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Geographical distribution of zebu breeds and their relationship with environmental variables and the human development index

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ABSTRACT: The environment is vital to the agricultural sector since it can cause adversities throughout the entire productive chain. This study evaluated the geographical distribution of zebu breeds in Brazil and correlated their occurrence with environmental variables and the human development index. Herds of purebred zebu cattle (*Bos indicus*) in Brazil were classified as beef, dairy, and dual-purpose breeds, and all breeds were spatialized in the ArcGIS program. Environmental (precipitation, temperature, relative humidity index) and the human development index (HDI) were examined. We conducted regression and logistic analyses. Zebu cattle showed a lower distribution in the Northeastern states compared to other locations, possibly due to harsh weather conditions, namely long periods of high temperatures and lower precipitation, directly affecting local livestock. Beef breeds were evenly spread throughout the country in regions influenced by environmental variables of higher precipitation, normalized difference vegetation index (NDVI), temperature, relative humidity (RH), and temperature humidity index (THI), as well as properties without smallholder farmers and rivers and streams with riparian vegetation. The regions for dual-purpose and dairy breeds were predominantly cultivated with cutting forages (*e.g.*, sugarcane - *Saccharum officinarum*), with the integration of crops, livestock and/or forestry (*i.e.*, combining different activities in the same area) and areas with a rotational grazing system (*i.e.*, grazing management), indicating a higher occupation in fertile lands. The Gir breed, the only dairy breed evaluated in this study, was seen in establishments with smallholder farmers, characterized by small to medium farms, and in regions at higher altitudes.
Keywords: *Bos indicus*, GIS, adaptation, cattle, spatial statistics

Introduction

In Brazil, cattle breeders have searched for improved and more efficient animals for their herds. This has favored the introduction of different cattle breeds in the country, such as *Bos indicus* (*i.e.*, zebu breeds), which has the largest number of cattle heads due to its adaptation capacity (Lima et al., 2021). However, little attention has been given to the environmental distribution of these different genotypes in Brazil. Herds show production differences mainly in terms of distinct local or regional climatic factors and in the management practices of each herd.

Brazil has a large territorial extension that contributes to the heterogeneity of cattle systems (McManus et al., 2016), determined mainly by the differences between climates, economies, and availability of natural resources for animal production. This diverse environment provides conditions for the same genotype to express itself differently, hindering the identification of genetically superior individuals, regardless of breed. Thus, the genotype interaction with the environment (G × E), should be evaluated to determine their effects on the animals (Baye et al., 2011). The G × E can modify genetic, phenotypic and environmental variances, thus modifying the estimated genetic and phenotypic parameters (Diaz et al., 2011).

Changes in climatic conditions may cause unpredicted adaptations of animals, especially in developing countries, where stressors are more intense and more changes may occur. Moreover, information is scarce on the impacts of climate stress on cattle breeds used for food production in South America (Thornton et al., 2007). The first studies that evaluated the distribution and production of Holstein cattle, sheep, and goat species in Brazil related to climatic and environmental factors and the human development index (HDI) indicated that these factors influence the distribution of these breeds in Brazil (Costa et al., 2014; McManus et al., 2014a, b). Changes in livestock activities, such as ways to increase animal comfort, improvement of reproductive management, and creation of public policies to boost cattle raising (*e.g.*, access to financing programs for smallholders), could contribute to a better understanding of the influence of environmental and socio-economic factors on different breed distributions.

This study evaluated the spatial distribution of zebu breeds registered in Brazil and investigated a possible link between environmental variables and the HDI.

Materials 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 the 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).

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 riparian vegetation, establishments with or without smallholder farmers, areas with cultivated cutting forages (CCF), degraded cultivated pastures (DCP) or in good condition (CPGC), areas with integrated crop-livestock forest systems (ICLFS), areas with rotational grazing system (RGS), and the human development index (HDI).

Environmental data in the study were obtained from different sources, as Hermuche et al. (2013) detailed. Precipitation: average rainfall values from sensor images Tropical Rainfall Measuring Mission over a 10-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. The Average Normalized Difference Vegetation Index, derived from Moderate Resolution Imaging Spectroradiometer (MODIS) images, was acquired from NASA (2012) and processed using ENVI 4.5. Data on relative humidity from the National Institute of Meteorology – INMET – results from approximately 30 years of observation of 283 meteorological stations spread throughout the territory.

Temperature: 10-year average from the Moderate Resolution Imaging Spectroradiometer (MODIS) images, product mod11, consists of the mean monthly surface temperature with a 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 data on 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.

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

Breeds	Type	N° of animals	N° 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

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

All variables were spatialized with Lat/Long geographic projection and WGS 84 Datum in ArcGIS 10.5. The weighted mean center (latitude and longitude) was calculated for each breed in the survey, using the number of herds and animals registered per municipality. The actual location of each breed in the country was determined using the Measuring Geographic Distribution tool, available in ArcGIS, from which distribution and midpoint maps were generated.

The data were transformed to square root and logarithmic, seeking the normalization by the coefficient of variation. The environmental variables and the HDI by breed, considering herd and animal as a reference, were compared using the variance analysis (PROC GLM) in SAS (Statistical Analysis System, version 9.4). 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 (0/1) of breed types (beef, dairy and dual-purpose) according to environmental variables and human development indicators. The breed types were considered dependent and environmental variables and human development indicators as the independent variables.

The logistic regression was:

$$\log\left[\frac{p}{1-p}\right] = \beta_0 + \beta_1\left(Env_1\right) + \beta_2\left(Env_2\right) + \dots ,$$

where p is the probability of breed presence in a municipality, the constant (β_0) moves the curve left and right, and the slope (β_1) defines the curve's steepness. Env were the environmental variables tested. Model selection was carried out considering Nagelkerke's R^2, area under the Receiver Operating Characteristic (ROC) curve, Akaike information criterion (AIC), and Schwarz's Bayesian information criterion (BIC). All data were analysed using SASv9.4 (Statistical Analysis System Institute, Cary, North Carolina).

Results

The highest concentration of animals per area was observed in the Centre-West region, followed by the Southeast, part of the North (mainly Pará State), Northeast and Southern regions. This latter showed a lower frequency of zebu cattle breeds. The Nellore breed was widely distributed

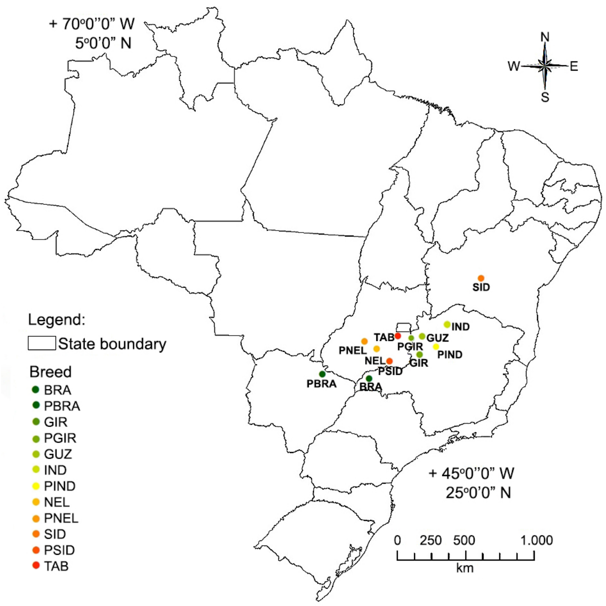

Figure 1 – Geographic midpoint of different zebu breeds in Brazil. BRA = Brahman; PBRA = Polled Brahman; GIR = Gir; PGIR = Polled Gir; GUZ = Guzerá; IND = Indubrasil; PIND = Polled Indubrasil; NEL = Nelore; PNEL = Polled Nelore; SID = Sindhi; PSID = Polled Sindhi; TAB = Tabapuã.

throughout the country, corroborated by the breed's midpoint in the geographic centre of the country (Figure 1). The nucleus of the Sindhi breed was more towards the Northeast, in the central region of Bahia (BA) State, while the Brahman breed the midpoint was more to the South, near the junction of Mato Grosso do Sul (MS), São Paulo (SP), and Minas Gerais (MG) States. However, midpoints of the breeds tended towards centralization throughout the country.

The correlation between the geographical midpoints calculated based on 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 (Figure 1). Most breeds show a nationwide distribution, except for Sindhi and Indubrasil and polled breeds (Figure 2).

The national distribution of zebu breeds varied by type of production. For beef (Figure 3A), and dual-purpose (Figure 3C) animals, 80 % of the herds were less than 1,000 km from the breed midpoint, and for dairy (Figure 3B), 80 % of the herds were up to 800 km from the midpoint, except for the Polled Sindhi – dual-purpose (Figure 3D) and Polled Indubrasil – dual-purpose (Figure 3D), which presented 80 % of the herds less than 500 km from the midpoint.

The analysis of variance (ANOVA) showed that Nellore, Polled Nellore, Brahman, and Tabapuã breeds occurred in areas with higher rainfall (Table 2). Beef breeds usually occurred in areas with higher precipitation, NDVI, and RH. The logistic regression also showed that higher precipitation, NDVI, RH, temperature, and THI favored beef breeds (Figure 4). In contrast, the probability of occurrence of dairy breeds reduced with an increase in these measurements. Dual-purpose breeds were little affected by these variables.

Polled Brahman, Nellore, and Sindhi breeds occurred in areas with CPGC, although Polled Brahman occurred in regions with higher HDI. In comparison, Sindhi occurred in areas with lower HDI influencing the geographic distribution of these breeds. Beef and dairy breeds occurred in regions with higher HDI, while beef breeds had a higher occurrence in CPGC (Table 2).

Dairy breeds occurred in areas at higher altitudes, followed by beef and dual-purpose breeds (Table 2), as seen in the logistic regression analysis where the variation to 1,500 m led to a ± 50 % increase in the probability of occurrence of the dairy breeds. An increase in altitude caused a decrease in the likelihood of occurrence of beef breeds, while a rise in altitude showed no effect on the occurrence of dual-purpose breeds (Figure 5).

The presence of rivers and streams with riparian vegetation (RSRV) and rivers and streams without riparian vegetation (NRSRV) was significant for the occurrence of breeds by type of production (Figure 5). A higher occurrence of dual-purpose and milk breeds was observed in areas with CCF. The increase of 50 ha in CCF reflected a rise of ± 50 % in the occurrence of dairy and dual-purpose breeds (Figure 5). A higher occurrence of beef breeds was observed in both DCP and CPGC (Table 2).

Areas with ICLFS showed 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 ± 12.5 to ± 95 % in the probability of occurrence of dual-purpose breeds. For dairy breeds, the increase in the probability of occurrence was 50 %. For beef breeds an increase in ICLFS was accompanied by a decrease in their occurrence (Figure 5).

Dairy breeds tended to occur in establishments with smallholder farmers (SF) (Figure 5). Establishments without smallholder farmers (WSF) presented a higher occurrence of beef cattle, corroborating with the regression analysis where larger farms explored beef breeds (Table 2 and Figure 5).

The use of management technologies, such as RGS, favored the occurrence of dual-purpose breeds compared to the others (Table 2). This difference was more visible in the logistic regression, where the increase from 5 to 20 ha in RGS caused an increase from ± 5 to ± 75 % in the probability of dual-purpose breed occurance. However, this management option decreased the occurrence of beef breeds (Figure 5).

Discussion

The zebu breeds analyzed were all pure in origin (PO) and genealogically registered by the Brazilian Association

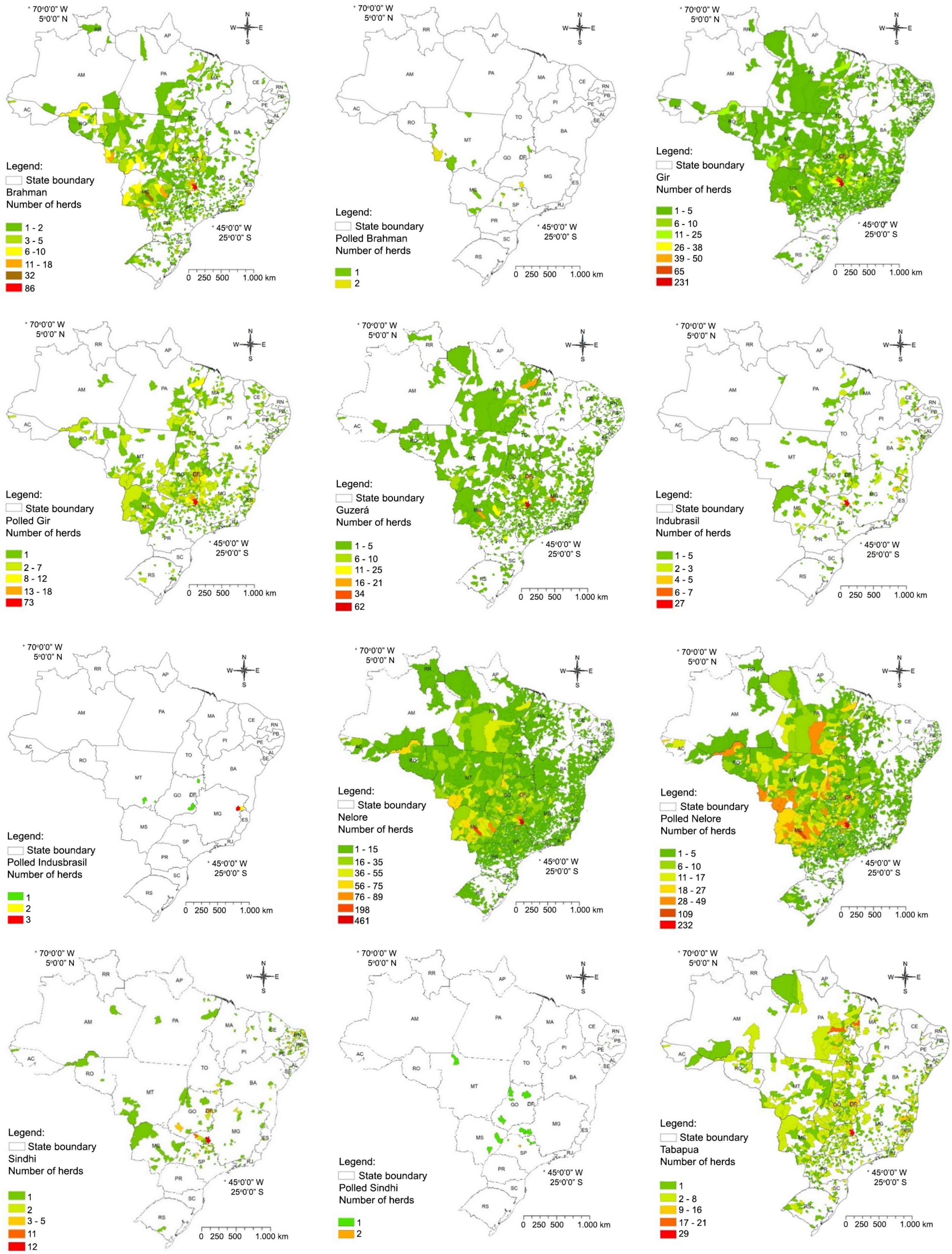

Figure 2 – Distribution maps by municipality of zebu breeds in Brazil.

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	RSRV	NRSRV	SF	WSF	CCF	DCP	CPGC	ICLFS	RGS	HDI
Brahman	0.429^{a}	0.60	72.25	28.06	77.67	5.89	29.03	21.17	6.24	9.61	2.24	2.41	7.10^{ab}	2.21	1.50	0.83^{abc}
Polled Brahman	0.418^{ab}	0.57	72.07	29.23	79.24	5.98	29.25	20.23	5.57	10.34	2.13	2.38	7.52^{a}	2.19	1.46	0.85^{a}
Gir	0.415^{ab}	0.60	71.78	28.70	77.81	5.94	27.78	21.96	6.39	9.35	2.29	2.40	6.97^{ab}	2.24	1.53	0.80^{abc}
Polled Gir	0.416^{ab}	0.59	71.07	28.19	78.45	5.91	28.67	21.72	6.20	9.50	2.27	2.43	7.13^{ab}	2.24	1.52	0.81^{abc}
Guzerá	0.417^{ab}	0.60	72.29	28.15	77.79	5.82	28.08	22.20	6.28	9.42	2.28	2.42	6.93^{ab}	2.25	1.53	0.80^{abc}
Indubrasil	0.398^{b}	0.59	70.76	28.79	78.55	5.84	28.69	22.70	6.37	9.46	2.34	2.43	7.03^{ab}	2.31	1.59	0.79^{bc}
Polled Indubrasil	0.408^{ab}	0.58	69.94	29.25	79.12	6.27	29.74	24.76	5.67	9.88	2.33	2.47	7.29^{ab}	2.50	1.46	0.83^{abc}
Nelore	0.422^{a}	0.60	72.28	28.21	77.87	5.86	28.08	21.55	6.35	9.48	2.24	2.43	7.03^{a}	2.22	1.53	0.80^{abc}
Polled Nelore	0.425^{a}	0.60	72.09	28.47	78.20	5.88	28.36	21.42	6.29	9.59	2.22	2.45	7.14^{ab}	2.21	1.52	0.80^{abc}
Sindhi	0.397^{b}	0.58	70.51	29.27	79.19	5.63	27.36	21.98	6.35	9.40	2.36	2.30	6.48^{a}	2.40	1.64	0.77^{c}
Polled Sindhi	0.422^{ab}	0.56	68.67	29.86	79.86	6.25	30.10	20.69	5.81	10.59	2.20	2.47	7.17^{ab}	2.23	1.51	0.83^{ab}
Tabapuã	0.425^{a}	0.60	71.83	28.50	78.22	5.84	28.90	21.71	6.30	9.66	2.23	2.4	7.24^{ab}	2.22	1.51	0.81^{abc}
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	9.16
Type																
Dual-purpose	0.412^{c}	0.598^{b}	71.81^{b}	28.40	78.10	5.81^{c}	28.12^{ab}	22.24^{a}	6.29	9.44^{b}	2.30^{a}	2.41^{b}	6.90^{c}	2.27^{a}	1.55^{a}	0.79^{b}
Beef	0.424^{a}	0.603^{a}	72.16^{a}	28.31	78.00	5.87^{b}	28.39^{a}	21.48^{c}	6.31	9.56^{a}	2.23^{b}	2.44^{a}	7.10^{a}	2.21^{c}	1.52^{b}	0.80^{a}
Dairy	0.415^{b}	0.596^{b}	71.59^{b}	28.33	78.00	5.93^{a}	28.02^{b}	21.90^{b}	6.34	9.39^{b}	2.29^{a}	2.41^{b}	7.01^{b}	2.24^{b}	1.53^{b}	0.80^{a}
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	9.21

Precip = Precipitation (mm per day); NDVI = normalized difference vegetation index (%); RH = relative humidity (%); Temp = temperature (°C); THI = temperature humidity index (%); Alt = altitude (m); RSRV = rivers and streams with riparian vegetation (ha); NRSRV = rivers and streams without riparian vegetation (ha); SF = establishments with smallholder farmers (ha); WSF = establishments without smallholder farmers (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 the Tukey test ($p < 0.05$).

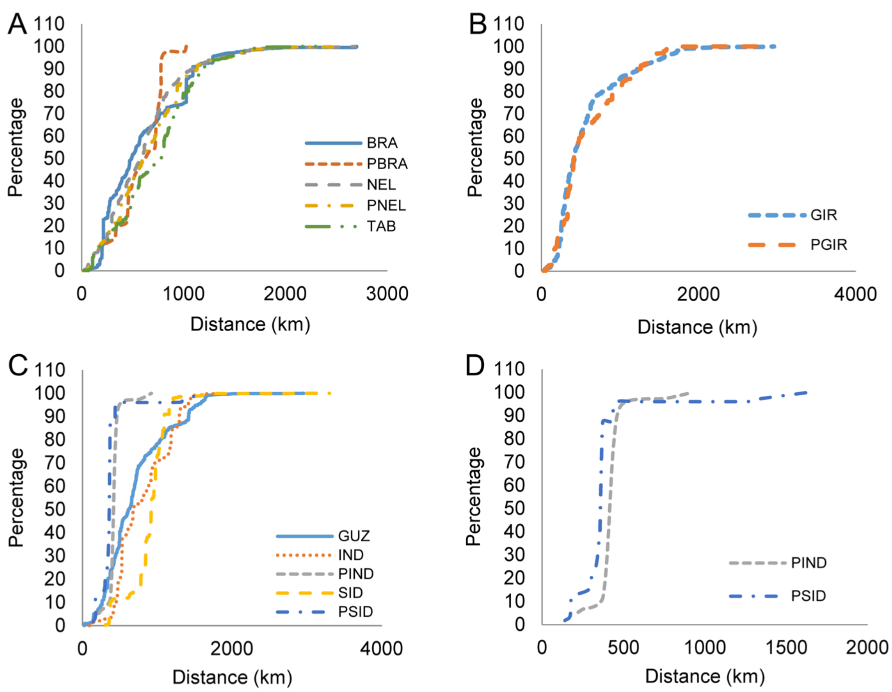

Figure 3 – Percentage of herds by distance from breed midpoint by type of production. A = beef breeds, B = dairy breeds and C = dual-purpose breeds, D = Polled Indubrasil and Polled Sindhi breeds. BRA = Brahman; PBRA = Polled Brahman; GIR = Gir; PGIR = Polled Gir; GUZ = Guzerá; IND = Indubrasil; PIND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

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 Central-West region, followed by Southeast and Northern

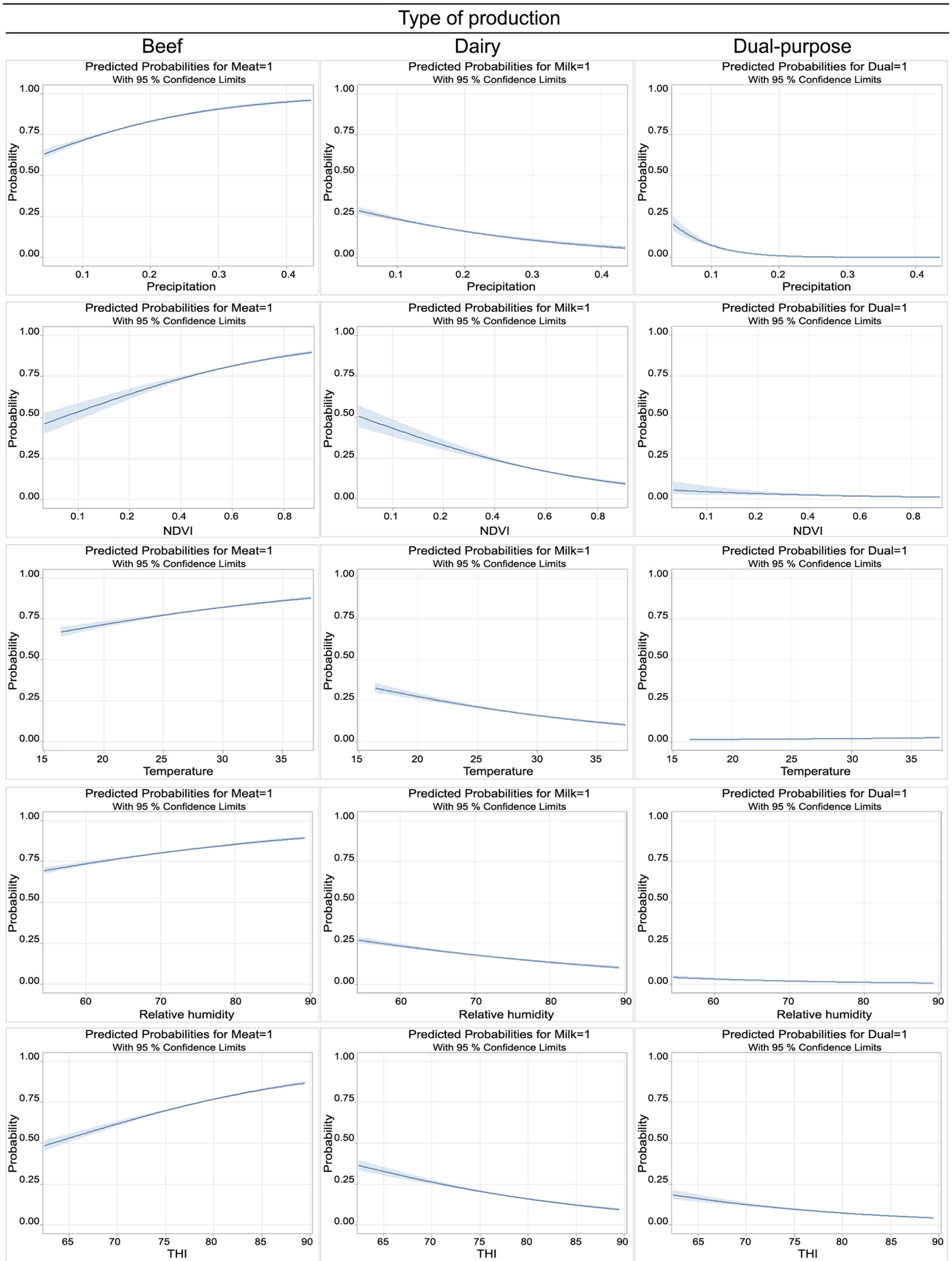

Figure 4 – Effect of climate variables on distribution of zebu cattle breeds in Brazil. NDVI = normalized difference vegetation index; THI = temperature humidity index.

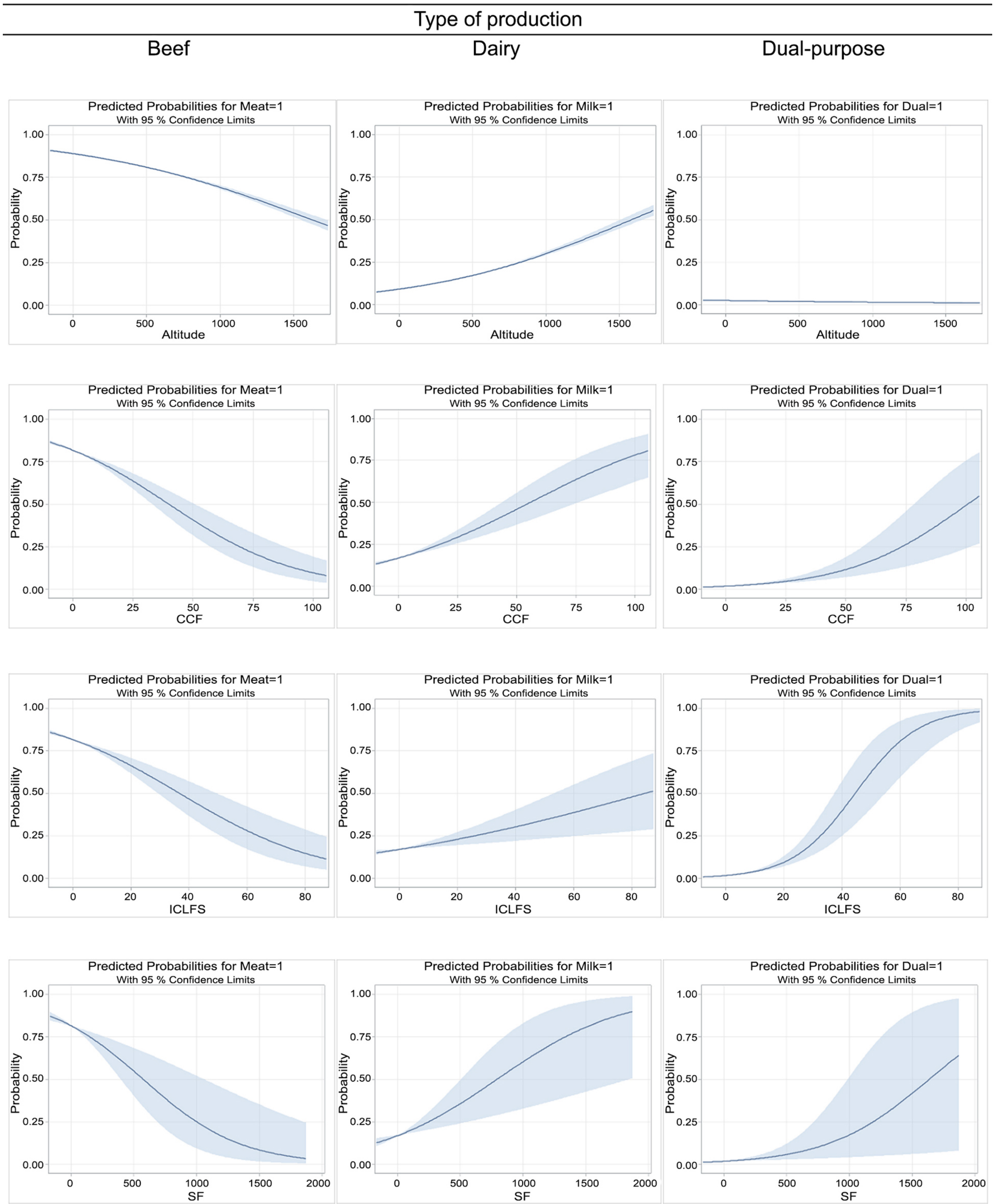

Figure 5 – Effect of environmental variables and the human development index on distribution of zebu cattle breed type in Brazil. CCF = areas with cultivated cutting forages; ICLFS = areas with integrated crop-livestock forest systems; SF = establishments with smallholder farmers; RGS = areas with rotational grazing system; RSRV = rivers and streams with riparian vegetation; NRSRV = rivers and streams without riparian vegetation; HDI = human development index.

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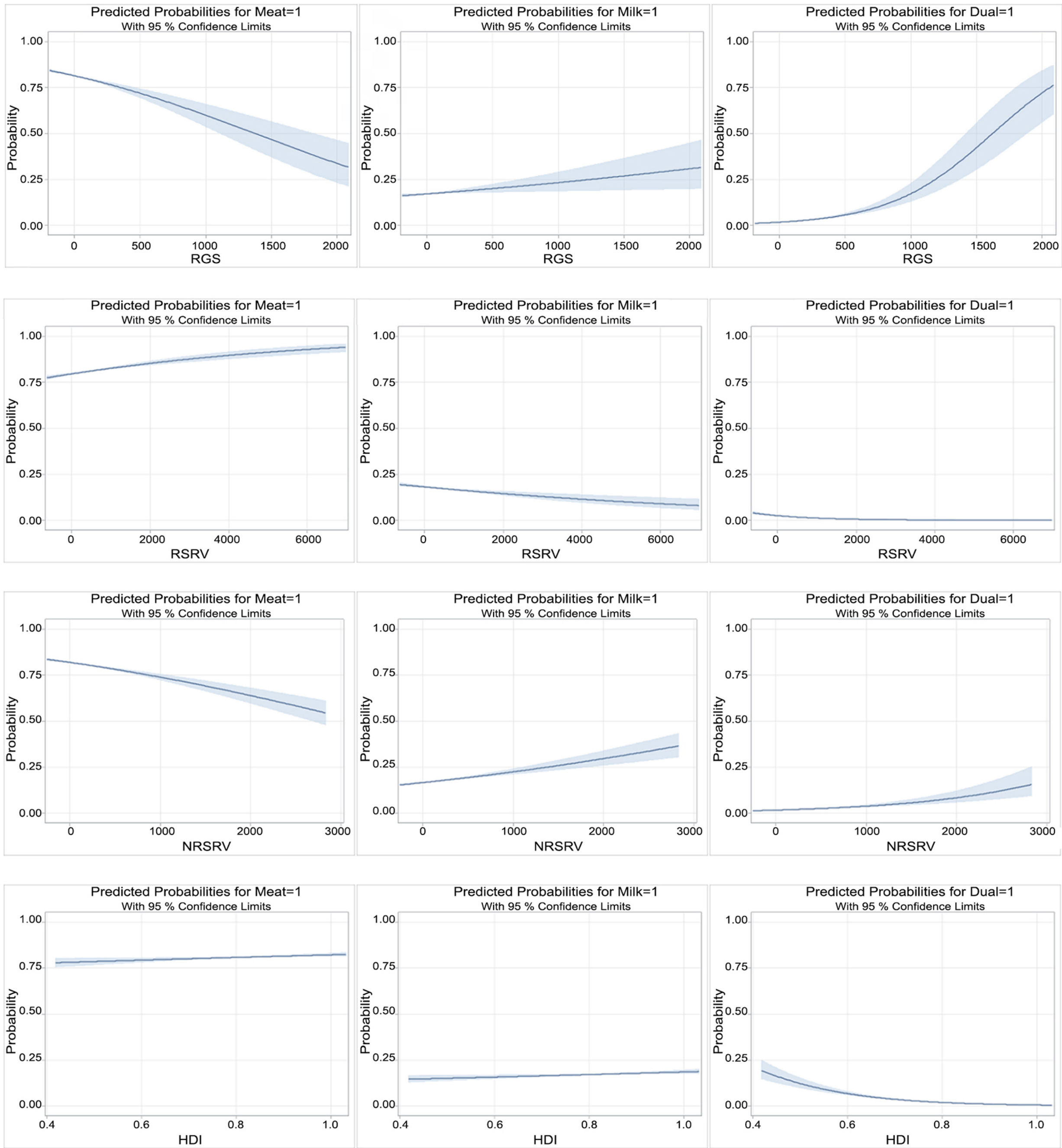

Figure 5 – Effect of environmental variables and the human development index on distribution of zebu cattle breed type in Brazil. CCF = areas with cultivated cutting forages; ICLFS = areas with integrated crop-livestock forest systems; SF = establishments with smallholder farmers; RGS = areas with rotational grazing system; RSRV = rivers and streams with riparian vegetation; NRSRV = rivers and streams without riparian vegetation; HDI = human development index.

regions, explained by their well-known livestock farming aptitude, supported by research data (IBGE, 2012). This was evident in the midpoint position of these breeds. Almost all were located in the country's central region, as reported by McManus et al. (2016). The latter authors observed this central location as the midpoint for all cattle production in Brazil. These authors investigated the dynamics of cattle production in Brazil. They reported a movement towards the Northeastern regions, which has implications for environmental factors, such as pasture type, temperature, and humidity, and the need for political and infrastructure changes to foster the livestock sector.

The lower occurrence of zebu cattle breeds in the country's Southern region was due to the traditional use of European breeds in subtropical or temperate climates (Alfonzo et al., 2021).

In the Northeastern states, a region known as the drought polygon, a more negligible occurrence of zebu cattle herds was observed due to their high susceptibility to long periods of high temperatures and absence of rainfall (Lôbo et al., 2011). Such an environment 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 breed was observed for this region, indicating a more regional use of this breed (Panetto et al., 2017; Mello et al., 2020). Sindhi animals are seen to have excellent rusticity and tolerance to thermal stress, maintaining high productive and reproductive efficiency in adverse environments (Saraiva et al., 2015; Oliveira et al., 2017).

Geographic distribution maps showed an expected trend, where the Nellore breed is widely distributed throughout the country (Figure 2), possibly due to its adaptation to different environments (Lima et al., 2021). The Indubrasil breed, developed by crossbreeding in Brazil, was highly used in the middle of the last century, but its use has declined. Calculating the midpoint also helps understand breed distribution and the eventual need for conservation measures (McManus et al., 2014b).

The national distribution of the zebu cattle breeds, when analyzed by type of production, beef, dairy and dual-purpose, showed that most 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 disease epidemics and inbreeding due to a potential lack of adequate numbers of outbred animals for reproduction. Therefore, increased crossbreeding may arise, reducing purebred numbers. Diseases, especially infectious, can be catastrophic for a very localized breed (McManus et al., 2014b). A high degree of kinship in genomic samples was observed in Nellore animals reared close to each other (Mudadu et al., 2016). Special attention should be paid to the Polled Sindhi and Indubrasil breeds, which may suffer more significant impacts due to the shorter herd distances (midpoint < 500 km) compared to the other breeds. Therefore, preventive measures should be taken for the preservation of these breeds.

Climate plays a vital role in cattle raising in Brazil, mainly beef cattle, as 97 % of the herd is reared on native and/or planted pastures (Nääs et al., 2010). Precipitation was the only climatic variable influencing the occurrence of Nellore, 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. (2014). These authors also indicated the adaptation of beef cattle animals due to climatic effects.

Complementary results were verified when the breeds were analyzed by type (beef, dairy and dual-purpose). Beef breeds usually occur in areas with more significant rainfall, NDVI, temperature, THI, and relative humidity, in more humid and hotter regions, corroborating with McManus et al. (2016). Similar results were found for *Bos indicus* breeds in the USA (McManus et al., 2021),

Areas with pastures in good conditions and the HDI influenced the occurrence of Nellore, Polled Brahman, and Sindhi breeds. Brahman and Sindhi polled breeds tend to be used on farms with access to production technologies, surrounded by different regions regarding socio-economic development. The Brahman breed occurs in regions with the highest HDI, while Sindhi is observed in regions with the lowest HDI. High HDI reflects better human development conditions, usually attributed to more prosperous regions. This, in turn, can favor better 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 Sivalogathasan, 2013) and increase added value to livestock products (Soesilowati et al., 2017). In addition, the ability of a farmer to adapt to changes was affected by the HDI (Peñalba and Elazegui, 2013). Most farmers in Southern Brazil only had primary school education, and most of these farmers did not keep records nor carried out adequate management practices (Costa et al., 2013).

The beef zebu cattle breeds occurred in both cultivated pasture areas with good (CPGC) and degraded (DCP) conditions, possibly because these breeds are spread over a large part of the Brazilian territory and reared in various environments, consequently in different pasture quality situations. There are approximately 190 Mha of pasture sustaining 209 million cattle heads in Brazil (Jank et al., 2014). Of this, about 74 Mha are native species, 99 Mha *Brachiaria* spp. and 17 Mha of other cultivars (Anualpec, 2008) and 8 Mha are renewed each year, and about 4 Mha are occupied by ICLFS. This means that a significant number of cattle heads are reared on suboptimal pastures, such as seen in 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 a lack of understanding of the importance of these measures by cattle farmers and a lack of adequate infrastructures, such as electrification and roads. Studies on cattle herd distribution, such as our study, can help identify where increased public policies (fiscal incentives, access to financing systems, among others), infrastructure, and specific training are necessary to improve production.

However, breeds of beef cattle also occurred in RSRV areas and WSF establishments, possibly due to a large number of animals of this cattle breed in the data favored by favorable market conditions, as reported by McManus et al. (2014b) in a study with sheep breeds distribution in Brazil. Moreover, these beef breeds had a high distribution in the Brazilian territory influenced by the commercialization through the Breeders' Associations of Brazil, which may also have favored the marketing of beef zebu breeds.

In areas with CCF, RGS, and ICLFS, the occurrence of dual-purpose and dairy breeds was higher, as these breeds occur in more fertile soils. This was also observed by McManus et al. (2016) and McManus et al. (2014a). In addition, dairy production can be favored by higher altitudes, possibly due to better climate conditions. Riparian vegetation for rivers and streams plays an essential role in climate regulation, heat absorption, and humidity regulation (Silvano et al., 2005). Nevertheless, in recent years, riparian vegetation has reduced (Taniwaki et al., 2017), mainly due to corn (*Zea mays*) plantations for silage, sugarcane plantations (*S. officinarum*), citrus, silviculture, urbanization, and pastures, which have been 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), directly affecting the animals' performance.

A trend of dairy breed occurrence was observed in SF, showing a historical tendency where small to medium-sized family-owned properties usually explore dairy breeds. This was also seen by agricultural research data (IBGE, 2012), where more than 80 % of the farms fall into this category.

The current study investigated breed occurrence due to environmental and socio-economic factors. When a factor changes, others and their relationships may also change (Costa et al., 2013). Intensification of production systems was suggested as the means for the cattle industry to reduce pressure on forest margins and free-up land for soybean (*Glycine max*) or sugarcane (*S. officinarum*) production (Barcellos et al., 2011). Expansion of cropped areas resulted in a significant reduction of pastures and, thus, the number of cattle heads and higher economic growth compared to neighboring regions (Sparovek et al., 2009).

The replacement of beef cattle for soybean (*G. max*) crops was observed in the savanna region of Brazil (Maranhão et al., 2019). Therefore, beef cattle migrated to the Amazon region, which may explain some of the results found here, with beef cattle occurrence in regions with higher temperatures and lower rainfall. However, large regions show overlaps between cattle crop productions due to the need for alternative feed sources, mainly those linked to dairy and dual-purpose cattle. The correct interpretation of these results can contribute to a better understanding of the adaptation of zebu breeds to different environments, helping in the choice of the most adequate breed to be explored.

Conclusions

Zebu cattle breeds showed high adaptability to a broad range of climates. Still, environmental variables and the human development index may have influenced the distribution of these cattle breeds in Brazil. Beef breeds showed greater distribution and adaptation to the tropical climate with higher temperature and humidity levels, which may have influenced the distribution of the Nellore breed, the largest in the country.

Authors' Contributions

Conceptualization: Lima, P.R.M.; McManus C.M. **Formal analysis**: McManus, C.M. **Methodology**: Lima, P.R.M.; Peripolli, V.; Josahkian, L.A.; McManus, C.M. **Writing-review & editing**: Lima, P.R.M.; Peripolli, V.; Josahkian, L.A.; McManus, C.M.

References

Alf onzo, E.P.M.; McManus, C.M.; Campos, G.S.; Portes, J.V.; Padilha, A.H.; Peripolli, V.; Braccini-Neto, J. 2021. Spatial distribution of Brazilian bovine taurine breeds associated with climatic, physical and socioeconomic variables. Arquivo Brasileiro de Medicina Veterinária e Zootecnia 73: 693-702. https://doi.org/10.1590/1678-4162-12206

Anuário da Pecuária Brasileira [Anualpec]. 2008. Brazilian Livestock Yearbook = Informa Economics FNP, São Paulo, SP, Brazil (in Portuguese).

Barbosa, B.R.P.; Santos, S.A.; Abreu, U.G.P.; Egito, A.A.; Comastri Filho, J.A.; Juliano, R.S.; Paiva, S.R.; McManus, C. 2014. Heat tolerance in Nelore branco, Nelore vermelho and Pantaneira breeds in the Pantanal region, Brazil. Revista Brasileira de Saúde e Produção Animal 15: 854-865 (in Portuguese, with abstract in English).

Barcellos, J.O.J.; Queiroz-Filho, L.A.; Ceolin, A.C.; Gianezini, M.; McManus, C.; Malafaia, G.C.; Oaigen, R.P. 2011. Technological innovation and entrepreneurship in animal production. Revista Brasileira de Zootecnia 40: 189-200.

Baye, T.M.; Abebe, T.; Wilke, R.A. 2011. Genotype environment interactions and their translational implications. Personalized Medicine 8: 59-70. https://doi.org/10.2217/pme.10.75.

Costa, J.H.C.; Hötzel, M.J.; Longo, C.; Balcão, L.F. 2013. A survey of management practices that influence production and welfare of dairy cattle on family farms in southern Brazil. Journal of Dairy Science 96: 307-317. http://dx.doi.org/ 10.3168/jds.2012-5906

Costa, N.S.; Hermuche, P.; Cobuci, J.A.; Paiva, S.R.; Guimaraes, R.F.; Carvalho Jr., O.A.; Gomes, R.A.T.; Costa, C.N.; McManus, C.M. 2014. Georeferenced evaluation of genetic breeding value patterns in Brazilian Holstein cattle. Genetics and Molecular Research 13: 9806-9816. https://doi.org/10.4238/2014. November.27.8

Costa, N.S.; Silva, M.V.G.B; Panetto, J.C.C.; Machado, M.A.; Seixas, L.; Peripolli, V.; Guimarães, R.F.; Carvalho Jr., O.A.; Vieira, R.A.; McManus, C. 2020. Spatial dynamics of the Girolando breed in Brazil: analysis of genetic integration and environmental factors. Tropical Animal Health and Production 52: 3869-3883. https://doi.org/10.1007/s11250-020-02426-z

Diaz, I.D.P.S.; Oliveira, H.N.; Bezerra, L.A.F.; Lôbo, R.B. 2011. Genotype by environment interaction in Nelore cattle from five Brazilian states. Genetics and Molecular Biology 34: 435-442. https://doi.org/10.1590/S1415-47572011005000024

Hermuche, P.; Guimarães, R.F.; Carvalho Jr., O.A.; Gomes, R.A.T.; Paiva, S.R.; McManus, C.M. 2013. Environmental factors that affect sheep production in Brazil. Applied Geography 44: 172-181. https://doi.org/10.1016/j.apgeog.2013.07.016

Instituto Brasileiro de Geografia e Estatística [IBGE]. 2012. Agricultural Census = Censo Agropecuário. IBGE, Rio de Janeiro, RJ, Brazil. Available at: http://www.ibge.gov.br/home/estatistica/economia/agropecuaria/censoagro/default.shtm [Accessed May 5, 2012] (in Portuguese).

Jank, L.; Barrios, S.C.; Valle, C.B.; Simeão, R.M.; Alves, G.F. 2014. The value of improved pastures to Brazilian beef production. Crop and Pasture Science 65: 1132-1137. http://dx.doi.org/10.1071/CP13319

Lima, P.R.M.; Peripolli, V.; Silva, L.O.C.; McManus, C. 2021. Spatial distribution of genetic values of Nelore breed in Brazil. Livestock Science 250: 104599. https://doi.org/10.1016/j.livsci.2021.104599

Lôbo, R.N.B.; Pereira, I.D.C.; Facó, O.; McManus, C.M. 2011. Economic values for production traits of Morada Nova beef sheep in a pasture based production system in semi-arid Brazil. Small Ruminant Research 96: 93-100. https://doi.org/10.1016/j.smallrumres.2011.01.009

Maranhão, R.L.A.; Carvalho Júnior, O.A.; Hermuche, P.M.; Gomes, R.A.T.; McManus Pimentel, C.M.; Guimarães, R.F. 2019. The spatiotemporal dynamics of soybean and cattle production in Brazil. Sustainability 11: 2150. https://doi.org/10.3390/su11072150

McManus, C.M.; Barcellos, J.O.J.; Formenton, B.K.; Hermuche, P.M.; Carvalho Jr., O.A.; Guimarães, R.F.; Gianezini, M.; Dias, E.A.; Lampert, V.N.; Zago, D.; Braccini-Neto, J. 2016. Dynamics of cattle production in Brazil. PlosOne 11: e0147138. https://doi.org/10.1371/journal.pone.0147138

McManus, C.M.; Hermuche, P.; Paiva, S.R.; Daltro, D.S.; Alfonzo, E.P.M.; Facó, O. 2014a. Distribution of goat breeds in Brazil and their relationship with environmental controls. Bioscience Journal 30: 1819-1836.

McManus, C.M.; Hermuche, P.; Paiva, S.R.; Moraes, J.C.F.; Melo, C.B.; Mendes, C. 2014b. Geographical distribution of sheep breeds in Brazil and their relationship with climatic and environmental factors as risk classification for conservation. Brazilian Journal of Science and Technology 1: 3. https://doi.org/10.1186/2196-288X-1-3

McManus, C.; Hermuche, P.M.; Paiva, S.R.; Guimarães, R.F.; Carvalho Jr., O.A.C; Blackburn, H.D. 2021. Gene bank collection strategies based upon geographic and environmental indicators for beef breeds in the United States of America. Livestock Science 254: 104766. https://doi.org/10.1016/j.livsci.2021.104766

Mello, R.R.C.; Sinedino, L.D.P.; Ferreira, J.E.; Sousa, S.L.G.; Mello, M.R.B. 2020. Principal component and cluster analyses of production and fertility traits in Red Sindhi dairy cattle breed in Brazil. Tropical Animal Health and Production 52: 273-281. https://doi.org/10.1007/s11250-019-02009-7

Mudadu, M.A.; Porto-Neto, L.R.; Mokry, F.B.; Tizioto, P.C.; Oliveira, P.S.N.; Tullio, R.R.; Nassu, R.T.; Niciura, S.C.M.; Tholon, P.; Alencar, M.M.; Higa, R.H.; Rosa, A.N.; Feijó, G.L.D.; Ferraz, A.L.J.; Silva, L.O.C.; Medeiros, S.R.; Lanna, D.P.; Nascimento, M.L.; Chaves, A.S.; Souza, A.R.D.L.; Packer, I.U.; Torres Jr., R.A.A.; Siqueira, F.; Mourão, G.B.; Coutinho, L.L.; Reverter, A.; Regitano, L.C.A. 2016. Genomic structure and marker-derived gene networks for growth and beef quality traits of Brazilian Nelore beef cattle. BMC Genomics 17: 235. https://doi.org/10.1186/s12864-016-2535-3

Nääs, I.A.; Romanini, C.E.B.; Salgado, D.D.; Lima, K.A.O.; Vale, M.M.; Labigalini, M.R.; Souza, S.R.L.; Menezes, A.G.; Moura, D.J. 2010. Impact of global warming on beef cattle production cost in Brazil. Scientia Agricola 67: 1-8.

National Aeronautics and Space Administration [NASA]. 2012. Image Gallery Available at: https://www.nasa.gov/multimedia/imagegallery/index.html [Accessed Feb 20, 2012].

Oliveira, A.A.; Seixas, L.; Azevedo, H.C.; Teixeira, K.M.; McManus, C.; Melo, C.B. 2015. Evaluation of the use of good practices in dairy cattle herds. Brazilian Journal of Veterinary Medicine 37: 73-77.

Oliveira, L.T.; Bonafé, C.M.; Silva, F.F.; Ventura, H.T.; Oliveira, H.R.; Menezes, G.R.O.; Resende, M.D.V.; Viana, J.M.S. 2017. Bayesian random regression threshold models for genetic evaluation of pregnancy probability in Red Sindhi heifers. Livestock Science 202: 166-170. https://doi.org/10.1016/j.livsci.2017.06.005

Panetto, J.C.C.; Silva, M.V.G.B.; Leite, R.M.H.; Machado, M.A.; Bruneli, F.A.T.; Reis, D.R.L.; Peixoto, M.G.C.D.; Verneque, R.S. 2017. Red Sindhi cattle in Brazil: population structure and distribution. Genetics and Molecular Research 16: gmr16019501. https://doi.org/10.4238/gmr16019501

Peñalba, L.M.; Elazegui, D.D. 2013. Improving adaptive capacity of small-scale rice farmers: comparative analysis of Lao Pdr and the Philippines. World Applied Sciences Journal 24: 1211-1220. https://doi.org/10.5829/idosi.wasj.2013.24.09.13274

PNUD. 2013. Programa de Desenvolvimento das Nações Unidas. Atlas of Human Development = Atlas de Desenvolvimento Humano. Available at: http://www.pnud.org.br/IDH/Atlas2013.aspx?indiceAccordion=1&li=li_Atlas2013 [Accessed Sep 23, 2012] (in Portuguese).

Saraiva, C.A.S.; Gonzaga Neto, S.; Henriques, L.T.; Queiroz, M.F.S.; Saraiva, E.P.; Albuquerque, R.P.F.; Fonseca, V.F.C.; Nascimento, G.V. 2015. Forage cactus associated with different fiber sources for lactating Sindhi cows: production and composition of milk and ingestive behavior. Revista Brasileira de Zootecnia 44: 60-66. https://doi.org/10.1590/S1806-92902015000200004

Shiota, A.M.; Santos, S.F.; Nascimento, M.R.B.M.; Moura, A.R.F.; Oliveira, M.V.; Ferreira, I.C. 2013. Physiological parameters, hair coat characteristics and thermal gradients in nellore heifers in summer and winter in tropical environment. Bioscience Journal 29: 1687-1695. (in Portuguese)

Silvano, R.A.M.; Udvardy, S.; Ceroni, M.; Farley, J. 2005. An ecological integrity assessment of a Brazilian Atlantic Forest watershed based on surveys of stream health and local farmers' perceptions: implications for management. Ecological Economics 53: 369-385.

Soesilowati, E.; Kariada, E.; Marguani, M. 2017. Model for empowering farmers at dry land through quadruple helix approach. Journal of Arts & Humanities 6: 1-9. https://doi.org/10.18533/journal.v6i4.1131

Souza, A.C.B.; Egito, A.A.; Peripolli, V.; McManus, C.M. 2022. Bovine landscape genetics in Brazil. Scientia Agricola 79: e20200142. DOI: http://doi.org/10.1590/1678-992X-2020-0142

Sparovek, G.; Barretto, A.; Berndes, G.; Martins, S.; Maule, R. 2009. Environmental, land-use and economic implications of Brazilian sugarcane expansion 1996-2006. Mitigation and Adaptation Strategies for Global Change 14: 285-298. http://doi.org/10.1007/s11027-008-9164-3

Taniwaki, R.H.; Cassiano, C.C.; Filoso, S.; Ferraz, S.F.B.; Camargo, P.B.; Martinelli, L.A. 2017. Impacts of converting low-intensity pastureland to high-intensity bioenergy cropland on the water quality of tropical streams in Brazil. Science of the Total Environment 584: 339-347. http://doi.org/10.1016/j.scitotenv.2016.12.150

Thornton, P.; Herrero, M.; Freeman, A.; Mwai, O.; Rege, E.; Jones, P.; McDermott, J. 2007. Vulnerability, climate change and livestock: research opportunities and challenges for poverty alleviation. Journal of SAT Agricultural Research 4: 1-23.

Xiaobo,W.; Sivalogathasan, V. 2013. Intellectual capital for innovation capability: a conceptual model for innovation. International Journal of Trade, Economics and Finance 4: 139-144. http://doi.org/10.7763/IJTEF.2013.V4.274