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CALL FOR COLLABORATION

Ecosystem and biogeochemical coupling in terrestrial ecosystems under global change: A roadmap for synthesis and call for data

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Abstract

Coupled ecosystems may offer a wider array of highly valuable ecosystem services. However, empirical evidence supporting the role of ecosystem coupling for the functioning of ecosystems and the mechanisms driving the coupling-functioning relationship is scarce. Moreover, global environmental change may decouple ecological interactions and biogeochemical cycles well before an overall degradation of ecosystems can be detected, yet the functional implications of this decoupling remains unresolved. Here, we introduce a collaborative call to carry out a synthesis of previously conducted experimental studies to evaluate how global change affects ecosystem and biogeochemical coupling and their relationships with ecosystem functioning. For this, we seek to collate existing biotic, abiotic and ecosystem function data from field experiments carried out across the globe. We anticipate that this new collaborative global synthesis will help us gain novel scientific insights that would be out of reach for individual research groups. It will also allow for the initiation of a meaningful dialogue between experimental ecologists and a wide range of stakeholders and end users aimed at preserving and enhancing ecosystem functioning through strengthening ecosystem and biogeochemical coupling.

Introduction

An assumption of scientists since Humboldt and Darwin is that highly sustainable and functional ecosystems, i.e., those offering a wide array of highly valuable ecosystem services, are those with a more tightly coupled transfer of energy and materials (Heleno et al. 2014, Körner & Spehn 2019). This transfer is driven by the structure of ecological networks (Bascompte 2009) and by linked biogeochemical processes (Schlesinger et al. 2011) that occur at different spatial and temporal scales. This relates to the concept of coupling (Risch et al. 2018), which will form the backbone of the proposed collaborative synthesis study. Despite these assumptions, the concept of ecosystem coupling has rarely been tested in such an integrative way as its system-level definition requires.

Ecosystem coupling refers to the degree of connection among all groups of organisms of an ecosystem, such

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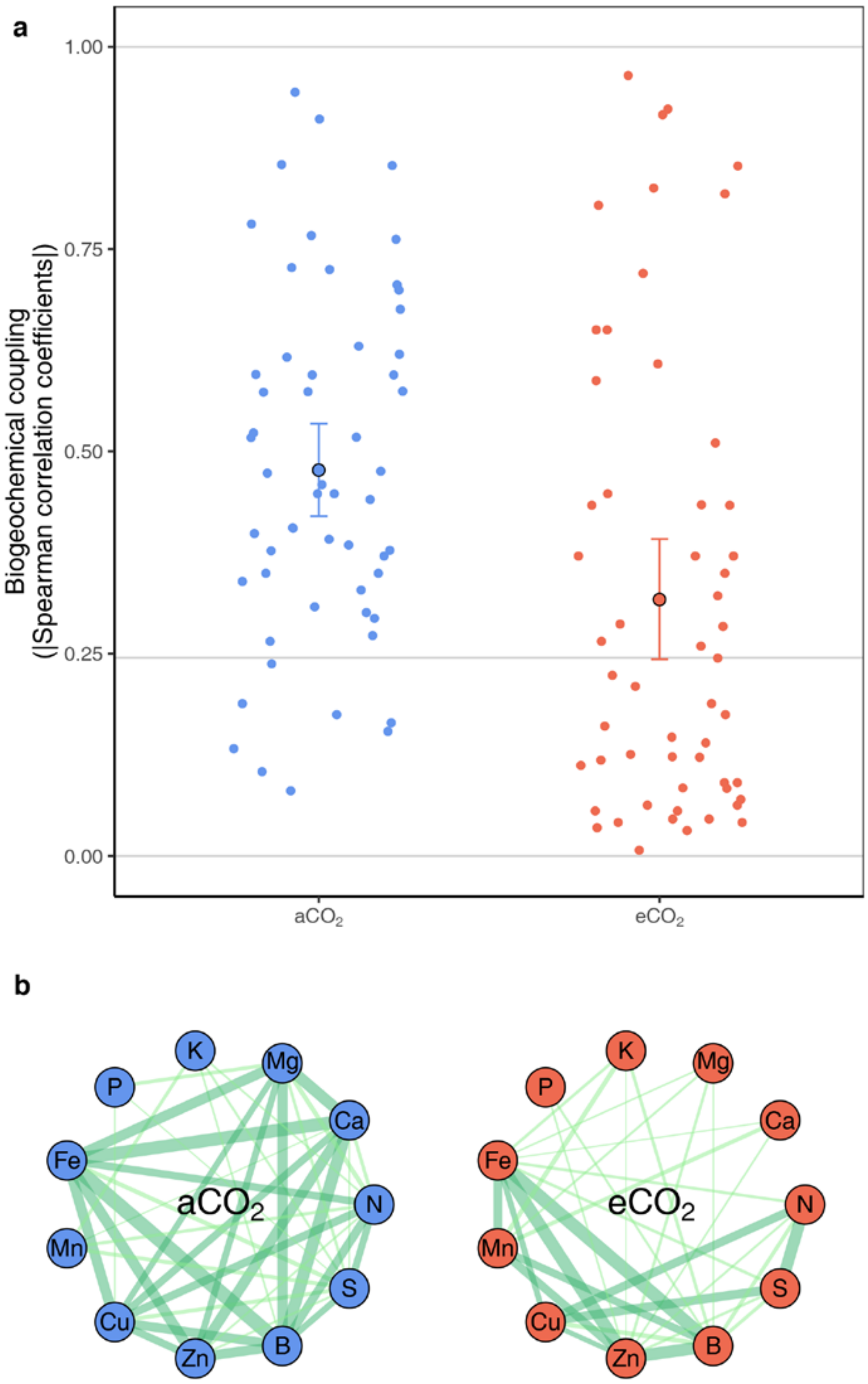

Figure 1. Example of biogeochemical coupling as affected by global environmental change. In the top panel (a), we show the degree of biogeochemical coupling (as defined by Spearman-Rank correlation coefficients, in absolute value) between eleven nutrient cycles under ambient (~400 ppm) and elevated (~550 ppm) atmospheric CO_2 conditions at the EucFACE experiment (Ochoa-Hueso et al. 2019). Treatments are significantly different at $P < 0.05$. Data presented are from February 2016 and were measured using Plant Root Simulators. Coloured dots are individual pairwise correlations between nutrient cycles ($n = 55$). Black dots are the mean ± 95% CI of those correlations. In the network graphs of the bottom panel (b), the width of the lines connecting biogeochemical cycles is proportional to the strength of the association between two cycles from the top panel. Only those correlations with coefficients above the null model threshold, depicted as the light grey line at 0.25 correlation units, are shown. Individual networks like these ones can be compared against randomly generated null models using permutations (e.g., $n = 999$) to determine whether they are more or less coupled than what could be expected only by chance. In the proposed collaborative study, networks under manipulated conditions will be compared against networks under control conditions using the natural logarithm of the response ratio. Being able to calculate multiple response ratios at the site level will allow us to infer the generality of the response of coupled ecosystems to global change.

as bacteria, archaea, fungi, protists, plants and animals, through a variety of biotic interactions, and of these taxa with their surrounding physico-chemical environment (biotic-abiotic interactions; Ochoa-Hueso 2016, Ochoa-Hueso et al. 2019, Risch et al. 2018). Likewise, biogeochemical coupling (Figure 1), i.e., the coupling of elemental cycles, is key for animal, plant and microbial nutrition (Amundson et al. 2015, Chapin 1980, Schlesinger et al. 2011, Stolz, 2016) and is an inherent characteristic of soils in healthy ecosystems (Gao et al. 2013, Ochoa-Hueso et al. 2019, Soussana and Lemaire 2014). Empirical evidence supporting the role of ecosystem and biogeochemical coupling for ecosystem functioning and the mechanisms driving these relationships is, however, surprisingly scarce (Berdugo et al. 2017, Risch et al. 2018).

Global change, including land-use intensification, nutrient additions, biodiversity loss and gain, and alterations of temperature and precipitation, may decouple ecological interactions and biogeochemical cycles well before an overall degradation of the ecosystem can be detected (Figure 1; Ochoa-Hueso 2016; Ochoa-Hueso et al. 2019, Risch et al. 2018). By ecosystem degradation we mean a change in structure and functioning that will negatively impact the delivery of ecosystem services (Rapport et al. 1998). To develop a more comprehensive understanding of the generality and fate of ecosystem coupling in a changing environment, information from different ecosystems worldwide and abiotic and biotic contexts would be required. Coordinated experimental networks (Borer et al. 2014, Verheyen et al. 2016), curated biodiversity data (e.g., Edaphobase, Burkhardt et al. 2014), and metaanalysis of existing comparable information (Koricheva et al. 2013) have advanced our un-derstanding of general principles in ecology, and prompted recent global collaboration and synthesis efforts (Maestre & Eisenhauer 2019) and calls for data contribution (Smith et al. 2019).

Call for data

The main goal of our collaborative call is to carry out a synthesis of previously conducted experimental studies to evaluate how global change drivers affect ecosystem and biogeochemical coupling and their relationships with ecosystem functioning. For this, we seek to collate existing raw data from field experiments carried out across the globe, where at least one of the following global change drivers was experimentally manipulated: (i) land-use intensity (e.g., conventional vs. organic/regenerative/conservation land-use); (ii) precipitation (e.g., irrigation, drought); (iii) warming; (iv) soil nutrients; (v) atmospheric CO_2; (vi) plant diversity; (vii) invasion of exotic species. Land-use intensity studies are likely to come from field experiments in agricultural sites, while studies concerning the other global change drivers should come from field experiments carried out in any kind of managed or unmanaged terrestrial ecosystem. To be included, experiments should meet these criteria: (i) they should provide information about one or several key biotic ecosystem constituents, which includes soil microbial, soil faunal or plant communities, and/or a number of soil and plant macro- and micro-nutrients (at least four). Ideally, different types of communities should have been measured simultaneously, but this is not essential. (ii) At least three experimental replicates per treatment are needed to calculate coupling at the treatment level, based on co-occurrence network analysis (Ochoa-Hueso et al. 2019, Risch et al. 2018). (iii) Ideally, but not necessarily, there should be data available on soil properties and variables related to ecosystem functioning, preferably ecosystem-level biomass, respiration and/or microbial activity.

Interested collaborators are asked to send published or unpublished raw data on: (i) plant and soil biodiversity, including bacteria, fungi, protists and all kinds of micro-, meso- and macrofauna, at the highest taxonomic resolution that is available; (ii) soil biogeochemical data concerning as many chemical elements of the periodic table as possible, either as contents or extractables; (iii) plant element content data (again, we are looking for as many elements as possible); (iv) soil properties and functions such as soil pH, organic matter content, ecosystem-level biomass, soil respiration, litter decomposition, mineralization, microbial enzymes, substrate-induced respiration and greenhouse gas emissions. These data will be sent by email to the corresponding author using the format shown in the example spreadsheet found at http://bit.ly/2RijdgX. Deadline for data submission is 31st July 2020.

Roadmap for synthesis

Once all the data are compiled, we will calculate treatment-level ecosystem and biogeochemical coupling metrics based on the available information from each site using correlation-based co-occurrence network analyses (Ochoa-Hueso et al. 2019, Risch et al. 2018). Then, we will calculate response ratios at the treatment level for each site, defined as the logarithm of the quotient of ecosystem and biogeochemical coupling under manipulated global change and control/ambient conditions (Koricheva et al. 2013). Different levels of the same global change driver within each site will be considered independently. We will use these response ratios to calculate if changes in coupling due to global change drivers significantly differ from zero using a null modelling approach. Any significant deviation from zero, either positive or negative, would indicate that global change can significantly alter the way in which ecosystem constituents and/or biogeochemical cycles are interconnected.

We will not use raw data for any other purpose than the one related to the calculation of coupling and co-occurrence network-related metrics, and we will not share these data with anyone else without prior explicit consent. If co-authors would like a written agreement before sharing their data, we encourage them to ask. We will carry out these analyses separately for biodiversity-related metrics and for biogeochemical data. Land-use intensification, on one hand, and the rest of global change drivers, on the other hand, will also be considered independently. Anyone who contributes usable data will be invited as co-author of publications, provided that they are willing to contribute to edit and revise the manuscript/s and provide input once the first versions of the papers are sent out.

The main goal of this project is to generate knowledge on the impacts of global change on network configuration and the coupling of biogeochemical cycles. Subsequently, we believe that this study will serve as an important benchmark for future applied projects as we need to mechanistically understand how, why and under what circumstances changes in ecosystem and biogeochemical coupling mirror alterations in ecosystem functioning if we are to develop tools to mitigate the ecological impacts of global change on ecosystems. Understanding these mechanisms can open new avenues for preserving and enhancing ecosystem functioning through strengthening ecosystem and biogeochemical coupling (Solé et al. 2018), which will ensure a more reliable provisioning of ecosystem services. This information can be particularly helpful for geoengineering and ecological restoration projects as well as in agroecosystems, where precisely engineered soil networks with a more efficient ability to cycle nutrients internally from soil organic matter may facilitate the transition from highly intensive conventional systems to sustainable ones (Schrama et al. 2018, Wubs et al. 2016). We anticipate that building upon an extensive collaborative global network to collate data will help us to gain novel scientific insights that would be out of reach for individual research groups or even research consortia and will also allow for the initiation of a meaningful dialogue between experimental scientists and a wide range of stakeholders and end users.

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References

Amundson, R., Berhe, A.A., Hopmans, J.W., Olson, C., Sztein, A.E. & D.L. Sparks (2015): Soil and human security in the 21st century. - Science 348: 1261071.

Bascompte, J. (2009): Disentangling the web of life. - Science 325, 416–9.

Berdugo, M., Kéfi, S., Soliveres, S. & F.T. Maestre (2017): Plant spatial patterns identify alternative ecosystem multifunctionality states in global drylands. - Nature Ecology & Evolution 1, 3.

Borer, E.T., Harpole, W.S., Adler, P.B., Lind, E.M., Orrock, J.L., Seabloom, E.W. & M.D. Smith (2014): Finding generality in ecology: A model for globally distributed experiments. - Methods in Ecology and Evolution 5, 65–73.

Burkhardt, U., Russell, D.J., Decker, P., Döhler, M., Höfer, H., Lesch, S., Rick, S., Römbke, J., Trog, C., Vorwald, J., Wurst, E. & W.E.R. Xylander (2014): The Edaphobase project of GBIF-Germany—A new online soil-zoological data warehouse. - Applied Soil Ecology 83, 3–12.

Chapin, F.S. (1980): The mineral nutrition of wild plants. - Annual Review of Ecology, Evolution, and Systematics 11, 233–260.

Gao, Y., Yu, G., & N. He (2013): Equilibration of the terrestrial water, nitrogen, and carbon cycles: Advocating a health threshold for carbon storage. - Ecological Engineering 57, 366–374.

Heleno, R., Garcia, C., Jordano, P., Traveset, A., Gómez, J.M., Blüthgen, N., Memmott, J., Moora, M., Cerdeira, J., Rodríguez-Echeverría, S., Freitas, H. & J.M. Olesen (2014): Ecological networks: Delving into the architecture of biodiversity. - Biology Letters 10, 4–6.

Koricheva, J., Gurevitch, J. & K. Mengersen, (2013): Handbook of meta-analysis in ecology and evolution. - Princeton University Press.

Körner, C. & E. Spehn, E. (2019): A Humboldtian view of mountains. - Science 365, 1061.

Maestre, F.T. & N. Eisenhauer (2019): Recommendations for establishing global collaborative networks in soil ecology. - Soil Organisms 91, 73–85.

Ochoa-Hueso, R. (2016): Nonlinear disruption of ecological interactions in response to nitrogen deposition. - Ecology 97, 2802–2814.

Ochoa-Hueso, R., Piñeiro, J. & S.A. Power (2019): Decoupling of nutrient cycles in a Eucalyptus woodland under elevated CO2. - Journal of Ecology 107, 2532-2540.

Rapport, D.J., Costanza, R. & A.J. McMichael (1998): Assessing ecosystem health. - Trends in Ecology & Evolution 13, 397–402.

Risch, A.C., Ochoa-Hueso, R., van der Putten, W.H., Bump, J.K., Busse, M.D., Frey, B., Gwiazdowicz, D.J., Page-Dumroese, D.S., Vandegehuchte, M.L., Zimmermann, S. & M. Schütz (2018): Size-dependent loss of aboveground animals differently affects grassland ecosystem coupling and critical functions. - Nature Communications 9, 3684.

Schlesinger, W.H., Cole, J.J., Finzi, A.C. & E.A. Holland (2011): Introduction to coupled biogeochemical cycles. - Frontiers in Ecology and the Environment 9, 5–8.

Schrama, M., de Haan, J.J., Kroonen, M., Verstegen, H. & W.H. Van der Putten (2018): Crop yield gap and stability in organic and conventional farming systems. - Agriculture, Ecosystems & Environment 256, 123–130.

Smith, G.R., Crowther, T.W., Eisenhauer, N. & J Van Den Hoogen (2019): Building a global database of soil microbial biomass and function: A call for collaboration. - Soil Organisms 91, 140–143.

Solé, R. V, Montañez, R., Rodriguez-Amor, D., Vidiella, B. & J. Sardanyés (2018): Population dynamics of synthetic terraformation motifs. - Royal Society Open Science 5, 180121.

Soussana, J.-F. & G. Lemaire (2014): Coupling carbon and nitrogen cycles for environmentally sustainable intensification of grasslands and crop-livestock systems. - Agriculture, Ecosystems & Environment 190, 9–17.

Stolz, J.F. (2016): Gaia and her microbiome. - FEMS Microbiology Ecology 93, fiw247.

Verheyen, K., Vanhellemont, M., Auge, H., Baeten, L., Baraloto, C., Barsoum, N., Bilodeau-Gauthier, S., Bruelheide, H., Castagneyrol, B., Koricheva, J., Loreau, M., Godbold, D., Haase, J., Hector, A., Mereu, S., Messier, C., Muys, B., Nolet, P., Paquette, A., Parker, J., Perring, M., Ponette, Q., Potvin, C., Reich, P., Smith, A., Weih, M., Scherer-Lorenzen, M., Jactel, H., Koricheva, J., Loreau, M., Mereu, S., Messier, C., Muys, B., Nolet, P., Paquette, A., Parker, J., Perring, M., Ponette, Q., Potvin, C., Reich, P., Smith, A., Weih, M. & M. Scherer-Lorenzen (2016): Contributions of a global network of tree diversity experiments to sustainable forest plantations. - Ambio 45, 29–41.

Wubs, E.R.J., van der Putten, W.H., Bosch, M. & T.M. Bezemer (2016): Soil inoculation steers restoration of terrestrial ecosystems. - Nature Plants 2, 16107.