An Acad Bras Cienc (2023) 95(Suppl. 2): e20220746 DOI 10.1590/0001-3765202320220746
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

ECOSYSTEMS

The historical ecology of the world's largest tropical country uniquely chronicled by its municipal coat-of-arms symbology

JULIANO A. BOGONI, HENRIQUE VILLAS BOAS CONCONE, VÍTOR CARVALHO-ROCHA, KATIA M.P.M.B. FERRAZ & CARLOS A. PERES

Abstract: Coats-of-arms representing municipal counties express local patterns of rural economics, natural resource and land use, features of the natural capital, and the cultural heritage of either aborigines or colonists. We reconstruct the subnational economic and political timeline of the world's largest tropical country using municipal coats-of-arms to reinterpret Brazil's historical ecology. We assessed all natural resource, biophysical, agricultural, and ethnocultural elements of 5,197 coats-of-arms (93.3%) distributed throughout Brazil. We extracted socioenvironmental co-variables for any municipality to understand and predict the relationships between social inequality, environmental degradation, and the historical ecology symbology. We analyzed data via ecological networks and structural equation models. Our results show that the portfolio of political-administrative symbology in coats-of-arms is an underutilized tool to understand the history of colonization frontiers. Although Brazil is arguably Earth's most species-rich country, generations of political leaders have historically failed to celebrate this biodiversity, instead prioritizing a symbology depicted by icons of frontier conquest and key natural resources. Brazilian historical ecology reflects the relentless depletion of the natural resource capital while ignoring profound social inequalities. Degradation of natural ecosystems is widespread in Brazilian economy, reflecting a legacy of boom-and-bust rural development that so far has failed to deliver sustainable socioeconomic prosperity.

Key words: land use, tropical forest, ecological elements, fauna, flora, public policy.

INTRODUCTION

Brazil is arguably Earth's most biodiverse country, harboring the largest set of known and unknown species (Moura & Jetz 2021). Natural vegetation remnants distributed across diverse ecosystems span 60% of its territory (Oliveira et al. 2017), which includes dense tropical rainforests, dry forests, wetlands, wooded savannas, and grasslands (Mittermeier et al. 1997, Soares-Filho et al. 2014). Since colonial times, however, Brazil has been gradually consolidated into an agricultural country (McNeill 1986). Intensification of agricultural practices and land ownership concentrated on few large landholdings resulted in the chronic devastation of Brazil's natural resources, especially over the last 60 years with the onset of modern mechanization and fertilizers (Navarro et al. 2021). Despite the high environmental cost, this model of exploitation elevated Brazil to one of the 10 largest economies (Polaski et al. 2009, Muller & Muller 2014), while also simultaneously creating one of the world's most unequal nations (Beghin 2008, Goés & Karpowick 2017).

Brazil's history and ecology is thousands of years old prior to these modern events.

Paleoindians have occupied the Brazilian territory for millennia before European settlement (Goebel et al. 2008). Hundreds of well-stablished sedentary ancient indigenous societies occupied Brazil for at least 3,500 years before present (ybp; Mann 2006). By historically managing natural resources, these multiple ethnicities exerted — and still do — a strong relationship with their landscapes and ecological elements (Clement & Junqueira 2010, Begotti & Peres 2020). Many ecological elements, including apex carnivores, are a strong symbol of ancient Amerindian power and values (Saunders 1998), which remains traditional in their societies via oral history. Archeological sites in Brazil reveals the vastness of relationships of both paleo-indigenous and pre-historic humans with multiple ecological elements. For instance, in the Serra da Capivara National Park (Piauí, Brazil) rock paintings containing faunistic elements were dated from 22,000 to 3,500 ybp (Lahayea et al. 2013). Meanwhile in Southern Brazil, some ethnic groups (Kaingang and Xokleng) cultivated araucaria seeds (*Pinhão*) for food and religious rituals centuries before colonization (Reis et al. 2014).

Post-Columbian Brazil's historical and political ecology begins in the early 16th century, with the arrival of a Portuguese fleet led by Pedro Álvares Cabral, followed by the foundation of the first coastal municipalities in the 1530s. Most of Brazil's post-"discovery" history has been told at the regional scale, while ignoring local historical perspectives. Natural resource exploitation of the Brazilian territory by European settlers begun in coastal regions with timber extraction, mainly Brazil-wood (*Paubrasilia echinate* (Lam.) Gagnon, H. C. Lima & G. P. Lewis) — which is known as the "Brazil-wood cycle". Consequently, the first Brazilian municipalities (e.g. São Vincente, Olinda, Recife, and Vila Velha) were established in the 1530s along the eastern coastline (Dean 1996). The extractivism economic model gradually changed into agricultural practices, which were concentrated in inland plateaus (McNeill 1986). This was followed by the implementation of "Hereditary Captaincies" by the Portuguese Crown. This arrangement was a highly unequal system of agrarian distribution and resource exploitation based on geopolitical subdivisions of the Brazilian territory (Burns 1993). Although lasting only 16 years, the legacy of hereditary captaincy practices left profound geopolitical, social, and environmental scars that still can be witnessed today (Fausto 1994, Cintra 2013). For example, after Brazil's independence in 1822, massive deforestation and land degradation occurred over the subsequent decades. Rapid post-independence population growth — alongside the consolidation of the sugarcane, coffee, and cacao agricultural cycles — led to overwhelming natural vegetation loss (Leal & Câmara 2003).

Other historical events were noteworthy in terms of the territorial expansion of what is now Brazil. As an embryonic would-be nation-state Brazil pushed farther west through the "Sesmarias" system, the cattle conquest of western portions of Hereditary Captaincies, the advances of the Jesuit missionaries, the Bandeirantes conquest of the interior hinterlands, the consolidation of mining routes, and most recently the Agribusiness expansion into central and northern Brazil (Burns 1993, Dean 1996, Fausto 1994). The European "conquest" through the Hereditary Captaincies and Sesmarias systems, the Jesuit and Bandeirantes missions, the modern frontier expansion, in addition to overexploiting natural resources, decimated indigenous peoples (McNeill 1986, Dean 1996). Before European arrival, *ca.* 3.5 million indigenous people lived in Brazil (Burns 1993). Currently, indigenous peoples have declined by >90%, in the aftermath of centuries of persecution, slavery and disease transmission (Dean 1996). Some cultures were completely extirpated, and with them, all of their ecological history and resource use systems (Dean, 1996). Others still persist under mounting pressure from multiple threats across all Brazilian biomes (Begotti & Peres 2020).

During most of Brazil's history, the Atlantic Forest and Caatinga biomes were the most detrimentally affected by the colonization and occupation processes. Currently these biomes experience poor urban planning and overcrowded settlements in highly disturbed landscapes. The Atlantic Forest encompasses ~17% of Brazil's territory but holds 70% of the Brazilian population (~147 million people), further aggravating the pressures on wildlife (Canale et al. 2012). Covering almost 10% of the national territory, the Caatinga harbors ~15% of the Brazilian population (~31.5 million people), and was initially occupied during the colonization period when large cattle ranches and subsistence agriculture were established mainly along major rivers (da Silva et al. 2017).

The Cerrado spans 23% of the Brazilian territory and has largely succumbed to agricultural conversion in the last few decades. The strong recent pressure posed by the agri-business industry has led to wholesale conversion of over 45% of all natural areas into croplands and cattle pastures (Klink & Moreira 2002, Projeto MapBiomas 2020). Coupled with high levels of endemism, this rapid process of land-use change has led to high levels of threatened species in both the flora and fauna (Myers et al. 2000, Cavalcanti & Joly 2002). The Pampa biome, located in southernmost Brazil, has also experienced high rates of land-use change since the 1970s (Projeto MapBiomas 2020). In contrast, the Amazon and Pantanal biomes retain over 80% of their native vegetation cover (Projeto MapBiomas 2020). This difference is related to the more recent history of exploitation, poor physical access, and low human density (Tritsch & Le Tourneau 2016). The first Amazonian municipality was established in 1571 (Tutóia, coastal Maranhão), and most counties in Amazonia (83%) were not emancipated until after the 1900s (Instituto Brasileiro de Geografia e Estatística [IBGE] 2016). Amazonia contains few but large municipal counties (497; 8.9% of Brazilian municipalities), many of which larger than several European countries (> 100,000 km^2; e.g., Barcelos, Amazonas and Altamira, Pará) (IBGE 2016). European colonization of the Pantanal started in the early 16th century for cattle ranching, which is still the main economic activity of this macroregion. Most of the agrarian occupation of the Pantanal was carried out by very large private ranches, which account for 95% of this biome (Zimmermann et al. 2005), which explains the creation of few municipalities.

The overall process of human occupation across Brazil has intensified since the 1950s after the last major industrialization process, known as "*The Great Acceleration*" (Steffen et al. 2015). This paradigm shift deflected the focus from local environmental knowledge and human-environment relationships, leading to rapidly growing globalization and later the rise of the environmental crisis (Alexiades 2003, Steffen et al. 2015). From colonization to globalization, cultural and social differences have become ever more profound. Inevitably, these issues have prompted conflicts of interest between distinct sets of stakeholders directly connected to land stewardship, whereby private interest sought the privatization of public resources, and local subsistence communities — who had long held traditional sociocultural relationships with the land they occupied — were marginalized and brushed-aside as obstacles to national development (Alexiades 2003, Reyes-Garcia et al. 2013).

Anthropogenic forces promote the historical reorganization and (re)construction of spaces wherever humans have settled (Bird et al. 2008). Yet, municipalities within Brazilian biomes — from the most to the least exploited — are largely faithful to the ancestral tradition of their foundational coat-of-arms (e.g. Berg 2015). A coat-of-arms is a visual scheme on an escutcheon, forming the central element of the full heraldic achievement that in its entirety entails armour, supporters, or historic items (Fox-Davies 2012). The creation and use of coats-of-arms harks back to the European aristocracy of the 12th century and, beyond personal or familyhood symbols, they are currently used as representations of administrative sectors, including states, provinces, and municipalities (Fox-Davies 2012). Coats-of-arms are symbolic of local self-affirmation, often engraved in official documents, public buildings, and vehicles, and can be viewed by millions of people (Cascudo 1956, Canto 2018). The creation of Brazilian municipal coat-of-arms is usually rubber-stamped a few years after political emancipation (i.e. dates of official decrees). In general, municipal laws are created to establish the coat-of-arms, and be used to help with its interpretation. Coat-of-arms are usually projected to represent the prevailing natural, agricultural, and/or ethnocultural elements of new jurisdictions, and can often be used to identify their occupants (Berg 2009, Fox-Davies 2012). Given that most the historical ecology of Brazil was never documented or is unavailable, municipal heraldic symbols can be a powerful and unexplored tool to provide a spatiotemporal mosaic of the historical ecology and land use at a manageable spatial scale.

To our knowledge, no other study anywhere has explored the entire graphic information on the historical ecology contained in the municipal coats-of-arms. Here, we assessed all 5,570 Brazilian municipal coats-of-arms to identify their explicit natural, agricultural, and ethnocultural elements (Fig. 1), illustrate prevailing regional differences, and build a timeline of this historical symbology throughout Brazil. We further predict the variation in modern socioenvironmental metrics based on the historical ecology contained in county-level coats-of-arms. We hypothesize that: (i) the relationships with the land, rural economy, and the natural history of municipal-counties have been lost over time, the latter represented by a biased reference to economically important native species compared to natural elements that did not yield local revenues; (ii) there is a clear spatiotemporal separation between the historical ecology rooted in the past and the modern land-based economy and current diversity of natural resources; and (iii) the historical ecology contained in the coats-of-arms is a strong predictor of contemporary social inequality and environmental degradation throughout the country.

MATERIALS AND METHODS

Coat-of-arm elements and municipal- level co--variables

From 2019 to 2020, we searched online (using Google search) for the coats-of-arms of all 5,570 Brazilian municipalities and systematically noted all explicit elements of native fauna (e.g., jaguar, tapir, whales, hummingbirds), flora (e.g., palm fruits, araucaria trees), natural resource use (e.g., timber extraction, mining, rubber tapping), agricultural practices (e.g., manual and mechanized techniques), common crops (e.g., coffee, sugar cane, maze, manioc, grape), livestock (e.g., swine, cattle, and sheep), landscapes (e.g., rivers, lagoons, coastlines),

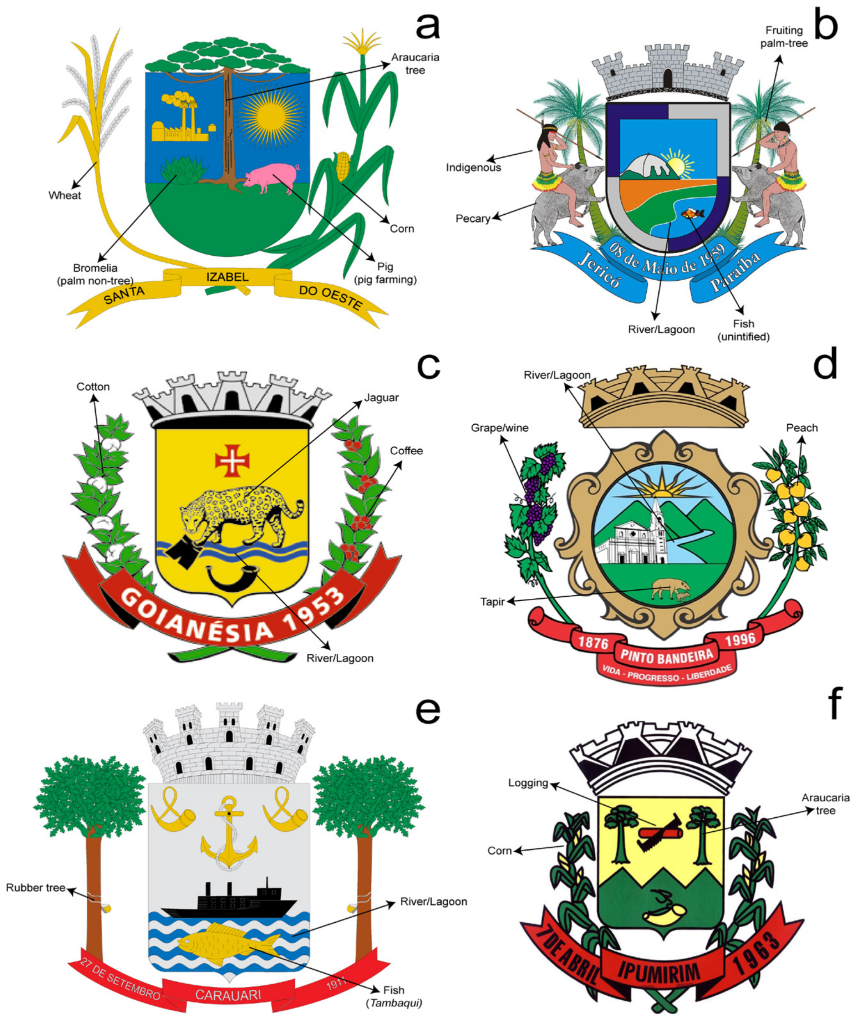

Figure 1. **Examples of how we extracted information from coats-of-arms representing each of 5,197 municipal counties (93.3%) throughout Brazil. (a) Santa Izabel do Oeste (Paraná state), (b) Jericó (Paraíba state), (c) Goianésia (Goiás state), (d) Pinto Bandeira (Rio Grande do Sul state), (e) Carauari (Amazonas state), and (f) Ipumirim (Santa Catarina state).**

traditional indigenous, Afrobrazilian, rubber tapping, and fisheries communities and their representative elements, forest representation (e.g., an explicit set of trees), solitary unidentified trees, and other pictorial natural or cultural elements that could be visually identified (Fig. 1). We also used information on county-level nomenclature and consulted their specific legislation concerning coats-of-arms whenever necessary to help identify the elements they depicted. For coats-of-arms depicted by more than one version, we jointly considered the elements in all versions. The coats-of-arms of Brazilian municipalities were jointly analised by H. Concone, V. Carvalho-Rocha and J. Bogoni, under J. Bogoni's leadership, who determined identifications of graphic elements.

We then aggregated these natural, agricultural, and ethnocultural elements (Supplementary Material - Table SI) into six major functional groups, from resource use to the celebration of native elements lacking any direct reference to economic activities to facilitate a concise analytical approach. These symbology groupings were (1) natural resource use (e.g., commercially-valuable trees, mining, fishing); (2) agriculture (e.g., crop cultivars, mechanized agriculture); (3) livestock (e.g., cattle and swine); (4) ethnic elements (e.g., indigenous); (5) wild vertebrate fauna (i.e., all species identified as native vertebrates); and (6) invertebrate fauna.

We also noted the emancipation date of each municipality using the oldest date indicated in each coat-of-arms or by accessing official county webpages. Exotic elements to native biotas (e.g., lion, tiger) were identified and aggregated into a single group but were not considered in further data analyses. We took this approach given that large fierce carnivores are traditionally used to depict courage or nobility, rather than any clear relationship with wild nature or land-use across the country. These elements amounted to only 2.3% of all elements found in the coat-of-arms symbology in this study (Table SI).

We also georeferenced each municipality, extracted the nearest linear distance to the East Coast (the "cradle" of colonial Brazil), and obtained their human population density (HPD; 2010), human development index (HDI; 2013), and poverty index (POV; 2010; representing the proportion of individuals with per capita household monthly income ≤ US$ 27.41 dated from August-2010) based on the Brazilian Institute of Geography and Statistics (IBGE 2016) and Brazil's Human Development Atlas (PNUD 2013). We used these three indices to represent municipal-scale socioeconomic metrics. Additionally, we used remote sensing information available in Projeto MapBiomas (2020) and extracted the municipal county area (km^2; 2018) and the percentage of remaining native vegetation cover (NCR) in 2018. We also derived an index of native vegetation change (gain-loss, GLN) by comparing the area (km^2) of native vegetation cover between the years 1985 and 2018, representing the longest timeline available in Projeto MapBiomas during the data acquisition process. These last two indices were used to represent municipal-scale environmental metrics.

Biome-based regionalization and Brazilian political periods

We regionalized our approach based on all major six Brazilian phytogeographic biomes: (1) Amazon; (2) Caatinga; (3) Cerrado; (4) Pantanal; (5) Atlantic Forest; and (6) Pampa. Further, we segmented the history expressed in each coat-of-arms based on their respective Brazilian political eras: (1) Colonial: from 1500 to 1822; (2) Imperial: from 1823 to 1888; (3) Old-Republic: from 1889 to 1930; (4) Vargas era: from 1931 to 1946; (5) Democratic period: from 1947 to 1963; (6) Military dictatorship: from 1964 to 1985; and (7) New-Republic: from 1986 to 2018 (Fausto 1994).

Data analysis

We first built several timelines that showed the first and last year any given element of each symbol group were depicted in county-level coat-of-arms within each biome. We also depicted (1) the cumulative emergence of six symbology groups, and (2) the distance to Brazil's East Coast in relation to the year of municipal decrees. Further, we used a network approach (Newman 2004) to describe the spatiotemporal variation of symbology groupings. We conducted this network analysis by joining each biomes and their historical periods, and then disaggregating them into single biomes. Network analysis enables the visualization of prominent regional variation in Brazilian historical ecology across different time periods. By examining the topology and metrics of the network, we can effectively separate the component of historical ecology that is deeply rooted in the past from the contemporary land-based economy and present-day diversity of natural resources. Thus, grouped elements were summarized per biome and historical period, using the following three network metrics: (1) connectance; (2) modularity; and (3) nestedness (Boccaletti et al. 2006).

Connectance — ranging from 0.0 to 1.0 — represents the proportion of interactions observed describing the total number of possibilities within biomes or historical-period interactions *vs.* their symbol groups (e.g., Boccaletti et al. 2006). Thus, a highly connected network expresses that all periods (or periods within biomes) have a good representativeness of coat-of-arms elements. Modularity (M) quantifies the propensity of the nodes to cluster into cohesive groups (Newman, 2004). For instance, network modularity increases if any period shows a more exclusive set of coat-of-arms elements. Nestedness (N) represents the hierarchical shape of interactions (period *vs.* elements), in which less connected interactions form a subset of the most connected interactions, thus expressing structural fitting (Almeida-Neto et al. 2008). We used Newman's approach (Newman 2004) to quantify modularity, by comparing the obtained M with 1000 null distributions, created *a priori*, with a network degree ranging from 0.0 to the mean of the degree observed across all networks. We based significance level ($p \leq 0.05$) on the ratio at which values equal to or larger than the observed M occur in the null M distributions (Bascompte et al. 2003). For nestedness, we used the NODF criteria (Almeida-Neto et al. 2008). NODF ranges from 0.0, when the matrix is entirely non-nested, to 100, when the matrix is perfectly nested (Almeida-Neto et al. 2008). We also compared the N value of the network with the value generated by 1000 null distributions, adopting the same aforementioned criteria for M significance (Bascompte et al. 2003). Network analysis was performed using R 3.5.3 (R Core Team 2020) based on then *bipartite* R package (Dormann et al. 2008).

We used structural equation modeling (SEM; Grace 2006) to disentangle the interrelationship between social (HPD, HDI, and POV), environmental (NCR and GLN), and the historical ecology contained in the coats-of-arms. To do so, we simultaneously modeled how the six symbology groupings depicted in the coats-of-arms can predict the social and environmental metrics of Brazilian municipalities. To account for the co-influences between response variables, we also included in the model the co-interrelationship between (i) HDI, POV, HPD, and NCR; (ii) NCR and GLN. In presenting our results, we calculated standardized path coefficients and the R^2 of each response variable based on the proportion of explained predictor variance (Kamata & Bauer 2008, Shipley 2009). We performed the SEM analysis using the *lavaan* R package (Rosseel 2012) within the R 3.5.3 platform (R Core Team 2020).

RESULTS

Timeline and overall trends

Brazilian municipal counties were created between 1531 and 2017, with a boom in the 1950s (Fig. 2a). The geographic distribution of these counties is clearly disproportionate, as most of them are distributed in heavily populated Brazilian states in the Atlantic Forest and Caatinga biomes (Fig. 2). For instance, there are 2,775 counties across the Atlantic Forest (total area = 1,180,287 km^2; 2.35 counties per 1000 km^2) and 1,082 in the Caatinga biome (823,094 km^2; 1.31 per 1000 km^2). On the other hand, the Pantanal (153,884 km^2; 0.10), Pampa (162,450 km^2; 0.68), Cerrado (1,986,473 km^2; 0.55), and the Amazon biomes (4,206,177 km^2; 0.12) collectively encompass only 1,713 counties (Fig. 2b). Human population density (HPD) across the Brazilian territory is also very skewed. The Pantanal (HPD = 9.2 ± 18.6 *sd*) and the Amazon (30.8 ± 157.8) are least populated according to the 2010 population census, or way below the national average (114.5 persons/km^2). In contrast, counties across the Atlantic Forest are most heavily settled (166.7 ± 772.3 persons/km^2).

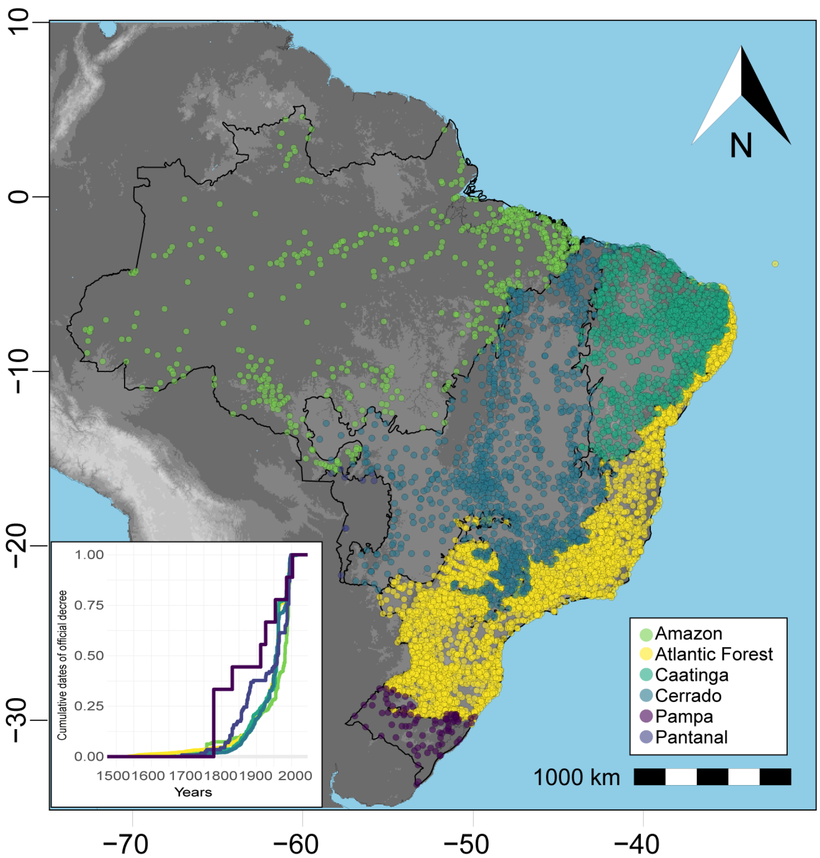

Figure 2. Spatial distribution of the 5,570 municipal-counties and cumulative dates of official decree (lower frame) since 1500 across the six major Brazilian biomes. Circles represent municipal counties colour-coded by biome. Black lines represent biome boundaries. The background (in grayscale) represents the elevation profile (obtained from NASA's ASTER Project, available at https://asterweb.jpl.nasa.gov/gdem.asp). The same colours are used in panels to highlight different biomes.

We classified and computed pictorial elements contained in 5,197 (93.3%) of the 5,570 Brazilian municipal coats-of-arms. For the remaining 373 counties, we were unable to find coat-of-arms images, or they were in extremely low resolution (i.e. unreadable), rendering symbology classification unfeasible. Readable coats-of-arms yielded 15,273 symbols representing 197 distinct pictorial elements (Table SI). Agricultural cultivars (e.g. maze, coffee, wheat, sugarcane, cotton, soybean) and livestock (e.g. bovine cattle) were represented in 43.7% of all symbols. In contrast, most depictions of wild fauna (vertebrates and invertebrates) appeared only once (Table SI). When symbols were grouped into categories, agriculture represented 48.6% of all occurrences, followed by natural resource extraction (30.5%), livestock (13.2%), native vertebrates (5.3%), ethnocultural elements (2.1%), and native invertebrates (0.4%).

Through the timeline reconstructed for each biome, we observed a long history of praising non-native elements of the countryside (i.e. cropland and livestock) since the 1650s. Starting in the 1530s, municipalities across the Atlantic Forest biome were the first to extol elements of frontier conquest such as agriculture, livestock, and natural resource extraction including gold and gemstone mining (Fig. 3). Surprisingly, municipalities in the Pantanal, the Brazilian biome most heavily occupied by livestock, only started depicting cattle ranching by the 1920s. Additionally, icons of native ethnic groups and invertebrates are conspicuously missing from municipal coats-of-arms in this biome (Fig. 3). Although vertebrate wildlife icons begin to appear in all-biomes coats-of-arms alongside those of other symbol groupings (e.g., agriculture), the degree to which they are depicted is very low (5.3%), six-fold less frequently than natural

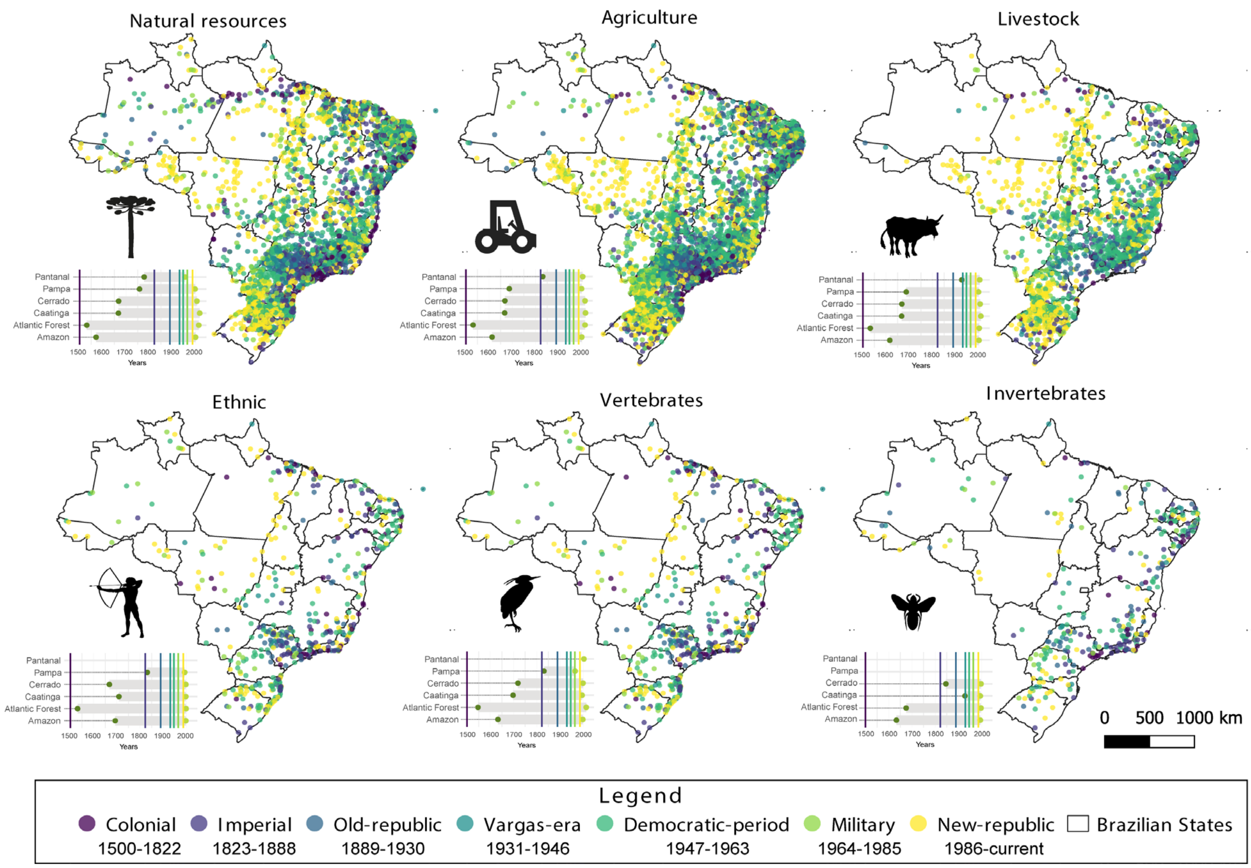

Figure 3. Timeline of the six mutually exclusive groupings of symbols depicted in Brazilian municipal coats-of-arms. Circles represent municipalities, and are colour-coded according to their years of creation (i.e. municipal decree) within the most widely accepted periods of Brazilian postcolonial history.

resources (30.5%) (See details in Table SI). The cumulative timeline of emerging symbology was very disproportionate. While natural resources, agriculture and livestock amounted to14,086 items, native ethnic groups, vertebrates and invertebrates icons accounted for only 916 items (15.4-fold fewer) (Fig. 4). Moreover, distance to Brazil's East Coast in relation to the municipal-county decree of creation reveal a highly clumped pattern, with the relatively recent emancipation (in the last 100-200 years) of the vast majority of counties far from the East Coast (Fig. 4).

Network metrics and predictive models

Considering all biomes combined over all historical periods, we detected a wide variation in network topology and their respective metrics. Overall, network connectance was high (C = 0.82) and modularity was low (M = 0.07). Further, modularity was lower than that predicted by null distributions (M_{null} = 0.13; $p < 0.001$). The overall network was highly nested (Nestedness = 68.8), contrary to the pattern of modularity, mainly due to the high concentration of agricultural cultivars, natural resources, and livestock symbols (Fig. 5a), although the value did not diverge significantly from the null distribution (N_{null} = 67.7; $p = 0.24$). However, when biomes are considered separately, we observed a wide variation in network metrics. Following their rapid administrative emancipation, municipal counties in the Atlantic Forest, Caatinga and Cerrado biomes were strongly associated with agriculture in the democratic-period (1947

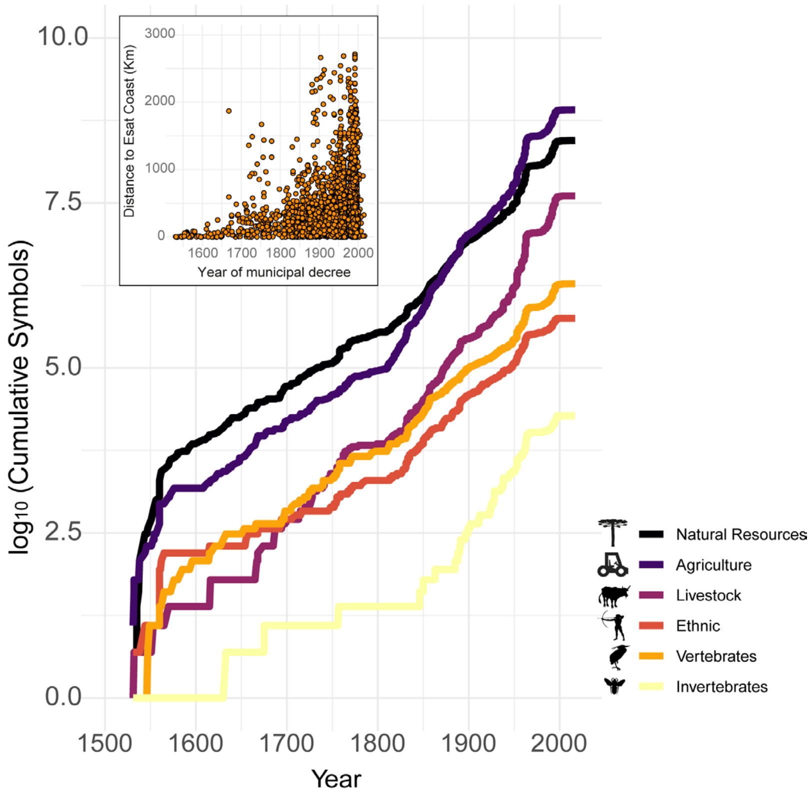

Figure 4. Cumulative symbology (log_{10}-scaled) emerging from Brazilian municipal coats-of-arms since the European conquest in the 1500s. In the upper frame, the distance (km) to Brazil's East Coast in relation to the municipal-level political emancipation (i.e. decree of municipal creation).

– 1963). In contrast, local districts in Amazonia, the Pampa, and Pantanal biomes did not show marked references to agricultural elements until after the end of the military dictatorship (i.e. since 1986). Connectance across all biome networks was high (typically > 0.90) (Fig. 5b). The biome showing the highest modularity value was the Pantanal (M = 0.40; $p < 0.01$). Nestedness also was highly variable, ranging from 0.0 (Atlantic Forest) to 72.2 (Pampa), and all nestedness values were lower than expected by chance, except for the Pampa grasslands.

Structural equation models showed that contemporary human density (HDI) and poverty (POV) values of Brazilian counties can be predicted by the historical ecology exhibited in their coats-of-arms (Fig. 6). An increase in the representation of livestock and wild vertebrate symbols indicate a slight decrease in HDI [-0.02; p = 0.04; -0.02; $p < 0.01$]. Similarly, a decrease in POV was indicated by an increase in agricultural symbols [-0.12; $p < 0.01$], while POV had a strong negative influence on HDI [-0.87; $p < 0.01$]. We also observed that remaining native vegetation cover (NCR) was positively related to extractive industries based on natural resources [0.16; $p < 0.01$], but negatively related to cropland agriculture [-0.20; $p < 0.01$]. As expected, native vegetation cover and human population density were negatively related [-0.09; $p < 0.01$] (Fig. 6). In summary, the pictorial history of municipal counties could explain 76%, 10%, and 3% of the variance in their modern human population density, degree of environmental intactness, and a measure of per capita wealth, respectively (Fig. 6; see all SEM estimates in Table SII).

DISCUSSION

Since the dawn of 18th century modern science, a growing interest in understanding human-environment relationships has been shared by several academic disciplines, including theoretical and applied ecology (Szabó 2015).

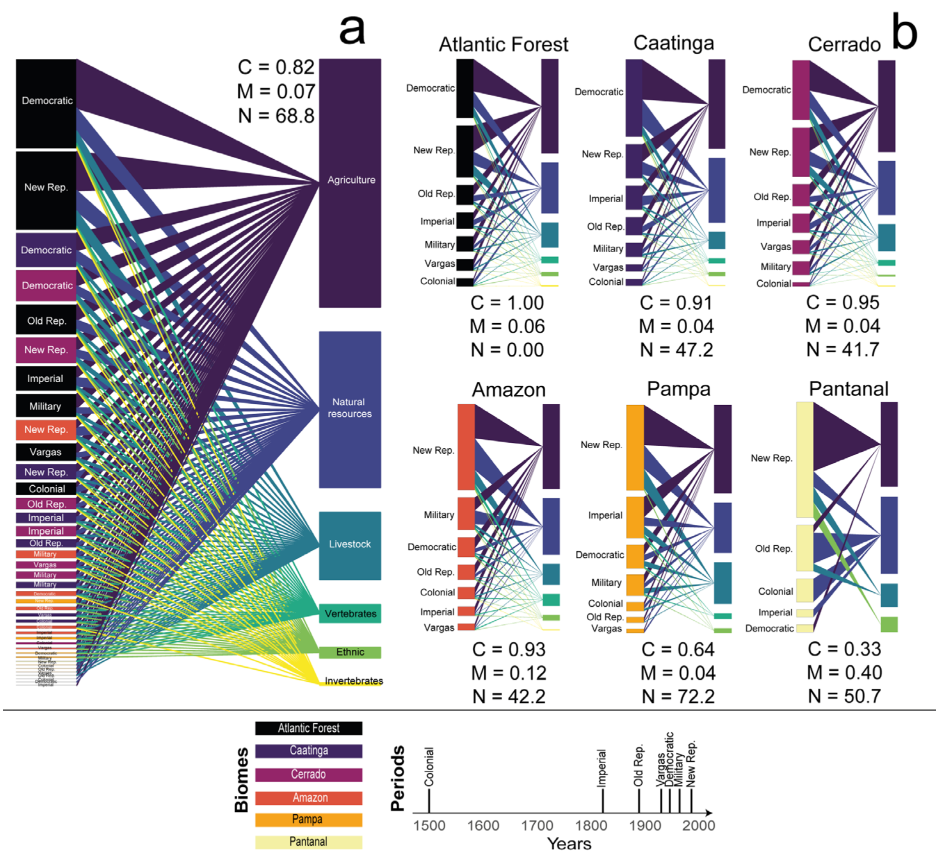

Figure 5. Results of network analysis between historical periods and symbol groupings considering all municipal level coat-of-arms considered here. (a) Bipartite network between biome-historical-period and cropland agriculture, extractive resource use, livestock, ethnic, vertebrate, and invertebrate symbol groups. (b) Same approach as A but considering each biome-historical-period separately. Network elements in a and b are colour-coded according to biomes in the left, and symbol groups in the right, respectively. C: connectance; M: modularity; N: nestedness.

Our findings demonstrate a clear human-environment linkages in postcolonial Brazilian history that are strongly emphasized by a settlement mentality dominated by frontier conquest of the hinterlands, including agricultural expansion at the expense of natural ecosystems. Brazil's land use trajectories have been profoundly impacted by the Brazilwood, sugarcane, coffee, mining, and rubber exploitation cycles, and more recently by modern mechanized agriculture and industrialization. All these events culminated in still ongoing high deforestation rates and the decimation of Brazilian ethnic groups (McNeill 1986). Accordingly, our county-level results showed that Brazil continues to celebrate environmental devastation, while largely overlooking the intrinsic and economic value of its natural heritage. Furthermore, the elements of this development paradigm were strong predictors of modern land use change that was also co-related with social inequality right across the Brazilian territory.

In particular, our results showed that cropland and grazeland agriculture, and natural resource use represented the vast majority (92.2%) of heraldic elements in municipal coats-of-arms. In contrast, wild vertebrates (5.3%), ethnic elements (2.1%), and invertebrates (0.4%) were rarely depicted, and increasingly rarefied along the historical timeline. These were also absent in individual biomes, such as the Pantanal wetlands and the Pampa grasslands, if we exclude the transitional location of municipal counties straddling those biomes. Similar results were observed in an earlier study concerning the avifauna representation in Brazilian municipal coats-of-arms. This study showed that bird species were explicitly depicted only a few times, appearing in only

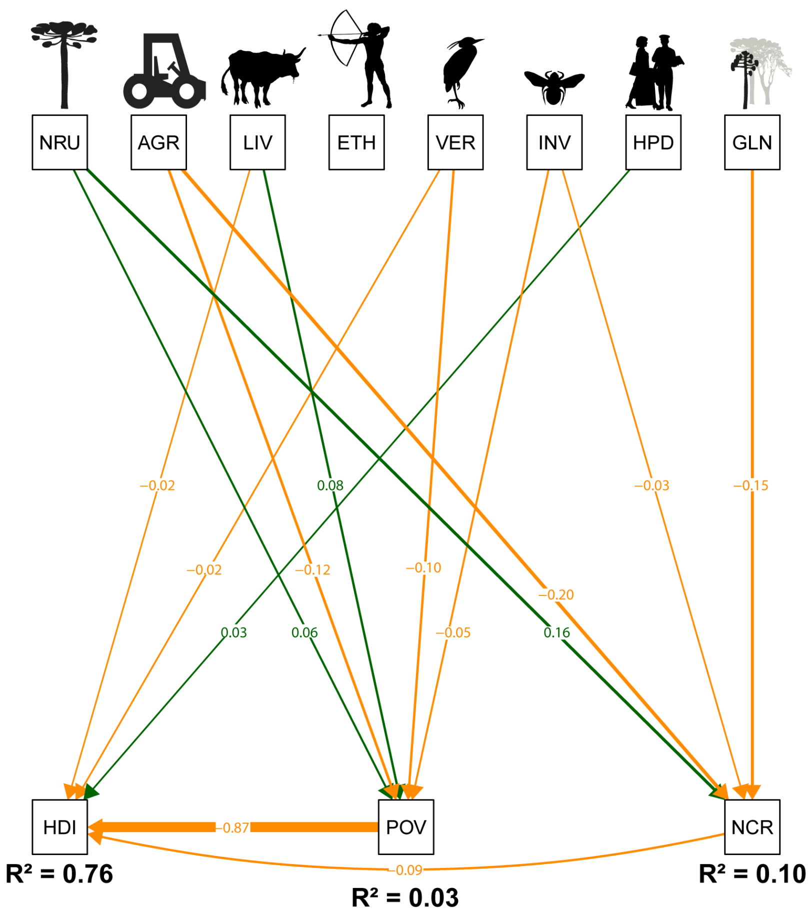

Figure 6. Structured Equation Model (SEM) used to predict socioenvironmental variables (human development index [HDI], poverty [POV], and the remaining native vegetation cover [NCR]) based on symbol groupings present in municipal coats-of-arms and other socioenvironmental co-variables. Acronyms of predictive variables are: NRU – natural resource use; AGR – agriculture; LIV – livestock; ETH – ethnic elements; VER – vertebrates; INV – invertebrates; HPD – human population density; and GLN – gain or loss of native vegetation cover from 1985 to 2018. Only significant ($p < 0.05$) SEM pathways are depicted. Variables associated with uninformative pathways were removed for better visualization. Positive and negative effects are highlighted in green and orange, respectively.

5.1% of the emblems (Canto 2018). In absolute values, we recorded only 806 symbols depicting wild vertebrates across the 5,197 coats-of-arms examined here (15.5%), representing at least 79 distinct species. This value is trivial considering the species richness of Brazil's known vertebrate fauna (> 8,200 species), and their value in terms of endemic species, endemism centers, and biodiversity hotspots (Myers et al. 2000). In contrast, this analysis yielded 2,013 pictorial symbols of all domesticated vertebrate species combined as shown by 1,727 coat-of-arms, amounting to a 33.3% incidence rate. Brazil is now the world's largest bovine beef exporter and pictorial references to bovine cattle alone appeared 1,595 times (30.7%). This harks back to notions that the Brazilian interior hinterlands were colonized under the hooves of cattle (Medrado 2018). Moreover, our results show that there were two notable events in the 1900s: (1) agriculture overcame natural resources in terms of local representation across Brazil; and (2) municipal counties far away from the east coastline began to be rapidly created. A total of 92.8% (N = 4,822) of municipal counties carry some historical brand of territorial conquest (i.e. natural resources, agriculture and/or livestock), whereas only 17.6% (N = 916) depict some allusion to ethnic and/or biodiversity icons.

The discrepancy found in the prevailing record of development "progress" (i.e., key crops, animal husbandry, and natural resource extraction), rather than elements of the natural capital (e.g., natural monuments, native plants, vertebrates and invertebrates) was reflected in the observed high nestedness values

(68.8%). This pattern reveals that an increase in the creation and emancipation of new municipalities — mainly since the Old-Republic era — was followed by rapid development of often predatory environmental exploitation that culminated in accelerated rates of habitat change. Icons of agriculture were particularly enshrined since the Military and New-Republic era (37.8% of all symbols from 1964 to 2018). Since 1964, road building, cattle ranching and cropland expansion have massively encroached upon Amazonian forests (specifically in the states of Rondônia, Mato Grosso, and Pará), in contrast to more sustainable patterns of natural resource use which still dominate nontimber extractive livelihoods along Amazonian rivers. On the other hand, and according to our expectations, wild vertebrate symbols showed two peaks spanning the historical periods: (i) during the Colonial and Imperial eras (from 1500 to 1889; 30.8% of the total); and (ii) reappearing only a century later, during the New-Republic era (from 1986 to 2018; 11.7% of the total).

These discrepant patterns are consistent with modern rates of biodiversity declines, particularly in the most degraded biomes, such as the Atlantic Forest and the semi-arid dry forest and thorn shrublands of the Caatinga (Leal et al. 2005). These highly threatened biomes were the cradle of 15th-century Portuguese settlement from hereditary captaincies and other early forms of colonial land distribution, leading to highly modified anthropogenic landscapes (Fausto 1994, Dean 1996). Importantly, we note that although the onset of municipal emancipation may not reflect the exact trigger of land exploitation, coats-of-arms apparently reveal a "nostalgic past", and represent an important tool in rescuing otherwise poorly documented subregional environmental histories. For example, although the largest extant South American felid — the Jaguar (*Panthera onca*) — has been locally extirpated in a vast proportion of its original range (Sanderson et al. 2002, Paviolo et al. 2016), some counties created after the modern range contraction of this species still portrays this felid in their coat-of-arms. We observed a similar pattern for the one of the largest South American forest ungulates — the Tapir (*Tapirus terrestris*) —, which is depicted in counties of central Rio Grande do Sul, where this species has been virtually extinct for nearly a century. Among four counties that depicted tapirs in this region, three were emancipated from larger counties in the 1980-1990s, long after this "ghost" species had been driven to extinction at a regional scale. Furthermore, at a national scale, large vertebrates like the jaguar and tapir were illustrated in only 21 and 11 of all coats-of-arms, respectively. A similar pattern occurs with representations of indigenous peoples. Although we identified 304 symbols of native Brazilians, 50.5% of them are portrayed in coats-of-arms of counties created since the 1950s, and located in mesoregions where these indigenous groups are now only a pale shadow of their former past, due to hundreds of years of persecution and territorial encroachment.

Throughout the 20th century, the pace of anthropogenic simplification of natural ecosystems rapidly increased in most of Brazil's hinterlands, led by deliberate geopolitical thinking in successive administrations to redistribute agrarian strongholds (Dean 1996, Leal & Câmara 2003). Domesticated ungulates, including cattle and goats, had already profoundly altered Brazilian savannah and dry forest landscapes. Agricultural land use rapidly expanded far into previously savannah and forest wildlands, particularly after the 1960 relocation of the national capital to Brasília (McNeill 1986). In Southern Brazil, a marked selective logging cycle primarily based on Araucaria timber exploration had been established from the 1920s to the 1990s (McNeill 1986, Lacerda, 2016). For instance, the Itapiranga county coat-of-arms (located on the Uruguay River bank in Santa Catarina) displays a clear reference to the locally known as "*Balseiros do Uruguay*". This period is characterized by a rapacious logging industry stimulated by the former "*Instituto Nacional do Pinho*" government agency, which virtually decimated the Araucaria forests across the Southern interior plateaus. This pattern is shared across 15% of all counties in southern states. As another example, the Ipumirim county (Santa Catarina) rapidly converted all of its transitional evergreen and semi-deciduous forest areas into fast-growing exotic tree monoculture (*Pinus* spp. and *Eucalyptus* spp.), dominating the local economy.

Although almost the entire Brazilian Amazon remained an inaccessible roadless wilderness until 1971, this biome has since succumbed to a history of rampant deforestation, illegal logging, goldmining, and more recently anthropogenic wildfires, all of which facilitated by haphazard infrastructure expansion. More sustainable nontimber extractive industries, including natural rubber and Brazilnut harvesting, have been gradually replaced by cattle pasture and cropland expansion (Serrão et al. 1996, Peres 2003). Freshwater fisheries and, more recently, soybean monoculture are well represented in Amazonian coats-of-arms. However, other less visible lingering economic activities are also illustrated, such as the animal skin trade (e.g. Parintins, state of Amazonas). The wildlife skin trade increased in the early 20th century and accelerated in the 1960s (Smith 1976), and still survives today as an illegal harvest associated with the wild meat trade (Fa et al. 2002, Antunes et al. 2016). This trade was encouraged by the Brazilian Government during the Military Dictatorship, with an estimated annual kill of at least 15,000 jaguars and 80,000 ocelots during the 1960s and 1970s (Smith 1976).

Although the two-decade Brazilian Military Dictatorship is sometimes referred to as an "economic miracle" (de Barros & Graham 1978), our results corroborate the notion that this period had a huge impact on development, most of which cannot be described as sustainable (Grinberg 2008, Pinho 2020). Our network analysis shows that this period was not as prominent in terms of national progress compared to the Democratic and the New Republic, which occurred before and after Military Dictatorship, respectively. Important connections with natural resource use and agriculture occurred during this period in the Amazon, followed by a development model that has since led to massive deforestation and ethnic genocide (Albert 1992). It is worth noting that deforestation rates across the Amazon have risen steeply since the onset of the Bolsonaro administration (INPE 2020), which revived the geopolitical ideology of the Military Dictatorship (Garcia 2019).

Our high connectance and high nestedness network results shows that: (i) in terms of connectance, for each region and political period, at least one municipal county prioritized each symbol grouping, but (ii) in terms of nestedness, those icons were extremely concentrated into natural resources extraction and agriculture, including key crops and livestock species. Conversely, the low modularity values show that this pattern is homogeneous across the country and throughout its postcolonial history. These recurrent paradigms of territorial conquest and development progress did not solve the profound social and environmental problems that has beset the country to date. Our predictive models show that local natural resource use and agricultural expansion has been coupled with natural vegetation loss, but growing poverty at the household scale. In turn, vegetation loss had a negative effect on human development index (HDI) which was strongly correlated with poverty. Suppression, conversion and degradation of natural vegetation reached its highest levels in densely populated biomes such as Atlantic Forest and the Caatinga. However, despite five centuries of European settlement, coupled with industrial scale timber extraction and agriculture in the Atlantic Forest, there is growing evidence that increasingly larger secondary forest areas have recovered in the last two decades (Lira et al. 2012, Joly et al. 2014, Rezende et al. 2018).

On the other hand, Amazonian forests now appear to be following the same historical trajectory of the Atlantic Forest in the 17th – 20th century. Contemporary rates of forest loss in both fringe and central areas of the Brazilian Amazon have increased due to both legal and illegal deforestation, land grabbing and recurrent wildfires, which initially burn as ground (or surface) fires but eventually reach tree crowns, with wholesale shifts in the structure of the ecosystem (Barlow & Peres 2004, 2008). This represents a reedition of the old-fashioned military development paradigm at the expense of pristine environments. These practices lead to an overwhelming decline in the baseline natural capital and ecosystem services, on which future cleaner development will depend (Moreno-Mateos et al. 2020). The Cerrado, Caatinga and Pampa have also witnessed a sharp increase in biodiversity erosion caused by human activities and not least habitat loss to agriculture (Klink & Machado 2005, Leal et al. 2005, Roesch et al. 2009). These activities figure prominently in municipal coats-of-arms of these biomes.

Across the Pantanal wetlands, human occupation by European colonists dates back to the early 16th century (1530s), with the settlement of very large (>200,000 hectares) cattle ranches throughout the region (Wilcox 2017). Even though the first municipal counties (e.g. Corumbá, Ladário, Cáceres, Miranda) were created in the 1770s, livestock-related coats-of-arm symbology only appeared in the 20th century. Due to the annual flood pulse, which inundates as much as 80% of the Pantanal for up to six months every year (Gonçalves et al. 2011), the very few county headquarters in the region are restricted to fringe upland areas. It follows that the Pantanal is still considered the most preserved Brazilian biome, even though it is almost completely within private landholdings (Zimmermann et al. 2005). However, most threats to the Pantanal and its wildlife are related to more predatory land use practices in neighbouring regions, such as the highlands of the Upper Paraguay River Basin. This area is mainly comprised of the Cerrado wooded scrublands, which has been heavily converted into mechanized agriculture since the 1960s (Harris et al. 2005, Projeto MapBiomas 2020). These threats are reflected in the frequent depiction of agricultural symbols in their coats-of-arms, especially during the New Republic period. During this period, the federal government begun to provide transformational fiscal incentives for the establishment of modern agriculture in central-western Brazil (Silva et al. 1998). It is worth noting that, ecotourism and wildlife safaris are currently important alternative sources of revenue in the Pantanal, rivalling or exceeding the income from cattle ranching (Tortato et al. 2017), yet this biodiversity value is seldom depicted.

Natural habitat conversion accounts for most biodiversity loss globally (Maxwell et al. 2016). Our results provide a punctuated profile of the historical conversion of natural forest, wooded savannah, and grassland areas into cropland and cattle pastures, particularly as new political districts were created farther west. About one-third of all coats-of-arms examined here had symbols depicting bovine cattle, and

80% displayed at least one cultivar typical of each region, including a total of 7,416 incidences of agricultural crops, as shown in 3,954 coat-of arms (76.1%). These elements are present in most of the Atlantic Forest (88.7%) and Cerrado (85.8%), but are also common (>30%) in other biomes. In contrast, the presence of native fauna and flora in coats-of-arms is extremely rare. Our results reinforce that, despite the skewed selectivity of pictorial information portrayed in coats-of-arms, this overall picture realistically reflects the single-minded utilitarian philosophy in shaping the history of territorial expansion and conquest of the largest tropical country. This symbology portfolio has been a severely underutilized tool in understanding the dynamic nature of natural resource and land use over time in any New World country. This territorial conquest marched forward blindfolded and eroded both local biotas and traditional ecological knowledge of local indigenous societies, both of which were largely brushed aside, while bringing with it the same set of domesticated species that uniformly pave the way to every western civilization. Our results also show that both past and contemporary Brazilian society has failed to appreciate the natural history value of this megadiverse country. Instead, worldviews of early colonists taming the land under the plow, axe, and cattle hooves were transfixed in short-term economics based on alien land-use practices that paid little or no regard to the potential value and grandeur of newly occupied territories. Most symbolic representations thus culturally celebrate the conquest of natural ecosystems, rather than natural assets *per se* and the original indigenous inhabitants, and indeed alternative sources of more sustainable income (e.g. extractivism, ecotourism).

Culture is a trait of human societies. Each society, group, or community may construct their own culture. This is often dynamic, changing through time and space due to several factors such as contact with other groups or the observation of new phenomena. Culture is based on the ability to symbolize and attribute meanings, so that each society builds and passes on throughout its history a world subject to movement and alteration (Concone 2011). Cultural issues change over time and, therefore, symbols are linked to the moment of interest. For example, an animal may be very abundant in an area or in the local folklore, but over time the population abundance may decline and the original reason is lost, but that symbology can still be maintained by tradition. Hence, symbols are important representations for a given group and may be related to different realities and moments (Concone 2011). Coat-of-arms are created by legal decrees (Berg 2015), our results reveals that this symbology historically reflects individual interests of political leaders (or a small interest groups) at the expense of broader collective interests.

It took almost three centuries — since the first Brazilian coin (the *pataca*) was forged in 1695 — to break tradition with a reverence of public figures typically linked to the aristocracy and slavery, and depict some flagship icons of Neotropical biodiversity. A series of *Cruzeiro* coins released in the 1990s began depicting some vertebrate species (e.g., manatee, hummingbird, marine turtle, angelfish), likely because of the first major UN Conference on Environment and Development, held in Rio de Janeiro in 1992. Subsequently, Brazilian currencies, including the *Cruzeiro-Real* (1993-1994) and *Real* (1994-present), showcased native wildlife, and *Real* banknotes in circulation today have displayed native species representing Brazilian biodiversity, such as the hawksbill sea turtle, great egret, red-and-green macaw, golden lion tamarin, jaguar, grouper and maned wolf. Although these initiatives may be unhelpful in curbing biodiversity loss, Brazilian society now acknowledges at least some elements of the native fauna. This is noteworthy since knowledge is but the first step in overcoming any conservation challenge. Few political districts across the vast Brazilian territory were branded with a legacy of any element of native biodiversity, and when this is the case they usually depict species that had already been long extirpated. This apparent oblivion for the national natural heritage represents a mean area of 24,087 km^2 where over 2.75 million Brazilian citizens currently live. In doing so, Brazil has historically failed to perpetuate a natural history storyline to future generations of the world's largest tropical country. Yet, this forlorn story of territorial, biotic and ethnocultural conquest continues to this very day with an inexorable "march of progress" that so predictably homogenizes and impoverishes our wildlands.

Acknowledgments

We thank the two anonymous reviewers for their valuable suggestions on our manuscript. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
JAB was supported by the São Paulo Research Foundation (FAPESP; grants 2018-05970-1 and 2019-11901-5). JAB is was supported by Conselho Nacional de Pesquisa e Desenvolvimento Científico e Tecnológico (CNPq) postdoctoral fellowship (grant 150261/2023-3). HVBC has a scholarship granted by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) – Brazil. VCR was supported by a studentship granted by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001). KMPMBF is funded by research grant (308632/2018-4 and 303940/2021-2) from the Conselho Nacional de Pesquisa e Desenvolvimento Científico e Tecnológico (CNPq). We thank anthropologist Maria Helena Villas Boas Concone for important insights on Brazilian culture.

REFERENCES

ALBERT B. 1992. Indian Lands, Environmental Policy and Military Geopolitics in the Development of the Brazilian Amazon: The Case of the Yanomami. Dev Change 23(1): 35-70. https://doi.org/10.1111/j.1467-7660.1992.tb00438.x.

ALEXIADES MN. 2003. Ethonobotany in the Third Millenium: expectations and unresolved issues. Delpinoa 45: 15-28.

ALMEIDA-NETO M, GUIMARÃES P, GUIMARÃES JR PR, LOYOLA RD & ULRICH WA. 2008. Consistent metric for nestedness analysis in ecological systems: reconciling concept and measurement. Oikos 117: 1227-1239.

ANTUNES AP, FEWSTER RM, VENTICINQUE EM, PERES CA, LEVI FR & SHEPARD GH. 2016. Empty forest or empty rivers? A century of commercial hunting in Amazonia. Sci Adv 2: 1-15.

BARLOW J & PERES CA. 2004. Ecological responses to El Niño-induced surface fires in central Brazilian Amazonia: management implications for flammable tropical forests. Philos Trans R Soc Lond B Biol Sci 359(1443): 367-380. https://doi.org/10.1098/rstb.2003.1423.

BARLOW J & PERES CA. 2008. Fire-mediated dieback and compositional cascade in an Amazonian forest. Philos Trans R Soc Lond B Biol Sci 363(1498): 1787-1794. https://doi.org/10.1098/rstb.2007.0013.

BASCOMPTE J, JORDANO P, MELIÁN CJ & OLESEN JM. 2003. The nested assembly of plant - animal mutualistic networks. Proc Natl Acad Sci 100(16): 9383-9387. http://doi.org/10.1073/pnas.1633576100.

BEGHIN N. 2008. Notes on Inequality and Poverty in Brazil: Current Situation and Challenges. From Poverty to Power: How Active Citizens and Effective States Can Change the World, Oxfam International.

BEGOTTI RA & PERES CA. 2020. Rapidly escalating threats to the biodiversity and ethnocultural capital of Brazilian Indigenous Lands. Land Use Policy 96: 104694.

BERG TJ. 2009. Território, cultura e regionalismo: aspectos geográficos em símbolos estaduais. Master Thesis, Universidade Estadual Paulista. (Unpublished).

BERG TJ. 2015. Geografia e Heráldica: lendo a representação da paisagem nos brasões de armas dos estados brasileiros. Geografia Ensino e Pesquisa 19: 123-133.

BIRD RB, BIRD WD, CODDING BF, PARKER CH & JONES JH. 2008. The "fire stick farming" hypothesis: Australian Aboriginal foraging strategies, biodiversity, and anthropogenic fire mosaics. Proc Natl Acad Sci 105(39): 14796-14801.

BOCCALETTI S, LATORA V, MORENO Y, CHAVEZ M & HWANG DU. 2006. Complex networks: Structure and dynamics. Physics Reports 424: 175-308.

BURNS EB. 1993. A History of Brazil. 3rd Edition. Columbia University Press.

CANALE GR, PERES CA, GUIDORIZZI CE, GATTO CAF & KIERULFF MCM. 2012. Pervasive defaunation of forest remnants in a tropical biodiversity hotspot. PLoS ONE 7: e41671.

CANTO JBM. 2018. Representação da avifauna nos brasões, bandeiras e hinos dos estados e de municípios brasileiros. Atualidades Ornitológicas 202, 67-81.

CASCUDO LC. 1956. Geografia do Brasil holandês. Rio de Janeiro: Editora José Olympio e Instituto Nacional do Livro.

CAVALCANTI RB & JOLY CA. 2002. Biodiversity and conservation priorities in the Cerrado region. In: Oliveira PS & Marquis RJ (Eds), The Cerrados of Brazil: Ecology and Natural History of a Neotropical Savanna. Columbia University Press, p. 69-88.

CINTRA JP. 2013. Reconstruindo o mapa das capitanias hereditárias. Anais do Museu Paulista: História e Cultura Material 21(2): 11-45.

CLEMENT CR & JUNQUEIRA AB. 2010. Between a pristine myth and an impoverished future. Biotropica 42: 534-536.

CONCONE MHVB. 2011. A noção de Cultura. Revista Kairós Gerontologia 14(4): 51-66.

DA SILVA JMC, BARBOSA LCF, LEAL IR & TABARELLI M. 2017. The Caatinga: understanding the challenges. In: Da Silva JMC, Leal IR & Tabarelli M (Eds), Caatinga: The Largest Tropical Dry Forest Region in South America. Springer International Publishing, p. 3-19.

DE BARROS JRM & GRAHAM DH. 1978. The Brazilian economic miracle revisited: private and public sector initiative in a market economy. Latin American Research Review 13(2): 5-38. http://www.jstor.org/stable/2502516.

DEAN W. 1996. With Broadax and Firebrand: The Destruction of the Brazilian Atlantic Forest. University of California Press, California.

DORMANN CF, GRUBER B & FRUEND J. 2008. Introducing the bipartite Package: Analysing Ecological Networks. R News 8(2): 8-11.

FA JE, PERES CA & MEEUWIG JJ. 2002. Bushmeat Exploitation in Tropical Forests: an Intercontinental Comparison. Conserv Biol 16(1): 232-237.

FAUSTO B. 1994. História do Brasil, 1st ed. Edusp, São Paulo.

FONSECA CR, ANTONGIOVANNI M, MATSUMOTO M, BERNARD E & VENTICINQUE EM. 2017. Conservation Opportunities in the Caatinga. In Da Silva JMC, Leal IR & Tabarelli M (Eds), Caatinga: The Largest Tropical Dry Forest Region in South America. Springer International Publishing, p. 429-443.

FOX-DAVIES AC. 2012. A Complete Guide to Heraldry. EBook #41617, ISO-8859-1.

GARCIA A. 2019. Brazil under Bolsonaro: social base, agenda and perspectives. J Global Faultiness 6(1): 62-69. https://doi.org/10.13169/jglobfaul.6.1.0062.

GOEBEL T, WATERS MR & O'ROURKE DH. 2008. The late Pleistocene dispersal of modern humans in the Americas. Science 319(5869): 1497-1502.

GOÉS C & KARPOWICK I. 2017. Inequality in Brazil: A Regional Perspective. IMF Working Paper, International Monetary Fund, WP/17/225.

GONÇALVES HC, MERCANTE MA & SANTOS ET. 2011. Hydrological cycle. Braz J Biol 71(1): 241-253. https://doi.org/10.1590/S1519-69842011000200003.

GRACE JB. 2006. Structural equation modeling and natural systems. Cambridge University Press, New York.

GRINBERG N. 2008. From the "Miracle" to the "Lost Decade": intersectoral transfers and external credit in the Brazilian economy. Braz J Political Econ 28(2): 291-311. https://doi.org/10.1590/S0101-31572008000200007.

HARRIS MB, TOMAS WM, MOURÃO G, SILVA CJ, GUIMARÃES E, SONODA E & FACHIM E. 2005. Safeguarding the Pantanal wetlands: threats and conservation initiatives. Conserv Biol 19: 714-720. https://doi.org/10.1111/j.1523-1739.2005.00708.x.

IBGE. 2016. Estimativas populacionais para os municípios e para as Unidades da Federação brasileiros 2016. Available at: https://www.ibge.gov.br/. Accessed: 18 March 2020.

INPE - INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS. 2020. Monitoramento do Desmatamento da Floresta Amazônica Brasileira por Satélite Available at: http://wwwobtinpebr/OBT/assuntos/programas/amazonia/prodes Access: 28 November 2020.

JOLY C, METZGER JP & TABARELLI M. 2014. Experiences from the Brazilian Atlantic Forest: ecological findings and conservation initiatives. New Phytologist 204: 459-473. https://doi.org/10.1111/nph.12989.

KAMATA A & BAUER DJA. 2008. Note on the Relation between Factor Analytic and Item Response Theory Models. Structural Equation Modeling: A Multidisciplinary Journal 15(1): 136-153.

KLINK CA & MOREIRA AG. 2002. Past and current human occupation, and land use. In Oliveira PS & Marquis RJ (Eds), The Cerrados of Brazil: Ecology and Natural History of a Neotropical Savanna. Columbia University Press, p. 69-88.

KLINK CA & MACHADO RB. 2005. Conservation of the Brazilian Cerrado. Conserv Biol 19(3): 707-713. https://doi.org/10.1111/j.1523-1739.2005.00702.x.

LACERDA AEB. 2016. Conservation strategies for Araucaria Forests in Southern Brazil: assessing current and alternative approaches. Biotropica 48(4), 537-544. https://doi.org/10.1111/btp.12317.

LAHAYEA C ET AL. 2013. Human occupation in South America by 20,000 BC: the Toca da Tira Peia site, Piauí, Brazil. J Archaeol Sci 40: 2840-2847.

LEAL CG & CÂMARA IG. 2003. The Atlantic Forest of South America: biodiversity status, threats, and outlook, 1st ed., Island Press, Washington.

LEAL IR, SILVA JMC, TABARELLI M & LACHER T. 2005. Changing the Course of biodiversity Conservation in the Caatinga of Northeastern Brazil. Conserv Biol 19(3): 701-706. https://doi.org/10.1111/j.1523-1739.2005.00703.x.

LIRA PK, TAMBOSI LR, EWERS RM & METZGER JP. 2012. Land-use and land-cover change in Atlantic Forest landscapes. Forest Ecol Manag 278: 80-89. https://doi.org/10.1016/j.foreco.2012.05.008.

MANN CC. 2006. 1491: New Revelations of the Americas before Columbus. Vintage Books.

MAXWELL SL, FULLER RA, BROOKS TM & WATSON JEM. 2016. Biodiversity: The ravages of guns, nets and bulldozers. Nature 536: 143-145. https://doi.org/10.1038/536143a.

MCNEILL JR. 1986. Agriculture, Forests, and Ecological History: Brazil, 1500-1984. Environ Rev 10(2): 122-133. https://doi.org/10.2307/3984562.

MEDRADO J. 2018. The Indian zebu in Brazilian lands. Revista de Agricultura e História Rural 75, 115-138. https://doi.org/10.26882/histagrar.075e05m.

MITTERMEIER RA, MITTERMEIER CG, GIL PR & WILSON EO. 1997. Megadiversity: Earth's Biologically Wealthiest Nations. CEMEX.

MORENO-MATEOS D, ALBERDI A, MORRIËN E, VAN DER PUTTEN WH, RODRÍGUEZ-UÑA A & MONTOYA D. 2020. The long-term restoration of ecosystem complexity. Nature Ecol Evol 4(5): 676-685. https://doi.org/10.1038/s41559-020-1154-1.

MOURA MR & JETZ W. 2021. Shortfalls and opportunities in terrestrial vertebrate species discovery. Nature Ecol Evol 5: 631-639.

MULLER B & MULLER C. 2014. The Economics of the Brazilian Model of Agricultural Development. International Research Initiative on Brazil and Africa. International Research Initiative on Brazil and Africa (IRIBA). School of Environment, Education and Development. University of Manchester.

MYERS N, MITTERMEIER RA, MITTERMEIER CG, FONSECA GAB & KENT J. 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853-858. https://doi.org/10.1038/35002501.

NAVARRO AB ET AL. 2021. Isotopic niches of tropical birds reduced by anthropogenic impacts: a 100-year perspective. Oikos 130(11): 1892-1904. 10.1111/oik.08386.

NEWMAN MEJ. 2004. Analysis of weighted networks. Phys Rev E-Statist, Nonlin Soft Matter Phys 70(52): 1-9.

OLIVEIRA U ET AL. 2017. Biodiversity conservation gaps in the Brazilian protected areas. Sci Rep 7: 9141, doi: 10.1038/s41598-017-08707-2.

PAVIOLO A ET AL. 2016. A biodiversity hotspot losing its top predator: The challenge of jaguar conservation in the Atlantic Forest of South America. Sci Rep 6, 37147. https://doi.org/10.1038/srep37147.

PERES CA ET AL. 2003. Demographic threats to the sustainability of Brazil nut exploitation. Science 302(5653): 2112-4. doi: 10.1126/science.1091698.

PINHO CES. 2020. The responses of the authoritarian national developmentalism to the structural economic crisis (1973-1985). Braz J Politic Econ 40(2): 411-431. https://doi.org/10.1590/0101-31572020-3020.

PNUD - BRAZILIAN ATLAS OF HUMAN DEVELOPMENT. 2013. Ranking IDH Municípios. Available at: http://www.atlasbrasil.org.br/2013/en. Accessed: 08 April 2020.

POLASKI S, FERREIRA-FILHO JBS, BERG J, MCDONALD S, THIERFELDER K, WILLENBOCKEL D & ZEPEDA E. 2009 Brazil in the Global Economy: Measuring the gains from trade. Carnegie Endowment, PNUD.

PROJETO MAPBIOMAS. 2020. Coleção 2018 da Série Anual de Mapas de Cobertura e Uso de Solo do Brasil. Available at: https://mapbiomas.org/estatisticas?cama_set_language=pt-BR. Accessed: 09 April 2020.

R CORE TEAM. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. Available at https://www.R-project.org/.

REIS MS, LADIO A & PERONI N. 2014. Landscapes with Araucaria in South America: Evidence for a cultural dimension. Ecol Soc 19(2): 43.

REYES-GARCIA V, RUIZ-MALEN I, PORTER-BOLAND L, GARCIA-FRAPOLLI E, ELLIS EA, MENDEZ ME, PRITCHARD DJ & SANCHEZ-GONZALEZ MC. 2013. Local Understandings of Conservation in Southeastern Mexico and Their Implications for Community-Based Conservation as an Alternative Paradigm. Conserv Biol 27(4): 856-865.

REZENDE CL, SCARANO FR, ASSAD ED, JOLY CA, METZGER JP, STRASSBURG BBN, TABARELLI M, FONSECA GAB & MITTERMEIER RA. 2018. From hotspot to hopespot: An opportunity for the Brazilian Atlantic Forest. Perspect Ecol Conserv 16: 208-214. https://doi.org/10.1016/j.pecon.2018.10.002.

ROESCH LFW, VIEIRA FCB, PEREIRA VA, SCHÜNEMANN AL, TEIXEIRA IF, SENNA AJT & STEFENON VM. 2009. The Brazilian Pampa: a fragile biome. Diversity 1(2), 182-198. https://doi.org/10.3390/d1020182.

ROSSEEL Y. 2012. lavaan: An R Package for Structural Equation Modeling. J Stat Soft 48(2): 1-36.

SANDERSON ES, JAITEH M, LEVY MA, REDFORD KH, WANNEBO AV & WOOLMER G. 2002. The Human Footprint and the Last of the Wild. BioScience 52(10): 891-904.

SAUNDERS NJ. 1998. Icons of Power: Feline Symbolism in the Americas. London: Routledge.

SERRÃO EAS, NEPSTAD D & WALKER R. 1996. Upland agricultural and forestry development in the Amazon: sustainability, criticality and resilience. Ecol Econ 18(1): 3-13. https://doi.org/10.1016/0921-8009(95)00092-5.

SHIPLEY B. 2009. Confirmatory path analysis in a generalized multilevel context. Ecology 90: 363-368.

SILVA JSV, ABDON MM, SILVA MP & ROMERO HR. 1998. Levantamento do desmatamento no Pantanal brasileiro até 1990/91. Pesq Agropec Bras 33: 1739-1745.

SMITH NJH. 1976. Spotted Cats and the Amazon Skin Trade. Oryx 13(4): 362-371. https://doi.org/10.1017/S0030605300014095.

SOARES-FILHO B, RAJÃO R, MACEDO M, CARNEIRO A, COSTA W, COE W, RODRGIUES H & ALENCAR A. 2014. Cracking Brazil's Forest Code. Science 344: 363-364.

STEFFEN W, BROADGATE W, DEUTSCH L, GAFFNEY O & LUDWIG C. 2015. The trajectory of the Anthropocene: The Great Acceleration. The Anthrop Rev2(1): 81-98.

SZABÓ P. 2015. Historical ecology: past, present and future. Biol Rev 90: 997-1014. https://doi.org/10.1111/brv.12141.

TORTATO FR, IZZO TJ, HOOGESTEIJN R & PERES CA. 2017. The numbers of the beast: Valuation of jaguar (*Panthera onca*) tourism and cattle depredation in the Brazilian Pantanal. Glob Ecol Conserv11: 106-114. http://dx.doi.org/10.1016/j.gecco.2017.05.003

TRITSCH I & LE TOURNEAU FM. 2016. Population densities and deforestation in the Brazilian Amazon: new insights on the current human settlement patterns. Appl Geog 76: 163-172.

WILCOX RW. 2017. Cattle in the Backlands: Mato Grosso and the evolution of ranching in the Brazilian tropics, first ed. University of Texas Press. Austin, Texas.

ZIMMERMANN A, WALPOLE MJ & LEADER-WILLIAMS N. 2005. Cattle ranchers' attitudes to conflicts with jaguar *Panthera onca* in the Pantanal of Brazil. Oryx 39: 406-412. https://doi.org/10.1017/S0030605305000992.

SUPPLEMENTARY MATERIAL

Table SI-SII.

How to cite

BOGONI JA, CONCONE HVB, CARVALHO-ROCHA V, FERRAZ KMPMB & PERES CA. 2023. The historical ecology of the world's largest tropical country uniquely chronicled by its municipal coat-of-arms symbology. An Acad Bras Cienc 95: e20220746. DOI 10.1590/0001-3765202320220746.

Manuscript received on September 2, 2022;
accepted for publication on August 2, 2023

JULIANO A. BOGONI[1,2,3,4]
https://orcid.org/0000-0002-8541-0556

HENRIQUE VILLAS BOAS CONCONE[2,7,8]
https://orcid.org/0000-0003-3832-1347

VÍTOR CARVALHO-ROCHA[3,5]
https://orcid.org/0000-0002-4747-1219

KATIA M.P.M.B. FERRAZ[2]
https://orcid.org/0000-0002-7870-8696

CARLOS A. PERES[3,5,6]
https://orcid.org/0000-0002-1588-8765

[1]Universidade Federal de Mato Grosso do Sul, Departamento de Ecologia, Instituto de Biociências, Cidade Universitária, Av. Costa e Silva s/n, Pioneiros, 79070-900 Campo Grande, MS, Brazil

[2]Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz", Laboratório de Ecologia, Manejo e Conservação de Fauna Silvestre (LEMaC), Av. Pádua Dias, 11, Agronomia, 13418-900 Piracicaba, SP, Brazil

[3]School of Environmental Sciences, University of East Anglia, Norwich, NR4 7TJ, UK

[4]Universidade do Estado de Mato Grosso, Centro de Pesquisa de Limnologia, Biodiversidade e Etnobiologia do Pantanal; Programa de Pós-Graduação em Ciências Ambientais, Laboratório de Mastozoologia, Cidade Universitária, Av. Santos Dumont, s/n, 78200-000 Cáceres, MT, Brazil

[5]Universidade Federal de Santa Catarina, Programa de Pós-Graduação em Ecologia, Campus Universitário Reitor João David Ferreira Lima, s/n, Trindade, 88040-900 Florianópolis, SC, Brazil

[6]Instituto Juruá, R. Ajuricaba, 359, Aleixo, 69083-020 Manaus, AM, Brazil

[7]Universidade de São Paulo, Programa de Pós-Graduação Interunidades em Ecologia Aplicada, Escola Superior de Agricultura "Luiz de Queiroz" (ESALQ) e Centro de Energia Nuclear na Agricultura (CENA), Av. Pádua Dias 11, Agronomia, 13418-900 Piracicaba, SP, Brazil

[8]Instituto Pró-Carnívoros, Av. Horácio Netto 1030, Chácaras Interlagos, 12945-010 Atibaia, SP, Brazil

Correspondence to: **Juliano André Bogoni**
E-mail: bogoni.ja@gmail.com

Author Contributions

JAB: conceptualization, data acquisition, data analysis and figures, writing & revising the original draft; HVBC: data acquisition, review and editing; VC-R: data acquisition, review and editing; KMPMBF: review and editing; CAP: review and editing.