

# Geographical Distribution of Zebu Breeds in Brazil And Their Relationship With Environmental Variables and Human Development Indicator

**Paulo Ricardo Martins Lima**

Universidade de Brasilia

**Vanessa Peripolli** (✉ [vanessa.peripolli@hotmail.com](mailto:vanessa.peripolli@hotmail.com))

Instituto Federal de Educacao Ciencia e Tecnologia Catarinense - Campus Araquari <https://orcid.org/0000-0002-0463-4727>

**Luiz Antônio Josahkian**

Associação Brasileira de Criadores de Zebu

**Concepta McManus**

Universidade de Brasilia Instituto de Ciências Biológicas: Universidade de Brasilia Instituto de Ciencias Biologicas

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## Abstract

The aim of this study was to evaluate the geographical distribution of zebu breeds in Brazil and correlate their occurrence with environmental variables and human development indicator. The herds of purebred zebu cattle in Brazil were classified as beef breeds (Brahman, Polled Brahman, Nelore, Polled Nelore and Tabapuã), dairy breeds (Gir and Polled Gir), and dual-purpose breeds (Guzerá, Indubrasil, Polled Indubrasil, Sindhi and Polled Sindhi), all breeds being spatialized in ArcGIS program. Variables examined included environmental and human development indicator. The statistical analysis included analysis and logistic regression. The lower distribution of zebu cattle in the states of Northeast compared to other locations is probably due to its extreme climate, highly susceptible to long periods of high temperatures and lower precipitation, which directly affects local livestock. The beef breeds were evenly spread throughout the country. The location occupied for beef breeds was influenced by environmental variables, showing a higher incidence with increased precipitation, normalized difference vegetation index (NDVI), temperature, relative humidity and temperature humidity index (THI), as well as establishments without family agriculture and rivers and streams with forest protection. The location used for dual-purpose and dairy breeds was influenced by areas with cultivated cutting forages, areas with integrated crop-livestock forest systems and areas with rotational grazing system, indicating a higher occupation in fertile lands. The Gir breed, the only one with dairy exploration in this study, showed herds in establishments with family agriculture, characterized by small to medium farms, and in regions with higher altitude.

## Introduction

Brazil is important in the world scenario due to its high agricultural potential, related to an increased demand for world food consumption, leading farmers to seek more efficient production systems to offer a high quality product at low cost (Faria et al. 2008). Cattle breeders have been looking for improved and more efficient animals, leading to the introduction of different bovine breeds in the country, among them zebu breeds that, due to their flexible adaptability, currently represent around 80% of the national herd (Abiec 2015). However, little attention has been given to the distribution of these different genotypes in Brazil correlated to the environment. According to Carneiro et al. (2006), differences among herds in production variability have generally been attributed to differences in local or regional climatic factors and in the management types of each herd.

The continental proportions of the country, i.e large territorial extension, contribute to the heterogeneity of the cattle systems (McManus et al. 2016), determined in great part by the differences among climate, economy and natural resources availability related to animal production. This diversity of environments provides opportunities for the same genotype to express itself differently, making it difficult to identify genetically superior individuals (Lopes et al. 2008) regardless of breed. Thus, the genotype environmental interaction, attributed to geographic distribution in Brazil, must be analyzed in different environments to determine its effect on the animal (Baye et al. 2011), since it can cause changes in genetic, phenotypic and environmental variances, thus modifying the estimated genetic and phenotypic parameters (Diaz et al. 2011).

According to Thornton et al. (2007), changes in climatic conditions may generate unknown changes in the adaptation of animals, especially in developing countries, where stressors are more intense and the volume of changes expected is greater. Moreover, information on the impacts of climate stress on the wide variety of breeds used for food production in South America is lacking (McManus et al. 2011). The first studies on the influence of climatic, environmental factors and human development indicator on the distribution and production of commercial species in Brazil indicated a climatic, environmental and socioeconomic influence (Costa et al. 2014; McManus et al. 2014a,b). Changes on livestock activities, such as measures to increase animal comfort, improvement of the reproductive management, and also construction of public policies in favor of advance herd of cattle, can improve understanding of how different breed distributions are affected by environmental and socio-economic factors.

Therefore, the aim of this study was to evaluate the spatial distribution of zebu breeds registered in Brazil and to seek a possible link with environmental variables and human development indicator.

## Material And Methods

The location of all herds of purebred zebu cattle in Brazil was obtained from the genealogical register of the Brazilian Association of Zebus Breeders (ABCZ) and spatialized by municipality. The breeds were classified as beef breeds (Brahman, Polled Brahman Nelore, Polled Nelore and Tabapuã), dairy breeds (Gir and Polled Gir), and dual-purpose breeds (Guzerá, Indubrasil, Polled Indubrasil, Sindhi and Polled Sindhi) (Table 1).

Table 1  
Zebu breeds in Brazil, their classification and number of herds

Breeds	Type	Nº of animals	Nº of herds	Mean animals/herd
Brahman	Beef	524,666	1,918	274
Polled Brahman	Beef	82	26	3
Gir	Dairy	637,639	5,772	110
Polled Gir	Dairy	55,938	1,413	40
Guzerá	Dual	605,811	2,556	237
Indubrasil	Dual	47,020	426	110
Polled Indubrasil	Dual	317	10	32
Nelore	Beef	20,962,135	18,241	1150
Polled Nelore	Beef	3,055,239	9,135	334
Sindhi	Dual	42,220	309	137
Polled Sindhi	Dual	884	21	42
Tabapuã	Beef	640,763	1,914	335

The climatic and environmental variables considered were precipitation, normalized difference vegetation index (NDVI), relative humidity (RH), altitude, temperature, temperature humidity index (THI), rivers and streams with and without forest protection, establishments with or without family agriculture, areas with cultivated cutting forages, degraded cultivated pastures or in good condition, areas with integrated crop-livestock forest systems, areas with rotational grazing system as well as human development indicator known as human development index (HDI).

Environmental data in the study were obtained from different sources, as detailed by Hermuche et al. (2013). Precipitation: average rainfall values from sensor images Tropical Rainfall Measuring Mission over a ten year basis, with a spatial resolution of 0.25°, or approximately 27 km, acquired from National Aeronautics and Space Administration - NASA (2012) and processed using the Envi 4.7 software. Average Normalized Difference Vegetation Index (NDVI), derived from Moderate Resolution Imaging Spectroradiometer (MODIS) images, acquired from NASA (2012) and processed using ENVI 4.5. Relative humidity from the National Institute of Meteorology – INMET and are the result of the average of a range of approximately 30 years of observation of 283 meteorological stations distributed throughout the territory.

Temperature: ten year average from the Moderate Resolution Imaging Spectroradiometer (MODIS) images, product mod11, which consists of the mean monthly surface temperature with spatial resolution of 1 km. Original images were acquired from NASA (2012) and redesigned in the program Moderate Resolution Imaging Spectroradiometer images Reprojection Tool (MRT extension geotif, geographic projection Lat/Long and Datum WGS 84). Temperature and Humidity Index – THI: calculated from the data of temperature and humidity previously acquired using the following formula:  $THI = Ta + (0.36 \times To) + 41.5$  - where Ta is the dry bulb temperature and To is the dew point temperature.

Altitude: based on data obtained from the Shuttle Radar Topography Mission, acquired from (NASA, 2012). The other variables were collected from the 2006 Brazilian Agricultural Census and Municipal Animal Production Study (IBGE 2012). Human Development Index (HDI) from United Nations Development Programme (PNUD 2013).

All variables were spatialized with Lat/Long geographic projection and WGS 84 Datum in ArcGIS 10.5, as well as weighted mean center (latitude and longitude) that was calculated for each breed in the survey with the number of herds and animals registered per municipality to assess the actual localization of each breed in the country by the Measuring Geographic Distribution tool, available in this computer program, allowing to generate the maps of distribution and midpoints of zebu breeds.

The data were transformed to square root and logarithmic seeking the normalization by the coefficient of variation. The environmental variables and human development indicator by breed considering herd and animal as reference were compared using the variance analysis (PROC GLM) in version 9.4 of SAS® (Analysis System Institute, Cary, NC, USA). The general model was:

$$Y_{ijk} = \mu + ENV_i + BREED_j + e_{ijk}$$

Where Y is the number of animals or herds in a municipality, ENV are the environmental factors in the study and BREED are the breeds.

The differences were tested by the Tukey test ( $P < 0.05$ ). Logistic regression (PROC LOGISTIC) was performed to test the presence of breed types (beef, dairy and dual-purpose) according to environmental variables and human development indicator, where the breed types was considered the dependent variable and environmental variables and human development indicator as independent variables.

$$\text{The logistic regression was: } \log \left[ \frac{p}{1-p} \right] = \beta_0 + \beta_1 (ENV_1) + \beta_2 (ENV_2) + \dots$$

Where  $p$  is the probability of breed presence in a municipality, the constant ( $\beta_0$ ) moves the curve left and right and the slope ( $\beta_1$ ) defines the steepness of the curve. Env are the environmental variables tested.

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).

## Results

The highest concentration of animals per area was observed in the Centerwest region, followed by the Southeast and part of the North, mainly due to state of Pará, Northeast and finally the South region, which showed a lower frequency of zebu cattle breeds. The Nelore breed was widely distributed throughout the country, corroborated by the midpoint of the breed that was in the geographic center of the country (Fig. 1). The midpoint of the Sindhi breed was more towards Northeast, central area of Bahia (BA) and for the Brahman breed more to the South, near the junction of Mato Grosso do Sul (MS), São Paulo (SP) and Minas Gerais (MG) States. However, there was a trend towards centralization of the midpoints of the breeds across the country.

The correlation between the geographical midpoints calculated with reference to the number of herds and the number of animals was above 0.90 for both latitude and longitude, showing that both can be used to exemplify the results (Fig. 1). The distribution of herds is shown in Fig. 2. Most breeds show a nationwide distribution, except for Sindhi and Indubrasil as well as polled breeds.

When analyzing the national distribution of zebu breeds by type of production, for beef and dual-purpose breeds (Fig. 3), it was observed that 80% of the herds were less than 1,000 km from the midpoint of the breeds and for dairy breeds, 80% of the herds were up to 800 km from the midpoint, except for the Polled Sindhi (dual-purpose) and Polled Indubrasil (dual-purpose), which presented 80% of the herds less than 500 km from the midpoint (Fig. 4).

The analysis of variance (ANOVA) showed that Nelore, Polled Nelore, Brahman and Tabapuã breeds occurred in areas with higher precipitation (Table 2). Beef breeds usually occurred in areas with higher precipitation, NDVI and relative humidity. The logistic regression also showed that higher precipitation, NDVI, relative humidity, temperature and THI favored the beef breeds (Fig. 5). In contrast, with dairy breeds, the probability of occurrence of dairy breeds reduced with an increase in these measures. Dual-purpose breeds were little affected.

Table 2  
Means of environmental variables and human development indicator by zebu breeds and type of production in Brazil

Breed	Precip	NDVI	RH	Temp	THI	Alt	RSFP	NRSFP	EFA	NEFA	CCF	DCP	CPGC	ICLFS	RGS
Brahman	0.429 <sup>a</sup>	0.60	72.25	28.06	77.67	5.89	29.03	21.17	6.24	9.61	2.24	2.41	7.10 <sup>ab</sup>	2.21	1.50
Polled Brahman	0.418 <sup>ab</sup>	0.57	72.07	29.23	79.24	5.98	29.25	20.23	5.57	10.34	2.13	2.38	7.52 <sup>a</sup>	2.19	1.46
Gir	0.415 <sup>ab</sup>	0.60	71.78	28.70	77.81	5.94	27.78	21.96	6.39	9.35	2.29	2.40	6.97 <sup>ab</sup>	2.24	1.53
Polled Gir	0.416 <sup>ab</sup>	0.59	71.07	28.19	78.45	5.91	28.67	21.72	6.20	9.50	2.27	2.43	7.13 <sup>ab</sup>	2.24	1.52
Guzerá	0.417 <sup>ab</sup>	0.60	72.29	28.15	77.79	5.82	28.08	22.20	6.28	9.42	2.28	2.42	6.93 <sup>ab</sup>	2.25	1.53
Indubrasil	0.398 <sup>b</sup>	0.59	70.76	28.79	78.55	5.84	28.69	22.70	6.37	9.46	2.34	2.43	7.03 <sup>ab</sup>	2.31	1.59
Polled Indubrasil	0.408 <sup>ab</sup>	0.58	69.94	29.25	79.12	6.27	29.74	24.76	5.67	9.88	2.33	2.47	7.29 <sup>ab</sup>	2.50	1.46
Nelore	0.422 <sup>a</sup>	0.60	72.28	28.21	77.87	5.86	28.08	21.55	6.35	9.48	2.24	2.43	7.03 <sup>a</sup>	2.22	1.53
Polled Nelore	0.425 <sup>a</sup>	0.60	72.09	28.47	78.20	5.88	28.36	21.42	6.29	9.59	2.22	2.45	7.14 <sup>ab</sup>	2.21	1.52
Sindhi	0.397 <sup>b</sup>	0.58	70.51	29.27	79.19	5.63	27.36	21.98	6.35	9.40	2.36	2.30	6.48 <sup>a</sup>	2.40	1.64
Polled Sindhi	0.422 <sup>ab</sup>	0.56	68.67	29.86	79.86	6.25	30.10	20.69	5.81	10.59	2.20	2.47	7.17 <sup>ab</sup>	2.23	1.51
Tabapuã	0.425 <sup>a</sup>	0.60	71.83	28.50	78.22	5.84	28.90	21.71	6.30	9.66	2.23	2.4	7.24 <sup>ab</sup>	2.22	1.51
CV (%)	10.83	11.76	6.75	9.00	4.18	14.62	18.37	18.24	15.78	16.62	16.90	17.68	16.43	17.06	15.28
Type															
Dual-purpose	0.412 <sup>c</sup>	0.598 <sup>b</sup>	71.81 <sup>b</sup>	28.40	78.10	5.81 <sup>c</sup>	28.12 <sup>ab</sup>	22.24 <sup>a</sup>	6.29	9.44 <sup>b</sup>	2.30 <sup>a</sup>	2.41 <sup>b</sup>	6.90 <sup>c</sup>	2.27 <sup>a</sup>	1.55 <sup>a</sup>
Beef	0.424 <sup>a</sup>	0.603 <sup>a</sup>	72.16 <sup>a</sup>	28.31	78.00	5.87 <sup>b</sup>	28.39 <sup>a</sup>	21.48 <sup>c</sup>	6.31	9.56 <sup>a</sup>	2.23 <sup>b</sup>	2.44 <sup>a</sup>	7.10 <sup>a</sup>	2.21 <sup>c</sup>	1.52 <sup>b</sup>
Dairy	0.415 <sup>b</sup>	0.596 <sup>b</sup>	71.59 <sup>b</sup>	28.33	78.00	5.93 <sup>a</sup>	28.02 <sup>b</sup>	21.90 <sup>b</sup>	6.34	9.39 <sup>b</sup>	2.29 <sup>a</sup>	2.41 <sup>b</sup>	7.01 <sup>b</sup>	2.24 <sup>b</sup>	1.53 <sup>b</sup>
CV (%)	10.86	11.77	6.76	9.04	4.20	14.63	18.41	18.25	15.81	16.64	16.91	17.69	16.48	17.07	15.31

Precip: Precipitation (mm/day); NDVI: normalized difference vegetation index (%); RH: relative humidity (%); Temp: temperature (°C); THI: temperature humidity index (%); Alt: altitude (m); RSFP: rivers and streams with forest protection (ha); NRSFP: rivers and streams without forest protection (ha); EFA: establishments with family agriculture (ha); NEFA: establishments without family agriculture (ha); CCF: areas with cultivated cutting forages (ha); DCP: areas with degraded cultivated pastures (ha); CPGC: areas with cultivated pasture in good condition (ha); ICLFS: areas with integrated crop-livestock forest systems (ha); RGS: areas with rotational grazing system (ha); HDI: human development index (%); CV: coefficient of variation. Means in the same column with different letters indicate a difference according to Tukey test ( $P < 0.05$ ).

Polled Brahman, Nelore and Sindhi breeds occurred in areas with cultivated pasture in good condition (CPGC), although Polled Brahman occurred in areas with higher HDI while Sindhi in areas with lower HDI influencing the geographic distribution of these breeds. Beef and dairy breeds occurred in areas with higher HDI, and in CPGC there was a higher occurrence of beef breeds (Table 2).

Dairy breeds occurred in areas with higher altitude, followed by beef and dual-purpose breeds (Table 2), as seen in the logistic regression analysis where the variation to 1,500 meters led to a  $\pm 50\%$  increase in probability of occurrence of the dairy breeds, and the increase in altitude caused a decrease in the probability of occurrence of meat breeds. For dual-purpose breeds, there was no effect on the occurrence with the altitude increase (Fig. 5).

The presence of rivers and streams with forest protection (RSFP) and rivers and streams without forest protection (NRSFP) shown significant for the occurrence of breeds by type (Fig. 5). In areas with cultivated cutting forages (CCF), a higher occurrence of dual-purpose and milk breeds was seen. The increase of 50 ha in CCF reflected an increase of  $\pm 50\%$  in the occurrence of dairy and dual-purpose breeds (Fig. 5). A higher occurrence of beef breeds was seen both in areas with degraded cultivated pastures (DCP) and areas with cultivated pasture in good condition (CPGC) (Table 2).

In areas with integrated crop-livestock forest systems (ICLFS) there was a higher occurrence of dual-purpose breeds, followed by dairy and beef breeds (Table 2). As observed in the logistic regression, the increase from 20 to 80 ha in ICLFS caused an increase from  $\pm 12.5\%$  to  $\pm 95\%$  in the probability of occurrence of dual-purpose breeds. For dairy breeds, the increase in the probability of occurrence was 50%, and for beef breeds decreased the probability of occurrence (Fig. 6).

A trend towards dairy breeds was observed in establishments with family agriculture (EFA) (Fig. 6). Establishments without family agriculture (NEFA), presented a higher occurrence of beef type, corroborating with the regression analysis where very latifundio farms explored beef breeds (Table 2 and Fig. 6).

The use of management technologies, such as rotational grazing system (RGS) favored the occurrence of dual-purpose breeds when compared to the others (Table 2). This difference was more visible in the logistic regression, where the increase from 5 to 20 ha in the RGS caused an increase from  $\pm 5\%$  to  $\pm 75\%$  in the probability of occurrence of dual-purpose breeds. However, this management decreased the probability of occurrence of beef breeds (Fig. 6).

## Discussion

The zebu breeds analyzed were all pure in origin (PO), that is, genealogical registered by the Brazilian Association of Zebus Breeders (ABCZ). This study was limited to the Zebu breeds in this herd book breeds as other breeds have been studied elsewhere and by other research groups (for example Costa et al. 2014 for Holstein-Friesian; Costa et al. 2020 for Girolando; Souza et al. 2022 for Locally Adapted breeds in Brazil). The highest concentration of zebu breeds occurred in the Midwest, followed by the Southeast and North, explained by their well known livestock farming aptitude. This was evident with the position of the midpoint of these breeds, being almost all located in the central region of the country, as seen by Teixeira and Hespanhol (2014) and McManus et al. (2016), who observed the same location as the midpoint for all cattle production in Brazil. These last authors, looking at the dynamics of cattle production in Brazil show a tendency towards north western regions which has implications not only for environmental factors, such as pasture type, temperature and humidity but also for the need of political and infrastructure changes, aiming to fostering the livestock sector.

The lower occurrence of zebu cattle breeds in the South region was due to the traditional use of European breeds, as verified by Braga et al. (2015). Regardless of the type of use, the proportion of herds with European breeds increases the further one moves towards the southern states of the country.

In the states of the Northeast, a region known as the drought polygon, a smaller occurrence of zebu cattle herds was observed due to their highly susceptibility to long periods of high temperatures and absence of precipitation (Lôbo et al. 2011), which directly affects the selection of local livestock, favoring the occurrence of other species such as sheep and goats (Hermuche et al. 2013; McManus et al. 2014a). However, a higher occurrence of the Sindhi breeds was observed for this region, indicating a more local occupation (Panetto et al. 2017; Melo et al. 2020). This is because Sindhi animals have shown great rusticity and tolerance to thermal stress, maintaining high productive and reproductive efficiency in the adverse environments (Souza et al. 2007; Furtado et al. 2012; Saraiva et al. 2015; Oliveira et al. 2017).

Geographic distribution maps showed an expected trend, where the Nelore breed is widely distributed throughout the country (Fig. 2), possibly due to its adaptation to different environments (Bianchini et al. 2006). The Indubrasil breed, developed by crossbreeding in Brazil, was highly used in the middle of the last century (Santiago 1975), but interest has decreased in its use (Carneiro et al. 2009). Calculating the midpoint also helps us understand breed distribution and eventual need for conservation measures (McManus et al. 2014b). For example, breeds with low distribution from the midpoint are more vulnerable to climatic or health disasters.

The national distribution of the zebu cattle breeds when analyzed by type of production, beef, dairy and dual-purpose showed that the majority of herds (80%) are less than 1,000 km from the midpoint of the breeds. This proximity between the herds can lead to problems, such as breed loss during possible health epidemics and increased inbreeding due to a possible lack of effective numbers of animals. Therefore increased crossbreeding may arise reducing purebred numbers. According to McManus et al. (2014b), diseases, especially infectious, can be catastrophic for a very localized breed. Also, Mudadu et al. (2016), observed a high degree of kinship in genomic samples from Nelore animals that were reared close to each other. Special attention should be paid to the Polled Sindhi and Polled Indubrasil breeds, which, due to the shorter distance (midpoint <500 Km), may suffer greater impacts when compared to the other better distributed breeds.

Climate is important for raising cattle in Brazil, especially for beef cattle, as 82% of the herd was reared at pasture (Quintiliano and Paranhos da Costa 2008). Precipitation was the only climatic variable influencing the occurrence of Nelore, Polled Nelore, Brahman and Tabapuã beef breeds. These breeds have a wide distribution throughout the country, probably due to the similarities in physical characteristics (skin and coat pigmentation) and adaptation to climatic effects (usually with dark skin and light coat), as verified by Shiota et al. (2013) and Barbosa et al. (2014a,b) who likewise indicated adaptation of beef cattle animals to the climatic effects.

Complementary results were verified when the breeds were analyzed by type (beef, dairy and dual-purpose). Beef breeds usually occurred in areas with greater precipitation, NDVI, temperature, THI and relative humidity, that is, in more humid and hot regions, corroborating with McManus et al. (2016).

Areas with pastures in good conditions and the human development index influenced the occurrence of Nelore, Polled Brahman and Sindhi breeds. Polled Brahman and Sindhi breeds tend to be used on farms with access to production technologies, but surrounded by different regions regarding socio-economic development, Brahman being in regions with the highest HDI and Sindhi with the lowest. High HDI reflects in better human development conditions, usually attributed to richer regions, which in turn can lead to access to better forms of livestock breeding, due to access to better education conditions, per capita income, and life expectancy by cattle farmers, creating a favorable situation. Studies show that intellectual capital can improve innovation capabilities (Xiaobo and Sivalogathan 2013) and increase added value to livestock products (Soesilowati et al. 2017) while Peñalba and Elazegui (2013) also showed that the ability of a farmer to adapt to change was affected by HDI. Costa et al. (2013) found that most farmers in a state in southern Brazil only had primary school education, and that most of these farmers did not keep records and carried out inadequate management practices.

The beef zebu cattle breeds occurred in both cultivated pasture areas with good (CPGC) and degraded (DCP) conditions, possibly due to these breeds are spread over a large part of the Brazilian territory, being reared in various environments and consequently in different pasture quality situations. There are approximately 190Mha of pasture sustaining 209 million cattle in Brazil (Jank et al. 2013). Of this about 74Mha are native species, 99Mha *Brachiaria* spp and 17Mha of other cultivars (ANUALPEC 2008). 8Mha is renovated each year and about 4Mha are occupied by integrated crop-livestock systems. This means that a significant number of cattle are reared on suboptimal pastures as seen by Costa et al. (2013) with dairy cows in southern Brazil. Oliveira et al. (2015) also showed that implementation of hygiene regulations on farms was limited by lack of understanding of the importance of these measures by cattle farmer, as well as lack of adequate infrastructure such as electrification and roads. Distribution studies such as the present one can thereby help to identify where increased public policies (fiscal incentive, access to finance, among others), infrastructure, and specify training are necessary to improve the production.

However, beef type also occurred in areas of rivers and streams with forest protection (RSFP), and establishments without family farming (NEFA), probably due to the high number of animals of this type in data worked, favored by the aptitude of the market, as seen also by McManus et al. (2014b) in a study with sheep breeds distribution in Brazil. Also, these beef breeds had a high distribution in the Brazilian territory influenced by the commercialization made by the Breeders' Associations of Brazil, which may also have favored beef Zebu breeds.

In areas with cultivated cutting forages (CCF), areas with rotational grazing system (RGS), and areas with integrated crop-livestock forest systems (ICLFS), there was a higher occurrence of dual-purpose and dairy breeds, characteristics of more fertile soils. This was also seen by McManus et al. (2014a) and McManus et al. (2016) who observed an increase in breeds with dairy aptitude in more productive regions. In addition, dairy production can be more favored in areas with greater elevation in relation to sea level, maybe due to better climatic conditions. Forest protection for rivers and streams was important for climate regulation, heat absorption and humidity regulation (Silvano et al. 2005). Nevertheless, in recent years, there has been a reduction in this protection (Taniwaki et al. 2017), especially due to corn plantations for silage, sugarcane plantations, citrus, silviculture, urbanization, and pasture creation which have been shown to be linked to dairy cattle production (Costa et al. 2014). Most farms do not have shade protection or adequate water supply for cattle (Costa et al. 2013), which directly affects performance.

A trend towards dairy breed occurrence was observed in establishments with family agriculture (EFA<sup>[1]</sup>), showing a historical tendency, where small to medium-sized properties managed by families usually explore dairy breeds. This was also seen by Guilhoto et al. (2006) and Wilkinson (2013), as well as agricultural research data (IBGE 2012), where more than 80% of the farms fall into this category.

The present study looked at breed occurrence relative to environmental and socio-economic factors. As one factor changes, so may others and the relationships between them (Costa et al. 2013). Barcellos et al. (2011) suggested intensification as the means for the cattle industry to reduce pressure on forest margins and free-up land for soybean or sugarcane production. Sparovek et al. (2009) showed that this expansion resulted in a significant reduction of pastures and number of cattle and higher economic growth compared to neighboring areas. Maranhão et al. (2019) showed soybean production replacing beef cattle production in the savanna region of Brazil. The latter migrated to the Amazon region which may explain some of the results seen here, with beef cattle seen in regions with higher temperatures and lower rainfall. Nevertheless, there are large regions of overlap with these productions as well as other crops due to the need for alternative sources of feeding, especially for dairy and dual-purpose cattle.

[1] "Family Agriculture" is considered as defined in the Item II of Article 4 of the Land Act, Law No. 4504 of November 30, 2004: "a farm that is directly and personally operated by the farmer and his family, to absorb their entire workforce, providing them with subsistence as well as social and economic progress, with a maximum area fixed by region and type of operation, and occasionally worked with the help of others."

## Conclusion

Zebu cattle breeds showed high adaptability to a broad range of climates, but environmental variables and human development index influenced the distribution of these breeds of cattle in Brazil. Preventive measures need to be taken for the conservation of Polled Sindhi and Polled Indubrasil due to their low geographical distribution making them vulnerable to change. The correct interpretation of these results can contribute to better understand the adaptation of each zebu breed individually to different environments, helping in the correct choice of the breed to be explored.

## Declarations

### Author contributions

All authors contributed to the study conception and design. Methodology and Writing - Review & Editing were performed by P.R.M. Lima, V. Peripolli, L.A. Josahkian and C. McManus. Formal analysis was performed by C. McManus. Project administration and Writing-original draft were performed by P.R.M. Lima. Investigation was performed by P.R.M. Lima and L.A. Josahkian. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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### Data availability

All data used in this study will be presented upon request.

### Compliance with ethical standards

### Conflict of interest

The authors declare that they have no conflict of interest.

### Ethics approval

Not applicable.

### Consent to participate

All authors have given their consent that this work is valid and represent their views of the study, and all authors have given their consent for this work to be published.

#### Consent for publication

Not applicable.

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## Figures

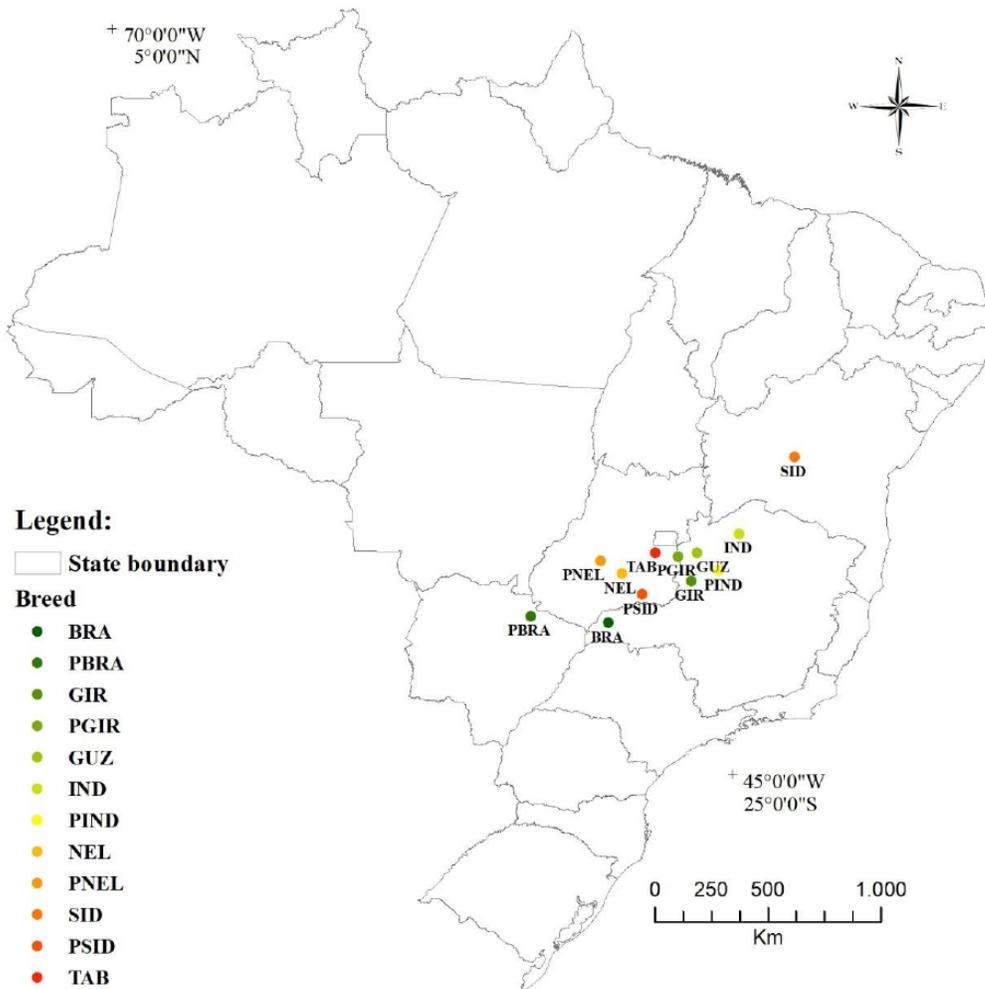


Figure 1  
 Geographic midpoint of different zebu breeds in Brazil. BRA: Brahman; PBRA: Polled Brahman; GIR: Gir; PGIR: Polled Gir; GUZ: Guzerá; IND: Indubrasil; PIND: Polled Indubrasil; NEL: Nelore; PNEL: Polled Nelore; SID: Sindhi; PSID: Polled Sindhi; TAB: Tabapuã.

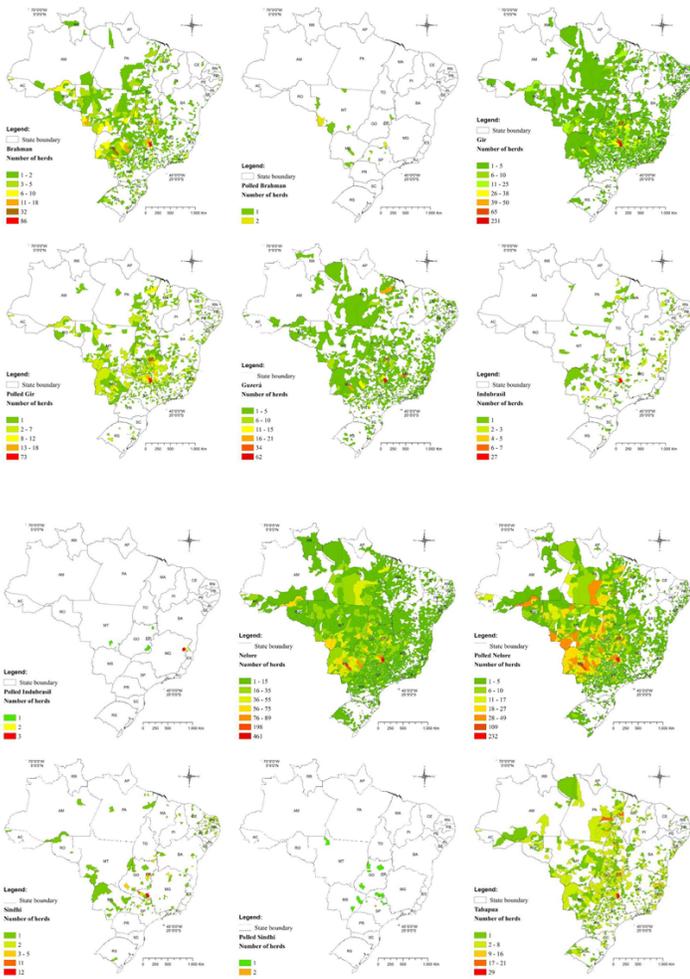
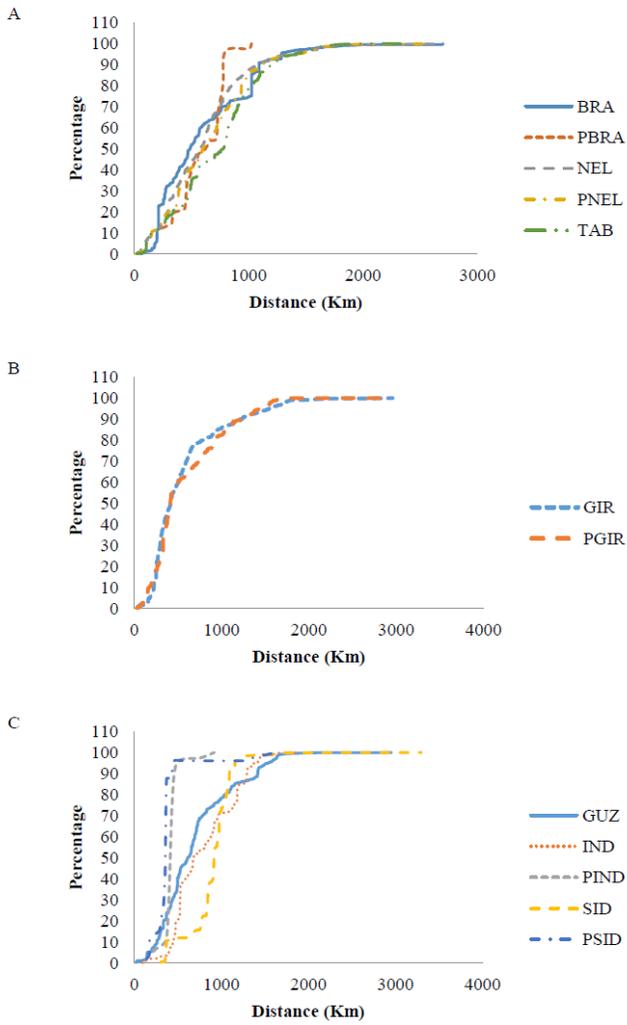
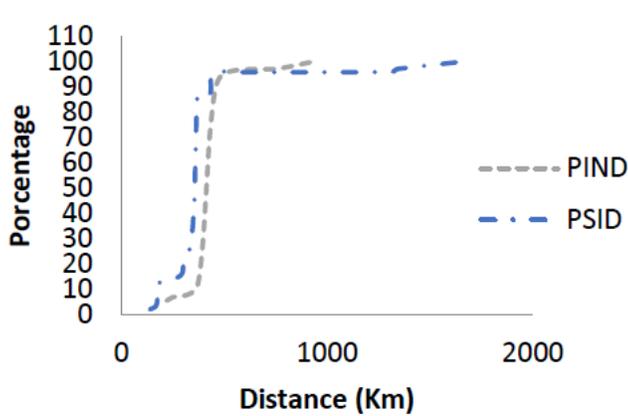


Figure 2

Distribution maps by municipality of Zebu breeds in Brazil.

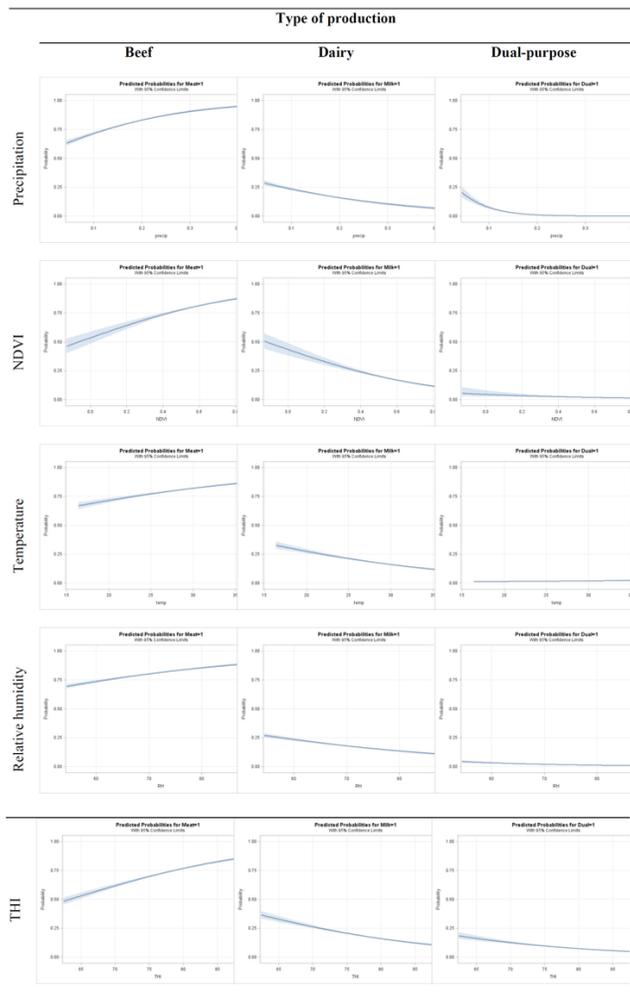


**Figure 3**  
 Percentage of herds by distance from breed midpoint by type of production. A: beef breeds, B: dairy breeds and C: dual-purpose breeds. BRA: Brahman; PBRA: Polled Brahman; NEL: Nelore; PNEL: Polled Nelore; TAB: Tabapuã; GIR: Gir; PGIR: polled Gir; GUZ: Guzerá; IND: Indubrasil; PIND: Polled Indubrasil; SID: Sindhi; PSID: Polled Sindhi.



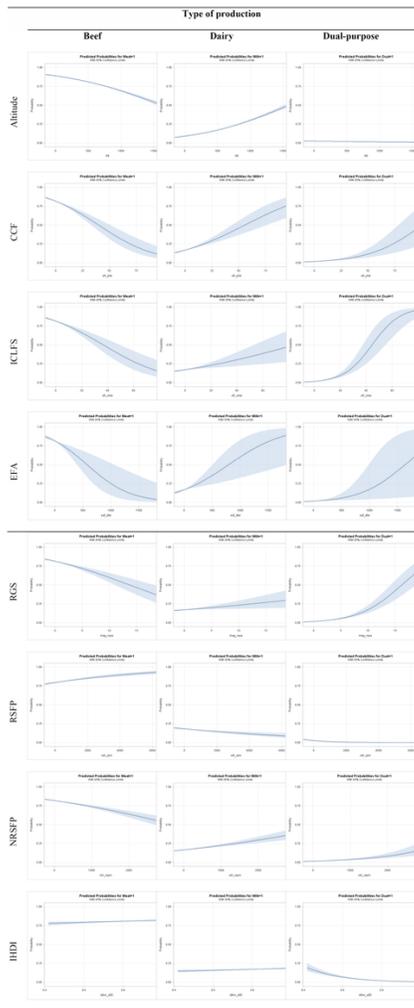
Breed	Midpoint distance (km)
Polled Indubrasil (PIND)	494
Polled Sindhi (PSID)	493

**Figure 4**  
 Distribution summary of Polled Indubrasil and Polled Sindhi breeds in Brazil. PIND: polled Indubrasil; PSID: polled Sindhi.



**Figure 5**

Effect of climatic variables on distribution of zebu cattle breed type in Brazil.



**Figure 6**  
 Effect of environmental variables and human development indicator on distribution of zebu cattle breed type in Brazil. CCF: areas with cultivated cutting forages; ICLFS: areas with integrated crop-livestock forest systems; EFA: establishments with family agriculture; RGS: areas with rotational grazing system; RSFP: rivers and streams with forest protection; NRSFP: rivers and streams without forest protection; HDI: human development index.