

Habitat Preference and Effects of Coastal Fragmentation in the Sand-Dwelling Spider *Allocosa brasiliensis* (Lycosidae, Allocosinae)

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Abstract

Allocosa brasiliensis is a sand-dwelling wolf spider considered a good bioindicator to evaluate the quality of coastal dune ecosystems from Uruguay. Habitat fragmentation and human activities have impacted and reduced the Southern Uruguayan coast during the last decades. The aim of the present study was to evaluate the density, surface activity and habitat preference of *A. brasiliensis* in beaches with different human impact. For that purpose, we sampled during the night with head lamps and applied the capture-mark-recapture method. Females were more abundant than males and were the most recaptured sex. The most fragmented beaches showed lower number of burrows and individuals, especially in immatures stages. We found that the most suitable sandy habitat for *A. brasiliensis* should present a vegetation cover optimum of 25% - 50% of the surface. This study could provide tools for the implementation of future management conservation plans of the Southern Uruguayan coastline.

Keywords

Allocosa brasiliensis, Wolf Spiders, Sandy Coast, Bioindicator, Ecology

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1. Introduction

Biodiversity loss as a consequence of human activity is one of the topics of environmental sciences that has focused more attention in the last two decades [1]. Several authors have cited examples of the reduction of biodiversity and abundance of arthropods (Butterflies [2], Crustaceans [3], arthropods assemblages of the sand-dunes [4] [5] among others) associated with the human impact. In Portugal, a study [3] proposed that the dune recovery mechanisms by building artificial shorelines in two sandy beaches studied were the responsible for the change in the macrofaunal assemblages and for the decline of the specialist species that was reflected in a biodiversity loss for this ecosystem. One of the main anthropic actions against conservation of biodiversity is habitat fragmentation in natural landscapes [6]. Habitat fragmentation negatively affects species communities in ecosystems, leading to the reduction of its natural areas, the isolation of their populations, increasing of edge effect, and consequently, causing a trend towards species extinction [7]. Nowadays, a quarter of the world's population lives in coastal areas [5] [8]. This phenomenon, along with the impacts of changes in land use, results in the alteration of coastal ecosystems in many parts of the planet, causing fragmentation and reduction of the natural environments [5] [9] [10]. Coastal areas generally are characterized by narrow shore parallel bands that comprise species assemblages specially adapted to live in changeable climatic conditions and environmental constraints such as strong winds, sand movements, high evaporation, high salinity, and limited nutrients [11] [12].

Sand dunes are distributed worldwide, mainly in tropical and temperate zones, with a great bio-geographical variation [12]. They are located along the littoral in sandy beaches [13]. Coastal dunes are essential links in the ecology of the beaches because they represent the border with the water, where this interface is characterized by the presence of physical, chemical and biological gradients [14]. One key for the conservation of the coastal dunes in fragmented landscapes is the knowledge of the biotic and abiotic components and the ecological relationships between them. The fauna in sandy beaches are dominated by arthropods, where spiders and other arachnids constitute an important part of invertebrate assemblages [7] [15]-[19]. Arthropods have been recognized as suitable ecological indicators of human stress and they have been used in monitoring plans for sandy coastal conservation [4] [20].

The original coastal landscape in Southern Uruguay used to be dominated by a wide sandy coastal strip with fixed and dynamic dunes associated to psammophile vegetation [16]. Since the twentieth century, urbanization reduced dramatically this wide coastal area to only a few meters in several zones along of the 714 km of coast at the South of the country [21]-[24]. This modification caused the reduction or loss of dunes, the replacement of native vegetation by exotic species, mainly *Acacia longifolia* (Andrews) Willd (Fabaceae), *Pinus* spp. (Pinaceae) and *Eucalyptus* spp. (Myrtaceae), and the fragmentation of the coast [25].

Studies carried out in the Uruguayan coast indicated that wolf spiders are abundant representatives of the fauna in sandy dunes [16]. *Allocosa brasiliensis* (Petrunkevitch, 1910) is a very common wolf spider in the Southern Uruguayan coastline. This nocturnal species constructs burrows in the sand [26]-[29], and shows sex-role reversal: males are bigger than females and females are the mobile sex that initiates courtship [30]. Copulation take place inside male burrows [30] [31] and males show reversed sexual cannibalism (they prey on rejected females) [18] [32]. *A. brasiliensis* shows morphological and behavioral features strongly associated to inhabiting the dune lines of natural sandy coasts and it has been catalogued as a good bio-indicator for coastal environments in Southern Uruguay [33]. The close relationship between the conservation of the dune line and the presence of *Allocosa brasiliensis* are strongly linked. Our aim was to know how landscape fragmentation impacts in the availability of a suitable habitat, population dynamics and density of *A. brasiliensis*. This knowledge could be critical for improving the efficiency of restoring plans of the dune lines in the Uruguayan Southern coast.

2. Material and Methods

2.1. Study Area

We chose two coastal sites of dissipative beaches in the coastal strip of Southern Uruguay. Site A was located in the Eastern region of Montevideo city, where beaches along 22 km of coast have been highly modified during several decades. The coastal ecosystem was drastically reduced to less than a hundred meters wide of sandy coast, conserving none or only one line of dunes. Furthermore, the coast has been fragmented in patches by sev-

eral kinds of constructions where sand connections are interrupted [23]. Native psammophile vegetation was mainly reduced to the dune line, mostly represented by *Panicum racemosum* (P. Beauv.) (Poaceae), *Senecio crassiflorus* (Poir.) D. C. (Asteraceae) and *Hydrocotyle bonariensis* Lam. (Apiaceae). The Northern area of the beaches shows exotic vegetation such as *Acacia longifolia* and *Pinus* sp. [16] [33]. In this site, two neighboring beaches were selected for the study: the Mulata beach (M1) (34°53'S, 56°4'W) with 212 m long and Verde beach (M2) (34°53'S, 56°4'W) with 455 m long (Figure 1(A) and Figure 1(B)). These beaches are in process of being incorporated in an environmental beach management system and a restoring plan of the dune lines. Both beaches are separated by a yacht club and a spring along 200 mts. Site B is located in Canelones, 9.5 km to the East from site A. This is a 17 km long of coastline where beaches are wider and less fragmented, mostly with two fixed dune lines with native psammophile vegetation and connected with patches of floodplain plant communities. The edge of the coast with urbanization presents forestation with exotic species similarly to what was indicated above for site A. We selected two beaches with similar length than those chosen for Montevideo: Lagomar (C1) (34°50'S; 55°58'W) and San José de Carrasco (C2) (34°51'S; 55°58'W) (Figure 1(C) and Figure 1(D)). As in site A, both areas are separated 200 m from each other, but in site B there is no interruption of the sandy coast. The temperature during the data collection was between 11.6°C to 25°C in site A and in site B the temperature was between 16.9°C to 26°C.

2.2. Sampling Design

Field work was performed biweekly from October 2009 to January 2010. This period was chosen because it coincided with the reproductive season where the species presents the highest surface activity [28] [30] [31]. Due to its crepuscular habits, we performed night samplings with visual detection of the exemplars by using head lamps. We sampled four plots covering the first line of dunes, the nearest to the coast line, on each beach: (M1 and C1: 50 × 50 m, in small beaches; M2 and C2: 100 × 50 m, large beaches). We counted all walking individuals and burrows of *A. brasiliensis* on each plot. We sexed the individuals and later released them. To estimate individual mobility we used the capture-mark-recapture method, this method has been used to study the surface activity, home range and population dynamics in wolf spiders and other ground hunters species [34]-[37]. We only considered adults and juveniles in penultimate or antepenultimate stage. The marking was done with permanent markers, on the dorsal region of the abdomen. Each mark showed a characteristic color and shape combination that allowed us to identify each specimen when it was recaptured. This method was previously tested in the laboratory where the ink did not cause damage to spiders or changes in their behavior. Data from recaptures were taken 24 hours after spiders being marked and during the study period. Due to bad weather con-

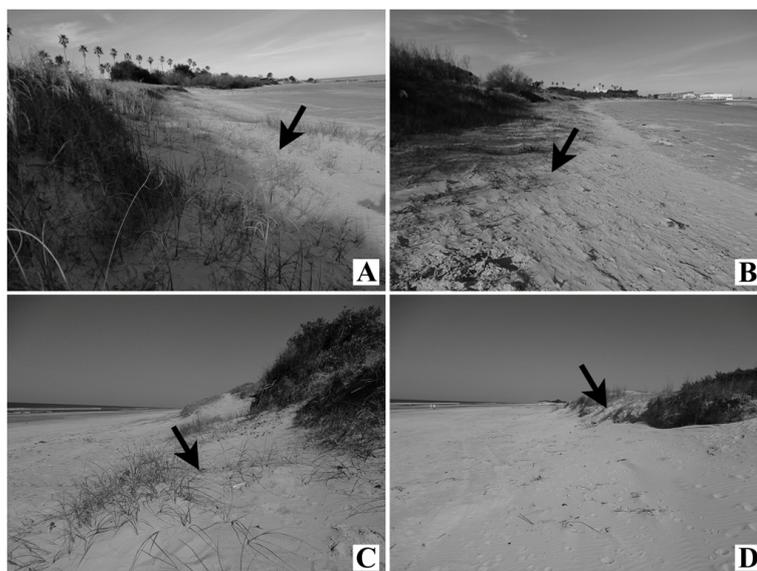


Figure 1. Study areas. A, B, Site A: A = Mulata (M1), B = Verde (M2). C, D, Site B: C = Lagomar (C1), D = San José de Carrasco (C2).

ditions, only in three cases we did not perform the samplings 24 hours after capture, and they were performed between 2 - 5 days after. The spider records were geo-referenced to determine the distance between the capture and recapture sites. Vegetation cover was measured following the Braun-Blanquet method [38]. Ten quadrats (0.25 m^2) were georeferenced where surface activity was reported to be higher, along a transect on each site (A and B). We calculated Braun-Blanquet density score and frequency for each psammophile plant species at each quadrat. Density was calculated as the average value of the Braun-Blanquet score in all the quadrats surveyed by site. The Braun-Blanquet cover scale utilized: r: 1 or few individuals; 1: low abundance, with cover <5%; 2: cover 5% - 20%; 3: cover 25% - 50%; 4: cover 50% - 75%; *: quadrat without vegetation cover.

2.3. Data Analysis

At a regional scale, data were compared between the two sites (A and B) and at local scale between beaches of each site (see [39]). We used spider density to allow comparisons between plots of different sizes. The normality and homogeneity of variances were checked with Shapiro Wilk and Levene tests, respectively [40]. Data distribution did not fit the requirements for parametric tests so we finally used the non parametric test Mann-Whitney U-Test [41] to test the null hypothesis of no difference in density of marked, recaptured and non-marked specimens of *A. brasiliensis* between the sites. We used a hierarchical cluster analysis to explore how the plots were grouped in base to the similarity of the spider density, using the Bray Curtis as similarity index for the construction of the dendrogram (constrained, Unweighted Pair Group Method Average (UPGMA) algorithm and Bootstrap $N = 2000$) [40] [42]. We also applied the Non Metric Dimensional Scaling analysis (NMDS) using the Bray Curtis as similarity [43]. This technique is commonly used in ecological studies, specially to evaluate if the environmental disturbance affects the species composition, association of arthropods with plant species and other relationships between species and other biotic or abiotic variables [40] [44] [45]. The goodness of this method is the stress, which relates the distance between objects in a small space considering its similarity [44] [46]. It is considered that stress values greater than 0.25 are too poor to explain the presence or not of possible patterns that connect the species with the sites [46].

The capture points and the displacement distance of marked individuals were calculated on satellite images using Google Earth (<http://earth.google.com/>). For the study of the suitable area of the species, each plot was divided into four zones based on presence or absence of dunes and by the cover vegetation type: A: dune with psammophile vegetation; B: zone with exotic species of shrubs and trees; C: open sandy areas outside the dune and roads for traffic people through the beach; D: intertidal zone. Based on satellite images, the four zones were delimited in polygons and analyzed with Qgis 2.2. Valmiera [47]. Density of marked spiders in each zones were considered for estimating habitat preference using the Kruskal-Wallis non-parametric analysis of variance. If we found significant differences, the Mann-Whitney test with the Bonferroni correction was applied. To test whether there was a correlation between temperature and the number of specimens observed, we performed a simple linear regression analysis of the density of *A. brasiliensis* in function with the temperature. This relation was analyzed at local and a regional scale. A Chi^2 was calculated for comparing paired frequency data on the base of an expected distribution. Data analyses were performed using Past Paleontological Statistics Software 2.16 [48].

3. Results

3.1. Abundance

In site A, we registered 247 individuals and marked 147 exemplars (54.4% in M2), and in site B we observed 663 individuals and marked 246 individuals (57% in C2) (Table 1). At each beach, the highest abundance and density of this species were found on the dunes (M1 = 89%, M2 = 91%, C1 = 93%, C2 = 77%) (Figure 2).

At a regional scale, spider abundance was higher in site B ($\text{Chi}^2: p = 0.0001$; Mann-Whitney test: $U = 26$; $p = 0.0086$) (Table 1). Differences were also found when comparing the abundance of spiders between beaches of the site A and B with the same size: M1 versus C1 ($U = 32$; $p = 0.02$) and M2 versus C2 ($U = 18.5$; $p = 0.002$). The sex ratio was biased to females both at regional (site A: $U = 135$, $p = 0.0013$; site B: $U = 115.5$, $p = 0.00032$) and local scales (M1: $U = 35$, $p = 0.029$; M2: $U = 34$, $p = 0.027$; C1: $U = 26$, $p = 0.0079$ and C2: $U = 31.5$, $p = 0.018$). At a regional scale female ($U = 242$; $p = 0.343$) and male ($U = 281$, $p = 0.889$) abundances were not significant. The number of burrows was 3 times higher in site B than in site A (Mann-Whitney test, $U = 115$, $p = 0.0003$) (Table 1).

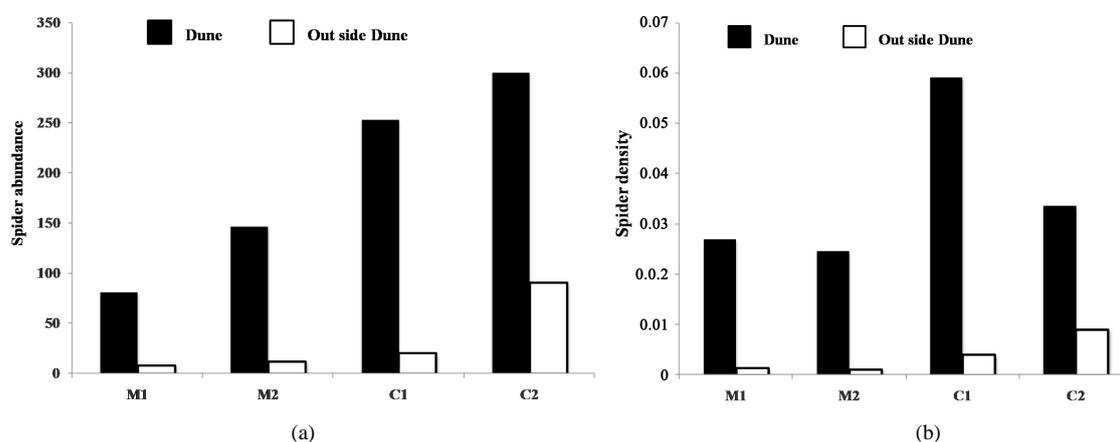


Figure 2. (a) Abundance of exemplars of sand-dwelling wolf spider (*A. brasiliensis*) observed in dunes or outside dunes in the studied beaches; (b) Density of *A. brasiliensis* observed in dunes or outside dunes in the studied beaches.

Table 1. Abundance of specimens of sand-dwelling wolf spider (*A. brasiliensis*) observed in the study sites. MM: marked males, MF: marked females, MI: marked immatures. TM: totally marked, R: recaptures, I: not marked immatures, B: burrows.

Categories	Beaches			
	Site A-M1	Site A-M2	Site B-C1	Site B-C2
MM	12	20	16	13
MF	31	36	48	46
MI	24	24	42	81
TM	67	80	106	140
R	11	1	3	2
I	22	78	167	250
B	26	37	88	101

3.2. Density

We found differences in density between sites A and B ($U = 26$; $p = 0.00856$), but not at a local scale (**Table 2**). The cluster analysis (cophenetic correlation = 0.8822) (**Figure 3**) and the NMDS analysis showed differences between sites A and B (stress index = 0), further indicating that the shortest beach in the most fragmented site (M1) appears clearly separated from the rest of the beaches (**Figure 4**). Furthermore, NMDS indicates that the beaches of the Site B are more similar to each other than beaches of the Site A (**Figure 4**).

3.3. Habitat Preference and Temperature

The records and density of specimens were higher at the dune line (**Figure 2** and **Figure 5**; **Table 3**). The Kruskal-Wallis test showed significant differences in the density of marked exemplars between the four zones of each beach (**Table 4**).

At a local scale, the NMDS analysis showed that zones with different vegetation cover appear as two isolated fragments in site A (M1-M2: stress index = 0.24) conversely to beaches of the site B where zones showed high connection between them (C1-C2: stress index = 0.15) (**Figure 6**). Of all the plots surveyed, the spider density was higher in the line of dunes (**Table 3**), showing significant differences with areas occupied by exotic species of shrubs or trees (**Table 4**). Regarding the existence of a relationship between temperature and spider's density, at a local scale, the beaches did not present a linear relationship. The same was observed when we analyzed the data at a regional scale (Site A: $p = 0.587$; Site B: $p = 0.238$) (**Figure 7(a)** and **Figure 7(b)**). But when we com-

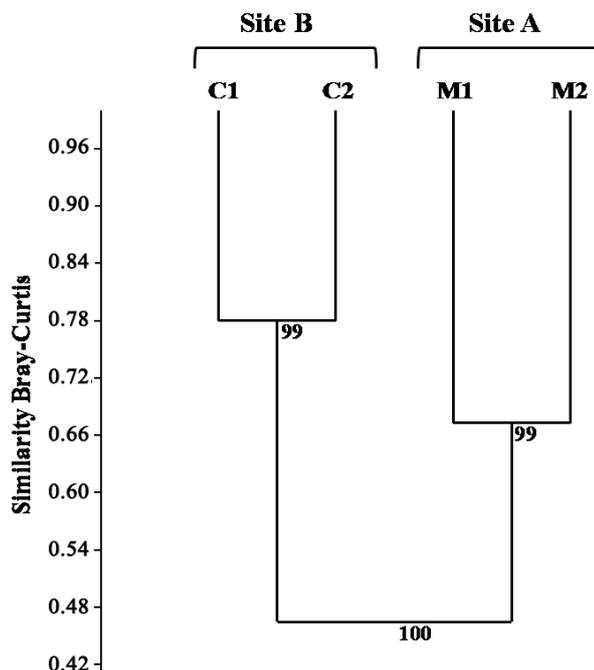


Figure 3. Dendrogram of the relationship of the density *A. brasiliensis* in the studied beaches using the Bray-Curtis similarity index (I. coph. coord: 0.8808). M1: Mulata, M2: Verde, C1: Lagomar and C2: San José de Carrasco.

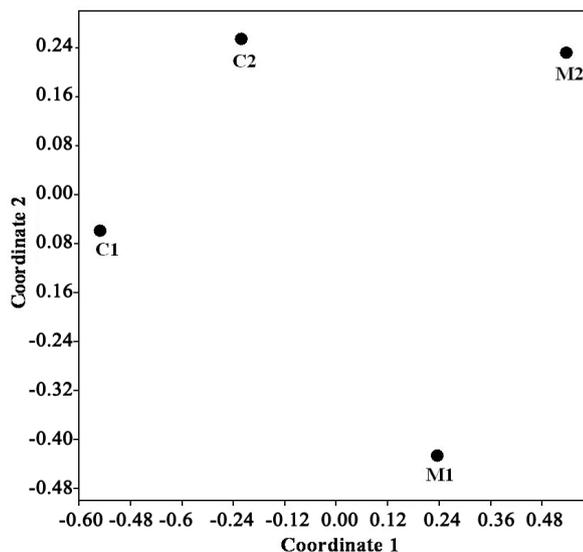


Figure 4. Non-metric multidimensional scaling (NMDS) of the density of *A. brasiliensis* in the four studied beaches using the Bray-Curtis similarity index. M1: Mulata, M2: Verde, C1: Lagomar and C2: San José de Carrasco.

pared all the data set in the study beaches as if it was a single population, we found a mild linear trend between the spider density and temperature ($r = 0.3803$; $p = 0.008$) (Figure 7(c)).

We observed three psammophile plant species in the quadrats. *P. racemosum* presented the higher values of abundance, rating an average of 2.1 (Site B) to 2.5 (Site A) in the Braun-Blanquet cover scale, which represents

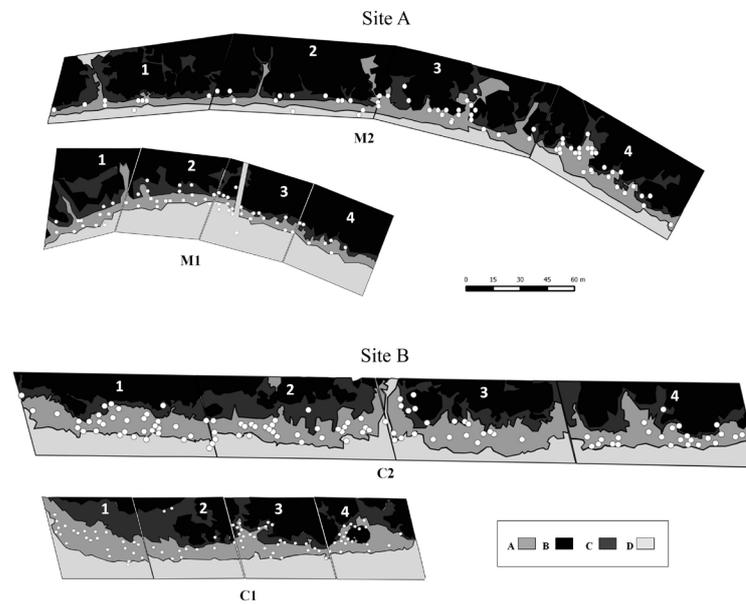


Figure 5. Spatial distribution of marked specimens of *A. brasiliensis* in different vegetation types in beaches of sites A and B. A: dune with psammophile vegetation, B: zone with exotic species of shrubs and trees, C: open sandy areas outside the dune, D: intertidal zone. M1: Mulata, M2: Verde, C1: Lagomar and C2: San José de Carrasco.

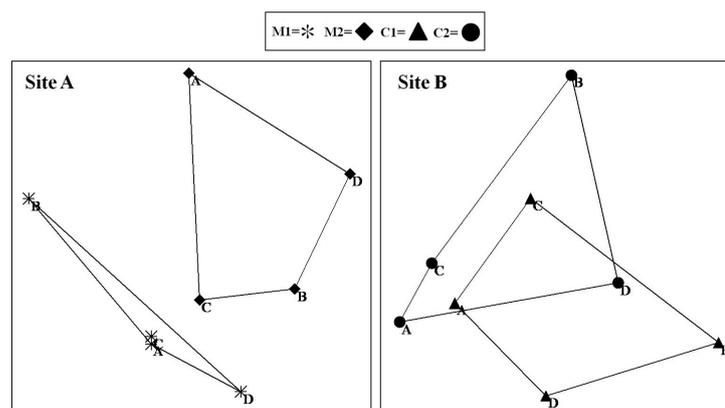


Figure 6. NMDS analysis of habitat preference of *A. brasiliensis* in sites A and B, using the Bray-Curtis similarity index as a measure. M1: Mulata, M2: Verde, C1: Lagomar and C2: San José de Carrasco, A: dune with psammophile vegetation, B: zone with exotic species of shrubs and trees, C: open sandy areas outside the dune, D: intertidal zone.

25% - 50% of the quadrats surface analyzed (Table 5). Furthermore, this species was the most frequent with values of 90% (Site A) to 80% (Site B) of presence in the quadrats analyzed. The others two species registered were *H. bonariensis* and *S. crassiflorus* but with lower frequency and coverage (Table 5).

3.4. Recaptures and Distances Covered

We recaptured 17 exemplars of *A. brasiliensis* along the study (4.3%). Females were the most recaptured sex with 53% of the cases. Highest values of recapture (16.4%) were observed in M1 (site A) (Table 6). We found significant differences in the total number of marked and recaptured individuals between sites A and B ($\chi^2 =$

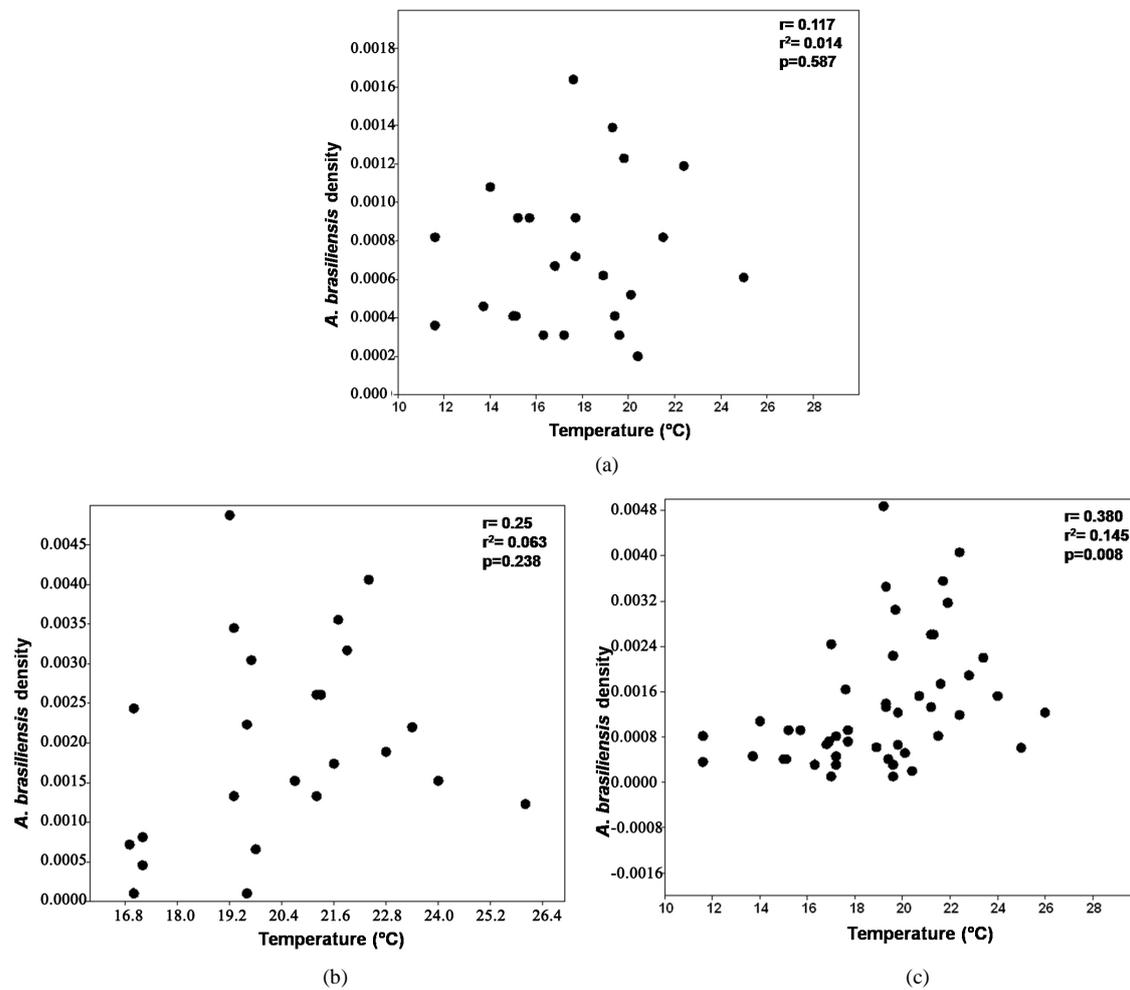


Figure 7. Comparison of the density of the marked and observed exemplars with the temperature in *A. brasiliensis*: (a) Site A; (b) Site B; (c) Both sites.

Table 2. Comparisons of density of *A. brasiliensis* between beaches. U = Mann-Whitney (U test) with the Monte Carlo correction. p = statistical significance. In bold letters, statistically significant values ($p \leq 0.05$).

Beaches	Marked specimens		Immature + marked	
	U	p	U	p
C1 vs. C2	53	0.2851	52	0.2598
M1 vs. M2	40	0.06812	66	0.7501
M1 vs. C1	47	0.1564	33	0.0260
M1 vs. C2	41.5	0.8396	25.5	0.0078
M2 vs. C2	54	0.3114	19	0.00241
C1 vs. M2	32	0.02231	27	0.01014
A vs. B	43	0.0998	27	0.01018

7.41; $p = 0.006$). Most of the specimens were recaptured within 24 hours after marking. M1, showed higher values of recaptures ($N = 11$).

A positive correlation between time and distance of recapture was observed at a regional scale in site B ($n =$

Table 3. Area, abundance and density of *A. brasiliensis* for each zone and beach N: abundance. A: dune with psammophile vegetation, B: zone with exotic species of shrubs and trees, C: open sandy areas outside the dune, D: intertidal zone. a = abundance; d = density. Area in square meters.

Vegetation zones	C1			C2			M1			M2		
	Area	a	d	Area	a	d	Area	a	d	Area	a	d
A	2406	78	0.0324	5560	102	0.0183	1188	35	0.0295	3275	49	0.015
B	2421	3	0.0012	5462	2	0.0004	4143	2	0.0005	10604	9	0.0008
C	1870	21	0.0112	3379	16	0.0047	1834	23	0.0125	2684	21	0.0078
D	2786	4	0.0014	4603	20	0.0043	2300	7	0.003	2317	1	0.004

Table 4. Comparisons of density of *A. brasiliensis* per plot in the studied beaches. Kruskal-Wallis test. p = statistical significance. In bold letters, statistically significant values ($p \leq 0.05$).

Plots	C1				C2				M1				M2			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
A vs B	0.001	0.229	0.001	0.007	0.001	0.0001	0.012	0.001	0.002	0.006	0.098	0.069	0.014	0.039	0.066	0.002
A vs C	0.001	0.79	0.358	0.314	0.0001	3 E-05	0.317	0.014	0.033	0.753	0.974	0.859	0.178	0.437	0.258	0.315
A vs D	0.003	0.070	0.002	0.003	6 E-03	0.004	0.099	0.47	0.071	0.018	0.179	0.069	0.014	0.006	0.002	0.001
B vs C	-	0.229	0.006	0.104	0.003	0.317	0.230	0.148	0.149	0.015	0.097	0.148	0.069	0.223	0.755	0.002
B vs D	0.317	0.317	0.229	0.317	0.015	0.952	0.229	0.006	0.148	0.317	0.684	-	-	0.149	0.014	0.952
C vs D	0.317	0.070	0.025	0.033	0.148	0.317	0.732	0.129	0.859	0.044	0.179	0.148	0.069	0.032	0.070	0.002

11; $r = 0.924$; $r^2 = 0.854$; $b = 2.4703$; $p = 0.025$) and when we analyzed the total data of recaptures ($n = 17$; $r = 0.857$; $r^2 = 0.734$; $b = 1.427$; $p = 0.0000112$) (Figure 8). In site A values were almost near significant ($N = 12$; $r = 0.570$; $r^2 = 0.325$; $b = 2.2219$; $p = 0.053$). The distance of displacement of the spiders ranged between 0 to 115.4 meters. One male from M1 (Site A) and a one female from C1 (site B) presented the highest values of distance and recapture time period (54.1 meters in 26 days; 115.4 in 53 days respectively (Table 6).

4. Discussion

This study revealed that *A. brasiliensis* presents higher values of abundance and density in less reduced and fragmented beaches with more availability of open dunes as site B (Table 1 and Table 2). These beaches offer more suitable areas for constructing burrows, better cryptic condition against predators and reduce the competition with other wolf spiders, as *Schizocosa malitiosa* (Tullgren, 1905), which it is associated with sandy habitats impacted by human influence [16].

The chance of an organism to inhabit a certain fragmented habitat depends on its ability to move among exotic and original patches of vegetation [49]. In all the beaches, females were more abundant than males and they were the sex with higher recaptures (Table 1, Table 6). This is in agreement with the sex-role reversal reported for this species [30] [31], and consequent higher mobility in this sex. Also, females of *A. brasiliensis* need to forage intensively before mating because after that they will remain buried in male burrows, ovipositing there and exiting for spiderling dispersal, approximately one month later [18] [29] [31]. Intense foraging activity will also be reflected by high surface activity during the summer of the Southern hemisphere.

The reduction of suitable habitat in combination with fragmentation may lead to a decrease in dispersal rates, promoting the isolation of populations [50]. Our results showed that the highest displacement and recapture time was recorded in less fragmented beaches suggesting more dispersal and probably higher longevity. As was expected, recaptures were more frequent in the beach with less suitable habitat for the species (M1), where patches of dunes with psammophile vegetation were scarce (Figure 5). The higher number of individuals and burrows were observed in the dunes, which indicates that the main surface activity of the species takes place on these

Table 5. Abundance plant and score of the Braun-Blanquet cover scale. r: 1 or few individuals; 1: low abundance, with cover <5%; 2: cover 5% - 20%; 3: cover 25% - 50%; 4: cover 50% - 75%; *: quadrat without vegetation cover.

Site	Quadrat	Species	Abundance	Score
A	1	<i>P. racemosum</i>	7	2
A	2	<i>P. racemosum</i>	14	3
A	3	<i>P. racemosum</i>	22	3
A	4	<i>S. crassiflorus</i>	6	+
A	4	<i>P. racemosum</i>	18	4
A	5	<i>P. racemosum</i>	17	2
A	6	<i>P. racemosum</i>	9	2
A	6	<i>Brassica</i> sp.	2	r
A	7	<i>S. crassiflorus</i>	6	2
A	8	<i>P. racemosum</i>	32	2
A	9	<i>P. racemosum</i>	23	3
A	9	<i>H. bonariensis</i>	1	r
A	10	<i>P. racemosum</i>	22	2
B	1	<i>P. racemosum</i>	11	2
B	1	<i>Oenothera mollisima</i> L.	1	r
B	2	<i>P. racemosum</i>	4	2
B	3	<i>P. racemosum</i>	25	3
B	3	<i>H. bonariensis</i>	4	1
B	3	<i>S. crassiflorus</i>	1	r
B	4	<i>P. racemosum</i>	25	4
B	5	<i>P. racemosum</i>	25	4
B	6	<i>P. racemosum</i>	8	3
B	7	<i>S. crassiflorus</i>	1	r
B	8	<i>S. crassiflorus</i>	11	1
B	8	<i>P. racemosum</i>	14	2
B	9	-	-	-
B	10	<i>P. racemosum</i>	3	1
B	10	<i>H. bonariensis</i>	3	1
B	10	<i>Oenothera mollisima</i> L.	1	r

areas of the coastal coastline (Figure 5). [51] indicated an association between the structure and diversity of vegetation with the distribution of dune spiders in sandy coasts of North-West England. [16] reported the presence of *A. brasiliensis* in the dunes lines of the southern Uruguayan coast. Our study showed that the species is mainly present in dunes covered with psammophile vegetation in relation with sandy areas outside the dune (Figure 6). This habitat preference could be due to the fact that the sand in fixed dunes is less compacted, what can facilitate the construction of the burrows (Figure 1). Also, open habitats can help localization of male burrows by the females. Surfaces where the species was rare or absent presented humid and more compacted sand

Table 6. Recapture data of *A. brasiliensis*. F: female, M: male, I: immature. Displacement: distance between mark and recapture points.

Beach	Sex	Recapture period (days)	Displacement (m)
M1	F	1	9.5
M1	F	1	13.3
M1	I	1	8.4
M1	I	5	15.9
M1	F	9	0.5
M1	F	9	3.8
M1	F	1	23.2
M1	F	1	10.2
M1	I	1	3.83
M1	I	2	14.5
M1	M	26	54.1
M2	M	15	2.58
C1	F	13	4.9
C1	F	53	115.4
C1	F	2	2.4
C2	F	1	31.3
C2	I	1	7.9

as it was observed in the inter-tidal zone or surfaces occupied by exotic vegetation which show a thick mulch of leaf litter covering the sand. Moreover, sandy areas without psammophile vegetation reported few specimens, probably due they represent trails where people walk to the beach, and for this reason they are not suitable sites for burrow construction (Figure 5). Habitat structure is closely linked to microclimatic influences which determine spider distribution [52]. In recent restored dunes, the spider colonizes only when psammophile vegetation is fixed in the sand (M. Simó (personal observation, 2012)). Our results indicate that *A. brasiliensis* is very sensitive to changes in the vegetation cover of the sand. Dunes with psammophile vegetation were the best predictors to find a burrow or surface activity for this species. In contrast, leaf litter in patches with exotic vegetation was a negative indicator for *A. brasiliensis* occurrence. This result agrees with studies on other sandy wolf spider as *Geolycosa xera*, that show that this spider species and leaf litter substrata are mutually exclusive [53].

The present study indicates that *A. brasiliensis* showed higher rates of mobility and higher number of burrows in beaches with more availability of the dune lines with psammophile vegetation, condition that constitute the best suitable habitat for the species establishment (Table 1, Table 6, Figure 2 and Figure 5). Construction of burrows implies energetic costs associated with silk production to maintain stable the walls of the burrow and costs of digging activities per se, and a high risk of predation due to the performance of conspicuous behaviors at the open field while digging [28]. In this scenario, the substrate seems important for a more efficient digging. Along with this, field observations suggest a potential high rate of relocation of the burrows, something expected if we consider the changeable conditions of coastal environments. [29] indicated that adult burrows of *A. brasiliensis* were more frequent at the base of sand-dunes where humidity values were higher. Furthermore, they observed that temperature buffering increased with depth, providing thermal stability and good conditions for eggs development. The presence of psammophile vegetation in open sandy areas represent a critical component to preserve the suitable habitat conditions for the species and avoid the negative effects of high levels of evotranspiration and temperature changes.

Our results are agree with [33] in the sense that *P. racemosum* is the more frequent plant species in the *A.*

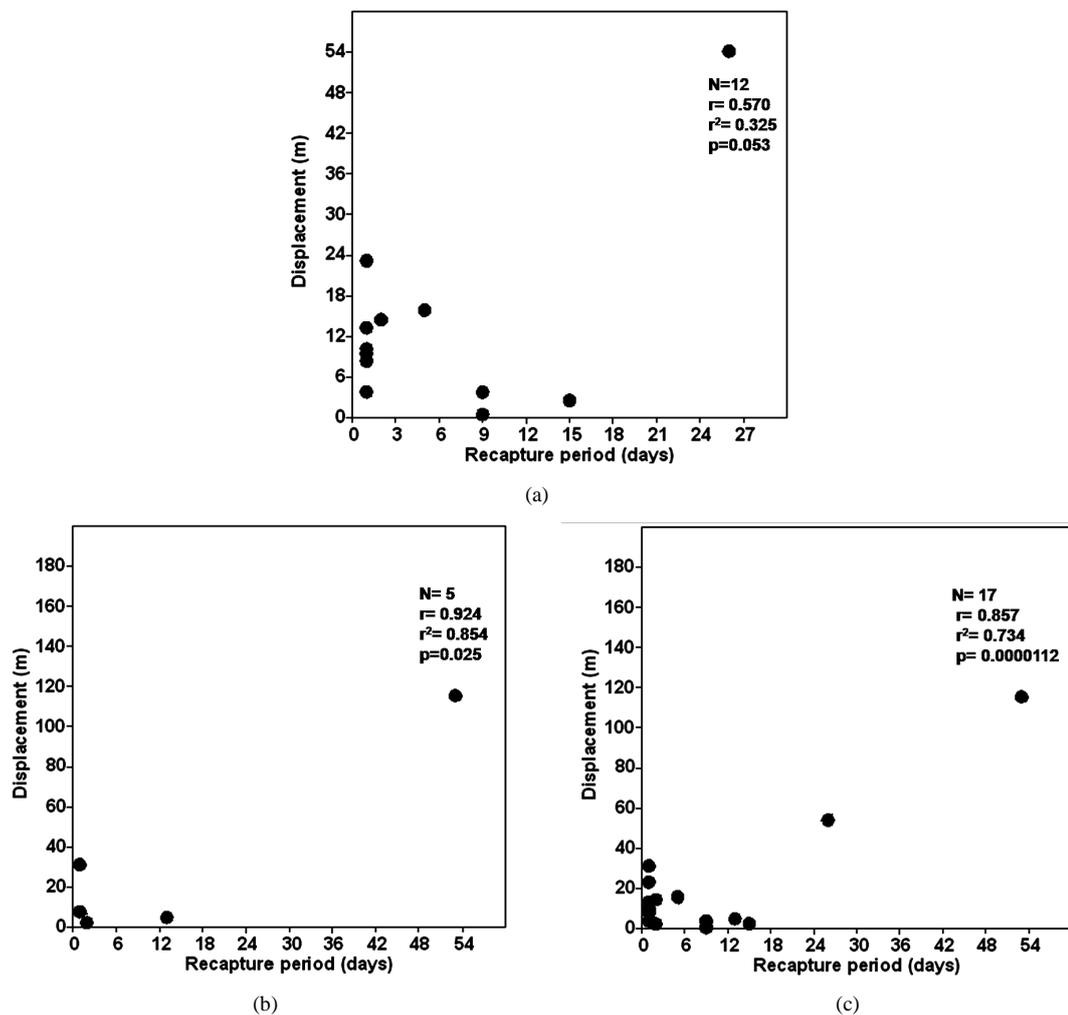


Figure 8. Linear relationship of the time of recapture and distance covered of the recaptured individuals of *A. brasiliensis*. (a) site (a) (b): site (b) (c): both sites. N: number of exemplars recaptured.

brasiliensis habitat. As these authors indicated, other two native species were also reported in the present study as *S. crassifolius* and *H. bonariensis* (Table 5). All these are considered dune-forming species based in the structure of rhizomes [33] [54]. The vegetation cover here studied, indicated that the most suitable sandy habitat for *A. brasiliensis* should present a vegetation cover of 25% - 50% of the surface (Table 5). We argue that this percentage is optimum because it has the compaction of the sand needed for burrow building. Furthermore, *P. racemosum* probably could play a critical role in the dispersal way of the species by ballooning. [15] indicated that the reduction of suitable habitat and fragmentation increased selection pressures that affect behavioural traits conducting reduction of the dispersal rates in the wolf spider *Pardosa monticola* Clerck, 1757 from dune habitats of Netherlands. Along with this, and although the dispersal mechanisms of *A. brasiliensis* are not well known, the species could be influenced by the fragmentation habitat reducing ballooning but increasing the cursorial dispersion.

This species presents the reproductive period and its higher surface activity in warmer months [16] [18]. As was expected, we found that for most beaches *A. brasiliensis* density increased with temperature (Figure 7). During summer concurrence of people to the beaches is high and this fact seems to be negative in M1, probably because the suitable area was the smallest of the beaches we studied. Also, unlike other beaches of this study, M1 registered the highest number of recaptures what associated with the lowest number of spiders and burrows, suggesting the occurrence of a small and probably threatened local population. To get a more realistic view of which factors most affect the population abundance and density of *A. brasiliensis* we should have a more time of

counting and tracking individuals in the field.

Studies with alive spiders in their natural habitat are difficult because we cannot control all variables (temperature, anthropic modifications, precipitation, preys offer, among others) that may influence in the results. Another aspect to consider was the duration of the study, we only could follow a period of their highest surface activity, because the project that financed this study should be conducted in a year. These can have been some of our study's limitations. Therefore it would be like a photograph of what was happened with these populations of *A. brasiliensis* at this time, with this environmental conditions and this should not affected the outcome of the study. In order to avoid these limitations, future researches will be aimed at evaluating the effect of dune recovery practices such as, wood runners for the access to the beach, influence of the dune recovery procedure applied, among others and increase the time of the population monitoring.

The spatial analysis revealed a high level of fragmentation in site A, where patches of different ground cover zones are clearly isolated between neighboring beaches (**Figure 6**). Habitat degradation, often associated with anthropogenic impact, could lead to reduced diversity and density with declining fragment size and increasing fragment age [55]. Moreover, it was reported that ground active spiders, could increase significantly in density and morpho-species richness with increasing fragment age [56]. As was indicated by [57], retention of small fragments at small intervals across a broad geographical scale appears to be an important element of any plan for biodiversity conservation. [4] remarked the importance of the knowledge of the bio-ecology of the sandy dune macro-invertebrates of the sandy dune, previous to restoration plans in order to order to evaluate and minimize the impact during this process.

5. Conclusion

This study provides data to be applied in environmental management plans of restoration and conservation of the Uruguayan coastal line considering *A. brasiliensis* as bio-indicator. Finally, we would like to highlight the importance of restoring connections between patches of fixed dunes with native vegetation to allow mobility and gene flow among populations of species inhabiting Uruguayan coastal areas. Further studies could be focused in evaluating other factors such as beaches with different stages of conservation and the effects of tourism on the natural history of this species.

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