Chapter 7
Bacteria and Fungi in Green Roof Ecosystems

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Abstract Green roofs are one way by which cities are attempting to alleviate some of the problems associated with impervious surfaces in urban environments such as the urban heat island effect and stormwater runoff. In addition, green roofs provide a number of ecosystem services such as the provision of habitats for organisms residing in and migrating through the city that have only recently been studied and documented. Microorganisms such as fungi and bacteria have been found to be diverse and abundant components of green roof growing substrate and may contribute to some of the other benefits green roofs provide such as the removal of organic pollutants from precipitation. Here, we review several functional groups of microbes that may be useful for understanding in terms of green roof design and maintenance: mycorrhizal fungi, decomposer fungi, endophytes, N-fixing bacteria, and pathogens. These microbes interact with plant species and growing substrate in complex ways that require further investigation. The ecology of these microbial groups should also be considered, including their dispersal rates and how they respond to regional differences such as climate and seasonality. We highlight several research priorities for this area of work, which may ultimately facilitate greater functionality in green roof systems.

Keywords Soil · Microbes · Fungi · Bacteria · Urban parks · Mycorrhizae

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R. Sutton (ed.), *Green Roof Ecosystems,* Ecological Studies 223,
DOI 10.1007/978-3-319-14983-7_7

7.1 Introduction

Green roofs are so named for the vegetation that covers the otherwise impervious roof of a building. However, the fabric of the vegetated surface is supported by the growing medium in which an abundant and diverse community of microbes resides (Fig. 7.1). These microbes regulate a variety of the ecosystem services for which green roofs are valued such as the retention of water following precipitation events (Gaffin et al. 2009), the removal of air pollution (Yang et al. 2008), and the cycling of nutrients that support plant growth (Kremen 2005). Plants in non-engineered ecosystems cohabit with a variety of different microbes in their leaves, on their leaf surfaces, in their roots, and in the soil surrounding their roots.

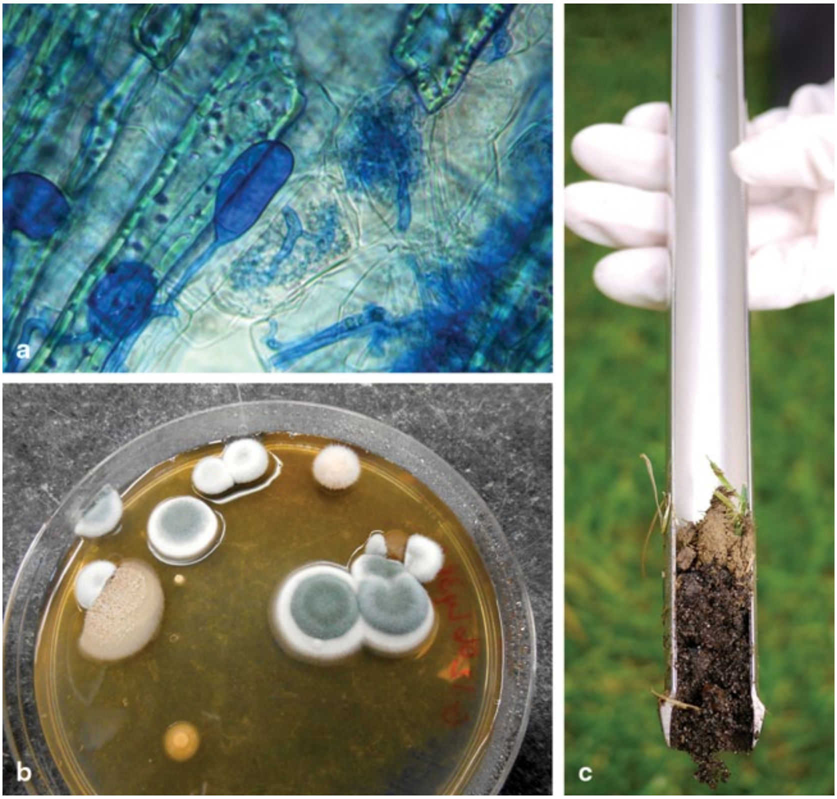

Fig. 7.1 Microbial communities of green roofs can be studied and visualized with a variety of techniques. Microscopy can be used to assess mycorrhizal colonization (a), culturing can be used for assaying nutrient preferences and physiological capabilities for some microbes (b) and molecular techniques can be used for DNA and/or RNA sequences from bulk soil cores (c). In panel a, the plant roots were cleared and the mycorrhizal fungal tissue was selectively stained *blue*; the *tree-like structures* are arbuscules and the globular structures are vesicles of the AM fungi. In panel b, fungal colonies were grown on selective media assessing for heavy metal tolerances of difference species cultured from *green* roof soils in New York City. Panel c depicts a soil core (0–10 cm) from a *green* roof located on the Barnard College campus that was subsequently sequenced for both bacterial and fungal DNA. (*Photo credits: Krista McGuire (a and b); Sara Payne (c)*

These plant-associated microbes have been considered an extension of a plant's phenotype (Kristin and Miranda 2013), and complex feedbacks occur that may even shape plant traits (Friesen et al. 2011). In addition to engaging in biotic interactions, microorganisms and plants on green roofs must also cope with extreme abiotic conditions such as aridity, high winds, ultraviolet light exposure, and high temperatures. These harsh conditions may interfere with some symbioses and cause a reduction in microbial abundance. However, very few studies to date have evaluated the composition and function of green roof microbes, despite their anticipated importance to the survival and performance of green roof plants.

Initial research has shown that the microbes most prevalent on green roofs are bacteria and fungi, which are also globally ubiquitous and the most diverse and abundant components of terrestrial soils (Hawksworth 2001; Curtis et al. 2006; Pace 1997; Fierer and Jackson 2006). These microbes shape terrestrial ecosystems in particular by performing critical roles in the biogeochemical cycling of N, P, and C, including degrading soil organic matter into compounds required for plant survival and growth (Swift et al. 1979; Wardle et al. 2004). Microbes can also influence plant diversity and productivity (Klironomos 2002; van der Heijden et al. 1998; van der Heijden et al. 2008; Schnitzer et al. 2011). It is becoming increasingly evident that in order to understand the functioning of ecosystems it is paramount to characterize the assemblages of fungi and bacteria in soils. Numerous studies have examined microbial community composition and associated ecosystem services in non-built environments (Bru et al. 2011; Bell et al. 2005); however, the identities and functions of the urban microbiota are only beginning to be uncovered (Xu et al. 2014; McGuire et al. 2013).

Green roofs are constructed environments representing 'novel ecosystems' that often contain species assemblages not observed in the absence of human intervention (Hobbs et al. 2006). Nonetheless, the same biotic and abiotic factors that operate in unconstructed environments will also likely be operating in green roof communities. Here, we provide a review of the information that exists on green roof microbial communities and give recommendations on future research priorities. We also review the role of specific functional groups of microbes in non-engineered ecosystems to inform how microbes might be functioning in engineered roof communities (Table 7.1).

Table 7.1 Microbial groups likely to be important in green roof ecosystems

Microbial group	Specific taxa	Function
Arbuscular mycor- rhizal fungi (AM)	500–1500 species of fungi from the *Glomeromycota* phylum	Mutualistic with plants to facilitate soil nutrient uptake
Decomposers	Bacteria and fungi from numerous phyla	Nutrient cycling; organic contaminant degradation
Endophytes	Fungi from *Ascomycota* phylum	Diverse, mostly unknown, but some are protective against plant herbivores and pathogens
N-fixing bacteria	Plant-associated and free-living bacteria and cyanobacteria	Convert atmospheric nitrogen (N_2) to ammonia (NH_3)

7.2 Microbial Groups in Green Roofs

7.2.1 Mycorrhizal Fungi

One of the most important groups of plant-associated microbes that are likely to play an important role in green roof plant communities are mycorrhizal fungi. Broadly, mycorrhizae are mutualistic associations between plant roots and soil fungi in which photosynthetically derived carbon (C) from the plant is exchanged for limiting nutrients that the fungi take up from soils.

There are seven different types of mycorrhizal associations that are classified according to their anatomical structures and the groups of fungi that engage in the partnerships (Smith and Read 2008). However, the herbaceous plants that are cultivated on green roofs (notably those from the *Crassulaceae, Asteraceae, Poaceae, Fabaceae*) will almost exclusively form arbuscular mycorrhizal (AM) associations (Fig. 7.1a). Arbuscular mycorrhizal (AM) fungi (phylum *Glomeromycota*) are the oldest mycorrhizal association that evolved approximately 460 million years ago with the migration of plants from aquatic habitats onto land (Redecker et al. 2000; Schussler et al. 2001; Wang and Qiu 2006). As such, most plants have retained the capacity to form AM associations and they are currently estimated to be present in >90% of all plant species (Schussler et al. 2001; Wang and Qiu 2006). In non-engineered systems, mycorrhizal fungi enhance plant survival and performance in harsh environmental conditions that are similar to what are experienced on roof top environments, such as frequent soil drying, shallow soils for root nutrient foraging, and low nutrient conditions. AM fungi have long been known to aid plants in drought tolerance (Auge 2001). Mycorrhizal fungi also increase the volume of soil that a plant has access to for nutrient foraging, which would be beneficial on roofs that have minimal fertilizer inputs (Schwartz and Hoeksema 1998).

While only a few studies to date have looked at mycorrhizal fungi in green roof systems, the evidence so far indicate that AM fungi are diverse and abundant in both plant roots and growing substrate. In one study that evaluated AM fungal colonization in green roof plant roots in the UK, it was found that *Sedum* and moss both had high colonization levels averaging 50% or more (Rumble and Gange 2013). Another study evaluating AM colonization across green roofs in Nova Scotia found that three plant species (*Solidago, Poa*, and *Danthonia*) had high levels of colonization, but that *Sedum acre* had low colonization (John et al. 2014). These findings suggest that individual species of *Sedum* vary in their degree of AM fungal colonization, although the extent to which the degree of mycorrhizal dependency relates to long-term viability and stress-tolerance in the plants is not known. In another study from New York City that sequenced fungal DNA in green roof growing substrate containing native grassland communities, the second most abundant group of fungi was the *Glomeromycota*, which accounted for 20% of the total fungal community (McGuire et al. 2013). There were a total of 154 OTUs (operational taxonomic units) of AM fungi detected across the ten roofs sampled in the latter study. While the next-generation sequencing used in that study could not separate out AM fungi by species, the genera *Glomus* and *Rhizophagus* were the most abundant AM fungi, which are widespread and associate with a variety of plants. Future studies should evaluate whether or not these particular AM fungal taxa are better suited for tolerating the urban environment and to what extent they are benefiting their associate plants. Mycorrhizal functioning can exist along a continuum from mutualism to parasitism, and in disturbed ecosystems, the reversal of mutualisms to more parasitic relationships has been observed (Kiers et al. 2010). However, it is also possible that the abiotic stresses experienced on green roofs may result in greater symbiont reliance due to poor environmental quality (Schwartz and Hoeksema 1998).

7.2.2 Decomposers

Another group of microbes likely to play a significant role in green roof ecosystems are decomposers or saprotrophs. Free-living bacteria and fungi that decompose organic material are responsible for the majority of nutrient cycling in soils, and their activity influences soil-atmospheric gas exchanges and soil C storage (Conrad 1996; Canfield et al. 2010; Six et al. 2006; Trivedi et al. 2013). On established green roofs, the senescent leaves of the perennial vegetation, root turnover, root exudates, and dead microbial biomass will be the dominant inputs driving decomposer activity. Compost mixed with growing substrate prior to green roof construction will also provide substrate for microbial decomposers, but eventually those organic food sources will be exhausted unless further compost is added. Immediately following a green roof installation, when compost volume is high, there will likely be an abundance of nutrients available for decomposers, and their degradation capacity may be saturated. If so, there is the chance that excess nutrients will run off of buildings following precipitation events (Gregoire and Clausen 2011; Chen 2013). This leakage of nutrients may contribute to eutrophication and could be more detrimental to the ecosystem than having a gray roof (Chap. 5). For this reason, understanding the decomposition capacity on a roof should be a key research priority to inform the quantity of compost that should be added to the growing substrate. This information could also aid in minimizing the loss of effective soil volume that results from imbalances of organic matter inputs with decomposition rates. To date, no studies to our knowledge have evaluated decomposition rates on green roofs.

The high temperatures of rooftop environments and the mechanical disturbance of precipitation falling directly onto the shallow growing substrate are also likely to impact microbial decomposer composition and activity (Davidson and Janssens 2006). Fungal decomposers may be particularly important on green roofs, as they are less sensitive to water stress than bacteria (Manzoni et al. 2012). A recent study found that green roofs in New York City had higher fungal to bacterial ratios than park soils (McGuire et al. 2013), which may be due to the aforementioned drought tolerance of fungi. However, in mechanically disturbed soils, bacteria become more prevalent, as hyphal networks of fungi become damaged, so these ratios may change in regions that experience high levels of precipitation or foot traffic on shallow substrate. Bacteria and fungi have differing physiological capacities (de Boer et al. 2005; Waring et al. 2013), so if decomposer abundance is fungal rather than bacterial-dominated, there will be biogeochemical consequences that can affect C and N cycling.

7.2.3 Nitrogen-Fixing Bacteria

Nitrogen (N)-fixing bacteria are a group of microbes that may be crucial to the survival of certain groups of plants on green roofs. Nitrogen is an essential limiting nutrient for plant growth, namely since it serves as a building block for chlorophyll, as well as proteins, DNA, and RNA. Atmospheric N is one of the most abundant elements, however is rendered unusable for ecosystem use until the bacteria can convert atmospheric N_2 to ammonia, a readily usable form of nitrogen (Berthrong et al. 2014). The majority of reactive nitrogen is produced during N-fixation by bacteria, and is estimated to amount to nearly 100–300 Tg of nitrogen per year on land (Fields 2004). Generally, nitrogen fixing bacteria are characterized as a type of plant growth- promoting rhizobacteria (PGPR), which can be defined as free-living bacteria capable of colonizing plant roots and providing benefits to the host plant (Nadeem et al. 2014). There are three broad categories of N-fixing bacteria based on their photosynthesis abilities and associations with plant roots: root-associated, free-living photosynthetic, and free-living non-photosynthetic N-fixing bacteria. Symbiotic N-fixing microbes require compounds derived from host plant rhizospheres, whereas free-living photosynthetic nitrogen-fixing bacteria can utilize self-produced sugars, and free-living non-photosynthetic bacteria must acquire energy from decomposing organic matter.

Herbaceous plants found on green roofs form many of these associations with the N-fixing bacteria due to the wide range of benefits that the N-fixing bacteria provide to plants. For instance, two herbaceous plant families commonly cultivated on green roofs, Poaceae and Fabaceae, are able to form close associations with N-fixing bacteria *Azospirillum* and *Bradyrhizobium*, respectively (Saikia et al. 2014; Sanchez-Pardo and Zornoza 2014). N-fixing bacteria provide benefits to these plants such as: increased plant growth (Prabha et al. 2013), improved water and nutrient uptake (Bertrand et al. 2000; Kraiser et al. 2011; Mishra et al. 2014), and suppressed pathogen attack (Ji et al. 2014). Additionally, N-fixing bacteria exhibit a diverse tolerance to varying soil pH and aluminium concentrations, which enable plant survival in acidic soils, commonly experienced on green roofs. By inoculating green roof substrates with N-fixing bacteria, it is likely that green roof vegetation will exhibit increased survival.

7.2.4 Endophytic Fungi

Endophytic fungi are another diverse group of plant-associated microbes that can be found in the leaf, stem, and root tissues of most plant species, and may assist with plant survival on green roofs (Rodriguez et al. 2009). Some endophytes protect plants against herbivores and pathogens, as most of them produce protective alkaloid compounds (Clay and Schardl 2002). There are other endophytes that have been shown to confer tolerance of plant hosts to stressful environments (Rodriguez et al. 2008). In addition to endophytes, other bacteria and fungi that have been detected in the phyllosphere of plants (i.e., microbes residing in and on leaves) may or may not be endophytic, but may also contribute to plant survival and environmental tolerance in roof environments. However, phyllosphere microbial communities in trees have been found to be sensitive to urbanization, so it is unclear what their abundance might be or role they play in green roof ecosystems. In one study of the oak (*Quercus*) phyllosphere in urban and non-urban environments it was found that urban phyllosphere microbial communities were distinct and less diverse than phyllosphere communities in nonurban environments (Jumpponen and Jones 2010). In another study evaluating endophytes in rural and suburban forests of Japan corroborated these results and found fewer endophytes in suburban ecosystems (Matsumura and Fukuda 2013). Thus, while endophytes and other phyllosphere microbes have the potential to be beneficial in green roof communities, their abilities to tolerate urban environments need further investigation.

7.2.5 Pathogens

Plant pathogens are the most detrimental microbes for the maintenance and longevity of green roof plant communities. Pathogens may be particularly problematic on roofs that are planted with only a few species of plants, as monocultures of plants have long been known to be susceptible to pathogen outbreaks because they will accrue specialized plant pathogens that can easily spread to conspecific neighbors (Shipton 1977). However, these pathogens are somewhat difficult to detect prior to attack, as most soil-borne pathogens grow saprophytically in the rhizosphere in order to increase in numbers and outcompete the established beneficial microbes to access the host plant (Berendsen et al. 2012). There have been no published studies to date on pathogen dynamics in green roof communities to our knowledge, although one study observed pathogens in moss panels that were planted with single clones (Akita et al. 2011). Future research may uncover ways by which microbial inoculum can be managed and added to green roof plant communities to effectively reduce pathogenic outbreaks (Gopal et al. 2013).

7.2.6 Microbial Interactions

The various functional groups of microbes in green roof ecosystems are not self-contained and there are numerous examples of how these groups engage in antagonistic, commensal, and mutualistic relationships with each other in soils. For example, N-fixing bacteria may have indirect negative effects on plant pathogens because when N is high and not a limiting factor for plant growth, plants will synthesize and store high levels of nitrogen-rich compounds to aid in future defense mechanisms. Such defense mechanisms include biosynthetic enzymes, proteinase inhibitors, chitinases, alkaloids, and glucosinolates (Schultz et al. 2013; Friesen et al. 2011). When plants are under attack, photosynthesis is suppressed, thus forcing the plant to rely on these nitrogen-compound stores (Gomez et al. 2010; Schultz et al. 2013). Mutualistic microbes such as N-fixing bacteria and mycorrhizal fungi may also negatively impact pathogens, as they contribute to plant defense by producing antagonistic molecules on the plant interior and can modify the expression of plant defense pathways (Fravel 1988, Liu 2013). There are also synergies between decomposer bacteria and mycorrhizal fungi. Some bacteria in the rhizosphere actually facilitate mycorrhizal colonization of plant roots and are appropriately called, 'mycorrhiza helper bacteria' (Garbaye 1994). Decomposer bacteria in the genus *Pseudomonas* have also been studied extensively for their antagonistic effects on root pathogens (Weller et al. 2002; Fravel 1988). *Pseudomonas fluorescens* bacteria can actually enhance the upregulation of certain transcription factors involved in plant disease resistance (Van der Ent et al. 2009). These dynamic interactions are complex and difficult to study, but they are important to understand, as they may ultimately impact green roof functioning and may be useful for inoculum-based management strategies.

7.3 Plant-Soil-Microbial Feedbacks: Considerations for Green Roof Design

Plant choice on green roofs will impact the communities of resident fungi and bacteria, which may ultimately affect roof function. For example, the chemical constituents of plant tissue (including root tissue), root exudates, and plant residues can affect microbial biomass, microbial species composition, and microbial activity rates (Philippot et al. 2013; Bardgett and Shine 1999). Plant genomes also help mold the structure and functioning of their associated microbiomes; in turn, these microbiomes contribute to plant fitness (Turner et al. 2013). The plants chosen for cultivation on green roofs usually require low maintenance and are selected based on their abilities to tolerate the harsh roof environment. At present, the majority of green roofs worldwide contain European species belonging to the genus *Sedum* (Crassulaceae), which are hardy, succulent plants that can tolerate the rooftop environment in temperate climates. Recently, however, there has been an interest in experimenting with plant communities native to the regions where green roofs are being built, to facilitate habitat provisioning for associated native biodiversity in the urban environment and to increase ecosystem services (Lundholm et al. 2010). While there have been many studies examining how microbes benefit plants and vice versa, there is still much to uncover about how extreme abiotic conditions experienced on the green roof affect microbe-plant interactions.

The choice of growing medium will also have a significant effect on the composition and function of green roof microbial communities, as microbes strongly respond to their biochemical environment (Fierer et al. 2009). Soil organic matter (SOM) in particular exerts a significant influence on microbial communities, especially in terms of microbial biomass, community structure and function, and substrate utilization (Wardle 1992). Available SOM is thought to promote the production of polysaccharides, which allow better uptake and release of water and fosters the aggregation of soil particles, leading to improved soil structure. Microbes are essential in facilitating the micro-aggregation of soil particles (Duchicela et al. 2012). Certain groups of microbes, notably the AM fungi, are additionally crucial in promoting macro-aggregate formation and durability. In general, natural soil systems have a limited nutrient supply, and as a consequence, microbial biomass is tightly and positively linked to SOM, which greatly impacts microbial function, including microbial activities in carbon and nitrogen cycling (Booth et al. 2005; Cookson et al. 2006). Fluctuating amounts of SOM may also lead to alterations in microbial community composition, and since microbial communities vary widely in their ability to break down organic compounds, changing levels of SOM could promote the survival of certain microbes and hinder the persistence of others (Degens and Harris 1997). Soil pH, which is also linked to SOM, also strongly influences the incorporation of soil organic carbon and nitrogen into the microbial biomass and is one of the most significant predictors of bacterial community composition worldwide (Lauber et al. 2009).

The structural constituents of the growing substrate will also influence resident microbes, as soil texture is recognized to be a critical factor in shaping microbial community structure by influencing the availability of water and SOM in soils (Bossio et al. 1998; Wardle 1992; Wakelin et al. 2008). High silt and clay content positively correlate with SOM and microbial biomass; however, high clay content negatively impacts nitrogen mineralization by shielding organic nitrogen from microbial degradation (Strong et al. 1999). The physical organization of soil particles also exerts a strong influence on the growth and function of fungal hyphae. Highly compacted soils may have narrow sand pores, which prevent hyphae from extending throughout the soil matrix and limit hyphal diameter, especially of AM fungi (Drew et al. 2003; Wakelin et al. 2008). In disturbed soils aggregates are disrupted and as a result, fungi are unable to form extended hyphae (Wardle 1992). In green roofs, the growing substrate is often porous, which may be conducive to fungal growth. However, the porosity will also facilitate substrate drying, which may prevent certain species from establishing, and may select for taxa that can tolerate frequent wetting and drying.

In order to maintain local biodiversity in a green roof habitat, it would presumably be beneficial to select local substrates and their indigenous microbial communities as a component of the growing substrate. Developers of green roofs have been looking to use locally derived granular wastes as green roof starting materials (Oberndorfer et al. 2007), but substrates are often obtained from many sources, and each source harbors its own resident microbial population. When this mixture of foreign substrates and microbes is introduced into a new environment, the species present initially can prevent colonization by later species and change the overall community structure (Dickie et al. 2012). These effects, referred to as priority effects, can be deleterious to efforts of promoting local biodiversity if growing substrate is sourced from non-local materials.

7.4 Environmental and Regional Differences Affecting Rooftop Microbes

Urban green roofs are exposed to elevated levels of organic pollutants, which may be an additional selecting factor for microorganisms that can survive in these habitats. Heavy metals such as lead, arsenic, and copper and other organic contaminants are particularly of interest based on their prevalence and toxicity in urban atmosphere, soils, and groundwater (Clark et al. 2008; Srogi 2007). Microorganisms can tolerate these contaminants and high metal concentrations by utilizing a variety of physicochemical mechanisms to efficiently capture dissolved metal ions and convert metals from toxic to non-toxic forms. Other microbes can adapt to polluted urban areas by developing metal-resistance or utilizing contaminants as substrates through natural means of detoxification (Nikel et al. 2013; Hanif et al. 2010; Vullo et al. 2008). In a study of green roof fungal communities in New York City, the most abundant taxa were identified as fungi capable of degrading organic contaminants and tolerating heavy metal contamination such as *Pseudallescheria, Peyronellaea*, and *Thielavia* (McGuire et al. 2013).

Regional differences among green roof communities must also consider dispersal dynamics of microbes across the fragmented landscapes both within cities and across local urban to rural gradients, as local and regional wind patterns are likely to shape the community of fungi dispersing from green spaces on to green roofs and vice versa. Green roof ecosystems can be compared to island habitats residing within the ‘ocean’ of the urban environment. In actual island communities, two key processes that maintain species diversity over time are immigration and extinction. For green roof microbial communities, the ecological processes underpinning community assembly and the maintenance of diversity through time may be similar in some ways to island habitats, although the stress tolerance needed for immigrant propagules to survive and establish may cause higher extinction rates than would be observed in island ecosystems. The transport of propagules to green roof communities will be limited by the dispersal capabilities of individual taxa, as well as the distance a roof is from a source population of propagules. While it was historically thought that all microbes were everywhere (Baas-Becking 1934) we now know that dispersal limitation can occur for some microbial groups. For example, AM fungi are unlikely to be actively dispersed by animals across green roof habitats, unless they can be carried by birds and insects, as the dispersal of AM fungi is often accomplished by animals in non-engineered landscapes (Lekberg et al. 2011). Biogeographical structuring is also apparent for many microbial taxa, further supporting the notion that 'everything is not everywhere'. However, since dispersal is rarely assessed in microbial systems, the mechanisms of dispersal limitation versus environmental filtering cannot be disentangled without further studies that simultaneously address both processes.

7.5 Practical Applications and Future Research Priorities

Managing microbial inoculum to enhance green roof functionality can only be done with significantly more research on plant-microbial feedbacks in rooftop environments. However, additions of AM fungal inoculum have been standard practices in horticultural science, (Azcon-Aguilar and Barea 1997) and may also prove to be a useful management strategy for green roofs to maximize plant nutrient uptake, growth, and survival. The particular assemblages of AM fungi will need to be plant community specific, as the degree of benefit will likely vary with different plant-fungal combinations. Also, the particular mycorrhizal fungal taxa will need to be able to withstand the urban and rooftop environments. There are less than 500 species of AM fungi currently described, although total estimates are upwards of 1300 species (Kivlin et al. 2011; Opik et al. 2014). Considering that there are more than 300,000 species of described plants, and more than 75 % of them form AM associations (Wang and Qiu 2006), there are clearly many species of plants that share the same AM fungi. While most AM fungi are considered to be host-generalists, different combinations of AM fungi can have differential effects on plant performance (Helgason et al. 2002).

In addition to the practical considerations, green roofs can also be utilized to study basic ecological processes such as microbial community assembly and population dynamics. For instance, a microbe that is beneficial to the plant in one interaction can be detrimental to another host genotype. Additionally, plant-microbe mutualisms can evolve into parasitism in certain environmental contexts. With this in mind, practical benefits can be gained to ensure plant-microbe compatibility when selecting green roof vegetation.

Urban centers experience greater rates of deposition of heavy metals and other organic pollutants compared to non-urban areas (Chillrud et al. 1999). These potentially toxic compounds pose as a threat to human health since they can leach into local water sources from vehicles and streets or be inhaled. A major research priority is to determine if the various green roof-associated microbes are able to actively degrade organic contaminants and bioaccumulate heavy metals. Upon identifying various microbial strains possessing pollutant and metal detoxification capabilities, they can be inoculated in green roofs, which would serve as an appealing bioremediation effort in urban spaces.

7.6 Summary

Although microbes are essential to the functioning of green roofs as ecosystems, there is still much to understand about the drivers of microbial diversity and their spatial distribution throughout urban centers. Microbial interactions and their relationships to aboveground plant communities are inherently complex (Bonfante and Anca 2009). First, we must identify which plants both persist best on green roofs and provide high levels of desired functions (e.g., cooling, transpiration, habitat, appearance, etc.). Upon selecting types of plants, long-term persistence of these species on rooftop environments is intricately linked to how microbial dynamics contribute to their survival or failure to thrive (Table 7.1). Plant-associated microbes that enhance survival may be inoculated in establishing green roofs to increase plant longevity in the harsh conditions. These beneficial microbes can prevent colonization by pathogens, mediate host immunity, and help plants distinguish between mutualists versus pathogens. By utilizing a combination of culture-based and molecular techniques, microbes should be identified and studied to understand their interaction with green roof vegetation. Further research priorities should include determining to what extent green roof microbial communities are shaped by abiotic versus biotic factors over time since establishment, how microbial taxa can disperse via air and establish in green roof environments, and how local microsite conditions modify the novel microbial communities planted on green roofs. Ultimately, this information will be invaluable to the design of optimal green roof communities and will enhance sustainability efforts in urban environments.

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