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ARTÍCULO

MORPHOMETRIC DIFFERENCES BETWEEN CAPTIVE AND WILD JAGUARS (*Panthera onca*) IN VENEZUELA

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RESUMEN

In Venezuela, the earliest anecdotal record of a captive jaguar (*Panthera onca*) dates to a male housed in Maracay between 1918 and 1935. From 1996 to 2009, body measurements of 22 captive jaguars in Venezuelan zoos were recorded and compared with data from 25 wild jaguars published by Hoogesteijn and Mondolfi (1992). Morphometric analysis focused on head-and-body length (HBL), tail length (TL), total body length (TBL = HBL + TL), and body weight (BW). Measurements were obtained under anesthesia using a clock scale for BW. Sexes were analyzed separately, and descriptive statistics and Student's t-tests ($p < 0.05$) were applied to detect significant differences. Captive males exhibited 8.78% and 12.13% shorter TBL and HBL, respectively, compared to wild males, while no significant differences in BW were observed among females. Principal component analysis revealed distinct morphometric patterns between captive and wild populations. Body mass index (BMI) further highlighted body condition variations, with some captive males underweight, possibly due to dietary issues, while others exhibited excess fat, likely due to reduced physical activity. Simple linear regression and correlation analyses indicated that body weight variability explained by body length was 8.55% for males and 9.83% for females. These findings emphasize captivity's impact on jaguar morphology and underscore the importance of optimal husbandry practices. This study provides essential insights for captive management and conservation efforts aimed at maintaining physical and morphological integrity in jaguar populations.

Keywords: Biometry, Jaguar, Sex, Venezuela, Zoo.

Diferencias morfométricas entre jaguares cautivos y silvestres (*Panthera onca*) en Venezuela

ABSTRACT

En Venezuela, el registro anecdótico más antiguo de un jaguar (*Panthera onca*) en cautiverio corresponde a un macho en Maracay entre 1918 y 1935. Entre 1996 y 2009 se tomaron mediciones corporales de 22 jaguares en zoológicos venezolanos, comparándolas con datos de 25 jaguares silvestres publicados por Hoogesteijn y Mondolfi (1992). El análisis morfométrico incluyó longitud cabeza-cuerpo (HBL), longitud de la cola (TL), longitud total (TBL = HBL + TL) y peso corporal (BW). Las mediciones se realizaron bajo anestesia, usando una balanza de precisión para BW. Los datos se analizaron por sexo mediante estadísticas descriptivas y pruebas t de Student ($p < 0{,}05$) para detectar diferencias significativas. Los machos cautivos presentaron TBL y HBL un 8,78% y 12,13% menores, respectivamente, que los machos silvestres, mientras que no se observaron diferencias significativas en BW entre las hembras. Un análisis de componentes principales reveló patrones morfométricos distintos entre las poblaciones cautivas y silvestres. El índice de masa corporal (IMC) evidenció variaciones en la condición corporal, con algunos machos cautivos por debajo de su peso, posiblemente por dietas inadecuadas, y otros con exceso de grasa debido a la reducción de actividad física. El análisis de regresión lineal simple y los coeficientes de correlación mostraron que la variabilidad del peso explicada por la longitud corporal fue del 8,55% en machos y del 9,83% en hembras. Estos hallazgos destacan el impacto del cautiverio en la morfología del jaguar y subrayan la importancia de prácticas óptimas de manejo para la conservación de su integridad física y morfológica.

Palabras clave: Biometría, Jaguar, Sexo, Venezuela, Zoológico.

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INTRODUCCIÓN

Panthera onca (Linnaeus, 1758), the largest felid of the Americas and the third largest of the genus *Panthera* Oken 1816, after the tiger (*P. tigris*) and the lion (*P. leo*), is classified as Vulnerable in Venezuela's Red Book of Fauna (Jedrzejewski *et al.*, 2015). The species exhibits a broad weight range, from 31 to 158 kg, and total body length ranging from 154 to 241 cm (Emmons, 1997). Specifically, in Venezuela, Hoogesteijn and Mondolfi (1992) reported that males have a mean weight of 96 ± 18 kg (range: 68 – 121 kg) and a mean length of 212 ± 18 cm (range: 181 – 234 cm), while females have a mean weight of 56 ± 7 kg (range: 43 – 65 kg) and a mean length of 186 ± 7 cm (range: 176 – 196 cm). Similarly, Linares (1998) observed comparable weight and length values.

Jaguars have been maintained in zoos globally for over a century, with the first recorded captive jaguar being a female at the Philadelphia Zoo in 1875 (Johnson, 2013; McMillan, 1995). As of 1999, the International Species Information System (ISIS) documented 239 jaguars across 111 zoos worldwide, with 86.2% of these individuals born in captivity. Recent records, including those by Jiménez González *et al.* (2020), document 38 jaguars in 8 Colombian zoos.

In Venezuela, the first documented captive jaguar appeared in January 1946 at El Pinar Zoo in Caracas (Johnson, 2013; McMillan, 1996), although anecdotal evidence suggests a male was housed in the private zoo of President Juan Vicente Gómez in Maracay between 1918 and 1935. Boher and Trebbau (1992) reported a total of 43 jaguars (22 males, 21 females) in Venezuelan zoological collections, with reproduction being relatively successful, often producing surplus animals. The latest available inventory by the National Foundation of Zoological Parks and Aquariums (FUNPZA) in 1998 lists 35 individuals (16 males, 19 females).

The enclosures housing jaguars in Venezuelan zoos are typically limited in size and spatial complexity compared to their wild habitats. Factors such as noise, lighting, temperature, humidity, enclosure surface, substrate types, and exposure to environmental elements are potential stressors that may affect the health and behavior of captive jaguars. In response to these stressors, the release of adrenocorticotrophic hormone (ACTH) stimulates the adrenal cortex, leading to increased production of glucocorticoids (GC) and androgens. Elevated GC levels may result in altered behaviors, including increased aggression or depression, excessive grooming, hyperactivity, and alterations in appetite, potentially leading to immunosuppressive effects, such as autoimmune conditions (Koscinczuk, 2014).

Diet and nutrition also significantly influence the physical condition of captive jaguars. Unlike their wild counterparts, many zoo-housed jaguars are fed meat-based diets supplemented with vitamins but lacking organs, skin, or connective tissues. Such dietary differences may contribute to morphological variations in body structure and dimensions. Studies of other pantherine felids suggest that skull shape differences between captive and wild individuals are linked to dietary differences that impact chewing loads (Hartstone-Rose *et al.*, 2014; Zuccarelli, 2004). An imbalanced calcium-to-phosphorus ratio in captivity may further exacerbate these differences.

Despite the documented morphological variations between wild and captive animals, few studies have specifically focused on the impact of captivity on the anatomy of jaguars and other felids (Hartstone-Rose *et al.*, 2014; O'Regan and Kitchener, 2005). Research on this topic has predominantly targeted primates (Altmann *et al.*, 1993; Bolter and Zihlman, 2003; Lewton, 2017; Phillips-Conroy and Jolly, 1988; Turner *et al.*, 2016), carnivores (Zuccarelli, 2004; Hailemariam *et al.*, 2015; Saragusty, 2014; Weber Rosas *et al.*, 2009), and mice (Courtney Jones *et al.*, 2018; McPhee, 2004).

A common physical alteration observed in generations of captive-born animals is a reduction in sexual dimorphism, potentially linked to altered rates or ages of sexual maturity. Alternatively, morphological changes in captivity may arise from shifts in selection pressures, favoring traits that maximize fitness in the confined environment (Mathews *et al.*, 2005; Schulte-Hostedde and Mastromonaco, 2015). However, these changes should not be interpreted as "adaptive" in an evolutionary sense, as insufficient time for selective pressures to act precludes true evolutionary adaptation, though phenotypic responses to the captive environment may occur.

On the other hand, obtaining accurate data on external measurements and weight in live jaguars both in captivity and in the field is perhaps the main difficulty to overcome. The difficulty in handling and obtaining reliable data in jaguars will depend on the immobilization techniques and the experience of the recorder to reduce the risk of accidents and measurement errors. For some researchers, the skins deposited in museums should not be measured. Because skins can be affected by the processes of preparation and fixation of the tissues, with some influence of the statistical analyses commonly used.

Based on the above, this study provides biometric data of captive jaguars collected between 1996 and 2009 and its comparison with the data published of free-living ones by other authors to assess whether significant morphological differences exist between captive and wild populations in Venezuela.

MATERIALS AND METHODS

The morphometric analysis was conducted on 47 jaguars all originating from Venezuela. This included 22 individuals housed in captivity across 10 facilities (nine zoos and one private) (Figure 1). Of these captive jaguars, 10 were confirmed to have been born in captivity based on zoo records. The remaining 12 were likely wild caught, as many were confiscated or donated without detailed provenance records; specific geographic origins and capture histories were unavailable for most, and when reported, relied on anecdotal information from the facilities. All these animals were adults, ranging from 3 to 17 years of age. For individual details, see Appendix I. Also, data on 25 free-living jaguars (data published earlier by Hoogesteijn and Mondolfi,1992) were used for the comparison.

Figure 1. Relative geographic location of sampling localities. Red = Zoos, Blue = Private collection. 1 = Metropolitano del Zulia, 2 = Chorros de Milla, 3 = Paraguaná, 4 = Bararida, 5 = Association of Cattle Breeders of Valencia, 6 = Las Delicias, 7 = Caricuao, 8 = El Pinar, 9 = Generalísimo Francisco de Miranda, 10 = La Guaricha.

This study was conducted in strict adherence to ethical and welfare standards for animal research. Informed consent was obtained from the administrative representatives of each participating facility prior to the study's commencement. All protocols were designed and executed following the principles of good veterinary practice and animal welfare, as stipulated by the Law on the Practice of Veterinary Medicine (Official Gazette No. 28.737, 24 September 1968) and the Law on the Protection of Wild Fauna (Official Gazette No. 28.289, 11 August 1970). Ethical approval was granted by the Animal Research Ethics Committee, and all efforts were made to minimize the number of animals used while ensuring the generation of scientifically robust and reliable data.

Linear Morphometry. The evaluation of morphometric variation in this study focused on three body measurements and body weight. The point-to-point measurements were Head-and-body length (HBL) = from the tip of the muzzle/nose to the base of the tail, and Tail length (Tl) = from the base of the tail to the end of the last caudal vertebra, excluding the terminal tuft of hair. Total body length (TBL) was calculated by adding HBL and Tl (Figure 2). The measurements were taken by the author on anesthetized animals following an anesthetic protocol using a xylazine-ketamine combination as described by Cañizales (2019), with calibrated tape measures in centimeters (cm) and two or three repetitions for an accuracy level of ±1.0 cm to minimize recorder error. Body weight (BW) was recorded using a clock scale, which can weigh up to 200 kg.

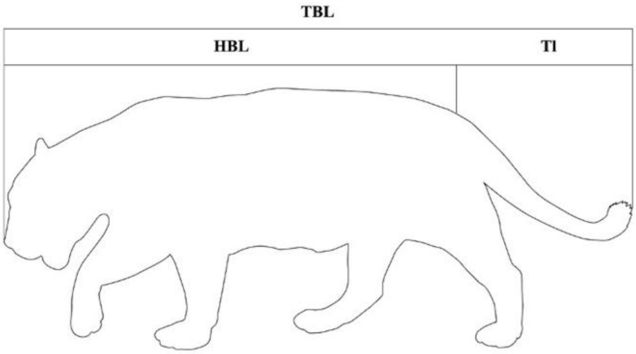

Figure 2. Schematic drawing showing external body measurement points in jaguars. (TBL) total body length, (HBL) head-body length, (Tl) tail length.

All data were used to calculate descriptive statistics (Mean, Standard Deviation, Minima, Maxima, Coefficient of Variation). The sexes were analyzed separately. Student's t-test ($p \leq 0.05$) was used to determine if there were significant differences in morphometric data between males and females, both in captivity and in the wild, as well as between animals of the same sex in both situations. Violin plots were generated to illustrate size differences. Additionally, as an exploratory descriptive tool, a principal component analysis (PCA) was performed. This multivariate technique considers different variables to determine patterns of morphometric variation between groups, as well as to evaluate the degree of separation between them, aiming to achieve maximum homogeneity so that forms are grouped according to their degree of similarity. The graphs were obtained using the PAST 4.03 program (Hammer *et al.*, 2001).

Body Condition. The following scoring systems were employed to assess and assign the degree of body symmetry and muscle development: the Body Condition Score (BCS), which evaluates body fat coverage by visual estimation on a 1–9 scale (1 = Very thin, No detectable body fat; 9 = Obese, Heavy fat cover), and the Muscle Condition Score (MCS), which evaluates the firmness or turgidity of the muscle masses around the temporal bones, scapulae, lumbar vertebrae, and pelvic bones by palpation on a 1–4 scale (1 = No muscle wasting, normal muscle mass; 4 = Marked muscle wasting). Both scoring systems were based on the criteria outlined by AZA (2016), Baldwin *et al.* (2010), and Laflamme (1997).

To contrast the body mass ratio between captive and free-living animals, a Body Mass Index (BMI) was calculated. The formula used for this calculation is as follows:

$$BMI = (\bar{X}_1 - \bar{X}_2 / [(\bar{X}_1 + \bar{X}_2)/2]$$

where $\overline{X}_1$ is the mean weight in sample 1 (captive animals) and $\overline{X}_1$ is the mean weight in sample 2 (wild animals). This formula provides the difference in mass relative to the average mass of the individuals (De La Torre and Rivero, 2017). To model potential differences between males and females, body weight and length measurements were analyzed using linear regression.

RESULTS

A total of 47 jaguars (combined captive or wild) were included in this study, comprising 27 males and 20 females. Among the males, 12 were captive and 15 were free-living. For the females, 10 individuals were of captive origin, and 10 were wild.

Linear morphometry. The morphometric comparison between captive and free-living jaguars revealed notable differences in body measurements and variability. Figure 3 illustrates the average body length of jaguars differentiated by sex.

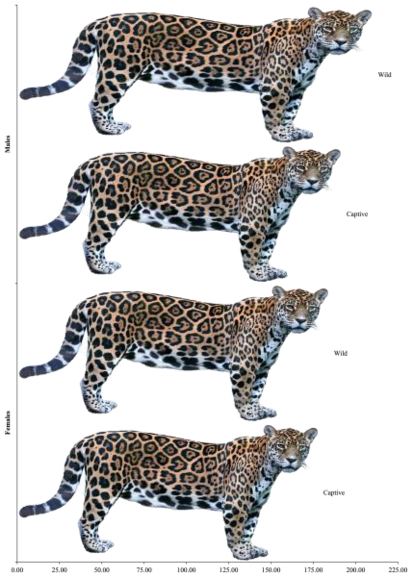

Figure 3. Comparison of average body length between captive and free-living male and female jaguars.

Total body length (TBL) was higher on average for free-living males (211.67 ± 18.34 cm) compared to captive males (193.08 ± 20.51 cm), showing a 9% greater mean value (Table 1). The largest TBL was recorded in a free-living male, measuring 234 cm. Similarly, free-living females exhibited a longer mean TBL (185.60 ± 6.69 cm) compared to their captive counterparts (179.40 ± 9.56 cm, Table 1). Captive males also showed lower mean values for head-body length (HBL), and body weight (BW) compared to their free-living counterparts. In contrast, captive females exhibited a slightly higher mean HBL compared to free-living females.

Table 1. Mean and standard deviation of morphometric measurements and body mass of captive and free-living jaguars by sex. All measurements are in centimeters, and body mass is in kg. TBL, Total body length; HBL, Head-body length; Tl, Tail length; BW, Body mass; SD, Standard deviation, Min, Minimum; Max, Maximum; *(n)*, sample size; CV, coefficient of variation (Bold values indicate lower variation).

Variable	Captive jaguars This study						Free-living jaguars Hoogesteijn and Mondolfi (1992)					
	Males			Females			Males			Females		
	Mean ± SD	Min – Max *(n)*	CV	Mean ± SD	Min – Max *(n)*	CV	Mean ± SD	Min – Max *(n)*	CV	Mean ± SD	Min – Max *(n)*	CV
TBL	193.08 ± 20.51	138 – 216 (12)	0.106	179.40 ± 9.56	161 – 196 (10)	**0.053**	211.67 ± 18.34	181 – 234 (15)	**0.087**	185.60 ± 6.69	176 - 196 (10)	**0.036**
HBL	131.25 ± 21.19	70 – 152 (12)	0.161	127.30 ± 7.18	115 – 138 (10)	**0.056**	149.36 ± 12.68	126 – 170 (15)	**0.085**	126.70 ± 5.54	116 – 134 (10)	**0.044**
Tl	61.83 ± 4.11	56 – 70 (12)	**0.066**	52.10 ± 7.75	41 – 62 (10)	0.149	60.79 ± 9.89	33 – 71 (15)	0.163	58.90 ± 5.13	50 – 66 (10)	**0.087**
BW	65.50 ± 11.33	45 – 87 (12)	0.173	52.30 ± 9.56	40 – 70 (10)	0.183	95.87 ± 17.61	68 – 121 (15)	0.184	55.89 ± 6.86	43 – 65 (9)	0.123

The significance of differences in all morphometric variables between captive and free-living males was confirmed by t-test:
TBL: t = 2.451; DF = 22; $p = 0.011$
HBL: t = 2.590; DF = 17; $p = 0.010$
BW: t = 5.423; DF = 24; $p < 0.001$

In contrast, no significant differences were found between captive and free-living females for any variable:
TBL: t = 1.681; DF = 16; $p = 0.056$
HBL: t = -0.209; DF = 17; $p = 0.418$
BW: t = 0.947; DF = 16; $p = 0.179$

The coefficient of variation (CV) did not differ significantly between captive and free-living jaguars for either sex. Among males, CV comparisons yielded no statistical significance [t = - 0.0910, DF = 6, $p = 0.4652$; captivity (all three variables ≥ 10%); free-living (two variables ≥ 10%)]. Similarly, no significant differences were observed among females [t = 0.9769, DF = 5, $p = 0.1867$; captivity (two variables ≥ 10%); free-living (one variable ≥ 10%)].

Sex-Based Morphometric Differences. Among captive jaguars, males exhibited a significantly longer total body length (TBL) compared to females (t = 2.058; DF = 16; $p = 0.028$). Additionally, the mean body weight (BW) of captive males was significantly higher than that of females (t = -2.965; DF = 20; $p = 0.004$). However, no significant difference was found in head-body length (HBL) between captive males and females (t = -0.605; DF = 14; $p = 0.277$). In free-living jaguars, all morphometric variables measured were significantly greater in males than in females:
TBL: t = 5.305; DF = 18; $p < 0.001$
HBL: t = 6.092; DF = 19; $p < 0.001$
BW: t = 7.835; DF = 20; $p < 0.001$

Morphometric Variation. The violin plot (Figure 4) illustrates the distribution and size differences by sex for both captive and wild jaguars, highlighting the multimodal nature of the data. Captive males displayed significantly lower mean total body length (TBL), and head-body length (HBL) compared to free-living males (TBL: t = 2.451; DF = 22; *p* = 0.011; HBL: t = 2.590; DF = 17; *p* = 0.010). In contrast, no significant differences were observed between captive and free-living females for these variables (TBL: t = 1.681; DF = 16; *p* = 0.056; HBL: t = -0.209; DF = 17; *p* = 0.418).

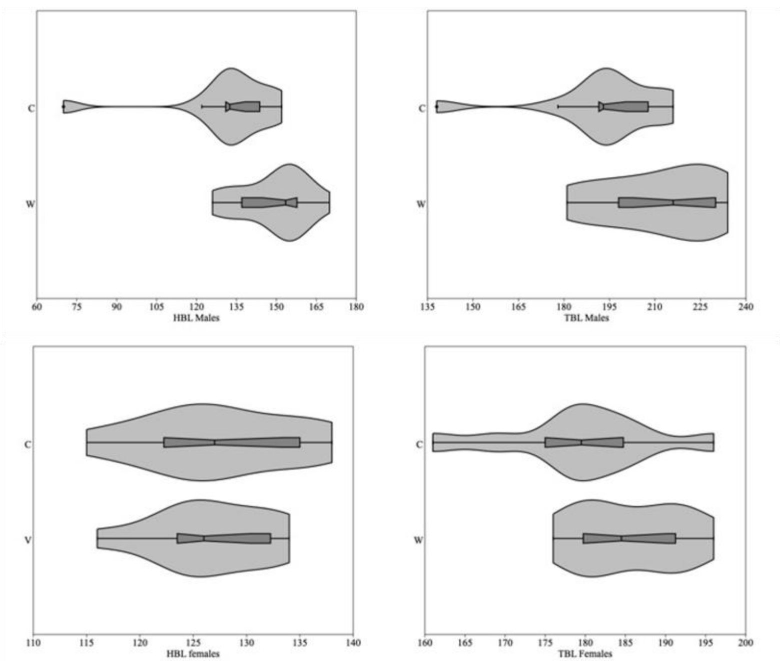

Figure 4. Violin plot of HBL and TBL of captive (c) and free-living (w) jaguars. The central thick black bar represents the interquartile range. The left and right thin black lines extending from it represent the 95 % confidence intervals. The grey areas represent the distribution of all values.

The principal component analysis (PCA) explained 96.93% of the total variance within the first two components (Fig. 5). PC1 accounted for 83.25% of the variance, primarily driven by total body weight and length, and separated free-living males along with some larger captive males from females and smaller captive males. PC2 explained 13.67% of the variance and primarily differentiated individuals by body length. The observed overlap between captive and wild specimens underscores a continuum of morphometric variation rather than distinct population clusters.

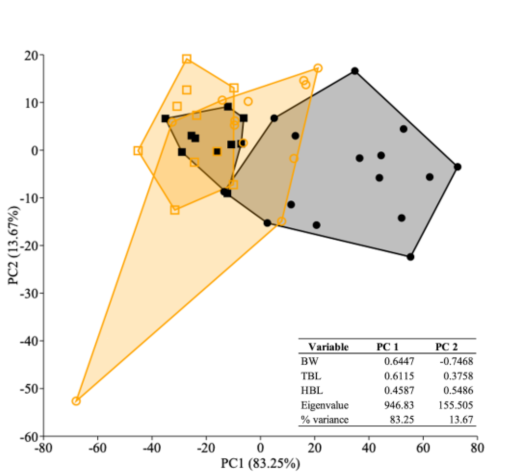

Figure 5. Bivariate plot of principal component analysis. (●) free-living males, (■) free-living females, (○) captive males, (□) captive females. Lines were drawn around each group to aid visualization. The loadings, eigenvalues and % variance of the variables are shown.

Body Condition and Morphometric Relationships. The maximum recorded body weight (BW) for captive jaguars in this study was 87 kg for males and 70 kg for females. In contrast, free-living jaguars reported by Hoogesteijn and Mondolfi (1992) exhibited higher maximum weights: 121 kg for males and 65 kg for females. The BW of captive females did not differ significantly from that of their wild counterparts ($t = 0.947$; DF = 16; $p = 0.179$). However, captive males were significantly lighter than free-living males ($t = 5.423$; DF = 24; $p = 0.000$).

Among the 22 captive jaguars, body condition scores (BCS) ranged from 3 to 5, while muscle condition scores (MCS) ranged from 2 to 3. Both sexes were evenly distributed across BCS categories, except for a slight but significant overrepresentation of males with a BCS of 5 compared to females (Table 2). The body mass index (BMI) comparison revealed that free-living males were 0.38 times heavier than their captive counterparts. Free-living females showed a smaller difference, being 0.07 times heavier than captive females.

Table 2. Body Condition Scores (BCS) and Muscle Condition Scores (MCS) of captive Jaguars by sex. BCS is based on visual and palpatory evaluation, where 1 = emaciated, 5 = ideal, and 9 = grossly obese. MCS ranges from 1 = severe muscle wasting to 4 = no muscle wasting.

BCS			MCS		
	Males	Females		Males	Females
3 (n = 3)	1	2	2 (n = 9)	5	4
4 (n = 3)	1	2	3 (n = 13)	7	6
5 (n = 16)	10	6			

The relationship between total body length (TBL) and body weight (BW) is illustrated in Figure 6 (a and b) for males and females, respectively. Both sexes exhibited a moderate heterogeneous distribution with a positive upward slope, though some points deviated from the regression line. Captive males (red dots) consistently showed lower BW values compared to free-living males (black dots).

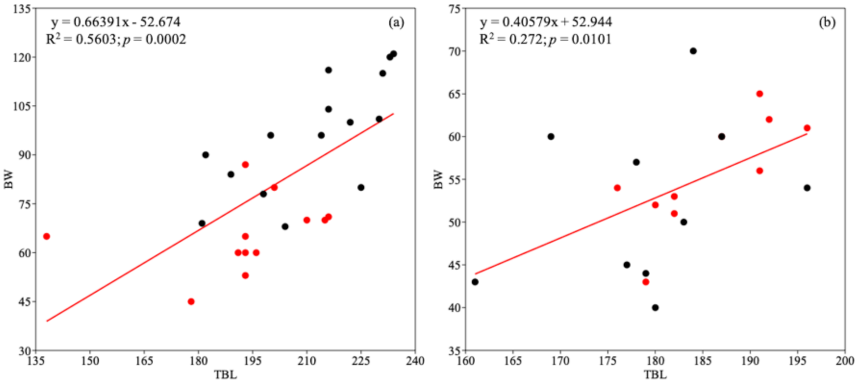

Figure 6. Linear regression between BW and TBL of male (a) and female (b) jaguars. The red dots represent captive animals. The black dots represent free-living animals. The values of the slope, intercept and correlation coefficients are reported.

Linear regression analyses indicated that total body length (TBL) explained a substantial proportion of the variability in body weight (BW) in males ($R^2 = 0.5603$), accounting for 56.03% of the variation. In females, the relationship was weaker, with body length explaining 27.2% of the variation in body weight ($R^2 = 0.272$).

DISCUSSION

For many endangered mammal species, captive individuals represent the only available subjects for studies on reproduction, behavior, diet, and morphology. While sample sizes in captivity may often fall short of meeting statistical assumptions, they can still provide valuable insights into biological phenomena. In contrast, field studies involving elusive species such as jaguars face considerable logistical, financial, and personnel challenges, including the need for chemical immobilization and specialized equipment. Additionally, the quality and availability of museum specimens are often variable, and the collection of new biological material is increasingly constrained by ethical and legal considerations. Nonetheless, studies have reported morphological differences between free-living and captive adult mammals across various species (Courtney Jones *et al.*, 2018; O'Regan and Kitchener, 2005; Turner *et al.*, 2016).

Linear Morphometry. In this study, captive male jaguars exhibited mean total body length (TBL) and head-body length (HBL) values that were 8.78% and 12.13% lower, respectively, compared to wild counterparts reported by Hoogesteijn and Mondolfi (1992). However, no significant differences were observed among females. These differences may be attributable to biological (e.g., intrinsic growth rates, age) and environmental factors (e.g., housing conditions, diet) or could reflect population differences and measurement variability.

Age determination in most terrestrial mammals typically relies on external criteria such as fur color, tooth eruption, and secondary sexual characteristics. In captivity, additional indicators such as lens opacity, ossification of ear ossicles, and radiographic evaluation of bone development may be employed. Proper intake of essential nutrients, hormonal balance, and overall health status are critical for ossification and final body dimensions (Zoran, 2002). Jaguars in Venezuelan zoos are typically fed meat (beef, chicken, horse, or pork) without organ supplementation, with feeding schedules every two days. This contrasts with the more diverse and organ-inclusive diets observed in the wild.

It is worth noting that some length measurements reported in earlier studies (e.g., Emmons, 1997; Linares, 1998) were obtained from skins, which are prone to distortion during preservation and tanning processes. Historically, measurements often followed the curvilinear body contour, yielding longer values compared to the standard straight-line method. These discrepancies likely explain some reported differences. Interestingly, female lengths were consistent with wild measurements from Hoogesteijn and Mondolfi (1992).

Given that free-living male jaguar, originating from diverse Venezuelan ecoregions, displayed significant morphometric variability, the reduced total body length (TBL) and head-body length (HBL) observed in captive males may be partially attributable to captivity-related factors, as supported by O'Regan and Kitchener (2005), who highlight the impact of constrained environments on felid morphology. The mixed birth origins within the captive sample-comprising approximately 45% (10/22) confirmed captive-born, and the remainder likely wild-caught—introduce additional complexity to these morphometric differences. Captive-born individuals may exhibit accentuated generational effects of captivity, such as diminished body size resulting from dietary inconsistencies (e.g., lack of diverse prey tissues) or restricted enclosure space limiting physical development, as noted by O'Regan and Kitchener (2005). However, given the lack of definitive birth origin data for all specimens, these generational influences remain speculative and warrant further investigation with genetic validation.

Body Condition. Captive males in this study exhibited a mean body mass (BW) of 65.50 kg, 31.68% lower than free-living males reported by Hoogesteijn and Mondolfi (1992). This finding is somewhat unexpected, as captive animals generally tend to be fatter and less muscular than their wild counterparts. Although, this is more often observable in developed countries where the food supply is guaranteed all the year-round, it is important to consider that Venezuelan zoos typically base food allocation on 3% of an animal's live weight, with rations provided every other day. In contrast, captive females were 6.42% heavier than their wild counterparts, possibly due to reduced physical activity in captivity. Larger female body sizes may also provide an advantage in protecting offspring and deterring infanticide. While no statistically significant differences in female BW were found, the relationship between TBL and BW did not exhibit a meaningful increase, likely due to the limited sample size. Additionally, differences in weighing methods may have contributed to the observed variability.

Body and Muscle Condition Scoring. A limitation of the Body Condition Score (BCS) and Muscle Condition Score (MCS) systems is the potential for investigator bias. These two assessments are not directly correlated, as overweight animals may still exhibit substantial muscle loss. Nevertheless, BCS assessments have demonstrated good inter-assessor consistency despite their subjective nature (AZA, 2016; Baldwin *et al*., 2010; Laflamme, 1997).

In this study, most captive jaguars were categorized within BCS category 5 and MCS category 3. Due to the absence of reference values for captive jaguars in Venezuela, these scores likely represent the highest observed conditions for this population. Comparative studies conducted in European zoos indicate that jaguars (*Panthera onca*) tend to exhibit higher BCS values across multiple facilities, with an average BCS of 6 (range: 3-8) (Kleinlugtenbelt *et al.,* 2023). These observations suggest variations in management practices, nutritional regimens, and environmental factors influencing body condition patterns in captive large carnivores across different regions.

Morphometric Variability and Captivity Effects. The BMI for captive males and females compared to their wild counterparts was 0.38 and 0.07, respectively. Free-living Venezuelan jaguars reported by Hoogesteijn and Mondolfi (1992) exhibited a BMI of 0.53, slightly higher than the 0.42 reported by De La Torre and Rivero (2017) for Mexican jaguars. These variations may reflect differences in prey availability (Hoogesteijn and Mondolfi, 1992).

The differences observed in the values associated with BMI between captive and free-living animals could be based on the availability of food resources and physical activity. In captivity activity levels differ markedly from those in nature. Although the variables of size and type of soil or substrate of enclosures were not evaluated in this work, they partly determine the degree of activity and consequently the muscular development or fat accumulation of the animals. Captive animals, on the other hand, are routinely supplied and do not need to spend energy searching for food.

Finally, this study confirms the existence of significant morphological differences between captive and wild adult jaguars in Venezuela. Captive males exhibited shorter total body length (TBL), head-body length (HBL), and lower body weight (BW) compared to their wild counterparts, with differences likely attributable to a multifaceted interplay of dietary deficiencies, enclosure-related environmental constraints, and potentially underlying genetic factors. The elevated morphometric variability in captive males may stem from heterogeneous captive management practices, including inconsistent nutrition and limited genetic diversity within zoo populations, which can exacerbate phenotypic plasticity or founder effects. Conversely, the relatively stable morphological measurements in wild jaguars are probably shaped by consistent ecological pressures, such as predation dynamics and resource availability, that select for size homogeneity within populations.

These findings underscore the critical need to account for captivity-induced effects when interpreting morphometric data in conservation biology and ecological research contexts. They emphasize the imperative for enhanced dietary protocols -incorporating organ meats and balanced calcium-phosphorus ratios- and more expansive, enriched enclosures to approximate the physical demands of free-living habitats, thereby promoting the health, welfare, and reintroduction potential of these Vulnerable felids. Although primarily ascribed to environmental influences of captivity (e.g., suboptimal diets lacking diverse tissues and reduced locomotor activity leading to adiposity or muscle atrophy), the observed differences could also reflect inherent genetic variability. As evidenced by Hoogesteijn and Mondolfi (1992) and Lorenzana *et al.* (2020), jaguar populations across Venezuelan ecoregions exhibit clinal morphometric and genetic differentiation, with larger-bodied individuals in the nutrient-rich Llanos contrasting smaller forms in the Amazon basin, driven by local adaptations to prey abundance and habitat productivity. Given the heterogeneous and often undocumented origins of the captive jaguars (e.g., mixed wild-caught and captive-born individuals from diverse regions), a genetic component cannot be discounted, necessitating genomic approaches -such as whole-genome sequencing or microsatellite genotyping- in future investigations to parse environmental versus heritable contributions (Schulte-Hostedde and Mastromonaco, 2015). This interpretive caution does not negate the demonstrated impacts of captivity but refines our understanding, advocating for integrated genetic-morphometric studies to bolster ex situ conservation strategies.

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APPENDIX I

Individual Morphometric Data and Origin Details of Captive Jaguars (*Panthera onca*) from Venezuelan Zoos and Facilities, 1996–2009.

ID	Sex	Age (years, months)[1]	Zoo	Origin	HBL (cm)	TL (cm)	TBL (cm)	BW (kg)
1	Male	3	Metropolitano del Zulia	Captive-born	150	60	210	70
2	Male	6,8	Metropolitano del Zulia	Captive-born	131	62	193	65
3	Female	7,1	Metropolitano del Zulia	Captive-born	125	62	187	60
4	Female	9	Metropolitano del Zulia	Captive-born	123	55	178	57
5	Female	10	Paraguaná	Captive-born	126	53	179	44
6	Male	17	Bararida	Captive-born	131	62	193	87
7	Female	5,9	Bararida	Captive-born	115	54	169	60
8	Female	4,6	Bararida	Captive-born	135	61	196	54
9	Male	6	Chorros de Milla	Wild-caught[a]	138	58	196	60
10	Male	9	Valencia	Wild-caught[b]	145	70	215	70
11	Male	11	Las Delicias	Wild-caught[b]	140	61	201	80
12	Male	6	Las Delicias	Wild-caught[b]	152	64	216	71
13	Male	16	Las Delicias	Wild-caught[b]	131	62	193	60
14	Female	9,11	Las Delicias	Wild-caught[b]	128	56	184	70
15	Female	3	Las Delicias	Wild-caught[b]	128	55	183	50
16	Male	9	Caricuao	Wild-caught[b]	70	68	138	65
17	Female	4	Caricuao	Wild-caught[b]	135	42	177	45
18	Female	5	Caricuao	Wild-caught[b]	138	42	180	40
19	Male	5	El Pinar	Captive-born	131	62	193	53
20	Female	8	El Pinar	Captive-born	120	41	161	43
21	Male	12	Francisco de Miranda	Wild-caught[c]	134	57	191	60
22	Male	11	La Guaricha	Wild-caught[d]	122	56	178	45

Footnote: [1]For jaguars with Wild-caught origin, the age represents the number of years maintained in captivity following their initial capture, as precise wild age at capture was not determinable due to lack of documentation. For captive-born individuals, age reflects their total lifespan in captivity. Approximate geographic origins for wild-caught individuals are indicated with superscripts: [a] = Barinas, [b] = Cojedes, [c] = Guárico, [d] = Monagas, reflecting the federal entity of origin based on anecdotal zoo reports.