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Geographical distribution of sheep breeds in Brazil and their relationship with climatic and environmental factors as risk classification for conservation

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Abstract

Background: The aim of this study was to evaluate the distribution of sheep breeds in Brazil, correlate their occurrence with environmental factors and determine their risk for extinction.

Methods: The localization of all flocks of purebred sheep (commerical and naturalised, hair and wool) in Brazil was spatialized in ARCGIS along with climatic (Thermal Humidity Index, precipitation, solar radiation, relative humidity) and physical environmental controls (altitude, pasture type). Data were analysed using analysis of variance, logisitic regression and cluster analyses. Distance matrices were constructed using longitude/latitude and those from environmental controls and these were correlated using Mantel test.

Results: Santa Ines and Dorper were the most popular breeds with a countrywide distribution. Over 80% of most breeds occurred within 500 km of their midpoint which has implications for their conservation and vulnerability as those breeds with few flocks and restricted geographical distribution are at higher risk. This was especially evident for the naturalised breeds. Spatial distribution of breeds was highly correlated with environmental controls and two distinct clusters were found. Spatial distribution of breeds was highly correlated with environmental controls. Naturalised sheep breeds in Brazil tend to be more localized than commercial breeds which may mean they are at greater risk. Hair and wool sheep tend to occur in specific environments.

Conclusions: Flocks in the center west and northeast tend to further away from the midpoint for the breed, making germplasm exchange, and therefore avoidance of inbreeding and their conservation, more difficult.

Keywords: Logistic regression; Mantel correlation; Naturalized; Pasture type; Temperature; Precipitation

Background

Brazil has 27 breeds of sheep registered by the Association of Sheep Breeders (ARCO) accredited by the Ministry of Agriculture, Livestock and Food Supply (MAPA). Both wool and hair sheep are reared and, with the expansion of sheep production in Brazil, especially to areas where this activity is not traditional (Hermuche et al., 2013a, b), it is important to investigate the relation of breed with climatic factors, as breed associations tend to market their breed independent of its adaptability to the region (McManus et al., 2010).

According to Carson et al. (2009), the investigation of breed distribution provides a valuable foundation for future research into genetic diversity within and between breeds, and serves as a baseline of information to enable population trends to be examined and a robust evidence-base for policy decisions on Farm Animal Genetic Resources (FAnGR). Most studies find high correlations between genetic diversity and geographic distance (Pariset et al., 2009; Kijas et al., 2012) but the lack of knowledge on distribution of breeds may hinder the establishment of effective breeding programs. The definition of eco-cultural niches (Krebs et al., 2012) highlights the combination of cultural, anthropogenic, biotic and abiotic environmental parameters characterising the space where the population exists and may yield valuable information on distribution of breed types within a country or region.

Production environment descriptors are also important and Alderson (2009) states that most current systems of evaluation of genetic endangerment consider only population size. He proposes a model system which encompasses the other important factors of geographical concentration and genetic erosion. Reist-Marti et al. (2006) proposed a number of factors that contributed to priority for conservation among a group of African cattle breeds. Among these factors were the total population size of the breed and trends in population size in the previous 10 years, distribution of the breed within the country, degree or risk of indiscriminate crossbreeding, level of organization of farmers, existence of ongoing conservation schemes, political stability of the country, sociocultural importance of the breed, and the reliability of this information. In general, these factors all contribute to the risk of extinction of the population.

Geographical information could also contribute to breed prioritization, and specific multivariate methods have been developed to consider geographical variables in procedures related to management of animal genetic diversity (Boettcher et al., 2009). Such approaches may be particularly useful in identifying animals or groups of animals to conserve when no distinct breeds are defined and the genetic make-up of the population of animals is expected to vary according to the geography of a given landscape. Among landscape features, space is most likely to influence the genetic structuring of a set of individuals or populations (Jombart et al. 2008). Novembre et al. (2008) described the genetic variability according to geography and found a close correspondence between genetic and geographical distances among human populations in Europe, although this is not always the case (Qing et al., 2009). An analogous approach could be applied to livestock breeds for which no genetic data (such as molecular genotypes) are available. In this paper we aimed to evaluate the spatial distribution of registered purebred sheep flocks in Brazil and relate their distribution to climatic and environmental factors to use in risk evaluation in conservation programs.

Methods

The localization of all flocks of purebred sheep in Brazil was spatialized by municipality from a data bank supplied by ARCO (Brazilian Association of Sheep Breeders). Breeds were classified as commercial (international breeds with readily available germplasm in other countries including Australian Merino, Poll Merino, Ideal, Corriedale, Romney Marsh, Texel, Hampshire Down, Ile de France, Suffolk, Lincoln, Karakul, Border Leicester, Southdown, Lacaune, Wiltshire Horn, Polypay, Poll Dorset, Dorper, White Dorper and South African Mutton Merino (SAMM)) or naturalized (locally adapted - Bergamácia Brasileira, Morada Nova, Santa Inês, Somális Brasileira, Rabo Largo, Cariri and Crioula) and as wool or hair (Table 1). Vegetation cover was from the average annual (2011) Normalized Difference Vegetation Index (NDVI) derived from MODIS images (Moderate Resolution Imaging Spectro-radiometer). NDVI is expressed by the equation: NDVI = (NIR-red)/(NIR + red) where: reflectance channels in the near infrared (NIR) and visible red (RED). This index is sensitive to the presence of chlorophyll and healthy vegetation and ranges between −1 and 1. The value 1 reflects the most photosynthetically active vegetation. The images were acquired from NASA site (2012) and converted from the sinuzoidal projection to geographic lat/long in Modis Reprojection Tool (MRT) (geographic projection Lat/Long and Datum WGS 84), and the annual average was processed in the software ENVI 4.7.

Precipitation values were average rainfall from 2000 to 2010 captured from image sensor TRMM (Tropical Rainfall Measuring Mission) with a spatial resolution of 0.25°,

Table 1 Sheep breeds in Brazil, their classification and number of flocks as well as distances (km) from mid-point of breed occurrence

Breed	Type	Use	Number of Flocks	Number of Municipalities	Km from mid-point			
					Mean	SD	Min	Max
Border Leicester	Wool	Commercial	29	14	184	129	77	398
Bergamácia Brasileira	Wool	Naturalized	54	45	940	522	181	2,297
Cariri	Hair	Naturalized	43	41	580	546	25	2,416
Corriedale	Wool	Commercial	490	71	206	845	29	3,092
Crioula	Wool	Naturalized	61	45	326	314	41	1,683
Dorper	Hair	Commercial	1073	654	1,013	455	68	2,735
East Friesian	Wool	Commercial	3	3	336	135	216	482
Hampshire Down	Wool	Commercial	246	147	379	495	15	2,758
Ideal	Wool	Commercial	345	61	194	534	19	2,597
Ile de France	Wool	Commercial	583	210	392	461	22	2,627
Karakul	Wool	Commercial	39	26	278	539	107	2,848
Lacaune	Wool	Commercial	27	23	466	212	158	919
Merino	Wool	Commercial	137	36	245	762	54	2,974
Morada Nova	Hair	Naturalized	151	102	677	623	85	2,777
Poll Dorset	Wool	Commercial	67	59	700	619	70	2,421
Polypay	Wool	Commercial	5	5	132	48	91	198
Rabo Largo	Hair	Naturalized	30	25	370	397	69	1,595
Romney Marsh	Wool	Commercial	92	40	348	641	81	3,038
Santa Ines	Hair	Commercial	3397	1385	970	522	13	3,013
Somalis Brasileira	Hair	Naturalized	179	122	504	581	36	2,755
South African Mutton Merino	Wool	Commercial	2	2	50	-	50	50
Suffolk	Wool	Commercial	734	353	488	677	21	2,590
Texel	Wool	Commercial	682	283	522	795	35	2,941
White Dorper	Hair	Commercial	248	197	793	472	165	2,308

or about 27 km. For the present study, we used 3B43 product images, which are the average monthly precipitation values. The images were acquired on the website of National Aeronautics and Space Administration (NASA, 2012) and processed using Envi 4.7.

The surface temperature data are images from the MODIS product mod11, which represents the average monthly surface temperature. These were redesigned with the software MRT extension geotif, geographic projection Lat/Long and Datum WGS 84. Aiming to filter temperature data for elimination of unreliable pixel values, we used a mask based on quality control Automatic Quality Control (QC) of the images, which indicates confidence in the processing of the Land Surface Temperature (LST) (Wan, 1999; 2007). After conversion of the temperature from Kelvin to degrees Celsius by means of a Band Math tool in Envi 4.7, average temperature of the period was calculated (2000 to 2011).

The average elevation of the municipality was based on data obtained from the SRTM (Shuttle Radar Topography Mission), which consisted of data acquisition from a radar of the entire surface of the earth (with the exception of extreme latitudes) with a resolution of 90 meters for preparation of a world digital terrain model. In this study we used data from the processing of SRTM for a hydrologically consistent model (hydroshed) from the National Aeronautics and Space Administration (NASA, 2012).

Relative humidity data were from the National Institute of Meteorology (INMET) and are the result of the average of a range of approximately 30 years of observations of 283 weather stations distributed throughout the territory. The stations were spatialized in ArcGis9.3 and humidity data were interpolated by the Topogrid module of the same software, with a pixel of 1 km.

The Temperature and Humidity Index (THI) relates the thermal comfort range of animals to the ambient temperature and relative humidity (Thom, 1959). For the calculation we used data of temperature and humidity previously acquired considering the following equation: $THI = Ta + (0.36 \times To) + 41.5$ where: Ta = ambient temperature (°C) and To = temperature of the dew point (°C).

Solar radiation was calculated in ArcGis 9.3 based on data from the SRTM topography, since the topography is an important factor that determines the spatial variability of insolation. The variation in orientation, elevation (tilt and aspect) and shadows from topographical features affect the amount of insolation received at different locations; this variability therefore contributes to the variability of the microclimate. In this case the parameters considered were: multiple days in the year 2011, taking into account five days to 160 days, with an interval of 14 days and 0.5 hours.

The weighted mean center (latitude and longitude) for each breed was calculated using the number of flocks registered per municipality. No information was available on flock size. Information on vegetation type by municipality was collected from the 2006 Brazilian Agricultural Census (IBGE, 2012a), the last available, as well as population, area and Gross Domestic Product (GDP) of the Municipality from IBGE (2012b). Human development Index (HDI) was available from the United Nations Development Programme (PNUD, 2013). This included percentage of cover of brush and pasture (natural, planted, degraded), areas of forest or shrub, population, GDP, HDI and number of animal units per farm. Variance Inflation (>10) and collinearity (condition index – CI >30) were examined using Proc REG as these are essentially characteristics of the explanatory variables. As expected THI, temperature and relative humidity showed high values for these traits. The final model included altitude, precipitation, NDVI, temperature, solar radiation, number of animals per farm and per km^2, area of native and planted pastures, shrub and forest as well as HDI and animals per area.

All variables were spatialized in ArcGis 9.3 (Additional files 1 and 2) with geographic projection Lat/Long and Datum WGS 84 from the Zonal Statistics tool based on vector data relating to municipalities (IBGE, 2012c). Data were transformed using Box-Cox transformations. Means of the climatic conditions per breed were compared using an analysis of variation (PROC MIXED) in SAS® (Statistical Analysis System v. 9.3, Cary, North Carolina, USA). Differences were tested using Tukey ($P < 0.05$). A binomial and multivariate logistic regression was carried out to test the presence of commercial, naturalized, wool or hair breeds according to the environmental controls. Model selection was carried out considering Nagelkerke's R^2, area under the ROC curve, Akaike information criterion (AIC) and Schwarz's Bayesian information criterion (BIC).

Cluster analyses were used to group the breeds according to environmental similarity and compared to mean distances using Mantel test in PASSaGE (Rosenberg et al., 2011).

Results and discussion

Poll Merino, Lincoln, Southdown, and Wiltshire Horn have no flocks registered. There were two wool naturalized breeds (Bergamácia Brasileira and Crioula) in this study while the rest were hair breeds (Table 1). International breeds recognised in Brazil include 20 international breeds (http://www.arcoovinos.com.br/sitenew/ferramenta/imagens/documentos/12.pdf) Australian Merino, Poll Merino, Ideal, Corriedale, Romney Marsh, Texel, Hampshire Down, Ile de France, Suffolk, Lincoln, Karakul, Border Leicester, Southdown, Lacaune, Wiltshire Horn, Polypay, Poll Dorset, Dorper, White Dorper and South African Mutton Merino (SAMM) and 7 breeds formed in Brazil include Bergamácia Brasileira, Morada Nova, Santa Inês, Somális Brasileira, Rabo Largo, Cariri and Crioula. It should also be noted that the "wool" from the Crioula is medulated like hair, different from wool from commercial breeds which is not (Moraes & Souza, 2011). Although the Santa Inês is a Brazilian breed, it was considered as commercial due to its wide distribution and recent history as to crossbreeding (Paiva et al., 2005, McManus et al., 2010). The number of animals per flock could be an important factor in making decisions on conservation priorities (Reist-Marti et al., 2006) but this information was not available in this study.

According to Carson et al. (2009) knowledge on breed distribution can indicate regions at risk from diseases that can wipe out populations of Animal Genetic Resources (AnGR). In Brazil, the smaller commercial breeds are at greater risk than the naturalized breeds which tend to have a wider distribution. Breeds such as Border Leicester, SAMM and Polypay were brought to Brazil for crossbreeding purposes and apparently were not successful, or the breeders were not interested in them. In contrast, the Romney Marsh, was formerly one of the most important breeds in the Southern Region, but nowadays presents only 92 registered flocks in 40 municipalities, which could an indication that some actions of conservation of animal genetic resources should be planned also for commercial exotic breeds. The Crioula could possibly be the breed with highest risk, for example, from a localized disease outbreak. It's distribution is concentrated in the South of the country with the lowest variability making these populations more at risk. The Northeastern States are in a region called the drought polygon, highly susceptible to long periods of high temperatures and no precipitation (Lôbo et al., 2011) which may directly affect the local breed selection.

Diseases, especially infectious, may be catastrophic for breeds with a localized distribution and certain breeds may be made extinct because of this. In the 1920s in the USA, Foot and Mouth Disease in the United States caused the loss of more than 120,000 livestock and deer (Ackerman & Giroux, 2006). In the case of Brazil, while the Crioula can be found in a region that includes a State that is Foot and Mouth Disease free without vaccination, the risk of this disease is low. On the other hand, naturalized sheep such as the Pantaniera in Mato Grosso or Mato Grosso do Sul are more at risk from Foot and Mouth Disease. This ecotype has not yet been recognized by Ministry of Agriculture as a breed but its distribution is limited to the Pantanal region which has frontiers with Paraguay and Bolivia. Other diseases may also be a threat. For example, Peste des Petits Ruminants (PPR) can occur in an epizootic form and it may have dramatic consequences with morbidity up to 90% and mortality up to 80% (Lefevre & Diallo, 1990). Abd El-Rahim et al. (2010) reported a severe outbreak of Peste des Petits Ruminants in flocks of sheep and goats in four districts in Egypt during 2006. According to McKellar (2006), epidemics of sheep scab can also be devastating and leave many small farmers indebted and destitute. Most flocks in the Northeast of Brazil have a small effective size (Lôbo et al., 2011) but local farmers are dependent on them for family sustenance. Therefore, information on breed distribution is important in protecting threatened well adapted Animal Genetic resources.

The number of flocks per breed registered varied from 2 for SAMM to 3397 for Santa Inês. The breeds with the lowest number of flocks registered are classified as commercial and were imported into Brazil in recent years to diversify production options (such as Lacaune for milk, or Karakul for pelt). Several Brazilian naturalized ecotypes or genetic groups are not yet recognized as local breeds (such as the Pantaneira and Barriga Negra (called Black Belly in English)). The observations here are in agreement with FAO (2007a, b) who observe that most livestock production systems depend on species originally domesticated in other regions of the world. They also state that these systems depend on breeds developed in other countries and regions, making most countries highly interdependent with respect to animal genetic resources. The limited geographical distribution of some breeds makes them vulnerable (Alderson, 2009), especially those in harsh environments and at risk from disease, drought or even human action such as crossbreeding.

The Degree of Endangerment (DE) of a breed is classified by four major methods: FAO (Scherf, 2000), the European Union (European Commission, 2002), the European Association of Animal Production (Gandini et al., 2004) and NGOs (Alderson, 1994). Assessment within the FAO and the European Union systems are based on demographic risk (Gandini et al., 2004) indicating that those breeds with few flocks and restricted geographical distribution are at higher risk. Some breeds in Brazil were more localized and others (Additional files 1 and 2; Table 1) recently imported breeds such as Dorper and White Dorper have spread rapidly throughout the country, while most of the naturalized breeds have a localized distribution. This shows either a certain gullibility on the part of the Brazilian farmer in believing propaganda about an imported breed that has not been widely tested in the country, and may potentially bring health or production problems (Ianella et al., 2011) or may represent the fact that Brazilian farmers adapt quickly to new technologies. Nevertheless, this adaptability may reflect in instability in the business, leading to insecurity in the marketplace (Hermuche et al., 2012;2013a).

According to Blackburn & Gollin (2009), successful introduction of new breeds into the USA has been based on several production traits, as well as the interest and acceptance of the private sector. On the other hand, introduction to take advantage of single traits has not been sustainable, especially when other economically important traits were compromised. In any case, such replacement processes may involve considerable costs and substantial investments in learning and gaining experience (Hoffmann, 2010).

In Brazil, there is a notable lack of breed variety in the center west and especially in the north of the country, with a dominance of Dorper, White Dorper and Santa Inês. This is in part due to the recent expansion of sheep farming to these areas (Hermuche et al., 2013a) and the aggressive marketing carried out by these breed associations. There are some naturalised genetic groups in this region such as the Pantaneira in the Pantanal region of the center-west or Barriga Negra (Black Belly) in the north. These are not yet recognized as breeds by the Ministry of Agriculture although are naturalized and well adapted to their environments. Almost all exotic breeds are registered but several naturalized Brazilian breeds are not, this reflects Brazilian regulations for breed recognition (McManus et al., 2010). Regulations governing genealogical register of animals (Brazilian Law 4716/1965) included the wording “genealogical register of domestic animals” which led to various interpretations but also limited the participation of smaller breeds, in poorer areas less developed regions (especially the Northeast in the case of sheep) with low HDI and poorly organised farmer’s associations. In 2008, the Commission on Agriculture, Animal Production, Supply and Rural Development in the House of Deputies in the Brazilian National Congress approved a change in the wording in the Law proposal 7210/2006 to “genealogical register of animals of agricultural interest”, which is hoped should facilitate the registration of smaller populations, ecotypes and breeds.

The concentration of commercial breeds in the South reflects the history of wool production in this region, followed by the wool crisis and a change to meat production but on a smaller scale. This region is also sub-tropical with better pastures and climatic conditions than in the Northeast, the other traditional sheep producing region of the country. The individual breed societies carry out breed promotional activities but only Sheep Breeder’s Association have the required network and know-how to carry out genealogical register of sheep in Brazil being licensed by the Ministry of Agriculture to do these notarial procedures since 1942.

The midpoint for production is in Figure 1. It can be noted that the midpoint for the two most popular breeds (Santa Inês and Dorper) is close to the midpoint production for all breeds (Hermuche et al., 2013b). Most of the naturalized breeds are to the northeast of these, while the commercial breeds are to the southwest as well as the Crioula. The midpoint for most commercial breeds is in Rio Grande do Sul State, reiterating the importance of this state for commercial sheep production in Brazil in the past century. The distribution close to the Atlantic Ocean is also important, reflecting the lack of agricultural development in the interior of the country until the 1970s based on

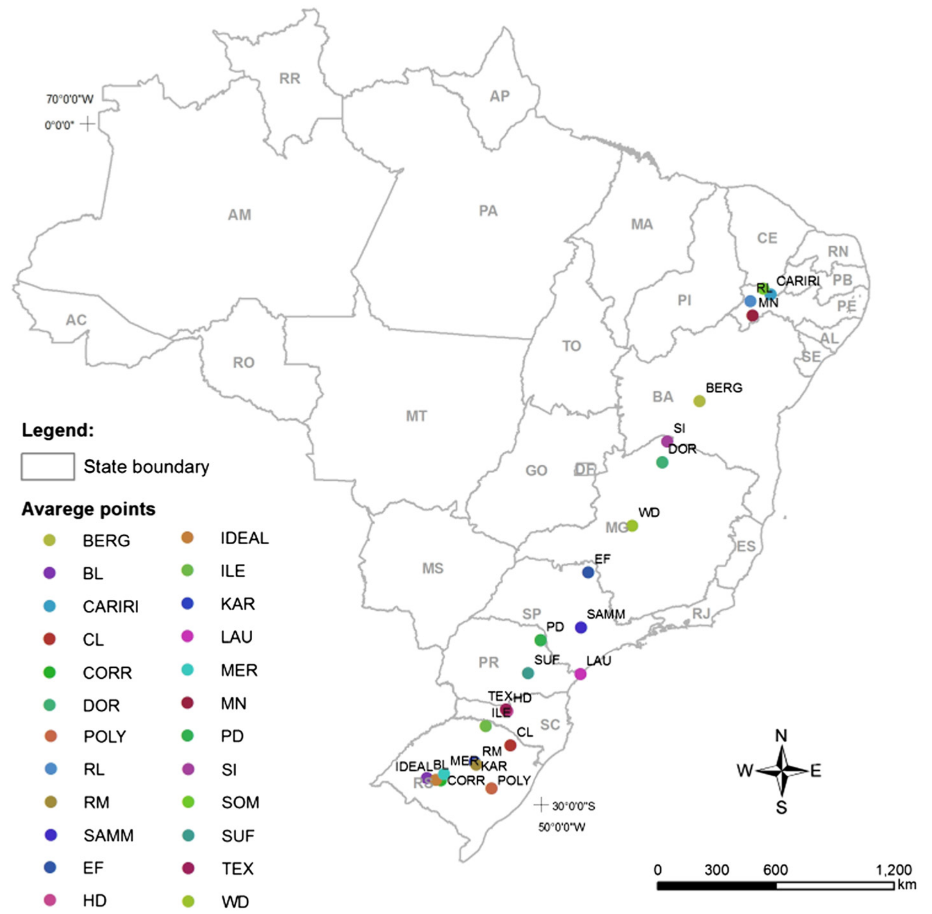

Figure 1 Midpoint for production by sheep breed in Brazil. BERG: Bergamácia Brasileira; BL □ Border Leicester; CL- Crioula; CORR □ Corriedale; DOR- Dorper; POLY □ Polypay; RL □ Rabo Largo (Fat Tail); RM □ Romney Marsh; SAMM □ South African Mutton Merino; EF □ East Friesian; HD □ Hampshire Down; ILE - Ilê de France; KAR- Karakul; LAU- Laucaune; MER- Merino; MN □ Morada Nova; PD □ Poll Dorset; SI □ Santa Inês; SOM □ Somalis Brasiliera; SUF □ Suffolk; TEX - Texel; WD □ White Dorper.

cattle and soybean as well as possible benefits in terms of climate (humidity, wind) in literal states.

Another question that arises with the national distribution of some breeds is the question of genotype x environment interaction. Unlike the British study (Carson et al., 2009), Brazil is a continental sized country ranging from the equator to the Tropic of Capricorn, englobing at least six different and distinct ecosystems. Most of the breeds have no formal breeding plans in place and studies have shown that breed success depends largely on environmental factors, especially in stressful environments. Also the smaller naturalized breeds tend to have less propaganda. Some breeding actions taken by farmers to “improve” the Santa Ines in terms of production capacity have also resulted in a worsening of their adaptive ability and resistance to parasites (McManus et al., 2009a, b; 2010).

Southern and Southeastern farmers are nearer to their breed midpoints than those from the other regions especially those in the Northern region of Brazil (Figure 2). Seventy five percent of farmers from the South are less than 500 km from the breed midpoint while in the Southeast this same percentage are between 500 and 100 km. In contrast 25% of farmers in the center west, 3% in the North and 30% in the northeast are within 500 km of the breed midpoint. This may affect the development of sheep farming in these regions. While 50% of commercial flocks are within 750 km from the breed midpoint, for naturalized flocks this is approximately 450 km, showing a lower distribution of these flocks. Hair sheep show a wider distribution than wool sheep, mainly due to the fact that two of the largest breeds (Dorper and Santa Inês) are in this group.

In the comparison between commercial and naturalised flocks, the significant parameters included the Temperature Humidity Index, altitude, vegetation (NDVI), solar radiation, number of animals per farm, area of pasture and shrub as well as the Human Development Index. The hair *vs* wool comparison included Temperature Humidity Index, altitude, precipitation, solar radiation, number of animals per farm, area of native pasture, shrub and forest as well as the Human Development Index. Figure 3 shows the logistic regressions for groups of animals (Naturalized and hair sheep) in accordance with climatic factors. Commercial and wool probabilities are 1 minus the values for

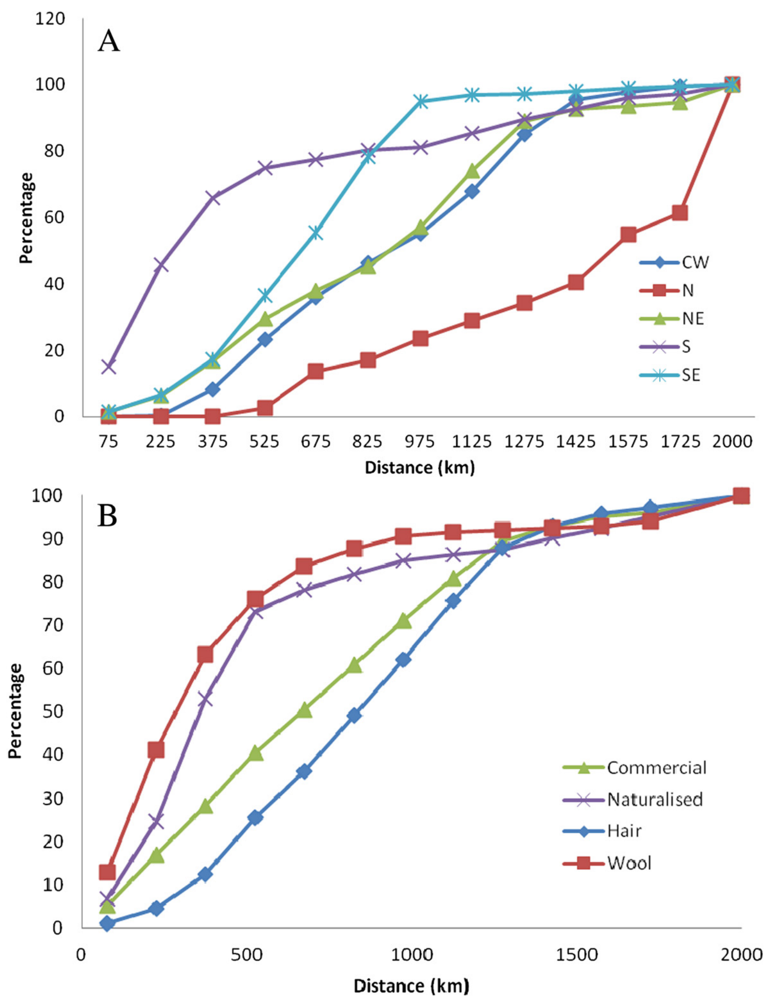

Figure 2 Percentage of flocks by distance from breed mid-point by region of the country (A) and type of flock (B). Legend: CW □ Centerwest; N □ North; NE □ Northeast; S □ South; SE □ Southeast.

Naturalized and hair respectively. The area under the ROC curve for hair vs wool was 0.83 and for commercial vs naturalized was 0.76. The fact that the Crioula (wool) was included in the naturalized breeds and Santa Ines (hair) in commercial meant that there was an even distribution of these throughout the country when these factors were studied meaning that the logistic regressions has low sensitivity in this case. On the other hand significant differences in the distributions of hair and wool breeds meant that these factors were important for these groups. The commercial breeds tended to be reared in regions with more vegetation (NDVI better pastures), lower temperatures and higher rainfall. As Temperature Humidity Index, temperature and altitude increase wool breeds have less probability of occurring (Figure 3).

Animals with wool occur less in areas with more brush and shrubs whereas as naturalised breeds occur more in these areas (Figure 4). The naturalized breeds occur more in municipalities with poorer natural pastures compared to wool breeds. Krebs et al. (2012) used logistic modelling with the presence of giant chestnuts as response variable compared with 65 environmental and cultural predictors.

In agreement with Figure 2, mean values per breed for environmental controls show that naturalised and hair breeds generally occur in areas with higher Temperature Humidity Index and temperatures, lower solar radiation, precipitation and relative humidity (Table 2). No differences were seen between breeds for NDVI. Regions with higher forest concentration have less hair and naturalized sheep which tend to appear in regions with lower Human Development Index. Naturalized sheep tend to appear in regions with higher number of animals per farm while hair sheep in regions with less animals. This is probably due to the effect of Santa Inês and Crioula having a distribution including the South and Southeast of the country where other animal industries such as cattle, but especially pigs and poultry, are concentrated.

The correlation between distances calculated using geographical midpoint and climatic data in the Mantel test was 0.78. This indicates a strong geographic correlation between climatic and geographical distances.

Two main groups of breeds were seen (Figure 5), one with the hair and two wool breeds (Bergamácia a naturalized breed and East Friesian which is only present in three municipalities). The other group has the commercial wool breeds as well as the naturalized Crioula wool breed. This is in accordance with the earlier analyses. The commercial hair breeds (Dorper, White Dorper and Santa Inês) were in the same cluster as the naturalized breeds. This reflects their wider distribution, especially in regions such as the North and Centerwest which have few other breeds and a more recent development of sheep farming (Hermuche et al., 2013b).

Conclusion

Knowledge of spatial distribution of breeds can aid in developing production environment descriptors and classify breeds for conservation as spatial distribution of breeds was highly correlated with environmental controls. Naturalised sheep breeds in Brazil tend to be more localized than commercial breeds which may mean they are at greater risk. Hair and wool sheep tend to occur in specific environments. Flocks in the center west and northeast tend to further away from the midpoint for the breed, making germplasm exchange, and therefore avoidance of inbreeding and their conservation, more difficult.

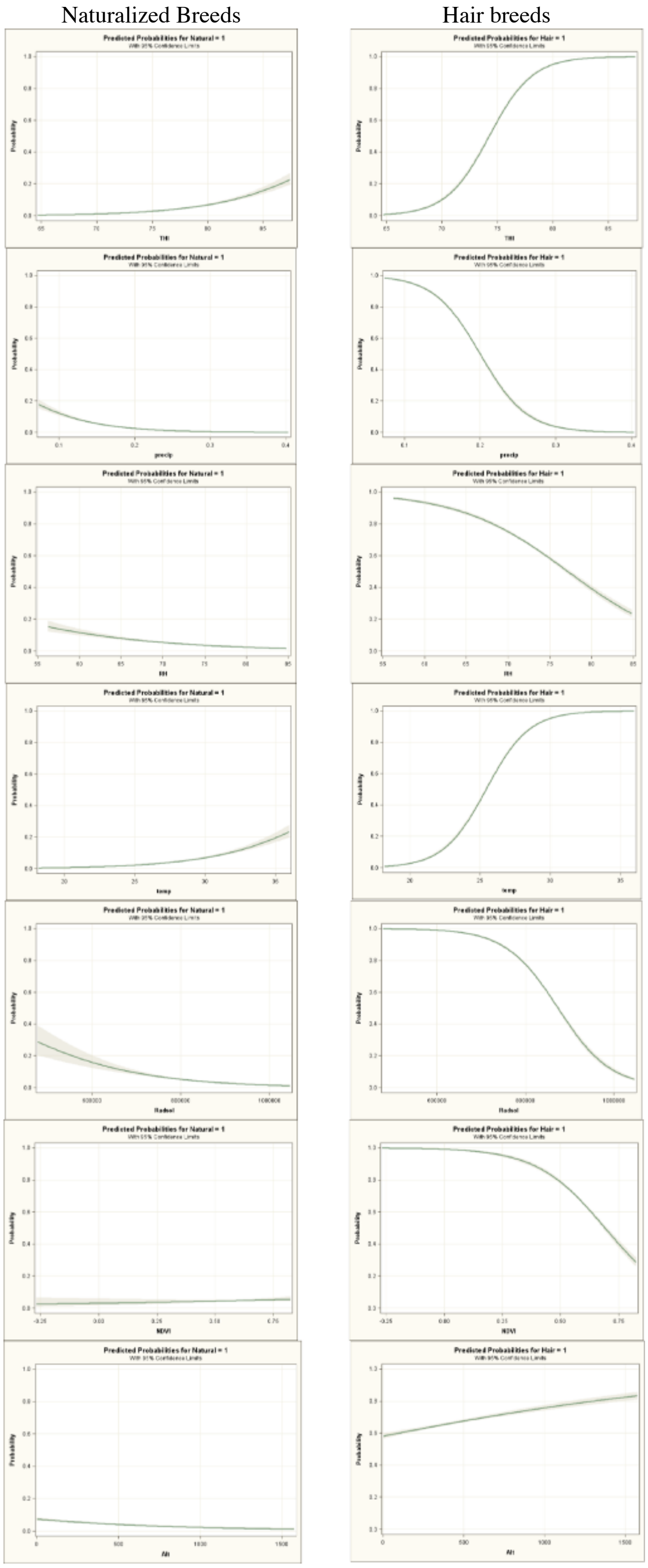

Figure 3 Effect of climatic and environmental controls on distribution of sheep breed type in Brazil. Legend: THI □ temperature humidity index; Alt □ altidude (m); NDVI □ Normalized Difference Vegetation Index; Radsol- Solar Radiation; temp □ mean temperature (oC); precip □ mean precipitation (mm/day); RH □ mean relative humidity (%).

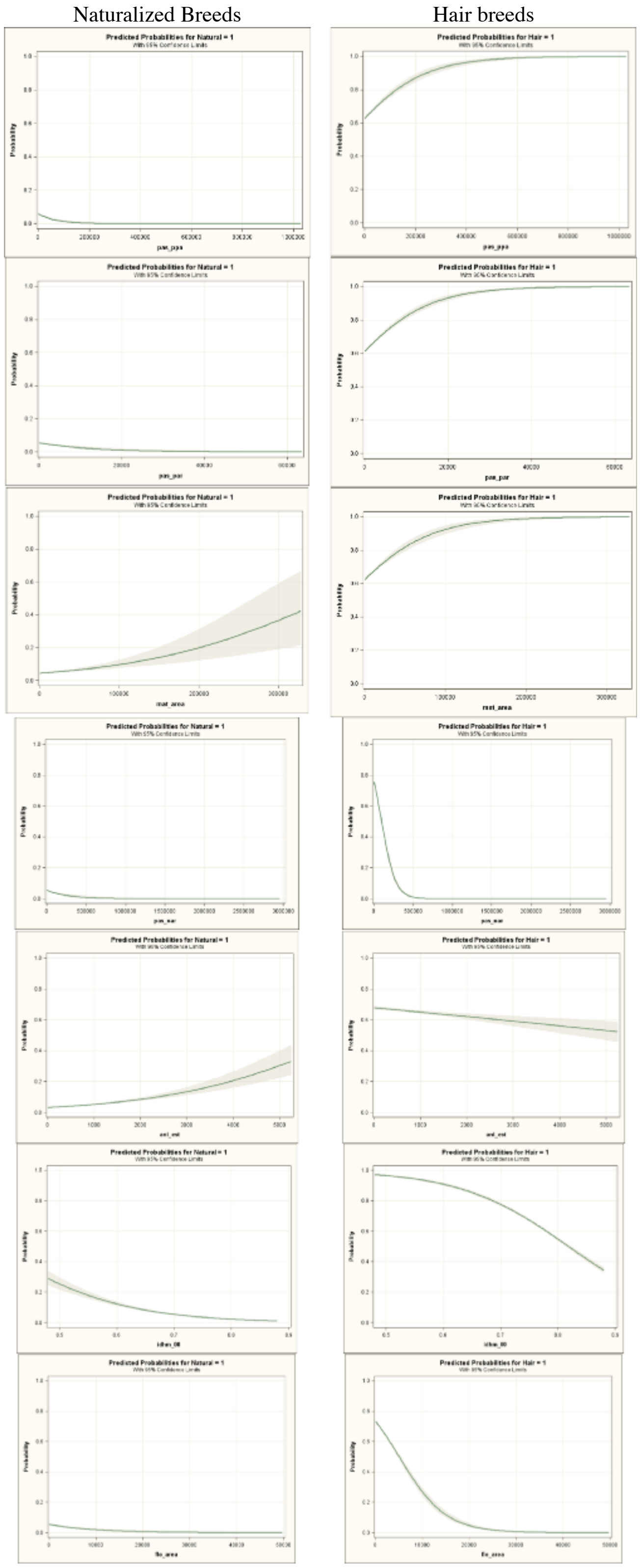

Figure 4 Effect of municipal controls on distribution of sheep breed type in Brazil on a municipal scale. Legend: Pas_PPA – planted pastures in good conditions; Pas_Nar – natural pastures; Pas_Par – planted pastures; mat_area – area of shrub or bush; flo_area; idhm_00 – HDI; ani_est number of animals per farm.

Table 2 Means of environmental control variables by breed of sheep in Brazil

Breed	THI	Alt	Precip	NDVI	RH	Temp	Radsol
Bergamácia	79.40^{abc}	338.08^{bcd}	0.14^{de}	0.60	69.85^{ab}	29.47^{ab}	809269^{abcd}
Border Leicester	72.77^{def}	221.39^{cd}	0.20^{ab}	0.62	73.96^{a}	23.79^{f}	844277^{abcd}
Cariri	79.34^{abc}	291.53^{bcd}	0.15^{bcde}	0.61	72.72^{a}	29.21^{abc}	779557^{d}
Crioula	72.10^{f}	414.08^{bcd}	0.20^{ab}	0.63	75.04^{a}	23.89^{f}	861944^{ab}
Corriedale	72.63^{ef}	211.83^{cd}	0.20^{ab}	0.61	73.72^{a}	24.36^{ef}	864737^{ab}
Dorper	78.26^{abcde}	439.28^{bcd}	0.16^{abcde}	0.59	72.13^{a}	28.4^{abcd}	818555^{abcd}
East Friesian	74.55^{cdef}	1004.17^{a}	0.20^{ab}	0.64	70.25^{ab}	25.88^{cde}	784693^{cd}
Hampshire Down	71.99^{f}	502.62^{bc}	0.20^{ab}	0.63	75.17^{a}	24.02^{f}	868941^{a}
Ideal	72.76^{ef}	270.76^{bcd}	0.21^{a}	0.62	73.85^{a}	24.37^{ef}	862658^{ab}
Ilê de France	72.63^{ef}	493.68^{bc}	0.20^{ab}	0.63	74.09^{a}	24.80^{ef}	862118^{ab}
Karakul	72.40^{f}	257.18^{bcd}	0.20^{ab}	0.63	74.50^{a}	23.98^{f}	860678^{ab}
Lacaune	72.72^{ef}	536.10^{bc}	0.20^{ab}	0.65	74.43^{a}	24.31^{ef}	862121^{ab}
Merino	72.66^{ef}	217.74^{cd}	0.20^{ab}	0.59	73.24^{a}	24.72^{ef}	854721^{abc}
Morada Nova	80.81^{ab}	359.92^{bcd}	0.15^{cd}	0.58	70.10^{ab}	29.90^{ab}	786324^{cd}
Poll Dorset	74.55^{cdef}	522.96^{bc}	0.19^{abcd}	0.62	73.97^{a}	25.84^{cdef}	843221^{abcd}
Polypay	71.66^{f}	105.03^{d}	0.19^{abcd}	0.57	74.19^{a}	23.54^{f}	876793^{a}
Rabo Largo	81.93^{a}	402.24^{bcd}	0.12^{e}	0.55	65.32^{b}	31.49^{a}	806037^{abcd}
Romney Marsh	71.54^{f}	365.06^{bcd}	0.20^{ab}	0.61	74.77^{a}	23.65^{f}	857168^{abc}
SAMM	75.92^{bcdef}	617.32^{b}	0.18^{abcd}	0.59	72.28^{a}	26.78^{bcdef}	845480^{abcd}
Santa Inês	78.27^{abc}	430.47^{bcd}	0.16^{abcde}	0.58	71.52^{a}	28.47^{abcd}	814794^{abcd}
Somali	80.64^{ab}	320.08^{bcd}	0.14^{de}	0.60	70.68^{ab}	29.85^{ab}	791840^{bcd}
Suffolk	74.61^{cdef}	521.03^{bc}	0.19^{abc}	0.61	73.66^{a}	25.74^{cdef}	853912^{bcd}
Texel	73.67^{def}	460.84^{bcd}	0.20^{ab}	0.62	74.43^{a}	25.00^{def}	854377^{bcd}
White Dorper	76.96^{bcde}	528.20^{bc}	0.17^{abcd}	0.60	72.67^{a}	27.52^{bcde}	820255^{abcd}

THI temperature and humidity index, *Alt* altitude (m); Precipitation (mm/day); *NDVI* normalized difference vegetation index, *RH* relative humidity, *Radsol* solar radiation. Numbers followed by different superscript letters in the same column are significantly different ($P<0.05$) using the Tukey test.

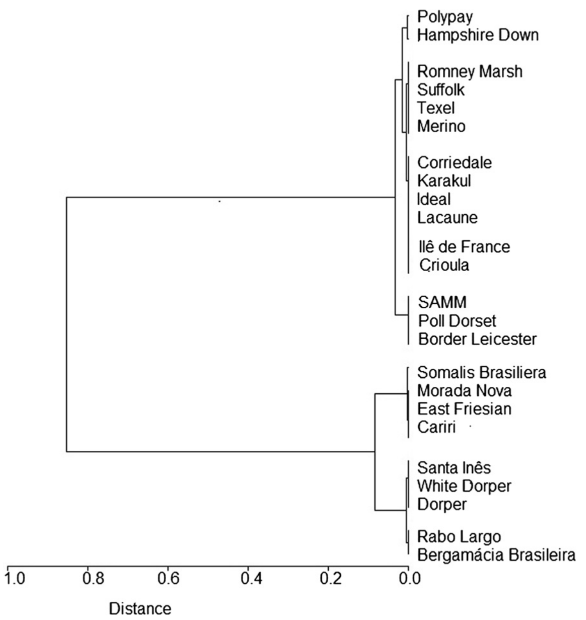

Figure 5 Dendrogram of sheep breeds in Brazil according to environmental variables.

Additional files

Additional file 1: Maps of Distributions of Sheep Breeds in Brazil.

Additional file 2: Distance of flocks from sheep breed Mid-point in Brazil.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
CM conceived the ideas, analysed the data and was the main author; PH is a post-doctor scholarship holder and was responsible for the geographical analysis of data; SRP is a researcher at EMBRAPA and provided genetic data while JCFM also a researcher at EMBRAPA collected the distribution data; CBM is an associate professor who reviewed the disease threats while CQM is an adjunct professor who aided in paper writing and revision. All authors read and approved the final manuscript.

Authors' information
Concepta McManus is an animal breeder interested in the conservation of animal genetic resources, especially adaptability of breeds and how this affects their geographical distribution, availability and ultimately risk of extinction given changes in environments. At present is an associate professor at the University of Brasilia.

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