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Research Article

Can footprints of small and medium sized felids be distinguished in the field? Evidences from Brazil's Atlantic Forest

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Abstract
Carnivores, particularly felids, face threats in many regions of the world. They are a crucial component of biodiversity with a functional role in the top of the food chain. Therefore, they have been the target of surveys and monitoring and ecological studies, most of which are based on footprint identifications, an efficient and low-cost method compared to other approaches. In these cases, species identifications may suffer from a high degree of bias due to the overlap in the size and shape of footprints among species. We experimented with small to medium captive wild felids of five species: ocelot, *Leopardus pardalis*, margay *L. wiedii*, oncilla, *L. guttulus*, domestic cat, *Felis catus*, and jaguarondi, *Puma yagouaroundi*).We tested for differences in footprint measurements, including main pad and toe pad sizes. We used humid sand as substrate and took measurements from several front and hind footprints of seven animals per species (except jaguarondi, for which only four animals were available). Our results showed that ocelot is the only species for which it is possible to obtain 100%-accurate footprint identifications, mainly because of its footprint area (*i.e.,* length x width). The remaining species presented a wide variation in measurements, making them almost impossible to distinguish based solely on footprint dimensions. Our results suggest that researchers should restrict identification to the genus level or adopt a multidisciplinary sampling strategy by combining footprint detection with camera-trapping, visual observation, scat collection, molecular ecology techniques, and/or face-to-face interviews with local residents.

Key-words: Species identification; Paws metric; Wild cats; Tropical Forest; medium-small Felids

Resumo
Os carnívoros, dentre esses os felideos em particular, enfrentam variadas ameaças em muitas regiões do mundo, sendo considerados um componente crucial da biodiversidade ao assumirem uma papel funcional no topo da cadeia-trófica. Assim, estas espécies têm sido alvo de inúmeros estudos ecológicos e monitorizações, frequentemente baseados na identificação de pegadas, uma vez que é um método com alta eficiência em relação ao seu custo e requer logística limitada. Este tipo de identificação das espécies pode estar associada a um alto grau de viés devido à similaridade em tamanho e forma das pegadas. Implementamos uma experiência com felinos de pequeno e médio tamanho (jaguatirica, *Leopardus pardalis*; gato-maracajá, *L. wiedii*; *gato-do-mato-pequeno L. guttulus*; gato doméstico, *Felis catus*; e jaguarundi, *Puma yagouaroundi*) num cercado, com o objetivo de testar as diferenças entre diversas métricas associadas ao tamanho das pegadas, da almofada principal e das almofadas digitais. Usamos como substrato areia húmida e os experimentos e mensurações foram efetuados em várias pegadas anteriores e posteriores de sete indivíduos diferentes de cada espécie (com a excepção de jaguarundi, para a qual apenas quatro animais foram utilizados na experiência). Os nossos resultados mostraram que jaguatirica é a única espécie para qual é possível obter uma identificação 100% correcta baseada nas métricas das pégadas (especialmente usando a área da pégada, *i.e.,* comprimento x largura). As restantes espécies apresentaram uma grande variação das métricas consideradas, tornando-se quase impossível distingui-las baseado apenas em medições de pegadas. Este resultado sugere que os investigadores deveriam restringir a identificação a níveis taxonómicos mais elevados ou adotar uma estratégia amostral multidisciplinar, combinando a detecção de pegadas com a armadilhagem fotográfica, observação visual, coleta de dejetos e sua identificação com recursos a técnicas de ecologia molecular e/ou entrevistas presenciais.

Palavras-chave: Identificação de espécies; Métricas das almofadas das pegadas; Gatos silvetres; FlorestaTropical Húmida; Pequenos e médios felinos

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Introduction

Felids are widely distributed throughout the world, occurring in all continents except Australasia and Antarctica [1], and many of these predator species are threatened throughout their range [1]. Most species are difficult to detect in the wild, due to their nocturnal and elusive behaviours, wide-ranging nature, low density, and pelage camouflage [2-4]. These characteristics hinder traditional capture techniques, or impose great sampling efforts to obtain satisfactory results. In short-term studies with limited budgets, such as species surveys and rapid faunal assessments, or even in monitoring programs, indirect evidences of species occurrence and abundance have been useful approaches, benefiting from the wide home ranges and movements of most felids. Most of these indirect evidences (*e.g.,* scats, footprints, scent-marks, claw-raking signs) are usually detected along trails or dirt roads [5].

Scats and footprints are commonly used evidences of felids' presence [6]. However, scat morphometry and species scent have raised questions about a possible significant bias associated with such methods [7], which is only minimized by very expensive molecular ecological techniques [8]. Therefore, among low cost approaches, footprint surveys have been considered the most accurate alternative for confirming species occurrence [3, 9]. Footprints are particularly useful for medium and large-sized Neotropical felids [10-19] because most small mammals are not heavy enough to leave identifiable marks on the soil [20]. In addition, most taxa are much more diverse than large mammals, and only voucher-based identifications are reliable [21]. Several field identification guides have been published for Neotropical mammals to assist wildlife biologists and naturalists in the wild. These guides are based on characteristics of footprints, such as size and shape [9, 22-24], and some are particularly focused on canid [25] and felid [3] footprints.

Felid identifications based on footprint size and shape are more difficult in areas where two or more similar sized species may occur. For example, in the Brazilian Atlantic Forest six wild species are known to occur in sympatry: jaguar (*Panthera onca*), puma (*Puma concolor*), jaguarundi (*P. yagouaroundi*), ocelot (*Leopardus pardalis*), oncilla (*L. guttulus*), and margay (*L. wiedii*) [26-28]. These species have different body size and mass, but with some overlap that allows us to classify them in small (jaguarundi, oncilla, and margay), medium (ocelot) and large size (jaguar and puma) felids [9, 27]. Although adults of large size species, such as jaguar and puma, can be identified by their footprint characteristics [29] — and even individually identified, depending on the substrate [30-32] —

footprint identification of small cats is still a controversial issue [3, 9, 24]. Although many field guides widely used by ecologists and wildlife conservationists propose distinctions among small species based on their footprint shape and size [3, 24], several authors recommend caution in discriminating those species because of the broad overlap in many measurements [9]. For example, in the Brazilian Atlantic Forest, several studies that surveyed felids used those field guides or relied on specialists for footprint identification [17, 33-36], but the contradictory metrics used in each field guide raise questions about the footprint metrics that should be used to identify felids. Moreover, field guides often neglect the known overlap between small felid footprint size and shape, as well as the possible bias introduced by the presence of domestic cats (*Felis catus*), which often become feral [9]. Several authors have adopted more conservative methods, providing identifications to the genus level [11, 15-16, 37-42], or only associating footprints with species when (1) individuals were observed by the team [41, 43], (2) settlers confirmed the species presence in face-to-face interviews [42], or (3) in the presence of complementary methods (*e.g.*, scats collected near footprints are identified by molecular techniques or microscopic analyzes of fur found in feces [44]).

There is therefore some controversy about the accuracy of felid identifications based on footprints, particularly in areas where two or more species similar in size may occur. We tested species discrimination based on footprints, pads, and toe pad measures in order to establish criteria for species identification based on footprint metrics of small to medium-sized felids that inhabit the Brazilian Atlantic Forest, including feral cats.

Methods

Data collection

The study was based on experiments with captive animals, in enclosures of the wildlife recovery center of the *Centro Brasileiro para Conservação dos Felinos Neotropicais da Associação Mata Ciliar*. The Center is located in the Jundiaí County, São Paulo State, Brazil (23°3'20.97" S, 46°59'50.94" W; Fig. 1). Animals used in the experiments were hosted at the recovery center since birth (offspring of adult animals already kept in the center) or received after campaigns to rescue orphans or nomad cubs. We selected seven adult animals per species, with no kinship relation (confirmed by the center's catalogue): ocelot (age: 11.42 ± 4.03 years), margay (6.14 ± 2.03 years), oncilla (5.16 ± 2.60 years), domestic cat (7.4 ± 3.4 years). For jaguarundi (4.5 ± 0.5 years) we only used four animals, the total hosted in the recovery center.

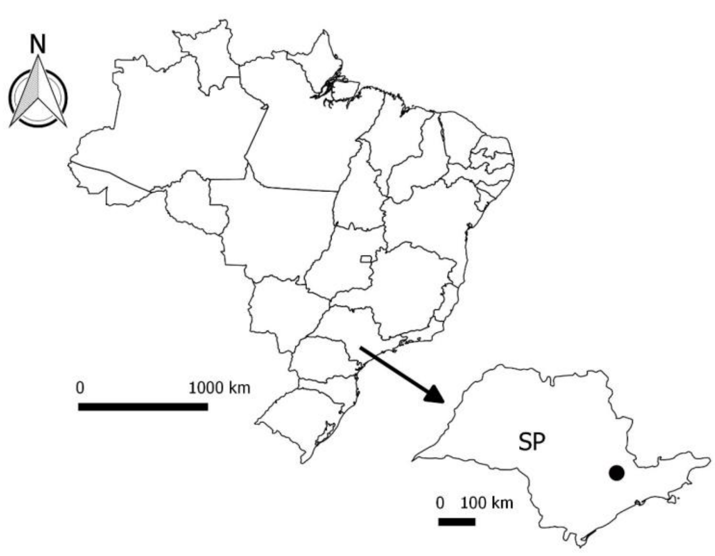

Fig. 1. Location of the "*Centro Brasileiro para Conservação dos Felinos Neotropicais da Associação Mata Ciliar* (●), Jundiaí county, São Paulo state (SP), Brazil.

We first tested for differences in footprints between the most common soft substrata in the study area: humid fine sand and humid red clay (mud). This comparison was performed using seven domestic cats as models to minimize the stress on wild animals associated with handling.

To collect domestic cat footprints in red clay and sand, animals were induced to walk over a container (15 × 1.0 m) with a thin layer of 0.5 cm of clay and through an area of soil with 80 cm^2 of sand (0.5 cm in depth), respectively. For each animal we selected the best front paw and hind paw footprint (*i.e.,* better marked, with obvious edges) from the animal's right paws, which were measured using a caliper accurate to 0.02 mm. We obtained eight different measurements (Fig. 2): Total length (TL); Total width (TW); Main pad length (MPL); Main pad width (MPW); Distance between the main pad border and the closest toe pad border (MPB-TPB); Distance between the lateral toe pad borders (DLTPB); Toe pad length (TPL); and Toe pad width (TPW). For each footprint, MPB-TPB, DLTPB, TPL and TPW values represent the sum of all toe measurements in the footprint. Thus, values of these four variables presented in appendices 1 and 4 represent means and standard deviations of the sum for the measurement of the toe.

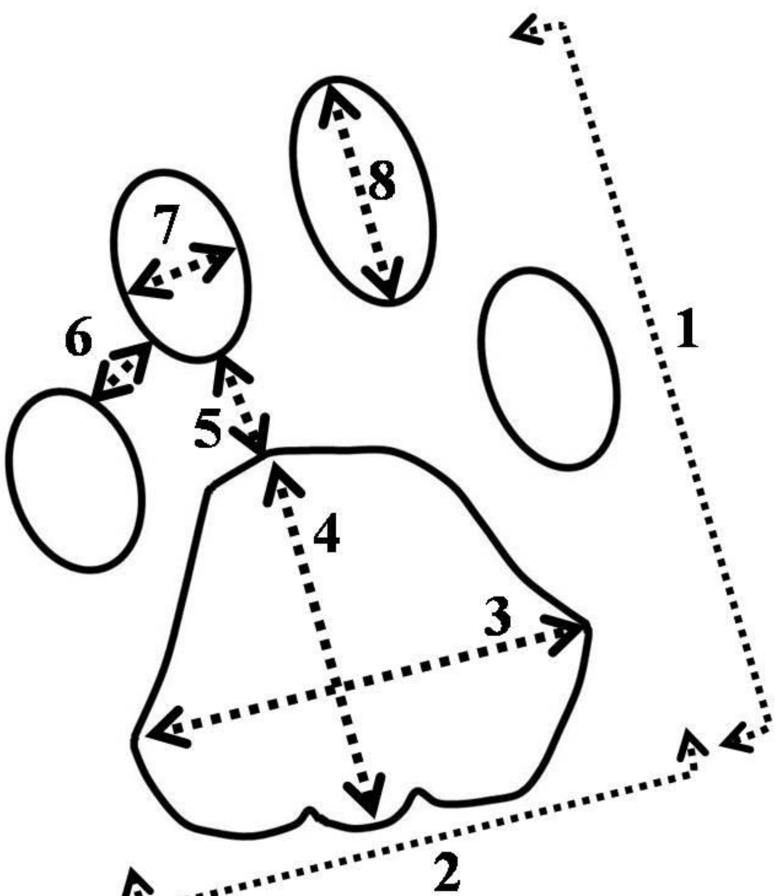

Fig. 2. Measurements taken from felid footprints. 1 - Total length (TL); 2 - Total width (TW); 3 - Main pad width (MPW); 4 - Main pad length (MPL); 5 - Distance between the main pad border and the closest toe pad border (MPB-TPB): 6 - Distance between the lateral toe pad borders (DLTPB); 7 - Toe pad width (TPW); 8 - Toe pad length (TPL).

Since no differences between such metrics were found between domestic cat footprints in sand and red clay (see results), we focused our analysis only on wild felid sand footprints. Two strategies were used to register wild felid footprints: (1) a 80 cm^2 sand layer (0.5 cm in depth) was set in paths commonly used by the studied animals; (2) when animals avoided walking on the soil or moved more randomly, an 80 cm^2 wood platform, covered with 0.5 cm of sand, was set near the entrance of their resting sites, often on trees. To maximize the success of the experiment and reduce the number of trials (*i.e.,* minimize the stress) bait was added to the sand plots (*e.g.,* raw meat).

We registered the aforementioned eight metrics plus five others: 1) the product of the total length by the total width (TL × TW), representing an index of the total area of the footprint [45]; 2) the ratio of the total length by the total width, an index of the footprint shape (TL / TW [45]; *i.e.,* values > 1 indicate an elongated footprint, ratios equal to 1 designate a round or squared footprint, and ratios < 1 are characteristics of wider footprints); 3) the ratio of the toe length and the toe width, representing a toe shape index (TPL / TPW), which is an important metric in species differentiation by several authors [3, 24]; 4) and 5) the product and the ratio of the main pad length by the width (MPL × MPW; MPL / MPW), respectively. Thus, we tested the efficiency of 13 footprint metrics to discriminate wild felid species in the Brazilian Atlantic Forest.

Data analysis

We first tested whether the 13 variables were normally distributed, and whether their variances were homogeneously distributed using Shapiro--Wilk's and Levene's test, respectively [46]. None of the variables presented significant deviation from the normal distribution ($p > 0.05$), but TPL, TPW, DLTPB, and TL/TW presented heterogeneity of variances ($p < 0.05$).

We then compared domestic cat's footprint metrics between sand and clay substratum using ANOVA for repeated measures [47]. After excluding clay experiments from the analysis (see results), we tested for differences in the 13 metric variables among all studied species by using a multifactorial ANOVA [47]. Interspecific differences were tested by two *post-hoc* tests: *Tukey* test (*Q*) for variables with homogeneity of variances; and *Dunnet test* (T3) for variables that presented heterogeneity of variances [48].

To assess the efficiency of each of the 13 variables in discriminating among the different species, we used Classification Trees, a non-parametric alternative to discriminant analysis that does not require a prior variable selection and is robust to outliers [49-50]. Because some of the tested variables presented heterogeneity of variances, even after data transformation (*e.g.,* DLTPB), this ordination method was more suited to the data structure, allowing us to predict a discrete category *(i.e*., species), based on classification variables (*i.e.,* metrics). Classification Trees are a graphical representation, composed by nodes or leaves, and branches, as a result of consecutive binary decisions using several hierarchic models [49]. In each Classification Tree node the following information is provided: decision values for the continuous variables that allow the division into categories (values lower than those indicated in the tree node for a specific variable imply following the left branch of the tree); number of observations that are transferred into the next decision node; node number; and name of the discriminated group within the categorical variable (in our case, felid species) (Fig. 3 and 4). For each discriminating variable, a value ranging from 0 to 100 was assigned, representing its potential importance in identifying species (see [49]). All analyses were performed using the software Statística 8.0 [51] and SPSS [52].

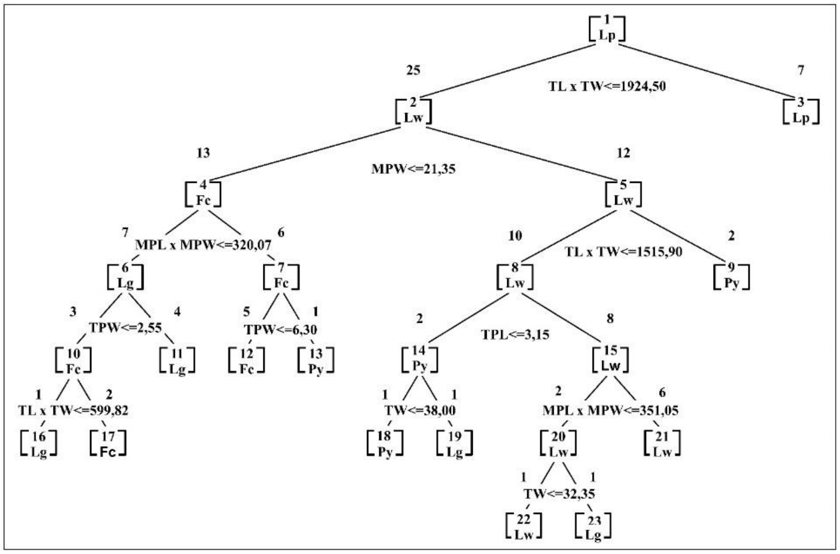

Fig. 3. Binary Classification Tree, based on front footprint measurements for five felid species inhabiting Brazil's Tropical Forest. Lp – ocelot (*Leopardus pardalis*); Lw – margay (*Leopardus wiedii*); Lg – oncilla (*Leopardus guttulus*); Py – jaguarundi (*Puma yagouaroundi*); Fc – domestic cat (*Felis catus*); TW – Total width; TL × TW – product of the total length by the total width; MPW – Main pad width; MPL × MPW – product of the main pad's length by the width; MPB-TPB – Distance between the main pad border and the closest toe pad border; DLTPB – Distance between the lateral toe pad borders. In each tree node (a rectangle in the figure) is represented the rank/number of the node as well as the acronym of the variable used to discriminate groups/species. Each tree branch connects two nodes and shows the number of observations (*i.e.,* individuals) that are transferred to the next node. The decision criteria associated with the discriminant categorical variable is presented below each node (individuals with higher values than those indicated are included in the right branch and those with lower values in the left one).

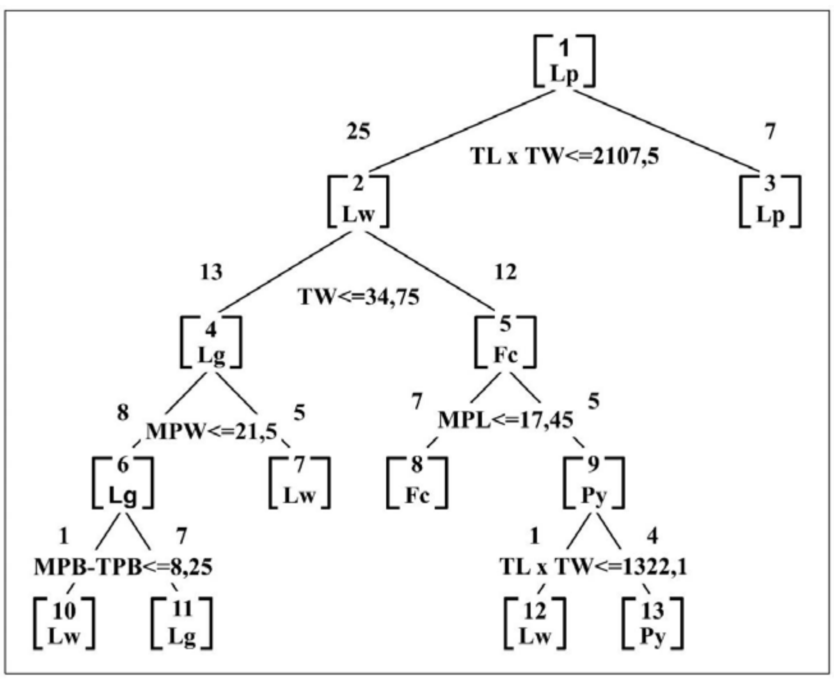

Fig. 4. Binary Classification Tree, based on the hind footprints metrics for five felid species inhabiting Brazilian Atlantic Forest. Lp – ocelot (*Leopardus pardalis*); Lw – margay (*Leopardus wiedii*); Lg – oncilla (*Leopardus guttulus*); Py – jaguarundi (*Puma yagouaroundi*); Fc – domestic cat (*Felis catus*); TW – Total width; TL × TW – product of the total length by the total width; MPW – Main pad width; MPL - Main pad length; MPB-TPB – Distance between the main pad border and the closest toe pad border. In each tree node (a rectangle in the figure) is represented the rank/number of the node, as well as the acronym of the variable used to discriminate groups/species. Each tree branch connects two nodes and shows the number of observations (*i.e.,* individuals) that are transferred to the next node. The decision criteria associated with the discriminant categorical variable is presented below each node (individuals with higher values than those indicated are included in the right branch and those with lower values in the left one.

Results

The means and standard deviations for the 13 footprint metrics of the considered felid species are presented in Table 1 and Appendix 1. We did not detect any significant difference between the footprint measurements of domestic cats in sand or red clay ($F = 45.77$; $p = 0.108$). Thus, the remaining analyses were focused only on footprints from soft sand.

Table 1 Mean and standard deviation (± SD) for footprint measurements.

Taxa[1]	Front paw[2]			
	TL (mm)	TW (mm)	TL × TW (mm²)	TL / TW (mm)
Lp	50.30 ± 4.58	54.26 ± 6.22	2735.44 ± 448.00	0.93 ± 0.12
Lw	32.20 ± 2.07	39.00 ± 5.48	1263.62 ± 240.01	0.83 ± 0.08
Lg	26.79 ± 3.83	31.86 ± 6.57	871.29 ± 286.18	0.85 ± 0.11
Py	35.12 ± 3.93	40.65 ± 4.78	1435.91 ± 276.39	0.86 ± 0.09
Fc – Sand	26.87 ± 3.77	32.07 ± 4.69	839.20 ± 212.74	0.84 ± 0.07
Fc – Red clay	28.00 ± 1.20	29.03 ± 2.16	812.71 ± 65.03	0.96 ± 0.07
	Hind paw			
Lp	51.26 ± 4.30	24.26 ± 5.78	2591.727 ± 529.88	1.02 ± 0.08
Lw	33.41 ± 5.64	19.51 ± 5.43	1112.57 ± 231.38	1.00 ± 0.15
Lg	27.94 ± 4.93	15.04 ± 2.71	832.70 ± 221.71	0.95 ± 0.12
Py	40.07 ± 1.71	21.10 ± 3.17	1587.35 ± 323.34	1.03 ± 0.14
Fc – Sand	34.17 ± 1.02	16.17 ± 1.28	1382.70 ± 167.96	0.84 ± 0.07
Fc – Red clay	35.46 ± 0.89	17.20 ± 1.51	1418.74 ± 137.13	0.89 ± 0.05

1 - Lp – ocelot (*Leopardus pardalis*); Lw – margay (*Leopardus wiedii*); Lg – oncilla (*Leopardus guttulus*); Py – jaguarundi (*Puma yagouaroundi*); Fc – domestic cat (*Felis catus*). 2 - TL – Total length; TW – Total width.

The ANOVA showed that ocelot presented bigger front and hind footprints than all other species, although the size of the hind main paw (MPL and MPW) was similar to that of margay and jaguarundi (Appendices 2 and 3). Moreover, the distance between the borders of the lateral toe pad (DLTPB) in ocelot was similar to that of other species. A similar pattern was observed for the distance between the main pad border and the closest toe pad border (MPB-TPB), although differences were detected between ocelot and jaguarundi (Appendix 4).

Regarding the smaller felids, jaguarundi showed larger front and hind footprints (TL × TW) than oncilla, and greater front footprint and hind footprint total width than domestic cat (Appendices 2 and 3). Toe pads revealed high interspecific variation between metrics, with the exception of ocelot that always presented bigger toe pads, especially main pads (Appendix 4). The ratio between footprint total length and width was not significantly different (Appendices 1 and 4), indicating that the shape of the footprint in these species is similar. Ocelot front toe pads were wider (*i.e.,* width bigger than length) than those of oncilla and domestic cat, while domestic cat showed also wider hind toe pads than margay and oncilla (Appendix 4).

The results were confirmed by the classification tree analysis, which managed to classify all (100%) of the individuals analyzed, without detected errors during classification, based on the front and hind paw footprints (Fig. 3 and 4). Ocelot was separated from the remaining small felid species in the first node, based on the area of the front and hind footprints (TL × TW), which were always larger than 1,924.5 mm² and 2,107.5 mm², respectively (Fig. 3 and 4; Appendix 5). The remaining felids showed an overlapping heterogeneity of metrics (Appendix 5), making identification based on a single measurement less accurate. The accuracy was only improved by using simultaneously several metric criteria. For both front and hind footprints, the measurements that most helped to identify the species were the total length and width of the footprint and the length and width of the main pad (Fig. 5).

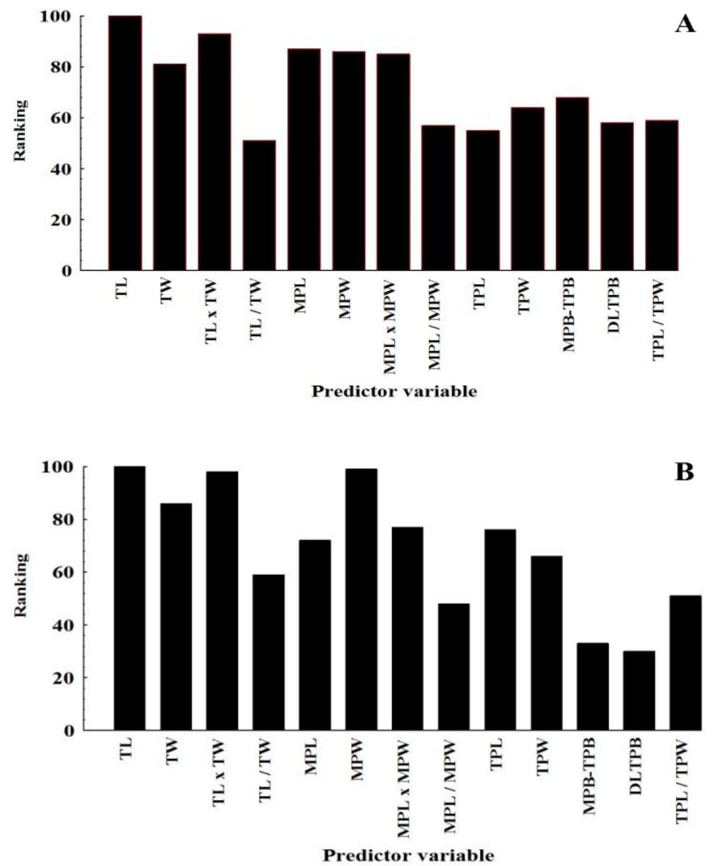

Fig. 5. Ranking of footprint variables from the front (A) and hind (B) paws, based on their contribution to the discrimination of Brazil's Atlantic Forest felids. TL – Total length; TW – Total width; TL × TW – Product of the total length and total width; TL / TW – the ratio of the total length by the total width; MPL – Main pad length; MPW – Main pad width; MPL × MPW – Product of the main pad's length by the width; MPL / MPW – Ratio of the main pad's length by the width; TPL – Toe pad length; TPW – Toe pad width; MPB-TPB – Distance between the main pad border and the closest toe pad border; DLTPB – Distance between the lateral toe pad borders; TPL / TPW - Ratio of the toe length by the toe width.

Discussion

Our initial tests revealed that the size and shape of domestic cat front and hind footprints were not different between the two substrata tested (*i.e*., sand and red clay). Although it is often recognized that footprint size and shape vary with the type of the substratum [53], when comparing footprints within the same substrate it is assumed that the differences found derive from variation in the footprint size and shape, and not from a substratum effect.

One important result of this study is that, with the exception of ocelot, footprints of the domestic cat are similar to those of other small wild felids, corroborating Becker and Dalponte [9]. This is particularly important for surveys in anthropic areas, where domestic or feral cats can occur and bias results. Wildlife biologists using only footprints to confirm species presence in such environments should be aware of this bias and adapt their sampling strategy to minimize it (*e.g.,* use multiple monitoring approaches). Although Bertrand and Morisot [54] used five measurements to differentiate ocelot, oncilla and margay, the authors did not describe the percentage of identification success among species, reporting only the general percentage for all species combined; their results seem to show a clear separation only between small (oncilla and margay) and medium cats (ocelot) (see Fig. 3 in [54]).

Ocelot, a larger and heavier carnivore (body and tail length 102.4 –136.9 cm; body mass 7.2–16.5 kg [1, 27]), presented larger front and hind footprints and is the only felid in our study that could be accurately distinguished from the remaining species based on footprint measurements alone. Classification trees based on front and hind footprints distinguished 100% of felid tracks, with no size overlap with other felids. Our data show that felid footprints with an area of the front and hind paws larger than 1,924.5 mm^2 and 2,107.5 mm^2, respectively, should be considered a track of ocelot. However, this identification is only accurate if the study area is not inhabited by jaguars or pumas, whose juveniles may have footprints with measurements that overlap those of the ocelot in our study. The identification of the remaining small felids had a lower accuracy, with frequent overlap of most of the metrics considered.

We cannot confirm some of the results and criteria for species identification based on footprints mentioned by other authors. For example, Oliveira and Cassaro [3] reported that, besides footprint total length and width, the distance between toe pads and the distance between the main pad and the closest toe pads are discriminant variables. Our data show great overlap of such metrics among species, with the exception of ocelot, which always presented significantly higher values. Thus, from our data it was impossible to distinguish small felids based on footprint total size and pad size, and configuration as well. This limitation is enhanced in field studies because it is impossible to distinguish between front and hind footprints in such conditions (unless sand plots are used in combination with camera traps). Moreover, Oliveira and Cassaro [3] and Morro-Rios et al. [24] note that the toe pads shape of ocelot, margay and domestic cat are more oval than pointed, which may be used as an identification criteria. Our data do not corroborate these results, as we recorded a wide shape variation between species. Nevertheless, ocelots showed wider toe pads than oncilla and domestic cat, with the latter wider than margay and jaguarundi. However, we advise some caution in the use of such criteria. Another author [24] describes the jaguarundi footprint as being small, with an oval main pad (with a triangular shape less defined and three lumps on the hinder edge), and four round toe pads, forming a semi-circle in front of the main pad. No such format was detected in any of the footprints we collected from this species.

Other studies focused only on small felids [23] stating that jaguarundi footprints could be distinguished from those of other Brazilian small cats by their slightly sharpened main pad and toe pads slightly apart. We could not find such differences among species, even considering larger felids such as ocelot. Identifications of jaguarundi in the wild, without other sighting data (*e.g.,* animal observations, photographs) may only be possible when only oncilla and domestic cat are also present, because the former has a front footprint significantly larger than the latter species. As our data revealed, jaguarundi show great overlap in their measurements with other small felids, with the probability of accurate identifications significantly lower than 100%.

Many investigations have reported occurrence and distribution range extensions for felids in the Brazilian Atlantic Tropical Forest, based on footprint identification [18, 33-39, 43, 55-56] from different field identification guides (*e.g.,* [3, 9, 22-24, 57-59]). However, none of the above-mentioned studies have used other complementary approaches to confirm their results (*e.g.,* camera trap, molecular analyzes of scats). Some field guides suggested that wildlife biologists should identify footprints based on the prior knowledge of the local assemblage. Nevertheless, some authors have recognized the bias associated with felid footprint identification, conservatively including in their surveys microscopic analyzes of fur found in scats detected near the footprints [44], while others have identified footprints only to the genus level (*Leopardus* sp.), have provided inaccurate identifications (small cats; [11, 15-16, 39, 41-42], or even did not consider small felid footprints [60].

The high overlap in footprint measurements in this and other studies [9], and the bias associated with this approach, were also detected for other taxa. For example, Angeli et al. [45], working with *Mazama* sp. (Artiodactyla) in the Brazilian Atlantic Forest, reached the same conclusions.

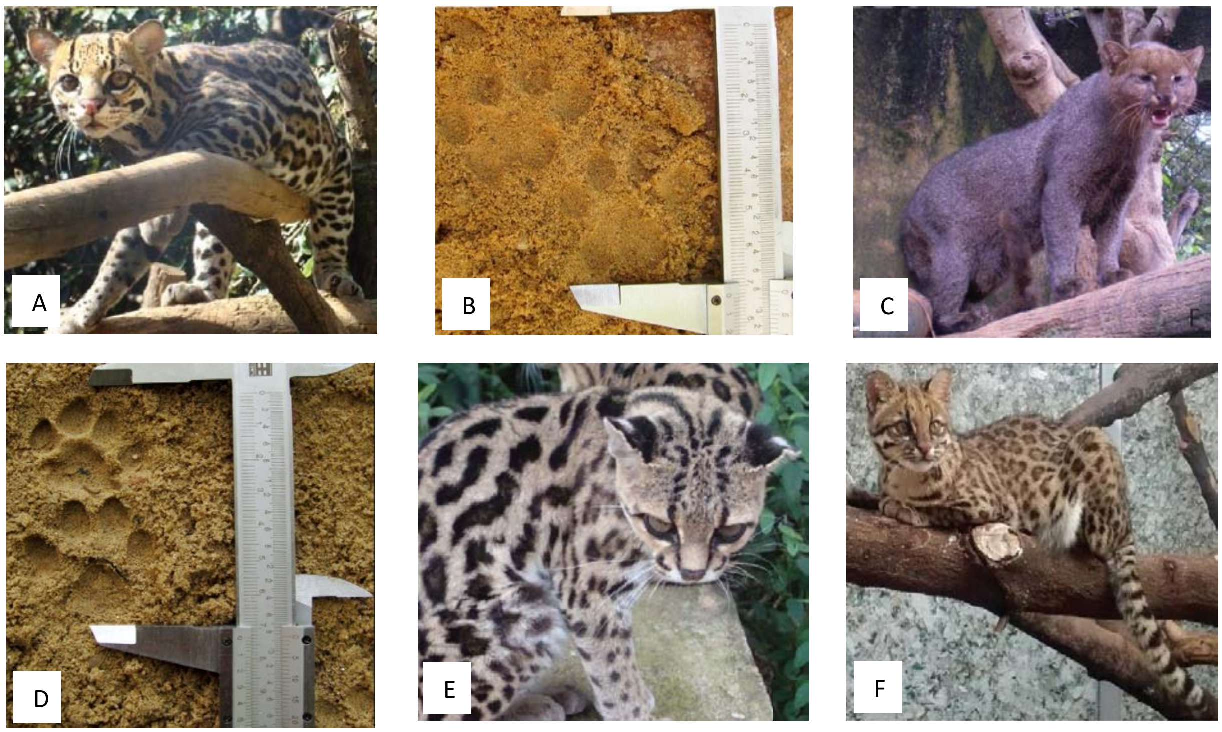

Fig. 6. Wild felid species tested in the present study and some examples of footprints printed in sand. A - Ocelot (*Leopardus pardalis*); B – Ocelot footprint; C – Jaguarundi (*Puma yagouaroundi*); D – Jaguarundi footprint; E – Margay (*Leopardus wiedii*); F – Oncilla (*Leopardus guttulus*) (Photos: William D. Carvalho).

Implications for conservation

The Brazilian small felids studied here (Fig. 6) have very similar footprints in size and shape (except the ocelot), and the use of only these criteria for confirming the species presence in a particular area may be error-prone [9]. Consequently, we suggest more caution to improve presence data quality, thus assuring that the conservation value of a particular area, particularly for small felids, is properly assessed. We suggest restricting identification to higher taxonomic levels (*e.g.*, genus) or size groups (*e.g.,* small felids), or adopting a multidisciplinary sampling strategy to increase the accuracy of identification. For example, in surveys or monitoring studies including felids, footprint detection should be used in association with camera-trapping (together with sand plots or in the same track as footprint surveys), scat collection and identification using molecular ecology techniques [8, 16], and face-to-face interviews with local people reporting visual observation of species or hunting activities.

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Appendix 1. Mean and standard deviation (± SD) for the main and toe paws measurements.

Taxa[1]	Front paw[2]								
	Main pad				Toe pad			MPB-TPB (mm)	DLTPB (mm)
	MPL (mm)	MPW (mm)	MPL × MPW (mm^2)	MPL / MPW (mm)	TPL (mm)	TPW (mm)	TPL / TPW (mm)		
Lp	29.30 ± 3.31	33.63 ± 5.54	998.70 ± 249.64	0.88 ± 0.08	15.85 ± 2.50	14.21 ± 4.07	1.19 ± 0.33	3.80 ± 1.46	4.02 ± 1.32
Lw	17.80 ± 2.15	23.28 ± 1.90	416.73 ± 77.28	0.76 ± 0.07	10.61 ± 0.31	7.85 ± 0.16	1.35 ± 0.15	4.66 ± 0.30	4.84 ± 0.45
Lg	14.17 ± 2.63	19.51 ± 2.16	279.54 ± 75.72	0.72 ± 0.10	10.58 ± 1.52	7.33 ± 1.40	1.48 ± 0.28	4.05 ± 1.35	3.44 ± 1.20
Py	17.65 ± 2.53	23.00 ± 3.04	409.33 ± 105.19	0.77 ± 0.10	11.42 ± 1.83	8.38 ± 1.10	1.38 ± 0.28	5.00 ± 1.73	4.75 ± 2.30
Fc – Sand	15.87 ± 3.29	20.35 ± 0.59	322.03 ± 64.09	0.78 ± 0.17	10.00 ± 1.24	6.75 ± 0.77	1.49 ± 0.19	3.58 ± 1.18	3.02 ± 1.50
Fc – Red clay	15.93 ± 2.04	18.10 ± 1.37	289.98 ± 53.72	0.87 ± 0.07	10.02 ± 1.11	7.09 ± 0.78	1.41± 0.12	2.26 ± 0.69	2.06 ± 0.95
	Hind paw								
Lp	17.19 ± 2.98	11.99 ± 1.71	764.72 ± 306.80	0.84 ± 0.17	17.19 ± 2.98	11.99 ± 1.71	1.44 ± 0.25	5.77 ± 2.64	4.27 ± 1.92
Lw	10.69 ± 1.11	7.67 ± 0.59	451.29 ± 144.05	0.84 ± 0.21	10.69 ± 1.11	7.67 ± 0.59	1.39 ± 0.11	5.50 ± 2.20	4.05 ± 1.72
Lg	10.47 ± 1.48	7.68 ± 1.65	289.46 ± 86.34	0.80 ± 0.11	10.47 ± 1.48	7.68 ± 1.65	1.39 ± 0.25	5.12 ± 1.88	3.38 ± 1.10
Py	12.45 ± 1.59	8.34 ± 1.06	482.94 ± 108.94	0.93 ± 0.10	12.45 ± 1.59	8.34 ± 1.06	1.50 ± 0.21	6.63 ± 3.56	4.44 ± 3.17
Fc – Sand	13.16 ± 1.87	8.24 ± 0.93	311.35 ± 30.23	0.83 ± 0.04	13.16 ± 1.87	8.24 ± 0.93	1.59 ± 0.21	5.08 ± 1.38	4.60 ± 1.39
Fc – Red clay	11.54 ± 0.70	8.30 ± 0.80	367.35 ± 55.99	0.80 ± 0.02	11.54 ± 0.70	8.30 ± 0.80	1.69 ±0.12	4.71 ± 0.97	5.28 ± 3.16

1 - Lp – ocelot (*Leopardus pardalis*); Lw – margay (*Leopardus wiedii*); Lg – oncilla (*Leopardus guttulus*); Py – jaguarundi (*Puma yagouaroundi*); Fc – domestic cat (*Felis catus*). 2 - MPL – Main pad length; MPW – Main pad width; MPB-TPB – Distance between the main pad border and the closest toe pad border; DLTPB – Distance between the lateral toe pad borders; TPL – Toe pad length; TPW – Toe pad width.

Appendix 2. ANOVA and *post-hoc* tests (*Tukey - Q*) results for comparisons between front footprints metrics.

Taxa[1]	Footprint[2]								Main pad[2]							
	TL (mm)		TW (mm)		TL × TW (mm^2)		TL / TW (mm)		MPL (mm)		MPW (mm)		MPL × MPW (mm^2)		MPL / MPW (mm)	
ANOVA	F = 44.3 *p* < 0.001		F = 15.94 *p* < 0.001		F = 37.97 *p* < 0.001		F = 1.03 *p* = 0.405		F = 30.64 *p* < 0.001		F = 19.29 *p* < 0.001		F = 28 *p* < 0.001		F = 2.03 P = 0.121	
Post-hoc	*Q*	*p*	*Q*	*p*	*Q*	*p*	*Q*	*p*	*Q*	*p*	*Q*	*p*	*Q*	*p*	*Q*	*p*
Lp x Lw	11.34	<0.001	6.10	0.002	10.72	<0.001	2.27	ns	9.55	<0.001	7.25	<0.001	9.45	<0.001	2.54	ns
Lp x Lg	14.73	<0.001	8.95	<0.001	13.57	<0.001	1.83	ns	12.56	<0.001	9.89	<0.001	11.68	<0.001	3.36	ns
Lp x Py	9.51	<0.001	5.44	0.006	9.46	<0.001	1.53	ns	9.67	<0.001	7.45	<0.001	9.57	<0.001	2.39	ns
Lp x Fc	14.68	<0.001	8.87	<0.001	13.56	<0.001	2.15	ns	11.15	<0.001	9.30	<0.001	10.98	<0.001	2.16	ns
Lw x Lg	3.38	ns	2.85	ns	2.85	ns	0.44	ns	ns	ns	2.64	ns	2.22	ns	0.82	ns
Lw x Py	1.83	ns	0.66	ns	1.25	ns	0.74	ns	ns	ns	0.20	ns	0.12	ns	0.15	ns
Lw x Fc	3.33	ns	2.77	ns	2.84	ns	0.12	ns	ns	ns	2.05	ns	1.52	ns	0.37	ns
Py x Lg	5.22	0.009	3.51	ns	4.11	0.054	0.30	ns	ns	ns	2.44	ns	2.10	ns	0.97	ns
Py x Fc	5.17	0.010	3.43	ns	4.09	0.055	0.61	ns	ns	ns	1.85	ns	1.40	ns	0.22	ns
Lg x Fc	0.005	ns	0.08	ns	0.01	ns	0.31	ns	ns	ns	0.58	ns	0.69	ns	1.20	ns

1 - Lp – ocelot (*Leopardus pardalis*); Lw – margay (*Leopardus wiedii*); Lg – oncilla (*Leopardus guttulus*); Py – jaguarundi (*Puma yagouaroundi*); Fc – domestic cat (*Felis catus*). 2 - TL – Total length; TW – Total width; MPL – Main pad length; MPW – Main pad width; ns – not significant).

Appendix 3. ANOVA and *post-hoc* test (*Tukey - Q*) results for comparisons between hind footprint measurements.

Taxa[1]	Footprint[2]								Main pad[2]							
	TL (mm)		TW (mm)		TL × TW (mm^2)		TL / TW (mm)		MPL (mm)		MPW (mm)		MPL × MPW (mm^2)		MPL / MPW (mm)	
ANOVA	F = 28.04 $p < 0.001$		F = 19.13 $p < 0.001$		F = 27.94 $p < 0.001$		F = 1.82 $p = 0.156$		F = 4.61 $p = 0.006$		F = 5.10 $p = 0.004$		F = 7.26 $p < 0.001$		F = 0.43 $p = 0.784$	
Post-hoc	*Q*	*p*	*Q*	*p*	*Q*	*p*	*Q*	*p*	*Q*	*p*	*Q*	*p*	*Q*	*p*	*Q*	*p*
Lp x Lw	9.45	<0.001	8.26	<0.001	10.23	<0.001	0.36	ns	2.52	ns	3.30	ns	4.05	0.059	0.01	ns
Lp x Lg	12.35	<0.001	10.05	<0.001	12.16	<0.001	1.39	ns	4.90	0.01	5.14	0.010	6.14	0.001	0.65	ns
Lp x Py	5.92	0.002	5.18	0.009	6.94	<0.001	0.11	ns	1.68	ns	3.38	ns	3.64	ns	1.22	ns
Lp x Fc	9.05	<0.001	4.59	0.020	8.28	<0.001	3.43	ns	4.29	0.04	4.90	0.015	5.82	0.003	0.23	ns
Lw x Lg	2.89	ns	1.78	ns	1.93	ns	1.02	ns	2.37	ns	1.83	ns	2.09	ns	0.65	ns
Lw x Py	3.52	ns	3.08	ns	3.28	ns	0.48	ns	0.84	ns	0.08	ns	0.40	ns	1.23	ns
Lw x Fc	0.40	ns	3.67	ns	1.94	ns	3.07	ns	1.77	ns	1.60	ns	1.76	ns	0.23	ns
Py x Lg	6.42	0.001	4.87	0.010	5.21	0.009	1.51	ns	3.22	ns	1.75	ns	2.50	ns	1.88	ns
Py x Fc	3.12	ns	0.59	0.006	1.33	ns	3.55	ns	2.61	ns	1.52	ns	2.17	ns	1.46	ns
Lg x Fc	3.30	ns	5.46	ns	3.88	ns	2.04	ns	0.60	ns	0.23	ns	0.32	ns	0.42	ns

1 - Lp – ocelot (*Leopardus pardalis*); Lw – margay (*Leopardus wiedii*); Lg – oncilla (*Leopardus guttulus*); Py – jaguarundi (*Puma yagouaroundi*); Fc – domestic cat (*Felis catus*). 2 - TL – Total length; TW – Total width; MPL – Main pad length; MPW – Main pad width; ns – not significant).

Appendix 4. ANOVA and *post-hoc* test results for comparisons between front and hind toe pad measurements.

Taxa[1]	Toe pads[2]											
	Front paw						Hind paw					
	TPL (mm)	**TPW (mm)**	**TPL / TPW (mm)**	**MPB-TPB (mm)**		**DLTPB (mm)**	**TPL (mm)**	**TPW (mm)**	**TPL / TPW (mm)**	**MPB-TPB (mm)**		**DLTPB (mm)**
ANOVA	F = 43.10 $p < 0.001$	F = 58.44 $p < 0.001$	F = 6.16 $p < 0.001$	F = 6.57 $p < 0.001$		F = 6.09 $p < 0.001$	F = 53.82 $p < 0.001$	F = 52.28 $p < 0.001$	F = 4.09 $p = 0.003$	F = 1.69 $p = 0.154$		F = 1.45 $p = 0.221$
***Post-hoc*[3]**	*p*	*p*	*p*	*Q*	*p*	*p*	*p*	*p*	*p*	*Q*	*p*	*p*
Lp x Lw	<0.001	<0.001	ns	2.89	ns	ns	<0.001	<0.001	ns	0.57	ns	ns
Lp x Lg	<0.001	<0.001	<0.001	0.84	ns	ns	<0.001	<0.001	ns	1.39	ns	ns
Lp x Py	<0.001	<0.001	ns	4.04	0.034	ns	<0.001	<0.001	ns	1.85	ns	ns
Lp x Fc	<0.001	<0.001	<0.001	2.63	ns	ns	<0.001	<0.001	ns	1.81	ns	ns
Lw x Lg	ns	ns	ns	2.05	ns	0.02	ns	ns	ns	0.81	ns	ns
Lw x Py	ns	ns	ns	1.14	ns	ns	0.015	ns	ns	2.43	ns	ns
Lw x Fc	ns	ns	ns	5.53	<0.001	0.004	<0.001	ns	0.01	1.23	ns	ns
Py x Lg	ns	ns	ns	3.20	ns	ns	0.005	ns	ns	3.24	ns	ns
Py x Fc	0.03	0.04	ns	3.68	<0.001	0.03	ns	ns	ns	3.66	ns	ns
Lg x Fc	ns	ns	ns	3.47	ns	ns	<0.001	ns	0.01	0.42	ns	ns

1 - Lp – ocelot (*Leopardus pardalis*); Lw – margay (*Leopardus wiedii*); Lg – oncilla (*Leopardus guttulus*); Py – jaguarundi (*Puma yagouaroundi*); Fc – domestic cat (*Felis catus*). 2 - TPL – Toe pad length; TPW – Toe pad width; MPB-TPB – Distance between the main pad border and the closest toe pad border; DLTPB – Distance between the lateral toe pad borders; ns – not significant). 3 - *Tukey* – *Q* and *p* values; *Dunnet* – *p* values.

Appendix 5. Species classified by type of measure (%) and number of branches (in parenthesis).

Metrics[1]	Front paw[2]					Hind paw[2]				
	Lp	Lw	Lg	Py	Fc	Lp	Lw	Lg	Py	Fc
TL	-	-	-	-	-	-	-	-	-	-
TW	-	14.58 (22)	28.57 (19 and 23)	25.00 (18)	-	-	-	-	-	-
TL × TW	100 (3)	-	14.28 (17)	50.00 (9)	28.57 (16)	100 (3)	14.28 (12)	-	100 (13)	-
TL / TW	-	-	-	-	-	-	-	-	-	-
MPL	-	-	-	-	-	-	-	-	-	100 (8)
MPW	-	-	-	-	-	-	71.42 (7)	-	-	-
MPL × MPW	-	85.71 (21)	-	-	-	-	-	-	-	-
MPL / MPW	-	-	-	-	-	-	-	-	-	-
MPB-TPB	-	-	57.14 (11)	-	-	-	14.28 (10)	100 (11)	-	-
DLTPB	-	-	-	25.00 (13)	71.42 (12)	-	-	-	-	-
TPL	-	-	-	-	-	-	-	-	-	-
TPW	-	-	-	-	-	-	-	-	-	-
TPL / TPW	-	-	-	-	-	-	-	-	-	-
Total (%)	100	100	100	100	100	100	100	100	100	100

1 - TL – Total length; TW – Total width; TL × TW – product of the total length by the total width; TL / TW – the ratio of the total length by the total width; MPL – Main pad length; MPW – Main pad width; MPL × MPW – Product between main pad length and main pad width; MPB-TPB – Distance between the main pad border and the closest toe pad border; DLTPB – Distance between the lateral toe pad borders; TPL – Toe pad length; TPW – Toe pad width; TPL / TPW - the ratio of the toe length by the toe width. 2 - Lp – ocelot (*Leopardus pardalis*); Lw – margay (*Leopardus wiedii*); Lg – oncilla (*Leopardus guttulus*); Py – jaguarundi (*Puma yagouaroundi*); Fc – domestic cat (*Felis catus*).