



Consumption and Preferences for Wild and Domestic Meat in Indigenous Communities in the Brazilian Atlantic Forest

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Wild animals have traditionally been the main sources of protein available, if not the only, to numerous indigenous populations worldwide. However, greater access to markets, reduced availability or access to wildlife, and policies in support of agricultural development, have shifted food habits toward domestic and industrial sources of protein. In this study, we evaluated consumption patterns and preferences/avoidances for wild animals (wildmeat, crustaceans, and fish) in comparison to domestic sources of protein among the Potiguara living on the Brazilian coast. Using data from 843 semi-structured interviews applied to students from 28 indigenous villages, we found that domestic meats were more consumed and preferred as compared to wild animals (aquatic and game animals), despite the high abundance of fish and crustacean resources in the surveyed area. Consumption and preference for game were higher among male students while avoidance was higher among female students. The avoidance of domestic meats and fish was low for both genders. The occupation of the fathers affected students' food habits, in those nature-related occupations (farmer, fisherman/woman, sugarcane worker) conditioned greater consumption of wildmeat and fish, while non-nature related occupations lead to greater consumption of protein from domestic sources. The consumption of protein from all sources increased with the distance between villages and a protected area. Our results indicate that the younger generation of Potiguaras does not regularly consume wildmeat and fish and their preference for domestic sources of protein is shaped by the socio-environmental context, access to different types of meat, and taste preferences.

Keywords: wildlife, game, fish, domestic protein, diet, ethnozoology, nutrition, protect area

INTRODUCTION

The use of wild animals for food is a millennial practice across diverse cultures (Alves et al., 2018; Anderson, 2020; Braga-Pereira et al., 2021a) and continues to contribute to diet diversification around the world (Hanazaki et al., 2009; Powell et al., 2015; Alves and van Vliet, 2018; Donders and Barriocanal, 2020; Oliveira et al., 2022). Wild animals harvested to meet nutritional needs include numerous taxa, but vertebrates make the bulk of the animals sought after for their meat, fat, bones, and eggs (Bodmer et al., 1997). Between 230 and 833 million people rely on wild meat (the meat from wild mammals, reptiles, amphibians, and birds) as a source of protein (Nielsen et al., 2018). Insects, mollusks, crustacea, and fish are also sought after as a source of protein, particularly in coastal or riverine ecosystems (Vallega, 2013). In Brazil, for example, shellfish catching is a common extractive activity concentrated close to estuaries (Nishida et al., 2006, 2008) and land crabs (*Brachyura* crabs) represent one of the major groups in terms of economic relevance in mangrove ecosystems (Alves and Nishida, 2002, 2003; Alves et al., 2005; Nishida et al., 2006; Nordi et al., 2009; Capistrano and Lopes, 2012; Nascimento et al., 2012, 2016, 2017). The traditional knowledge of indigenous people across the globe has played a key role in identifying living organisms that are endowed with nutritional and medicinal values important for humans. These traditional human societies have accumulated a vast store of knowledge about animals through the centuries, and this zoological knowledge is an important part of our human cultural heritage (Kendie et al., 2018; Braga-Pereira et al., 2021b).

Nowadays, while indigenous communities continue to represent this legacy through the continuation of practices that involve the use of wild animals for food, several factors linked to globalization, such as access to markets, migration, urbanization, and changes in lifestyles, have induced the rapid replacement of wild animals (van Vliet et al., 2014; Donders and Barriocanal, 2020; Leyva-Trinidad et al., 2021) to the advantage of domestic and industrial sources of protein, often incentivized by the market and governmental programs (Sarti et al., 2015; Bellinger and Andrade, 2016). For example, in the Bolivian Amazon, the Tsimané's diet is characterized by an increase in market foods (in particular pasta, refined sugar, salt, and oil) and a decreased consumption of game (Kraft et al., 2018). Chicken and eggs are now the most frequently consumed source of protein among Ticuna, Cocama, and Yagua children in Puerto Nariño, Colombia, far beyond fish and game (van Vliet et al., 2015a). Recent studies in Brazil suggest that particularly in the North-Eastern region contemporary Indigenous diets are lacking in quality, and are characterized by a high prevalence of purchased foods (Welch et al., 2021).

While most of the recent literature looking at nutritional transitions in South America has focused on the Amazon region (Coimbra and Santos, 1991; Santos and Coimbra, 2003; Tavares et al., 2003; Lourenço et al., 2008; Welch et al., 2009; Nardoto et al., 2011; van Vliet et al., 2015a; Donders and Barriocanal, 2020) and the Andes (Walrod et al., 2018; Chee et al., 2019), less is known about the changes observed in nutritional patterns in the Atlantic forest biome. This forest represents the second-largest

rainforest of the American continent. Being home to 30% of the Brazilian indigenous lands (ISA, 2021), but also coincides with the most urbanized areas of Brazil (Tabarelli et al., 2005). Even though it has been largely destroyed, the Atlantic forest biome is still home to more than 8,000 endemic species of vascular plants, amphibians, reptiles, birds, and mammals (Myers et al., 2000) and includes several key formations such as mangroves, restingas (coastal forest and scrub on sandy soils), high-elevation grassland (campo rupestre), and brejos (humid forests resulting from orographic rainfall in otherwise semidesert scrub in the northeast of Brazil) (Câmara, 2003).

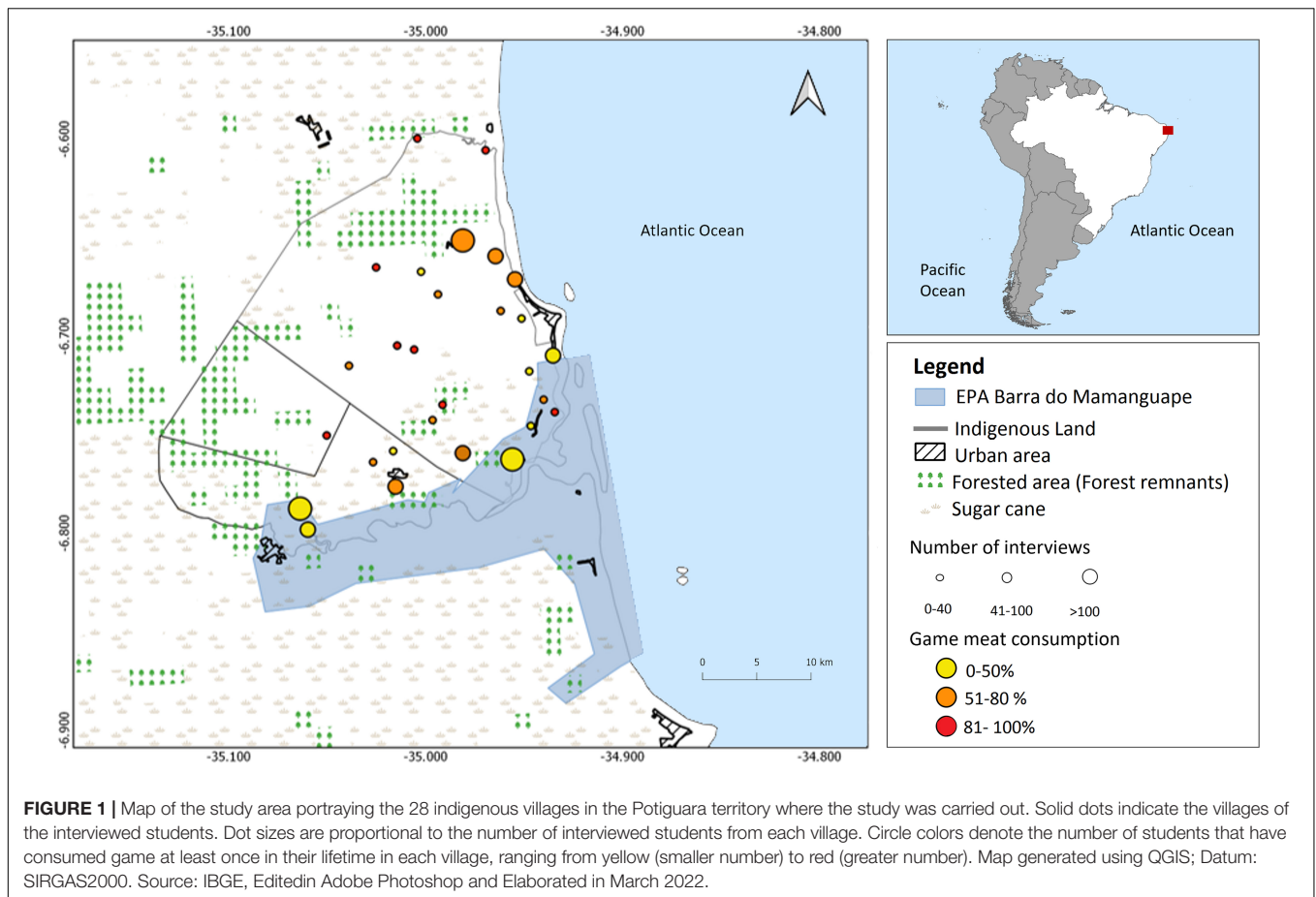
In the current study, we investigated the consumption of wild animals and domesticated animals among the Potiguara living in the Atlantic Forest. The Potiguara have traditionally based their livelihoods on the use of marine wild animals (such as shellfish, crabs, and fish) and terrestrial wild vertebrates as main sources of food (Rocha et al., 2008). Based on semi-structured interviews conducted among Potiguara teenagers, we assessed the frequencies of consumption of wild and domesticated animals and preferences or aversion for different animal species. We analyzed the influence of gender, socio-economic background of the household, and access to market and natural resources as predictors for consumption and preference behaviors.

METHODS

Study Area and the Potiguara Indigenous

The research was carried out in indigenous schools of the Potiguara Indigenous Land (Potiguara IL) (33,757 ha). The Potiguara IL is in the Atlantic Forest biome and spreads over three municipalities, Baía da Traição, Marcação and Rio Tinto, in the State of Paraíba, Brazil (Figure 1). It was demarcated in 1983, homologated in 1991, and its population is divided among 32 villages. The Potiguara IL partially overlaps with two designated protected areas, the Area of Relevant Ecological Interest Manguezais da Foz do Rio Mamanguape and the Environmental Protection Area Barra do Rio Mamanguape (EPA BRM) (Rodrigues et al., 2008). This region includes the Mamanguape River estuary which harbors *ca.* 6,000 ha of reasonably preserved mangrove ecosystem, the largest of its kind in the State of Paraíba. The mangrove forest at Mamanguape is typically well preserved although certain sites show signs of anthropogenic disturbance. Main land use types in the Potiguara IL are sugar cane fields (*ca.* 10,000 ha), crops and pastures (*ca.* 5,100 ha), fallows and *carrasco* (*ca.* 4,800 ha), (a shrubby phytophysiology typical of North-eastern Brazil) gardens and small-scale farmings (about 1,300 ha), forest remnants and open arboreal savanna, named "Tabuleiro" (*ca.* 8,400 ha) (Cardoso and Guimarães, 2012).

The mangrove is an economically profitable environment for the Potiguara. It is where fish, crustaceans, and mollusks are obtained, and a space upon which many of the inhabitants of the area depend for a living (Nishida et al., 2008; Rocha et al., 2008). Fishermen and women have a very keen knowledge of the mangrove and are hence able to locate aquatic animals and develop efficient techniques for capturing them (Nishida et al.,



2006; Rocha et al., 2012). Part of the fish is consumed or given to kinspeople and neighbors with whom one is on friendly terms, and part is sold in the village or the local market when the catch is bigger (Araújo, 2019).

During the eighteenth century, deforestation for sugar cane plantations transformed the physical scenery and the social and technical relations among the Potiguaras. The expropriation of lands and the expansion of sugar cane cultivation led to widespread discontent, requiring the Potiguaras to seek the demarcation of their lands as early as the 1980s. Intense deforestation did not simply result in the drastic reduction of animal and vegetal populations (both in individual numbers and in variety); the phenomenon also caused significant modifications in hydrography. With the mills, sugarcane stretched into the productive space of the Potiguara, ravaging existing areas of vegetation and restricting agricultural and fishing activities (Araújo, 2015).

As of 1993, the use of wild resources by the Potiguara was further restricted by the creation of the EPA BRM, which was created primarily to protect manatee (*Trichechus manatus*) and other aquatic species (Federal decree No. 924, 10 September 1993). Currently, fisheries (fishes, crustaceans, and mollusks), aquaculture (shrimp farming), and agriculture (crops and ranching) are regulated inside the EPA BRM (Mourão and Nordi, 2003; Araujo and Nishida, 2007; Rodrigues et al.,

2008; Cardoso and Guimarães, 2012; Nascimento et al., 2016). Over time, conflicts have arisen between distinct modalities of management or access to and use of resources, and by the socially unequal display of the environmental damages and risks caused by industrial endeavors during the historical process. It is precisely against the conditions imposed by dominant policies that the Potiguara seek to impose their power, to access and control the resources present in their territory—through the household ecology, where they build domanial spaces and define mobilities (Araújo, 2019).

The villages are scattered throughout the indigenous territory, connected by unpaved roads and a paved road that connects them to the nearest urban centers of the Mamanguape, Baía da Traição, Rio Tinto, and Marcação cities in less than 30 min drive. In these neighboring towns, industrialized foods of animal and vegetable origin are readily available in the supermarkets (Cardoso and Guimarães, 2012). In the villages themselves, there are small grocery stores that also supply industrialized products, meat from domestic animals, and processed meats.

Ethics Statement

This research was authorized by the Brazilian Agency for Indigenous Affairs (FUNAI) (No. 94/AAEP/PRES/2017) and indigenous leaders in compliance with CNS Resolution No. 304 of 2000. The research project was approved by the Research

Ethics Committee and the National Research Ethics Commission (CEP/CONEP) number CAAE 7695941790008069, following Resolution No. 466/2012 of the National Health Council (CNS) of the Ministry of Health (no. 2,491,305). Authorizations to conduct the research in schools and free and informed consent forms were obtained from school principals, teachers, legal age students (18 plus), and parents or legal guardians in the case of underage students. The research process was thoroughly explained before each classroom and the interviewees were assured that their identities would not be disclosed. Still, some students refused to participate in the study, as well as 1 of the 10 Potiguara IL schools within the educational levels targeted by the study.

Data Collection

We conducted data collection between February and August 2018 in nine public schools (State and municipally managed, 8 and 1, respectively) of the Potiguara IL, located in the municipalities of Baía da Traição (three schools), Rio Tinto (two schools) and Marcação (four schools). These schools were attended by students from 28 indigenous villages, seven of which are located inside the EPA BRM. Before the study, a pilot was carried out with 83 random students from three schools to verify if students understood the proposed questions and to verify the need for adjustments in the questionnaire. Subsequently, visits were made to all public schools ($n = 10$) within the Potiguara IL to explain the research goals and to request authorization from the schools' directors to carry out the research.

Nine schools granted us the authorization requested. Out of the 84 classrooms present in those 9 schools, we used a sub-sample of 64 classrooms (about 7 classrooms per school) trying to cover different school levels. For the elementary school, we covered an average of 1.4 classrooms per scholar level ($SD = 0.11$) and for high school, we covered an average of 1.14 classrooms per scholar level ($SD = 0.13$). Authorization from the teacher was also requested before applying the questionnaire to the students.

Questionnaires were applied individually to 843 students out of 1,850 (45.6%) enrolled in Potiguara IL public schools. Interviewed students were 55% ($n = 463$) female and 45% male ($n = 380$), aged 10 to 73 years old (94.4% between 10 and 20 years, 4.1% between 21 and 30, and 1.5% between 31 and 73) and attending Middle and high school. Interviewees lived in villages located inside or outside the EPA BRM (321 and 522 students, respectively). To reduce any risks of potential bias in responses, due to the restrictions of hunting within the PA, the objectives of this study were framed around nutrition and food security, not around conservation or environmental education. The teachers in each classroom, who are trusted and respected by the students, were in charge of explaining the research goals to the class and reading out loud a consent form guaranteeing the confidentiality of the student's identity in the classroom. Moreover, the teacher explained that the children should not feel any shame or reservations to share their nutritional preferences and habits and that no judgment would be made on their choices, which would remain anonymous. In each classroom, a researcher distributed the questionnaires among the students and, after the classroom

teacher read the questionnaire aloud, we asked the students to answer the questions. A researcher and a teacher in each classroom clarified possible doubts of the students about the questions. The questionnaire was divided into the following sections:

- (1) Social information: The first section of the questionnaire inquired about the socioeconomic background of the respondent's household, such as the student's parents' occupation, age, and gender.
- (2) Meat consumption: The students were asked to list the type of animals they consumed, the frequency of consumption, and the last time they had consumed that animal. As a follow-up, a 24-h recall was used to assess recent consumption of animal protein (from domestic or wild origin). The 24-h recall method is a low-cost and effective tool for rapid evaluations, collecting information from several respondents in a minimum amount of time (van Vliet et al., 2014).
- (3) Meat taste preference and meat avoidance: Students were asked to select three types of preferred sources of protein-based on a multiple-choice list derived from all available sources of protein in the region. The question asked: "Among the sources of protein listed below, please list those that you like eating the most in terms of taste?" Students were also asked to freely mention animals protein that they would avoid eating if offered.

Data Compilation

The occupation of the students' fathers and mothers was independently categorized as (1) nature-related (fisher, farmer, or sugarcane plantation worker) and (2) not nature-related (service industry worker, public or private employee, business owner, merchant, unemployed or retired).

Spatial information was downloaded from the Brazilian Institute of Geography and Statistics (IBGE, 2010). The shortest distance from each village to the EPA BRM boundary was manually estimated using the Measure Distance tool in Google Earth. For villages located within the EPA, BRM distance was set to zero.

Meat protein classification: Wild animals were categorized as aquatic animals (mollusks, crustaceans, and fish) and game (terrestrial mammals, birds, reptiles, and amphibians). Species identification was determined through visits to local communities and by consulting recent ethnotaxonomic and ethnozoological studies conducted in the study region (Mourão and Nordi, 2003; Araujo et al., 2006; Feijó and Langguth, 2013; Nascimento et al., 2016). For non-wild meat, we considered the domestic source of protein (eggs, the meat of cow and pig, chicken, etc.) and processed meat (canned meat/fish, etc.).

Data Analysis

Consumption and Taste Preference for Domestic or Wild Animals

We performed a linear model to investigate the relationship between species consumed in the last 24 h and preferred species.

Effect of Social Variables on Consumption and Preference

We used generalized linear mixed models (GLMMs) to verify if social factors influenced on the:

- (1) Consumption of domestic, fish, and game meat in the day before the interview (24-h recall);
- (2) preference for these different protein sources;
- (3) consumption of game in previous weeks.

Predictor variables included: (i) distance from the students' villages in relation to the environmental protection area; (ii) students' sex; (iii) students' age; (iv) mothers' occupation, and (v) fathers' occupation. We considered the student and the student village predictor variables of random effect, while other predictor variables were considered as fixed effects. We tested and found no collinearity ($p > 0.06$) between all predictor variables.

We used residual checks to verify whether our models were, in principle, suitable or otherwise. We used the Akaike information criterion to select models of interest if ΔAIC values > 6 (ΔAIC obtain from the difference between a null and complete model AIC values) (Harrison et al., 2018). To evaluate the performance of each model we used the receiver operating characteristic (ROC) curve and its area under the curve (ROC AUC). The ROC AUC scores can vary from 0.5 (predictive ability expected by chance) to 1 (perfect predictive ability), with values higher than 0.7 indicating good predictive capabilities of the models (Swets, 1988; Stringham et al., 2021). All inferential analyses were performed in R ver. 3.5.3 (R Core Team, 2019) using packages MuMin, lme4 (Oksanen et al., 2013), and pROC (Robin et al., 2021).

Factors Related to Rejection of Domestic and Wild Species

We performed Principal Component Analysis (PCA) to find out how the causes used by students to explain rejection (feelings) were related to different species and students' gender. We interpreted the results when the first two components of the PCA (PC1 and PC2) represented at least 70% of the variation in the data.

The data matrix was transformed using the Hellinger method so that the PCA could properly represent our data. We used an Anosim permutation test *a posteriori* to verify the existence of groupings of cited species and the sex of the interviewee.

RESULTS

The interviewed Potiguara students ($n = 843$) reported consuming a variety of vertebrate and invertebrate species, both domestic and wild. Among vertebrates, the most representative group were mammals ($n = 14$ species) and fish ($n = 13$ species). Among invertebrates, there were five species of crustaceans and one of mollusk (**Supplementary Material**). A total of 51% of the students consumed game meat from 22 taxa at least once in their lifetime. Of those, 46% had consumed game meat during the year of the interview (the year 2018) and 54%

in past years. The game species consumed by most students were armadillos (Dasypodidae) ($n = 237$; 28%), capybara (*Hydrochoerus hydrochaeris*) ($n = 166$; 20%) and iguana (*Iguana iguana*) ($n = 128$; 15%).

The 24 h-recall survey yielded 40 species of animals consumed belonging to 32 genera distributed among aquatic animals ($n = 24$), game ($n = 9$), and domestic ($n = 5$) species. Despite the lower number of domestic species consumed, 70% of the 1,945 reported events of animal consumption were domestic meat sources ($n = 1,359$). From this, beef ($n = 377$; 28%) and chicken ($n = 263$; 19%) were the most consumed sources of domestic meat. Wild animals were only consumed by 40% of the respondents in the 24 h recall ($n = 586$). Of those, most had consumed aquatic animals (95%), and 5% had consumed game. Armadillos (Dasypodidae) was the game taxon consumed by most students ($n = 11$), followed by capybara ($n = 5$) (**Figure 2**).

Preference

Potiguara students cited a total of 45 taxa as preferred meat divided among aquatic wildlife (24 taxa and 12 identified species), game animals (15 taxa and 9 identified species), and six domestic species¹. However, from a total of 2,559 citations of preferred meat, the percentage of domestic sources (1,459; 57%) was significantly higher than that of wild sources (1,110; 43%) ($p = 6.932e-16$). The preferred items among domestic sources were beef ($n = 458$ citations, 31%) and processed meats ($n = 315$ citations, 28%).

Considering only wild animals, preference for aquatic animals was significantly higher than that for game ($p < 2.2e-16$) (**Table 1**). The most cited items were crustaceans ($n = 521$ citations, 46%), fish ($n = 234$, 22%) and mollusks (16%). Across all taxa, preference and consumption on the previous day were positively correlated ($p < 2.2e-16$) (**Figure 2**).

Social Factors Affecting Consumption and Preference for Different Sources of Meat

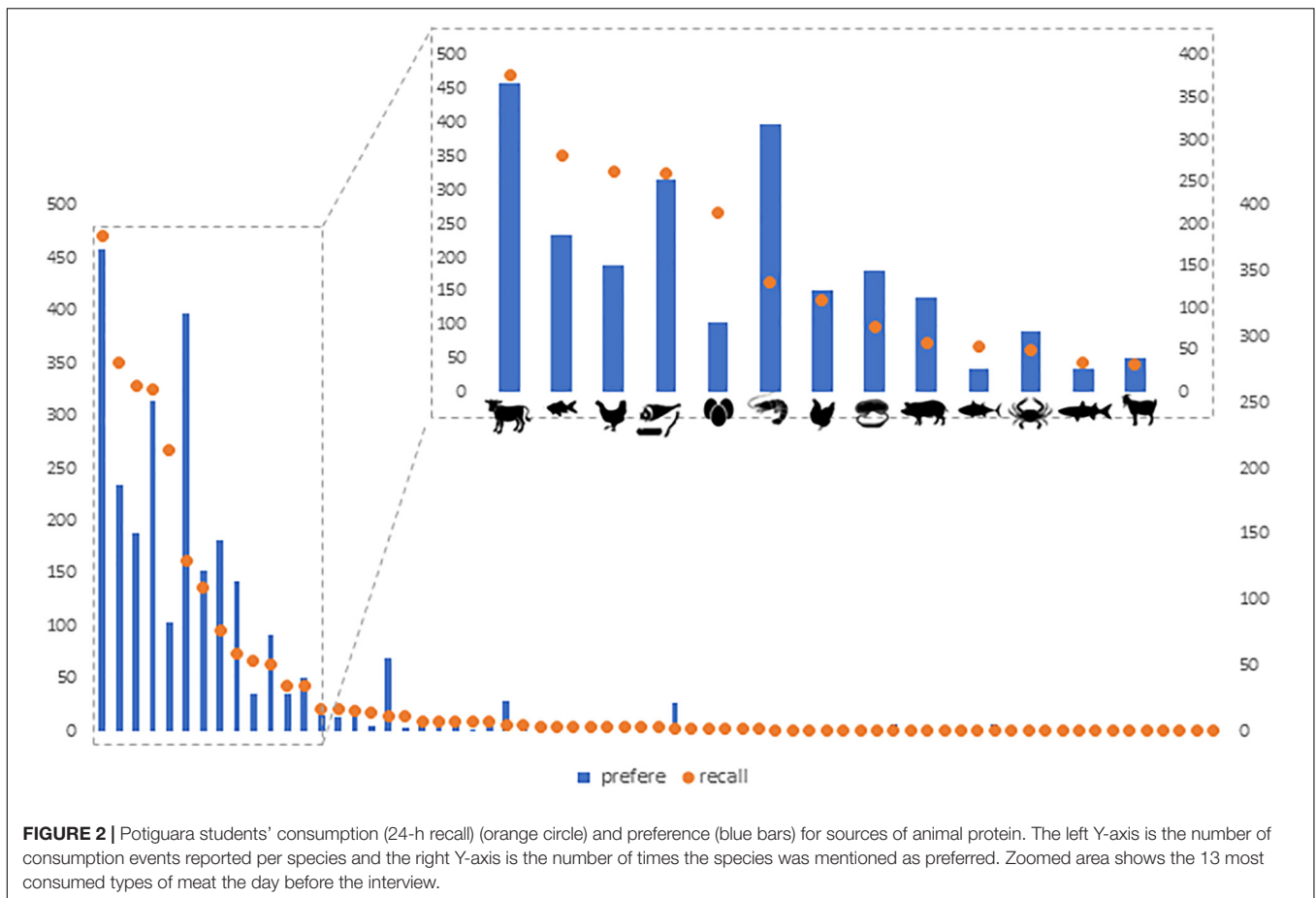
A total of 321 students in the study's cohort lived in villages within the protected area (EPA BRM) and 116 (36%) of them had consumed game at least once. The proportion of students from outside the protected area ($n = 522$) who had consumed game meat was almost double (60%, $n = 314$) that of students living inside the protected area (**Figure 1**). Our analyses show that consumption of game in previous weeks (**Figure 3A**) and preference (**Figure 3C**) increased with the distance from the protected area. The consumption of fish and domestic meat (but not the preference) also increased with the distance from the protected area (**Figures 3D,F**). We found that male students and students whose fathers are involved in nature-related work eat game more often (24 h survey and overall) and show a higher preference for it (**Figures 3A–C**). Fish consumption was higher for students whose fathers are involved in nature-related work (**Figure 3D**), while a non-significant trend indicates that students whose parents do not develop nature-related work consume more

¹<https://www.sciencedirect.com/science/article/abs/pii/S0006320710000182>

TABLE 1 | Estimates of generalized linear mixed models selected based on the Akaike Information Criterion (AIC) and the area under the curve (AUC) of the receiver operating characteristic (ROC).[†]

Response variable	Predictor variables	Estimate	Std. Error	z-value	Pr (> z)	AIC	AIC null model	ΔAIC	AUC
Game consumption	Fathers' occupation (Nature related ÷ Not nature related)	1.61E-01	7.63E-02	2.111	0.0351*	1485.4	1546.2	60.8	0.759
	Mothers' occupation (Nature related ÷ Not nature related)	8.34E-02	9.24E-02	0.902	0.3675				
	Male sex	2.78E-01	6.95E-02	3.998	7.03E-05***				
	Age	4.19E-03	7.76E-03	0.539	0.5899				
	Distance to the protected area	4.00E-05	8.44E-06	4.743	2.52E-06***				
Game recall	Fathers' occupation (Nature related ÷ Not nature related)	8.20E-01	4.91E-01	1.668	0.095695	241.96	245.2	3.2	0.692
	Mothers' occupation (Nature related ÷ Not nature related)	4.07E-01	4.54E-01	0.896	0.370381				
	Male sex	7.92E-01	4.03E-01	1.963	0.050068				
	Age	-4.06E-02	6.19E-02	-0.656	0.511943				
	Distance to the protected area	3.93E-05	4.59E-05	0.856	0.392201				
Game preference	Fathers' occupation (Nature related ÷ Not nature related)	4.70E-01	1.99E-01	2.369	0.01809*	661.64	719.64	58.0	0.704
	Mothers' occupation (Nature related ÷ Not nature related)	1.10E-01	2.20E-01	0.498	0.61897				
	Male sex	7.70E-01	1.79E-01	4.311	1.84E-05***				
	Age	-3.03E-02	2.71E-02	-1.117	0.26451				
	Distance to the protected area	7.31E-05	2.00E-05	3.65	0.00028***				
Fisheries Recall	Fathers' occupation (Nature related ÷ Not nature related)	2.41E-01	1.15E-01	2.092	0.0368*	1135.0	1165.0	30.0	0.715
	Mothers' occupation (Nature related ÷ Not nature related)	1.40E-01	1.35E-01	1.035	0.301				
	Male sex	1.01E-01	1.04E-01	0.969	0.3328				
	Age	9.04E-03	1.08E-02	0.841	0.4007				
	Distance to the protected area	3.06E-05	1.26E-05	2.424	0.0156*				
Fisheries preference	Fathers' occupation (Nature related ÷ Not nature related)	-1.79E-02	1.28E-01	-0.14	0.889	1020.4	1021.4	1.0	0.571
	Mothers' occupation (Nature related ÷ Not nature related)	5.92E-02	1.60E-01	0.371	0.711				
	Male sex	1.15E-01	1.18E-01	0.975	0.33				
	Age	8.24E-03	1.25E-02	0.661	0.509				
	Distance to the protected area	2.23E-05	1.45E-05	1.542	0.124				
Domestic recall	Fathers' occupation (Nature related ÷ Not nature related)	-5.67E-02	3.12E-02	-1.821	0.06902	1940.9	1948.1	7.2	0.695
	Mothers' occupation (Nature related ÷ Not nature related)	-3.59E-02	4.02E-02	-0.893	0.37235				
	Male sex	-1.61E-02	2.90E-02	-0.556	0.57813				
	Age	2.09E-03	3.23E-03	0.646	0.51818				
	Distance to the protected area	8.17E-06	3.63E-06	2.252	0.0246*				
Domestic preference	Fathers' occupation (Nature related ÷ Not nature related)	-2.10E-02	2.33E-02	-0.899	0.369	2001.5	2003.5	2.0	0.609
	Mothers' occupation (Nature related ÷ Not nature related)	1.19E-02	2.98E-02	0.399	0.69				
	Male sex	-2.53E-02	2.17E-02	-1.17	0.242				
	Age	-8.42E-04	2.44E-03	-0.345	0.73				
	Distance to the protected area	3.27E-06	2.72E-06	1.2	0.231				

[†]Estimate values indicate the coefficient associated with the variables listed on the left and represent how response variables values would change as a result of a one-unit variation in the predictor variables (log x). The standard errors are the average estimates of how response variables would fluctuate if the study was executed the same way, however, with new data. The Z-values indicate the level at which the explanatory variables would have a significant effect. Pr (> |z|) are listed as two-tailed p-values that correspond to the z-values following a normal distribution pattern. Significance levels are as follow: ns p > 0.05; *p ≤ 0.05; ***p ≤ 0.001.



domestic meat (**Figure 3F**). We did not find any influence of the variables analyzed on the preference for aquatic animals and domestic resources (**Figures 3E,G**).

Avoidances

Most of the students expressed rejection to some type of meat ($n = 677$; 80.3%). Among those students, 77% cited game animals ($n = 524$ students), 20% domestic animals ($n = 133$) and 3% aquatic wildlife ($n = 20$). A total of 42 taxa were mentioned, being 34 wild and 8 domestics. Taxa rejected by more students were snakes ($n = 114$) and armadillos ($n = 61$). Disgust (14%) and pity (13%) were the most common causes for rejecting different types of meat.

The PCA analysis described a total of 77% of the data variance and shows how different causes for rejection (feelings) are related to the most rejected animal species and the gender of the students (**Figure 4**). Rejection toward the meat of some species was shown to be related to people's feelings and their perception of its visual appearance. For male and female students, the feeling of pity was associated with the sloth (*Bradypus variegatus*) and the Brazilian rabbit (*Sylvilagus brasiliensis*), while certain qualities of the meat, like smell, taste, and appearance, motivated the rejection of caiman (*Caiman latirostris*). The rejection of pork and snake meat by students of both genders was strongly related to them being considered harmful if eaten.

DISCUSSION

In this paper, we assessed the dietary patterns among the Potiguara, particularly the consumption of animal-based sources of protein. Our study confirms trends observed in other parts of South America where industrial meats bypass the consumption of wild-sourced proteins among the younger generations of indigenous peoples (Murrieta and Dufour, 2004; Nardoto et al., 2011; van Vliet et al., 2015b). This transition is particularly common as urbanization progresses, domestic and industrialized sources of animal protein become readily available, and wildlife decreases as a result of habitat fragmentation and water pollution (Nardoto et al., 2011; Prist et al., 2012; van Vliet et al., 2014, van Vliet et al., 2015b,c; Vanegas et al., 2016). In this context, our study shows that young Potiguara does not consume game animals frequently and that they prefer to eat beef or industrial meats.

The higher consumption of domestic sources of animal protein outside the protected area might be associated with the dense road network and easier access to food markets from neighboring urban centers. Connection to markets via roads has been pointed out in several places as an important determinant of household food consumption (Kramer et al., 2009). This is because the roads allow access to industrialized products, thus

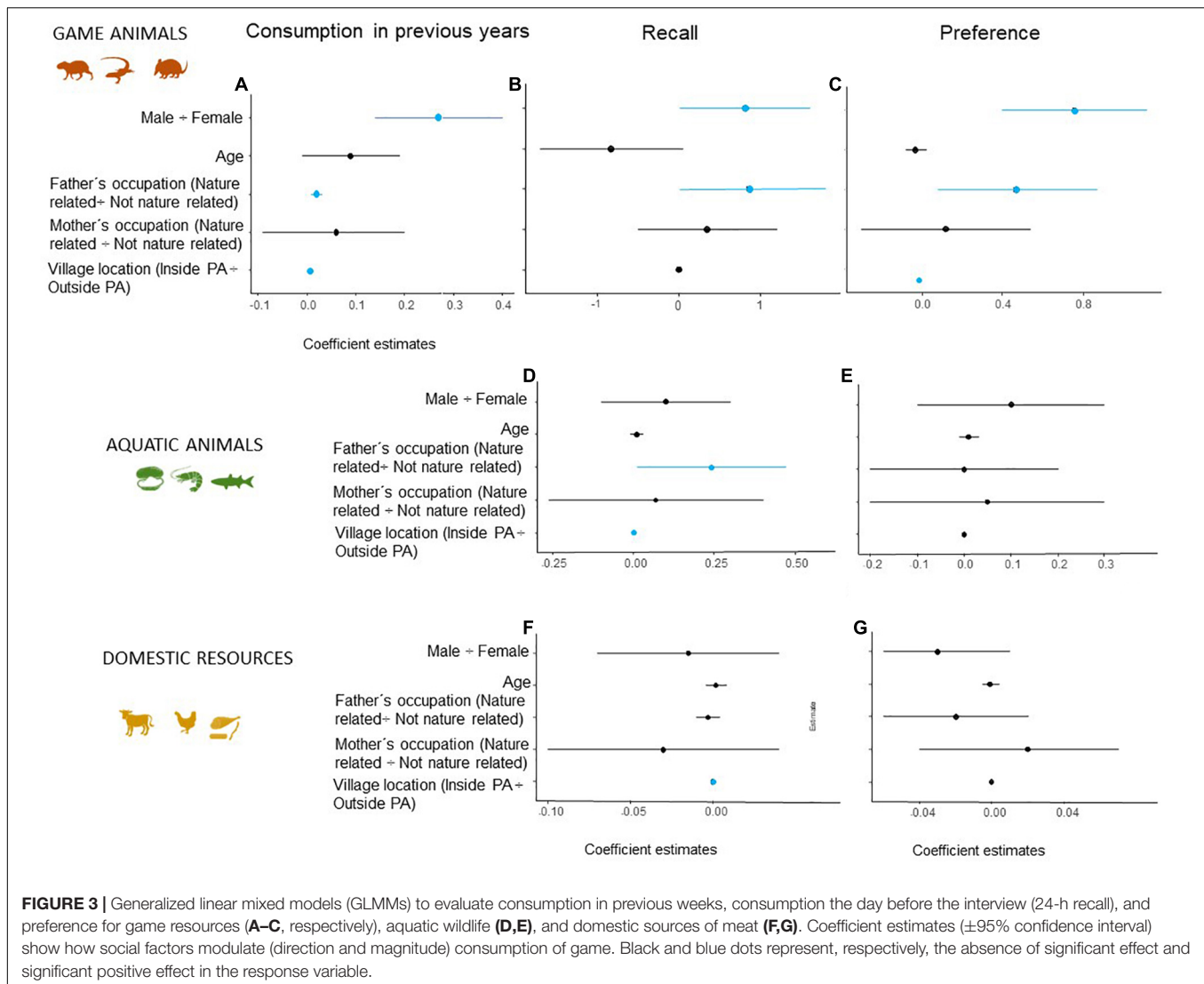


FIGURE 3 | Generalized linear mixed models (GLMMs) to evaluate consumption in previous weeks, consumption the day before the interview (24-h recall), and preference for game resources (A–C, respectively), aquatic wildlife (D,E), and domestic sources of meat (F,G). Coefficient estimates ($\pm 95\%$ confidence interval) show how social factors modulate (direction and magnitude) consumption of game. Black and blue dots represent, respectively, the absence of significant effect and significant positive effect in the response variable.

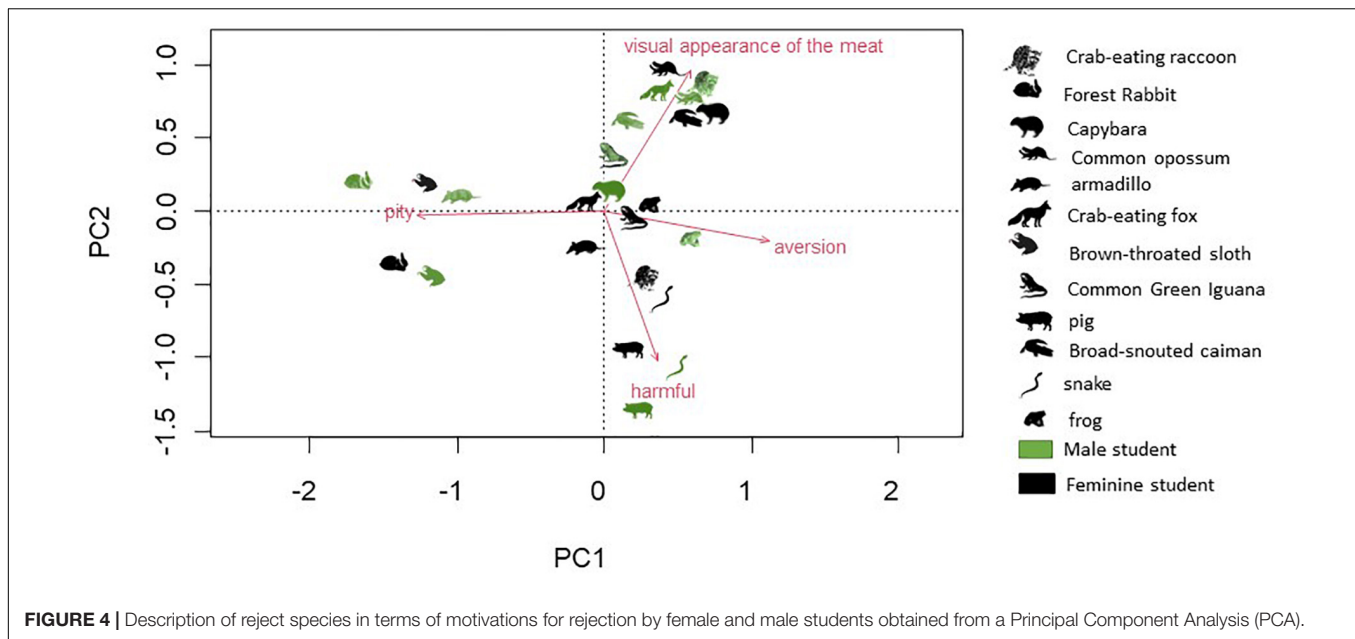
providing a diet shift from traditional to market-based foods. Conversely, the low frequency of game consumption found can probably be explained by low wildlife abundance. In our study site, the landscape is composed of small forest remnants immersed in a matrix of agricultural fields, sugarcane plantations, and shrimp farming ponds. Most villages are connected and nearby urban centers through a network of highways and dirt roads (Cardoso and Guimarães, 2012).

Wildlife abundance in the Potiguara IL has dramatically decreased since the agricultural and real estate expansion in the 1980s, a general pattern across the Atlantic Forest of Northeastern Brazil, which has led to the highest defaunation rates of terrestrial vertebrates in the country (Bogoni et al., 2018). These changes have a marked effect on the consumption of game animals in the study area.

In contrast, aquatic wildlife represents a considerable portion of the Potiguara diet, the majority of the Potiguara population depends on aquatic wildlife harvested at the Mamanguape river estuary and mangrove, especially fish and crustaceans

(Mourão and Nordi, 2003; Araujo et al., 2006; Araujo and Nishida, 2007). For instance, the third most consumed animal recorded by the 24-h recall method was crab *Ucides cordatus* which for decades has been a key source of income in the region. Other species widely available in the region are commonly consumed by the young Potiguara, such as clams, “marisco” *Anomalocardia brasiliensis*, and *Mugil curema* (e.g., mullet/tainha). Rocha et al. (2008) recorded 68 species of fish, crustaceans, and mollusks used for food or income in the estuary of the Mamanguape River, many of which were also recorded in this study (e.g., mullet/tainha *Mugil curema*, snook/camurim *Centropomus* sp.). Aquatic wildlife has a prominent status as part of the Potiguara identity and is the main staple in Potiguara’s traditional feasts, such as during the “shrimp festival” when fish and crustaceans are shared among villages (Cardoso and Guimarães, 2012).

The high consumption of aquatic wildlife recorded in this study could be related to the numerous rivers and abundant aquatic resources (Rocha et al., 2008;



Cardoso and Guimarães, 2012) which provide enough food for Potiguara households. As observed in Amazonia, greater fish availability induces lower reliance on hunting (Sarti et al., 2015; Endo et al., 2016) and this is yet another reason for the low game consumption. The healthy estuary is in stark contrast with the highly fragmented forest remnants of the region (Alves and Nishida, 2002). Villages situated in the coastal areas have access to marine environments with a variety of plant and animal species that are not available to inland communities (Turner, 1995; Mitchell and Donald, 2001; Mulrennan and Bussi eres, 2018), therefore, they are expected to be incorporated into the local diet. As remarked by Alves and Rosa (2006), the use of more accessible resources possibly is related to historic aspects, for example, the knowledge focusing on species familiar to the locals, reflecting the transmission of knowledge through generations.

We found that both consumptions of aquatic animals and game increased with the distance from the protected area. This might be because, inside the protected area, the use and management of aquatic resources are allowed, but hunting is forbidden (Brasil, 2000). On the other hand, indigenous peoples have rights to their land and their natural resources, game species included, warranted by the Brazilian constitution (Brasil, 1988). Since the Potiguara IL and the EPA BRM (the protected area) partially overlap, the Potiguara must constantly navigate a legal limbo of conflicting rules. Hunting is portrayed as a negative or criminal activity by the environmental agencies in charge of the EPA BRM and this contributes to further marginalizing this activity. Fears of being penalized by law enforcement jeopardize the role that hunting used to play in the protein complementation of the Potiguara living inside the protected area. Although we found a low consumption of game meat as compared to aquatic resources and domestic sources of animal protein, this consumption still occurs and deserves attention, both from the point of

view of food security discussed previously, and in relation to the target species conservation. Regarding this, we emphasize that in the studied areas where hunting is allowed there is no management and monitoring program of game fauna. These programs could reduce potential impacts of hunting on game, in addition to promoting a better understanding of the current consumption and importance of game animals for the Potiguara population. Regarding on that, successful initiatives have integrated scientific and local knowledge into local hunting rules and sustainable harvest of target species, while promoting biodiversity conservation and empowering local people (Campos-Silva et al., 2018).

In our study, the consumption of wild animals (game and fisheries) was higher among children whose fathers have nature-related occupations. This pattern might result from their higher exposure to wild resources during worktime, especially among those fathers whose income comes from exploiting wild resources (e.g., fishers). Opportunistic hunting upon chance encounters during agricultural or other activities has also been reported in Madagascar (Gardner and Davies, 2014). In the studied region women play an important role in supporting families by harvesting wild species for food, such as “camurim”/snook *Centropomus* sp., and for traditional medicine use, such as seahorse *Hippocampus reidi* and tarpon *Megalops atlanticus* (Rocha et al., 2012). Nevertheless, a statistically significant relationship was not found between fisher mothers and students’ consumption of fishing resources, maybe due to the low proportion of fisher mothers among the study’s cohort (ca. 4%).

The lack of effect of age on the consumption of game meat by the Potiguara might be explained by the small age range of the cohort of students in the study (94.4% aged 10–20 years). Possibly, younger people consider consuming game meat an outdated tradition, especially in more urbanized areas.

Studies covering a wider age range have shown that game meat consumption is lower among younger people, who often regard it as not socially acceptable (Luiselli et al., 2019). We found a greater preference for game meat among male students, who also consumed it more often when compared to female students. In a study developed in Cameroon based on 1 year of weekly recall, data men reported eating game meat more often than women (149 women, 117 men, aged 16–75 years). However, this pattern was not stable across all age groups. Consumption of game meat was more frequent among younger men than among younger women (<35 years of age), whereas older women ate game meat more often than older men (aged 35–54 years) (Duda et al., 2018).

Nearly one-fourth of the students ($n = 205$) deemed wild meat of certain species as repulsive, such as snake, frog, and the lizard *S. merianae*. The main reasons for students to reject the meat of certain animals were related to feelings of pity and disgust, considering its consumption harmful, and to specific qualities of the meat, like smell, taste, and appearance. A similar pattern has been recorded in traditional communities elsewhere and is often related to food taboos (Barboza et al., 2016), animals' morphology or smell (Figueiredo and Barros, 2016), and the feeding habits of scavenger species (Souza and Alves, 2014). Prevalent rejection of sloths might result from peoples' affection since they are regularly observed in green spaces near the communities or urban areas, and the species is often subject to awareness campaigns developed by conservation projects in the area. We postulate that the greater preference for domestic meat and aquatic resources among Potiguara students is mainly due to the greater students' familiarity with those sources of protein.

The nutritional transition evidenced in our study area among the young Potiguara leads to concerns already raised in other studies that have recorded the rapid changes taking place in the diets of Indigenous peoples (Kuhnlein, 2009; Welch et al., 2009; van Vliet et al., 2015a). These transitions are sensitive indicators of the ecological and cultural costs that the changes brought about by modernity imply for indigenous people (Dounias and Froment, 2011; van Vliet et al., 2015a). The replacement of game meat or fish for industrialized meats and the change to a more sedentary lifestyle leads to increasing rates of overweight, obesity, and associated chronic diseases such as cancer, heart disease, and diabetes (Popkin, 1994; Popkin and Gordon-Larsen, 2004; Parrotta et al., 2015). The transformations of landscapes, economies, and lifestyles of these populations represent threats to their sovereignty and food security, which go beyond that since the right to healthy food is interconnected with ethnic identity, traditional knowledge systems, sustainability, and wellbeing (van Vliet et al., 2018, 2022; Jacob et al., 2021; Welch et al., 2021). In this sense, nutritional transitions and their implications for indigenous peoples must be seriously taken into consideration in public policies, especially those focused on biodiversity conservation, food, nutrition, and health.

Despite its growing dietary importance, information on animal protein consumption by indigenous groups from Brazil is scarce, emphasizing the need for further research on the topic. To our knowledge, this is the first study to address the role that wild animals and domestic and processed meat/fish

play in the food security of coastal indigenous populations from Brazil.

Although we focused our interviews mainly on young people, we believe that our results can extrapolate this scope, since students' eating habits are a reflect of the daily eating behaviors of the homes where these students are inserted. This study illustrates that wild animal's consumption and preference by Potiguara students are modulated by a set of environmental and social factors, such as students' father's occupation, policies, and regulations, deforestation, and urbanization that shape the use of wildlife as a source of food and determine their role in securing food sufficiency among traditional populations.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The research project was approved by the Research Ethics Committee and the National Research Ethics Commission (CEP/CONEP), in accordance with Resolution No. 466/2012 of the National Health Council (CNS) of the Ministry of Health (No. 2,491,305). This research was authorized by the Brazilian Agency for Indian Affairs (FUNAI) (No. 94/AAEP/PRES/2017) and indigenous leaders in compliance with CNS Resolution No. 304 of 2000. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

CS, NV, and RA conceived the ideas and designed the methodology. CS collected the data. CS, FB-P, and AB compiled and analyzed the data. CS and FB-P wrote the original draft. CS, FB-P, AB, NV, and RA edited the manuscript. All authors gave final approval for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fevo.2022.900398/full#supplementary-material>

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