



## EFFECT OF THE PANTANAL'S FLOODING HISTORY IN MORPHOMETRIC ASPECTS OF THE SOLITARY PARASITOID *Campsomeris dorsata* (HYMENOPTERA: SCOLIIDAE)

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**Abstract:** The shape of an organism and the variation between related groups lie at the core of understanding evolution and interactions between phenotypes, genotypes, and environmental spaces. Due to the relief conditions and hydrological profile of the region, the areas inside the Pantanal have different flood histories in respect to the flood duration and the amount of water retained in the plain. The objective of this work was to evaluate the effect of the environmental flooding gradient on the geometric morphometry variation of *Campsomeris dorsata* (Hymenoptera: Scoliidae) wings in Pantanal, to understand if the variations in spatial distribution related to the flooding history interferes in the morphology of the wings by identifying where, how, and to what magnitude such changes occur. The wings were mounted between blade and coverslip, labeled, and prepared for morphometric measurements. The points of intersection of wing veins (landmarks) were determined using a stereoscopic microscope coupled with a camera. The linear measurements of the landmarks were transformed using Procrustes to remove the size effect, leaving only the shape of the wings. The transformed data was evaluated using PCA and MANOVA to identify if there were differences in relation to the geographical location of occurrence. Thirty-three male *C. dorsata* wings were measured, and there was a clear separation between 3 distinct wing form groups along the Pantanal distribution. The variation in wing shape could be associated with selection from local environmental conditions in areas with distinct flooding histories, influencing migratory aspects among populations within the Brazilian Pantanal. The data for this small species, that has low dispersal capacity, is solitary, and presents an intimate relationship with soil characteristics, which directly reflects flooding aspects in the Pantanal, only reinforces the need to conserve more areas in the Brazilian Pantanal, since genetic diversity is an important factor for conservation.

**Keywords:** geometric morphometric; landmarks; wasp; wetland regime; wings.

### INTRODUCTION

The shape of an organism and the variation between related groups of species lie at the core of understanding evolution and the interactions between phenotypes, genotypes, and environmental spaces (Jungers *et al.* 1995). Morphometry refers to the statistical study of the variation of form in relation to the causal factors, that

is, morphometry does not only quantify biological forms, but infers about the causes of such forms. Structures of biological origin can be analyzed using geometric morphometry techniques, which consider the shape of morphological variation (Roggero & Passerin d'Entrèves 2005, Aytikin *et al.* 2007, Cardini *et al.* 2007). These studies allow many possibilities, ranging from wing veins, insect shells, to all kinds of skeletal structures, shells, and scales,

to dinosaur footprint fossils (Fornel & Cordeiro-Estrela 2012).

In the past few decades, mainly after the morphometric revolution, many geometric morphometric works have been published in different areas of biology. Such studies, that quantify organisms, may be related to ontogeny (Carvalho *et al.* 2011, Komatsu *et al.* 2018), intraspecific geographic variation (Roggero & Passerin d'Entrèves 2005, Cardini *et al.* 2007), taxonomy, systematics or evolution of morphological characters (Cardini *et al.* 2007, Salas-Lopez *et al.* 2017, Katzke *et al.* 2018), sexual dimorphism (Pretorius 2005, Olivier & Aranda 2018), ecomorphology or functional and biomechanical issues of biological forms (Jungers *et al.* 1995). Several sets of acquisition, processing, and analyzing methods used to preserve geometric information from the original data are based on Cartesian coordinates of anatomical landmarks on the  $X,Y = 2D$  or  $X,Y,Z = 3D$  plane (Fornel & Cordeiro-Estrela 2012).

Such variations in morphometric characteristics could be a reflection of genetic aspects within and among populations (Roggero & Passerin d'Entrèves 2005, Cardini *et al.* 2007, Francoy *et al.* 2011), adaptations to environmental gradients (Nunes *et al.* 2015), food stress (Gumiel *et al.* 2003), or exposure to extreme physical factors within the environment (Gumiel *et al.* 2003). Wing morphology has been used in taxonomic and systematic studies of insects (Danforth 1989) and has helped to detect sexual, intra- or inter-specific variations, and environmental variations in Hymenoptera (Pretorius 2005, Cardini *et al.* 2007, Barour *et al.* 2011, Katzke *et al.* 2018).

Hymenoptera (Arthropoda) is one of the largest orders in the Insecta class, with about 120 thousand known species (Goulet & Huber 1993, LaSalle & Gauld 1993). It comprises bees, ants, and wasps, with a high abundance of species in terrestrial environments. Among them are Scoliidae, wasps with cosmopolitan distribution, however, little is known about the biology of Scoliidae representatives, whose larvae are ectoparasitoids of underground Coleoptera larvae (Melo *et al.* 2012). Females are highly adapted to dig in the soil to reach hosts, which, when located (Inoue & Endo 2008), are paralyzed and receive a single egg. Some observations indicate that the female wasp can move the host deeper into the soil and prepare

a chamber before oviposition, which serves as a breeding cell (Nowell 1915). Adults of the genera *Scolia* and *Campsomeris* (~30 species) are often seen feeding on flowers (Ciotek *et al.* 2006) in the neotropical region (Bradley 1957). *Campsomeris dorsata* (Fabricius 1787) is distributed in Tropical and Subtropical South America, Northern to Southern Mexico, and the Eastern Islands of the Greater Antilles (Bradley 1957). Despite its wide distribution, little is known about the species' biology and, to date, no research has been done to describe morphometric variations or how possible environmental variations could influence such measurements.

The Pantanal is the world's largest tropical floodplain, which is greatly covered by water during the flood season (Silva & Abdon 1998). Due to the relief conditions and hydrological profile of the region, the areas inside the Pantanal have different flood histories in respect to the flood duration and the amount of water retained in the plain (Gonçalves *et al.* 2011), requiring both flora and fauna to adapt to this differential flood pulse (Hamilton 2002).

Since *C. dorsata* has an intimate relationship with the physical conditions of the soil and host availability, the historical effect of flooding in the different wetland regions are thought to have caused morphometric differences in *C. dorsata*. The objective of this study was to evaluate the effect of the environmental flooding gradient on the morphometric variation of *C. dorsata* wings from different floodplain areas in the Pantanal, to understand if the variations in the spatial distribution of historical flooding influences the morphology of *C. dorsata* wings by identifying where, how, and to what magnitude such changes occurred. We hypothesized that the differences between the localities with different flood histories would be reflected in the geometric morphometry of *C. dorsata* wings.

## MATERIAL AND METHODS

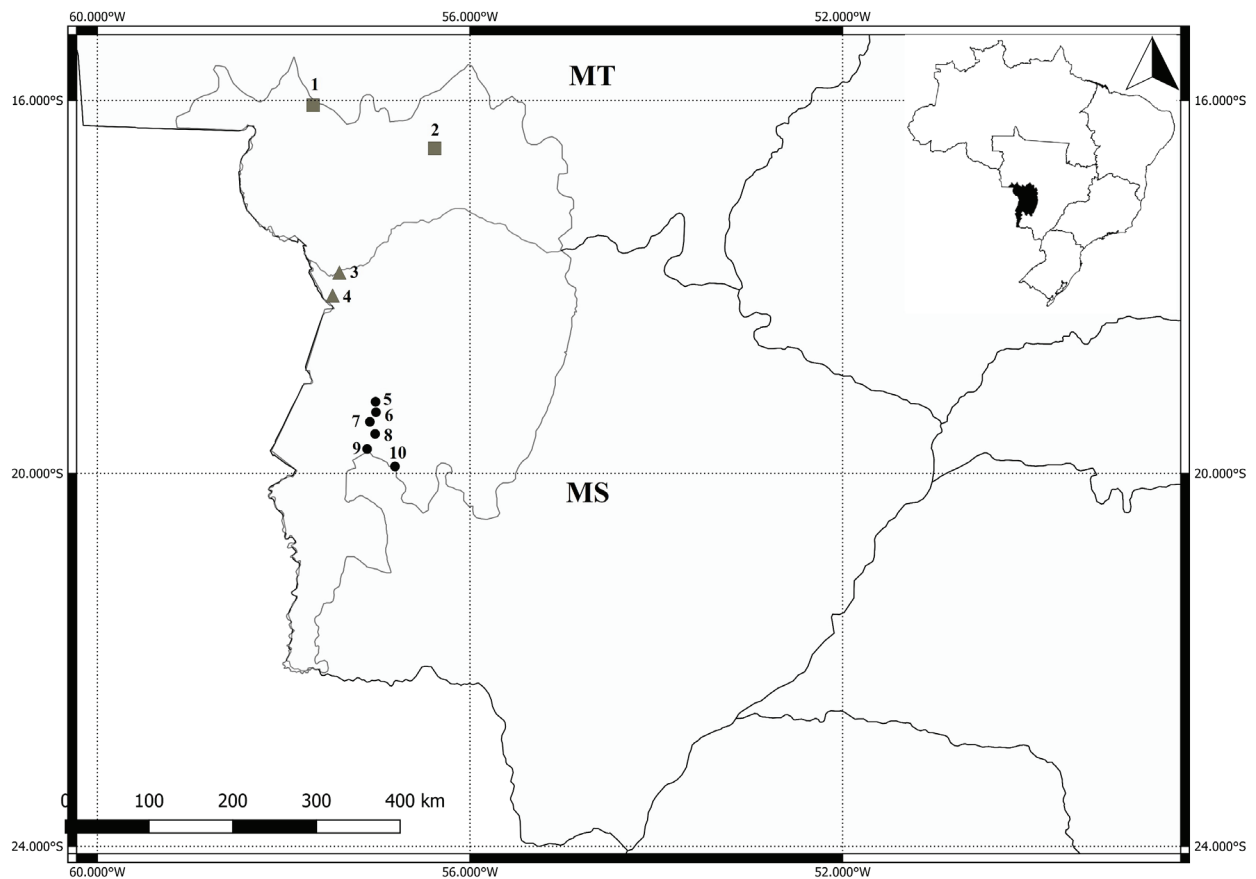
### Study area

The Pantanal, with an area of approximately 150,000 km<sup>2</sup>, is the largest continuous floodplain on the planet (Pott & Pott 1994) and occupies 38.21% of the Upper Paraguay basin (Silva & Abdon 1998). The climate of the region is tropical subhumid, with

dry winters and rainy summers and average annual precipitation between 1,000 and 1,500 mm in the Northern region and between 1,000 and 1,200 mm annually in the Southern region (Köppen 1948). The floristic composition is a mosaic of *Cerrado*, *Cerradão*, natural fields, floodplains, and aquatic environments such as freshwater or brackish ponds, rivers, ebbs, and corbels (Silva & Abdon, 1998, Silva *et al.* 2000). In the Northern region, the *Cerrado* is the dominant phytophysiology, followed by seasonally flooded semideciduous forests, semideciduous forests, and deciduous seasonal forests (Junk *et al.* 2006), while natural fields and flooded fields cover most of the Southern region (Silva *et al.* 2000), as well as seasonal forests and riparian forests (Pott *et al.* 2011).

### Samples

Throughout the inventory, 19 areas were sampled (Aranda & Aoki 2018), however the *C. dorsata* specimens used in this work were collected from 10 of the sampled Pantanal areas (Figure 1) during the wet (hot and humid) season from November 2015 to March 2016. Collections were authorized by the MMA and ICMBio (n: 48939-3 dated 05/11/2015). For analysis, the areas were separated into three groups according to their physical proximity and were established in relation to the different flood history (Aranda & Aoki 2018). Geographical groups were established in relation to the different flood history taking into account the intensity and duration of the flood. G1 is characterized by medium intensity and short duration, G2 by high



**Figure 1.** Collection points of *Campsomeris dorsata* (Hymenoptera: Scoliidae) distributed in the Brazilian Pantanal from November 2015 to March 2016. 1: Pousada Sinímbu (Cacéres, MT), 2: Estância Seu Preto (Poconé, MT), 3: Pantanal National Park (Poconé, MT), 4: RPPN Homem Pantaneiro Institute (Corumbá, MS) (Corumbá, MS), 6: Arara-Azul Farm (Corumbá, MS), 7: Santa Clara Farm (Corumbá, MS), 8: Pantanal-UFMS Study Base, MS), 10: Salobra Village (Miranda, MS). ■ corresponds to geographical group 1, ▲ geographical group 2 and ● geographic group 3. Geographical groups were established in relation to the different flood history.

intensity and long duration and G3 by medium intensity and medium duration.

Malaise traps (flight interception) and Möerick baits (attractive trays) were used to capture the specimens. In each area, 10 Malaise traps and 10 sets of Möerick, in yellow and red colors containing ethylic-aqueous solution, were installed within a radius of approximately 2 km. Each set of Moerick baits contained 8 trays of each color (15 x 12 x 6 cm length/width/height each). The traps were exposed for approximately 50 hours per area, totaling 500 h of Malaise and 1,000 h of Möerick per area (500 h Möerick yellow, 500 h Möerick red). Additionally, active searches were carried out using entomological nets for a total of 50 hours in each area.

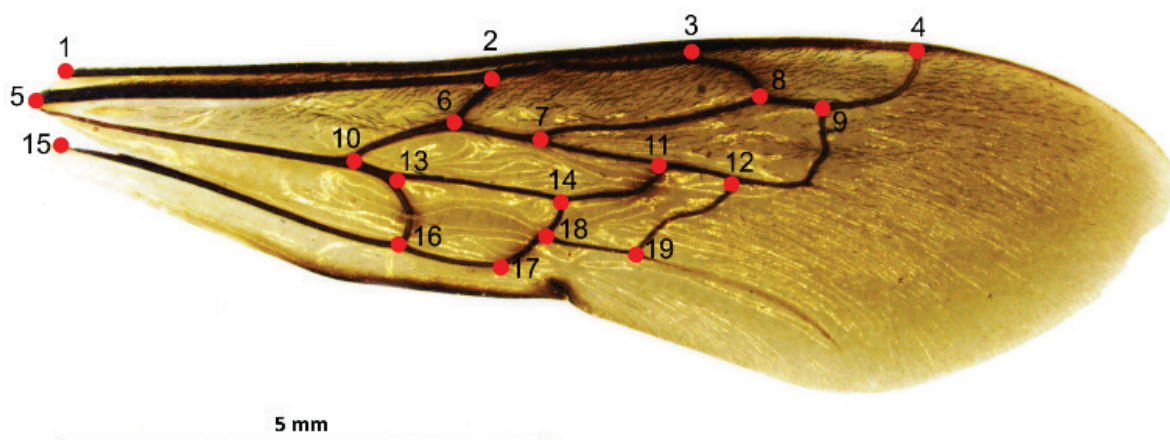
### Morphometric measurements

The specimens were stored in 70% alcohol and appropriately labeled. In previous screenings, the material was identified, and the males were separated and processed, where the right anterior wing was removed from all specimens using an entomological scalpel. Only males were used since they were more abundant than females and since the species presents sexual dimorphism. The wings were mounted between blade and cover slip, labeled, and prepared for morphometric measurements. With the prepared wing, the points of vein intersections (landmarks) were determined using a stereomicroscopic microscope Bel photonics XTL series coupled with an Opticam © OPT 5.1 MP camera, where 19 positions of the

landmarks were measured (Figure 2) using OPTHD 3.7 software to place positions on the cartesian plane X and Y. The wings were always aligned in the same position and the landmarks' positions in both planes were noted.

### Statistical analyses

To interpret the wing data, the linear measurements of the landmarks were transformed by Procrustes to remove the effect of size, measuring only the shape of the position taken. Procrustes analysis is commonly used to compare the shape of two or more objects, where the shape is characterized mathematically by removing the effects, scale, and rotation via a series of transformations (Klingenberg & McIntyre 1998, Debat *et al.* 2000, Klingenberg *et al.* 2002). To identifying where, how, and to what magnitude such changes in wings landmarks occurred, the transformed data was evaluated using a principal component analysis (PCA) and observed the distribution of the X and Y values. Principal deformation means from the PCA were used to verify the landmarks with greatest variation, in the graphics the warmer colors represent the largest variations of landmarks positions. To test the hypothesis that was a separation of individuals in relation to their geographical location and relation to the different flood history of occurrence, the scores of the main axes were tested using MANOVA for comparisons between the pre-established geographical groups. The analyzes were performed using the free software Past® 3.17 (Hammer *et al.* 2001) using the alpha of 0.05.



**Figure 2.** Landmarks of the vein intersections on the right anterior wing of a male *Campsomeris dorsata* (Hymenoptera: Scoliidae) collected in the Brazilian Pantanal.



## RESULTS

Wings from 33 male individuals ( $\Delta$ ) of *C. dorsata* were measured, nine  $\Delta$  belonged to group one, 11  $\Delta$  belonged to group two, and 13  $\Delta$  to group three. The positions that presented the greatest variations were the landmarks: 8, 10, 11, 12, 14, all in the central-distal region of the wing (Table 1; Figure 3a-b). The distal center positions of the intersections of the veins presented variations in both the X and Y axis and the warmer colors represent the largest variations of landmarks positions. Regarding the distinction of the groups, we observed a separation of the three geographic groups in relation to the

geometric morphometry of the wings (Figure 4A). Group 1 shows a greater distribution of the points in the PCA and may be related to the greater geographical distance between the sampling points. While group 2 and 3 show geographical proximity between the sampling points, in this way the spatial distribution in PCA became more compact, mainly within group 3. The first four axes explained 83% of the variation (Figure 4B) and the first four scores were tested with MANOVA, which showed a significant effect on distinction of the groups ( $F = 5.565$ ,  $p < 0.05$ ) as can be seen in the low overlap of the distribution of the groups in the PCA.

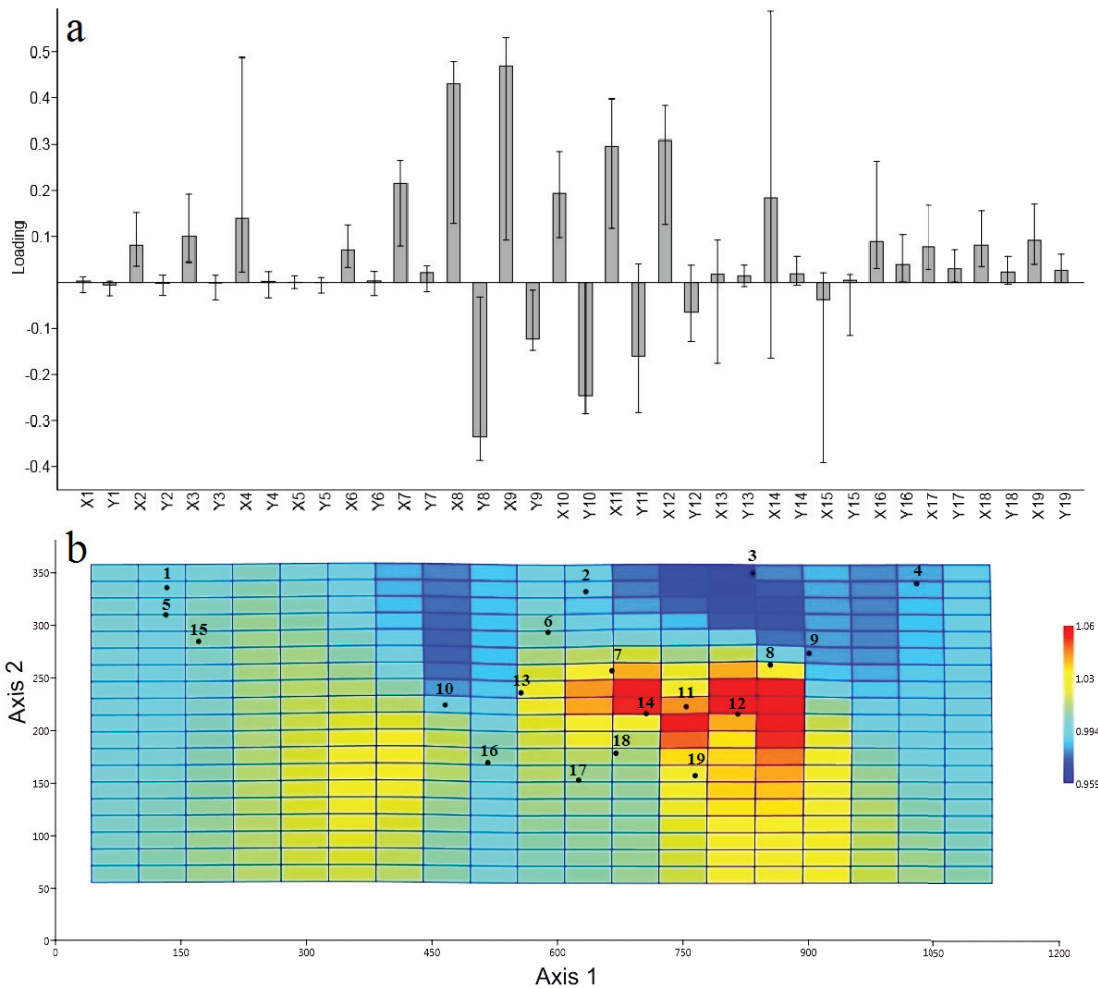
**Table 1.** Mean values and standard deviation (SD) of the X and Y axes positions of the landmarks of *Campsomeris dorsata* (Hymenoptera: Scoliidae) wings from the geographic groups in the Brazilian Pantanal. To G1: Group 1, G2: Group 2, G3: Group 3, see Figure 1.

Axis	G1		G2		G3		General	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
X1	113.87	5.04	121.84	4.18	121.84	4.17	115.41	2.59
X2	580.75	17.83	638.3	12.4	638.3	12.39	615.44	9.8
X3	772	21.65	843.46	16.78	843.46	16.77	815.06	12.24
X4	870.62	112.84	1074.69	21.79	1074.69	21.79	1010.27	35.86
X5	120	5.79	121.53	3.67	121.53	3.67	118.31	2.51
X6	542.25	15.78	589.15	11.67	589.15	11.67	570.27	8.46
X7	625.5	18.39	646.77	41.02	646.76	41.02	645.1	19.38
X8	758.5	87.34	851.76	60.89	851.76	60.89	832.58	36.8
X9	818.5	97.34	876.77	72.71	876.76	72.71	878.37	42.3
X10	372.25	50.97	484.07	37.13	484.07	37.13	446.17	23.13
X11	632.25	58.19	768	49.57	768	49.57	733.31	29.65
X12	737.25	41.03	799.38	57.57	799.38	57.57	794.89	29.18
X13	587.75	54.21	530.69	17.53	530.69	17.53	538.55	17.69
X14	573.37	79.13	690.61	14.28	690.61	14.28	686.75	42.78
X15	202.62	92.85	123.3	4.15	123.3	4.15	153.68	28.26
X16	439.5	50.15	527.07	11.43	527.07	11.43	498.13	16.24
X17	570	23.94	624.92	13.98	624.92	13.98	606.93	10.78
X18	621.5	18.16	675.15	13.5	675.15	13.49	651.55	10.5
X19	710.62	20.00	768.76	15.51	768.76	15.51	745.96	11.07
Y1	134.5	11.45	114.69	2.86	114.69	2.86	121.93	3.84
Y2	132.62	10.17	125.53	8.49	125.53	8.49	125.68	4.81
Y3	115.25	9.88	109.69	8.18	109.69	8.18	108.27	4.72
Y4	125	11.6	121.23	9.32	121.23	9.32	118	5.41
Y5	153.62	10.31	144.92	8	144.92	8.01	147.51	4.69
Y6	168.37	11.07	164.76	8.71	164.76	8.71	164.2	4.99
Y7	190.87	10.47	179.92	9.69	179.92	9.69	181.75	5.29

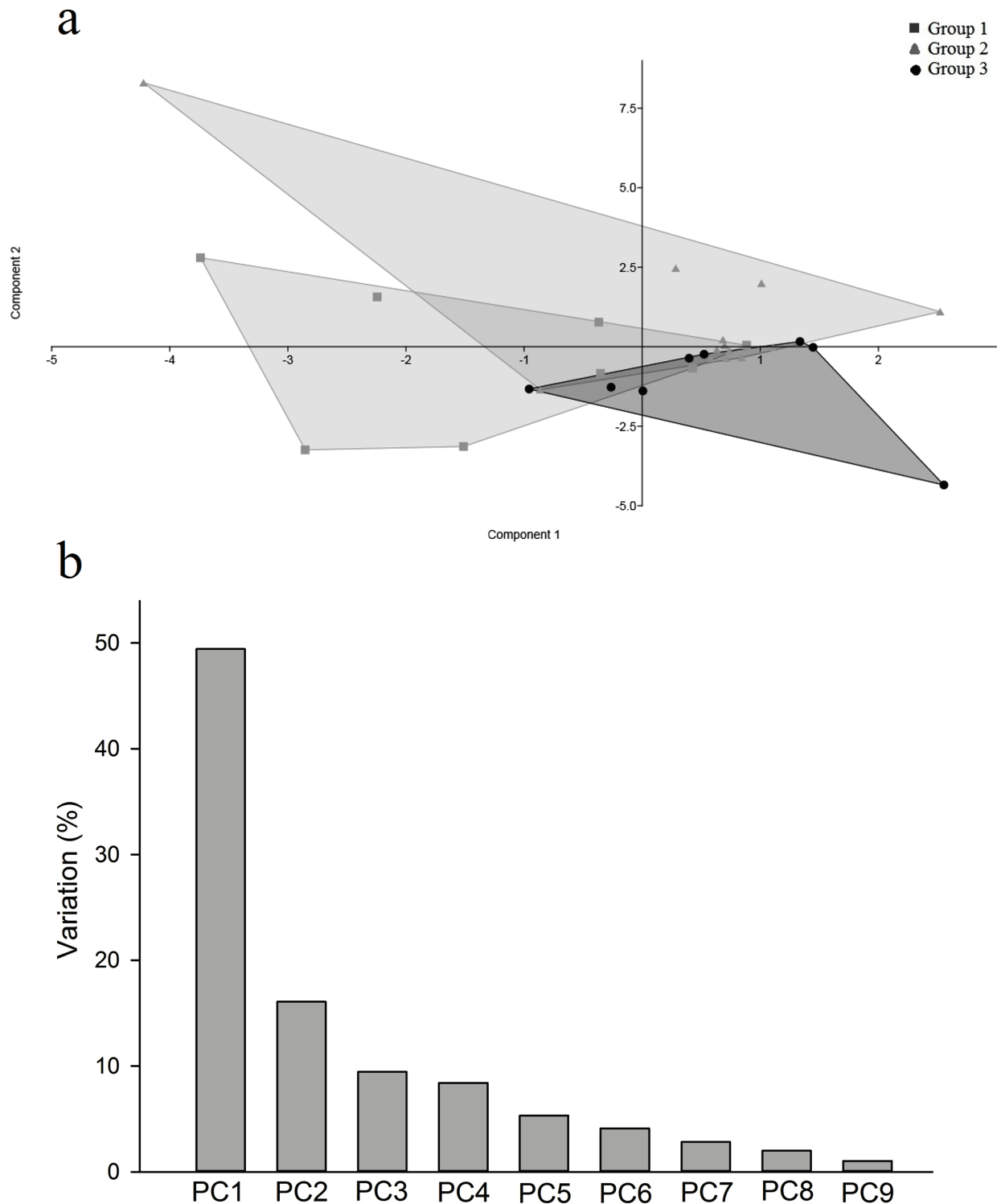
**Table 1.** Continued on next page...

Table 1. ...Continued

Axis	G1		G2		G3		General	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Y8	228	67.98	214.53	56.61	214.53	56.61	198.24	31.3
Y9	199.75	27.57	193.38	22.44	193.38	22.44	185.2	12.68
Y10	257	53.53	246.61	42.09	246.61	42.09	235.17	23.73
Y11	216.5	13.8	266.23	45.21	266.23	45.21	236.07	20.83
Y12	239.12	14.11	255.46	21.69	255.46	21.69	241.89	10.6
Y13	220.62	11.89	225.38	9.42	225.38	9.42	221.17	5.48
Y14	233.12	14.01	247.53	9.62	247.53	9.62	240.65	5.91
Y15	182.12	13.07	164.07	8.81	164.07	8.81	172.68	6.94
Y16	263.62	20.2	308.84	23.86	308.84	23.86	286.89	12.5
Y17	296.62	15.6	310.53	11.07	310.53	11.07	303.58	6.8
Y18	275.12	14.39	284.69	10.09	284.69	10.09	278.31	6.21
Y19	296.12	15	305.61	10.72	305.61	10.72	299.41	6.54



**Figure 3.** Distribution of the X and Y (A) and principal axes loading values (B) of the landings analyzed from the male wings of *Campsomeris dorsata* (Hymenoptera: Scoliidæ) in the Brazilian Pantanal representing locations with greater variations in landmarks. The warmer colors represent the largest variations of landmarks positions.



**Figure 4.** Principal component analyses of the groups based on geographic distances as a function of the 19 landmarks (A) and Principal component scores accounting for variation in forewing (B) analyzed from the males of *Campsomeris dorsata* (Hymenoptera: Scoliidae) in the Brazilian Pantanal. The first four major components represent the majority of variation in the data (83%).

## DISCUSSION

Regardless of wing size, the variations in the positions of points were significant between the areas. There were significant differences in morphometric variation of *C. dorsata* along its Pantanal distribution. Morphometric variation is a good indicator of genetic variation and could be used to evaluate such variation when genetic data is unavailable. Other studies about insects indicate geographic variation in wing shape as an indicator of genetic changes (Hoffmann & Shirriffs 2002, Hoffmann *et al.* 2005). The variation in wing shape could be associated with selection through local environmental conditions in areas with different flooding histories, influencing migratory aspects among populations within the species' range in the Brazilian Pantanal. Due to the presence of intensity and duration of floods, host availability, nesting sites or even soil physical conditions are affecting biological aspects of the species, causing morphological variations in the venation pattern.

In the literature, the different effects of environmental variations on wing shape have been well recorded for various insect groups, being related to natural variations or promoted by man as the effect of urbanization (Hoffmann & Shirriffs 2002, Hoffmann *et al.* 2005, Roggero & Passerin d'Entrèves 2005, Aytakin *et al.* 2007, Sadeghi *et al.* 2009, Banaszak-Cibicka *et al.* 2017, Wells *et al.* 2018), assuming an important role in the genetic control of innumerable genes involved in the development process.

The effect of local environmental changes related to flood pulses within the Pantanal is reflected in the species composition of several taxonomic groups of various forms (Zeilhofer & Schessl 1999, Oliveira & Calheiros 2000, Alho & Silva 2012, Catian *et al.* 2018), as well as in the genetic aspects of some species (Borba *et al.* 2013). Highly dispersed species can compensate for these environmental differences and maintain interlocking populations (Faria *et al.* 2008). However, species with a lower degree of dispersion could be more sensitive to such variations, as is the case for *C. dorsata*. It would be interesting to genetically approach insect populations or other groups with reduced local dispersal capacity in the Pantanal wetland to verify if such a premise is valid.

Due to the biology of Scollidae, *C. dorsata*

presents such variations in the geometric morphometry of wings as a function of the different soil conditions in the areas (environmental factor), or even due to the use of different host species (nutritional factor). Soil characteristics, consequently related to the flood history in the Pantanal, are important for Scollidae wasp, since the kairomones produced by its hosts are more easily detected in less heterogeneous and less compacted soils (Inoue & Endo 2008). Scoliid wasps can locate hosts above-ground (Inoue & Endo 2008), therefore, soil conditions and distinct vegetation formation in relation to the characteristics of the areas which are influenced by the flood pulse, can lead to such morphological responses. Scoliidae males show the patrol behavior of the area in search of newly emerged females, in this way they present the disfigurement in spots due to the availability of the females, not dispersing, on average, over 1 km (Tani & Ueno 2013).

Our data indicates that there are significant variations in the venations of the wings of *C. dorsata*, such variations are distinguished between the groups sampled along the Pantanal, maybe the changes in morphology can be reflected in genetic aspects of *C. dorsata*, a small species that has low local dispersal capacity, is solitary, and presents an intimate relationship with soil characteristics. Consequently, the soil is directly affected by the flood regime in the Pantanal, which reinforces the need for conservation of more areas within the Brazilian Pantanal, since genetic diversity is an important factor for conservation.

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