

Spider community responds to litter complexity: insights from a small-scale experiment in an exotic pine stand

Luciana R. Podgaiski¹ & Gilberto G. Rodrigues²

1. Departamento de Ecologia, Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves, 9500, prédio 43422, sala 119, 91501-970 Porto Alegre, RS, Brazil. (podgaiski@gmail.com)

2. Departamento de Zoologia, Universidade Federal de Pernambuco, Av. Prof. Moraes Rego, s/n, 50670-420 Recife, PE, Brazil.

Received 3 April 2016.

Accepted 22 September 2016.

DOI: 10.1590/1678-4766e2017007

ABSTRACT. Conservation of biodiversity in agroecosystems is an urgent need, and a suitable approach to maximize animal biodiversity and their services is the restoration of habitat heterogeneity. Here we investigated the value of increasing litter complexity in tree plantations of exotic pine for ground spiders. We hypothesized that increasing the litter complexity of these systems, as it would be the case in ecologically designed plantations, would increase spider aggregations. We performed a small-scale litter manipulation experiment within an exotic pine stand in the municipality of Minas do Leão, Rio Grande do Sul, Brazil, and compared spider diversity in simple (only pine needles) and complex substrates (with the addition of diverse native broadleaves). We found 1,110 spiders, 19 families and 32 morphospecies. The most abundant families were Linyphiidae, Theridiidae and Salticidae, and the dominant morphospecies were *Thymoites* sp. 2 and *Lygarina* sp. Web-building spiders represented 61% of total spider abundance, and 17 species, while hunting spiders, 49% and 15 species. As expected, densities of spider individuals and species from both web-building and hunting spiders were higher in complex litter substrate. Potential preys (Collembola) also responded positively to the treatment, and had influence of spider community patterns. Our results suggest that ensuring some degree of plant and litter diversity within pine stands (e.g. understory establishment) might foster spider aggregations and possibly help to conserve their diversity at local-scales.

KEYWORDS. Habitat complexity, habitat selection, species diversity, foraging strategy.

RESUMO. Comunidade de aranhas responde a complexidade da serapilheira: percepções de um experimento de pequena escala em um talhão de pinus exótico. A conservação da biodiversidade em agroecossistemas é uma necessidade urgente, e uma abordagem adequada a maximizar a biodiversidade animal e seus serviços é a restauração da heterogeneidade de habitats. Aqui nós investigamos o valor do aumento da complexidade da serapilheira em plantações exóticas de pinus para aranhas de solo. Nossa hipótese é que aumentando a complexidade da serapilheira nestes sistemas, como seria o caso em plantações com *design* ecológico, as agregações de aranhas aumentariam. Nós realizamos uma manipulação experimental de pequena escala em uma plantação exótica de pinus no município de Minas do Leão, Rio Grande do Sul, e comparamos a diversidade de aranhas em substrato simples (somente acículas de pinus) e complexo (com adição de folhas nativas diversas). Nós encontramos 1.110 aranhas, 19 famílias e 32 morfoespécies. As famílias mais abundantes foram Linyphiidae, Theridiidae e Salticidae, e as morfoespécies dominantes foram *Thymoites* sp. 2 e *Lygarina* sp. Aranhas de teia representaram 61% da abundância total de aranhas e 17 espécies, enquanto aranhas caçadoras, 49% e 15 espécies. Como esperado, densidades de indivíduos e de espécies de ambas construtoras de teia e caçadoras foram maiores em substrato complexo. Potenciais presas (Collembola) também responderam positivamente ao tratamento, e influenciaram os padrões das comunidades de aranhas. Nossos resultados sugerem que garantir algum grau de diversidade de plantas e serapilheira dentro de talhões de pinus (e.g. estabelecimento de sub-bosque) poderia promover agregações de aranhas e possivelmente ajudar a conservar sua diversidade em escalas locais.

PALAVRAS-CHAVE. Complexidade do hábitat, seleção de hábitat, diversidade de espécies, estratégia de forrageamento.

Spiders are predatory arthropods widely distributed across terrestrial ecosystems and agroecosystems (OTT *et al.*, 2007; CORCUERA *et al.*, 2015; MARÍN *et al.*, 2016; RICALDE *et al.*, 2016), being largely influenced by prey availability and habitat structure (HALAJ *et al.*, 1998). Spiders can display a range of different foraging strategies (CARDOSO *et al.*, 2011). Web-building (the ones that anchor prey-capture webs to the substrate) and hunting spiders (the ones actively pursuing or using a sit-and-wait strategy for prey capture, not using webs to trap prey) interact differently with habitat structure, but studies have revealed that the densities of both groups are commonly enhanced when habitat complexity

increases (LANGELLOTTO & DENNO, 2004). Spiders can affect ecosystem functions through top-down effects on herbivores or decomposers, and their foraging strategies are key functional traits to explain such effects (LIU *et al.*, 2015a). In general, they are considered beneficial to agroecosystems by controlling the abundance of various pest species (SUNDERLAND & SAMU, 2000). Nevertheless, studies and management actions employing habitat structural modifications to promote predators are still rare but are beginning to arise (e.g. HALAJ *et al.*, 2000; SCHMIDT-ENTLING & DÖBELI, 2009).

The conversion of natural complex ecosystems to

simplified agroecosystems markedly decline diversity across many taxa (e.g. FLYNN *et al.*, 2009). A valuable approach to maximize animal biodiversity and their mediated ecosystem services in agricultural landscapes is the restoration of habitat complexity, which is relevant from large spatial scales (e.g. across a gradient of different fields) to more local-scales (e.g. within a specific field) (BENTON *et al.*, 2003, SCHMIDT *et al.*, 2005). Heterogeneous habitats may present a larger variety of ecological niches to be exploited in comparison to simplified habitats, fostering possibilities of more species coexistence with a greater use of resources (FINKE & SNYDER, 2008). Plant diversity is one of the primary determinants of habitat complexity, and studies have shown that increasing the diversity of native plants in agroecosystems helps to conserve animal species (e.g. SMITH *et al.*, 2008; BENNETT & GRATTON, 2013).

Among agroecosystems, plantation forests are widespread all around the globe, not respecting biome characteristics neither native biodiversity. The majority of plantation forests, inclusive mega diverse countries as Brazil, still comprise intensively managed monocultures of exotic trees (e.g. *Eucalyptus*, *Acacia* and *Pinus*; PAQUETTE & MESSIER, 2010). Empirical evidence has demonstrated that industrial forests may achieve economic purposes while maintaining considerable habitat complexity and conserving a large fraction of the natural forest biodiversity, including both within- and between stand diversity. There are several recommendations to ecologically design tree plantations; some few examples are (1) planting trees in lower densities and allowing natural rich understory establishment and development (FONSECA *et al.*, 2009), (2) leaving natural vegetation margins and patches among the rows of planted trees, and (3) using native mixed-species, or polycultures (PAQUETTE & MESSIER, 2010). As these designs allow greater plant diversity, they potentially increase the leaf-litter layer complexity within the plantations. However, the challenge of shaping agricultural landscapes to meet joint production and conservation goals requires an increase in the economic and ecological research efforts (SCHERR & MCNEELY, 2008).

Here we focus on ground spider communities to explore the role of litter layer complexity on plantation forests. We performed a small-scale experiment (patch scale) within an exotic pine stand in southern Brazil (Rio Grande do Sul). Pure pine stands (*Pinus*) present a very simplified litter layer in terms of habitat structure for invertebrates due to the accumulation of a homogeneous needle-like substrate in the soil when compared to native ecosystems or broadleaved tree plantations. We hypothesized that increasing the litter complexity of these systems, as it would be the case in ecologically designed plantations where plant diversity is greater, would benefit spider communities (i.e. increase their aggregation in more complex litter, LANGELOTTO & DENNO, 2004). In order to test this hypothesis, we created two levels of substrate complexity in replicated plots: (1) simple, formed only by pine needles, and (2) complex, with the addition of diverse native broadleaves to the pine forest floor. We tested how densities of individuals and species

of spiders responded to the treatments taking into account major foraging strategies.

Besides several studies have investigated the relation of ground spiders to habitat features and complexity in different agroecosystems (e.g. SCHMIDT *et al.*, 2005; CORCUERA *et al.*, 2015; MARÍN *et al.*, 2016), to our knowledge there are no published studies addressing such topic in Brazil, particularly regarding to pine plantations. Specifically in South Brazil, some attempts were done in order to compare spider diversity patterns between agroecosystems and adjacent native ecosystems, such as the studies of BALDISSERA *et al.* (2008) in tree plantations, including pine, and native *Araucaria* forest, RODRIGUES *et al.* (2009) in rice field, grassland and native forest, and RODRIGUES *et al.* (2010) in *Eucalyptus* plantations and natural grasslands. Other studies in agroecosystems in South Brazil describe spider assemblages, for example, in olive groves (RICALDE *et al.*, 2016), corn plantations (DA SILVA *et al.*, 2014), citrus groves (OTT *et al.*, 2007) and irrigated rice (RODRIGUES *et al.*, 2008). Here we also expect to contribute with a very first view of the ground spider assemblages inhabiting pine plantations in the state of Rio Grande do Sul.

MATERIALS AND METHODS

Study area. A slash pine stand of *Pinus elliottii* Engelm (Pinaceae) settled in an intensively managed landscape in Southern Brazil was chosen as the model system to perform the experiment. In December 2007 we established the experiment in an area of approximately 20 ha in the municipality of Minas do Leão, Rio Grande do Sul, Brazil (30°09'44.2"S; 52°00'17.2"W). The landscape is characterized by a mosaic of coal mining activities and tree plantations (especially *Pinus*); native natural forests and grasslands are scarce or inexistent in a 10 km radius from the study site. Coal was exploited by opencast mining from the study site around the year 1980 and during 2001-2002, and the open cave was filled with remaining soil, coal wastes and coal combustion residues. Whereas vegetated with grasses, pine seeds from neighbor stands reached the land, quickly establishing a monospecific ecosystem. *Pinus elliottii* is native to the southeast United States and widely planted in Brazil. Plants from this genus are extremely invasive, advancing in deforested areas and natural ecosystems in South America (SIMBERLOFF *et al.*, 2012). The climate of the study site is temperate, with precipitation well distributed throughout the seasons (*Cfa* type according to the Köppen-Geigen climate classification, PEEL *et al.*, 2007).

Experimental design. We performed the experiment using a randomized block design. This design is efficient to control for spatial and temporal heterogeneity (e.g. patchy habitats and different sampling time), assuming that environmental conditions and biological communities are more similar within than between blocks, which is suitable to clearly detect the treatment effects of interest (GOTTELLI & ELLISON, 2013). Eight blocks were placed systematically within the study area with a minimum distance of 100 m.

Each block was composed by two experimental units of 90 x 60 cm distant 2 m from each other, assigned randomly to treatments.

We had two treatments per block: (1) simple and (2) complex substrate. Each treatment in each block received approx. 360 g of oven-dried leaves (60°C; 72 h) over the natural litter layer. The leaves were enclosed in nine nylon bags (30 x 20 cm; 20 mm mesh size; 40g of dry mass) per experimental unit. The simple substrate was composed exclusively by bags enclosing pine needles, and the complex substrate presented bags with pine needles and also with native broadleaves in different architectures to generate habitat heterogeneity. Details regarding the characteristics of the bags, native plant species used and other differences between treatments are found in Table I.

At two sampling occasions (after 3 and 6 months) we randomly selected four blocks, collected all bags, and brought them to the laboratory. Spiders and other invertebrates that colonized the litter were immediately extracted by hand, and using modified Berlese-Tullgren funnels during one week. We classified all the spiders in families and, based on family affiliation, in two different major foraging strategies: web-building (the ones that must anchor their hunting webs to the substrate) and hunting predators (the ones that actively pursue or use a sit-and-wait strategy for prey capture, not using webs to trap prey). To classify the groups, we checked DIAS *et al.* (2010) and CARDOSO *et al.* (2011).

The adult spiders were determined in morphospecies, and deposited in Museu de Ciências Naturais (MCN) of the Fundação Zoobotânica do Rio Grande do Sul (FZBRS), Porto Alegre, RS, Brazil. Other invertebrates were classified in orders. Among them, we considered Collembola as a potential

spider prey group (e.g. LIU *et al.*, 2015b). The remaining litter mass *per* experimental unit after 3 (four blocks) and 6 months (four blocks) was estimated after oven-drying the substrate from the bags (60°C; 72 h).

Data analyses. We evaluated the effects of habitat complexity on spiders by comparing their colonization patterns in the different substrate treatments. For that, we tested for differences in spider abundance and spider richness for both web-builders and hunters between substrate type using ANOVA in blocks, and considering the abundance of potential preys (Collembola) as covariate. Previously to the analyses, spider abundance and richness were standardized by a density measure in each experimental unit (individuals.g⁻¹ of dry litter, and species.g⁻¹ of dry litter respectively). The same standardization was performed to Collembola abundance. In addition, we also evaluated effects of substrate type on Collembola densities with ANOVA in blocks.

As species richness is very sensitive to the number of individuals sampled, we used individual-based rarefaction (interpolation) and extrapolation curves with 95% unconditional confidence intervals (COLWELL *et al.*, 2012) to compare total spider richness between treatments. We did not test direct time effects on spider colonization of the treatments, which was statistically controlled by the block design, and neither treatment effects on species composition. Due to the small scale of our experiment we are assuming that spiders colonizing the treatments came directly from the studied site. We carried out linear models in R version 3.0.2 (R DEVELOPMENT CORE TEAM, 2014), and interpolation (rarefaction) and extrapolation curves with INEXT online (HSIEH *et al.*, 2013).

Tab. I. Comparison between the substrate treatments (simple x complex) evaluated in the experiment in a pine stand in Minas do Leão, Southern Brazil.

Substrate treatment	Simple	Complex
Number of experimental units	8	8
Number of bags <i>per</i> experimental unit	9	9
Number of leaf species	1	5
Leaf species identity	<i>P. elliottii</i>	<i>P. elliottii</i> , <i>Inga marginata</i> <i>Cupania vernalis</i> <i>Luehea divaricata</i> <i>Schinus terebinthifolius</i>
Type of bags	Only single bags	5 single bags: one of each species 4 mixed bags: 25% (by volume) of each broadleaf species
Bag arrangement	Rectangle shape 3 x 3 bags over the natural litter layer.	Rectangle shape 3 x 3 bags over the natural litter layer. The pine bag was settled in the middle, surrounded by the bags with broadleaves (intercalating single and mixed bags)
Initial mass of each bag (g)	40	40
Initial mass of each experimental unit (g)	360	360
Average remaining mass and standard error in experimental units (g)	262.8 ± 8.67	200.8 ± 6.33
Average abundance and standard error of Collembola (individuals.g ⁻¹ of dry litter)	2.66 ± 1.53	8.20 ± 4.69

RESULTS

We found a total of 1,110 litter spiders from 19 families in the pine plantation. The most abundant families were Linyphiidae (27.6% of the total abundance), Theridiidae (23.2%), Salticidae (17.5%), Hahniidae (9%), and Oonopidae (6%). This pattern of dominance was found in both substrate types. Only 38% of the number of individuals was represented by adults, which were identified in 32 morphospecies (Tab. II). Linyphiidae was the richest family (11 species). The dominant species were *Thymoites* sp. 2 (25.2%, Theridiidae), *Lygarina* sp. (23%, Linyphiidae), *Oonopinae* sp. (10.2%, Oonopidae), *Hahniidae* sp.1 (10%, Hahniidae), *Orthobula* sp.1 (7.3%, Phrurolithidae) and *Neomaso damocles* Miller, 2007 (5.9%, Linyphiidae). *Thymoites* sp. 2 and *Orthobula* sp.1 were the only species recorded in all experimental blocks. Twenty morphospecies were found exclusively in complex litter patches (80% of the total number of hunting spiders and 47% of the total number of web-building species, Tab. II). Three species were exclusive from pine litter patches, although one of them is a pantropical synanthropic species (*Oecobius navus* Blackwall, 1859, Oecobidae).

Web-building strategy presented 676 individuals (61% of total spider abundance), 6 families and 17 species. Hunting spiders summed 434 individuals (49%), 13 families and 15 species. Complex litter substrate sheltered more densities of individuals and species of both web-building and hunting spiders (Table III, Fig. 1). Potential preys (Collembola) were also important to explain the spider community patterns (Table III), also being responsive to substrate type ($F^{1,7}=25.14$, $P=0.006$, Table I).

In average, there were 13.9 spider individuals and 2.2 morphospecies in each 100 g of dry simple substrate and 54.3 individuals and 5.7 morphospecies in each 100 g of dry complex substrate. This means that the density of individuals and morphospecies was respectively 74.3% and 38.2% higher in complex substrate. Interpolation (rarefaction) and extrapolation curves with 95% confidence intervals showed that the increase in spider richness was not an artifact of their increase in abundance (Fig. 2).

DISCUSSION

We experimentally investigated the role of litter layer complexity to ground spiders in an exotic pine stand

Tab. II. Spider community composition (adults only) sampled in simple and complex substrate treatments in a pine stand in Minas do Leão, Southern Brazil. Abundance values represent eight experimental units of each treatment.

Family	Morphospecies	Simple	Complex	Total
Hunting spiders				
Caponiidae	<i>Nops meridionalis</i> Keyserling, 1891	0	10	10
Ctenidae	<i>Isoctenus</i> sp.	0	1	1
Gnaphosidae	<i>Apopyllus silvestrii</i> (Simon, 1905)	0	1	1
	Gnaphosidae sp.	0	1	1
Oonopidae	Oonopinae sp.	2	41	43
Phrurolithidae	<i>Orthobula</i> sp. 1	3	28	31
	<i>Orthobula</i> sp. 2	0	1	1
	<i>Orthobula</i> sp. 3	0	1	1
	<i>Orthobula</i> sp. 4	0	1	1
Salticidae	<i>Aphirape</i> sp.	0	1	1
	<i>Breda</i> sp.	0	3	3
	Salticidae sp. 1	0	3	3
	Salticidae sp. 2	0	1	1
	Unidentatae sp.	1	0	1
Trachelidae	<i>Meriola mauryi</i> Platnick & Ewing, 1995	0	5	5
Web-building spiders				
Hahniidae	Hahniidae sp. 1	10	32	42
	Hahniidae sp. 2	0	1	1
Linyphiidae	<i>Erigone</i> sp.	0	2	2
	<i>Gigapassus octarine</i> Miller, 2007	0	6	6
	<i>Lygarina</i> sp.	42	55	97
	<i>Mermessus</i> sp.	0	1	1
	<i>Neomaso arundicola</i> Millidge, 1991	0	1	1
	<i>Neomaso damocles</i> Miller, 2007	10	15	25
	<i>Neomaso</i> sp. 1	0	1	1
	<i>Neomaso</i> sp. 2	1	0	1
	<i>Scolecurea cambara</i> Rodrigues, 2005	5	2	7
	<i>Smermisia vicosana</i> (Bishop & Crosby, 1938)	7	5	12
	<i>Sphecozone</i> sp.	1	6	7
Mysmenidae	<i>Itapua</i> sp.	0	2	2
Oecobidae	<i>Oecobius navus</i> Blackwall, 1859	1	0	1
Theridiidae	<i>Thymoites</i> sp. 1	0	5	5
	<i>Thymoites</i> sp. 2	46	60	106
Total abundance of adult spiders		129	292	421
Total morphospecies richness		12	29	32

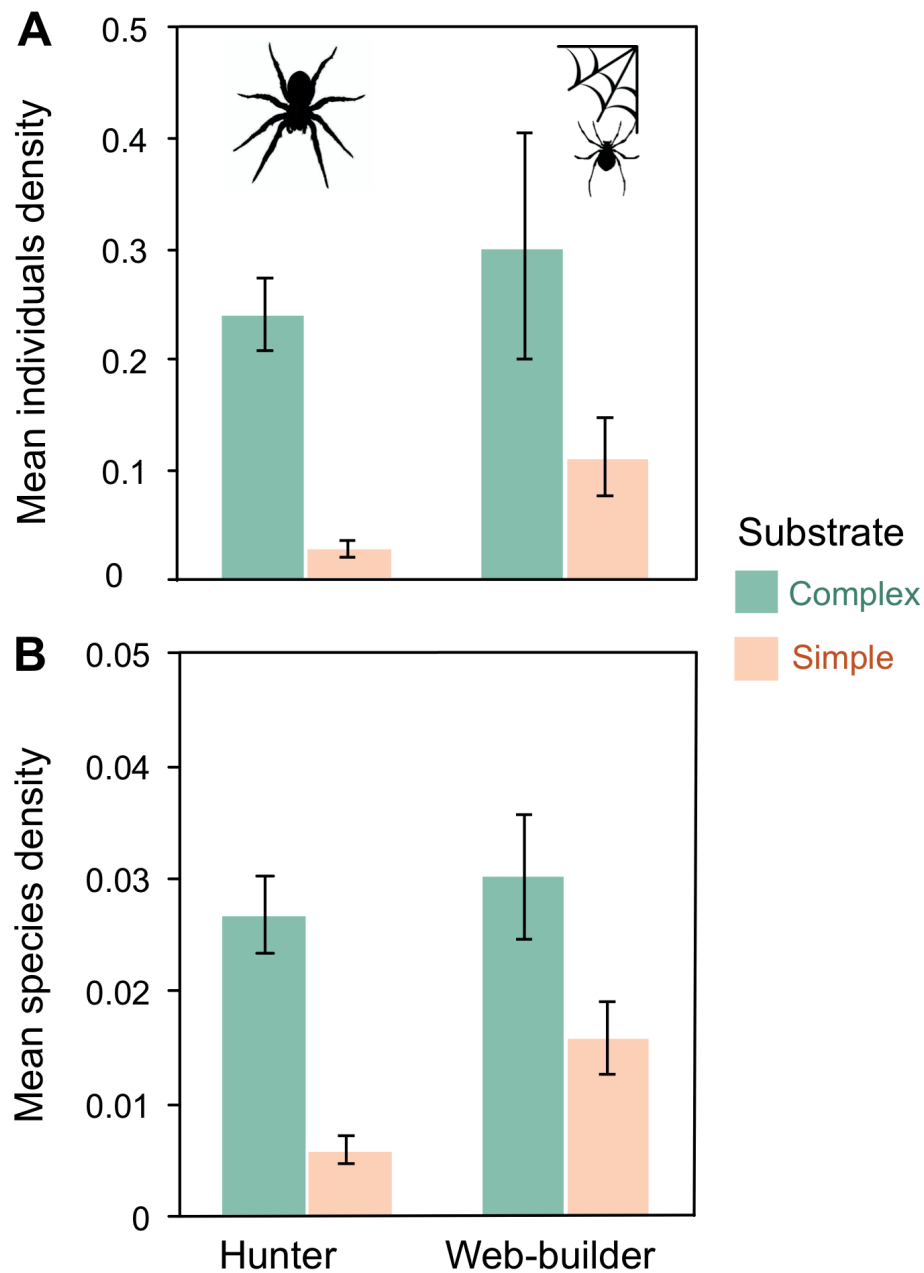


Fig. 1. Mean density of individuals (A, individuals.g⁻¹ of dry litter) and morphospecies (B, species.g⁻¹ of dry litter adults only) \pm standard error of hunting and web-building spiders in simple and complex substrate treatments in a pine stand in Minas do Leão, Southern Brazil.

settled in South Brazil. The spider community colonizing our experiment from this stand was mostly represented by spiders displaying web-building strategy, more specifically space web weavers (Linyphiidae and Theridiidae; DIAS *et al.*, 2012), and by ground hunters (Salticidae) in a little diminished proportion. Analogous pattern regarding these dominant ground families was also registered in DA SILVA *et al.* (2014) for corn plantations, and RODRIGUES *et al.* (2010) for *Eucalyptus* plantations in Rio Grande do Sul. In this former study, similarly to our results, a species of *Thymoites* (Linyphiidae) was also found to be very abundant in the leaf-litter, being frequent in all sampled sites. The spider richness

registered here for the pine plantation (32 morphospecies) is comparable to the richness found in these previous mentioned works (corn plantation= 27; *Eucalyptus* plantations= 35) and also to the forest floor of a native *restinga* forest nearby (44 morphospecies; RODRIGUES, 2005). A lack of published surveys on soil araneofauna makes difficult any further discussions about spider diversity in the study region.

Based in one of the cornerstones of ecology ('the habitat heterogeneity hypothesis', e.g. TEWS *et al.*, 2004), enhancing the complexity of agricultural systems from within individual fields to whole landscapes has been pointed out as a useful approach to ensure animal diversity (BENTON *et*

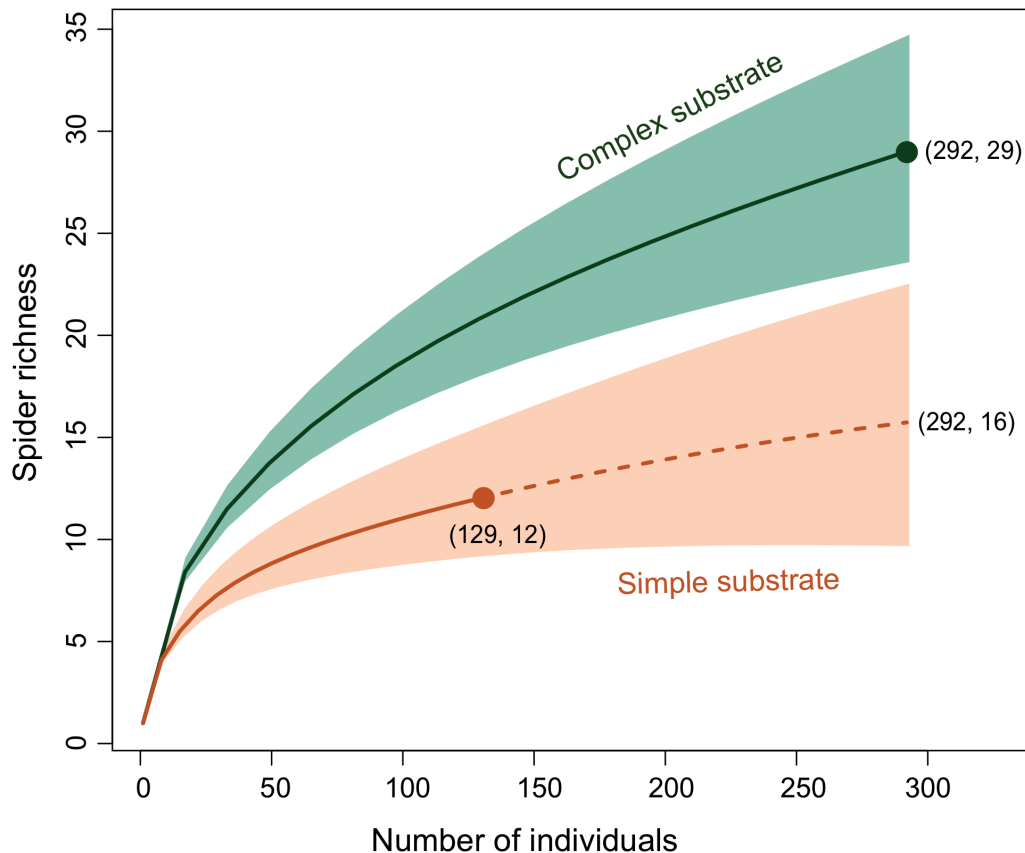


Fig. 2. Individual-based rarefaction (interpolation, solid lines) and extrapolation (dashed line) from eight experimental units (90 x 60 cm) of simple and complex substrate in a pine stand in Minas do Leão, Southern Brazil, under multinomial model, with 95% unconditional confidence intervals (shaded area, bootstrap with 1,000 replications) (based on COLWELL *et al.* 2012). In parenthesis, the number of individuals and morphospecies observed and estimated (extrapolation) respectively in each treatment.

Tab. III. F and P-values (in brackets) from analysis of variance for abundance and species richness of hunting and web-building spiders sampled in a pine stand in Minas do Leão, Southern Brazil. Sources of variation are substrate type (simple or complex), abundance of potential prey, and blocks (n=8). Abundance and richness were standardized by density measures (individuals.g⁻¹ of dry litter, and species.g⁻¹ of dry litter).

Response variables		Substrate type (df=1, 6)	Potential prey (df=1, 6)	Block (df=7, 6)
Abundance	Hunter	59.22 (<0.001)	12.34(0.012)	0.44 (0.846)
	Web-builder	5.83 (0.052)	14.90 (0.008)	0.82 (0.603)
Richness	Hunter	29.96 (0.001)	0.27 (0.620)	0.90 (0.558)
	Web-builder	17.45 (0.006)	36.19 (0.001)	1.15 (0.441)

al., 2003; SCHERR & MCNEELY, 2008). Our study supports such approach, and has experimentally shown in a patch scale that the substrate complexity within a very simplified system has a considerable influence on spider communities by aggregating more individuals and species. Web-building and hunting spiders had their diversities enhanced in complex patches formed by the addition of different types of leaves to the pine forest floor. The mechanisms behind such results in this system need further understanding, but they are possible related to: favorable structural proprieties, prey availability, and refuges from predation (see review in LANGELLOTTO & DENNO, 2004).

Broadleaves clearly present more habitat space than pure pine needles. The spaces within curled leaves, the underside of twisted leaves and the gaps between leaves with different sizes represent an improvement in microsites for foraging, reproduction and suitable microclimate (UETZ, 1974; WAGNER *et al.*, 2003). Web-building spiders rely on proper substrates to attach their webs (SAMU *et al.*, 1996); hence structured habitats provide more attachment sites than simple habitats. The complex litter patches that we created in the pine plantation could have supported improved aggregation of spiders due to more favorable structural proprieties than the pine litter.

Spiders are good at finding prey-rich patches (WISE, 1993). Both web-building and hunting spiders, which do not depend directly on habitat structure for foraging, may have benefited in complex patches because they encountered more abundant prey there. In complex structured habitats, prey location and capture could be more effective due to the increase in detection of substrate-born vibrations (LANGELOTTO & DENNO, 2006). Collembolans, and also many other macrofaunal groups as woodlice, beetles and small cockroaches (not showed here), were more abundant in complex litter patches. We indeed found a significant relationship between collembolan and spider densities. CHEN & WISE (1999), and HALAJ & WISE (2002) experimentally enhanced the resource base (detritus-addition) in forests of USA, and have found 2-4 times higher densities of collembolans and associated spiders than in controls. These results reveal substantial bottom-up effects propagating through the decomposition food web, which can also potentially explain our results (e.g. high quality resources elevated populations of detritivores, which reduced food limitation of predators and caused their densities to increase).

Further, as generalist predators that often prey on one another, spiders also may found proper spatial refuges from agonistic interactions in complex substrate, thereby reducing detectability, enhancing ability to scape and facilitating coexistence (FINKE & DENNO, 2002; JANSSEN *et al.*, 2007). Spiders tend to remain in habitats where conditions are optimal (SUNDERLAND & SAMU, 2000). Patches with complex substrate possibly received high immigrations associated with reduced emigration rates during the course of the experiment, as suggested by LANGELOTTO & DENNO (2004). Because of the small spatial scale evaluated here, it is expected that the immigrating species have come directly from the studied pine stand (i.e. not from other adjacent ecosystems) with individuals constantly moving around in search of suitable sites.

From an applied perspective, the results from this litter manipulation experiment suggest that integrating elements of habitat complexity in pine plantations, i.e. ensuring some degree of plant diversity to maintain a complex litter layer, might enhance spider aggregations. Allowing native understory establishment within the stand, or using polycultures (FONSECA *et al.*, 2009; PAQUETTE & MESSIER, 2010) are some examples of strategies that could be used to benefit generalist predators biodiversity and their mediated ecosystem services. The mixing of species stands comprising two or more tree commercial species is a strategy increasingly being considered to achieve ecological and economic goals in Europe (e.g. CAVARD *et al.*, 2011). However, a few recent studies have demonstrated that mixed stands of pine and oak trees showed no influence on ground-dwelling spider diversity when compared to single species stands (OXBROUGH *et al.*, 2012; BARSOUM *et al.*, 2014). Small-scale experimental approaches, like ours, provide important insights in ecological hypothesis testing under controlled situations. But the ecological design of tree plantations in order to support forest biodiversity require a lot of further

research integrating different taxa and trophic levels at larger spatial scales.

Acknowledgements. We are indebted to Maria A.L. Marques, Erica H. Buckup and Everton N.L. Rodrigues for helping in spider identifications, to Companhia Riograndense de Mineração for allowing access to the study site, to Ricardo Ott for lending Winkler extractors, which were adapted to modified Berlese-Tüllgren funnels for this study, and to Fernanda S. Silveira for helping in the lab work. Luciana R. Podgaiski received Master scholarship from CAPES (Brazil).

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