52 (0.17)	0.37 (0.2)

[1]Section II. Data on AnGR and activities for their management (FAO, 2007a); Section IV. Status in the implementation of the Global Plan of Action for Animal Genetic Resources – 2007–2013.
In bold, correlations found larger than 0.32, i.e. the overall average correlation across variables.

Table 3
Average correlations between responses to questions from the Country Reports for the *Second Report on the State of the World's Animal Genetic Resources*, grouped by species (in bracket standard deviation).

Species	Abbrev.	CaD	CaB	CaM	She	Goa	Pig	Chi	others	total
Dairy cattle	CaD	**0.4 (0.19)**	**0.39 (0.17)**	**0.37 (0.17)**	**0.34 (0.17)**	0.29 (0.16)	**0.33 (0.17)**	0.28 (0.15)	**0.35 (0.15)**	**0.34 (0.17)**
Beef cattle	CaB		**0.41 (0.17)**	**0.37 (0.16)**	**0.35 (0.16)**	0.3 (0.15)	**0.33 (0.15)**	0.28 (0.15)	**0.33 (0.14)**	**0.35 (0.16)**
Multipurpose cattle	CaM			**0.39 (0.19)**	**0.35 (0.17)**	0.29 (0.15)	**0.33 (0.16)**	0.26 (0.14)	**0.35 (0.16)**	0.34 (0.17)
Sheep	She				**0.34 (0.19)**	0.28 (0.17)	**0.32 (0.17)**	0.28 (0.16)	0.31 (0.16)	**0.32 (0.17)**
Goat	Goa					0.27 (0.18)	0.28 (0.18)	0.24 (0.15)	0.26 (0.14)	0.28 (0.16)
Pig	Pig						**0.32 (0.2)**	0.26 (0.14)	**0.32 (0.17)**	0.31 (0.17)
Chicken	Chi							0.28 (0.19)	0.26 (0.14)	0.27 (0.15)

In bold, correlations found larger than 0.32, i.e. the overall average correlation across variables.

designated non-OECD countries). The PCA procedure in R (Husson et al., 2011) was used.

PCA results were then compared to country indicators of economic and agricultural development from sources external to the survey. These indicators were the following: gross domestic product (GDP) (World Bank, 2015); agricultural value added as % of GDP (FAOSTAT, 2015); research and development (R&D) expenditures in agricultural sciences; and number of researchers (full-time equivalent) in agricultural science (42 countries provided by IFPRI (2014); 11 countries provided by Eurostat (2015)). R&D expenditures in agricultural sciences as % of GDP and as % of agricultural GDP were also used, as well as number of researchers (full-time equivalent) in agricultural science per 1000 inhabitants (density of researchers). These indicators were extracted for the year 2010 and compared to values computed on the first axis of PCA for 53 countries for which the above information was available. The Rural Access Index, estimating the proportion of the rural population which have adequate access to the transport system, was also considered (Roberts et al., 2006).

3. Results

3.1. Correlation analyses

Correlations across the 229 variables ranged between −0.32 and 1, with a mean of 0.316. Around 31% of the correlations computed were larger than 0.40, and were therefore significantly different from 0 for a P-value of 0.05 (after Bonferroni correction for 26,106 tests). As illustrated in Table 2, the correlations across topics and country-report sections ranged between 0.17 and 0.64, being on average higher within a given topic ($P<0.0001$). The number of breeds (falling under the topic diversity) reported was, in general, positively correlated with other variables, indicating that countries with larger numbers of recognized breeds tend to have more extensive AnGR-related activities. The reported extent of capacities and the GPA indicators (Section IV) for characterization and for conservation showed the highest correlations with other topics ($r=0.35$, 0.43 and 0.35, respectively). These two groups of GPA indicators also showed high correlations with the variables for their respective topics from Section II of the country reports ($r=0.49$ and 0.44, respectively). The average correlation between the groups of variables of the two country-report sections for the use and breeding programmes topic was relatively low in comparison ($r=0.28$). This may be explained by the fact that actions related to SPA 2 of the GPA not only include development of breeding programmes but also other activities related to the sustainable use of AnGR, such as the promotion of agro-ecosystems approaches in the management of AnGR and the provision of support to indigenous and local production systems, for example through value addition. Differential understanding of the term “sustainable use” in different countries may be an additional factor in this lower correlation.

In comparison to the range of correlations observed across topics, less variation (considering the same variables) was observed within and across livestock species, average correlations ranging between 0.24 and 0.40 (Table 3). Correlations were generally higher within species than between species ($P=0.0001$). Among species, the smallest correlation was reported between goats and chickens ($r=0.24$) and activities for chickens were generally less correlated with activities reported in other species. This difference seems to be linked to the heterogeneity in breeding activities for chickens (Supplementary Table 3), which is related to the fact that a lot of countries (such as the United States of America) rely almost entirely on private companies rather than on national breeding programmes for the implementation of selection activities in chickens.

As previously stated, the topic of capacity in AnGR management was generally highly correlated with other AnGR topics ($r=0.35$). Table 4 presents results in more detail, breaking the capacity topic down into ten different areas and showing their average correlations with each of the other AnGR topics (considering both sections II and IV of the country reports). The largest average correlations with AnGR management topics were

Table 4
Average correlations between capacities reported in different topics and areas of animal genetic resources (AnGR) management (in bracket standard deviation).

Areas of AnGR management	AnGR diversity	Characte rization	Use and Breeding	Conserv ation	Biotech nologies	total
Education	0.21 (0.12)	**0.37 (0.11)**	0.31 (0.11)	**0.39 (0.09)**	0.25 (0.11)	**0.33 (0.13)**
Research	0.27 (0.17)	**0.43 (0.14)**	**0.36 (0.11)**	**0.43 (0.09)**	**0.36 (0.11)**	**0.4 (0.13)**
Knowledge	0.28 (0.17)	**0.42 (0.14)**	**0.37 (0.13)**	**0.42 (0.1)**	**0.33 (0.14)**	**0.39 (0.14)**
Awareness	0.2 (0.18)	**0.33 (0.1)**	0.28 (0.11)	**0.35 (0.09)**	0.25 (0.09)	0.31 (0.12)
Infrastructure	0.27 (0.16)	**0.39 (0.12)**	**0.36 (0.13)**	**0.43 (0.11)**	**0.36 (0.12)**	**0.39 (0.14)**
Stakeholders	0.25 (0.17)	**0.37 (0.15)**	**0.35 (0.14)**	**0.36 (0.11)**	**0.35 (0.12)**	**0.37 (0.14)**
Policy	0.26 (0.16)	**0.38 (0.11)**	0.29 (0.13)	**0.38 (0.1)**	0.24 (0.13)	**0.33 (0.15)**
Policy implementation	0.25 (0.16)	**0.4 (0.12)**	0.28 (0.13)	**0.38 (0.14)**	0.26 (0.13)	**0.34 (0.16)**
Law	0.23 (0.17)	**0.37 (0.1)**	0.31 (0.13)	**0.36 (0.12)**	0.26 (0.11)	**0.33 (0.14)**
Law implementation	0.24 (0.13)	**0.35 (0.11)**	0.31 (0.13)	**0.32 (0.14)**	0.25 (0.13)	**0.32 (0.15)**

In bold, correlations found larger than 0.31, i.e. the overall average correlation across variables.

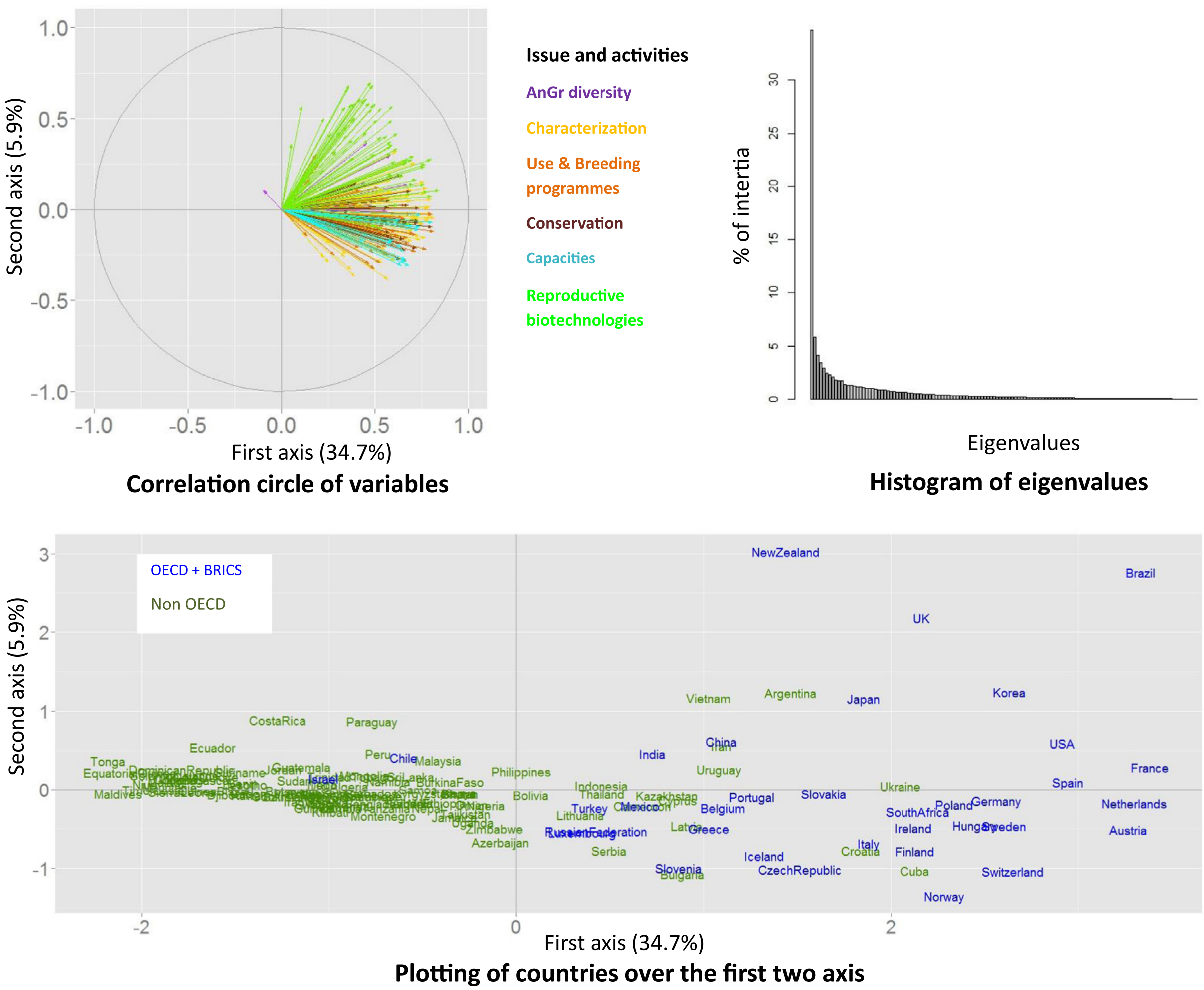

Fig. 1. PCA results considering the 128 countries.

observed for capacities in research, knowledge and infrastructure (r=0.40, 0.39, and 0.39 respectively). Individual correlations were especially large with characterization and conservation activities, which are rather well-defined technical areas, as compared to use and breeding, which are influenced by complex social, economic and cultural factors.

Supplementary Table 2 shows average correlations between variables related to the ten areas of capacity in AnGR management and variables from Section IV of the country reports for each of the national-level SPs. Capacities reported in research were also substantially correlated with the national-level SP implementation of the GPA (0.52 on average). The relationship was especially large for SP13, i.e. establishment or strengthening of national educational and research facilities (r=0.63), but also for SP4 (establishment of national species and breed development strategies and programmes, r=0.61).

3.2. Principal component analysis

A large part of the variability (34.7%) across all variables of the data set could be explained by one synthetic variable, which could be interpreted as the general extent of AnGR related activities. As shown by Fig. 1(A), all variables with the exception of one (ratio between exotic and total number of breeds, $r=-0.1$) were positively correlated to this first axis, with an average correlation of around 0.56. The highest correlations were 0.84, 0.81 and 0.81 for the use of molecular genetic information in multipurpose cattle, level of progress in SP4 implementation (species and breed development strategies and programmes) and implementation of pedigree diversity studies in multipurpose cattle. When grouping the variables by topics (Table 2), characterization (Section IV), conservation (Section IV) and capacities (Section II) showed the highest correlations with the first axis (0.75, 0.67 and 0.68) respectively. As shown in Fig. 1(C), countries with large values on the first axis were mostly OECD and BRICS countries, reporting in general a high level of activities related to AnGR management. For instance, France, Brazil and the Netherlands (the three countries with the greatest values for axis 1) reported regular monitoring of population size for 100%, 100% and 83% of their sheep breeds (versus 43% on average), respectively, and pedigree recording for 100%, 82% and 100% of their goat breeds (versus 45% on average), respectively, and all three countries indicated a high level of capacity in research. However, not all OECD countries showed such a high level of AnGR activities; for example, Israel reported a low level of AnGR management activities, stating in its report that the country relied significantly on imported genetic material. Israel also reported having no local breeds at risk, and has thus no specific action taken in the area of AnGR conservation. Among non-OECD countries, only countries from Europe (Croatia, Ukraine), Asia (Islamic Republic of Iran, Viet Nam) and Latin America (Argentina, Cuba, Uruguay), showed high values for the first axis, the African country with the highest Axis 1 value (i.e. reporting the highest extent of AnGR related activities) being Cameroon.

The second axis explained only 5.9% of inertia, with correlations with variables ranging from -0.38 to 0.70. Variables showing high correlation with the second axis were mainly related to the use of reproductive and molecular biotechnologies, with an average correlation with axis 2 around 0.37 (see Table 2), and more specifically to the use of specific techniques such as cloning, genetic modification and transplantation of gonadal tissues. The 12 highest correlations, which were higher than 57%, corresponded to the availability of those three technologies for beef and dairy cattle, sheep, goats and pigs. This second axis discriminated several OECD and BRICS countries. For instance, New Zealand and Brazil (the two countries with the highest values for Axis 2) reported availability of the three above-mentioned technologies for beef and dairy cattle, at least at experimental level. In contrast, Norway, which had the lowest value for Axis 2, indicated that those technologies were not available, despite wide availability of other biotechnologies such as the use of molecular information (genomic selection), for example, which was reported to be widely available to dairy cattle breeders.

Undertaking distinct PCA analysis on OECD and BRICS countries and non-OECD countries did not change the results much (Supplementary Figs. 1 and 2). The respective first axes discriminated more clearly the non-OECD countries (26.4% of inertia explained) than the OECD and BRICS countries (19.8%), where countries were also differentiated according to the availability of reproductive and molecular biotechnologies, with the second axis explaining 10.3% of inertia (relative to only 5.9% for the non-OECD countries).

Table 5 shows correlations between the values for Axis 1 of the principal component analysis and national indicators related to agriculture, economy, and R&D. The largest correlation was with the number of researchers in agricultural sciences per inhabitant ($r=0.643$). Other significantly ($P<0.01$) large positive correlation coefficients were observed for GDP ($r=0.516$), absolute R&D expenditures in agricultural sciences ($r=0.496$), Rural Access Index ($r=0.449$), and number of researchers in agricultural sciences in total ($r=0.36$). In contrast, the correlation was significantly negative ($P=0.001$) for the agriculture value added as percent of GDP ($r=-0.43$). This result is related to the fact that in developing countries, which generally have a low level of AnGR activities, the economic contribution of agriculture and livestock to the national economy is greater than in more developed countries.

4. Discussion

The primary aim of this study was to assess, based on country reports, the patterns and differences among countries in AnGR management activity according to topics, species and technical capacity. Inasmuch as this analysis is based on country reports reflecting the judgement of national coordinators and advisory committees, some individual questions could have been interpreted slightly differently from country to country. As the subjectivity of answers is a crucial issue in the interpretation of the results of a survey, questions within the questionnaire were formulated so as to avoid, as far as possible, any interpretation bias. For instance, the concept of the "availability" of biotechnologies might be interpreted differentially, depending on whether it is understood in the sense of being technically and legally feasible, or in terms of whether there is actually some mechanism in place for delivering the respective technology to potential users (beyond research level). The objective in our case was to address the latter (i.e. to focus on service provision), and the question was formulated accordingly, countries were asked to indicate whether reproductive technologies were available at experimental level only, available to livestock keepers in some locations or production systems, or widely available to livestock keepers, thus limiting the risk of the question being misinterpreted. In general, however, most of the results were in agreement with other sources of information (where available) on country activities in the field of AnGR. For instance, it was not surprising to find that France, the Netherlands and the United States of America, which were for instance among the first countries to implement *ex situ* conservation and organize national cryobanks (Danchin et al., 2011), were among the countries with the highest levels of reported AnGR activities (Fig. 1).

The analyses clearly illustrates that the extent of implementation for most of the activities is positively correlated within and across countries. This result was expected, because (i) implementation of AnGR management requires certain resources, frameworks and capacities, which may be illustrated by the fact that developed countries indicate greater development of AnGR activities overall, and (ii) there are interdependencies among most of the activities. For instance, the development of breeding and conservation programmes requires the characterization of the respective breeds, which explains the close correlations between characterization and all other topics. Even the number of reported breeds is somewhat related to the extent of characterization activities, as these activities involve the development and recognition of local breeds. Historically, breed and stud books were established in Europe in the late 18th century at the beginning of industrial revolution (Audiot, 1995), while the term breed is not as clearly defined in many developing countries. This contributes to differences between OECD and non-OECD countries. AnGR management activities were also connected to the development of reproductive and molecular biotechnologies. For instance, artificial insemination and embryo transfer are highly relevant to both breeding and conservation programmes, while genomic tools can be used for characterization, selection and conservation of animal genetic resources.

Although much less discriminating than the general extent of AnGR activities, the availability of some specific reproductive and molecular biotechnologies (cloning, genetic modification), constitutes another source of differentiation across countries. This differentiation however occurs essentially in OECD and BRICS countries, probably because the application of related biotechnologies is still limited in developing countries. In developed countries, this may reflect differences in ethical concerns about the use of certain biotechnologies. For example in Norway, which showed the lowest value for the second axis of the principal component analysis, there is strong public opposition to the use of some biotechnologies, such as genetic modified food and animal cloning (Gaskell et al., 2000), and there is a legal and policy framework specifically developed to address animal ethics (Marie, 2006). In developing countries, it is difficult to predict whether, if these technologies were available, such ethical concerns would appear: a growing interest in genetically modified animals has been reported by several countries (FAO, 2012b), a few countries such as China and Argentina having begun to make strong

Table 5
Correlations between values computed on the main axis (representing extent of activities in animal genetic resources) of PCA and various indicators on agriculture, economy and R&D, based on 53 countries.

Indicator	r
GDP (US$)	0.516***
Agriculture, value added (% of GDP)	−0.43***
Agriculture, value added (US$)	0.18 NS
R&D expenditures in agricultural sciences (US$)	0.496***
R&D expenditures in agricultural sciences (% of GDP)	−0.198 NS
R&D expenditures in agricultural sciences (% of agricultural GDP)	0.25 NS
Number of Full Time Equivalent researchers in agricultural sciences	0.36**
Number of Full Time Equivalent researchers in agricultural sciences (per 1000 inhabitants)	0.643***
Rural Access Index	0.449***

NS non significant,

** $P<0.01$,

*** $P<0.001$.

investments in genetically modified animals for food production (Forabasco et al., 2013).

A second objective of the analysis was to identify factors that may trigger, or at least facilitate, the development of AnGR-related management activities. Rege et al. (2011) stated that in developing countries the lack of appropriate policies or the inability to implement such policies are major constraints to the development of the smallholder livestock sector. The positive medium correlations observed between the level of capacities reported in different areas and the implementation of AnGR activities provide interesting information in that respect. Adequate legal and policy frameworks, related for example to animal identification and registration, recognition of breeding organization or quality schemes for animal products, may indeed enhance the sustainable management of AnGR, as discussed in FAO (2015a). Level of infrastructure, which in this context relates, for example, to the existence of animal registration and recording schemes, breeding associations and the delivery of breeding services (such as artificial insemination), was also found to be highly correlated to the extent of AnGR management activities. In the executive summaries of country reports, numerous countries, especially in Africa, reported that the lack of infrastructure necessary for management and marketing of AnGR constituted a major constraint to the development of the livestock sector. Based on a study targeting Southern and Eastern African countries, Zonabend et al. (2013) pointed out that higher education, capacity building and institutional collaboration all constitute keys to the improvement of infrastructure related to AnGR activities, which is illustrated in our study by the high level of correlation estimated across the capacities reported in different areas of AnGR management ($r=0.60$).

Most importantly, capacities in research were more strongly correlated than any other areas of capacity to the implementation level of AnGR activities and progress in the implementation of GPA Strategic Priorities. Given this finding, it is worth speculating as to whether research, in its various aspects (institutions, human resources, technologies, etc.), is the main complementary enabling force for activities related to AnGR. For instance, it is clear that research institutions are major stakeholders in the field of AnGR management. For instance, country reports revealed that involvement of research institutions in genetic evaluation was more substantial than involvement of any other stakeholder group (i.e. governments, breeders' organizations, commercial companies, etc.) in both ruminant and monogastric species (FAO 2015a). Also, the high correlation observed between the values computed on the main axis of PCA and the number of researchers per inhabitant within countries (Table 5) illustrates how the level of research associates with the implementation of AnGR activities. Note that the 53 countries on which those correlations were computed included only countries from Africa, Asia and southern Europe. Given the fact that numerous developed countries with a high level of AnGR and research activities were omitted, the correlation has probably been underestimated. Our results also show the connection between the use of molecular and reproductive biotechnologies (artificial insemination, embryo transfer, genomic tools, etc.) with the extent of characterization, use and conservation activities. It is also worth noting that some developing countries are showing growing interest in genetically modified animals (FAO, 2012b). In developing countries, several studies have stated that integrated R&D is a requirement for the development of the agricultural sector and poverty reduction, especially in Asia and sub-Saharan Africa (Lenne and Thomas, 2006; Thirtle et al., 2003). It seems that agricultural R&D expenditures have greater effects on productivity in the sector than other type of spending (Mogues et al., 2015). It has been stated that one of the main challenges for agricultural knowledge science and technology should be to be able to provide livelihood options for the rural poor (IAASTD, 2009). Some studies in the field of animal breeding and genetics (Rege et al., 2011; Chagunda et al., 2015) have stressed that the focus should be on innovation and achieving social and economic outcomes in a sustainable manner. Participation of livestock keepers, farmers and pastoralists, as well as long-term sustainability of projects and innovations, should always be considered: there are multiple examples of inappropriate importation of technologies or genotypes that have failed to achieve the desired outcome (Leroy et al., 2015). Finally, strengthening of partnerships, among others those related to technology and capacity building, emphasized in SDG 18, can be considered to be a key to the successful implementation of all SDGs (ICSU and ISSC, 2015). Considering more particularly the management of livestock genetics, improvement of national, South–South and North–South institutional collaboration should be encouraged and funded (Chagunda et al., 2015), through adequate platforms or development of common infrastructure, for instance regional gene banks.

5. Conclusion

This analysis illustrates how the manifold activities behind AnGR management are interlinked at country level, with OECD and BRICS countries reporting, as might be expected, higher levels of AnGR-related activities. Our results show that efforts in AnGR management are generally directed towards all kinds of activities and species, as illustrated by the fact that a large part of the variability of the dataset could be explained by one synthetic variable. There are, however, some nuances in this, for instance the fact that the use of some reproductive biotechnologies, such as cloning or genetic modification, is limited in some developed countries because of ethical concerns. The low correlations of the extent of activities reported in chickens with those reported in other species could be related to differences in stakeholder involvement across countries, an issue that could be further investigated in future studies. The comparison of our results with economic and development indicators, allows quantification of how the extent of AnGR activities is related to economic and developmental factors, with the somewhat paradoxical observation that countries that are economically the most reliant on agriculture and livestock tend to be less advanced in terms of implementation of AnGR-related management activities. Our results also indicate that capacity in research is strongly associated with the implementation of AnGR activities. Therefore, it can be recommended that funding and policies aimed at improving AnGR management should integrate research into development strategies.

Conflict of interest statement

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

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The views expressed in this information product are those of the authors and do not necessarily reflect the views or policies of FAO.

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Appendix A. Supplementary material

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