Plant Ecol (2020) 221:749–751
https://doi.org/10.1007/s11258-020-01068-3

Editorial: Special thematic issue on applying microbial community research to improve conservation and restoration outcomes

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Published online: 11 August 2020
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Although soil microbial communities, e.g. fungi and bacteria, are still largely considered a "black box", their central role in ecosystem processes and function is indisputable. Despite the important role they play in carbon and nitrogen cycling, decomposition and plant health, there have been few attempts to incorporate soil microbial communities into conservation and restoration practice (Birnbaum et al. 2019). This special issue combines efforts to present plant–soil-microbe research that focuses on improving conservation and restoration outcomes.

The motivation for this special issue came from talks presented at the Ecological Society of Australia [Brisbane, 25–30 November 2018] symposium special session on "Applying microbial communities to improve conservation and restoration outcomes". This one-day symposium covered a broad range of practical as well as theoretical studies including, among others, rethinking plant–soil feedbacks, the role of bacterial and fungal communities in restoration, and the role of microbes in alleviating soil water repellency (SWR). In total, ten presentations were delivered highlighting the ongoing important plant–soil-microbe research conducted in Australia.

Harnessing our understanding of soil microbial communities, i.e. diversity and function, to improve restoration outcomes is an exciting research frontier that can be informative and facilitate both conservation and restoration efforts. Exploiting microbes to conserve natural ecosystems, however, requires a detailed understanding of the microbial contribution to aboveground diversity. In fact, soil microbial communities play a crucial role in nutrient cycling, physical formation of soil, as well as plant growth regulation (Harris 2009). For example, Wood and colleagues explored soil community dynamics in relation to non-random mortality processes in a tropical rainforest (Wood et al. 2020). The authors found a clear relationship between seedling density and microbial community composition, hinting at the possibility of density-dependent seedling mortality as a key process in maintaining rainforest diversity—critical information that will guide future attempts to

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identify microbial indicators of rainforest soil function for use in conservation monitoring.

Microbes, however, have also been associated with negative outcomes for plant establishment and growth. For example, fungal and bacterial growth have been held responsible for the severity and persistence of soil water repellency (SWR) (Mao et al 2019; Lowe et al. 2019), which can critically limit plant development. The work of Ruthrof et al. (2019), however, invites us to rethink SWR as an opportunity rather than a challenge in the context of dry ecosystems, whereby SWR can be harnessed as a "drought-proofing" tool for plant survival in water-limited soils. As such, improving our knowledge on the role of bacteria and fungi in SWR can inform management efforts in the future.

There are several studies in this special issue that discuss practical aspects of the soil microbial community in restoration (Yan et al. 2019; Bermúdez-Contreras et al. 2020; Gooden et al. 2019; Torres-Martínez et al. 2020). For example, Gooden et al. (2019) compared root colonization levels of arbuscular mycorrhizal fungi (AMF) and dark septate fungi (DSF) in remnant and restored dunes in eastern Australia. They found that AMF colonization was the same between remnant and restored dunes, while DSF colonization was two-times lower in plants growing in restored dunes. DSF has been reported as especially beneficial to plants growing in nutrient poor and high-stress ecosystems, such as coastal sand dunes, thus the significant decrease of DSF colonization may have negative effects on restoration and persistence of native vegetation in restored dunes. Similarly, Torres-Martínez et al. (2020), assessed the role of AMF and DSF for bald cypress seedling performance under varying flooding regimes in south-eastern Louisiana, USA. The authors determined that, while flooding diminished colonization of DSF, seedlings were more sensitive to the initial microbial composition in soil than flooding, highlighting the need of improving our understanding of plant microbe interactions in swamps to maximize restoration efforts.

The use of microbes as ecological indicators of restoration processes was investigated by Yan et al. (2019). In this study, the authors looked at the bacterial community from a 16-year coastal restoration chronosequence and found that shifts in soil bacterial community structure were related to changes in vegetation composition and soil properties, with communities from the oldest revegetation sites being more similar to remnant (undisturbed) reference sites. This suggests that changes in bacterial communities mirror time since restoration and can be used to monitor efficacy of restoration interventions.

Bermúdez-Contreras et al. (2020) studied the effects of different revegetation techniques: direct seeding versus transplanting tube-stock on root mycorrhizal colonization and root fungal communities in highly disturbed riparian ecosystems. These authors found strong evidence that revegetation technique influenced the mycorrhizal colonization rate as well as fungal diversity in roots. Specifically, direct seeded plants had more diverse fungal communities that were more similar to the extant vegetation, and better growth rates, whereas tube-stock plants had highest mycorrhizal colonization with no observable benefit to plant growth rate. These results have important implications for riparian revegetation and restoration practices, providing strong support that direct seeding achieves more successful restoration outcomes than tube-stock transplanting (Bermúdez-Contreras et al. 2020).

Finally, the works of Bates et al. (2019) and Waymouth et al. (2020) cover two different methodological aspects of plant–soil ecology studies: the assessment of plant–soil feedbacks and spatial heterogeneity within soil microbial community structure and function to design appropriate sampling protocols, respectively. Bates et al. (2019) propose a novel approach to evaluate plant–soil feedbacks. Plant–soil feedback (PSF) experiments are widely used to test the effect of soil microbial communities on plant growth and fitness. PSF usually involves two stages where in the first stage of the experiment the soil microbial communities of interest and soil bio-geochemical properties are "amplified" and in the second stage the effect of these modified soil microbial communities and abiotic properties on plant biomass are assessed (Mariotte et al. 2018). Often, the results of PSF are presented as log-response ratios. However, the uncertainty associated with these ratios is rarely shown. Bates et al. (2019) present three ways, i.e. an analytical formula, bootstrapping, and model fitting, to calculate the uncertainty associated with log-response ratios in plant–soil feedback studies. This is important as calculating and presenting the uncertainty associated with feedback ratios will allow for better comparisons across plant–soil feedback studies and will facilitate meta-analyses (Bates et al. 2019). In parallel, the study by Waymouth et al. (2020) assessed whether spatial heterogeneity in aboveground communities is indeed reflected in belowground communities using nine 25 m × 25 m quadrats in a riparian ecosystem. Sampling in riparian ecosystems is often obstructed by different disturbances and thus strategies to minimize sampling effort are desired. Indeed, Waymouth et al. (2020) found evidence that spatial variation of microbial communities (i.e. fungi, bacteria and archaea) were most strongly related to vegetation composition, particularly subcanopy, and to a lesser extent, soil chemical properties. They concluded that a relatively small sampling effort was sufficient to adequately capture the characteristics of such soil communities (Waymouth et al. 2020).

In conclusion, improved understanding of belowground soil processes is guaranteed to lead to more informed ecological understanding of ecosystem processes and thus result in more successful practical outcomes in restoration and revegetation, too. Several studies from this special issue have already shown that while we are only scratching the surface and beginning to understand above and belowground linkages, the outcomes are promising. With the availability of novel molecular tools that help us explore the soil microbial communities and their interactions with the aboveground, we will be ever better equipped to provide solutions to existing ecological questions and challenges, while opening up new avenues for novel research.

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