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Abstracts (Abstracts are listed in alphabetical order by the last name of the presenting author, which is highlighted in bold type.)

Bacterial networks and fungal connections; understanding interactions among biocrusts biological constituents

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Abstract: Biocrusts are complex mosaics of algae, lichens, mosses, fungi, cyanobacteria, and other bacteria. Individually and collectively, biocrust organisms perform multiple ecosystem services, but little is known concerning interactions between constituents. To better understand links in crustal biology, we constructed network co-occurrence models of bacterial communities from target-metagenomes of the 16S rRNA gene, and measured the translocation of ^{15}N-NH_4^+ and ^{15}N-NO_3^- within *Microcoleus*- and lichen-dominated crusts. Based on our network models, bacterial communities were slightly more complex and connected beneath *Artemisia tridentata* compared to grass-dominated soil interspaces. For example, shrub biocrusts contained at least 1.2-times the number of edges (significant correlations) between nodes or species, and a 33% increase in the mean degree of nodes (average number of edges connected to a species). Although cyanobacteria contributed as much as 15% of the relative recovery in biocrusts, none of the highly connected or potential keystone species within the community were cyanobacteria. Beneath shrubs and in interspaces, keystone species were dominated by three Alphaproteobacteria (Acetobacteraceae, Rhizobiales, and Sphingomonadaceae) known to thrive in dry soils, and four Actinobacteria (Actinomycetales, Geodermatophilaceae, Micromonosporaceae, and Nocardioidaceae) tightly associated with lichens and mosses. Also, other keystone species were associated with the degradation of fungal or bacterial bioproducts, such as the Chitinophagaceae (Bacteroidetes) and Phycisphaerae (Planctomycetes). As for the movement of nutrients, within 24 hours, ^{15}N-NH_4^+ traveled further than ^{15}N-NO_3^- in *Microcoleus*-dominated crusts. Movement of ^{15}N in moss-dominated crusts was limited. The biomass of Ascomycota species correlated with the ^{15}N-NH_4^+ isotopic concentrations present in *Microcoleus* crusts. Our findings identify that bacterial communities may rely on mosses and

lichens to create complex assemblages of bacterial species and fungi may act as conduits moving inorganic N among biocrusts constituents.

Rapid culture of N-fixing soil lichens and biocrusts for rehabilitation of drylands

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Abstract: Land use in aridlands has led to unprecedented disturbance that has implications at multiple scales. Biocrusts are an important, easily damaged and not easily repaired component of these ecosystems. Assisted recovery of biocrusts is needed to repair lost ecosystem functions and reduce damage to human and ecosystem health. Two large hurdles exist in successful biocrust rehabilitation: 1) culturing and increasing biocrust biomass, and 2) successful reintroduction to the environment. While successes have happened on both fronts, little has been achieved with later successional biocrust organisms (bryophytes and lichens) and on scales relevant to land managers. We cultivated biocrusts in a greenhouse, targeting later successional mosses, and reintroduced them to disturbed soils in the field. The biocrust materials were subjected to various preparations to induce stress tolerance in the natural environment prior to reintroduction or reduce environmental stress after reintroduction. In the Great Basin Desert, near Salt Lake City, Utah, we applied greenhouse grown biocrust inoculum back to its site of origin with one of twelve hardening treatments , representing all combinations of: 1) long-term hydration regime (2, 3, 4, and 5 days of continuous hydration per week punctuated by a desiccation event), and 2) short-term hardening (luxury water in the greenhouse, 50% light exposure outside with 3 hour daily hydrations, or full light exposure, with 3 hours daily hydration) . We expected biocrusts with shorter hydration periods over the growing period, with the harshest hardening conditions to have the greatest survival and establishment in the field. After one year, we found a 40-80% increase in total cover after inoculation, regardless of pretreatment. Light cyanobacteria increased the most dramatically, but mosses and lichens were sensitive to hardening treatments. These later successional groups benefited from shorter hydration and hardening where water led to drought stress. In a second test with biocrust organisms grown from the Colorado Plateau (Canyonlands Research Center), we treated cultivated biocrusts to 21 days of no hardening (luxury greenhouse conditions) or gradual introduction to full sunlight with hydration lasting through the daylight hours. In this experiment, we tested methods to ameliorate stress experienced by biocrust organisms. Biocrusts were added at 20% cover alone, with jute cloth, two weeks of daylight hour irrigation, or both. Preliminary results after five months suggest that hardening, again, had little effect, but addition of jute cloth aided recovery. In all cases, our results suggest that cultivating and reintroducing biocrusts to the field is possible. The next steps are to scale up to areas relevant to land managers and ecosystem function.

Nostoc and *Mojavia* species isolated from the soils of the Atacama Desert, Chile

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Abstract: Enrichment cultures of 88 different soil collections from the Atacama Desert resulted in the isolation of 31 strains of Nostocaceae from five sites. From these, 14 strains were chosen to represent all distinct morphotypes in each of the five sites for detailed morphological and molecular analyses. Molecular analyses revealed the existence of seven distinct lineages within *Nostoc* and one lineage within *Mojavia*. Two of the *Nostoc* lineages were too close to *N. lichenoides* to justify separation into new species, despite some differences in morphology and ecology. The combined evidence based on morphology, ecology, phylogenic placement, and secondary structure of the 16S-23S ITS region in the ribosomal operon indicates that the remaining five lineages within *Nostoc* are five separate and diagnosable new species. The *Mojavia* species is also new, being morphologically very distinct from the other described species in the genus.

Multiscale effects of biological soil crusts on dryland hydrology – a modelling framework to assess the impacts of global change

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Abstract: Biological soil crusts play an essential role in regulating patch- to landscape-scale hydrological and ecological processes in drylands worldwide. Through affecting soil surface properties such as roughness, porosity, and soil aggregation, they can alter local hydrological patterns and those changes vitally govern surface water redistribution. Thus, biological soil crusts are important contributors to multiple ecosystem processes such as a heterogeneous vegetation pattern formation. However, the effect on hydrological processes can vary among different crust types. Thus, the net effect is highly dependent on the crusts' community composition. Moreover, biological soil crusts are vulnerable to external disturbances, and different species might be affected differently by changes in climate or land use. The resulting shift in community composition might then lead to altered ecosystem functioning, and thus to a potential increase in degradation risk of drylands under global change. Here, we present a conceptual framework on the link between environmental conditions, community composition of biological soil crusts, and their impact on local- to landscape-scale hydrological processes. This framework will provide the base to assess the influence of biological soil crusts on hydrological

processes in drylands with a special focus on future changes in environmental conditions and increasing abiotic stress. Using this framework, we will develop a simple community dynamics model for the most abundant biological soil crust types based on experimental data from southern Spain. The community dynamics model will then be incorporated into a landscape-scale ecohydrological model based on patch-scale data quantifying the impact of soil crusts on hydrological processes. This will allow for a dynamic assessment of the influence of biological soil crusts on hydrological processes and spatially heterogeneous water availability under global change.

Desert terraria: characterization of a Mojave Desert moss community under quartz rocks

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Abstract: Desert mosses are extremely desiccation-tolerant and all their biological functions are limited to infrequent post-rainfall periods. We discovered that some Mojave Desert moss species find refuge under semi-translucent quartz rocks where moisture seems to persist for a longer period of time than in adjacent hyperlithic (above rock) environments. This study characterized the moss communities growing in quartz hyperlithic and hypolithic (below rock) microenvironments in a western, high-elevation Mojave Desert site. Study samples were collected by sampling each unique moss species or distinct morphology in approximately 0.5 cm clumps around and under each quartz rock along two 15 m linear north-south transects. Collections were analyzed in the lab for species identification and length of previous year's growth. Of the 53 total samples, 67.9% were *Syntrichia caninervis* (Pottiaceae), the dominant species of the Mojave Desert biocrust. *Tortula inermis* (Pottiaceae) accounted for 28.3% of the samples and 3.8% were *Bryum argenteum* (Bryaceae). Of note, *S. caninervis* was significantly more likely to be in hyperlithic environments while *T. inermis* was more likely to be found in hypolithic microenvironments (p-value < 0.01) where the low light and lower evapotranspiration rates under quartz may be more conducive to its growth. The previous year's shoot growth of *S. caninervis* samples in hyperlithic and hypolithic environments also differed significantly. Recent growth of hypolithic shoots was 62.2% longer than that of hyperlithic shoots (p-value <0.001), perhaps due to higher water retention under quartz rocks. Additionally, hypolithic *S. caninervis* appeared to have less of its characteristic dark brown pigment. These results indicate that western high elevation Mojave Desert quartz rocks provide a hypolithic environment, distinct from the surface one, for some moss species to flourish. Quartz rocks may prevent small, respiratory carbon loss-inducing rainfalls from ever reaching hypolithic mosses while allowing larger rainfalls to keep tissues hydrated for longer.

Males of the Mojave Desert moss *Syntrichia caninervis* (Pottiaceae) are rare and shy

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Abstract: Female biased sex ratios are a common phenomenon in bryophyte populations; a pattern that, for some species, appears to be correlated with increased environmental stress. Natural populations of the dioicous moss *Syntrichia caninervis* are highly female-biased in expression of gametangia. This may be because males experience greater mortality and are therefore rare (the rare male hypothesis), or males may simply produce sexual structures less frequently (the shy male hypothesis). To distinguish between these two alternatives, we used double digest restriction-site associated DNA (RAD) sequencing to survey the clonal diversity within two Mojave Desert populations of *S. caninervis* and determine whether genetic sex ratios are consistent with sex expression ratios. We first identified 200 candidate sex-associated loci in 21 known sex samples by selecting RAD sequences that were only found in one sex. Next, we searched for these markers within RAD sequences of 131 branches of unknown sex from two sites that differed in water availability, and potentially, level of stress. Samples that only had potential sex-associated loci from a single sex were identified as that sex. About two thirds of the 200 candidate loci tested showed signature of sex linkage in the full dataset. The observed phenotypic female:male sex ratio was 18:1 for the higher elevation, less stressful site (SCH) and no sex expression was observed at a dryer lower elevation site (SCL). However, using the putative sex-linked markers, we found a 2:1 genetic female bias in SCH, suggesting that males in this population are "shy", while SCL was entirely genetically female, suggesting that males are absent. Together, these results suggest that: (1) both the rare male and shy male hypotheses may contribute to observed phenotypic sex ratios, and (2) sex-specific differences in life history interact with environmental stress to determine the proportion of males in *S. caninervis* populations.

Reflections on a life: the awesomeness of studying biocrusts

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Abstract: I have always loved playing in the dirt. When I was very young, my poor mother would dress me for church on Sunday and soon learned she had to barricade me in my room until it was time to leave or I would be outside, covering myself with dirt and ruining my clothes. All weekends, summers, and holidays, I would spend my free time roaming in the sagebrush, digging forts, and finding treasures, every time coming home so dirty my mother would make me take my shoes off at the front door and undress in the bathtub to minimize the mess I would

otherwise make. Things did not change much as I grew older. My first undergraduate focus was in geology, but even though it satisfied the yearning for rocks and soil, it was not alive enough, and so I moved to biology. By graduate school, I wanted to know what structured above-ground plant community distribution, and thus animals, and try as I might to pin things on the plants themselves, it always came back to the soils. And then I encountered Kimball Harper, one of the brightest ecological minds ever found on this planet. He called me one day in 1983 and asked if I knew anything about soil lichens and mosses; I said no, nothing, and he invited me to join him on a field trip. That day set the rest of my life on a more awesome trajectory than I could have ever imagined. With my eyes now opened, I began seeing that these little guys covered just about every soil surface around me. However, it only took a brief look at the literature to realize that little was known about them except their names. And so I set out to find out what role they played in desert ecosystems and have been continuously amazed that no matter what thread I follow, there they are, in the midst of things. In 1999, Otto Lange came to visit Martyn Caldwell at Utah State, where Otto had spent time many years previously. As lichens, especially those on soils, were Otto's first love, he asked Martyn about finding them in Utah. Martyn sent him to visit me and we had SO MUCH FUN, running around and seeing all the crusties. We would laugh so hard in restaurants that people would stare. That connection with Otto set in motion the writing of the "green bible". One of the most gratifying aspects of almost 30 years of crust work is seeing how the importance of biocrusts has taken root in many people's minds, including scientists, land managers, and the public. And we now have multi-generations of students studying biocrusts, with the students of students now finding faculty jobs and recruiting their own students. When I started this work, it was difficult to fill a 15 minute talk about crusts; now I could fill hours. I am hugely grateful to those of you out there who have taken up the biocrust banner, as now it is hoisted high, it will stay there. In this talk, I will discuss the highlights of this crusty life that has culminated in these international (can you believe it? International!! Over 100 people!!) biocrust meetings.

Functional diversity of biocrusts in drylands: from ecological indicators to ecosystem services contribution

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Abstract: Biological soil crusts, or biocrusts, are one of the most diverse components of drylands; they are composed of complex communities of soil lichens, mosses, liverworts, cyanobacteria, and other microorganisms living on soil surface. Furthermore, biocrusts are very important contributors to drylands functioning and services by fixing carbon and nitrogen, protecting soil surface from erosion forces, promoting soil formation and stability, regulating hydrological cycles, and taking part in biotic interactions. These key roles performed by biocrusts have drawn the attention of ecosystem and applied ecological research in the last

decades. However, quantitative measures of biocrust functional diversity and their contribution to ecosystem services are scarce in the literature. The project "BSCES" funded by Research Executive Agency (European Commission) aimed to measure functional diversity of biocrusts in drylands and quantify their contribution to ecosystem processes and services along environmental gradients. In the last two years, we have characterized biocrust communities in terms of taxonomic and functional diversity in arid to dry sub-humid areas from the Mediterranean and southwestern USA regions. To do so, we selected a wide range of habitats, from shrublands, grasslands, and mixed forests to dune systems where climatic, soil, and land-use activities shape biocrust communities and determine their functional composition. We classified biocrust species in functional groups regarding their functional attributes (e.g., morphological, anatomical, physiological, chemical), resulting in a large database of biocrust functional traits and quantitative indices of functional diversity (e.g., the Rao's quadratic entropy). Also, we measured how these traits influence ecosystem processes (e.g., topsoil humidity and temperature, soil nutrient content) and quantified how their contribution to ecosystem services vary along climatic, fertility, or grazing gradients. Our findings place biocrusts as a powerful tool not only for ecosystem services assessment in drylands, but also for ecological restoration, offering a large set of multidisciplinary applications to be explored.

Rapid restoration of moss biocrusts on field slope under spray-seeding and broadcasting

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Abstract: Natural development of biocrusts generally takes decades. Artificial rapid restoration of biocrusts is a potentially effective way to achieve soil erosion control, especially in some hostile environments. The feasibility and effects of artificial moss biocrust restoration are discussed in this study. Spray-seeding and broadcasting were selected as inoculation techniques and four factors were used in an experiment: Hoagland, indole butyric acid (IBA), polyacrylamide (PAM), and shading. There were several major results. First, the maximum cover of moss biocrusts reached 77% and 54% through spray-seeding and broadcasting, respectively, after 30 days of cultivation; after 60 days, the cover under both inoculation treatments reached >85%. Second, Hoagland played a significant role in promoting cover, density, and biomass of moss biocrusts under both inoculation approaches. There was no obvious effect on moss biocrust development when IBA was 7 days or 14 days, and PAM did not impact moss biocrust development while soil moisture in the 0-5 cm profile was kept in the range of 15-25%. Third, shading always benefited moss biocrust development. Both spray-seeding and broadcasting are feasible approaches to achieve high cover of moss biocrusts on field slopes, which contributes to an engineering application for fast restoration of biocrusts at a large-scale to conserve soil and water.

Net primary productivity of a cyanobacterial biological soil crust in Northwest Queensland, Australia

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Abstract: Biological soil crusts (biocrusts) comprised of communities of cyanobacteria, algae lichens, and bryophytes together with heterotrophic bacteria, and microfungi in varying proportions. Their global role was assessed recently and it was found that cryptogamic covers (rock, soil, epiphytic) fix ~3.9 Pg carbon (C) per year, referring to about 7% of the net primary production of terrestrial vegetation. However, these extrapolations still contain a number of uncertainties and only a very few long-term measurements under field conditions have been performed, often resulting in a negative carbon balance. However, as biocrusts thrive in their habitats for decades, carbon has to come into the system somehow. Here we present the results from a one year semi-continuous (every 30 minutes) CO_2 gas-exchange measurement of a biological soil crust in the Australian northern savannah of the Boodjamulla National Park. The biocrust covers about 25% of the soil surface and reaches a chlorophyll a content of up to 440 mg/m². The biocrust samples were dominated by the filamentous cyanobacterium *Symplocastrum* sp., forming numerous erect and tapering bundles of cyanobacterial trichomes. We used the upper 5-8 mm of the crust for the measurements. No activity in CO_2 gas exchange was detected during the dry season month from mid-April to mid-November. Net photosynthesis occurred from mid-November to mid-April and resulted in a total carbon gain of 2.8 g/m² per year. In the first month of the rainy season (November), the sum of net photosynthesis – dark respiration was negative. Positive values were reached from December to March, getting slightly negative again in April. This is one of the first reports where long-term measurements in the field detected positive carbon gain.

Climate change interactions alter the abundance of cyanobacteria in a semiarid grassland

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Abstract: Climate change will raise temperatures and modify precipitation patterns, impacting both ecosystem structure and functioning in global drylands. Cyanobacteria are biocrust constituents that play critical roles in driving carbon and nitrogen cycling and provide better microhabitat conditions in systems affected by intense radiation or drought. However, we have limited knowledge on how the interaction between warming and reduced precipitation, two major climate change components in many drylands worldwide, will affect the composition and abundance of biocrust-forming cyanobacteria. To throw some light on this subject we conducted a manipulative field experiment in central Spain (Aranjuez) to evaluate how warming (ambient vs. ˜2.5°C increase), rainfall exclusion (ambient vs. ˜30% reduction in total annual rainfall), and biocrust cover (incipient vs. well-developed biocrusts) affect the abundance and composition of biocrust-forming cyanobacteria during five years. We used quantitative qPCR and culture profiling to measure the abundance and composition of cyanobacteria, respectively. We found that, in general, the abundance of cyanobacteria decreases in response to interactive effects from increasing temperature and reduced precipitation. Interestingly, the magnitude of the effect seems to vary depending on annual climatic conditions. The abundance of cyanobacteria tends to increase with presence of moss and lichen crusts. Biocrust-forming cyanobacteria were dominated by species from the genera *Microcoleus*, *Schizothrix*, *Leptolyngbya*, *Scytonema*, *Nostoci*, and *Tolypothrix*. Preliminary results indicate that presence of well-developed crust increases the diversity of cyanobacteria, while reduced precipitation alters the composition of cyanobacterial communities. Our results indicate that the interactive effects of climate change will negatively affect the abundance and composition of cyanobacteria in drylands, with likely consequences for ecosystem functioning. We are currently conducting Illumina Miseq profiling to further evaluate the interactive impact of climate change on the composition and diversity of cyanobacterial communities.

Microbial community changes over successional stages of Australian biocrusts

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Abstract: Biological soil crusts (biocrusts) occur globally in a range of environments where biocrust level of development (or successional stage) may be used as a proxy measure to assess ecosystem health and functioning. Yet, how microbial communities change across differing biocrust stages within a given environment has not been resolved. Here, three different stages of biocrust (early, mid, and late) and bare soil were surveyed via high through-put sequencing to examine whether successional stages determined visually reflect distinct microbial communities. Biocrusts were sampled from three sites within a protected regeneration area of Australian semi-arid land. While richness significantly increased between bare and crusted soil, there was no difference between crust types and no significant difference in OTU diversity between any of the soil cover types. However, significant changes in the relative abundance of phylotypes was observed where the community shifted from heterotrophic bare soil to a bloom of filamentous cyanobacteria in early stages. While other cyanobacterial classes remained constant in mid and late stages, there was a significant reduction in Oscillatoriophycideae, compensated by increases in heterotrophic bacteria. As expected, indicator species analysis showed bare soil was defined by heterotrophic bacteria whereas crusted stages were defined by cyanobacteria, specifically *Phormidium*. Three dimensional ordination within a principle coordinates analysis (PCO) plot showed stages were differentiated along PCO1 which accounted for 11.6% of the variance. Sample site was associated with PCO2 (5.8%) while PCO3 accounted for 5.6% of variance.

Analysis of co-occurrence networks showed bare soil had the greatest number of significant correlations, density and average number of neighbours, features which reduced as crust stage advanced. The changes in community abundance and structure detected across different successional stages here are important considerations in utilizing biocrusts as ecosystem indicators.

Secrets of success: eco-physiological traits of early successional soil crusts

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Abstract: Eco-physiological characterization of photoautotrophic communities is not only necessary to know the response of carbon fixation to different climatic factors, but also to evaluate risks attached to changing environments. In biological soil crusts (BSC), the description of eco-physiological features is difficult due to the high variability in composition and variable methodological procedures. Especially for BSC in early successional stages, the available datasets are rare or focused on individual constituents. Although these crusts may represent the only photoautotrophic component in many heavily disturbed ruderal areas, like parking lots or building areas, these disturbed habitats are increasing in surface area worldwide. We analyzed the response of photosynthesis and respiration to changes in water status, temperature, and light in two early successional BSC, one dominated by the cyanobacterium *Nostoc commune*, one dominated by the green alga *Zygogonium ericetorum*. Independent of species composition, both crust types had convergent features like high-light acclimatization and no water-suprasaturation depression in carbon uptake. This particular setup may enable these communities to cope with a high variety of climatic stresses, and may therefore be a reason for their success in heavily disturbed areas with ongoing human impact. Nevertheless, a major divergence between the two BSC was their absolute carbon fixation rate on a chlorophyll basis, which was significantly higher for the cyanobacterial crust. This finding may have two major implications. First, due to the difference in light-reception pigments between cyanobacteria and eukaryotic algae, comparisons should be based on surface area rather than chlorophyll contents. Second, the carbon concentrating mechanism in cyanobacteria may, besides different desiccation characteristics, represent a major driver for increased fixation rates, and can thus be an explanation for the greater fitness of cyanobacterial crusts in comparison to green algal crusts on a global scale.

Future directions for arid land moss restoration in the Great Basin

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Abstract: Arid land mosses can be successfully established in the Great Basin with minimal effort, resulting in roughly 30% cover in a single year. However, numerous questions still exist surrounding how to effectively scale up moss restoration efforts and incorporate them into site- and landscape-scale restoration projects. Questions include how mosses are likely to influence plant community composition and ecosystem processes. Mosses are likely to affect the establishment of vascular plants directly and indirectly as mediated by abiotic factors such as possible increases in and retention of soil moisture. We will present how the role of mosses in restoration projects might be investigated experimentally.

Effects of warming and watering-induced moss death on CO_2 exchange in biocrust soils over an 8-year period

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Abstract: Evidence is mounting that biocrusts are sensitive to both temperature and precipitation changes associated with climate change. To examine the effects of warming temperatures on soil carbon (C) balance in a dryland ecosystem, we used infrared heaters to warm biocrust-dominated soils to 2-4°C above control conditions at a field site on the Colorado Plateau, USA. This treatment was crossed with a precipitation amendment treatment that resulted in the death of a major biocrust component, the moss *Syntrichia caninervis*. Within these crossed treatments, we monitored net soil exchange (NSE) of CO_2 every hour for a 21 month period in 2006-2007 and then again for a 9 month period from 2012-2014. We used an automated flux chamber system (5 per treatment), which quantified net CO_2 exchange of the biocrusts and the soil beneath them. In control plots, we observed measurable photosynthesis in biocrust soils when soils were wet (~12% of measurement days) throughout the course of the experiment. These observations included several snow events, providing evidence of substantial photosynthesis underneath snow by biocrust organisms in this dryland. On days during which soils were wet and biocrusts were actively photosynthesizing, biocrusts that were warmed had a substantially more negative C balance (i.e., biocrust soils took up less C and/or lost more C in warmed plots), a result that was magnified after 8 years of warming, suggesting degradation of biocrust photosynthetic capacity by the warming treatment. The watering treatment-induced moss death reduced photosynthesis rapidly during the first year of the treatment and showed little recovery over the 9-year period, suggesting that mosses make up a substantial fraction of biocrust photosynthetic capacity in this system, and that once lost, return slowly. Taken together, our data suggest a substantial risk of increased C loss from biocrust soils with climate change, particularly over longer time periods.

Spectral properties of cyanobacterial soil crusts, implications for detection using remote sensing

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Abstract: Biological soil crusts have many ecosystem functions, including carbon and nitrogen fixation and nutrient cycling and play an important role in landscape stability by protecting the soil against wind and water erosion. Several methods have been proposed to estimate the cover of biological soil crusts from remote sensing data, but these rely on active photosynthesis to alter the color of the crust. Analysis of spectral reflectance data of cyanobacterial soil crusts made in southwest Queensland in the austral winter and summer of 2015 demonstrate that our ability to detect their presence, and estimate their cover, is dependent on whether photosynthesis is taking place at the soil surface, and this is strongly limited by insolation, presumably due to UV intolerance of bacteria. High levels of solar radiation typical of clear sky conditions cause surface photosynthesis to decrease rapidly. These results suggest that successful estimation of cyanobacterial soil crust cover in semi-arid zones is only possible under a limited set of environmental conditions; surface photosynthesis is only detectable under limited solar irradiance conditions (i.e., at night or under thick cloud cover), when orbital remote sensing data of the surface cannot be acquired. We present the results from analyses of field measurements and remote sensing of cyanobacterial crusts in semi-arid Diamantina, Queensland, and a contrasting campaign in New South Wales, and discuss the potential for remote sensing and mobile devices for cyanobacterial crust identification.

Biocrusts mitigate the negative impacts of climate change on soil microbial communities and multifunctionality in terrestrial ecosystems

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Abstract: Climate change will negatively impact both soil microbial communities and multifunctionality (i.e., multiple functions related to climate regulation, nutrient cycling, and decomposition) in drylands worldwide. Biocrusts play a key role in supporting both soil microbes and multifunctionality. However, little is known on whether biocrusts can buffer the negative impacts of climate change on microbial communities and multifunctionality. Moreover, the role of soil microbial communities associated with different biocrust species in regulating the response of multifunctionality to global change remains unexplored. Here, we report results from two independent studies: 1) a cross-continental (North America, Europe, and Australia) survey covering 39 locations from arid to humid ecosystems where we evaluated the role of biocrust-forming mosses in regulating the responses of soil microbial communities and multifunctionality to changes in aridity; and 2) a microcosm experiment aiming to evaluate how biocrust-forming lichen species from Australia mediate the effects of simulated changes in rainfall frequency and nitrogen addition on multifunctionality, directly and indirectly via associated microbial communities. Compared to soil surfaces lacking biocrusts, biocrust-forming mosses enhanced multifunctionality in semiarid and arid, but not in humid and dry-subhumid environments. These results were mediated by the positive effects exerted by biocrust-forming mosses on the abundance of soil bacteria and fungi. Regarding our microcosm study, biocrust species always promoted multifunctionality compared to bare ground, though the strength and direction of the response was moduled by the identity of biocrust species. Most importantly, the relative abundance of specific microbial taxa associated with different lichen species modulated the response of multifunctionality to water frequency and N addition treatments. Our findings provide strong evidence that the maintenance of biocrusts is crucial to buffer negative effects of climate change on multifunctionality and soil microbes in drylands.

Complex role of the exopolysaccharidic matrix in biological soil crusts

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Abstract: In arid and semiarid environments, soil carbon sequestration (CO_2 fixation) by cyanobacteria and by biological soil crusts (BSC) is considered an eco-friendly and natural process to increase soil C content and a viable pathway to contrast desertification and to favor soil rehabilitation. Within this context, inoculation-based techniques with exopolysaccharide-producing cyanobacteria have proved to be a viable and sustainable pathway to increase soil biomass, soil stabilization, and to increase soil fertility. In this presentation, a particular focus will be given on the role of the extracellular polysaccharidic matrix (EPM) synthesized by cyanobacteria in giving the structure to natural or induced BSCs and to enhance their water trapping and retaining capability. EPM was extracted with methods aimed at separately removing the tightly bound exopolysaccharidic fraction (TB-EPS) and the loosely bound exopolysaccharidic fraction (colloidal EPS; C-EPS) from BSCs having different ages. The fractions were analyzed in terms of monosaccharidic composition, and molecular weight (MW) distribution. We observed that the relative amounts of uronic acids increase in the EPM with the age of the crusts, implying advantages for the community-water relations. In addition, we also

observed significant differences in MW distribution between the two EPS fractions, being TB-EPS mostly composed by one molecular fraction having high MW, while C-EPS showed to be also composed by low MW fractions. This difference suggests distinct roles of TB-EPS and C-EPS fractions within the crust system. Indeed, TB-EPS most likely affects BSC structure and water-retaining properties, while C-EPS most likely contributes to the intake of C in the soil, thus favoring the growth of the chemoheterotrophic microbial community. The role of EPM in water capture from non-rainfall sources, water maintenance at the topsoil, and in maintaining a high water potential was also shown.

Plant-biocrust-fungal interactions in arid lands: primary producer competition and microbial facilitation

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Abstract: Species interactions may couple the resource dynamics of primary producers that are disconnected in space and time. Arid ecosystems have low-density plant communities and biological crusts. Biocrust activity is rapidly stimulated by rainfall events, but plants require events large enough to infiltrate to roots. Many biocrusts fix nitrogen, but plant roots do not extend into the surface soil to intercept it directly. The fungal loop hypothesis proposes that fungi transport resources between plants and biocrusts, increasing productivity. However, this mechanism has not been tested experimentally. We studied 1) how plants and biocrusts interact, 2) how fungi affect plants and biocrusts, and 3) how rainfall regime affects these interactions. We transplanted bunchgrasses and biocrusts into pots in the field then manipulated 1) the presence/removal of each and compared the performance of each producer grown alone and with the other, 2) the connections between surface biocrusts and roots using mesh that excluded or allowed fungal connections, and 3) water regime (small weekly vs. large monthly additions). We hypothesized that plants and biocrusts could have facilitative or competitive interactions, but intact fungal connections would improve performance for both. Both plants and biocrusts showed evidence of competition. Biocrusts had 28% less chlorophyll when grown with bunchgrasses than when bunchgrasses were removed ($P<0.01$). Plants had 36% less biomass when grown with biocrusts ($P<0.01$). Biocrusts had generally higher chlorophyll content under large, infrequent water regimes ($P=0.06$), but plants had no difference in performance under alternate water regimes. When fungal connections were present, plant biomass was 44% higher and biocrust scytonomin content was 61% (suggesting reduced stress) lower under large, monthly water regimes than when connections were absent or under small, weekly water regimes (Tukey post-hoc $P<0.05$). These results support the fungal loop hypothesis because the presence of fungal connections enhanced the performance of both producers.

Shades of success: propagating the dominant drylands moss genus *Syntrichia*

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Abstract: The rapid cultivation of desiccation tolerant mosses is a branch of investigation stemming from a growing interest in biocrust rehabilitation. There is a need for techniques to grow many different biocrust taxa, not only quickly, but in quantities large enough for field application. Many mosses can be cultured within weeks, for example ruderal taxa such as *Bryum argenteum*. However, in the Northern Hemisphere, mosses of the genus *Syntrichia* are both common, and frequently dominant and therefore are a highly desired genus for use in rehabilitation. *Syntrichia* can be grown in growth chamber environments, and efforts to culture it at larger scales in the greenhouse have met with some success, but propagation techniques require considerable refinement to produce rehabilitation-relevant quantities. In our experience with *Syntrichia*, we have often observed slow growth rates compared to species from other genera, and periodic mortality events and chlorosis of tissue. We present the results of a series of experiments in which we manipulated environmental factors in a greenhouse, including: amendment of a sandy-soil cultivation substrate with varying levels of organic content; increasing relative humidity of cultivation units with plastic partitions, cellophane, and burlap; and addition of shade cloth. We found that shading was an important factor, which both increased growth and reduced chlorosis. Additionally, we found that *Syntrichia* spp. grown on sand performed better than *Syntrichia* spp. grown on an amended soil substrate. This result contrasts with that of the species *Bryum argenteum* and *Funaria hygrometrica*, which had a preference for potting soil rich in organic matter. These findings are an important advance for cultivation of the genus *Syntrichia*, and highlight the need to take a taxon-specific approach to the propagation of biocrust mosses.

The BLOCDUST model – the role of cyanobacteria-dominated biocrusts in the loess sediment formation: current state and future perspectives

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Abstract: Loess deposits are aeolian sediments formed by the accumulation of wind-blown dust particles (60-90% silt) comprised primarily of quartz, feldspars, and mica. The accumulation and formation of loess sediments is most intensive in arid and semi-arid regions, which are characterized by very weak and sparse vegetation. Despite the wide distribution of loess sediments, their mode of deposition is not yet fully understood, and no model of their formation is yet fully accepted. The latest hypothesis on the formation of loess sediments was proposed by the BLOCDUST model and for the first time a microbiological component was considered

essential in the formation of loess. The BLOCDUST hypothesis proposes a model of stabilization and deposition of dust particles through specialized extremophilic microbial communities formed on the loess sediment surface - cyanobacteria-dominated biocrusts. In order to explain the very mechanism of trapping, accumulation, and preservation of dust material, as well as loess texture and structure, the first *in vitro* formation of the loess sediment is currently being performed in two separate bioreactors at the University of Novi Sad, Serbia. The particle cementation pattern of cyanobacteria-dominated biocrusts has been studied through SEM/EDS – X-ray – calcimetry analyses, which have revealed the crucial role of extracellular polymeric substances in the process of loessification. Furthermore, the first results obtained by geochemical analyses of loess sediments indicate the presence of cyanobacterial biomarkers and thus further demonstrate the significance of cyanobacteria-dominated biocrusts in the accumulation and preservation of loess sediments. In order to fully explain the process of loessification, new technologies will be involved in future research. These include 3D geo-electrical imaging of loess sediments, structural analysis of biocrusts by confocal microscopy, and biochemical analyses of isolated strains with the aim to introduce novel cyanobacterial biomarkers into the field of loess research.

Biological soil crusts and rangeland management: role for crusts in state and transition models?

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Abstract: Management of rangeland ecosystems is challenged by high heterogeneity in soil-geomorphic attributes, low and variable precipitation, and ecosystem dynamics prone to threshold or hysteresis type transitions. The NRCS Ecological Site Information System and associated Ecological Site Descriptions (ESDs) and state and transition models (STMs) provide information and tools to help address these management challenges and have become the common currency land classification system used by all major US natural resource management agencies. ESDs classify landscapes based on soils, topography, and climate. STMs are imbedded within ESDs and provide descriptions of site dynamics, including putative ecological states, transitions between states and restoration pathways. ESDs and contained STMs are primarily focused on vegetation patterns and dynamics and associated management. Although some soil health parameters, including biological soil crusts (BSCs), are described for the reference state (e.g., rangeland health reference sheets), they are not fully integrated into ESDs and STMs. Even on the Colorado Plateau, which supports some of the most dramatic and diverse BSC communities in the world, BSC communities do not factor into definitions of ecological states or transition pathways. We provide results from a recent series of interagency STM workshops where we successfully incorporated biological soil crusts into STMs from the Colorado Plateau region of the southwestern US. In this example, loss of biological soil crusts help define at-risk states, indicating risk of transition to an undesired state. In rangeland systems of the US, land-use change and intensification is occurring at astounding rates. Successful restoration of ecosystems following soil-disturbing land uses will likely need to address soil degradation. ESDs and STMs are a primary management tool used by US federal agencies in planning and restoration efforts.

Appropriate integration of soil health concepts into ESDs and STMs is critical for effective adaptive management of rangeland landscapes in the US and globally.

Insolation and disturbance history drives biocrust biodiversity in western Montana rangelands

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Abstract: Biocrusts are an important ecosystem component in the grasslands and shrublands of the intermountain west. Despite this fact, biocrust community ecology is currently understudied in many areas, including Montana. At The MPG Ranch in western Montana, we collected cover and species composition data of bryophytes and lichens at 100 sites across the 4000-hectare property with potential biocrust habitat. We surveyed multiple combinations of aspect, dominant vegetation type, native and invaded range, and elevation. At each 15 m-radius site we collected data both at the whole site scale, and per major microsite present, such as grass-forb interspace or under shrubs. Quadrat data included biocrust cover, ground cover, and vascular cover data. We tested soils at each site to determine pH and soil texture. Preliminary analyses suggest that after disturbance history, aspect and insolation are the strongest drivers of biocrust diversity and abundance. Biocrust biodiversity was surprisingly unresponsive to soil texture or pH. Steep, north aspect slopes that receive greater periods of daily and seasonal shade harbored higher diversity and cover of biocrust than south aspect sites. These north aspect sites were also the least disturbed, both in regards to current ungulate use and historic ranching disturbance. Sites with the least biocrust diversity were either warm aspect and/or recently disturbed from tilling or other anthropogenic means. Biocrust diversity at each site ranged from 2 species (at the most disturbed sites) to 35 species (at the richest sites), with an average of 13 species. Sites with more vascular exotics tended to have less biocrust diversity, though a high number of exotics was not a strong predictor of biocrust diversity. Lichens make up the majority of the diversity of the biocrust community, although bryophytes are as abundant. To date we have detected about 60 lichen species and 25 bryophytes. The most frequently encountered bryophytes across sites were *Syntrychia* spp., *Bryum argenteum*, *Gemmabryum caespiticium*, and *Encalypta vulgaris*. The most frequently encountered lichens were *Cladonia* spp., *Peltigera* spp., *Leptogium* spp., and *Diploschistes muscorum.* Biocrusts account for an average of 30% of the known primary producer diversity, suggesting that they are a major component of local biodiversity in this region. We have developed a web-based app for users to view, to interact with and analyze the data in a GIS-like setting, and learn about the species of MPG Ranch. Such tools enable a wider appreciation of biocrusts and their biodiversity in broader scientific and management circles and in the general public.

Are shrub cover and grazing effects on biocrust richness mediated by soil heterogeneity and/or intransitivity?

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Abstract: Grazing and shrub encroachment are two major drivers of plant community composition and have been implicated in changes in biocrust community richness and composition. Considerable empirical and theoretical evidence suggests that livestock activity can change biocrust richness and composition, but the exact mechanisms are poorly known. For example, grazing and increasing shrub density may reduce spatial and temporal heterogeneity by simplifying soil surface structure or plant architecture and cover. This could alter crust richness by influencing intransitivity, the hierarchy of competitive interactions among the various biocrust species. We used two approaches to examine how grazing and shrubs affect biocrusts: 1) general linear mixed models to examine grazing and shrub density effects on biocrust composition, and 2) structural equation modelling to examine the direct and indirect effects of grazing and increasing shrub density on biocrust richness. Species occupancy models revealed no difference in species composition in relation to grazing, but more species in the interspaces than under the canopy. This was largely driven by two species, the lichen *Endocarpon pusillum* (under the shrubs) and the moss *Gigaspermum repens* (in the interspaces). Our structural equation models tested whether grazing and shrub effects on richness were direct, or whether they were mediated by changes in surface heterogeneity and the competitive hierarchy among interacting species. Finally, we tested which species contributed most to our intransitivity networks, and used recent information on biocrust traits to examine relationships with the traits of these species.

Biocrust inoculum development and soil stabilization strategies to promote biocrust restoration

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Abstract: Due to the importance of biocrust communities to the ecological functioning of dryland ecosystems, there is keen interest in restoration of these communities after soil surface disturbance. However, active biocrust restoration has remained extremely difficult to achieve in field settings, both because of questions surrounding how to create biocrust inoculum and how to

ensure the success of that inoculum in the environment. In a series of multi-factorial experiments, we examined the effects of biocrust inoculum type and soil stabilization strategies on biocrust development in disturbed soils at a cool desert site (Great Basin, Utah, USA). We inoculated experimentally disturbed soils with 3 types of biocrust inoculum: field collected (FC), which was biocrust that was collected at the site, mixed, and redistributed across plots; local biomass (LB) inoculum that was grown in the greenhouse under optimal soil moisture, temperature, and nutrient conditions from small samples collected in the field; and mixed isolate (MI) inoculum that was created in the laboratory from cyanobacterial cultures collected at the site. Experimental disturbance consisted of scraping the top 3 cm of the soil surface and then trampling with at least one pass of foot traffic. The soil removed in the scraping was used as the FC inoculum. Plots were prepared with two soil stabilization strategies. Straw checkerboards, in which straw served as silt fences, were installed in 3 x 1 m plots. In a second stabilization approach, polyacrylamide (DirtGlu) was applied to the soil surface in plots of the same size. The study was carried out in a factorial design of inoculum type by soil stabilization strategy on two soil types. We report on biocrust development (assessed as biocrust cover and chlorophyll a concentrations) and soil stabilization (soil aggregate stability, soil compaction, shear strength) after one year. We discuss these early results in the context of conducting larger scale biocrust restoration in dryland ecosystems.

The mechanical disturbance of biocrusts reduces soil fertility and microbial diversity in a sand dune ecosystem

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Abstract: In light of climate change and the projected growth of the global population, the need to produce more food will increase within the next decades, which constitutes a huge challenge for the goal of achieving land degradation neutrality, as formulated by the UNCCD. In this context, it is important to study and understand the effects of increased anthropogenic activity and land use change on the fragile biocrust communities in drylands around the world. We studied the effects of repeated mechanical disturbance of biocrusts on physical, chemical, and biological soil characteristics in three experimental sites along a rainfall gradient in the NW Negev Desert, Israel. The disturbance led to a depletion of fines and a reduction of water holding capacity, as well as a decrease in crust porosity. After the treatment, a loss of soil fertility was evident, caused by an increased leeching of soil nutrients (such as different N-compounds) and a loss of organic carbon, as well as plant available P and K. Immediately after the disturbance, the

penetration resistance of the biocrusts was reduced to almost zero, but no significant differences in crust stability could be detected after 4 and 5 years of recovery, demonstrating that this time is sufficient for the stability of the crust to recover. In most cases, the changes were more pronounced on plots that were repeatedly disturbed. Since it is closely linked to the available moisture, the cyanobacterial population structure changed not only along the rainfall gradient, but also with disturbance. Here, all disturbed plots showed much lower proportions of N-fixing cyanobacteria and a recovery of the disturbed plots to 50% of the control populations for the (more arid) southern station and 80% for the (moister) northern station after 4 years of recovery was observed.

Cyanobacteria response to extreme drought in hot desert biocrusts

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Abstract: Even though drylands are demonstrably among the most sensitive biomes to climate variability, our ability to predict their responses to predicted changes in climate is still quite limited. Biocrust are crucial for these ecosystems. To determine how biocrust communities will respond to climate change, it is important to study the behavior of crusts organisms under more extreme climatic conditions. Global warming is expected to modify precipitation patterns, increasing precipitation variability in arid and semiarid ecosystems. Additionally, models for the next 100 years in the southwestern US predict the occurrence of drought conditions more severe than any during the past 1500 years. The Extreme Drought in Grasslands Experiment (EDGE) imposes severe chronic droughts in grassland ecosystems across the central US, aiming to advance our understanding of patterns and mechanisms of ecosystem sensitivity to climate change. We sampled soil cores from a Chihuahuan Desert EDGE site located at the Sevilleta LTER in New Mexico, where a 66% reduction in growing season precipitation has been imposed since 2013. We performed *in situ* visual assessment of biocrusts cover (light vs. dark), followed by 16S rRNA gene sequencing and chlorophyll *a* measurements to evaluate the response of cyanobacteria to chronic, severe drought. There was an apparent reduction of well-developed (dark) biocrust in drought plots compared to controls. Negative effects in cyanobacterial relative abundance were also significant. The dominance of a single OTU (matching in the clade of *Microcoleus steenstrupii*) was exacerbated by drought. These findings show that drought conditions might be affecting biocrust cover, relative abundance of cyanobacteria, and select for specific types. Important processes like nitrogen and carbon fixation, and biocrust succession are likely to be affected by chronic severe drought. Thus, a deeper look into biocrust communities is essential to better understand how they will respond to increased climatic variability and prolonged drought.

Interactions among biocrust community states and warming temperatures could drastically reduce dryland soil fertility

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Abstract: Soil nitrogen (N) concentrations in dryland ecosystems tends to be quite low and may impose limits on net primary productivity of these ecosystems. Biological soil crusts (biocrusts) have long been invoked as key players in the nitrogen cycle and fertility of dryland soils. While a number of studies have verified the role of biocrusts in N fixation and emissions, relatively few studies have aimed to disentangle the influences of different biocrust community states from the influences of local soil properties on soil N pools. Separating the influence of biocrusts from local edaphic properties on dryland fertility is particularly important in the context of global change factors (e.g., climate change, N deposition), which have been experimentally demonstrated to alter not only biocrust community states, but also soil nutrient pools and soil microbial community structure and activity. We used a mixture of field and greenhouse experiments to disentangle the influence of soil properties and biocrust community states on soil N pools and forms under both ambient and warmed temperatures (+ 7°C over ambient). We found that late-successional biocrust communities (dominated by mosses) significantly increased soil N concentrations compared to early-successional communities (dominated by lightly-pigmented cyanobacteria) when both community types were maintained on a common, homogenized soil. Additionally, N concentrations were significantly greater under ambient than warmed temperatures regardless of biocrust community states. An analysis of leachate released during rehydration from desiccated states revealed that, on average, late-successional biocrusts release 37% more N and nearly 580% more C than early-successional biocrusts. Our results suggest that the loss of late-successional biocrust communities could combine with warmer temperatures to drastically reduce soil fertility in dryland ecosystems.

Characterization of hydrological regimes of moss and algal biocrusts under temperate climate using multispectral imagery

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Abstract: The influence of biocrusts on the distribution of water entering the soil surface is controlled by their ability to pass water into the solum (infiltration) or to retain water with their biomass (water holding capacity – WHC). While the influence of biocrusts on infiltration has been discussed controversially, there is little doubt that soil water retention increases with the amount of organic matter. We hypothesize that (I) infiltration differs between algal and moss biocrusts and that (II) algae and mosses have distinctive spectral characteristics. To facilitate the

modeling of biocrust mediated water distribution on a landscape level, we aim to classify respective crust types and to determine crust biomass from easily available remote sensing data, using the RGB and NIR channels in particular. A lysimeter experiment with algal and moss surface inoculation was used for VIS/NIR photography and to record high resolution reflectance spectra (350-2500 nm) of moist surfaces. PLS regression coefficients revealed a positive response of the red and green reflectances, and insignificant response of the blue reflectances to mosses. Reflectance data were used to develop a (R+nG-mB)/(R+nG+mB) type spectral index for crust type classification (mosses vs. algae). NDVI (R-NIR)/(R+NIR) has been selected to represent crust biomass. Both indices were correlated with infiltration and water contents of the lysimeters, where the respective k_s-values and van-Genuchten parameters of the biocrusts were deduced from lysimeter weights and meteorological records using inverse modeling in HYDRUS 1D. It was found that moss biocrusts had higher infiltration rates than algal biocrusts, and that the WHC increased with NDVI. Resulting crust type specific hydrological regimes could be identified using VIS/NIR imaging spectroscopy.

In crusts we trust

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Abstract: Researchers working on biological soil crusts, including he who writes here, have traditionally introduced published contributions on the subject with bold statements regarding the awe-inspiring wonders that our beloved, but surely undervalued, objects of research bring to the ecosystem, arid lands in general, and the biosphere they inconspicuously inhabit. This was likely to counteract a perceived lack of peer interest in the quaint, *rara avis*, miniscule systems upon which we chose to focus our perchance misguided efforts. As the success of this Biocrust3 meeting will show, the times of closeted discoveries, minority opinions, and ecological inferiority are all but a thing of the past; biocrusts are now mainstream, so let us rejoice. Having achieved this feat, however, the necessity for gratuitously bombastic claims is much diminished just as our standing in the ecological community has reached new heights. As with all mature disciplines, the time for rigor has come to crustology. In this contribution, I will critically review the evidence available to hold commonly used factoids and ecosystem services allegedly provided by biocrust as immutable dogma: from arid land fertilization and the prevention of soil erosion, to the portion of aridlands they cover, from the direct provision of nutrients to plants, to the warming of the soil, from element transmutation to the eradication of herpes. It is hoped that this update will be of general use to many introductions to come.

Microcoleus vaginatus carries a nitrogen-fixing microbiome that can help it colonize nutrient-deficient arid substrates

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Abstract: Biocrusts are arguably the most extensive biofilm on Earth. They constitute a carbon pool that exceeds 10^{14} g C, and are responsible for almost half of the nitrogen fixed on land. The cyanobacterium *Microcoleus vaginatus* is the pioneer of biocrust communities, but interestingly this architect of early biocrust successional stage does not fix nitrogen. Where does the initial nitrogen pulse come from to support the establishment of *M. vaginatus* as it colonizes bare soil? To answer this question, we compared the bacterial community firmly attached to *M. vaginatus* bundles (the "cyanosphere") to that of the bulk biocrust soil, using high throughput 16S rDNA gene sequencing. We found a distinct bacterial community that is significantly enriched in the cyanosphere of *M. vaginatus*, one that contains several of the recently identified heterotrophic biocruts nitrogen fixers. We hypothesized that nitrogen fixing heterotrophs could be differentially abundant in this community. Using real-time PCR, we demonstrated that the *nif*H genes were 100 fold more abundant in the cyanosphere than in the rest of the soil. In conjunction with recent metabolomics studies, this strongly suggests a symbiotic mechanism by which *M. vaginatus* provides carbon to the heterotrophic community in its cyanosphere and in exchange, this community provides *M. vaginatus* with fixed-nitrogen. This study reveals the existence of a differentiated microbial community associated with *M. vaginatus* and proposes a symbiosis with its cyanosphere that could be key to the early establishment of the biocrust.

Linking biological soil crust diversity to ecological functions

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Abstract: Data on biological soil crusts (BSCs) in temperate regions are sparse although these communities perform important ecological functions and can be frequently found in forest sites and grassland ecosystems. Our aim was to determine the biodiversity of BSC phototrophic microorganisms and link their occurrence to the ecological function of the crust. Crust-associated organisms were identified by using a combination of microscopy and molecular techniques. The functional role of the BSCs in the biogeochemical cycles of carbon, nitrogen, and phosphorous was evaluated using an array of state of the art soil chemistry methods including Py-FIMS (pyrolysis field ionization mass spectrometry) and XANES (x-ray absorbance near edge structure) spectroscopy. Total P as well as P fractions were quantified in all BSCs, adjacent soil underneath, and BSC-free soil. A remarkable accumulation of total P and a distinct pattern of P fractions in the crust were detected. Further, we observed an indication of a different P-speciation composition in the crust compared with BSC-free soil. The data allow answering the question whether BSCs act as sink or source for these compounds, and how biodiversity controls the biogeochemical function of BSCs.

Rapid cultivation of “fire moss” as a potential tool for burned area emergency response

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Abstract: With high severity wildfires increasing through the southwestern United States, land managers need new tools to facilitate post wildfire ecosystem stabilization and recovery. One potential tool is using the early successional mosses, *Funaria hygrometrica*, *Bryum argenteum*, and *Ceratodon purpureus*. These “fire mosses” complement and augment existing seeding and mulching treatments; they are desiccation tolerant, can be propagated and dispersed vegetatively, can increase infiltration and water holding, and can attain high cover within months of fire. Our first step in exploring fire mosses’ restoration potential is optimizing growth in a greenhouse setting. In the greenhouse, *F. hygrometrica*, *B. argenteum*, and a combination of both, were added to two substrates, commercial “topsoil” and a sand, coconut coir 1:1 mixture. We amended the substrates with ash, charcoal, and a combination of the two. We grew mosses on top of burlap and bare soil to explore the tradeoffs between ease of harvesting and propagation potential. We also grew moss on field collected soils as a reference to test our engineered substrates against. We found that *F. hygrometrica* can achieve 74% cover on topsoil and *B. argentum* can achieve 71% on topsoil amended with charcoal in nine weeks from an inoculated cover value of 20%. The addition of ash drastically inhibited growth rates and charcoal had mixed effects depending on species. Burlap had an inhibitory effect on growth rates but did not completely impede growth. These results indicate that fire mosses can be grown rapidly in a greenhouse setting using inexpensive organic materials purchased at a local nursery or hardware store. Our next experiments will focus on manipulating microclimate and propagule preparation methods to further improve moss cultivation rates in the greenhouse.

Application of chlorophyll fluorescence, CO2 gas exchange, and NDVI for the detection of spatial variances of photosynthesis of biological soil crusts on anthropogenic degraded soils

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Abstract: Degradation of soils and the destruction of vegetation as a result of anthropogenic disturbances affect ecosystem functions and properties worldwide. In Brandenburg (NE Germany) various ecosystems were degraded by different human activities like surface mining and military activities on sand dunes. These resulted in degraded open landscapes with an initial soil development. These new ecosystems are characterized by a high vulnerability to erosion, low water holding capacity, lack of nutrients, or low pH. For rehabilitation of degraded soils and vegetation, these post-mining and mobile sand dunes need specific restoration measures, but

beside inappropriate soil characteristics, insufficient water availability can limit plant growth. Even located in the temperate zone of Europe, Brandenburg belongs to the driest regions in Germany and faces long drought periods. In this context, the determination of the influence of biocrusts on carbon accumulation during initial ecosystem succession, small-scale investigations on photosynthetic capacity and active phase regarding biocrust formation and developmental stage, which vary from initial green algae-crusts to biocrusts dominated by soil lichens or mosses, are necessary. Hence, succession of biocrusts result in a spatiotemporal heterogeneity and distribution pattern. We could show that varying species abundance, composition, and crust succession affect photosynthetic capacity, and hence, carbon fixation capability. Different spatial hotspots could be analyzed under field conditions and monitored during the season. Long-term measurements of climatic parameters, which include radiation, temperature, precipitation, and desiccation of biocrusts, will be linked to photosynthetic performances under lab conditions. This spatial model can help to understand the impact of biocrusts on carbon accumulation in initial soils. Due to the potential to colonize soil surface under harsh conditions without human support, advantages of biocrusts can be used systematically as a supporting rehabilitation measure for physical stabilization, gain of organic carbon, and hence, facilitates the growth of indigenous vegetation during primary succession.

Endo/epilithic biological soil crust in the Sahara Desert petrogypsic horizons: a micromorphological approach

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Abstract: Biological soil crusts (BSC) have been reported to be present in a diverse range of environments on Earth, especially in extreme environments (hot and cold desert). In the Sahara Desert, gypsum soils occupy large areas and host a striking biological diversity in endolithic and/or epilithic BSC, but their soil micro-fabric has been much less studied than their biodiversity. Herein, we report the micromorphological approach of pedofeatures related to the BSC activities of petrogypsic horizons in the Sahara Desert ecosystem (North Africa). The study area is the edges of playa landscape (Ouargla Basin) in Algerian Sahara, actually under hyper-arid climate and characterized by gypsiferous and saline soils. Samples were taken at the end of winter (February 2016) from surface petrogypsic horizons containing active endolithic or epilithic BSC. Chemical and physico-chemical analysis (pH, salinity, calcareous, gypsum, texture, and organic matter) of soil samples were performed in the laboratory. Thin sections were made from undisturbed and impregnated soil of each BSC sample; they were studied with a polarizing light microscope. Additional undisturbed BSC soil aggregates were selected for scanning electron microscope observations and microanalysis (X-Ray Analyzer (EDXRA) microprobe). Thin section description showed that the crystalline pedofeatures are the dominant microfabric; gypsum is aggrading in form of lenticular or irregular crystal mosaic sutured intergrowths together with sparite and micro-sparite calcite. The common organic pedofeatures observed in thin sections include organic residues, infillings, and amorphous fine organic material. Organic residues are commonly derived from algae; they are often observed as infilling

in the inter-crystals (gypsum) porosity or randomly distributed in crystalline groundmass. Amorphous fine organic material in the interface calcite/gypsum crystals seems to be related to the CO2 pressure and geochemical dynamic (dissolution/precipitation) of these minerals in soil.

The role of biocrusts in regulating grass germination and establishment

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Abstract: Biocrusts play a critical role in the ecological functioning of global dryland ecosystems through provision of a suite of ecosystem services. Most importantly to dryland vascular plant communities, biocrusts can enhance soil water availability through modification of the soil environment (e.g., microtopography, porosity) and contribute to soil fertility via nitrogen fixation. Although biocrusts modify important plant limiting resources, the influence of biocrusts on surrounding vascular plants is mixed, whereby biocrusts have been shown to have both facilitative and inhibitory effects on plant establishment and growth. Specifically, some evidence suggests that biocrusts may promote native plant establishment while inhibiting exotic plant establishment. Disturbance may profoundly disrupt biocrust-plant interactions through alteration of the cover, composition, and functioning of biocrust communities, creating possible pathways for exotic plant establishment. Recently, new methods have emerged to restore biocrust communities following disturbance, yet it is unknown how biocrust restoration may influence biocrust-plant interactions. We evaluated the role of biocrust community composition and microtopography in regulating dryland native plant establishment and site-specific exotic plant invasibility. To achieve this, we conducted a full factorial greenhouse experiment to measure germination and establishment of native (*Aristida purpurea*, *Bouteloua eriopoda*) and exotic (*Eragrostis lehmanniana*) grass species on cyanobacteria or lichen-dominated biocrusts on contrasting soil textures (sandy, silty) in response to biocrust disturbance and early inoculum treatments compared to untreated controls. We also quantified how seed position on surface microtopography affected seed germination and establishment success. Responses differed among the three grass species, and findings suggest biocrust type, soil type, and disturbance may play important roles in regulating early stages of the plant life cycle. Findings from this study increase understanding of the role biocrusts in structuring xeric vascular plant communities, and the potential of biocrust restoration to be used as a tool to defend dryland ecosystems against exotic plant invasion.

Parking lots, pavements, and pollution - a review of biocrusts' life in the city

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Abstract: Urbanisation brings habitat loss, fragmentation, changes in hydrology and nutrient flow, increases in gaseous and soil pollution as well as changes in microclimate such as urban heat islands. The elements of biocrusts - moss, lichen, cyanobacteria, and fungi - are not immune

from these processes, yet have been little studied in towns and cities. The habitat template theory predicts that biocrust species of rocky outcrops, mountains, and cliffs might be found in the urban landscape. Other ecological theory would predict domination by species preadapted to increased disturbance (by trampling, for example) or to high levels of particulates (such as emitted from vehicles). Cities worldwide support a range of biocrusts on roofs, walls, pavements, and church yards, as well as vegetated urban parks, gardens, and street edges. Few papers investigate urban biocrusts; however, some patterns emerge. Species richness varies widely from only 30 mosses and 6 liverworts in industrial and commercial streetscapes in an Australian city, to 143 species in Cologne, Germany. Cities can support rare and endangered species, and even ones thought to be extinct have been found. Characteristics of urban biocrusts include an ability to survive drought and pollution and preference for light conditions rather than shade. In some locations they prefer moderate moisture and moderate acidity of substrate and are more likely to be a colonist. They are small spore producers (<20 um in diameter) and show a tendency for vegetative over sexual reproduction. Biocrusts are being studied for applications on green roofs, as bioindicators, and to reduce microdust. The urban environment presents an exciting, accessible study location to study the ecology, biodiversity, and physiology of biocrusts. The few studies to date suggest numerous hypotheses that could be tested experimentally to determine their mechanisms of persistence, contributing to our understanding of and conservation of biocrusts.

Solar energy development impacts on land-cover change, biological soil crusts, and protected areas

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Abstract: Decisions determining the use of land for energy are of exigent concern as land scarcity, the need for ecosystem services, and demands for energy generation have concomitantly increased globally. Utility-scale solar energy (USSE; i.e., $\geq$1 megawatt (MW)) development requires large quantities of space and land; however, studies quantifying the effect of USSE on land cover change and protected areas are limited. We assessed siting impacts of >160 USSE installations by technology type (photovoltaic (PV) vs. concentrating solar power (CSP)), area (in square kilometers), and capacity (in MW) within the global solar hot spot of the state of California (United States). Additionally, we used the Carnegie Energy and Environmental Compatibility model, a multiple criteria model, to quantify each installation according to environmental and technical compatibility. Lastly, we evaluated installations according to their proximity to protected areas, including inventoried roadless areas, endangered and threatened species habitat, and federally protected areas. We found the plurality of USSE (6,995 MW) in

California is sited in shrublands and scrublands, areas supporting diverse biological soil crust communities, and comprising 375 km^2 of land cover change. Twenty-eight percent of USSE installations are located in croplands and pastures, comprising 155 km^2 of change. Less than 15% of USSE installations are sited in "Compatible" areas. The majority of "Incompatible" USSE power plants are sited far from existing transmission infrastructure, and all USSE installations average at most 7 and 5 km from protected areas, for PV and CSP, respectively. Where energy, food, and conservation goals intersect, environmental compatibility can be achieved when resource opportunities, constraints, and trade-offs are integrated into siting decisions.

Molecular identification of microorganisms in colonized Lut Desert rocks and relevance to the search for life on Mars

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Abstract: The Lut Desert, located in central Iran, is one of the world's largest and hottest deserts. From 2003 to 2010, NASA's Aqua satellite recorded some of the hottest land surface temperatures on Earth in the Lut Desert. Surface landscapes in the Lut Desert are covered by rocks, sand, and salt with little to no evidence of visible life. The Lut Desert is also of interest as an analog to Mars. The only source of water in the Lut Desert is limited springtime rainfall. Due to the lack of bioavailable carbon sources, the soil harbors only low levels of microbial life. In the most arid regions of the desert, primary production by photosynthetic organisms is restricted to cyanobacteria found below translucent rocks. The saline and basic soil inhibits the growth of eukaryotic algae. So far, no reports on the biodiversity of Lut Desert microorganisms are available. Here, we report on the presence of hypolithic cyanobacteria along a transect of four sites within the core of the Lut Desert. At each site, the percentage of colonized rocks was determined. Analysis of the microorganisms collected at each site will allow identification of microbial biodiversity. Together, these results advance our understanding of the limits of life on Earth and inform the search for life on Mars.

Biological nitrogen fixation and N flows in an arid grazed grassland ecosystem using a stable isotope approach

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Abstract: Dinitrogen fixation (N-fixation) by biocrust covers consisting of cyanobacterial associations (including cyanolichens) is thought to provide the vast majority of nitrogen (N) flow into arid land ecosystems. But quantitative information concerning the extent of N flow, like plant uptake versus competition from other N cycling processes like microbial assimilation or N transformations, is virtually unknown. Furthermore, estimates of actual quantities of N fixed are lacking as a consequence of the use of the acetylene reduction assay that can detect presence of nitrogenase activity in biocrust covers, but can both grossly underestimate or overestimate N-fixation with respect to actual quatities of N_2 fixed. In this investigation, we used a natural abundance ^{15}N approach to examine N-flows in the upper 10 cm of soil in an intensively grazed dryland ecosystem in northern Mexico. Our results indicated roots of the predominantly C4 grass species growing in these lands absorb nearly 40% of their N from very recently fixed dinitrogen from biocrusts before amino acids or ammonium released through exudation or cell lysis undergoes decomposition or transformation via nitrification and/or subsequently denitrification. These observations challenge the long held belief that the primary way plant roots can effectively compete with microbes for N is by nitrogen retention over time. The C4 grass species we examined seemed to accomplish this feat by proliferating over 70% of roots in the upper 5 cm soil, with a range of from 68.5% to 79.8% for the four C4 species we examined, and in some cases directly into biocrust lichen thalli. Our results suggest that these grasses may indeed be more directly competitive with microbial communities than previously thought.

Environmental constraints of biocrustal application

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Abstract: On Earth, nearly 40% of the area is occupied by dryland ecosystems, in which vascular plants are sparse and it is typical for biocrusts make up a large proportion of the landscape. However, over the past few decades, planting techniques are considered to be the most promising technology in desertification control. Only in recent years, the unsuccessful planting of vegetation in restoring ecosystems has been recognized, and using biocrusts as an underexploited opportunity is being considered. In biocrustal technology, efficiency and quality of cyanobacterial cultivation is crucial, so the basics of environmental biology is greatly important. Cyanobacteria are the pioneers of the crustal formation, and only after cyanobacteria stabilize the shifting sand surface and improve conditions, lichens and mosses may colonize onto the cyanobacterial crust. Thus, inoculation of cyanobacteria is now the only feasible approach for reclaiming desert soils. By 2015, we had demonstrated biocrustal technology is really promising

at nearly 50 km2 scale, and determined the range of this technology is about 0.08 mm-0.1 mm daily maximum non-rainfall water (local non-rainfall water most abundant month). In order to further understand and promote biocrustal formation, we comparatively studied different stage biocrusts, from the micro-niches of main cryptogams within the millimeter crust, species composition, community structure, capacity of stabilization sand surface, and physiological adaption mechanism to desert environment. We then explored crustal succession patterns and preliminary threshold conditions, and developed the methods to determine the biomass of photoautotrophic organisms and diagnosis level of biocrusts development. Furthermore, deserts contain a considerable amount of organic C, and biocrusts themselves not only store amount of carbon, but crustal technology also enlarges organic carbon storage by facilitating whole ecosystem restoration. Thus, biocrustal technology is also an important approach to carbon emission reduction. Of course, the carbon amount of biocrusts is dynamic with the climate and environment; we predicted the consequence of climate change on crustal community by the model between light intensity, water, and temperature.

Mutually antagonistic effects between drought and sand burial enables crust moss *Bryum argenteum* to survive the two co-occurring stressors in a temperate desert in China

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Abstract: Due to the soil surface niche, small stature and poikilohydric in nature, crust moss is highly susceptible to drought and sand burial, which are two ubiquitous stressors in spring and autumn in most Chinese deserts. However, little information is available regarding how crust moss responds to the combined effects of the two stressors. A common garden experiment was conducted to evaluate the combined effects of drought (by spraying 4 and 6 mm (equivalent to the average rainfall, control), 2 and 3 mm (double drought), 1 and 1.5 mm (fourfold drought) distilled water at 8-day intervals in spring and autumn, respectively) and sand burial (sand depth of 0, 0.5, 1, 2, 4 and 10 mm) on shoot upgrowth, chlorophyll content, and PSII photochemical efficiency of a predominant crust moss, *Bryum argenteum* Hedw., in the Tennger Desert, China. The results showed that drought stress alone displayed uniform negative effects on the three parameters, while sand burial alone exhibited positive influences on shoot upgrowth and opposing effects on chlorophyll content and PSII photochemical efficiency depending on the depth of burial, wherein positive when the depth was shallow (0.5 and 1 mm) and negative when deep (2, 4, and 10 mm). However, the joint effects of drought and sand burial did not absolutely exacerbate their single negative effects on the three parameters of *B. argenteum*. Drought significantly ameliorated the negative effects of deep sand burial on the retention of chlorophyll content and PSII photochemical efficiency. Meanwhile, sand burial largely alleviated the negative effects of drought on shoot upgrowth of the crust moss. Therefore, the mutual protection provided by one stressor against the other between drought and sand burial may act as a critical mechanism that crust moss survive and recover from their combination in sandy desert ecosystems.

An image processing method developed for monitoring the cyanobacteria *Microcoleus* covered area

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Abstract: The monitoring of *Microcoleus* varieties on the soil surface is an important parameter for controlling its succession as well as its subsequent function. A simple, routine monitoring is useful for interpreting the culture surface in laboratory studies. However, monitoring becomes difficult as the culture surface has an irregular shape and cannot be estimated. In order to solve this issue, a nondestructive image processing method has been developed by our group for surface area analysis and determination of the covered area indicating cyanobacteria *Microcoleus* growth rate when inoculated on the desert soil and on the surface of solidified Bold's Basal Medium (BBM) agar. Digital photographs of the colored culture surface patterns were analyzed by Photoshop software in order to determine the covered area. A pixel based equation was obtained and used for growth rate determinations. The digital images were obtained from the surfaces during various cultivation conditions along with periods of incubation. Good agreement was achieved between the results obtained by the proposed method and the conventional pigments analysis. The detection limit of the proposed analytical method was found to be 0.35 µg/ml for chlorophyll extracted from the soil surface. As well, the relative standard deviation for determining 0.35 mg/ml of the chlorophyll was found to be 2.1%. The procedure was found to be simple, rapid, and reliable. This method was successfully applied for determining the *Microcoleus* culture covered area on the desert soil surface. A good agreement was achieved between the results obtained by the proposed method and the dry cell mass method. The results of this study can be used for easy, precise, and accurate measurement of *Microcoleus* succession on the soil surface, thereby eliminating the need for a separation step and the physical sampling during cultivation. In addition, it supports a better interpretation of the solid state culture of the soil bed.

Tardigrades display preferential grazing of soil algae

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Abstract: Tardigrades are microscopic soil invertebrates, distributed globally across terrestrial and aquatic environments. We focused on *Macrobiotus*, a tardigrade known to inhabit microbiotic soil crusts of desert ecosystems. Previous studies establish tardigrades as grazers of cyanobacteria and eukaryotic algae; however, they have not yet shown whether tardigrades exhibit preference between algal taxa found in soil crust communities. We hypothesize that *Macrobiotu*s feeds preferentially amongst the algal taxa. Tardigrades were extracted from soil

collected at the Sweeney Granite Mountains Desert Research Center in California. We created laboratory microcosms where tardigrades were presented with three cyanobacteria and three eukaryotic green algae species in pairs so that each combination of taxa was accounted for. Pairs were repeated in triplicate. Preference was scored based on proximity of individual tardigrades to algal patches after 48 hours and analyzed using the Bradley-Terry model. Our poster will display the results of the experiment.

Seasonal distribution of soil fungal and bacterial communities in seven microhabitats of an arid grassland

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Abstract: Arid and semiarid ecosystems are typified by sporadic rainfall and extremes in temperature that vary strongly across daily and seasonal timelines. We hypothesized that the composition of natural fungal and bacterial communities inhabiting surface soils in a cold arid grassland (Utah, USA) would respond significantly to these large temporal variations in seasonal environmental conditions. We also sought to determine how soil communities vary across spatial gradients at the microhabitat scale, and how these patterns are affected by the distribution of a native rhizomotous grass (*Pleuraphis jamesii*), an invading annual grass (*Bromus tectorum*), and biocrusts, which are patchy in this grassland. We sampled soil from the root zones of the two vascular plant species (~5 cm depth), from cyanobacterial- and lichen-dominated biocrusts (<1 cm depth), 5 cm beneath those biocrusts, and beneath moss-dominated biocrust (~ 1 cm depth) every month for a year. Samples were analyzed using high-depth ribosomal RNA gene (rDNA) sequencing of the fungal community (LSU gene) and the bacterial community (16S rRNA gene) with a multiplexed MiSeq platform (3 field reps/microsite X 10 time points). Despite the large temperature and moisture shifts across seasons, we did not see significant shifts in microbial compositional patterns within the fungal or bacterial communities. Instead, the community composition differed by microhabitat and these differences were stable across season. Within plant roots, the bacterial community also differed significantly and consistently between the native *Pleuraphis* and the invading *Bromus*. In contrast, the two grass species always harbored very similar fungal communities. Both fungal and bacterial communities differed in composition between plant root zones and biocrusts or below-biocrust samples. Microhabitat was an especially strong factor for the bacterial communities, which showed compositional differences that transitioned from cyanobacterial, to lichen, to moss biocrusts. Associations of these patterns with relative abundance of individual taxa, local soil geochemistry, and with prior studies on the impacts of *Bromus* invasion on natural grassland carbon cycling are in progress. Taken together, these results suggest strong microbial community assemblage around dryland biocrust and vascular plant communities, with intra-annual variability in climate playing a relatively minor role.

Modeling and simulation of the *Microcoleus* biofilm growth on dryland soil surface

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Abstract: The present study represents a mathematical model developed for predicting *Microcoleus* growth on the desert soil surface with various initial CO_2 concentrations. The model is applicable in development of biocrust related technologies with regard to soil restoration and environmental disaster prevention. A mass balance based model was developed for analyzing CO_2 penetration and formulation of the *Microcoleus* biofilm growth on the soil surface. The ordinary and the partial differential model equations were solved using 4th Runge-Kutta method run in the MATLAB software. The model outputs were compared with the experimentally obtained results from the inoculated *Microcoleus* spp. on the desert soil surface in Petri dishes. Thereafter, simulation analysis was performed applying effective parameters of the biofilm including thickness, initial CO_2 concentration, and biomass in the two steady and unsteady states. The simulation results reveals that the initial inoculum concentration and gas supply are important parameters in biocrust succession. The present model has the potential to provide investigators with a deeper insight regarding biofilm development of a taxon as it can predict the CO_2 supply and biofilm thickness. This model indicates the significance of the initially available CO_2 concentration for the cultured *Microcoleus* species as it affects the biofilm characteristics. Also, controlling the CO_2 levels is likely to be an effective method for exploiting and accelerating soil biocrust restoration processes. Refining and application of the model for the soil biofilm succession and biocrust restoration process would provide us with an optimized mean of biocrust restoration activities and a success in challenging with the land degradation, regeneration of a favorable ecosystem state transitions, and reduction in the dust emissions related problems in the arid and semi-arid areas of the world.

A trait-based approach to understanding the microbial moisture niche

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Abstract: Microbial communities comprise thousands of interacting species that carry out essential ecosystem processes. Insight into the assembly and maintenance of these complex communities may be gained by studying the functional traits of microorganisms. Functional traits are physiological, morphological, or behavioral characteristics that affect the performance or fitness of organisms under a set of environmental conditions. In this presentation, we focus on traits related to water availability because it is a master variable that affects microbial interactions and ecosystem functioning. Using a phylogenetically diverse collection of bacteria and fungi, we constructed physiological response curves to quantify the moisture niche of soil

microorganisms. We found that niche properties and functional traits related to desiccation were conserved at a coarse taxonomic scale. One of the traits that that has important consequences for microbial performance in dry soils is biofilm production. Using genetic knockouts in *Pseudomonas*, we demonstrated that biofilm production influences the desiccation phenotype by increasing survivorship, shifting the niche space, and reducing the minimum water potential needed to sustain a net-positive growth rate. Another microbial trait that is important in dry soils is dormancy, i.e., the ability of an organism to enter a reversible state of reduced metabolic activity. Our findings suggest that dormancy is prevalent in soils, which leads to a large "seed bank". Using stable isotope probing (SIP) techniques, we demonstrate that dormant bacteria rapidly resuscitate following rewetting, which leads to large pulses of ecosystem activity. In sum, trait-based approaches provide an opportunity to understand how microorganisms contend with environmental stress, but also how they affect ecosystem functioning. This framework may be useful for understanding the structure and function of biocrusts in dryland ecosystems.

Ecological restoration of alpine environments with biocrust inoculant

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Abstract: The harsh environmental conditions found in most alpine environments, including nutrient poor soils and short-cool growing seasons, can result in slow recovery rates after disturbance and present unique restoration challenges. The ability of biocrusts to stabilize soils and facilitate nutrient cycling are important to alpine soil pedogenesis. Establishment of biocrusts following disturbance events is, therefore, an important first step in restoring ecosystem function. At two alpine sites in northern Canada, in a full-factorial experiment, we evaluated the effects of inoculation and fertilization of disturbed soil surfaces with a local biocrust inoculant. Biocrust establishment and function were measured in treatment plots, and microclimatic conditions and function of mature biocrusts were also monitored throughout the growing season. Twelve weeks after inoculation, biocrust cover of inoculated plots was 33% at the mesic site and 21% at the xeric site and nitrogenase activity of inoculated plots corresponded to 68% and 11% of that of mature biocrusts for the mesic and xeric sites, respectively. We found extracellular polysaccharide content to be higher in the inoculant than in the treatment plots. Extracellular polysaccharide content was highest in the biocrust inoculant (78 µg glucose/g biocrust), and inoculated surfaces had an average of 14 µg glucose/ g of biocrust. Over time, fertilization alone resulted in a decline in EPS compared to control soils and had no effect when combined with inoculation; therefore, inoculation alone appears to be most effective at promoting EPS production. Our study demonstrates that inoculation may accelerate the establishment and recovery of alpine biocrust communities and associated ecosystem functions. Although further work is needed to develop effective harvesting, propagation, and application techniques, biocrusts may play a key role in successful ecological restoration of alpine environments.

Effects of snowfall on carbon exchange of biocrusts and the physiological and biochemical characteristics of their micro-organisms from desert biocrusts

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Abstract: Biocrusts grow on the soil surface in desert regions and withstand extreme temperature, drought, and radiation. Snowfall in winter is likely to be one of their important water resources in some desert area. However, few studies have explored the effects of snowfall on biocrusts until now. In this study, measurements of photosynthesis and respiration were continuously measured following the snowfall in southeast fringe of the Tengger Desert to clarify the effects of snowfall on carbon fixation. Five snowfall treatments were applied: snow removal (0S), snow decrease to half that of ambient conditions (1/2S), ambient snow (S), snow increase to 1.5 times that of ambient conditions (3/2S), and snow increase to twice that of ambient conditions (2S) to evaluate the snow cover effects in southern Gurbantunggut Desert. Also, a series of important physiological index were measured, including photosynthetic pigment content, proline content, water-soluble sugar content, water-soluble protein content, and malondialdehyde (MDA) content, to evaluate the effects of snowfall on physiological and biochemical characteristics of mico-organisms in biocrusts. The results indicate that photosynthesis and respiration of the biocrusts is ignorable in winter with very low temperatures in north China.

Diversity and ecology of cyanobacteria of biological soil crusts in Brazilian savannah

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Abstract: Biological soil crusts (biocrusts) are microbial assemblages highly dependent on the primary production of cyanobacteria, and some eukaryotic algae, at least during the first steps of their development. The last decade has seen an extraordinary effort to define and to identify the main cyanobacterial players in biocrusts. Most studies on biocrusts have taken place in North America, China, Australia, Europe, and the Middle East. However, little is known about cyanobacterial-dominated biocrusts in South America. To partially fill this gap of knowledge, we have investigated biocrusts from six national parks in the subtropical savannah in Brazil. A set of 36 cyanobacterial 16S rRNA gene libraries were constructed with sequences retrieved from six biocrust samples collected along two 200 m transects in each location. Total DNA of each sample was extracted, and partial 16S rRNA gene amplified and sequenced by using a MiSeq

(Illumina) sequencer. We identified 21 genera, with Leptolyngbya and Porphyrosiphon being the most abundant; no clades of Microcoleus, the most common "form-genus" in biocrusts of North America and Eurasia, were dominant in any sample. The cyanobacterial community in these locations seems, therefore, to be compositionally unique. A redundancy analysis was carried out as an ordination method to compare the community composition of our six locations and to look for spatial patterns driven by environmental variables. Forward selection of environmental variables showed that high annual temperature, precipitation, and air humidity explained 30% of the variation in the community composition among locations. We were able to clearly distinguish between OTUs phylogenetically related to Microcoleus and Leptolyngbya, associated with high values of mean annual precipitation, from those phylogenetically related with Porphyrosiphon, associated with high values of mean annual temperatures. Our results highlight the importance of this kind of work in poorly studied areas to deepen the study of the biogeography of biocrusts.

Biocrusts as modulators of ecosystem responses to climate change in drylands

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Abstract: Understanding how biotic communities affect biogeochemical responses to altered climatic conditions is crucial to improve our ability to forecast the ecological consequences of climate change. However, few studies so far have targeted biocrusts when studying this important topic. Given the key role of biocrusts in supporting both soil microbes and multiple ecosystem processes (e.g., soil respiration, atmospheric N_2 fixation, nitrogen mineralization), and their prevalence in dryland ecosystems worldwide, the potential for biotic feedbacks to climate change mediated by biocrusts is large. In this talk, I will synthesize recent and ongoing observational and experimental studies aiming to evaluate how biocrusts affect ecosystem responses to climate change. I will specifically discuss the potential role of attributes of biocrust communities (such as species richness) as modulators of these responses, and will highlight the potential of using biocrusts to gain a better understanding of the impacts of climate change on dryland ecosystems. Finally, I will identify the main gaps in our understanding of this important topic and the main research activities needed to fulfill them, including the need to establishing coordinated experiments and surveys across multiple continents.

Can biological soil crusts be used as indicators of ecosystem disturbance in Sahelian zone?

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Abstract: In the Sahelian zone in Africa, water shortage combined with low vegetation cover leads to modifications in soil physical properties and the occurrence of physical soil crusts, which is favourable to land degradation by water and wind erosion. In contrast, the presence of biological soil crusts (BSC), resulting from the colonisation of soil surface by mainly cyanobacteria, acts to increase soil stability and nutrient content, and thus prevents water and wind erosion and enhances soil productivity. However, the development of BSC and their ecological functions are affected by soil surface disturbance. In such conditions, mapping BSC patterns can provide useful information in assessing soil degradation due to future changes in land uses and climate. In this study, we characterized BSC and evaluated their ecological roles at local and regional scales through a comprehensive study including field work and laboratory analysis of samples collected along a consistent north-south pluviometric gradient and under varied land uses (crops, fallows, and grazing). Predictive models of the spatial distribution of BSCs at watershed (1/10.000), regional (1/100.000), and Sahelian (1/500.000) scales were developed using field data and high and medium resolution images. Values of C exchange rates and potential runoff and erosion values on different map units were used to establish carbon budget related to BSC and evaluate soil loss and vulnerability due to erosion and runoff.

Up against the wall of lichen biodiversity in soil crusts: the case of *Aspicilia* in the Columbia Basin

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Abstract: Biodiversity signal of lichens in biotic crust communities increases with taxonomic resolution from morphological groups, to traditional species concepts, to phylogenetic species concepts. Analysis of DNA sequences from lichens in soil crusts reveals previously unrecognized species. Many of these species might be separable by very subtle morphological differences, but these will be difficult to apply with traditional microscopic and chemical techniques. We illustrate this problem with the widespread genus *Aspicilia* in western North America. We show that unrecognized distinct lineages are frequently geographically separated and carry ecological information about soil characteristics and climate. If we assume that the number of previously unrecognized species in this genus is typical of biocrust lichens, then we would expect an approximate doubling of the regional number of species in the soil crust. Extrapolating from the most recent published lichen biodiversity estimate for soil crusts in the Columbia Basin, we would anticipate a true species count closer to 288 than the current estimate of 144. Incorporating these additional species into ecological studies of biocrusts can potentially increase the sensitivity of our results. Because traditional species concepts are notoriously difficult to apply and subject to investigator error, DNA sequencing of environmental samples may also provide more objectivity and repeatability for ecological studies of crust communities. But first we need to build a sequence library to link sequences with morphologies and traditional species, then use nextgen sequencing of composited superficial soil crust samples to generate community data sets. Such data can then be aggregated by functional attributes or by traditional species concepts to generate data matrices of sites × functions, sites × traditional species, or sites

× phylogenetic species. We suggest that this approach will provide a stable, repeatable basis for long-term monitoring and will improve studies of ecological factors affecting biocrust communities.

Influence of biocrusts on grass germination and establishment in two North American deserts

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Abstract: Biological soil crusts (biocrusts) can have a positive, negative, or neutral effect on the germination of vascular plants. We are conducting field and semi-controlled environment experiments to determine the extent to which grass seed morphology (e.g., size, shape, mass, and appendages) interacts with biocrust characteristics (e.g., species composition, microtopography, and disturbance) to differentially affect the germination and establishment of native and non-native grasses. Our experiments are being conducted on the Colorado Plateau, where biocrusts are pinnacled, and in the Sonoran Desert, where biocrusts are comparatively smoother. Standardizing for seed viability, preliminary analysis of germination/emergence of warm-season grasses in the Sonoran Desert shows mean (± SE) emergence is higher when seeds are placed in fissures of biocrusts or soil stabilizing polyacrylamide gel (PAM) crusts (17% ± 2) compared to seeds placed on the surface (6% ± 1). Fissure-placement effects may be biotic, abiotic, or a combination. Emergence was significantly higher for broken PAM crusts and biocrusts (9% ± 1) compared to intact crusts (4% ± 1). Cool-season grasses in the Sonoran Desert show similar trends. Preliminary analysis of autumn establishment on the Colorado Plateau shows cheatgrass was more likely to establish (mean ± SE) on bare soil and PAM crusts (18% ± 2) when compared to cyanobacteria or lichen biocrusts (10% ± 1). Cheatgrass was also more likely to establish in disturbed PAM crusts and biocrusts (18% ± 2) compared to intact crusts (7% ± 1). Experiments are being conducted with seed awns intact and removed to determine the effect of appendages. Removal of the awn from cheatgrass seed did not have a significant effect on autumnal establishment rates (11% ± 1 for intact seed vs. 15% ± 2 for seed with awn removed). Over the next year, we will be investigating grass establishment on biocrusts restored following non-native plant removal.

Interactions among *Bouteloua* grasses, soil type, moisture, and crust cyanobacteria in the Chihuahuan Desert grassland

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Abstract: Biological soil crusts (BSCs) are microbiotic communities of lichens, mosses, and cyanobacteria that create a living crust in the interstices amid vascular plants in xeric ecosystems. They are known to affect numerous soil properties and interact with local vascular plants in ways that affect nutrient exchange, water availability, and interspecific competition. However, the pathways of these plant-BSC microbe interactions are largely unexplored. In order to investigate associations between plant species identity, cyanobacteria density in circumambient BSC, and local soil type, we gathered crust material and soil near focal plants of two grass species (*Bouteloua eriopoda* [BOER] and *B. gracilis* [BOGR]). We assessed crust chlorophyll content via spectrophotometry, both in dry conditions and after rain, as a proxy for cyanobacteria density. We also quantified abiotic soil properties, including temperature, texture, and chemical composition. We found that crust cyanobacteria were distributed randomly with respect to plant species and soil type. Contrary to expectations, chlorophyll concentrations decreased following the first rain event of the monsoon season. BOER and BOGR inhabited distinctly different soil type patches. The findings of the study inform implications of continued climate change for *Bouteloua* spp. in Chihuahuan Desert grassland.

Differences in bacterial diversity of dark biocrusts across a gradient of disturbance by livestock grazing in semiarid grasslands of Mexico

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Abstract: Biocrusts are an integral part of arid ecosystems worldwide. In Mexico, dark-biocrust layers cover the vegetation-free interspaces of grasslands. While severe livestock trampling increases potential biocrust habitat, little is known how severe disturbance may affect the composition of dark-biocrust communities. In this study, we addressed the following questions: i) are cyanobacteria the dominant group that constitute dark-biocrusts or do other bacterial taxa contribute to community richness and diversity?, and ii) does dark-biocrust community composition change along a disturbance gradient caused by trampling of livestock? We employed metagenomics 16S rRNA gene sequencing to characterize the bacterial composition of dark-biocrusts in three grassland sites with contrasting degree of disturbance: i) no impact (NI), ii) medium impact (MI), and high impact (HI). We collected at each site three composite dark-biocrust samples in an area of 0.25 m^2. Metagenomic sequencing revealed that phylum richness decreased with increasing disturbance (NI=26; MI=25 and HI=23). Proteobacteria, Actinobacteria, and Cyanobacteria were the most abundant groups in all sites, in addition to Planctomycetes in site HI. Similarly, at the level of order, bacterial richness was high, and it also decreased with increasing disturbance intensity (NI=110; MI=97 and HI=91). The most common orders were Actinomycetales, Rhodospirillales, Acidobacteriales, Bacillales, and Gemmatales in all three sites. While Cyanobacteria were present with different genera and species in all sites,

they were by far not the most common group. Our samples included some novel species that have not been reported previously in North America's drylands. Considering dark-biocrusts have evolved under long-lasting grazing pressure, bacterial richness of these communities is overall unexpectedly high. However, more integral studies (metagenomics of 18S and 16S ribosomal regions) are required to fully characterize the richness, diversity and ultimately functioning of these complex microbial communities forming the dark-biocrusts in Mexico's grasslands.

Effect of inoculated cyanobacteria on the structure and development of induced biological soil crust

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Abstract: Cyanobacteria are feasible eco-friendly candidates to trigger soil improvement and enrichment. According to several studies, cyanobacteria could be employed as inoculants in different contexts, from agricultural to arid and hyper-arid systems. Successful soil inoculation with cyanobacteria leads to the development of cyanobacterial crusts, which are recognized as the first level of development of biological soil crusts, the latter being a key natural and ecologically fundamental component in many stressed ecosystems on Earth. Much of the success as inoculants is owed to the productivity and the characteristics of extracellular polysaccharides (EPSs) which are complex heteropolymers, which contribute to soil conglomeration and biolayer stability. In order to investigate the role of EPSs in cyanobacterial crust development during the first stages of the process, we employed different strains isolated from natural desert biological soil crusts and inoculated them, alone or combined, on fine sand in a microcosm (indoor) experiment. Besides monitoring the growth parameters and the development of the crusts, we evaluated EPS productivity during development and we investigated their composition and molecular weight distribution using ion-exchange chromatography and size-exclusion chromatography. Both loosely-bound (less condensed) and tightly-bound EPS fractions were considered in the investigation. In addition, some soil chemo-physical and hydrology-related soil parameters potentially affected by EPS excretion were monitored, at regular intervals, during crust development. The results obtained showed how the use of the selected strains led to the development of stable cyanobacterial crusts in very short times. This study prominently points out at the paramount role of EPSs in determining the observed variations in some of the parameters observed during the experiment duration.

Distribution of biological soil crusts and dominant functional groups in a system of paleodunes in the province of San Juan, Argentina

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Abstract: The Médanos Grandes, a relic of the paleoclimates, constitute a currently stable system formed by fixed dunes. The current climates and the vegetation seem to be determinant in the maintenance of its stability. In these systems, where the stability is a key element and there is absence of anthropic pressions, other factors could model the distribution of the biological soil crusts. The purpose of this work was to examine how the microenvironment provided by nebkas influences the distribution of the biological soil crusts at the site and microsite level. At the site level, we examined the spatial distribution of the dominant functional groups in the biological crusts by employing a spatial analysis through the analysis of the distance indexes. In order to determine the microsite effect, we measured the coverage of the component functional groups (mosses, crust lichens, and cyanobacteria) under the canopy of the dominant shrubs, *Tricomaria usillo* and *Atriplex lampa*, by means of a block design. Soil stability was quantified with the Herrick method. The presence of nebkas influences in a determinant way in the establishment of biological crusts, only located under the canopy of the dominant shrubs. Biological crusts showed a strong association with *Atriplex lampa,* but not with *Tricomaria usillo*. Significant differences were found in the distribution of the crusts dominated by mosses in the different expositions and they were predominant in the south exposition. The soil stability was null in the interpatches, it was bigger under the nebkas, and it was different between dominant groups. The microenvironment provided by the vegetation seems to impact the distribution of the biological crusts at two, well defined scales - at the local scale it could be through the soil stabilization and at microsite scale it could be by modifying the microclimate conditions under the nebka.

Creating the seeds of restoration: two approaches to producing compositionally explicit, location-specific biological soil crusts inoculum

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Abstract: Biological soil crusts (biocrusts) play important roles in improving soil fertility and promoting erosion resistance of arid lands. A variety of human disturbances, such as vehicle and foot traffic, can quickly damage these communities; natural recovery can take ~14-25 years. Attempting to increase natural recovery rates, we developed a “biocrust nursery” to supply inoculum for restoration. Two tactics were pursued: a whole community and a mixed isolates approach. We tested our approaches on biocrusts from sandy and silty soil in both cold and hot deserts of the southwestern US. Biocrust microbial community composition was determined for

each with high throughput sequencing of the 16S rRNA gene. The whole community approach used biocrust samples from the field to inoculate greenhouse-based scaling-up on virgin soil, according to parameters established by a full factorial experiment involving nutrients, light, and watering regimes. In addition, we monitored the microbial community composition for deviations from the initial field community. In the mixed isolates approach, we used the previously established community structure to target the isolation of major biocrust cyanobacteria such as *M. vaginatus*, *M. steenstrupii*, *Nostoc* sp., *Tolypothrix* sp., and *Scytonema* sp. at each location. Cyanobacteria were scaled up separately in a lab-based setting, then mixed into an inoculum that matched the relative abundances seen in the field. Both approaches yielded high quality, pedigreed inoculum in sufficient quantities to carry out large-scale field trials, which are currently ongoing. Whether either of the approaches result in significant increases of field adaptation and survival rates is not yet known. The inocula include local pioneers and all major cyanobacterial players essential for healthy biocrusts, and they are acclimated and adapted to their specific locations. We believe that ultimately, this nursery approach can be used to produce successful location-based inoculum.

Linking microbial community structure, activity and carbon cycling in biological soil crust

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Abstract: Biological soil crusts (BSCs) are communities of organisms inhabiting the upper layer of soil in arid environments. BSCs persist in a desiccated dormant state for extended periods of time and experience pulsed periods of activity facilitated by infrequent rainfall. *Microcoleus vaginatus*, a non-diazotrophic filamentous cyanobacterium, is the key primary producer in BSCs in the Colorado Plateau and is an early pioneer in colonizing arid environments. Over decades, BSCs proceed through developmental stages with increasing complexity of constituent microorganisms and macroscopic properties. Metabolic interactions among BSC microorganisms are thought to play a key role in determining the community dynamics and cycling of carbon and nitrogen. However, these metabolic interactions have not been studied systematically. We have recently completed studies investigating exometabolite niche partitioning in biocrust isolates. Notably, we have found limited overlap in the heterotroph depletion of exogenous metabolites, suggesting that biocrust bacteria minimize direct competition by using different fractions of the soil organic matter. We have now extended this study to additional isolates from two environments and found that there are strong correlations between these metabolic activities and the organism's phylogeny. With these initial insights into the coupling between biocrust bacterial metabolism and phylogeny, we are now examining succession occurring both over the course of a single wetting event (hours) and over many years as crusts mature from 'light biocrusts' to mature 'dark biocrusts' and will discuss initial findings using systems biology approaches to link measured changes in soil metabolites to the activities of specific taxa.

What distinguishes those that can from those that can't: the desiccation tolerance of biological sand crust-inhabiting cyanobacteria

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Abstract: Sands in hot and cold deserts are often covered by biological soil crusts (BSC). The BSCs stabilizes the sand, its destruction by anthropogenic and global change is a major cause of desertification. The BSCs are formed by the adhesion of the soil particles to extracellular polysaccharides excreted mainly by filamentous cyanobacteria, the pioneers and main primary producers in the BSC. The organisms inhabiting the BSCs are exposed to one of the most extreme and fluctuating environmental regimes in nature including frequent hydration/desiccation cycles, extreme irradiance, temperature amplitudes ranging from subfreezing during winter nights to over 60°C in midsummer days, and vast osmotic potential changes. To study the abilities of filamentous cyanobacteria to cope with this environment, we isolated an axenic culture of *Leptolyngbya* sp., that we named *Leptolyngbya ohadii* (in honor of Professor Itzhak Ohad), from BSC samples withdrawn from the Nizzana field station of the Hebrew University. To overcome the natural variability in ambient conditions, we constructed a fully automated environmental chamber capable of accurately simulating the dynamic abiotic conditions in the field. Our physiological experiments showed that the ability to revive after desiccation is strongly affected by the dehydration rate, light, and temperature conditions and also those during the desiccated phase. It clearly demonstrated that the organism must activate a defense mechanism which is modulated by various environmental cues during desiccation. Genomic information identified sets of genes present in cyanobacteria able to resurrect after desiccation, but not in sensitive strains. Transcriptome data, based on RNA Seq and RT-qPCR analyses, during desiccation under various simulated ambient conditions, is uncovering the genes involved and helps us to develop our current view, to be presented, on what distinguishes those that can (recover after desiccation) from those that can't and the mechanisms involved.

Remote sensing of sun induced fluorescence for biological soil crust monitoring

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Abstract: Biological soil crusts (BSCs) cover large parts of arid and semi-arid areas of the planet playing an important ecological role. This study examines the potential for solar induced fluorescence (SIF) to monitor the spatial distribution and the photosynthetic activity of BSCs. Different BSCs, i.e., cyanobacterial crusts, moss crusts, and lichen crusts, were sampled along a rainfall gradient of the Negev Desert where annual average precipitation ranges from 325 to 50 mm. BSC optical properties were measured by means of high resolution spectroradiometers under direct solar irradiance. SIF in the two emission peaks (at 685 nm and 740 nm) was estimated through the most innovative algorithms (i.e., spectral fitting method) which make use of the O_2-A and O_2-B absorption to decouple SIF from the upward radiance reflected from the surface. Different optical vegetation indices (NDVI – normalized difference vegetation index, MTCI – MERIS terrestrial chlorophyll index and PRI – photochemical reflectance index) were also calculated. The preliminary results of the study showed that, immediately after watering, the ratio between the red and far-red SIF peaks of BSCs becomes and stays well distinct from that of higher plants having a more complex tridimensional structure (e.g., shrubs and herbs). Such a distinctive SIF pattern is expected to open new opportunities to identify active BSCs from other vegetation types in a remote sensing framework. Experimental results that were obtained with the BSCs examined here will also be discussed in connection to the recent decision of the European Space Agency (ESA) (November 2015) to fund the new Earth-Explorer Satellite mission (EE8 - Fluorescence Explorer, FLEX) that will be specifically aimed at detecting and measuring SIF from space. Potential applications of FLEX data for ecology, climatology, and climate change science will be outlined.

Biological soil crusts microbiome diversity at Joshua Tree National Park, Granite Mountain, and Kelso Mountain

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Abstract: Biological soil crusts contain a wide variety of microbial communities that are essential to desert environment. Mosses, lichens, green algae, cyanobacteria, bacteria, and fungi can combine to form different types of biological soil crusts. Previous studies have mostly characterized biological soil crusts based on their morphology, which may underestimate the function and diversity of microbial communities that cannot be observed visually. As a result, this project aims to explore the composition of microbial communities and capture the biological soil crusts microbiome (BSCM). The functions and diversity of the microorganisms living in the crusts, especially fungi, in arid environments are still poorly understood. Understanding how microbes interact to form the biofilm that is the crust layers requires detailed accounting of the microbial community and their functions. Moreover, loss of biological soil crusts can contribute to increased soil erosion and reduced biodiversity in desert environments. This study will explore biological soil crusts microbiome, and test the hypothesis that crust microbial diversity is different between sites and by crust type, at both the morphological and molecular level. We

have used amplicon sequencing of environmental DNA to assess the composition of bacteria and fungal communities. Biological soil crusts were sampled from Joshua Tree National Park, Granite Mountain, and Kelso Mountain in California. Our preliminary sequencing and analysis of 16S from three sites shows that the bacterial contribution to BSCM is dominated by Cyanobacteria, Proteobacteria, and Actinobacteria phyla. Results from ITS fungal sequencing show significant variation between crust types and both known and unknown taxa. We have found that biological soil crusts microbiome varies by morphologically classified crust type and also between sampled sites. Lastly, the data from these BSCM will indicate the most abundant taxa in desert systems, which can be used to prioritize culturing efforts and begin to explore function diversity of the microbes.

Adaptation of microorganisms to harsh soil crust conditions: experimental and genomic approaches

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Abstract: Biological soil crusts (BSC) are formed by the adhesion of sand to extracellular polysaccharides secreted by filamentous cyanobacteria, the main primary producers in these habitats. The mechanisms involved in the ability of BSC inhabiting organisms to cope with extreme environmental conditions including extreme temperatures, excess light, and frequent hydration/dehydration cycles are largely unknown. To gain a better understanding of the relevant physiological and molecular mechanisms, we constructed an environmental chamber capable of accurately and reproducibly simulate the dynamic changes of the BSC conditions. It allows us to follow cyanobacterial physiological and molecular response to such environmental changes. The ability to revive after desiccation is strongly affected by the dehydration rate, radiation, and temperature conditions applied during desiccation and in the following dry state. Fast desiccation (<5 minutes) of isolated cyanobacteria led to a 60% lower fluorescence recovery rate compared with filaments exposed to natural dehydration. These results suggest that cyanobacteria activate protection mechanisms triggered by the rapidly changing environmental conditions, but which were not activated in 5 minute desiccation tests. Gene expression patterns during desiccation showed that the abundance of transcripts from most of the genes (73%) that were highly expressed in the dry state, started to increase long before actual water loss in response to elevating temperature and radiation. This indicates the importance of light and heat responsive genes during desiccation. Moreover, it is possible that the rising temperature and illumination serve as a warning signal of the forthcoming desiccation providing the cells with the time required to prepare themselves. Comparative genomics of the newly sequenced *Leptolyngbya ohadii* isolated from Nizzana BSC, reveals that many of the genes found only in desiccation tolerance cyanobacteria are highly expressed during desiccation.

Metabolic activity is strongly linked to environmental factors in biological soil crusts across Europe

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Abstract: The aim of this study, situated inside the big frame of the Soil Crust International Project (SCIN), is to obtain a deep understanding of physiological and environmental patterns controlling biological soil crust (BSC) distribution in Europe. BSC were studied at four sites across Europe (Almería, SE Spain; Hochtor, Austrian Alps; Homburg, Central Germany; and Öland, SE Sweden) following a latitudinal gradient. BSC samples were monitored over one year at each site for mesoclimate, microclimate, and metabolic activity using a long-term chlorophyll fluorescence system. Highly significant relationships were found between mean monthly activity and microclimate and, especially, mesoclimate in the four sites studied. The best correlation found was between mean monthly length of activity and mean air relative humidity, which apparently integrates amount of rainfall and length of drying period. The correlations were substantial enough that they can be used to model BSC activity using normal climate data, allowing inferences about the effects of climate change to be made, but also indicating that small changes in the environment will not produce massive alterations in activity. Mean monthly activity showed a saturation response to monthly rainfall at 40 mm, the same monthly rainfall known to produce maximal growth of lichens across Antarctica, suggesting that a general relationship might exist for all poikilohydric organisms.

Improving ecosystem function: facilitating restoration of degraded biocrusts using mixed culture inoculation

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Abstract: In arid and semiarid ecosystems, the biological soil crust (biocrust) community is ecologically critical. Key to the survival of biocrusts is the versatility and adaptability of cyanobacteria and green algae. Biocrusts are especially vulnerable to compressional forces, and are slow to recover without assistance. Given the importance of biocrusts to so many aspects of healthy ecosystem function, it would be advantageous if land managers prioritized restoring damaged biocrusts. Coastal sage scrub (CSS) is a unique and imperiled valuable habitat and is nearly unmatched in biodiversity. Recent work in biocrust restoration finds that assisted restoration speeds recovery of functionality in biocrusts. At present, studies of biocrust

restoration in CSS habitat do not exist. This study examines the feasibility of isolating and culturing a mix of endemic CSS cyanobacteria and green algae to inoculate native CSS soil, thereby facilitating recovery of disturbed biological soil crusts. It further looks at markers for culture growth, chlorophyll a, extractable polysaccharides, and stability to gauge whether inoculation and growth of the culture have increased soil function. Growth of mixed culture and increases in functionality are compared between autoclaved soil inoculations and native soil inoculations to determine the extent that native crust organisms can regrow without inoculation, and how the inoculum interacts with the native microbial community. A putative novel genus and species of cyanobacteria related to *Leptolyngbya* was isolated and tentatively included in the genus, *Trichotorquatus*. The mixed culture included a green algae, possibly a species of *Trebouxia*. Mixed inoculum added to native soil significantly increased chlorophyll a levels and soil stability, and increased extractable polysaccharides after just two months, demonstrating recovery of function. Autoclaving soil reduced increases in functionality indicating the importance of the intact soil community for growth. It may be possible in the future to restore CSS biocrust using mixed culture inoculation.

Effects of natural disturbances of biological soil crust on moisture retention in fog oasis of the Peruvian desert

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Abstract: Seasonal fog is the main source of moisture in the coastal desert oasis, called Lomas Formation; a unique ecosystem of the hyper arid band of the Peruvian coast. There extends a biological soil crust that interacts with the surrounding fauna and flora. To understand the role of the biocrust in retaining moisture in Lomas and the impact of natural disturbances made by fossorial birds, two sets of evaluations were generated in the National Reserve of Lomas de Lachay in Lima, Peru (S11°22′25″, W77°22′01″). Soil moisture in disturbances and in the adjacent un-disturbed biocrust was analyzed by the gravimetric method at two depths. Humidity of active and inactive disturbances, the adjacent biocrust, and bare soil in which the biocrust was withdrawn was compared 3 times for two months (15 samples each). Mounds of loose sand deposited on the biocrust is an active natural disturbance generated by birds excavating soil to build underground galleries, whereas inactive disturbances are those in which it has already formed a new layer of biocrust on the mound. It was found that disturbances had higher moisture retention ($F_{1,47}$=19,988, $P<0.05$) than biocrust, with no significant differences between depths (2 and 5 cm). Generating comparisons between the moisture contained in the first 5 cm soil, active disturbances contain more moisture than inactive ones. The bare soil, despite maintaining less moisture than active disturbances, had a tendency to overcome the moisture contained in inactive disturbances. The biocrust maintain lower moisture content in the soil acting as an impediment to infiltration. Disturbances that generate a mound of soil deposited on the biocrust would maintain moisture longer in this profile. These results suggest the importance of interactions between wildlife and biocrust, which appropriate spaces of greater moisture retention and could favor the establishment of Lomas' endemic flora.

Biocrust mapping methods and their potential applications in Earth sciences

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Abstract: In numerous studies, spectral absorption features related to the presence of photosynthetic and sunscreen pigments in biological soil crusts (biocrusts) were identified, and based on these studies, different classification techniques utilizing remote sensing data have been developed. These mapping methods open a wide range of opportunities to upscale and analyze existing information on well-known biocrust effects controlling drylands functioning on larger spatial scales. Here, we want to present two case studies where we combined local measurements with remote-sensing information and different biocrust mapping methods to quantify their influence at ecosystem scale. In the first study, we applied an existing classification index to identify areas dominated by biological soil and hypolithic crusts at two different sites in the Succulent Karoo, South Africa. Combining these with local biomass data, we demonstrate the relevance of the two biocrust types at the two different sites. In a next step, we used multi-temporal series of vegetation indices to analyze their annual pattern and differences in the physiological response of biocrust communities and vascular vegetation. In the second study, we estimated biocrust coverage within each pixel of a hyperspectral image from the Tabernas Badlands, located in the south-eastern part of Spain. We combined these data with runoff and erosion measurements conducted on small plots to then simulate the hydrological response of a small micro-catchment dominated by biocrusts and the negative effects of biocrust disturbance on the eco-hydrological functioning of the system. These two examples demonstrate the wide range of possibilities to combine plot data with remote sensing and biocrust mapping methods in order to upscale their effects on larger spatial scales. Once it is verified that the investigated parameters fit the intended spatial scale, there is a wide range of research questions that could be explored.

Lichen and bryophyte biotic soil crust recovery 12-16 years following wildfire in Idaho, USA

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Abstract: Long-term wildfire effects on biological soil crust (BSC) ecological functions in semi-arid sagebrush ecosystems likely depend on recovery of late-successional species, which often serve different ecological roles than early-successional species. Previous studies examining BSCs after wildfire have reported mixed results, suggesting that the effects of wildfire may depend on fire severity and pre-fire BSC community composition. We sampled lichen and bryophyte BSC cover, species richness, and community composition after four fires that were 12-16 years old, comparing burned areas with adjacent unburned areas. We collected a total of 65 species of lichens and 24 species of bryophytes in our study sites. Bryophytes were dominant at sites with silty soils, whereas lichens dominated coarser-textured, more alkaline soils. Even with more than a decade for recovery, fire had a consistently negative effect on BSC cover and species richness. Fire effects appeared to be modified by pre-existing conditions, with greater decreases in cover and richness from burning at sites with higher cover or richness in the adjacent unburned areas. Species associated with unburned sites included *Barbula convoluta*, *Syntrichia caninervis*, *Syntrichia subpapillosissima*, *Cladonia* sp., *Endocarpon loscosii*, *Physconia* sp., *Psora cerebriformis*, and *Psora tuckermanii*. Growth forms of lichens and bryophytes strongly associated with unburned plots included vagrant lichens, tall turf mosses, and squamulose lichens; these large growth forms are often associated with late-successional BSC communities. Fire severity, using both the relativized and non-relativized differenced normalized burn ratio (dNBR), was not related to post-fire cover or species richness, suggesting that remotely sensed fire severity is not a strong predictor of longer-term BSC community responses. Our results suggest that fire can have long-term effects on biological soil crust communities across a range of conditions and fire severities, but effects may differ among soil types and be greatest where BSC communities are well-developed.

Biological soil crust diversity and cheatgrass cover in six vegetation types of SW Idaho

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Abstract: Biological soil crust species (59) were recorded during surveys on the Orchard Combat Training Center in SW Idaho. Large macroplots were examined in each of 6 different vegetation type plots within a 34.7 m radius, approximately equal to one acre or 0.38 hectares. This is a modification of the national forest health monitoring protocols. Biocrusts were composed of 43 lichens, 14 bryophytes, and 1 cyanobacteria. Plot species and diversity differed significantly, ranging from only 2 to as many as 53 species of biocrusts in the individual 1 acre plot. The most striking result of this study was that areas with a high percent cover of biocrusts had little or no cheatgrass, even in a year with a wet spring (2014), which favored the abundant growth of cheatgrass throughout southwest Idaho. Additionally, a significant amount of the biodiversity in arid west plant communities is found in the biocrusts rather than in the vascular plant community. In spite of this, there is only minimal biological soil crust monitoring conducted on rangelands by most public land managing agencies. The use of large macroplots, such as those used in this study, captures more biodiversity in a rapid and efficient amount of time and can be correlated to a specific vegetation type, as compared to the use of many small

plots or sampling an entire area without defining a plot. However, sampling does need to be done by individuals knowledgeable about biocrust identification and diversity.

The effect of sand grain size on the development of cyanobacterial biocrusts

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Abstract: Biocrusts are critical components of desert ecosystems, significantly modifying the surfaces they occupy. Although the presence of fine soil particles is known to be conducive to biocrust development and recovery from disturbance, their influence on the inceptive development of biocrusts has not been empirically studied. In this study, the effect of substrate granulometry on the development of biocrusts was explored under controlled laboratory conditions of light, soil humidity, and temperature. A cyanobacterial inoculum of *Microcoleus Vaginatus* was applied to five sand fractions in the range of 1 - 2000 µm. The results showed that the biocrusts developed more rapidly on the fine fraction (<125 µm) than on the coarser fractions. While the biocrust cover on the fine fraction was spatially homogenous, it was patchy and discontinuous on the coarse fractions. The difference in the pore size between the different fractions is suggested to be the reason for these discrepancies in biocrust development, since large pores between the particles of coarse soil restrict and regulate filament spreading. It was found that the spectroscopic indices, the normalized difference vegetation index and the brightness index, were more sensitive to the biocrust development than the bio-physiological parameters of the biocrusts (polysaccharides, protein, and chlorophyll contents). The faster biocrust development on the fine fractions can explain various biophysical phenomena in aeolian environments.

Fulgensia fulgens and *Trichostomum crispulum*: an unbalanced coexistence

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Abstract: In biocrusts of Germany and Sweden, we observed that the lichen species *Fulgensia fulgens* and *Fulgensia bracteata* frequently grow on moss. We recorded the abundance of these interactions and also investigated the effects of *F. fulgens* on the moss *Trichostomum crispulum*. While 79% of *F. fulgens* thalli were found growing associated with mosses in a German biocrust,

up to 82% of *F. bracteata* thalli were moss-associated in biocrusts of Sweden. In 49% (Germany) and 78% of the cases (Sweden) they grew on the moss *T. crispulum*. The moss thalli underneath the lichen appeared dead. In close vicinity to the lichens the moss appeared weak, which suggested that the lichens may release substances harmful to the moss. We prepared a water extract from the *F. fulgens* and used this to water the moss thalli (n = 6) on a daily base over a time-span of three weeks. Once a week, maximum CO_2 gas exchange rates of the thalli were measured and at the end of the experiment the chlorophyll content of the moss samples was determined. In the course of the experiment, net photosynthesis (NP) of the treatment samples decreased, combined with an increase in dark respiration (DR). In the control samples (treated with artificial rain water) both NP and DR remained stable over time. The chlorophyll contents of the treatment samples were significantly lower than those of the controls. This supports our suggestion that water extracts of *F. fulgens* may indeed cause a dieback of the host moss. We expect the dieback to cause increased CO_2 concentrations below the lichen thalli, improving their overall photosynthetic performance. Dead and living biomass increase upon this association, promoting the growth of vascular plant vegetation and potentially supporting rehabilitation of disturbed lands.

The energy of biocrusts: how climate change disturbances in drylands may induce large, novel global climate change feedbacks

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Abstract: Drylands are the planet's largest biome, and evidence suggests these arid and semiarid ecosystems respond markedly to climate change. Biological soil crusts (biocrusts), which are surface soil communities of lichens, mosses, and/or cyanobacteria, are vital components of drylands, comprising up to 70% of surface cover and performing critical ecosystem functions, including soil stabilization and carbon and nitrogen fixation. Dryland ecosystems are expected to experience significant changes in temperature and precipitation regimes, and these climatic shifts are shown to affect biocrust communities by promoting rapid mortality in certain species. In turn, biocrust community shifts affect land surface cover, roughness, and color - changes with the potential to dramatically increase dryland albedo. We tested this hypothesis in a full-factorial warming (+4^{o}C) and watering (increased frequency of small monsoon-type events) experiment on the Colorado Plateau, USA. We quantified changes in shortwave albedo via multi-angle, solar-reflectance measurements. The climate treatments led to a significant increase of 33% in albedo averaged across treatments, which was positively related to increases in cyanobacteria cover following treatment-induced moss and lichen mortality. Combining these results with global irradiance and biocrust distribution datasets, we estimated radiative forcing effects and found strong negative forcing under climate change scenarios. We pinned our negative forcing

results against the recent IPCC AR5 global radiative forcing values for striking comparisons. Thus, changes to dryland biocrust communities could represent a significant and underappreciated feedback to future climate.

Species composition and distribution patterns of biological soil crusts in varied geomorphic units of Jaisalmer district of Indian Thar Desert

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Abstract: In India, the Thar occupies nearly 385,000 km^2 and about 9% of the area of the country, and is the most populous desert in the world, with a human density of around 84 persons per km^2. Within Indian Thar, the Jaisalmer district is located within a rectangle lying between 26°.4'- 28°.23' north parallel and 69°.20' - 72°.42' east meridians. The total area (38,401 sq km) of Jaisalmer district has major physiographic units like sand dunes, aeolian and alluvial plains, ridges and hillocks, etc. These landscapes usually contain sparse vegetation or can even be absent of vegetation. Nevertheless, in open spaces between the vascular plants and even under the small canopy, the soil surface is generally covered by a community of highly specialized organisms, such as mosses, lichens, liverworts, algae, fungi, cyanobacteria, and bacteria referred as biological soil crusts (BSCs). These organisms have extraordinary abilities to avoid desiccation and survive in extreme temperatures, high pH, and highly saline environments. Various efforts have been undertaken by taxonomists to explore bryophytes and algae from the Indian desert. However, studying community composition and distribution of BSCs alongside their ecological functions and ecosystem services has not been done. In this paper, we briefly summarize our findings on species composition and distribution patterns within selected geomorphic and hydro-geological units in this district of Thar Desert. Our research analysis also include an integration of different global studies on BSCs existence, types, distribution patterns, etc., which will eventually help us to critically envisage their potential role in terms of ecosystem functions, spatially and temporally, in Indian Thar. Our research will also allow for the comparison of BSCs ecosystem functions and services with other deserts of the world.

Late-lying snow dramatically disrupted lichen colonization process in the maritime Antarctic

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Abstract: The Antarctic Peninsula has been reported to be one of the areas on Earth that has registered the most intense warming in the last decades of the past century. This has had a dramatic effect in the ice balance and glacier extent in this area driving a massive loss of ice and

retreat of glacier fronts. One result has been extensive areas of newly exposed ice-free surfaces that are in process of colonization and, because of their particular ecological factors and ages, allow comparisons to be made of vegetation dynamics in different places of the maritime Antarctic. On Livingston Island (South Shetland Islands) lichen colonization on young moraines has been investigated for 24 years. Such pioneering lichen communities on new rock surfaces allow long-term measurements to be made of thallus growth whilst avoiding most of the interferences due to competition and coalescent thalli. The relatively low diversity of this system also offers the opportunity to determine the growth rate of each species and to discern the species-specific response to environmental changes. In our measurements, made in 1991 and 2002, evidence of high and increasing annual growth rates for six selected species was clearly detected. We anticipated a similar trend in our last check in 2015; but, contrary to this expectation, we found a clear disruption in the colonization process. Most of species showed a dramatic slowing down in their annual growth rate and many lichen thalli had completely disappeared. Over the same period, since 2002, there has been a break in the trend to longer melt seasons in this area, in agreement with the increase in snow fall forecast for the whole Antarctica. In this paper we relate our data about lichen colonization to the above trends in air and soil temperature and also to changes in ice balance, snow accumulation, and energy balance of the soil. Possible drivers for the dramatic disruption observed in lichen growth are discussed as well as implications for Antarctic vegetation.

Development of biological soil crusts and their impact on soil erosion in an early successional subtropical forest ecosystem

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Abstract: Biological soil crusts (BSCs) have the potential to protect soil surfaces against erosive forces by wind or water. However, research on the effect of BSCs on erosion processes is mostly focusing on arid and semi-arid environments. In particular, the extent of BSCs in early successional forests is rarely mentioned in literature. This study aims to investigate the influence of BSCs on soil erosion and their topographical development over time in an initial subtropical forest ecosystem. Therefore, measurements have been conducted within a forest biodiversity and ecosystem functioning experiment (BEF China) near Xingangshan, PR China. Interrill erosion was measured with 170 microscale runoff plots (0.4 m × 0.4 m) and the occurrence, distribution, and development of BSCs within the measuring setup were recorded. BSC cover in each ROP was determined photogrammetrically in five time steps (2011 to 2015). BSC species were classified to higher taxonomic levels. Higher BSC cover led to reduced sediment discharge and runoff volume due to its protection against splash energy, the adherence of soil particles, and enhanced infiltration. Canopy ground cover and leaf area index had a positive effect on the development of BSC cover at this initial stage of the forest ecosystem. Moreover, BSC cover decreased with increasing slope and northness. Mean BSC cover in runoff plots increased from 12% in the 2nd year after tree planting to 47% in the 6th year. BSCs in this study were moss-

dominated and 26 different moss species were classified. Our results show that BSCs can play an important role in early stage tree plantations even after six years of continuing canopy closure.

Bromus tectorum litter alters photosynthetic characteristics and the hydration period of biocrusts from sagebrush steppes

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Abstract: Invasion of sagebrush steppes by the grass *Bromus tectorum* has increased the amount of vegetation litter covering biocrusts, which could affect their metabolism and growth. To investigate this possible phenomenon, biocrusts dominated by the moss *Bryum argenteum* or the lichen *Diploschistes muscorum* were left uncovered (control treatment) or were covered with approximately 23.5 mg of *B. tectorum* litter per cm^2 of biocrust surface (litter treatment). The immediate effect of this litter cover was a reduction in net photosynthesis, which depending on light intensity and biocrust type, decreased between 1.0 µmol and 2.6 µmol CO_2 m^{-2} s^{-1}. In contrast, litter cover approximately doubled the hydration period in both biocrusts. To analyze the long-term effects of these changes in photosynthesis and the hydration period on biocrusts, control and litter-covered samples were exposed to field conditions for five and ten months. After these periods, the litter was removed and the photosynthetic characteristics of biocrusts from the two treatments compared. In both *B. argenteum* and *D. muscorum*, biocrusts that had been covered with litter for ten months had lower rates of gross photosynthesis and lower chlorophyll content than control samples. Similarly in both biocrust types, litter reduced the rate of dark respiration. For *D. muscorum*, this reduction fully compensated for the decrease in gross photosynthesis, resulting in similar net photosynthesis rates in the two treatments. In contrast, for *B. argenteum*, net photosynthesis was four-times greater in the control than the litter treatment. Also under litter cover, *D. muscorum* showed two adaptations to shade conditions: a decrease in the light compensation point and in the chlorophyll *a*/*b* ratio. These changes were not apparent in *B. argenteum*. Our results indicate that photosynthetic responses to litter cover vary among species of the crust biota and that the litter can reduce the photosynthetic capacity of biocrusts.

Nitrogen fixation in biocrusts and cryptogamic covers of cool terrestrial habitats

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Abstract: Cyanobacteria in cryptogamic covers are the main nitrogen fixers in high latitude ecosystems via the enzyme nitrogenase. The Icelandic highlands are mostly covered by cryptogams, including mosses, lichens, and biological soil crusts (biocrusts). Over 25% of cryptogam coverage in the Icelandic highlands is biocrust, characterized by the leafy liverwort *Anthelia juratzkana*. The mean annual temperature as well as the summer temperature is low, and nitrogen input by precipitation, decomposition, and mineralization is low. The alternative

vanadium-dependent nitrogenase system is known to be relatively more active at low temperatures than the canonical molybdenum-based system and we now have evidence that this alternative system is common and expressed in cyanolichens and in moss-associated cyanobacteria in Iceland. We also have indications based on $^{15}N/^{14}N$ isotope ratios that the vanadium-based system contributes substantially to nitrogen fixation in the liverwort biocrust. Preliminary metagenome analysis of the biocrust indicates abundance of cyanobacteria of the genus *Nostoc*. We are currently launching a project to estimate nitrogen fixation in eight major cryptogam EUNIS-classified habitats representing nearly 90% of cryptogam cover in uncultivated areas of Iceland. We will characterize the microbial communities of these habitats and determine which environmental and genetic factors are instrumental in this biological nitrogen fixation. Our methods will entail laboratory and field experiments, microbiology, chemical analysis, gene sequencing, and bioinformatics.

Biological soil crust dispersal rate

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Abstract: Application of biological soil crust inoculum is a promising tool to recover ecosystem services in degraded soils of drylands. Biocrust inoculum can be grown in greenhouse or lab facilities and then used to restore deteriorated areas in the field. Disturbed areas suitable for crust growth can be repopulated with different types of inoculum and recovery rates monitored. However, recovery rates after inoculation with biocrusts grown *ex situ* have not been decoupled from naturally occurring rates mediated by local biocrust communities due to our limited understanding of naturally occurring biocrust dispersal rates. Biological soil crust dwellers, especially cyanobacteria, are known to be motile through soil and can be dispersed through wind. In addition, recovery is highly likely to occur naturally through dispersal by surficial water runoff. To investigate biocrust propagule dispersal rates, we set up a greenhouse experiment with six control and six test plots. The test plots housed inoculum in a 5 cm by 35 cm strip while leaving an area of 35 cm by 17 cm without inoculum. The control plots accounted for airborne greenhouse contamination. The plots were watered every four days with an automated wicking watering system to simulate local annual precipitation frequency. The plots are being sampled during 5 intervals at different distances, and quantified by chlorophyll a analyses and microscopy. A known rate of dispersal without wind or runoff contributions would help guide restoration effort in deciding the size of inoculum patches as well as the optimum distance for inoculation away from natural crust.

Linking microbial community structure, activity, and carbon cycling in biological soil crust

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Abstract: Soils play a key role in the global carbon cycle, but the relationships between soil microbial communities and metabolic pathways are poorly understood. In this study, biological soil crusts (biocrusts) from the Colorado Plateau (Moab, UT) are being used to develop soil metabolomics methods and statistical models to link active microbes to the abundance and turnover of soil metabolites and to examine the detailed substrate and product profiles of individual soil bacteria isolated from biocrust. To simulate a pulsed activity (wetting) event and to analyze the subsequent correlations between soil metabolite dynamics, community structure, and activity, biocrusts were wetup with water and samples (porewater and DNA) were taken at various timepoints up to 49.5 hours post-wetup. DNA samples were sequenced using the HiSeq sequencing platform and porewater metabolites were analyzed using untargeted liquid chromatography/ mass spectrometry (LC/MS). Exometabolite analysis revealed the release of a breadth of metabolites including sugars, amino acids, fatty acids, dicarboxylic acids, nucleobases, and osmolytes. In general, many metabolites (e.g., amino acids) immediately increased in abundance following wetup and then steadily decreased. However, a few continued to increase over time (e.g., xanthine). Interestingly, in a previous study exploring utilization of soil metabolites by sympatric bacterial isolates from biocrust, we observed xanthine to be released by some Bacilli spp. Furthermore, our current metagenomics data show that members of the Paenibacillaceae family increase in abundance in late wetup samples. Previous 16S amplicon data also show a "Firmicutes bloom" following wetup with the new metagenomic data resolving this at genome-level. Our continued metagenome and exometabolome analyses are allowing us to examine complex pulsed-activity events in biocrust microbial communities. Ultimately, these approaches will provide an important complement to sequencing efforts linking soil metabolites and soil microbes to enable genomic sciences approaches for understanding and modeling soil carbon cycling.

Biological soil crusts emit large amounts of reactive nitrogen gases affecting the nitrogen cycle in drylands

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Abstract: Biological soil crusts (biocrusts) are distributed worldwide, especially in drylands, which currently cover ~40% of the Earth's surface. In these dryland systems, biocrusts play a major role in the fixation of atmospheric nitrogen, serving as a nutrient source in these strongly depleted ecosystems. In this study, we show that a substantial fraction of the nitrogen fixed by biocrusts is metabolized and subsequently returned to the atmosphere in the form of nitric oxide (NO) and nitrous acid (HONO). These gases affect the oxidizing capacity and radical formation within the troposphere, thus being of particular interest to atmospheric chemistry. Laboratory

measurements using dynamic chamber systems showed that dark cyanobacteria-dominated crusts, collected in the Succulent Karoo in South Africa, emitted the largest amounts of NO and HONO, being ~20 times higher than trace gas fluxes of nearby bare soil. By combining laboratory experiments, field measurements, and satellite observations, we made a best estimate of ∼1.7 ± 0.3 Tg $a^{-1}$of global reactive nitrogen emissions, which equals ~20% of the soil release under natural vegetation according to the latest IPCC report. Subsequent measurements of biocrusts from the Sultanate of Oman provided similar release patterns of NO and HONO. Cyanobacteria-dominated crusts, which were mainly restricted to depressions and runoff patches, again released high amounts of reactive nitrogen. Thus, our measurements show that dryland emissions of nitrogen oxides are largely driven by biocrusts. As biocrust emission patterns are driven by precipitation, alterations in global nitrogen oxide emissions are to be expected in times of globally changing climate.

The upside-down water collection system of *Syntrichia caninervis*

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Abstract: Desert plants possess highly evolved water conservation and transport systems, from the root structures that maximize absorption of scarce ground water, to the minimization of leaf surface area that enhance water retention. Recent attention has focused on leaf structures that are adapted to collect water and promote nucleation from humid air. *Syntrichia caninervis* Mitt. (Pottiaceae) is one of the most abundant desert mosses in the world and thrives in an extreme environment with multiple but limited water resources (e.g., dew, fog, snow, and rain), yet the mechanisms for water collection and transport have never been completely revealed. *S. caninervis* has a unique adaptation where it uses a tiny hair (awn) on the end of each leaf to collect water, in addition to that collected by leaves. Herein, we show that the unique multi-scale structures of the hair are equipped to collect and transport water in four modes: nucleation of water droplets and films on the leaf hair from humid atmospheres, collection of fog droplets on leaf hairs, collection of splash water from raindrops, and transportation of the acquired water to the leaf itself. Fluid nucleation is accomplished in nano structures, while fog droplets are gathered in areas where a high density of small barbs are present and then quickly transported to the leaf at the base of the hair. Our observations reveal nature's optimization of water collection by coupling relevant multi-scale physical plant structures with multi-scale sources of water.

Warming results in accelerated carbon loss from biological soil crust and soils in greenhouse mesocosms

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Abstract: Based on field warming experiments, we can expect reductions in cover and diversity of biocrusts on the Colorado Plateau in response to climate change in coming decades. Because these communities cover much of the plant interspaces in undisturbed areas of the Colorado Plateau, and exhibit significant rates of carbon and nitrogen fixation, as well as influence the ecosystem energy and water budget, reductions of biocrust may have substantial ecosystem-level impacts. We use greenhouse mesocosms to evaluate the temperature sensitivity of the carbon balance of soils with different successional stages of biocrust. Mesocosms, composed of homogenized soil and either early successional light cyanobacterial biocrust, late successional moss-lichen biocrust, or bare soil, were maintained for 83 days under 'ambient' or 'warmed'(+5°C) conditions, and subjected to a pulse watering regime. CO_2 fluxes were measured midday during wet, moist, and dry phases of the watering cycle to evaluate the interactive temperature and moisture sensitivity, in transparent chambers and again in opaque chambers, allowing us to partition net primary production (NPP) and respiration (R). Both NPP and R were largest in the late successional biocrust, and highly sensitive to soil moisture - when soils were dry, no measurable carbon fluxes were detected. Soil and biocrust R was greater in the warmed versus ambient treatment, and greater during the warm period of late summer than the cooler period in late fall. There was little direct effect of warming on NPP, although warming increased rates of drying, and low water content inhibited NPP. The different temperature response of R and NPP resulted in a negative balance of net ecosystem exchange in response to warming. Extended over multiple seasons this imbalance would result in 'carbon starvation', and cause desert biocrust communities to experience significant die-off.

Natural establishment of biological soil crusts on disturbed desert landscapes

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Abstract: Biological soil crusts (biocrusts) result from intimate associations between soil particles and cyanobacteria, algae, microfungi, lichens, and/or bryophytes living on and in the surface few millimeters of arid soils. Biocrusts play critical roles in nutrient cycling and soil stability. They are easily damaged by fire, off-road traffic, and livestock grazing. Depending on the nature of the disturbance, complete recovery can require decades to millennia. It has been suggested that attempts be made to accelerate biocrust recovery by inoculating disturbed sites with biocrust organisms. While agricultural applications of algae and cyanobacteria via irrigation has been successful in mesic areas, applications in arid areas have not been tried due to logistical constraints and costs. However, numerous attempts have been made to develop cyanobacterial amendments for use in inoculating disturbed arid soils, but success has been limited. Algae and

cyanobacteria are the most frequent initial colonizers of disturbed sites. A logical question relates to how cyanobacteria disperse so readily across long distances. The field of aerobiology may provide insight. Aerobiology was developed for the purpose of identifying airborne algae, cyanobacteria, and fungi that induce allergies, skin irritation, hay fever, rhinitis, sclerosis, and respiratory problems. Aerobiologists have collected and subsequently identified numerous airborne organisms in the atmosphere above population centers in hopes of identifying potential allergens. Only a small percentage of the collected organisms have been identified as causing medical issues. However, a large number of them are significant components of biocrusts. Despite the logical link between related airborne organisms and biocrusts, there has been no published information confirming the relationship. Nevertheless, such airborne organisms may be essential for natural crust re-establishment following disturbance. There may be logical reasons that artificial restoration attempts have been largely unsuccessful, and why natural mechanisms provide the reasonable answer.

Biological soil crusts: new findings, knowledge gaps, new directions

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Abstract: Research progress has led to the understanding that biological soil crusts (biocrusts) are often complete miniature ecosystems comprising a variety of photosynthesizers (cyanobacteria, algae, lichens, bryophytes), decomposers like bacteria, fungi, and archaea, and heterotrophic organisms, like protozoa, nematodes, and microarthropods that feed on them. Biocrusts are one of the oldest terrestrial ecosystems, playing central roles in the functioning of dryland ecosystems and presumably influencing global biogeochemical cycles. On the other hand, biocrusts have been shown to be highly sensitive to global change, being easily destroyed by mechanical disturbance or minor changes in climate patterns. Despite the large increase in biocrust research, we still see major knowledge gaps. Considering biodiversity studies, there are regions of potential biocrust occurrence where hardly any studies exist. Molecular identification techniques are increasingly employed, but genetically characterized entities need to be linked with morphologically identified organisms to determine their ecological roles. Although there is a large body of research on the role of biocrusts in water and nutrient budgets, we are still far from closing overall cycles. Results suggest that not all mechanisms have been identified yet, leading to sometimes contradictory results. Knowledge on how to minimize impact to biocrusts during surface-disturbing activities is still lacking, and despite some research, methods for effective biocrust restoration are not well-developed. In order to fill these research gaps, novel scientific approaches are needed. We expect that global research networks could be extremely helpful to answer scientific questions by tackling them within different regions, utilizing the same methodological techniques. Global networks could also be used for long-term monitoring and to conduct meta-analyses on already existing scientific data. Finally, experimental results obtained during multiple local studies need to be integrated and extrapolated to ecosystem and global scales in order to identify the overall role of biocrusts in the Earth system through time.

Biological soil crusts and associated cyanobacteria of Arctic, alpine, and Antarctic regions

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Abstract: Comprehending the composition and areal coverage of biological soil crusts (BSC) occurring in cold habitats is vital, due to their status as key players in productivity, biomass, colonisation, and biodiversity. Arctic, alpine, and Antarctic areas have received little attention in the burgeoning of BSC research and this should be endeavoured to be rectified. This contribution aims to describe the BSC and cyanobacterial composition of Arctic Svalbard, the Antarctic Island Livingston, and the Hohe Tauern, an alpine region of Austria. BSC variability was investigated using vegetation surveys based on classification by functional group. Vegetation types were assigned based on dominant functional groups and local topography to create a simple reference scheme allowing easy identification. The extensive and diverse BSC coverage found in all regions was extraordinary, up to 90% in some areas, considering the harsh climates documented. The cyanobacterial communities inhabiting the BSC of the three regions were investigated by different methods. Illumina sequencing, denaturing gradient gel electrophoresis (DGGE), direct isolation from cultures, and morphological methods have all been utilised. The combination of different methods allows a thorough insight into the cyanobacterial assemblages and also creates an opportunity for exploring the merits and drawbacks of the different methodologies. The results obtained show that the extensive cyanobacterial-dominated BSCs of Svalbard and Austria are composed of similar genera. More differences were observed between vegetation types within a site than between the geographical areas, promoting the importance of substrate rather than location on cyanobacterial community composition. Being able to explore and compare BSCs of Arctic, alpine, and Antarctic ecosystems may be essential for ongoing investigations into BSC functionality in cold climates.

Key landscape function indicators determined using hyperspectral reflectance in a dry sub-humid native grassland in southern Queensland, Australia

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Abstract: Native grasslands cover over 80% of significant ecosystems in Australia, stretching across arid, semi-arid, tropical, sub-tropical, and savannah landscapes. The aim of this study was to assess key landscape function indices across spatial scales in order to examine their correlation with hyperspectral reflectance measurements. Four land cover types (native pasture, biocrust

with native pasture, only biocrust, and bare degraded soil) were analysed for key landscape function (LFA) indices: stability, infiltration, and nutrient cycling. Both LFA and hyperspectral data were collected at overall (50 x 50 cm quadrat) and sub-cell (10 x 10 cm) levels, under wet and dry conditions, and with grass cover removed in order to incorporate the presence of biocrusts. Based on partial least squares (PLS) regression analysis, hyperspectral data related to LFA indicators produced moderate to high prediction accuracy. Under both dry and wet conditions, quadrat spectral measurements for LFA indicator 'nutrients' produced models that had a lower prediction accuracy than sub-cells. Under dry conditions, sub-cells regression correlations ranged from 0.838 to 0.864 between the predicted (model) and measured (observed) values for the cross-validated samples. LFA indicators in the quadrats were slightly lower in predictive ability of reflectance data compared to the sub-cells. Under wet conditions, sub-cells prediction accuracy improved for the same LFA indicators (correlations ranged 0.844-0.877). For the quadrats, the prediction model for 'infiltration' (wet) was better (83.0%) than dry (79.3%). Using PLS regression, LFA indicators were modelled accurately by hyperspectral reflectance of land cover features in both dry and wet conditions. Such relationships can be further explored by using airborne or space-borne remote sensing systems to enable mapping at higher spatial and temporal scales.

Cyanobacterial diversity and abundance facilitates increases in bioavailable N in the northern Australian savannah

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Abstract: At the Boodjamulla National Park (NW Queensland) research site, a detailed study of cyanobacteria diversity and abundance was carried out between November 2009 and May 2010 wet season. The aim of this study was to characterise the seasonal changes in cyanobacterial crusts and investigate links between community structure and the bioavailability of N. For identification purposes, a minimum of five samples of cyanobacterial crusts were retained from the accompanying bioavailable N study. In the glasshouse, these samples were resurrected over a 24-hour period. Cyanobacterial species were identified by key morphological traits and abundance for each species was ranked from dominant to rare (n=300). Cyanobacterial richness was a strong predictor of abundance over time (November-May). Diversity ranged from 4-19 with *Scytonema* dominant throughout the season, and was the key contributor to crust breakdown and reestablishment. Initially, disintegration of sheath material took place with apoptotic-like cell death in vegetative cells (November-January), followed by resurrection of a portion of desiccated filaments, and mass hormogonia release (January-February), then the vigorous growth of new material. This was evident in crust biomass and thickness that increased significantly over time. The flush of bioavailable N in November (2009) was linked to the breakdown of the crust. Significantly lower bioavailable N occurred across December to February at a time where cyanobacteria were reproducing and in a high growth phase. From late February to May, bioavailable N increased by a magnitude of four then doubled again across April-May. During this time, diversity and abundance peaked and heavy granulation (N-storage), particularly in

Scytonema, was recorded. The implications of this study show, in this environment, the maintenance of a diverse cyanobacterial crust facilitates seasonal N inputs.

Bioavailable N linked to wet-season cyanobacterial crust breakdown and resurrection: a study from the northern Australian savannah

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Abstract: Grazing is the major economic activity in northern Australia's savannah grasslands that cover in excess of 1.9 million km^2. Over time there have been significant declines in soil fertility, primarily as a result of overstocking and drought, consequently there is a pressing need to consider novel land management strategies. Cyanobacterial crusts dominate these soil surfaces where, after several dry months, wet-season rainfall kicks off their breakdown and regrowth. The focus of this study was to characterise bioavailable N that cyanobacterial soil crusts contribute on a seasonal basis to the soil-plant ecosystem. Biofertilisation trends were detailed from multiple soil samples between November 2009 (pre-wet season rains) and May 2010 (end of wet season). Sampling was timed before, during, and after major rain events that incorporated cyanobacterial surface crusts and immediately below the crust. In conjunction with increased biomass, cyanobacterial-mediated rates of N-fixation increased significantly from the commencement to the height of the wet season, then decreased towards the end of the wet season. A flush of bioavailable N was evident in November before more than halving across January to February, followed by an exponential increase from March to May. There were significant differences in depth and times with more in the crust layer (except November). The average ^{15}N isotope across the season was 0.9 with C:N ratios stable (average of 19.1). Total C and N both doubled across the course of the wet season. Seasonal biofertilisation paralleled cyanobacterial productivity (measured by net carbon uptake) at the same study site. Such well-defined seasonal trends and synchronisation in bioavailable N originating from cyanobacterial crusts characterised a significant contribution to soil fertility. Peak biofertilisation by cyanobacteria at the height of the wet season could be enhanced by targeted land management that incorporated aptly timed rest phases.

Can and should we merge our ecosystem rehabilitation efforts with assisted migration of biocrusts?

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Abstract: Climate change is expected to have a significant impact on the biotic components of drylands. However, biocrusts may buffer some of the effects of climatic change by exerting a

positive effect on multifunctionality and the abundance of soil bacteria and fungi in some dryland systems. In recent years, many researchers are demonstrating that biocrusts can be artificially grown or otherwise rehabilitated to return some functions to drylands. But as climate changes rapidly, we must ask ourselves if the biocrusts we are rehabilitating are maladapted to future climate regimes. Here, we propose that the assisted migration of biocrust species and genotypes is feasible and may be an important consideration to ensure future dryland functioning. Rehabilitation efforts could become assisted migration efforts if biocrust rehabilitation materials are selected from genetic stock more adapted to future conditions. Biocrust autotrophs appear to be characterized by relatively low global species diversity, compared to vascular plants. However, within those limited species numbers is an unknown amount of genetic and phenotypic variation to the many divergent dryland climates. This variation could be experimentally explored to determine responses to environmental stress within geographically separated populations of biocrust communities. Experimental manipulation of inoculated biocrust communities along elevational and latitudinal gradients could tell us about their resilience to environmental changes, as well as their ability to colonize novel ecosystems. Additionally, migrating biocrusts will not only maintain the ecosystem services of soil stability and nutrient cycling, but the bacteria, fungi, and other soil organisms that interact directly with plants could potentially also be moved within the biocrust–soil matrix, with the possibility of enhancing natural and assisted plant migration. Rehabilitating to ensure the continued presence of biocrusts in these changing dryland ecosystems may help maintain a high degree of functionality in drylands that might otherwise be lost.

Restoration of moving sand dunes with cyanobacterial crust: growth enhancement using artificial silt and clay size particles

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Abstract: One of the main problems in desertified lands worldwide is active, wind-borne sand dunes, which lead to the covering of fertile soils and agricultural fields. In regions with more than 100 mm of annual rainfall, sand dunes can be naturally stabilized by biocrusts (biological soil crusts). One of the main restraints of biocrust development is the typical lack of fine particles in sand dunes. Our study investigated the combined application of using artificial silt and clay size particles - coal fly-ash, which is the by-product of power stations and comprises of particles having a diameter of less than 100 μm, and bio-inoculant of filamentous cyanobacteria, isolated from nearby naturally stabilized sand dunes, on the soil surface of active sands for increasing resistance to wind erosion. Boundary-layer wind tunnel experiments were conducted in an experimental greenhouse to examine the effects of adding coal fly-ash and bio-inoculant to active sands. Biocrust development was evaluated via several physical and bio-physiological variables. In all the physical measurements and the bio-physiological variables, the treatment of "sand+inoculum+coal fly-ash" showed significant differences from the "sand-control". The

combination led to the best results of surface stabilization in boundary-layer wind tunnel experiments, with the lowest sand fluxes. The filamentous cyanobacteria use the fine particles of the coal fly-ash as bridges for growing toward and adhering to the large sand particles. The cumulative effects of biocrusts and coal fly-ash enhance soil surface stabilization and may allow long-term sustainability.

The role of cyanobacterial crusts, as an ecosystem engineer, on survival of planted trees during severe drought

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Abstract: The semi-arid regions of our world are subject to climatic changes, expressed in fluctuations in rainfall duration and amounts. In the semiarid northern Negev Desert, during biocrust formation, cyanobacteria secrete polysaccharides that adhere to soil particles and bind them together, thereby creating a smooth sustainable biocrust that covers the soil surface. These smooth cyanobacterial crusts reduce surface roughness and water infiltration, therefore enhancing overland water runoff following rainfall events. The objectives of this study were to describe the survival of three different tree species 20 years after planting, under two different soil surface treatments along slope contours: a) areas covered with natural cyanobacterial crusts and contour-ridges, and b) areas uncrusted as the result of plowing, which prevented the development of the cyanobacterial crusts and therefore increased water infiltration. We evaluate the effect of these two treatments on the ecological functions related to tree survival in Mediterranean semi-arid ecosystems, where water is the major limiting factor. Three tree species were tested: one with high drought tolerance, another with medium drought tolerance, and with low drought tolerance. Results showed that in both soil surface treatments none of the low drought tolerance species survived 20 years after planting. For medium-tolerant tree species, comparison between biocrusted and plowed areas showed that the cyanobacterial crusts help support tree survival two- to four-fold in the crusted area compared with those in the plowed area. Regarding the high drought tolerance trees, no significant effect was found between the plowed and crusted areas. Our report suggests that in the case of severe fluctuations in the amount of rainfall, the contribution of cyanobacterial crusts, if taken under consideration during management, might be positive for the periods of drought for afforestation and conservation in dry regions.

The effects of simulated nitrogen deposition on growth and photosynthetic physiology of three different successional biocrusts

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Abstract: Increasing nitrogen (N) deposition has become a threat in many terrestrial ecosystems, and the effects of N deposition have been widely studied. However, how biocrusts physiologically respond to N is unclear. In 2010, six simulated N deposition treatments, i.e. 0 (N0), 0.3 (N0.3), 0.5 (N0.5), 1.0 (N1), 1.5 (N1.5) and 3.0 (N3) g N m^{-2} a^{-1}, were applied on biocrust plots in the center of the Gurbantunggut Desert. The growth and physiological indicators of cyanobacterial, lichen, and moss crusts were determined after three years of exposure to N addition. Chlorophyll (a+b) contents, YII, soluble sugar concentration of the three biocrust types and moss individual biomass increased and then decreased with the enhancements of N, with peak values at different N applied rates. High N additions (N3) significantly decreased Fv/Fm. N addition non-significantly increased chl a/b of lichen crusts at N1.5 treatments and significantly decreased at N1 treatments compared to N0, while no significant effects of N addition were found in cyanobacterial crusts. The highest value of soluble sugar content of moss occurred at N0.3 treatments, while the cyanobacterial and lichen crusts occurred at N1.5 treatments. N addition had no significant effect on the proline contents of cyanobacterial and moss crusts. Lichen crusts had relatively lower proline contents in response to higher N addition rates, with a significant decrease being observed in response to N1.5 and N3 relative to N0.3. The soluble protein of cyanobacterial and lichen crusts were not significantly affected by N addition, but moss soluble protein increased and then decreased after a gradient of N addition. Among the three biocrusts, moss was the most sensitive to N treatments, followed by cyanobacterial and lichen crusts. Our results suggest that low levels of N addition do not significantly affect biocrust performance, but high N pollution negatively affects growth.

Topographic differentiations of hydraulic properties induced by biological soil crusts in fixed sand dunes

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Abstract: Biological soil crusts (BSCs) play an important role in surface soil hydrology. Many studies show that soils dominated with moss BSCs have higher infiltration rates than those

dominated with cyanobacteria or algal BSCs. However, it is not known if improved infiltration in moss BSCs is accompanied by an increase in soil hydraulic conductivity or water retention capacity. This hampers a better understanding of the surface soil hydrological processes modulated by BSCs. We investigated this problem in the Tengger Desert, where a 43-year-old re-vegetation program has promoted the formation of two distinct types of BSCs along topographic positions, i.e., the moss-dominated BSCs on the hollow and windward sides of the fixed sand dunes, and the algal-dominated BSCs on the crest and leeward slopes. Soil water retention capacity and hydraulic conductivity were measured using an indoor evaporation method and a field infiltration method and results were fitted to the van Genuchten-Mualem model. Unsaturated hydraulic conductivities under greater pressure (< about -0.01 MPa) and water retention capacities in the entire pressure head range were higher for both crust types than for bare sand. However, saturated and unsaturated hydraulic conductivities in the near-saturation range (> about -0.01 MPa) show decreasing trends from bare sand to moss crusts and to algal crusts. Our data suggest that topographic differentiation of BSCs not only significantly influences soil water retention and hydraulic conductivities, it also has a profound impact on the overall hydrology of the fixed sand dunes at landscape scale, as seen in the reduction and varied distribution in deep soil water storage.

Ecological adaption of moss species - the fundamental for moss crust restoration

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Abstract: Mosses are highly relevant to degraded lands restoration. Specifically, rehabilitation of biocrusts is important because of their versatile vegetative reproduction and desiccation tolerance characteristics. Knowledge of physiology and ecological adaptation of moss species to specific sites or regions is the fundamental for moss cultivation. We have investigated the photosynthetic response of four biocrustal moss species (collected from both arid and semiarid regions) to light, temperature, and moisture content under controlled laboratory conditions. Significant differences were observed in the optimum photosynthetic temperature and moisture content between different moss species from similar habitats, as well as between the species from different environments. Although collected from similar habitats, *Bryum argenteum* did not show significant changes in net carbon gain rate in the temperature range between 5^{o}C and 30^{o}C, while *Syntrichia caninervis* showed an optimum photosynthetic temperature range from 5^{o}C to 20^{o}C. Additionally, two species from the same genus of biocrustal moss were investigated, *Didymodon vinealis* and *D. tectorum*. *D. vinealis,* collected from an arid region, showed an optimum photosynthetic temperature range from 5^{o}C to 15^{o}C; however, *D. tectorum*, from a semiarid region, showed an optimum in temperature range of 15-20^{o}C. In addition, four distinct moisture response curves of photosynthesis were observed for the four moss species, and significant variation was detected in the optimum photosynthetic moisture content for the moss species. The significant variation in the optimum photosynthetic conditions between moss species was the reason, as well as the expressions, of the variation in the ecological adaption of

mosses. Moreover, the unique hydraulic adaption, namely, desiccation tolerance, of moss flora makes the cultivation, especially supplying the water, more complicate. Significant hazards were found in mosses when they were fully rehydrated at 35ºC. Such knowledge enlightens moss crust restoration in the aspect of species selection and the determination of culture conditions. Based on such knowledge, an improved culture procedure was formed for the biocrust dominant mosses species (*D. tectorum*) in the Loess Plateau region of China. With the procedure, 30% moss crust cover can be developed within four weeks, and an artificial moss crust with coverage of approximately 80% may be cultivated within eight weeks in the laboratory. However, the degradation in adaptability of cultured mosses to field conditions compared with natural growing conditions pose more challenge in moss crust restoration. To sum up, moss crust restoration raise urgent demands for knowledge on physiology and ecological adaptation of biocrust moss.

Ecological and physiological adaptability of *Syntrichia caninervis* Mitt in different microhabitats of a temperate desert

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Abstract: Moss crusts play important roles in the biomass of biological soil crusts (BSCs) and soil surface stabilization in desert ecosystems. This study aimed to test whether the presence of shrubs affects the growth and physiological characteristics of the bryophyte *Syntrichia caninervis* Mitt. in these ecosystems. Significant differences were observed in growth characteristics among different habitats. Population biomass and individual biomass are higher beneath live shrub canopies than dead shrubs and bare ground. However, population density appeared to exhibit an opposite trend compared with the biomass, with density in bare ground > dead shrubs > live shrubs. The height of *S. caninervis* Mitt showed significant decreasing trends from live shrubs to dead shrubs to bare ground. The Fv/Fm in *S. caninervis* under shrub canopies appeared significantly higher than that of bare ground. Except for Y(II), no significant differences were found among the three microhabitats. The contents of soluble proteins in the three microhabitats were highest under live shrubs than they were under the dead shrubs and bare ground. Contents of proline and soluble sugar under live shrubs would be high when the environment was severe (such as higher temperature or drought), while an opposite trend existed when the temperature became low or the water supply was sufficient. In summary, *S. caninervis* Mitt. could change their growth characteristics to adapt to extreme environments. Physiologically, *S. caninervis* Mitt. could accumulate soluble sugars, proline, and antioxidant enzymes in response to extreme temperature or water stress.