Soil Fungal Biomass and Enzyme Activity Respond to Environmental Moisture Gradients

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Project Objectives

We are examining the role of wind dispersal in facilitating migration of fungi to and within Southern California. We are using high-throughput pyrosequencing techniques to identify airborne fungi collected in five local ecosystems. These sites range from inland to coastal to island ecosystems and represent a variety of vegetation types, elevations, and climates. We are also characterizing fungal communities in soils from these plus 14 other sites in Southern California. This upcoming year, reciprocal transplants of fungal communities will be conducted among the air sampling sites to determine viability of the airborne fungi as well as habitat preferences of fungal taxa. We predict that (1) fungal community composition will be related to moisture availability; (2) airborne fungal taxa will vary among seasons, and between Santa Ana versus common northwesterly wind conditions; (3) relatively few fungal taxa can disperse over barriers such as the mountains and the ocean; and (4) migrating fungal taxa will be more likely to proliferate in ecosystems with similar environmental conditions to their native ecosystem.

To complement this regional project, we conducted a survey of the global biogeography of arbuscular mycorrhizal (AM) fungi. Arbuscular mycorrhizal fungi form associations with most land plants and can control carbon, nitrogen, and phosphorous cycling between above- and belowground components of ecosystems. Current estimates of global AM fungal distributions are primarily derived from geographic ranges of plant biomes. However, dispersal limitation, local environmental conditions, and interactions among AM fungal taxa may also be important. We assessed the relative strengths of each of these factors in structuring AM communities. We hypothesized that (5) AM fungi would be dispersal limited, owing to large spore size and belowground spore production. In addition, we predicted that (6) AM community composition would vary as a function of climatic and soil factors and plant community type. We also predicted that (7) local AM fungal communities would be phylogenetically clustered if environmental selection or dispersal limitation controlled community assembly, or over dispersed if interactions between fungal taxa were prevalent. We also hypothesized that (8) if AM fungi were influenced by one or more of these filters, community composition would differ significantly between sites (i.e., exhibit high beta diversity), perhaps leading to higher global diversity than previously estimated.
Approach and Procedures

To test Prediction 1, we have sampled soils within 19 ecosystems distributed across Southern California (Fig. 1). These ecosystems represent a range in ecosystem types (Davis et al. 1998), elevation (http://maps.google.com), soil types (http://soils.usda.gov/survey/geography/ssurgo/), and water availability (Conil and Hall 2006). Precipitation is highest in our westernmost sites, and declines as we move inland (Fig. 1). Mean annual temperature also varies, but only by a degree or two Celsius (Conil and Hall 2006). We have collected samples every three months. In each sampling site and sampling time, we compiled ten soil cores that are each 10 cm diameter x 10 cm deep. They were immediately placed on ice for transport to UCI. We measured soil moisture, soil pH, organic C, and resin-extractable N and P on portions of each sample (Robertson et al. 1999), and store the remainder at –20 °C for pyrosequencing. Fungal biomass is measured as hyphal length following standard procedures (Balser et al. 2005). Activities of polyphenol oxidase (lignin decomposition) enzymes were measured colorimetrically using the method of Sinsabaugh (1994).

Figure 1. Locations of soil sampling sites in Southern California.

To test Predictions 2 and 3, we have been capturing airborne fungi at five sites throughout the year (Fig. 2), and under common northwesterly conditions as well as Santa Ana winds. These sites form a transect from a low-lying inland desert to a yellow pine forest in the San Jacinto mountains, to moderate- and low-elevation grasslands nearer the coast, to a sage scrubland on Catalina Island. We are collecting fungi by using air sampling tubes installed near the tops of eddy flux towers. Instruments on the towers continuously record micrometeorological data (wind speed, wind direction, relative humidity, and temperature), so we can relate these variables to fungal assemblages in the samples. We have begun to pyrosequence fungi collected on the filters, and we should have community composition data within the next few months.
Figure 2. Air sampling sites in Southern California.

During the second year, we will test Prediction 4 by using “fungal cages” (sensu Reed and Martiny 2007) to assess proliferation of transplanted fungi in new habitats. Specifically, we will construct litterbags from nylon membranes containing 0.45 µm diameter pores. This pore size is small enough to prevent fungi from growing in or out of the bags, but it is large enough to allow passage of water, nutrients, dissolved organic compounds, and bacteria. Fungal inocula from each site will be added. Litterbags will be affixed to the soil surface in the recipient sites, incubated for 4 months, and then active fungi will be pyrosequenced.

To test Predictions 5–8, we conducted a synthesis of published environmental DNA sequences of AM fungi. We collected 9,905 sequences from the 18S region of rDNA and 5,056 sequences from the 28S region of rDNA. To examine the relative importance of potential spatial, environmental, and biotic controls over AM fungal distributions, we used non-parametric MANOVA to simultaneously analyze spatial (latitude, longitude and elevation), climatic (temperature, precipitation, humidity, PET), soil (soil series, soil moisture, soil temperature, pH), and plant (composition and NPP) variables (R Development Core Team 2009). To further distinguish between spatial, environmental and biotic controllers of local AM fungal community structure, we performed phylogenetic dispersion tests for each study site.

Results

We found that fungal biomass and polyphenol oxidase activity in Southern California soils were significantly positively correlated with mean annual precipitation of our soil sampling sites (Fig. 3). In the data synthesis, global AM fungal diversity was up to six times higher than previously estimated, largely owing to high beta diversity among sampling sites. Soil moisture (Fig. 4) and temperature, geographic distance, and plant community type were each significantly related to AM fungal community structure. AM fungal communities also exhibited a trend of phylogenetic clustering of species within sites, further suggesting that habitat filtering or dispersal limitation is a main driver of AM fungal community assembly.
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**Figure 3.** Variation in fungal biomass (as hyphal length) and polyphenol oxidase activity (a measure of the potential breakdown of lignin by microbes) in soil in relation to mean annual precipitation of Southern California sites.

**Figure 4.** Non-metrical scaling plot of AM community composition in relation to soil moisture of global survey sites. Symbols that are closer together have more similar community composition. Axis are non-metric. Aridic soils are driest, followed by xeric, ustic, udic, and perudic. Moisture regimes differed significantly from one another (P = 0.01).
Discussion

The results from our field-based study of Southern California soils complemented those from our survey of global soils, in that water availability was related to the abundance of soil fungi (in California) and the community composition of AM fungi (across the globe). Moreover, decomposer activity increased with precipitation rates in Southern California. Others have noted changes in the diversity of soil fungi over precipitation gradients in other regions (Jacobson 1997, O’Dell et al. 1999, Lindblad 2001). Thus, changes in precipitation regimes and water availability owing to human activities may lead to shifts in the prevalence, activity, and community composition of fungi. Annual precipitation in Southern California is predicted to decrease by 5 to 10% this century, owing to climate change (Christensen et al. 2007). Large rain and snow storms, in particular, should become rarer (Bell et al. 2004). These changes could lead to a concurrent decrease in decomposition by soil fungi. The extent to which fungi can migrate from other areas will be assessed in the second year of our project.

Our study is relevant to the Kearney mission because it addresses interactions between the atmosphere and soils across spatial scales ranging from individual ecosystems to western North America. Specifically, we are examining the role of the spatial dispersal of fungi in structuring communities in Southern California. If our predictions are supported, and fungi are able to migrate and establish from regions that vary as widely in climate as the Pacific Northwest, the Great Basin, and central Mexico, then decomposer communities in Southern California may be able to shift effectively with global change. The ecological function of the fungal community may then display a degree of resilience under environmental perturbations. This information would be of use to land managers and restoration ecologists, since they could make informed decisions about the extent to which fungal communities would need to be intentionally manipulated during restoration and conservation projects to maintain ecosystem services. For example, if fungi do not migrate easily, then they may need to be manually introduced into ecosystems to maintain ecosystem function.

References


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