



HAL
open science

Body size determines soil community assembly in a tropical forest

Zinger Lucie, Pierre Taberlet, Heidy Schimann, Aurélie Bonin, Frédéric Boyer, Marta De Barba, Philippe Gaucher, Ludovic Gielly, Charline Giguët-Covex, Amaia Iribar¹, et al.

► To cite this version:

Zinger Lucie, Pierre Taberlet, Heidy Schimann, Aurélie Bonin, Frédéric Boyer, et al.. Body size determines soil community assembly in a tropical forest. *Molecular Ecology*, 2019, 28 (3), pp.528-543. 10.1111/mec.14919 . hal-02079020

HAL Id: hal-02079020

<https://hal.science/hal-02079020>

Submitted on 18 Jan 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 **Soil community assembly varies across body sizes in a tropical forest**

2 **Authors**

3 Lucie Zinger*^{1,†}, Pierre Taberlet², Heidy Schimann³, Aurélie Bonin², Frédéric Boyer², Marta
4 De Barba², Philippe Gaucher⁴, Ludovic Gielly², Charline Giguët-Covex^{2,‡}, Amaia Iribar¹,
5 Maxime Réjou-Méchain^{1,5}, Gilles Rayé², Delphine Rioux², Vincent Schilling¹, Blaise
6 Tymen¹, Jérôme Viers⁶, Cyril Zouiten⁶, Wilfried Thuiller², Eric Coissac², Jérôme Chave¹.

7

8 **Affiliations**

9 ¹ Université Toulouse 3 Paul Sabatier, CNRS, ENFA, UMR 5174 Evolution et Diversité
10 Biologique (EDB), F-31062 Toulouse, France.

11 ² Univ. Grenoble Alpes, CNRS, Laboratoire d'Ecologie Alpine (LECA), F-38000 Grenoble,
12 France.

13 ³ INRA, UMR Ecologie des Forêts de Guyane (AgroParisTech, CIRAD, CNRS, Université
14 des Antilles, Université de la Guyane), 97310 Kourou, France.

15 ⁴ CNRS-Guyane, USR 3456, CNRS, Centre de recherche de Montabo IRD, 97334 Cayenne,
16 France.

17 ⁵ UMR AMAP, IRD, F-34000 Montpellier, France.

18 ⁷ Université Toulouse 3 Paul Sabatier, CNRS, IRD, UMR 5563 GET, F-31400 Toulouse,
19 France.

20

21 Present address:

22 † Ecole Normale Supérieure, PSL Research University, CNRS, Inserm, Institut de Biologie de
23 l'Ecole Normale Supérieure (IBENS), Plant and Diatom Genomics team, F-75005 Paris,
24 France.

25 ‡ Univ. Savoie Mont Blanc, CNRS, Ministère de la Culture et de la Communication,
26 EDYTEM, F-73000 Chambéry, France.

27

28 **Correspondance:** email: lucie@zinger.fr

29 **Keyword:** soil diversity, propagule size, niche determinism, neutral assembly, multi-taxa,
30 DNA metabarcoding, French Guiana.

31 **Short title:** Assembly of tropical soils communities

32

33 **ABSTRACT**

34 The relative influence of deterministic niche-based (i.e. abiotic conditions, biotic interactions)
35 and stochastic-distance dependent neutral processes (i.e. demography, dispersal) in shaping
36 communities has been extensively studied for various organisms, but is far less explored
37 jointly across the tree of life, in particular in soil environments. Here, using a thorough DNA-
38 based census of the whole soil biota in a large tropical forest plot, we show that soil
39 aluminium, topography, and plant species identity are all important drivers of soil richness
40 and community composition. Body size emerges as an important feature of the comparative
41 ecology of the different taxa at the studied spatial scale, with microorganisms being more
42 importantly controlled by environmental factors, while soil mesofauna rather display random
43 spatial distribution. We infer that niche-based processes contribute differently to community
44 assembly across trophic levels due to spatial scaling. Body size could hence help better
45 quantifying important properties of multitrophic assemblages.

46

47 **INTRODUCTION**

48 Over a century of documenting patterns of diversity has shown that niche-related,
49 demographic, dispersal and evolutionary processes are all important determinants of
50 ecological communities¹⁻³. However, their relative contribution across spatial scales and
51 organisms remains less well known^{2,4}, especially when it comes to the soil biota.

52 Soils are structurally complex environments⁵. They are often described as the “poor
53 man's tropical rainforest”⁶ due to the large and elusive diversity of organisms they harbour⁷.
54 Amplicon-based DNA analysis of environmental samples, or metabarcoding⁸ has recently
55 enabled unravelling novel macroecological patterns for soil fauna, nematodes, bacteria, fungi,
56 protists, and archaea across biomes and habitats^{7,9-11}. These patterns often co-vary with
57 environmental conditions such as pH and nutrient quality/availability. They also depend on

58 plant cover due to trophic and mutualistic/pathogenic interactions¹²⁻¹⁴, but this relationship
59 appears context-dependent¹⁵⁻¹⁷. Also, dispersal limitation or stochastic processes have been
60 unveiled in e.g. fungi or meiofauna^{10,18,19}, although other studies reported the predominance
61 of niche determinism^{11,20}.

62 Much of the difficulty in drawing general conclusions about soil community assembly
63 lies in that studies often focus on single taxonomic groups (but see^{17,20-22}) or consider different
64 spatial scales. In addition, soil organisms harbour large differences in life-history traits; in
65 particular their body size, whose spans six orders of magnitude (0.1 μm to 10 cm^7). This
66 property has important consequences for community assembly because organisms of different
67 body size are ruled by contrasting metabolic and demographic processes^{23,24}. Dispersal of
68 microorganisms is mediated by external agents and is assumed to occur across large spatial
69 distances. This, together with their large population size and short generation time, would
70 limit local extinction and ecological drift, resulting in a homogeneous global microbial
71 species pool^{20,25}. However, microorganisms are also more responsive to small-scale changes
72 in resources, subtle variations that may not be perceived by larger organisms^{24,26,27}. Hence,
73 microbial communities are often reported to be dominated by niche-based processes²⁵. In
74 contrast, larger organisms (e.g. mesofauna) are thought to be limited in their ability to
75 disperse and have longer reproduction times. They are hence more prone to ecological drift
76 and could display spatial aggregation patterns irrespective of environmental conditions (²⁸ and
77 references within). This has enormous consequences for the spatial scaling of soil biodiversity
78 and the major biogeochemical cycles and ecosystem services they sustain^{7,12,14}. However,
79 existing knowledge on the scaling of soil communities across body sizes is based entirely on
80 meta-analyses^{14,26,27} and is therefore indirect. This hampers our ability to predict the future of
81 this important biological component^{29,30}.

82 In order to assess the processes governing soil community assemblages, we combined
83 an extensive characterization of abiotic and plant cover conditions with a comprehensive
84 survey of soil biodiversity using DNA metabarcoding in a large tropical forest plot, where
85 samples were collected every ten meters. We sought to (i) determine which factor, both
86 abiotic (e.g. soil chemistry) and biotic (plant diversity, identity), influence soil communities
87 composition, (ii) evaluate the relative importance of niche-based versus neutral processes in
88 shaping these communities and (iii) determine how these effects depend on taxon body size.
89 We predicted that in communities of small-bodied organisms, niche based-processes would be
90 more important relative to larger organisms, which would display spatial aggregation patterns
91 that are consistent with neutrality.

92

93 **RESULTS**

94 We found a total of 2,502 archaeal, 19,101 bacterial, and 11,470 eukaryotic OTUs within the
95 12-ha plot (Table 1). Many of these OTUs were rare (relative abundance < 0.1%) and
96 accounted for 36 ± 10 % (SD values here and after) of archaea OTUs, 86 ± 2 % of bacterial
97 OTUs, and 80 ± 6 % of eukaryotic OTUs. Bacterial OTUs identified at the phylum level (88%
98 of OTUs, 94% of reads) corresponded mainly to Actinobacteria, Alphaproteobacteria, and
99 Acidobacteria. Identified eukaryotic OTUs (51% of OTUs, 70% of reads) belonged to fungi
100 (mainly Agaricomycetes, Glomeromycetes and Orbiliomycetes; Supplementary Table 1),
101 arthropods (mainly termites, mites and springtails) and annelids (Oligochaeta). Plants
102 represented only 2% of all OTUs (10 % of reads). For Archaea, the identified OTUs (3% of
103 OTUs, 64% of reads) corresponded to Nitrososphaeria and Methanomicrobia. Figure 2
104 illustrates the spatial variation in local diversity for the focal taxonomic groups. The pairwise
105 correlation of these spatial patterns, both in terms of OTU diversity and compositional

106 turnover, was moderate to low ($|r| < 0.7$) and showed low or no correlation with
107 plant ones (Supplementary Table 2-3).

108 The full RDA models, i.e. including abiotic, plant and spatial descriptors, explained 3-
109 13% of the variation in OTU composition across the 19 focal taxonomic groups (Fig. 3,
110 Supplementary Table 4). Spatial total effects contributed for 77 ± 9 % of the total explained
111 variation. Half of the spatial variation was explained by spatially structured abiotic conditions
112 (Fig. 1, Supplementary Table 5), in particular, soil aluminium and topographic variables (i.e.
113 elevation, convexity and wetness) or plant characteristics. They correlated negatively with the
114 OTU diversity of most unicellular taxonomic groups for soil aluminium and of several
115 bacterial groups and worms for topographic variables (Supplementary Fig. 1-2). The other
116 half of the spatial variation corresponded to pure spatial effects (41 ± 15 % of the total
117 explained variation). Only 7 ± 2 % of the total explained variation was due to pure abiotic
118 effects.

119 Plant total effects also explained a significant fraction of the explained variation ($28 \pm$
120 11 %, Fig. 3) and the plant pure effects were more important than pure abiotic ones in most
121 cases (13 ± 8 % of the total explained variation, Supplementary Table 4). The identity of the
122 dominant plant genera in soil samples as detected with the plant DNA marker was the best
123 plant predictors. These variables included 66 different dominant plant genera, 42 of which
124 were unambiguously identified. With OTU diversity instead of OTU composition, 4 to 46%
125 of the variation was explained and the relative importance of plant, abiotic and spatial factors
126 was similar to what observed above (Supplementary Table 6, Supplementary Fig. 3).

127 Across taxonomic groups, we found a negative relationship between dispersal unit size
128 and the fraction of variation in OTU composition explained by the environmental variables,
129 spatially structured or not (Fig. 4). This relationship held when the full variation or pure
130 abiotic effects were considered alone (Pearson's $r = -0.58$ and -0.51 respectively, $p < 0.05$).

131 We did not observe such a relationship when performing the analysis on OTU diversity
132 (Supplementary Figure 4).

133

134 **DISCUSSION**

135 Several recent reviews have emphasized the impressive development of publications
136 using high-throughput sequencing to describe the diversity in soils to the extent that it may
137 shift research effort away from fundamental questions in soil ecology and evolutionary
138 biology^{13,31}. They emphasize the focus on single taxonomic groups (mainly bacteria/fungi)
139 and the limited consideration for the biotic and abiotic environment at relevant spatial scales
140 are major obstacles to a mechanistic understanding of the processes regulating soil diversity
141 and functioning. This study is an attempt to address these limits, combining assessment of
142 environmental conditions with patterns of soil diversity across the tree of life at relatively
143 reduced spatial scales. We provide evidence for spatial scaling rules across soil taxonomic
144 groups and discuss the general implications of our findings for the assembly of soil
145 communities.

146 In the spirit of classical community ecology, we sought to understand the spatial
147 distribution of taxonomic groups using environmental and geographical variables. Although
148 the spatial patterns of soil communities differed widely amongst clades, they were all related
149 to several abiotic and biotic factors, albeit to a varying magnitude. This suggests that niche
150 processes always contribute to the community assembly of soil taxa at the studied spatial
151 scale, irrespective of the taxon.

152 We found total aluminium content to be an important predictor of microbial (i.e.
153 prokaryotes, protists) and nematodes communities. In addition, our study plot is an oxisol
154 with a $\text{pH} \leq 5$, conditions at which the toxic trivalent Al cation (Al^{3+}) predominates over the
155 other forms³². Al^{3+} competes with other nutrients, inhibits transport, and binds to DNA, ATP

156 or cell walls³², as do other metallic ions³³. In addition, aluminium abundance strongly
157 correlated with that of many other metals (e.g. Ti, Cu, Zn, Cd and Pb, Supplementary Table
158 4). We hence interpret the lower microbial diversity in Al-rich sites by its toxicity or that of
159 co-varying metals, as suggested for soil tropical microbes¹⁶. Also, high metal concentration
160 immobilizes nutrients that are essential for plant/microbial growth and protects organic matter
161 from biological degradation³⁴. This may explain why total N, C and P contents, which were
162 typical of tropical soils (Methods), were poor predictors of soil diversity. These measures
163 probably do not reflect their bioavailability. High metal conditions likely recruit microbial
164 taxa able to accumulate Al or to exudate organic acids and enzymes to immobilize Al and
165 increase P solubilisation^{33,34}. Because soil Al correlates negatively with soil pH (see
166 Methods), our results are also consistent with the decrease of microbial diversity as soil pH
167 decreases repeatedly observed^{16,20}. Soil metal content may hence provide a mechanistic
168 understanding of the pervasive soil-pH – microbial diversity relationship, and should be more
169 often considered in addition to other classical measurements.

170 Topographic variables were also important predictors of OTU composition for many
171 taxonomic groups. They co-vary with many soil properties (e.g. water availability,
172 biogeochemical processes) and most likely reflect meso-habitat heterogeneity. As such, they
173 are often used to predict tropical tree distributions (e.g.³⁵) and could be useful to model soil
174 communities. In particular, topographic variables are closely related to soil moisture, and
175 were the most important predictors of OTU diversity of flat/earthworms, known for their
176 sensitivity to this parameter^{36,37}, and of some bacterial groups, such as Deltaproteobacteria, an
177 anaerobic clade highly dependent on water availability³⁸. This observation generalizes
178 previous findings for soil bacteria³⁹ or animals⁴⁰ in tropical environments. We also retrieved
179 high arthropod:earthworm reads abundance ratios consistent with biomass of these groups
180 reported for the dry season³⁶, a time where the topographic control in soil humidity is highest

181 and where earthworms migrate deeper into the soil. Accordingly, the arthropod:earthworm
182 reads abundance ratios was lower in a pilot experiment conducted during the wet season.
183 Seasonal dynamics of soil communities should have important implications for
184 biogeochemical cycles, and may be directly impacted by the forecasted increased frequency
185 of Amazonian droughts⁴¹.

186 Our environmental parameters further included plant species distribution inferred from
187 DNA metabarcoding. Within our samples, we expected that plant DNA presence relates
188 directly to the quantity/quality of litter or roots exudates²⁶, which is poorly controlled by plant
189 diversity/community turnover *per se*⁴². In agreement with this expectation, we found that the
190 locally dominant plant genera influenced the community composition of most focal
191 taxonomic groups (previously termed the “tree identity effect”^{7,17}). Neotropical trees species
192 indeed greatly differ in the quantity, quality and chemistry of their litter⁴³ and this may hold
193 true for the chemical composition of their root exudates, their influence on soil physical
194 structure or their involvement in specific mutualistic/trophic interactions. This result hence
195 calls for a more mechanistic interpretation of plant-soil interactions^{13,14}.

196 The pervasive contribution of niche-based processes found here echoes previous meta-
197 analyses^{44,45}. However, environmental variables explained little variation, whether alone or
198 combined with spatial variables. Previous studies on various soil taxonomic groups reported
199 soil moisture, cation exchange capacity, nutrient or organic matter availability/quality to co-
200 vary with community composition^{11,17,20,37}. Although we have characterized the
201 environmental conditions to the best of our ability, we did not quantify directly these
202 important predictors. These often display strong spatial structures in tropical soils^{16,35} and
203 hence potentially contributed to the pure spatial effects observed here. We may also have
204 neglected parameters acting at fine spatial scales, which, together with the high number of
205 samples considered, most likely contribute to the amount of unexplained variance found for

206 all taxa. For instance, we did not quantify soil microstructure, which is important in
207 explaining the small-scale distribution of microbial organisms and water moisture^{26,31}, nor did
208 we quantify the geometry of roots as could be imaged by e.g. neutron tomography⁵. We also
209 did not considered soil organisms interactions. These parameters do exhibit considerable fine-
210 scale spatial heterogeneity and might explain the apparent idiosyncrasy of each sample. We
211 might therefore underestimate the contribution of niche-based processes, but expect this to be
212 consistent across the studied soil taxa.

213 A major problem in attempts to explain patterns of biodiversity is the difficulty of
214 observing ecological processes at the precise scale at which they manifest themselves⁴. Soils
215 are complex media where ecological processes operate at a hierarchy of scales, and any
216 attempt to interpret them should carefully examine the spatial scale of study and the grain of
217 the sampling unit^{5,26,27,31}.

218 For instance, we found no correlation between the species diversity/composition of
219 plants and that of our focal taxonomic groups, contrary to previous reports^{15,46}. We interpret
220 this discrepancy as a problem of size and sampling grain. Previous analyses were based on
221 sampling units of typically 20 to 30 m on a side where several soil samples were pooled and
222 compared with aboveground floristic surveys. At this scale, local plant community
223 composition averages over confounding environmental conditions. Our sampling unit was a
224 local soil core of ca. 15 g from which we inferred both local soil richness and plants. Thus, we
225 were able to relate the co-presence of microbial cells and plant cells at the centimetric scale¹³.
226 This allowed us to observe the “tree identity effect” reported above. Recently, Barberan et al.
227 (2015)¹⁶ reported that the strength of plant-microbial diversity relationship decreased with
228 decreasing sizes of sampling units and vanished at the scale of the sampling point. Our results
229 confirm these findings and extend them to the whole soil biota. Hence, soil biodiversity
230 cannot be inferred from plant floristic patterns at the field scale. As we did not find strong

231 similarities between the spatial patterning of the soil taxonomic groups, we confirm that this
232 conclusion extends to any inference of soil biodiversity patterns from one or few taxa²¹.

233 Such differences can be explained by strong among-clade differences in body size.
234 Indeed, a striking result from our analysis was that the amount of variation in diversity or
235 composition explained by environmental variables decreased significantly and linearly with
236 increasing propagule size across taxonomic groups.

237 The smallest body-size category includes bacteria, which was primarily explained by
238 environmental factors, owing to the clear environmental gradient at our site. This is in
239 agreement with the view that niche-based processes dominate bacterial community
240 assembly²⁵. Micro-eukaryotes displayed an intermediate amount of explained variation,
241 suggesting niche filtering is less important for these groups than for bacteria. This generalizes
242 previous comparisons of bacteria and fungi community assembly²². Whether it is due to
243 longer generation time, lower dispersal ability or broader resources distribution remains to be
244 determined. In fungi, the mycelium can spread across heterogeneous environments and the
245 apparent distribution of fungi may be less related to environmental conditions at the scale of
246 observation. Archaea and certain bacterial groups (i.e. Firmicutes and Bacteroidetes)
247 displayed similar features. These groups are of low abundance in soils or associated with
248 termites^{9,16,20,47}, which suggests that they have smaller population sizes in soils or dispersal
249 rates similar to those of macroorganisms, and could be hence more prone to ecological drift.

250 On the other hand, the OTUs corresponding to large-bodied organisms, i.e. arthropods,
251 annelids and flatworms, had a random spatial distribution. Soil mesofauna assembly may
252 hence be rather determined by neutral processes at the scale of our 12 ha plot and grain
253 studied. However, pure spatial variation, which is usually indicative of dispersal limitation,
254 was less important for this group than for microbes, which contrasts with previous reports^{28,44}.
255 We explain this result by the minimal distance between sampling points, 10 m, which was the

256 result of a compromise between spatial resolution and sampling effort. It may have been
257 insufficient to detect spatial aggregates for soil mesofauna, which usually displays spatial
258 aggregation below 10 m^{19,26,37}. This roughly corresponds to the horizontal distance
259 earthworms can disperse per year. Alternative sampling strategies should be hence considered
260 for multi-taxa assessments at the studied spatial scale. Still, studies using a finer sampling
261 grain suggest these aggregates to seldom covary with environmental factors and to most likely
262 result from stochastic processes^{19,37}. On the opposite end of the range, niche-based
263 community patterns emerge at scales larger than 12-ha where soils properties are highly
264 distinct in tropical trees³⁵ or mesofauna^{40,48}.

265 This observation is in line with Levin's argument on the problem of scales⁴. For a
266 unique studied area and sampling grain, we considered patterns of diversity at a multitude of
267 spatial scales across the studied taxa owing to their body size; with large-scale patterns (i.e.
268 microbes) being more predictable than fine-scale ones (i.e. mesofauna). This result further
269 points to an interesting juncture between two fields of ecological theory that have heretofore
270 been loosely connected, namely the role of body size in explaining the scaling rules of
271 metabolism²³ and that of environment and dispersal in explaining the assembly of ecological
272 communities². In that light the fact that small-bodied organisms are more influenced by
273 environmental conditions, while large-bodied organisms display neutral assembly is
274 consistent with the main predictions of macroecology² and soil science^{26,27}. Our finding of a
275 log-linear relationship between the contribution of niche-based processes in community
276 assembly and propagule size generalizes previous empirical observations in freshwater
277 ecosystems (²⁸ and references within). Although other important biological features also likely
278 explain the differences of spatial distribution between soil organisms (e.g. clonal/sexual
279 reproduction, mutualistic/pathogenic interactions, transport that is active, mediated by
280 animals, by water or wind), the body size trait constitutes an operational parameter that cuts

281 across the tree of life. It is indicative of the way organisms perceive – or move across –
282 space^{3,24,26,27} and of their trophic status in its broadest sense²⁹. Hence, our result provides
283 empirical evidence of spatial scaling rules across the soil food web.

284 The recent explosion of DNA-based studies has considerably increased our knowledge
285 on the taxonomic, genetic and functional diversity of soil organisms⁷, but has so far provided
286 limited understanding of the mechanisms shaping soil biodiversity³¹. We do believe that
287 quantifying soil biodiversity using amplicon-based techniques is a useful endeavour. It is
288 increasingly obvious that important properties of multitrophic systems, e.g. species richness,
289 distribution and extinction rates, cannot be easily retrieved from one or a small set of
290 surrogate taxa (this study, ^{21,30}). Co-occurrences multitrophic networks can now be
291 reconstructed using such DNA-based approaches⁴⁹, and these approaches hold great promises
292 in assessing soil ecological networks properties at spatial and temporal scales that have been
293 heretofore inconceivable. Our results show that accounting for body size differences helps
294 unravel spatial patterns in such complex communities and, combined with DNA-based
295 approaches, could improve predictive models of soil food webs.

296

297 **METHODS**

298 ***Study site and sampling***

299 The study site is located at the Nouragues Ecological Research Station, in the lowland
300 rain forest of French Guiana (latitude: 4° 4' 28" N, longitude: 52° 40' 45" W). Rainfall is 2861
301 mm.y⁻¹ (average 1992-2012), with a two-month dry season (< 100 mm.month⁻¹), from late
302 August to early November, and a shorter dry season in March. Our sampling campaign was
303 conducted November 7-20, 2012, towards the end of the dry season, which lasted from early
304 September to late November. Cumulated rainfall during the 60 days preceding the sampling

305 session was 134 mm, with 44 days without rain, and over 90% of the rainfall concentrated in
306 seven days.

307 We surveyed a 12-ha (300 x 400 m) plot established in 1992. This plot extends on a
308 gentle slope between a ridge and a small creek⁵⁰. The 5,640 trees occurring in the plot
309 (diameter at breast \geq 10 cm) belong to over 600 species, with the two dominant species
310 accounting each for only 2.3% of individuals⁵¹. Sand and clay fractions are about 40% each in
311 the soil top 10 cm. The parent material is Caribbean granite. Soil edaphic conditions are
312 typical of tropical oxisols, with an acidic pH (pH = 5.0) and low exchangeable cation content
313 (ECEC = 3.5 cmolc.kg⁻¹). The C:N and N:P ratios are typical of tropical forests⁵²
314 (median=13.4 and 40.5 respectively).

315 We sampled the plot following a regular grid scheme with a 10-m mesh, excluding
316 bordering points, hence resulting in a total of 1,132 sampling points. At each point, 50-100g
317 soil cores were collected with an auger at ~10 cm depth, excluding the organic horizon. We
318 did so because the organic and mineral horizons harbor different arthropods and microbial
319 communities^{53,54}. Lumping together these compartments may hence complicate the
320 interpretation of the spatial distribution of certain soil clades. Consequently, we focused on
321 the surface soil layer, which it is the most biogeochemically active in the mineral horizon⁵⁵.
322 The soil cores were stored and sealed in sterile plastic bags after collection and transported to
323 the field station laboratory. Extracellular DNA was extracted from 15 g of soil per soil core as
324 described previously^{56,57} within 4 hours after sample collection to prevent from microbial
325 growth. DNA was extracted twice for each soil core, and the remaining soil material was
326 dried and stored for analytical chemistry analyses.

327 ***Molecular analyses***

328 Soil biodiversity was surveyed through DNA metabarcoding using four DNA markers,
329 with primers targeting three in hypervariable regions of the *ssu* rRNA gene in Archaea (this

330 study), Bacteria⁵⁸ and Eukaryota⁵⁹ domains respectively (see Supplementary Table 7) and a
331 plastid DNA marker (P6 loop of the trnL intron⁶⁰) to characterize the plant composition at the
332 scale of the sampling point. The universal primers do not present particular amplification
333 biases (see Supplementary Material for a detailed description of primer similarity with
334 priming sites across phyla).

335 We conducted duplicated PCRs for each marker and each DNA extract, hence
336 representing a total of 18,112 independent PCRs. To discriminate PCR products after
337 sequencing, forward and reverse primers were tagged with a combination of two different 8-
338 nucleotide labels. Each PCR reaction was performed in a total volume of 20 µl and comprised
339 10 µl of AmpliTaq Gold® Master Mix (Life Technologies, Carlsbad, CA, USA), 0.25 µM of
340 each primer, 3.2µg of BSA (Roche Diagnostic, Basel, Switzerland), and 2 µl DNA template
341 that was 10-fold diluted to reduce PCR inhibition by humic substances. Thermocycling
342 conditions are shown in Appendix S1. All PCR products were then purified using a
343 MinElute™ PCR purification kit (Qiagen, Hilden, Germany). For each marker, PCR products
344 were distributed into 4 different sequencing libraries, which were pooled and loaded on up to
345 7 Illumina sequencing lanes, depending on the marker and sequencing platform used
346 (Supplementary Table 7), using the paired-end sequencing technology. To control for
347 potential contaminants⁶¹ and false positive caused by tag-switching events⁶², the sequenced
348 multiplexes comprised extractions/PCR blank controls, as well as unused tag combinations.

349 *Sequence analyses and curation*

350 The ca. 10⁹ sequencing reads produced were curated using the OBITools package⁶³
351 and R scripts (www.r-project.org).

352 We first assembled paired-end reads and assigned them to their respective samples and
353 taxonomic groups on the basis of the tags and primer sequences, by allowing 2 and 0
354 mismatches on primers and tags, respectively. Reads were dereplicated, and low-quality

355 sequences excluded (i.e. shorter than 7, 13, 50 and 100 nt for the plant, eukaryota, archaea and
356 bacterial markers, respectively; containing “Ns”; and singletons). We then clustered the
357 remaining unique sequences into operational taxonomic units (OTUs), as follows. We
358 computed pairwise dissimilarities between sequences (i.e. the number of mismatches, allowed
359 to be 0-3) using the Sumatra algorithm⁶⁴, then we formed OTUs using the Infomap
360 community detection algorithm⁶⁵. We excluded OTUs represented by a single sequence
361 because PCR/sequencing almost always produce at least one error on amplified fragments.
362 The true sequence of an OTU was assumed to be the most abundant one in the cluster.

363 OTUs were assigned a taxonomic clade with the ecotag program of the OBITools
364 package. Since this algorithm requires full-length barcodes as reference, we constructed a set
365 of reference databases for each marker by running in silico PCRs with the primer pairs used
366 here (Supplementary Table 7). This was done with the ecoPCR program⁶⁶ by using Genbank
367 (release 197; <ftp://ftp.ncbi.nlm.nih.gov/genbank>) and the MOTHUR-formatted SILVA
368 database (release 119; http://www.mothur.org/wiki/Silva_reference_files) as sequence
369 template. We here only considered references with unambiguous taxonomic annotation at the
370 order level. We also used a reference database of tropical plants occurring at the study site,
371 built with the plant primers, so as to improve plant OTU identification (available in⁵⁶ and the
372 Dryad Digital Repository, doi:10.5061/dryad.1qt12). At the end of this analysis, we had two
373 taxonomic assignments for each OTU. We gave priority to assignments from SILVA or our
374 local plant database when the similarity between the query and its best match was > 98%. We
375 did so because the SILVA and our local plant databases yield taxonomic annotations that are
376 more reliable than those from Genbank. Otherwise, the taxonomic assignment yielding the
377 highest similarity score was kept. Paired-end reads were assembled, assigned to their
378 respective samples/marker and dereplicated. Low-quality sequences were excluded; the

379 remaining ones were clustered into operational taxonomic units (OTUs) and assigned a
380 taxonomic clade.

381 We paid particular attention to minimize PCR/sequencing errors, contaminant and
382 false positive sequences as well as potential non-functional PCRs by using several
383 conservative quality criteria. First, we assumed that OTUs peaking in abundance in the
384 negative controls were a contaminant. Any OTU with a best-match similarity in any reference
385 database below $< \text{ca. } 75\%$ was considered as a chimera or highly degraded sequence. Any
386 OTU that did not fall into the clade targeted by the primer pair was also excluded. Finally, we
387 also curated the dataset from false positives caused by tag-switching events. This
388 phenomenon is suspected to occur during the preparation of the sequencing library and
389 translates into low abundance “contaminant OTUs” in samples coming from other samples
390 that were part of the amplicons multiplex. To remove them, we considered each OTU
391 separately and set to 0 any abundance representing $< 0.03\%$ of the total OTU abundance in
392 the entire dataset, similarly to ⁶². This abundance threshold was found to be the one for which
393 most OTUs with unused tag combinations could be removed from the dataset.

394 Verifying the success of our 18,000 PCRs was not possible. Therefore, we used the
395 PCR replicates to filter out potential non-functional PCR reactions, i.e. containing low
396 amounts of reads or high amounts of contaminants or false positives that could not be filtered
397 out with the process described above. First, for each sample we defined an average
398 community (hereafter centroid) by averaging OTUs counts of the four PCR replicates.
399 Second, we compared the distribution of dissimilarities (as defined by Euclidean distances) of
400 PCR replicates with their respective centroid (hereafter d_w) against the distribution of pairwise
401 dissimilarities between all centroids (hereafter d_b). As we expect $d_w < d_b$, we defined the
402 intersection of d_w and d_b distribution curves as the dissimilarity level above which a PCR
403 replicate is too distant from its centroid to be reliable. Any PCR above this threshold was

404 excluded from the analysis. This process was repeated iteratively until no more PCR were
405 removed from the dataset. If a sample was represented by only one PCR product, then it was
406 excluded during the iterative process. At the end of this procedure, the remaining PCR
407 replicates were summed for each sample. See Supplementary Table 8 for raw and curated
408 datasets statistics.

409 Finally, the sequencing depth of each sample was standardized for each marker by
410 randomly resampling a number of reads equal to the first quartile of read number across
411 samples. Although such procedure has been recently questioned⁶⁷, the data loss caused by
412 rarefaction is minimal when the subsampling size well covers the sample diversity, as it is the
413 case here. It had therefore no or weak effects on the dataset characteristics and the retrieve
414 patterns of diversity (Supplementary Fig. 5). Raw and curated sequencing data as well as
415 associated metadata are available on the Dryad Digital Repository under the accession XXX.

416 ***Focus taxonomic groups and body size***

417 Within the Eukaryota and Bacteria domains, we distinguished groups on the basis of
418 their taxonomic affiliation at the phylum level (Table 1). We did so because broadly defined
419 functional traits such as body size and trophic categories are relatively well conserved within
420 phyla^{38,68}. We restricted our analysis to the most abundant phyla (i.e. representing $\geq 1\%$ of the
421 total bacterial or eukaryotic OTU diversity). Archaea were analysed as a single group due to
422 imprecise taxonomic assignments.

423 Body size classes were defined as the size of the dispersal unit (propagule), rather than
424 that of the mature individual: in some taxa, like fungi, mature bodies may extend over large
425 areas through mycelium growth (i.e. the vegetative part of fungi). The intraspecific variability
426 of these mature forms besides vary from 1 to 2 orders of magnitude⁶⁹. This makes it difficult
427 to decide on an effective definition of a 'body'. In contrast, spore size is more stable and
428 proportional to the reproduction rate and to the fructification size of certain fungal groups^{69,70}.

429 This definition also cuts across the domains of life as it corresponds to average cell size for
430 unicellular organisms (i.e. archaea, bacteria and protists) and average body size of adults for
431 the soil meiofauna. For fungi, we used their spore size, as the operational definition of body
432 size¹⁸. Body sizes were inferred from⁷¹ for bacterial cells, from^{72,73} for fungal propagules, and
433 from⁶⁸ for the other groups (Table 1).

434 ***Environmental parameters***

435 *Soil chemistry and airborne lidar.* Total content in soil chemical elements was assessed on
436 one soil sample in two (i.e. every 20 meters). Soils were ground and attacked by hydrochloric
437 and nitric acid. Major element concentration was measured by inductively coupled plasma
438 optical-emission spectroscopy (ICP-OES). Carbon and nitrogen concentration was measured
439 by a CHN elemental analyzer (NA 2100 Protein, CE Instruments). All other chemical
440 elements were quantified by ICP-MS. In total, our dataset included 55 elemental
441 concentrations, which were krigged using an exponential variogram model so as to obtain
442 values for all the points of the initial sampling design. This analysis was conducted with the
443 *sp* (<http://rspatial.r-forge.r-project.org/>) and *gstat* (<http://gstat.r-forge.r-project.org/>) R
444 packages. Despite soil pH is a common predictor of soil microbes⁷⁴, we did not assess this
445 parameter here. Soil pH is indeed well known to correlate negatively with soil total
446 aluminium, in both temperate⁷⁵ and tropical soils⁷⁶. Because tropical soils are Al-rich,
447 conditions that are extreme for the soil biota³⁴, we believe this variable to be more relevant in
448 our study plot than soil pH *per se*, as the latter results from mixed biochemical/chemical
449 pathways and hence provides a poor mechanistic explanation of the processes shaping soil
450 communities. Airborne lidar data were obtained previously^{77,78} and were used here to retrieve
451 a 1-m² digital elevation model (DEM), from which we derived slope, light penetration, and
452 topographic wetness indices (see Supplementary Methods).

453 *Plants*. We used several plant-related variables to explain soil community assembly. The first
454 corresponded to the canopy closure derived from the lidar data. The other corresponded to
455 plant diversity (Shannon index) and the identity of the three most dominant plant genera in
456 each soil sample as inferred from the plant metabarcoding dataset. Dominant plant genera
457 represented on average $70 \pm 15\%$ of the plant reads in each sample, which provides a good
458 description of the local plant community composition. Sampling points for which we did not
459 obtained any plant sequences (330 of the 1,132) were redrawn by a multinomial resampling of
460 reads from neighboring points. This approach is reasonable because tree roots influence is
461 detectable up to 20 m from their corresponding stems in tropical forests¹⁶.

462 ***Statistical analyses***

463 To disentangle the relative importance of niche-based and neutral processes in the
464 assembly of soil communities, we used variation partitioning and redundancy analysis
465 (RDA^{44,79}) on each focus taxonomic group. We used RDA because preliminary analyses
466 indicated a linear relationship between soil diversity/community distribution and explanatory
467 variables. First, we Hellinger-transformed OTU tables to down-weight rare OTUs, as these
468 may be artifactual, as well as to preserves the Euclidean distance among sites⁸⁰. Next, we
469 constructed three parsimonious models by applying a forward selection procedure. This
470 avoids inflating the amount of explained variance and Type I error⁸¹.

471 A first model corresponded to RDAs including soil chemistry and lidar-derived data.
472 The second corresponded to RDAs including plant explanatory variables (Fig. 1,
473 Supplementary Table 9). For these two models, explanatory variables were preselected to
474 reduce multicollinearity ($|\text{Pearson's } r| \geq 0.7$, Supplementary Fig. 6) and normalized with a
475 Box-Cox transformation to meet the normality assumption. The third model was a spatial
476 RDA using spatial eigenvectors as explanatory variables, derived from a Principal
477 Components of Neighbours Matrices (PCNM) approach⁸². These represent spatial structures

478 at different spatial scales that allow modelling the spatial structure of community composition
479 variation. To further reduce inflation of R^2 statistics caused by the PCNM analyses⁸³, we
480 preselected PCNM eigenvectors prior the forward selection procedure. These corresponded to
481 eigenvectors explaining significantly ($p \leq 0.02$) the variability in the biological response, as
482 assessed though partial canonical redundancy analysis (pRDA). This pre-selection was
483 performed for each studied clade independently. Geographic coordinates were also included
484 in the model to account for possible linear trends along the study area⁸².

485 Abiotic, plant and spatial models were then combined into a single, “full” RDA
486 model, which was subjected to variation partitioning. This analysis decomposes the variance
487 of community composition explained either by abiotic, plant or spatial variables alone as well
488 their combined effects. The contribution of pure environmental vs. spatial effects in the
489 variation of community composition is usually considered to be indicative of the relative
490 importance of niche-base processes vs. dispersal limitation in the community assembly^{44,79},
491 provided that the environmental context is well characterized and that neutral processes are
492 not correlated with the environment. Significance of the total RDA models and pure effects
493 were determined with 1,000 Monte-Carlo permutations. We here only report R^2_{adj} statistics,
494 which are less inflated when the numbers of explanatory variables is high^[84]. To further
495 identify the environmental parameters that were spatially structured in our plot, each PCNM
496 eigenvector was regressed against the set of plant and abiotic variables using pRDA.

497 To test an effect of body size on community assembly patterns, we compared it with
498 the amount of variance explained by the full model and each pure effect using a Pearson
499 product-moment correlation test. Finally, we repeated the whole analysis by considering OTU
500 diversity as a response variable. OTU diversity was calculated as the exponential of the
501 Shannon entropy, an effective number of species⁸⁵ that is less sensitive to rare OTUs. All
502 analyses were conducted with the vegan R package (<http://vegan.r-forge.r-project.org/>).

503 **Data availability**

504 Raw and curated sequencing data as well as associated metadata and codes are available on
505 the Dryad Digital Repository (XXX provided upon manuscript acceptance).

506 **References**

- 507 1. Vellend, M. Conceptual synthesis in community ecology. *Quart. Rev. Biol.* **85**, 183-206
508 (2010).
- 509 2. Ricklefs, R. E. A comprehensive framework for global patterns in biodiversity. *Ecol.*
510 *Lett.* **7**, 1-15 (2004).
- 511 3. Hubbell, S. P. The unified neutral theory of biodiversity and biogeography Princeton
512 University Press, Princeton, USA (2001).
- 513 4. Levin, S. A. The problem of pattern and scale in ecology: the Robert H. MacArthur
514 award lecture. *Ecology* **73**, 1943-1967 (1992).
- 515 5. Hinsinger, P., Bengough, A. G., Vetterlein, D., & Young, I. M. Rhizosphere:
516 biophysics, biogeochemistry and ecological relevance. *Plant Soil* **321**, 117-152 (2009).
- 517 6. Giller, P. S. The diversity of soil communities, the 'poor man's tropical rainforest'.
518 *Biodivers. Conserv.* **5**, 135-168 (1996).
- 519 7. Bardgett, R. D. & van der Putten, W. H. Belowground biodiversity and ecosystem
520 functioning. *Nature* **515**, 505-511 (2014).
- 521 8. Taberlet, P., Coissac, E., Hajibabaei, M., & Rieseberg, L. H. (2012) Environmental
522 DNA. *Mol. Ecol.* **21**, 1789-1793.
- 523 9. Fierer, N., Strickland, M. S., Liptzin, D., Bradford, M. A., & Cleveland, C. C. Global
524 patterns in belowground communities. *Ecol. Lett.* **12**, 1238-1249 (2009).
- 525 10. Tedersoo, L., *et al.* Global diversity and geography of soil fungi. *Science* **346**, 1256688
526 (2014).
- 527 11. Wu, T., Ayres, E., Bardgett, R. D., Wall, D. H., & Garey, J. R. Molecular study of
528 worldwide distribution and diversity of soil animals. *Proc. Natl. Acad. Sci. USA* **108**, 17720-
529 17725 (2011).
- 530 12. Wardle, D. A. Communities and ecosystems: linking the aboveground and belowground
531 components. Princeton University Press, Princeton, USA (2002).
- 532 13. Dini-Andreote, F. & van Elsas, J. D. Back to the basics: The need for ecophysiological
533 insights to enhance our understanding of microbial behaviour in the rhizosphere. *Plant Soil*
534 **373**, 1-15 (2013).
- 535 14. Lavelle, P., *et al.* Soil function in a changing world: the role of invertebrate ecosystem
536 engineers. *Eur. J. Soil Biol.* **33**, 159-193 (1997).
- 537 15. Peay, K. G., Baraloto, C., & Fine, P. V. Strong coupling of plant and fungal community
538 structure across western Amazonian rainforests. *ISME J.* **7**, 1852-1861 (2013).
- 539 16. Barberán, A., *et al.* Relating belowground microbial composition to the taxonomic,
540 phylogenetic, and functional trait distributions of trees in a tropical forest. *Ecol. Lett.* **18**,
541 1397-1405 (2015).
- 542 17. Tedersoo, L., *et al.* Tree diversity and species identity effects on soil fungi, protists and
543 animals are context dependent. *ISME J.* **10**, 346-362 (2016).
- 544 18. Peay, K. G., Garbelotto, M., & Bruns, T. D. Evidence of dispersal limitation in soil
545 microorganisms: isolation reduces species richness on mycorrhizal tree islands. *Ecology* **91**,
546 3631-3640 (2010).
- 547 19. Bahram, M., *et al.* Stochastic distribution of small soil eukaryotes resulting from high
548 dispersal and drift in a local environment. *ISME J.* **10**, 885-96 (2016).

- 549 20. Ramirez, K. S., *et al.* Biogeographic patterns in below-ground diversity in New York
550 City's Central Park are similar to those observed globally. *Proc. R. Soc. London Ser. B* **281**,
551 20141988 (2014).
- 552 21. Schuldt, A., *et al.* Multitrophic diversity in a biodiverse forest is highly nonlinear across
553 spatial scales. *Nat. Comm.* **6**, 10169 (2015).
- 554 22. Powell, J. R., *et al.* Deterministic processes vary during community assembly for
555 ecologically dissimilar taxa. *Nat. Comm.* **6**, 8444 (2015).
- 556 23. Brown, J. H., Gillooly, J. F., Allen, A. P., Savage, V. M., & West, G. B. Toward a
557 metabolic theory of ecology. *Ecology* **85**, 1771-1789 (2004).
- 558 24. Woodward, G., *et al.* Body size in ecological networks. *Trends Ecol. Evol.* **20**, 402-409
559 (2005).
- 560 25. Barberán, A., Casamayor, E.O., Fierer, N. The microbial contribution to macroecology.
561 *Frontiers in Microbiology* **5**, 203 (2014).
- 562 26. Berg, M. P. Patterns of biodiversity at fine and small spatial scales. *In: Soil Ecology and*
563 *Ecosystem services (eds. Wall, D.H., et al.)*. Oxford University Press, Oxford, UK, 136-152
564 (2012).
- 565 27. Ettema, C. H. & Wardle, D. A. Spatial soil ecology. *Trends Ecol. Evol.* **17**, 177-183
566 (2002).
- 567 28. Bie, T., *et al.* Body size and dispersal mode as key traits determining metacommunity
568 structure of aquatic organisms. *Ecol. Lett.* **15**, 740-747 (2012).
- 569 29. Brose, U., *et al.* Climate change in size-structured ecosystems. *Philos. Trans. R. Soc.*
570 *London ser B* **367**, 2903-2912 (2012).
- 571 30. Veresoglou, S. D., Halley, J. M., & Rillig, M. C. Extinction risk of soil biota. *Nat.*
572 *Comm.* **6**, 8862 (2015).
- 573 31. Baveye, P. C., Berthelin, J., & Munch, J.-C. Too much or not enough: Reflection on
574 two contrasting perspectives on soil biodiversity. *Soil Biol. Biochem.* **103**, 320-326 (2016).
- 575 32. Piña, R. G. & Cervantes, C. Microbial interactions with aluminium. *Biometals* **9**, 311-
576 316 (1996).
- 577 33. Lemire, J. A., Harrison, J. J., & Turner, R. J. Antimicrobial activity of metals:
578 mechanisms, molecular targets and applications. *Nat. Rev. Microbiol.* **11**, 371-384 (2013).
- 579 34. Fujii, K. Soil acidification and adaptations of plants and microorganisms in Bornean
580 tropical forests. *Ecol. Res.* **29**, 371-381 (2014).
- 581 35. Baldeck, C. A., *et al.* Soil resources and topography shape local tree community
582 structure in tropical forests. *Proc. R. Soc. London Ser. B* **280**, 20122532 (2013).
- 583 36. Frago, C. & Lavelle, P. Earthworm communities of tropical rain forests. *Soil Biol.*
584 *Biochem.* **24**, 1397-1408 (1992).
- 585 37. Jiménez, J. J., Decaëns, T., Lavelle, P., & Rossi, J.-P. Dissecting the multi-scale spatial
586 relationship of earthworm assemblages with soil environmental variability. *BMC Ecol.* **14**, 26
587 (2014).
- 588 38. Martiny, J. B. H., Jones, S. E., Lennon, J. T., & Martiny, A. C. Microbiomes in light of
589 traits: A phylogenetic perspective. *Science* **350**, aac9323 (2015).
- 590 39. Bouskill, N. J., *et al.* Pre-exposure to drought increases the resistance of tropical forest
591 soil bacterial communities to extended drought. *ISME J.* **7**, 384-394 (2013).
- 592 40. Basset, Y., *et al.* Arthropod distribution in a tropical rainforest: Tackling a four
593 dimensional puzzle. *PloS One* **10**, e0144110 (2015).
- 594 41. IPCC. Climate change 2013: the physical science basis: Working Group I contribution
595 to the Fifth assessment report of the Intergovernmental Panel on Climate Change (Stocker TF,
596 *et al.*, eds.). Cambridge University Press, UK (2014).
- 597 42. Meier, C. L. & Bowman, W. D. Links between plant litter chemistry, species diversity,
598 and below-ground ecosystem function. *Proc. Natl. Acad. Sci.* **105**, 19780-19785 (2008).

- 599 43. Hättenschwiler, S., Aeschlimann, B., Coûteaux, M.-M., Roy, J., & Bonal, D. High
600 variation in foliage and leaf litter chemistry among 45 tree species of a neotropical rainforest
601 community. *New Phytol.* **179**, 165-175 (2008).
- 602 44. Cottenie, K. Integrating environmental and spatial processes in ecological community
603 dynamics. *Ecol. Lett.* **8**, 1175-1182 (2005).
- 604 45. Soininen, J. A quantitative analysis of species sorting across organisms and ecosystems.
605 *Ecology* **95**, 3284-3292 (2014).
- 606 46. Basset, *et al.* Arthropod diversity in a tropical forest. *Science* **338**, 1481-1484 (2012).
- 607 47. Engel, P. & Moran, N. A. The gut microbiota of insects - diversity in structure and
608 function. *FEMS Microbiol. Rev.* **37**, 699-735 (2013).
- 609 48. Decaëns, T., *et al.* DNA barcoding reveals diversity patterns of earthworm communities
610 in remote tropical forests of French Guiana. *Soil Biol. Biochem.* **92**, 171-183 (2016).
- 611 49. Faust, K. & Raes, J. Microbial interactions: from networks to models. *Nat. Rev.*
612 *Microbiol.* **10**, 538-550 (2012).
- 613 50. Chave, J., *et al.* Above-ground biomass and productivity in a rain forest of eastern
614 South America. *J. Trop. Ecol.* **24**, 355-366 (2008).
- 615 51. Baraloto, C., *et al.* Using functional traits and phylogenetic trees to examine the
616 assembly of tropical tree communities. *J. Ecol.* **100**, 690-701 (2012).
- 617 52. Turner, B. L. & Engelbrecht, B. M. J. Soil organic phosphorus in lowland tropical rain
618 forests. *Biogeochemistry* **103**, 297-315 (2010).
- 619 53. Baldrian, P., *et al.* Active and total microbial communities in forest soil are largely
620 different and highly stratified during decomposition. *ISME J.* **6**, 248-58 (2012).
- 621 54. Yang, C., *et al.* Using metabarcoding to ask if easily collected soil and leaf-litter
622 samples can be used as a general biodiversity indicator. *Ecol. Indic.* **46**, 379-389 (2014).
- 623 55. Silver, W. L., *et al.* Effects of Soil Texture on Belowground Carbon and Nutrient
624 Storage in a Lowland Amazonian Forest Ecosystem. *Ecosystems* **3**, 193-209 (2000).
- 625 56. Zinger, L., *et al.* Extracellular DNA extraction is a fast, cheap and reliable alternative
626 for multi-taxa surveys based on soil DNA. *Soil Biol. Biochem.* **96**, 16-19 (2016).
- 627 57. Taberlet, P., *et al.* Soil sampling and isolation of extracellular DNA from large amount
628 of starting material suitable for metabarcoding studies. *Mol. Ecol.* **21**, 1816-1820 (2012).
- 629 58. Fliiegerova, K., *et al.* Effect of DNA extraction and sample preservation method on
630 rumen bacterial population. *Anaerobe* **29**, 80-84 (2014).
- 631 59. Guardiola, M., *et al.* Deep-Sea, Deep-Sequencing: Metabarcoding Extracellular DNA
632 from Sediments of Marine Canyons. *PLoS One* **10**, e0139633 (2015).
- 633 60. Taberlet, P., Gielly, L., Pautou, G., & Bouvet, J. Universal primers for amplification of
634 three non-coding regions of chloroplast DNA. *Plant Mol. Biol.* **17**, 1105-1109 (1991).
- 635 61. Salter, S., *et al.* Reagent contamination can critically impact sequence-based
636 microbiome analyses. *BMC Biol.* **12**, 87 (2014).
- 637 62. Esling, P., Lejzerowicz, F., & Pawlowski, J. Accurate multiplexing and filtering for
638 high-throughput amplicon-sequencing. *Nucl. Acids Res.* **43**, 2513-2524 (2015).
- 639 63. Boyer, F., *et al.* OBITools : a Unix- inspired software package for DNA
640 metabarcoding.. *Mol. Ecol. Res.* **16**, 176-182 (2016).
- 641 64. Mercier, C., *et al.* SUMATRA and SUMACLUSt: fast and exact comparison and
642 clustering of sequences. *Programs and Abstracts of the SeqBio 2013 Workshop*, 27-29 (2013).
- 643 65. Rosvall, M. & Bergstrom, C. T. Maps of random walks on complex networks reveal
644 community structure. *Proc. Natl. Acad. Sci. U.S.A.* **105**, 1118-1123 (2008).
- 645 66. Ficetola, *et al.* An In silico approach for the evaluation of DNA barcodes. *BMC*
646 *Genomics* **11**, 434 (2010).
- 647 67. McMurdie, P. J. & Holmes, S. Waste Not, Want Not: Why Rarefying Microbiome Data
648 Is Inadmissible. *PLoS Comput. Biol.* **10**, e1003531 (2014).

- 649 68. Briones, M. J. I. Soil fauna and soil functions: a jigsaw puzzle. *Front. Environ. Sci.* **2**,
650 1-22 (2014).
- 651 69. Douhan, G. W., Vincenot, L., Gryta, H., & Selosse, M.-A. Population genetics of
652 ectomycorrhizal fungi: from current knowledge to emerging directions. *Fungal Biol.* **115**,
653 569–597 (2011).
- 654 70. Meerts, P. The evolution of spore size in Agarics: do big mushrooms have big pores?. *J.*
655 *Evol. Biol.* **12**, 161-165 (1999).
- 656 71. Portillo, M. C., Leff, J. W., Lauber, C. L., & Fierer, N. Cell size distributions of soil
657 bacterial and archaeal taxa. *Appl. Environ. Microbiol.* **79**, 7610-7617 (2013).
- 658 72. Ingold, C. T. Range in size and form of basidiospores and ascospores. *Mycologist* **15**,
659 165-166 (2001).
- 660 73. Bécard, G. & Pfeffer, P. E. Status of nuclear division in arbuscular mycorrhizal fungi
661 during in vitro development. *Protoplasma* **174**, 62-68 (1993).
- 662 74. Fierer, N. & Jackson, R. B. The diversity and biogeography of soil bacterial
663 communities. *Proc. Natl. Acad. Sci. U.S.A.* **103**, 626-631 (2006).
- 664 75. Driscoll, C. T. & Schecher, W. D. The chemistry of aluminum in the environment.
665 *Environ. Geochem. Hlth.* **12**, 28-49 (1990).
- 666 76. Abreu Jr, C. H., Muraoka, T., & Lavorante, A. F. Relationship between acidity and
667 chemical properties of Brazilian soils. *Sci. Agri.* **60**, 337-343 (2003).
- 668 77. Réjou-Méchain, M., *et al.* Using repeated small-footprint LiDAR acquisitions to infer
669 spatial and temporal variations of a high-biomass Neotropical forest. *Remote Sens. Environ.*
670 **169**, 93-101 (2015).
- 671 78. Tymen, B., *et al.* Evidence for arrested succession in a liana-infested Amazonian forest.
672 *J. Ecol.* **104**, 149-159 (2016).
- 673 79. Legendre, P. Studying beta diversity: ecological variation partitioning by multiple
674 regression and canonical analysis. *J. Plant Ecol.* **1**, 3-8 (2008).
- 675 80. Legendre, P. & Gallagher, E. Ecologically meaningful transformations for ordination of
676 species data. *Oecologia* **129**, 271-280 (2001).
- 677 81. Blanchet, F. G., Legendre, P., & Borcard, D. Forward selection of explanatory
678 variables. *Ecology* **89**, 2623-2632 (2008).
- 679 82. Dray, S., Legendre, P., & Peres-Neto, P. R. Spatial modelling: a comprehensive
680 framework for principal coordinate analysis of neighbour matrices (PCNM). *Ecol. Model.*
681 **196**, 483-493 (2006).
- 682 83. Gilbert, B. & Bennett, J. R. Partitioning variation in ecological communities: do the
683 numbers add up? *J. Appl. Ecol.* **47**, 1071-1082 (2010).
- 684 84. Peres-Neto, P. R., Legendre, P., Dray, S., & Borcard, D. Variation partitioning of
685 species data matrices: estimation and comparison of fractions. *Ecology* **87**, 2614-2625 (2006).
- 686 85. Jost, L. Entropy and diversity. *Oikos* **113**, 363-375 (2006).

687

688

689 **Acknowledgements**

690 We are indebted to the staff of the Nouragues Research Field Station (CNRS, French Guiana)
691 and the Nouragues Natural Reserve, for commodities and technical help during the field
692 session. We thank Johan Pansu, Guilhem Sommeria-Klein, Mélanie Roy and Renato Lima for
693 helpful discussions on the manuscript, as well as the Genotoul bioinformatics platform
694 Toulouse Midi-Pyrenees (Bioinfo Genotoul) and Pierre Solbes (EDB-Calc Cluster) for
695 providing computing and storage resources. The work was funded by the METABAR project
696 (ANR-11-BSV7-0020) and has benefitted from "Investissement d'Avenir" grants managed
697 by Agence Nationale de la Recherche (CEBA: ANR-10-LABX-25-01; TULIP: ANR-10-
698 LABX-0041; OSUG@2020: ANR-10-LABX-56; ANAEE-France: ANR-11-INBS-0001).
699 This work is dedicated to the memory of our colleague Serge Aubert.

700 **Author contributions**

701 L.Z., E.C., P.T. and J.C. conceived the study. L.Z, P.T., H.S., A.B, M.D.B, P.G., L.G., C.G.C,
702 A.I., M.R.M, G.R., E.C and J.C. contributed to the fieldwork and/or to DNA extractions. P.T.,
703 A.B., A.I. and D.R. conducted the laboratory work to produce the metabarcoding data. J.V.
704 and C.Z. performed the chemical analyses. B.T. provided the LiDAR data. L.Z. did the
705 bioinformatics and statistical analyses with the help of V.S., F.B., E.C, W.T. and J.C. The
706 manuscript was written by L.Z. and J.C. with input from all co-authors.

707 **Competing interests**

708 L.G. and P.T. are co-inventors of patents related to the gh primers and the use of the P6 loop
709 of the chloroplast *trnL* (UAA) intron for plant identification using degraded template DNA.
710 These patents only restrict commercial applications and have no impact on the use of this
711 locus by academic researchers.

712

713 **Figures and Tables**

714 **Table 1. Soil biota characteristics in the 12 ha plot.** Relative abundances were calculated

715 for each marker separately and correspond to the % of reads of each clade. Richness values

716 correspond to the number of OTUs (mean \pm SD for values per sample). Diversity values

717 correspond to the effective number of OTUs (exponential Shannon diversity index; mean \pm

718 SD for values per sample). Occupancy corresponds to the averaged proportion of samples

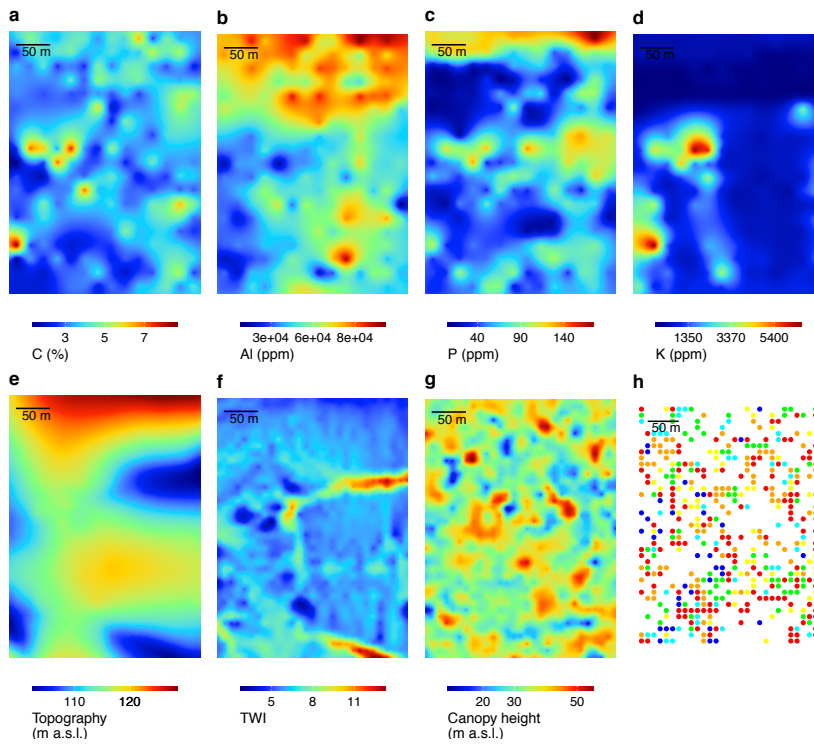
719 where an OTU is detected (\pm SD). NA: not applicable.

Clade	Total rel. abundance (%)	Total Richness (per sample)	Total Diversity (per sample)	OTU occupancy (%)	Propagule size (m)
Archaea	NA	2,502 (43 \pm 30)	30 (9 \pm 8)	1.707 \pm 6.197	0.5e ⁻⁶
Bacteria	NA	19,101 (1,391 \pm 232)	885 (453 \pm 102)	7.281 \pm 16.379	NA
<i>Acidobacteria</i>	19.81	1,601 (231 \pm 46)	132 (80 \pm 32)	14.42 \pm 22.686	0.5e ⁻⁶
<i>Actinobacteria</i>	20.578	1,696 (167 \pm 37)	86 (54 \pm 13)	9.869 \pm 20.329	5e ⁻⁶
<i>Bacteroidetes</i>	1.023	767 (31 \pm 12)	97 (22 \pm 8)	4.088 \pm 11.389	0.5e ⁻⁶
<i>Chloroflexi</i>	5.22	2,147 (136 \pm 48)	268 (73 \pm 29)	6.341 \pm 12.358	1e-6
<i>Firmicutes</i>	2.658	873 (19 \pm 6)	4 (3 \pm 2)	2.147 \pm 8.048	1e-6
<i>Alphaproteobacteria</i>	19.865	3,234 (303 \pm 57)	242 (129 \pm 25)	9.373 \pm 19.381	0.5e ⁻⁶
<i>Betaproteobacteria</i>	3.469	482 (45 \pm 13)	24 (14 \pm 7)	9.392 \pm 19.023	5e ⁻⁶
<i>Deltaproteobacteria</i>	4.364	1,357 (75 \pm 31)	73 (34 \pm 15)	5.513 \pm 14.073	0.5e ⁻⁶
<i>Gammaproteobacteria</i>	8.589	888 (72 \pm 11)	30 (21 \pm 5)	8.109 \pm 19.47	5e ⁻⁶
<i>Verrucomicrobia</i>	4.989	353 (51 \pm 12)	33 (22 \pm 5)	14.357 \pm 24.53	0.5e ⁻⁶
Eukaryota	NA	11,470 (475 \pm 137)	228 (51 \pm 23)	4.138 \pm 11.113	NA
<i>Ascomycota</i>	3.486	317 (25 \pm 9)	22 (8 \pm 3)	7.813 \pm 15.365	100e ⁻⁶
<i>Basidiomycota</i>	16.941	387 (31 \pm 8)	44 (8 \pm 4)	7.911 \pm 16.184	10e ⁻⁶
<i>Glomeromycota</i>	1.078	38 (7 \pm 2)	8 (5 \pm 1)	19.431 \pm 28.548	200e ⁻⁶
<i>Annelida</i>	6.623	49 (8 \pm 3)	6 (3 \pm 1)	17.182 \pm 23.828	20e ⁻³
<i>Arthropoda</i>	17.648	1,777 (63 \pm 21)	91 (15 \pm 7)	3.569 \pm 9.393	10e ⁻³
<i>Nematoda</i>	0.469	359 (9 \pm 5)	35 (6 \pm 2)	2.64 \pm 7.257	100e ⁻⁶
<i>Platyhelminthes</i>	0.538	117 (4 \pm 3)	15 (3 \pm 1)	3.361 \pm 9.778	20e ⁻³
<i>Protists</i>	1.947	1,610 (53 \pm 40)	126 (27 \pm 18)	3.29 \pm 8.488	100e ⁻⁶

720

721

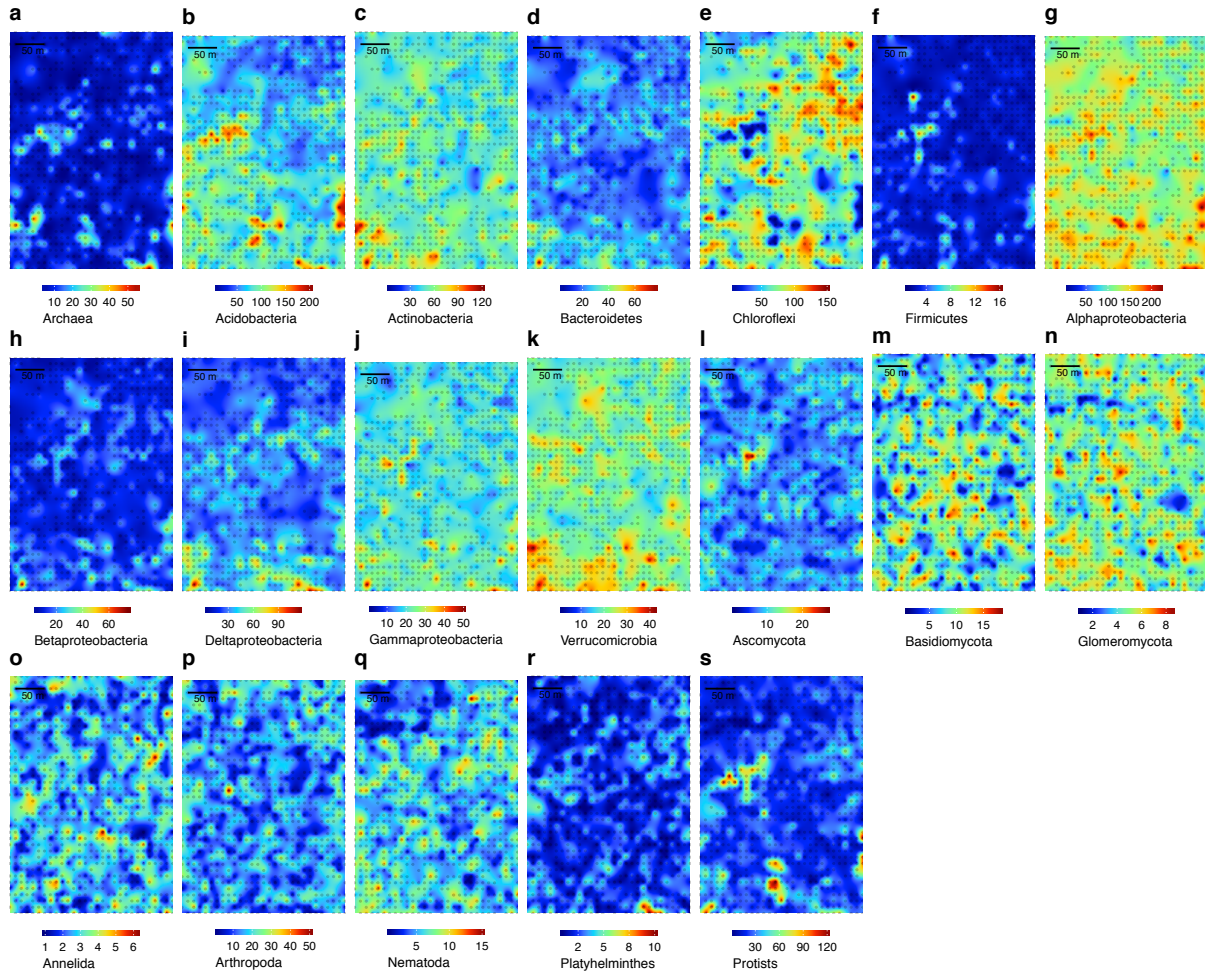
722 **Figure 1. Maps of environmental characteristics in the 12 ha plot. a-d)** Soil content in
723 Carbon, Aluminium, Phosphorous and Potassium. **e)** site topography, **f)** soil wetness (TWI
724 index, unitless) and **g)** canopy height as inferred from LiDAR data. **h)** Distribution of the
725 most dominant plant genus found in each soil sample as inferred from the plant molecular
726 dataset. Only the six most frequent dominant genera are shown: red: Apocynoideae; orange:
727 Andira; yellow: Ingeae; green: Brosimum; lightblue: Sapotaceae; blue: Drypetes. x/y axes are
728 not shown for representation purposes and range between 10-290 and 10-390 meters
729 respectively.



730

731

732 **Figure 2. Spatial distribution of OTU diversity per focal clade.** The colour scale is
733 expressed as effective numbers of OTUs (exponential Shannon diversity index) for archaea
734 (a), bacterial clades (b-k) and eukaryotic clades (l-s). Maps were obtained by ordinary
735 kriging. Grey dots represent the samples available for each clade.

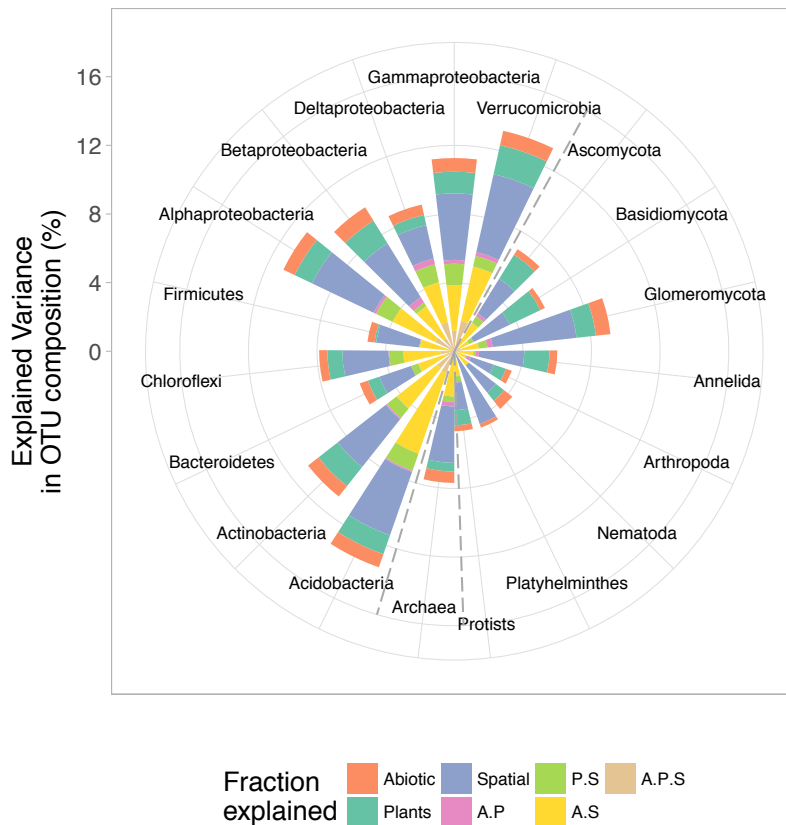


736

737

738 **Figure 3. Variation partitioning of OTU composition in each focus taxonomic group.**

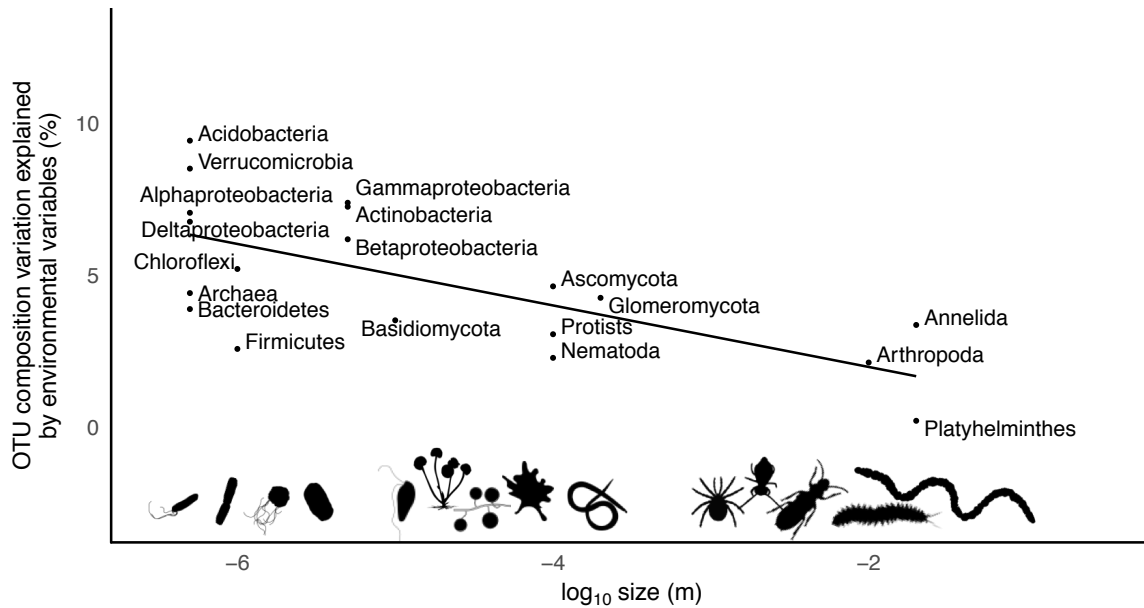
739 Variations of OTU composition are partitioned into pure (i.e. abiotic (A), plant (P) or spatial
740 (S)) and shared components (A.P, P.S, A.S and A.P.S). The corresponding R^2_{adj} statistics are
741 reported. See Supplementary Table 4 for corresponding R^2_{adj} values and their significance (for
742 pure components and full models only, shared components not testable).



743

744

745 **Figure 4. Variation of OTU composition explained by environmental variables**
746 **according to organism propagule size.** The variation (R^2_{adj} statistics) includes pure plants
747 and abiotic effects as well as their combined effect with spatial variables. The negative
748 relationship between organism propagule size and the variance explained by environmental
749 effects is significant (Pearson's $r = -0.67$, $p = 0.002$).



750

751