

Restoration strategy drives the leaf litter myriapod richness (Arthropoda: Myriapoda) on a protected area*

Fabiola Ospina-Bautista¹, Pablo A. López-Bedoya², Jaime Vicente Estévez³, Daniela Martínez-Torres⁴,
Sebastián Galvis Jiménez⁵.


Abstract

Objective: To determine the leaf litter myriapod community in two restoration strategies of a protective area of Colombia, a secondary forest and an Andean alder plantation. **Scope:** The knowledge of the biodiversity of invertebrates associated with leaf litter breakdown in restoration forests may contribute to assessing the restoration process efficiency and success. Within this forested soil biodiversity framework, myriapods influence organic matter dynamics by transforming leaf litter (or other plant-derived materials), reducing the surface of decomposition, and affecting decomposer communities and their interactions. **Methodology:** We designed a leaf litter translocation experiment using leaf litter of *Alnus acuminata* Kunth and *Hedyosmum bonplandianum* Kunth, the most abundant species in each restoration strategy underway from the 60s in the Reserva Natural Río Blanco y Quebrada Olivares, Manizales, Colombia. We measured the myriapod richness and abundance two and four months after beginning the leaf litter decomposition experimental trials. **Main results:** Classes Diplododa, Chilopoda, and Symphyla colonized the leaf litter in both restoration strategies. The restoration strategy affected myriapod richness, abundance and composition. Myriapod richness and abundance were greater in the Andean alder plantation, millipedes were the most abundance myriapods. Myriapod composition also differs among litter species. The plant composition of each restoration strategy could lead to differences in litterfall quality and, consequently, in the resources available for the colonization of the myriapod community, which contributes directly and indirectly to the decomposition process in the restoration strategies.


Keywords: Diplopoda, ecosystem processes, leaf litter, forest plantation, protected area.

*FR: 1-III-2021. FA: 14-X-2021.


¹ Grupo de Investigación en Ecosistemas Tropicales, Universidad de Caldas, Manizales, Caldas, Colombia. Email: Fabiola.Ospina@ucaldas.edu.co

 orcid.org/0000-0003-2498-1459 **Google Scholar**


² Grupo de Investigación en Ecosistemas Tropicales, Universidad de Caldas, Manizales, Caldas, Colombia. Email: pablo.lobe19@gmail.com

 orcid.org/0000-0002-5525-1291 **Google Scholar**


³ Grupo de Investigación en Ecosistemas Tropicales, Universidad de Caldas, Manizales, Caldas, Colombia. Email: Jaime.estevez@ucaldas.edu.co

 orcid.org/0000-0002-1141-6576 **Google Scholar**

⁴ Instituto de Ciencias Naturales, Universidad Nacional de Colombia, Bogotá, Colombia. Email: sdmartinez@unal.edu.co

 orcid.org/0000-0001-8865-927X **Google Scholar**

⁵ Instituto de Ciencias Naturales, Universidad Nacional de Colombia, Bogotá, Colombia. Email: sgalvisjimenez@gmail.com

 orcid.org/0000-0002-6041-7903 **Google Scholar**

CÓMO CITAR:

Ospina-Bautista, F., López-Bedoya, P.A., Estévez, J.V., Martínez-Torres, D., Galvis Jiménez, S. (2022). Restoration strategy drives the leaf litter myriapod richness (Arthropoda: Myriapoda) on a protected area. *Bol. Cient. Mus. Hist. Nat. Univ. Caldas*, 26(1), 13-23. <https://doi.org/10.17151/bccm.2022.26.1.1>



La estrategia de restauración define la riqueza de Miriápodos (Arthropoda: Myriapoda) de la hojarasca en un área protegida

Resumen

Objetivo: Determinar la comunidad de miriápodos asociada a la hojarasca en dos estrategias de restauración de un área protegida de Colombia, un bosque secundario y una plantación de aliso. **Alcance:** El conocimiento de la biodiversidad asociada con la descomposición de la hojarasca en un ecosistema restaurado podría contribuir a evaluar la eficiencia y el éxito de la restauración. Dentro de esta biodiversidad, los miriápodos influyen en la dinámica de la materia orgánica al transformar la hojarasca reduciendo la superficie de descomposición y afectando a las comunidades de organismos asociados a la descomposición. **Metodología:** Diseñamos un experimento de translocación utilizando hojarasca de *Alnus acuminata* Kunth y *Hedyosmum bonplandianum* Kunth, las especies más abundantes en cada estrategia de restauración que se puso en marcha desde los años 60 en la Reserva natural Río Blanco y Quebrada Olivares, Manizales, Colombia. Medimos la riqueza y abundancia de miriápodos después de dos y cuatro meses de descomposición de la hojarasca. **Principales resultados:** Las clases Diplododa, Chilopoda y Symphyla colonizaron la hojarasca de *A. acuminata* y *H. bonplandianum* en ambas estrategias de restauración. La estrategia de restauración afectó la riqueza, abundancia y composición de miriápodos. La riqueza y abundancia de miriápodos fue mayor en la plantación de aliso, los milpiés mostraron la mayor abundancia. La composición de miriápodos difirió entre las especies de hojarasca. La composición vegetal de cada estrategia de restauración podría generar diferencias en la calidad de la hojarasca y, en consecuencia, en los recursos disponibles para la colonización de la comunidad de miriápodos, lo que contribuye directa e indirectamente al proceso de descomposición en las estrategias de restauración.

Palabras clave: Diplopoda, Procesos del ecosistema, hojarasca, Plantación, área protegida

Introduction

The goal of ecological restoration is recovery to achieve a historical state close to the previous ecosystem of a degraded area that has resulted from human perturbation or natural disturbance (Hobbs et al., 2006). The restoration mechanisms to recover plant composition are categorized according to the degree of human intervention (McAlpine et al., 2016). Dispersion (Shiels and Walker 2003) and seed rain from surrounding forests create the secondary forest in abandoned lands or pastures (Aide et al., 2000), a process known as passive restoration. Active restoration also uses native or exotic species to develop and extend forest plantation (Hall et al., 2011). This plantation could have productive goals such as extract wood or protect hydric resources (Paquette and Messier, 2010). The coverage of secondary forests and forest plantations has increased worldwide (FAO, 2001); there are 300 million hectares of secondary forest in America, whereas there were nearly 60 million estimated hectares of forest plantation in 2015 (FAO, 2015).

Litter decomposition is proposed as an indicator of forest recovery, where soil fauna could be relevant in driving the magnitude and stability of organic matter breakdown in a restoration system (Barreto da Silva et al., 2018). Litter decomposition maintains soil fertility through the transfer of nutrients from plants to soil and vice versa (Guendehou et al., 2014; Patricio et al., 2012; Silver et al., 2014). Moreover, litter maintains the microclimatic conditions of the soil, offers a habitat to invertebrates (Cajaiba et al., 2017; Cole et al., 2016), and participates in filtering and reserving water in the soil (Caldeira et al., 2013).

In addition, soil invertebrates affect litter decomposition through fragmentation that stimulates microorganism colonization (Cole et al., 2016, Fujii and Takeda, 2017), dispersion of fungi propagules (Lilleskov and Bruns, 2005), grazing on microorganisms (Crowther et al., 2012), transformation of litter into pellets stimulating microorganism activity (Coulis et al., 2009; Coulis et al., 2013; Lavelle and Spain, 2001), and increasing nitrogen mineralization (David, 2014). Little is known about biodiversity associated to litter decomposition in an ecosystem under restoration processes. Similarly, there is scarce knowledge on the role of decomposition and decomposer fauna in order to assess restoration efficiency, except for a study on restoration strategies in Costa Rica, where litter invertebrates differ among plantations, nucleation/islands, and natural regeneration; abundance, richness, and diversity are higher in nucleation (Cole et al., 2016).

Among invertebrates, myriapods could contribute to litter decomposition in a restoration ecosystem. Millipedes (Diplopoda) are “litter transformers” (Lavelle and Spain, 2001) that break down the litter, ingest fungi from leaf litter, increase bacterial community, create compact fecal pellets reducing the surface of decomposition, and contribute to soil nutrient dynamics (David and Gillon, 2002; David, 2014). Furthermore, centipedes have a top down effect on collembola, which greatly contributes to leaf litter decomposition (Gunther et al., 2014; Santonja et al., 2018). We designed a litter translocation experiment to assess the myriapod community associated to litter decomposition in a secondary forest (passive restoration) and an Andean alder plantation (active restoration). We selected the most common plant species of each site in order to conduct a decomposition experiment for four months and measured the myriapod richness and abundance. Our goal was to determine the myriapod community associated to leaf litter decomposition in a secondary forest and an Andean alder plantation, and to assess if the myriapod community shifts with leaf litter species, litter exposure time, and restoration strategy. We predicted that plant litter quality and restoration strategy could lead to shifts in litter conditions during the decomposition time period and, therefore, to variations in the myriapod community associated to this ecosystem process.

Materials and methods

Study area

Our study was conducted at the Reserva Natural Rio Blanco y Quebrada de Olivares located in Manizales, Caldas in the Colombian Central Andes (Sanin et al., 2006). The reserve has an area of 4,932 ha between 2,150 and 3,700 m asl, where there are secondary forests and plantations of *Alnus acuminata* (Kunth) (Fagales: Betulaceae). The area is characterized by an annual mean temperature of 19 ± 3 °C, and a relative humidity of 90%. The annual mean precipitation is 2,500 mm, with most rainfall in two wet seasons: April - May and October -November. In addition, the reserve supplies freshwater to nearby cities, so it is a relevant site for the region (CORPOCALDAS, 2010).

Design

We selected four plots of 20x20m separated from each other by 300m in a secondary forest (N 5° 4'31.08" – W 75° 26'13.5"; altitude: 2635 m) and four plots in an Andean alder plantation (N 5° 4'8" – W 75° 26'29"; 2467 m). We conducted a litter translocation experiment with the most abundant leaf litter in the Andean alder plantation and secondary forest, *Alnus acuminata* and *Hedyosmum bonplandianum* (Kunth) (Chloranthales: Chloranthaceae), respectively. The plant species are similar in initial leaf thickness and leaf area, but differ in leaf dry-matter content; *H. bonplandianum* has the lowest leaf dry-matter content (mean +/- sd; *A. acuminata* 660.37+/-209.60; *H. bonplandianum* 323.17 +/-105.93).

We used 128 decomposition leaf bags of 30 cm x 30 cm and 9 mm aperture to allow the entrance of micro, meso, and macrofauna, for a total of 64 bags per site. We added 5 g of dry plant species to each decomposition bag, according to each treatment. We collected 32 bags per site every 60 days for four months. The myriapods were separated manually from the leaf litter collected; individuals were preserved in 96% ethanol and identified to the morphospecies level using the specialized literature (Adis, 2002; Scheller and Adis, 1996; Shelley and Mercurio, 2006; Triplehorn and Johnson, 2005). We did not include juveniles in the analysis, due to difficulties in the taxonomic identification.

Statistical analysis

We used Generalized Linear Models (GLMs, Crawley, 2007) with restoration strategy, litter species, and litter exposure time as fixed factors, and myriapod richness or abundance as response using the Gaussian error distribution. The models were

graphically checked for homogeneity of variance and error distribution. To compare the overall community structure of myriapods associated to litter decomposition among the litter plant species of each restoration strategy, we used a permutational multivariate analysis of variance (PERMANOVA), a non-parametric test that allows to investigate complex models including interactions (Anderson, 2014), with Bray Curtis as a dissimilarity measure and 999 permutations. For site and litter plant species, we used the SIMPER (Similarity percentage) procedure (Clarke, 1993) to identify the contribution of each morphospecies to the measures of Bray-Curtis dissimilarity. This allowed us to identify the morphospecies that were most important in differentiating each restoration strategy or litter type from the others. The statistical analyses were conducted in R statistical program (R Core Team, 2018) with the CAR package (Fox and Weisberg, 2011) for the GLM and vegan (Oksanen et al., 2018) for the PERMANOVA analysis.

Results

During the leaf litter decomposition process, we found 275 myriapod individuals that belong to 39 morphospecies. Of the total species, 26 species belonged to millipedes (Diplopoda); Polydesmida was the most abundant and diverse order (Table 1). Our analysis showed that leaf litter myriapod richness and abundance were affected by the restoration strategy, but not by leaf litter species or litter exposure time. The Andean alder plantation showed higher myriapod richness and abundance associated to litter decomposition (Table 2, Figure 1).

In addition, myriapod composition differed significantly between the restoration strategies and the leaf litter species (Table 2). For instance, *Hanseniella* sp. (Bagnall) (Symphyla: Scutigereidae) was dominant in the Andean alder plantation and *H. bonplandianum* litter, whereas Fuhrmannodesmidae family was the most abundant family in the secondary forest and *A. acuminata* litter. The morphospecies of Glomeridesmidae and Criptopidae inhabited *H. bonplandianum* litter of the secondary forest, whereas Pseudonannolenidae, Stemmiulidae, and Cryptodesmidae were exclusive of *A. acuminata* in the secondary forest. Cryptodesmidae and the genus *Newportia* (Gervais) (Scolopendromorpha: Scolopocryptopidae) were only found in *H. bonplandianum* litter of Alder plantation. In contrast, *Newportia* sp., *Scolopendrellopsis* sp., and the families Cryptodesmidae, Lophoprotidae, Ballophilidae, Rhinocricidae, and Scolopendridae were only found in *A. acuminata* litter of Alder plantation.

Tabla 1. Taxonomy of leaf litter myriapods in a secondary forest and an Andean alder plantation of a protected area from Central Andes (Manizales, Colombia).

Class	Order	Family	Abundance
Chilopoda	Scolopendromorpha	Cryptopidae	11
		Scolopocryptopidae	21
		Scolopendridae	1
Diplopoda	Geophilomorpha	Ballophilidae	1
		Cryptodesmidae	22
	Polydesmida	Fuhrmannodesmidae	75
		Cyrtodesmidae	25
		Pyrgodesmidae	10
		Chelodesmidae	4
	Glomeridesmida	Glomeridesmidae	32
	Polyxenida	Lophoproctidae	3
	Spirostreptida	Pseudonannolenidae	3
	Stemmiulida	Stemmiulidae	1
Spirobolida	Rhinocricidae	1	
Symphyla		Scutigereidae	64
		Scolopendrellidae	1

Tabla 2. Generalized linear model (GLM) of restoration strategy, litter species, and litter exposure time effects on myriapod richness and abundance. PERMANOVA of restoration strategy, litter species, and litter exposure time effects on myriapod composition. F- value and P-value (in parenthesis with significant values highlighted in bold) are showed.

	Restoration strategy	Litter species	Litter exposure time
Myriapod abundance $F_{1,126}$	12.51 (0.0005)	0.63 (0.420)	0.04 (0.83)
Myriapod richness $F_{1,126}$	11.25 (0.001)	1.57(0.211)	1.66 (0.199)
Myriapod composition $F_{1,93}$	5.86 (0.001)	2.39 (0.016)	0.91 (0.540)

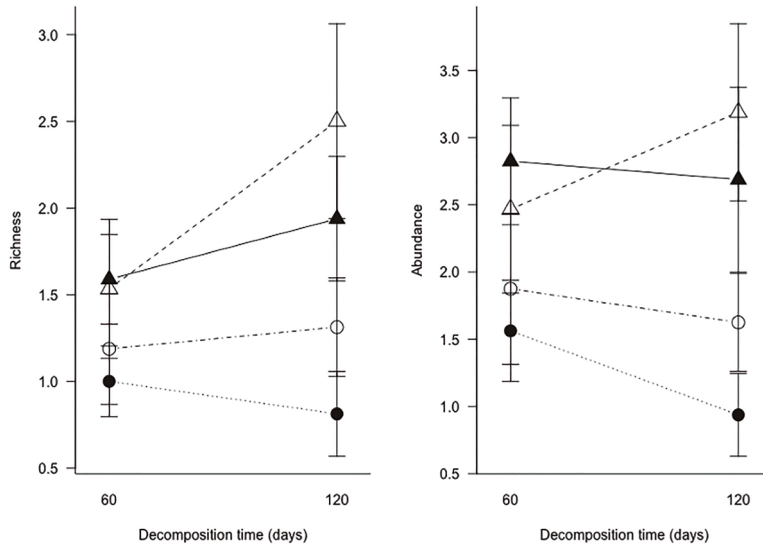


Figura 1. Myriapod richness and abundance of two litter species in a secondary forest and an Andean alder plantation of a protected area across litter exposure time. Secondary forest is represented by a circle, Andean alder plantation by a triangle, *H. bonplandianum* litter is shown in black, *A. acuminata* litter in white.

Discussion

In this study, we reported the myriapod richness and abundance associated with leaf litter decomposition in active and passive restoration strategies. Our results showed that classes Diplopoda, Chilopoda, and Symphyla colonized leaf litter of *A. acuminata* and *H. bonplandianum* in an Alder plantation and secondary forest. Restoration strategies lead to differences in myriapod richness and abundance, whereas exposure time and litter species do not show any effects. Myriapod composition shifted with restoration strategy and litter species.

We found myriapod families that had been reported in other studies, such as ScutigereLLidae, Fuhrmannodesmidae, Chelodesmidae, Cryptodesmidae, and Pyrgodesmidae (Vohland and Schroth, 1999). Millipedes were the most abundance myriapods in both restoration strategies. Millipedes influence leaf litter decomposition (Irmeler, 2000) through breakdown and transport of litter remains to a more favorable microhabitat for decomposition and to mobilize nutrients (Pramanik et al., 2001); moreover, millipedes influence microbial density and dispersion (David and Handa, 2010). Symphyla consume the microbial community, which affects leaf litter decomposition (Blakely et al., 2002).

Chilopoda are generalist predators, as they feed on Collembola, Diptera larvae, and Lumbricidae in the soil (Salmon et al., 2005). Cascading indirect effects of generalist predators on litter decomposition have been reported for spider species (Lensing and Wise, 2006). This same pattern could occur with centipedes in the Alder plantation and the secondary forest, which, by consuming springtails, could alter the effects of Collembola on litter microbial activity (Filser, 2002).

Myriapod richness, abundance, and composition shift with restoration strategy. Myriapod richness and abundance were greater in the alder plantation, millipedes were the most abundant and diverse. The same pattern has been found in plantations of native species (*Terminalia amazonia* and *Vochysia guatemalensis*) mixed with legume species, *Erythrina poeppigiana* and *Inga edulis*, in Costa Rica (Cole et al., 2016). It has also been observed in sites with different regeneration times in Brazil, where sites with low recovery time had high diplopod abundance (Frasson et al., 2016). This could reflect differences in plant composition between sites that could lead to variations in litterfall quality and, therefore, in the resources available for myriapod colonization, as reported for other soil invertebrates (Hansen and Coleman, 1998; Wardle et al., 2006).

Consumption preference of myriapods depends on leaf traits, such as toughness, thickness, and chemical characteristics or microbial activity (Carcamo et al., 2000; Coulis et al., 2013; David and Handa, 2010). The litter species used in this study differ in their initial litter quality, which leads to shifts in myriapod composition, but not in richness and abundance. The latter reflects myriapod species preference to litter species quality; for instance, morphospecies belong to Glomeridesmidae and Criptopidae colonized *H. bonplandianum* leaf litter. This litter was characterized by big leaves with low leaf dry-matter content, indicating a faster decomposition process and less resistance to physical hazards in comparison to *A. acuminata*. Those differences could lead to variations in the effect of myriapods on decomposition in response to litter species (Suzuki et al., 2013).

Decomposition time implies loss of leaf resource and changes in leaf traits, leading to shifts in fauna and fungal diversity and replacement of species (Anderson, 1985; Hasegawa and Takeda, 1993; Voříšková and PetrBaldrian, 2013). Despite this, decomposition time did not affect myriapod diversity and composition in the two restoration strategies, which implies that myriapod richness and abundance does not respond to shifts in the litter resource through time.

Restoration strategies produce shifts in the community of myriapods. The Alder plantation showed high myriapod diversity, in particular Diplopoda diversity, which contributes directly and indirectly to the decomposition process. Further research could be focused on assessing the top-down effect of myriapod predators, such as

Chilopoda, on the decomposition process, as well as on assessing the litter preference of the most abundant species of millipedes in both restoration strategies.

Author Contribution:

Fabiola Ospina-Bautista and Jaime V. Estévez conceived the research, secured funding, analyzed data, and wrote the manuscript. Pablo López-Bedoya conducted experiments. Daniela Martínez-Torres and Sebastián Galvis contributed to material analyses. All authors read and approved the final version of the manuscript.

Acknowledgements

This work is part of the project «Descomposición de hojarasca en una plantación de *Alnus acuminata* y en un bosque secundario» No. 2122416 supported by the Vicerrectoría de Investigaciones y Postgrados de la Universidad de Caldas, Colombia. We thank Aguas de Manizales for the permission to work at the Reserva Forestal Protectora de las Cuencas Hidrográficas de Río Blanco y Quebrada Olivares.

References

- Adis, J. (Editor). (2002). *Amazonian Arachnida and Myriapoda: Identification keys to all classes, orders, families, some genera, and lists of known terrestrial species*. Pensoft Pub.
- Aide, T. M., Zimmerman, J. K., Pascarella, J. B., Rivera, L., & Marciano-Vega, H. (2000). Forest regeneration in a chronosequence of tropical abandoned pastures: Implications for restoration ecology. *Restoration Ecology*, 8(4), 328-338. <https://doi.org/10.1046/j.1526-100x.2000.80048.x>
- Anderson, M. J. (2017). Permutational multivariate analysis of variance(Permanova). In *Wiley StatsRef: Statistics Reference Online*, pp. 1-15. American Cancer Society. <https://doi.org/10.1002/9781118445112.stat07841>
- Anderson, J.M., S.A. Huish, P. Ineson, M.A. Leonard, & Splatt, P.R. (1985). Interactions of invertebrates, microorganisms and tree roots in nitrogen and mineral element fluxes in deciduous woodland soils, pp. 377-392 In: A.H. Fitter, D. Atkinson, D. J. Read, M.B. Usher (Eds.) *Ecological interactions in soil: Plant, Microbes and Animals*. Blackwell Publishing.
- Barreto da Silva, W., Périco, E., Schmidt Dalzochio, M., Santos, M., & Cajaiba, R. L. (2018). Are litterfall and litter decomposition processes indicators of forest regeneration in the neotropics? Insights from a case study in the Brazilian Amazon. *Forest Ecology and Management*, 429, 189-197. <https://doi.org/10.1016/j.foreco.2018.07.020>
- Blakely, J. K., D.A. Neher, & Sponberg, A.L. (2002). Soil invertebrate and microbial communities, and decomposition as indicators of polycyclic aromatic hydrocarbon contamination. *Applied Soil Ecology*, 21(1), 71-88. [https://doi.org/10.1016/S0929-1393\(02\)00023-9](https://doi.org/10.1016/S0929-1393(02)00023-9)
- Cajaiba, R. L., Périco, E., Caron, E., Dalzochio, M. S., Silva, W. B., & Santos, M. (2017). Are disturbance gradients in neotropical ecosystems detected using rove beetles? A case study in the Brazilian Amazon. *Forest Ecology and Management*, 405, 319-327. <https://doi.org/10.1016/j.foreco.2017.09.058>
- Caldeira, M.V.W., R.D. Silva, S.R. Kunz, J.P. Zorzanelli, & Godinho, T.O. (2013). Biomassa e nutrientes da serapilheira em diferentes coberturas florestais. *Comunicata Scientiae* 4(2),111-119.
- Carcamo, H.A., T.A. Abe, C.E. Prescott, F.B. Holl, & Chanway, C.P. (2000). Influence of millipedes on litter decomposition, N mineralization, and microbial communities in a coastal forest in British Columbia, Canada. *Canadian Journal of Forest Research*, 30(5), 817-826. <https://doi.org/10.1139/x00-014>
- Clarke, K. R. (1993). Non-parametric multivariate analyses of changes in community structure. *Austral Ecology*, 18(1), 117-143. <https://doi.org/10.1111/j.1442-9993.1993.tb00438.x>
- Cole, R. J., K.D. Holl, R.A. Zahawi, P. Wickey, & Townsend, A.R. (2016). Leaf litter arthropod responses to tropical forest restoration. *Ecology and Evolution*, 6(15), 5158-5168. <https://doi.org/10.1002/ecc3.2220>
- Corporcaldas. (2010). *Reserva Forestal Protectora de las Cuencas Hidrográficas de Río Blanco y Quebrada Olivares*. Plan de Manejo.
- Coulis, M., S. Hätenschwiler, S. Rapior, & Coq S. (2009). The fate of condensed tannins during litter consumption by soil animals. *Soil Biology and Biochemistry*, 4, 2573-2578. <https://doi.org/10.1016/j.soilbio.2009.09.022>
- Coulis, M., S. Hätenschwiler, N. Fromin, & David, J.F. (2013). Macroarthropod-micro-organism interactions during the decomposition of Mediterranean shrub litter at different moisture levels. *Soil Biology and Biochemistry*, 64, 114-121 <https://doi.org/10.1016/j.soilbio.2013.04.012>

- Crawley, M.J. (2007). *The R Book: West Sussex*. John Wiley & Sons.
- Crowther, T.W., L. Boddy, & Jones, T.H. (2012). Functional and ecological consequences of saprotrophic fungus-grazer interactions. *ISME J*, 6: 1992-2001. <https://doi.org/10.1038/ismej.2012.53>
- David, J.F. & Gillon, D. (2002). Annual feeding rate of the millipede *Glomeris marginata* on holm oak (*Quercus ilex*) leaf litter under Mediterranean conditions. *Pedobiologia* 46(1),42-52. <https://doi.org/10.1078/0031-4056-00112>
- David, J.F. & Handa, I.T. (2010). The ecology of saprophagous macroarthropods (millipedes, woodlice) in the context of global change. *Biological Reviews*, 85(4), 881-895. <https://doi.org/10.1111/j.1469-185X.2010.00138.x>
- David, J. F. (2014). The role of litter-feeding macroarthropods in decomposition processes: A reappraisal of common views. *Soil Biology and Biochemistry*, 76,109-118. <https://doi.org/10.1016/j.soilbio.2014.05.009>
- FAO (Food and Agriculture Organisation). (2001). *State of the World's Forests 2001*.
- FAO (Food and Agriculture Organisation). (2015). *Evaluación de los recursos forestales mundiales 2015*. Second edition.
- Filser, J. (2002). The role of Collembola in carbon and nitrogen cycling in soil. *Pedobiologia*,46(3-4), 234-245. <https://doi.org/10.1078/0031-4056-00130>
- Fox, J. & Weisberg, S. (2011). An [R] Companion to Applied Regression, Second edition. SAGE.
- Frasson, J.M.F, J.L.O. Rosado, S.G. Elias, & Harter-Marques, B. (2016). Litter decomposition of two pioneer tree species and associated soil fauna in areas reclaimed after surface coal mining in Southern Brazil. *Revista Brasileira de Ciência do Solo*, 40(0). <https://doi.org/10.1590/18069657rbc20150444>
- Fujii, S., & Takeda, H. (2017). Succession of soil microarthropod communities during the aboveground and belowground litter decomposition processes. *Soil Biology and Biochemistry*, 110, 95-102. <https://doi.org/10.1016/j.soilbio.2017.03.003>
- Gunther, B., B.C. Rall, O. Ferlian, S. Scheu, & Eitzinger, B. (2014). Variations in prey consumption of centipede predators in forest soils as indicated by molecular gut content analysis. *Oikos*, 123(10), 1192-1198. <https://doi.org/10.1111/j.1600-0706.2013.00868.x>
- Guendehou, G. H., S. Liski, M. Tuomi, M. Moudachirou, B. Sinsin, & Mäkipää, R. (2014). Decomposition and changes in chemical composition of leaf litter of five dominant tree species in a West African tropical forest. *Tropical Ecology*,55(2), 207-220. <https://core.ac.uk/download/pdf/52269172.pdf>
- Hall, J., M. S., Ashton, E. J. Garen, E & Jose, S. (2011). The ecology and ecosystem services of native trees: Implications for reforestation and land restoration in Mesoamerica. *Forest Ecology and Management*, 261(10), 1553-1557. <https://doi.org/10.1016/j.foreco.2010.12.011>
- Hansen, R.A., & Coleman, D.C. (1998). Litter complexity and composition are determinants of the diversity and species composition of oribatid mites (Acari, Oribatida) in litterbags. *Applied Soil Ecology*, 9(1-3), 17-23. [https://doi.org/10.1016/S0929-1393\(98\)00048-1](https://doi.org/10.1016/S0929-1393(98)00048-1)
- Hasegawa, M., & Takeda, H. (1993). Changes in feeding attributes of four collembolan populations during the decomposition process of pine needles. *Pedobiologia* 39,155-169.
- Hobbs, R. J., S. Arico, J. Aronson, J.S. Baron, P. Bridgewater, V.A. Cramer, P.R. Epstein, J.J. Ewel, C.A. Klink, A.E. Lugo, D. Norton, D. Ojima, M.D. Richardson, E. Sanderson, F. Valladares, M. Vilà, R. Zamora, & Zobel, M. (2006). Novel ecosystems: Theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography*, 15(1), 1-7. <https://doi.org/10.1111/j.1466-822X.2006.00212.x>
- Irmler, U. (2000). Changes in the fauna and its contribution to mass loss and N release during leaf litter decomposition in two deciduous forests. *Pedobiologia*, 44(2), 105-118. [https://doi.org/10.1078/S0031-4056\(04\)70032-3](https://doi.org/10.1078/S0031-4056(04)70032-3)
- Lavelle, P., & Spain, A.V. (2001). *Soil Ecology*. Kluwer Academic.
- Lensing, J. R., & Wise, D.H. (2006). Predicted climate change alters the indirect effect of predators on an ecosystem process. *Proceedings of the National Academy of Sciences*, 103(42), 15502-15505. <https://doi.org/10.1073/pnas.0607064103>
- Lilleskov, E.A., & Bruns, T.D. (2005). Spore dispersal of a resupinate ectomycorrhizal fungus, *Tomentella subtilacinia*, via soil food webs. *Mycologia* 97(4), 762-769. <http://www.jstor.org/stable/3762225>
- Mcalpine, C., C.P. Catterall, R. Nally, D. Lindenmayer, J.L. Reid, K.D. Holl, A.F. Bennett, R.K. Runtig, K. Wilson, R.J. Hobbs, L. Seabrook, S. Cunningham, A. Moilanen, M. Maron, L. Shoo, I. Lunt, P. Vesik, L. Rumpff, & Martin, T.G. (2016). Integrating plant- and animal- based perspectives for more effective restoration of biodiversity. *Frontiers in Ecology and the Environment*, 14(1), 37-45. <https://doi.org/10.1002/16-0108.1>
- Oksanen, J., F. G. Blanchet, M. Friendly, R. Kindt, P. Legendre, D. McGlenn, P.R. Minchin, R.B. O'Hara, G.L. Simpson, P. Solymos, M.H. Stevens, E. Szoecs, & Wagner, H. (2018). *Vegan: Community Ecology Package. R package vegan, version 2.2-1*. <https://www.worldagroforestry.org/publication/vegan-community-ecology-package-r-package-vegan-vers-22-1>
- Paquette, A., & Messier, C. (2010). The role of plantations in managing the world's forests in the Anthropocene. *Frontiers in Ecology and the Environment*, 8(1), 27-34. <https://doi.org/10.1890/080116>
- Pramanik, R., K. Sarkar, & Joy, V.C. (2001). Efficiency of detritivore soil arthropods in mobilizing nutrients from leaf litter. *Tropical ecology*,42(1),51-58.
- Patricio, M. S., L.F. Nunes, & Pereira, E.L. (2012). Litterfall and litter decomposition in chestnut high forest stands in northern Portugal. *Forest Systems*, 21(2), 259. <https://doi.org/10.5424/fs/2012212-02711>
- R Core Team. (2018). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. <https://www.R-project.org/>
- Salmon, S., & Geoffroy, J. (2005). Earthworms and Collembola relationships: effects of predatory centipedes and humus forms. *Soil Biology and Biochemistry*, 37(3), 487-495. <https://doi.org/10.1016/j.soilbio.2004.08.011>
- Santonja, M., A., Aupic-samain, E. Forey, & Chauvat, M. (2018). Increasing temperature and decreasing specific leaf area amplify centipede predation impact on Collembola, *European Journal of Soil Biology*, 89, 9-13. <https://doi.org/10.1016/j.ejsobi.2018.08.002>
- Scheller, U., & Adis, J. (1996). A pictorial key for the symphylan families and genera of the Neotropical Region south of Central Mexico (Myriapoda, Symphyla). *Studies on Neotropical Fauna and Environment*, 31(1), 57-61. <https://doi.org/10.1076/>

- snfe.31.1.57.13316
- Shelley, R. M., & Mercurio, R.A. (2005). *Ectonocryptoides quadrimeropus*, a new centipede genus and species from Jalisco, Mexico; proposal of Ectonocryptopinae, analysis of subfamilial relationships, and a key to subfamilies and genera of the Scolopocryptopidae (Scolopendromorpha). *Zootaxa*, 1094(1), 25. <https://doi.org/10.11646/zootaxa.1094.1.2>
- Shiels, A. B., & Walker, L.R. (2003). Bird perches increase forest seeds on Puerto Rican landslides. *Restoration Ecology*, 11(4): 457-465.
- Silver, W.L., S.J. Hall, & Gonzáles, G. (2014). Differential effects of canopy trimming and litter deposition on litterfall and nutrient dynamics in a wet subtropical forest. *Forest Ecology and Management*, 332, 47-55. <https://doi.org/10.1016/j.foreco.2014.05.018>
- Suzuki, Y., S.J. Grayston, & Prescott, C.E. (2013). Effects of leaf litter consumption by millipedes (*Harpaghe haydeniana*) on subsequent decomposition depends on litter type. *Soil Biology and Biochemistry*, 57, 116-123. <https://doi.org/10.1016/j.soilbio.2012.07.020>
- Triplehorn, C.A. & N.F. Johnson. (2005). *Borror and DeLong's Introduction to the Study of Insects*. Thomson Brooks/Cole. 864 p.
- Vohland, K., & Schroth, G. (1999). Distribution patterns of the litter macrofauna in agroforestry and monoculture plantations in Central Amazonia as affected by plant species and management. *Applied Soil Ecology*, 13(1), 57-68. [https://doi.org/10.1016/S0929-1393\(99\)00021-9](https://doi.org/10.1016/S0929-1393(99)00021-9)
- Voříšková, J., & Baldrian, P. (2013). Fungal community on decomposing leaf litter undergoes rapid successional changes. *The ISME Journal*, 7(3), 477-486. <https://doi.org/10.1038/ismej.2012.116>
- Wardle, D.A., G.W. Yeates, G.M. Barker, & Bonner, K.I. (2006). The influence of plant litter diversity on decomposer abundance and diversity. *Soil Biology and Biochemistry*, 38(5), 1052-1062. <https://doi.org/10.1016/j.soilbio.2005.09.003>