Hands-On Ecological Restoration as a Nature-Based Health Intervention: Reciprocal Restoration for People and Ecosystems

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Abstract

There is growing concern that lack of access to natural habitats—especially ones with diverse soil microbiota and vegetation—exacerbates individual human and community health problems. Accordingly, practitioners concerned with both human and ecological health have proposed a number of nature-based interventions to improve human health. Two of many promising advances are the Microbiome Rewilding Hypothesis (MRH) and the Psycho-Evolutionary Restoration Hypothesis (PERH). While MRH primarily evaluates whether the restoration of soil microbiota can enhance human gut microbiome health and brain function, PERH tests whether reintroduction of native plant species rich in aromatic phytoncides can reduce depression and lower cortisol levels. Such complementary approaches to the reciprocal restoration of biodiverse habitats and human health are engaging people in nature-based initiatives around the world. We offer examples of programs involving youth directly in ecological restoration activities that may also benefit human health. In particular, we explore how restoring both microbiotic soil crusts and aromatic plant guilds in the urban heat islands—especially in hot, dusty desert cities—can reduce the psychological and physical impacts of diseases such as valley fever, asthma, and other diseases exacerbated by climate change. We report on pioneering tests of indicators of soil microbiome diversity, phytoncide/biogenic volatile organic compound (BVOC) diversity, and youth responses to restoration work that can be monitored concurrently over time. We call for more collaboration among restoration ecologists and ecopsychologists to better determine the ultimate and proximate causes of nature-deficit disorders and the impacts of ecological restoration interventions on physical and mental health. Key Words: Ecological restoration—Health intervention—Microbiome—Phytoncides—Climate change—Reciprocal restoration.

Introduction

Conservation biologists, restoration ecologists, epidemiologists, and public health scientists and practitioners are among those concerned that accelerating climate change is already having dramatically negative impacts on biodiversity, ecosystem health and integrity, and human health (Kolivras, Johnson, Comrie, & Yool, 2001; Liddicoat et al., 2018). Because it is well understood that frequent access to diverse, healthy environments can have moderate to exceptional benefits on physical health and psychological well-being, scientists and practitioners from many disciplines have come together on these issues to solve real-life problems (Martinez-Juarez et al., 2015; Wall, Nielsen, & Six, 2015).

In addition, popular scientific literature has generated an ever-growing audience and alliances of educators, planners, and laypersons interested in the issue of how the loss of biodiversity and access of natural habitats may be impacting human health, particularly for urban youth (Miller, 2013; Nabhan & Trimble, 1995; Williams, 2017). Some of these health concerns are attributed to the overuse of antibiotics and fungicides as explained by the Hygiene Hypothesis (Velasquez-Manoff, 2012), exposure to poor air quality, or lack of physical activity. Several of these authors and their readers are hopeful that as urban youth gain greater access to natural, agricultural, and restored sites near their homes and schools, physical and mental health problems may be mitigated or alleviated (Miller, 2013; Nabhan & Trimble, 1995; Williams, 2017).

Moving Toward Evidence-Grounded Interventions to Co-Benefit Ecosystem Health and Human Health

It is not surprising that more and more nature-based interventions—such as engagement in urban regreening or ecological restoration—are being initiated to improve community health. This engagement is happening at local, regional, and global levels, from urban gardens to the United Nations Decade on Ecological Restoration. An example of an organization with regional and international impact is the EcoHealth Network, which operates as facilitator and convener to a growing network of linked restoration sites concerned with the science, practice, and policy of restoring ecosystem "health" and human health while helping to trailblaze a "restorative culture" for global society (Cross, Nevill, Dixon, & Aronson, 2019).

It has been inferred from a number of studies that nature-based interventions may potentially improve the physical health of urban youth engaged in restored habitats with regard to the following indicators:

- greater anti-inflammatory capacity (Deans, 2017);
- greater cardiovascular fitness (Williams, 2017);
- greater resistance to endoparasites (Wall et al., 2015);
- greater resistance to infectious (especially respiratory) diseases (Liddicoat et al., 2018);
- reduced sensitivity to allergens (Wall et al., 2015);
- reduced frequency of nervous and musculoskeletal disorders (Robinson & Breed, 2019);
- reduced vulnerability to obesity and adult-onset diabetes (Deans, 2017);
- disease prevention (Mills et al., 2017).

There are also indications that nature-based interventions may have the capacity to positively affect the following indicators of mental health or psychological well-being:

- reduced anxiety (Chun et al., 2017);
- reduced vulnerability to autism spectrum disorders (Clarke et al., 2013);
- reduced stress-related cortisol levels (Park et al., 2007; Ibrahim, Somers, Luecken, Fabricius, & Cookston, 2017; Ward Thompson et al., 2012);
- greater perceived sense of restorativeness (Breitenbecher & Fuegen, 2019; Hartig, Korpela, Evans, & Gärling, 1997);
- reduced neurodevelopmental disorders (Clarke et al., 2013);
- reduced severity of depression (Chun et al., 2017);
- increased cognitive function (Bratman, Hamilton, & Daily, 2012);
- greater social cohesion (Chou, Wu, & Huang, 2017).

Hypotheses Regarding Ultimate and Proximate Causes of Nature-Deficit Disorders

The perceived ultimate causes of these presumed "nature-deficit disorders" (Louv, 2005), and the capacity for nature-based interventions to prevent or heal them, are often interpreted through the lens of Edward O. Wilson's Biophilia Hypothesis. It poses the possibility that the deep affiliations humans have with other life-forms and nature as a whole are rooted in our evolutionary history and hard-wired into our population genetics (Kellert & Wilson, 1993). When we become isolated from those ecological interactions with other species, our physical and psychological health is presumably challenged or compromised. Current medical findings also suggest that early childhood exposure to particular microorganisms protects against allergies and other immunological and inflammatory conditions. The Hygiene Hypotheses or Microbiome Deficiency Hypothesis suggests a human coevolution with "old friends"—microbes that have played a key role in immune system development during mammalian and human evolution. This "friendship"—a symbiotic relationship between a host and billions of microbial organisms—can be disrupted by a number of synthetic chemicals and pharmaceuticals, including biocides, disinfectants, pesticides, and antibiotics, each of which can reduce the density and diversity of beneficial microbiota considered necessary for human health and resilience (Francino, 2016; Gillings, Paulsen, & Tetu, 2015; Miller, 2013; Samsel & Seneff, 2013; Velasquez-Manoff, 2012).

The Biophilia Hypothesis and its heuristic value were first fully elaborated at a retreat for anthropologists, ecologists, and psychologists brought together by Edward O. Wilson and Stephen Kellert (Kellert & Wilson, 1993; Nabhan & Trimble, 1995). Since the publication of their 1993 book, *The Biophilia Hypothesis,* at least two complementary approaches to applying the Biophilia Hypothesis have developed, each with valid but still-debated interpretations of the proximate causes of particular physical and psychological disorders.

The first approach is the Microbiome Rewilding Hypothesis (MRH), with strategies being tested that favor restoring soil microbiotic diversity to enhance human gut microbiome health and brain function (Mayer et al., 2014; Mills et al., 2017; Wall et al., 2015). The second is the Psycho-Evolutionary Restoration Hypothesis (PERH), which focuses on exposing patients to old-growth or restored forest ecosystems. The plants selected for reforestation are rich in aromatic phytoncides—biologically active chemical components, also known as biogenic volatile organic compounds (BVOCs), that may reduce depression and lower cortisol levels (Miyazaki, Lee, Park, Tsunetgutsu, & Matsunaga, 2011; Park et al., 2007; Williams, 2017). Clearly, MRH and PERH are complementary, not competing approaches. Given the often very large spatial scales of lands and water bodies being slated for ecological restoration during the above-cited United Nations Decade on Ecological Restoration, the landscapes and seascapes undergoing restoration work will be heterogenous in many ways. As a result, different interventions must be conceived and implemented in different landscape units and different strategies applied for evaluating the impact on human populations—both those people participating in the work and those affected by it after the fact. Several studies document that frequent contact with the broadest possible biodiversity in "green spaces" is what generates a wide range of the health benefits from nature-based inventions, including stress reduction, improved mental health, and increased longevity (Barton & Pretty, 2010; Maas et al., 2009; Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006; Takano, Nakamura, & Watanabe, 2002; Ward Thompson et al., 2012). Initially, this was inferred from studies where the *lack of access* to natural habitats—especially ones with diverse soil microbiota and vegetation—exacerbates health problems. But that is changing, as ecological restoration projects and programs are proactively building human health considerations into their research and monitoring designs.

Today, newly designed initiatives have the capability to confirm tangible, verifiable health benefits clearly derived from ecological restoration itself (Mills et al., 2017; Speldewinde et al., 2015). As interest in the linkages between ecological restoration and human health grows, we expect to see a significant increase in related published research. For example, landscapes in South Korea where reforestation with hinoki cypress *(Chamaecyparis obtusa)* began in the1960s have recently become major research sites for the Korea Forest Research Institute. Its foresters, chemists, and psychologists are documenting the role that phytoncides (BVOCs) may play in lowering levels of the stress-related hormone cortisol and in reducing asthma symptoms among Korean patients who frequently walk trails in these forests (Williams, 2017).

A number of field, clinical, and laboratory studies from Japan and South Korea suggest that there are multiple benefits of frequent exposure to BVOCs from *shinrin-yoku* "forest bathing" under cypress, juniper, and pine foliage that includes camphor, humulenes, limonenes, pinenes, sabinenes, and terpenes (Park et al., 2007). However, the onset of these health benefits cannot be directly correlated with rates of forest restoration in South Korea over the equivalent time periods. Nevertheless, these case studies currently offer one of the best proxies we have of a positive feedback loop between forest restoration and human health restoration.

The Rise of Nature-Based Interventions Engaging Youth

Several proponents of nature-based interventions have suggested that youth engagement in therapeutic horticulture, biodiversity conservation, civic agriculture ("care farming"), time spent immersed in nature ("forest bathing"), and wilderness survival activities may qualify for "green prescriptions" (Robinson & Breed, 2019). Young people may therefore have the chance to tangibly engage in what Native American ecologist Robin Kimmerer (2013) calls *reciprocal restoration* of land health and human health. Specifically, there are critical research opportunities for explicitly evaluating to what degree the youth engaged in ecological restoration work crews exhibit positive or negative changes in their psychical and psychological health over the period of time in hands-on activities.

Among the many examples of field programs that engage youth in hands-on restoration programs in the United States are the Ashland Watershed Youth Training and Employment Program of the Lomakatsi Restoration Project in Ashland, Oregon; Earth Partnership of the University of Wisconsin Arboretum in Madison, Wisconsin; Franciscan Earth Care program of the Franciscan Action Network in Syracuse, New York; Growing the Next Generation of Ecologists Internship Program of the Institute of Applied Ecology in Corvallis, Oregon; Youth Stewards program of Grassroots Ecology, Palo Alto, California; GreenRoots in Boston, Massachusetts; and the Inner-City Youth Engagement in Urban Habitat Restoration program of the St. Mary's Youth Farm in San Francisco, California.

These field programs—among many others—have engaged African American, Asian American, Hispanic American, Native American, and immigrant youth from many other nations in hands-on restoration work within towns and urban areas (Grimm, 1997). In other countries around the world, there are many other programs that could be cited as well. However, there is as yet almost zero scientific literature on this kind of work, which reflects a major gap that needs to be addressed.

Evaluating One Program's Potential for Documenting the Benefits of Reciprocal Restoration Efforts of Human Health

To illustrate some of the core elements of youth ecological restoration programs and their specific impacts, we will take a closer look at Borderlands Earth Care Youth Institute, a summer program based at the Borderlands Restoration Network (a member of the EcoHealth Network) in Patagonia, Arizona, near the Arizona-Sonora Mexico border. Two of the authors, Nabhan and Monti, founded the program in 2012, which has involved more than 130 youth from 13 to 19 years of age (Adams, 2016). This program intentionally engages diverse groups of students in hands-on "reciprocal" restoration activities and as such may exemplify the opportunities for assessing how nature-based interventions improve the physical and psychological health of their participants.

The high school program engages both Anglo and Hispanic youth from low-income households in urban and rural communities along the Arizona-Mexico border in the Greater Sonoran Desert. The program's in-depth experiential learning and apprenticeships allow youth to become engaged in hands-on restoration work in coniferous forests, oak savannas, mesquite grasslands, deserts, wetlands, and urban landscapes in or near Douglas, Patagonia, Sonoita, and Nogales, Arizona (Weaver, 2017). Each crew and its facilitators spend 32 hours a week for 6 weeks of paid work focusing on restorative activities—working outdoors with other young people—that include direct contact with the soil microbiome and waterbodies, and volatile organic compounds from plants:

- building ponds for fish and aquatic wildlife;
- transplanting native semiaquatic plant species;
- constructing erosion control structures along watercourses;
- restoring springs and wetlands;
- regenerating migratory corridors for endangered species;
- removing invasive species;
- collecting and propagating seeds of native plants for pollinators;
- composting to build microbially rich soils;
- planting hedgerows of fruit and nut trees;
- sowing wildflower meadows;
- constructing check dams for rainwater harvesting and flood control;
- cultivating plants in gardens, farms, and nurseries.

In addition, students read essays on land ethics and nature and record their own perspectives in journals, thereby charting the arc of their intellectual, emotional, and social learning experiences. By engaging in group reflections on these topics, values are reinforced, restoration competencies are advanced, and team building takes place. This social process is surely restorative, as is also the physical exercise related to ecological restoration. This is an important area for study. Program documentation for evaluating outcomes currently consists of a baseline health record and a pre- and post-fieldwork questionnaire. The results consistently document the positive effects of the program, including increases in capacity for environmental restoration, leadership, sense of community and social responsibility, improved emotional and physical strength, and weight loss.

Toward Designing New Initiatives to Better Track How Ecological Restoration Benefits Affect the Health of Youth Participants

Youth restoration programs like these offer opportunities for researchers in ecopsychology, and other areas of human health and ecological restoration, to engage in robust inquiry into the impacts of ecological restoration interventions. In this instance, we can better evaluate the health of culturally diverse youth working in restoration programs such as the one described here, taking place in stark desert and transborder environments. Such inquiries could include the following:

(1) How nationality, ethnicity, population density, and other factors influence health outcomes;
(2) How outdoor physical work and participation in habitat or ecosystem restoration as part of a group can influence a perceived sense of restorativeness that not only reflects the changing quality of a site or " environment" but also other subjective and quantifiable measures to assess the potential of ecological restoration work to improve cognitive function, and other indicators of mental and physical health and, more broadly, human well-being;
(3) How knowledge, skills, principles, and values gained in restoring once-degraded habitats can be applied in other contexts; and
(4) How exposure to an enhanced soil microbiome and to plants rich in aromatic volatiles may impact respiratory health, oxidative stress, immune function, and inflammatory responses.

Youth restoration crews at the Borderlands Earth Care Youth Institute and programs like it often involve high school and college students in field activities during the height of summer heat and drought. This often follows months of student engagement in temperature-controlled classroom conditions that deprive them of extended daytime exposure to natural light habitats. This shift in learning environments sets up a replicable before/after (pre-post) contrast set for evaluating changes in psychological health.

To more fully measure and compare the impacts of such nature-based interventions on health, researchers have begun to use a variety of methodical tools, including surveys and physiological measures such as blood pressure, heart rate, and salivary cortisol levels. Miyazaki and his colleagues, for example, use extensive evaluation protocols to track physical and mental health changes of people that regularly walk any of 50 officially designated Forest Therapy trails in Japan (Miyazaki et al., 2011; Williams, 2017).

More interdisciplinary engagement is needed to develop meaningful measures to assess the impacts of nature-based interventions on human and ecosystem health. Ecopsychologists can play a pivotal role in design program components and measures that can offer means to correlate environmental restoration advances with physical and mental health measures to monitor the effects of nature-based solutions on urban youth.

Field research is also needed to measure indicators of soil microbiome diversity and survey plant diversity at the schoolyards and restoration sites frequented by youth participants in restoration. For this a number of methods already exist. For example, Liddicoat et al. (2018) have proposed and pilot-tested the use of ambient soil cation exchange capacity as a proximate indicator of soil microbiome health—and associated levels of infectious and parasitic disease risk—across regions of Australia.

Students themselves can be engaged in measuring plant species diversity and cover using a relatively simple rapid assessment method pioneered by McAuliffe (1990). Other investigators in arid lands have documented the cultural and ecological importance of trees by measuring canopy/understory relationships and the cultural importance among associated plants, particularly in relation to nurse plant guilds found in desert areas (Burquez-Montijo & Quintana, 1994; Monti, 2002; Tuxill & Nabhan, 1992).

We call for more integrated studies of restored habitats and their restoration stewards to be undertaken in both urban and rural settings. These studies should attempt to positively or negatively correlate the changes in ecological health (e.g., on soil microbial and plant diversity) to human health (such as gut microbiome and respiratory health) with and among specific biomes. If each integrated study could target the effects on a particular disease exhibiting an increasing prevalence in a particular landscape, the costs and benefits of restoration-based interventions could be better assessed.

Current Challenges

We are especially concerned that restoration efforts might be needed to alleviate the rising prevalence of diseases associated with accelerated climate change and urban heat island effects across the 40% of the planet's terrestrial surface found in arid and semiarid regions. One such heat-exacerbated disease which is reaching epidemic proportions in desert cities and agricultural valleys is coccidiomycosis (valley fever), a systemic fungal infection caused by the fungus *Coccidioides immitis* that is endemic in dry dusty environments of the Western Hemisphere, including the desert Southwest in the United States. The microscopic spores of the soil-dwelling *C. immitis* are dispersed by hot winds, drought, and soil disturbance (Kolivras et al., 2001). The number of reported cases is increasing as much as 80–98% from year to year in the Sonoran Desert and Mohave Desert regions of the Southwest, including dramatic increases in Arizona counties where Borderlands Restoration Network youth programs are engaged (Park et al., 2005). Its current prevalence appears to be a result of climate change, urban heat island effects, and soil disturbance from land clearing for peri-urban residential developments (Baptista-Rosas, Hinojosa, & Riquelme, 2007).

A common clinical presentation of valley fever is acute respiratory distress leading to coccidiomycosis pneumonia. In rare cases, the fungal infection invades not only the lungs but the meninges and the parenchyma (white matter) of the brain, causing stroke-like symptoms (Miller, 2016). This is a clear example of soil microbiome–human microbiome–brain interactions (Deans, 2017; Mayer et al., 2014; Miller, 2016; Velasquez-Manoff, 2012).

Extensive habitat restoration in desert environments could reduce the economic burden of this dust-borne disease. In both Arizona and California, there has been detailed tracking of the total economic and specific health care costs associated with valley fever for at least two decades. A recent analysis of the lifetime cost from all infections alone is US $700 million, with per patient costs ranging from US $20,000 to US $1,000,000 (Wilson et al., 2019).

The global public health crisis caused by COVID-19, a disease produced by acute respiratory syndrome coronavirus 2 (SARS-CoV-2), demonstrates the importance of addressing the potential for compounding health effects in regions where coccidiomycosis is endemic. In a summary of a report from the Chinese Center for Disease Control and Prevention, Wu and McGoogan (2020) show that the case fatality rate for COVID-19 was elevated among those with chronic respiratory disease (Wu & McGoogan, 2020). It is not too early to recognize the huge potential of ecological restoration for improving the health outcomes of COVID-19 and other zoonotic diseases.

Future Directions for an Increasingly Arid World

Ecological restoration is a complex, long-term task. Estimating, monitoring, and evaluating what success—or at least forward progress against a clear set of goals—will look like in a hotter, drier world affected by climate change may be even more daunting over the next generation (Falk, 2017). However, numerous restoration efforts in hot, dry landscapes have been documented in peer-reviewed literature (Bainbridge, 2007; Holmes et al., 2020; Whaley et al., 2015). These can help guide large-scale restoration of disturbed desert soils as a means to reduce respiratory diseases and other illnesses.

For example, recent efforts to inoculate transplants or seeds with arbuscular mycorrhizal fungi have dramatically increased the success of revegetation and soil stabilization efforts in desert landscapes (Zhang, Sun, Shi, & Feng, 2012). Another example from the North American deserts focuses on cyanobacteria that naturally form desert soil crusts, a community of organisms in topsoil that contribute to soil fertility and help prevent erosion (Johnson & MacGregor, 1971).

Biological soil crusts in arid regions are easily disturbed by people. Their reestablishment in disturbed drylands, for instance by inoculation treatments for cyanobacteria density, can contribute to ecological restoration goals (Chiquoine, Abella, & Bowker, 2016). Microbial inoculations can aid in the formation of islands of fertility and diversity (Burquez-Montijo & Quintana, 1994; Garner & Steinberger, 1989). These nursery grounds of diverse desert resources foster more stable desert nurse plant guilds that can serve as biofilters to reduce wind and water erosion in desert habitats (Carillo-Garcia, De LaLuz, Bashan, & Bethelenfalvy, 2002). Such nurse plant guilds of desert legume trees, cacti, and aromatic shrubs are the sources for the dispersal of soil microbiota to surrounding areas, measurably increasing diversity in the soil microbiome of landscapes (Burquez-Montijo & Quintana, 1994; Carillo-Garcia et al., 2002).

Remarkably, these desert nurse plant guilds are also extremely rich in the same phytoncides (BVOCs) found in the temperate forests of Korea and Japan, where they enhance the health benefits of *shinrin-yoku* (forest bathing) practices. Among the pervasive phytoncides in Sonoran Desert trees, shrubs, and herbs are the following: pinene *(Hyptis, Larrea, Lycium);* limonene *(Hyptis, Larrea, Lycium, Sambucus,* and *Capsicum);* linalool *(Hyptis, Sambucus, Portulaca);* camphor/kaempherol *(Hyptis, Larrea, Parkinsonia* and *Salvia);* and thymol (*Lippia, Portulaca,* and *Solanum)* and carvracol *(Lippia)* (Guenther et al., 2000; Nabhan et al., 2020; Tanowitz et al., 1984).

In fact, many plant species growing in extreme environments like deserts are particularly rich in phytoncides, which have evolved not only to repel herbivorous insects but also to reduce solar radiation and the loss of moisture by transpiration from the plants' leaves (Rinnan, Steinke, McGenity, & Loreto, 2014). It may well be that once restored, desert habitats rich in aromatic plants can provide health benefits to restoration workers, hikers, nearby dwellers, and hospital patients comparable to those in the temperate forest trails of Korea and Japan.

Conclusions

Many programs around the world are engaging young people in hands-on ecological restoration projects that promise to enhance not only ecosystem health but also human health. These programs will become more significant as climate disruptions damage natural habitats and increase health problems, including a group of health conditions called diseases of oxidative stress. There has been intriguing preliminary evidence from several different regions of the world that engagement with formerly damaged habitats that are sites of active ecological restoration work can benefit participants and nearby populations as reflected by data on a number of different indicators of physical and psychological health. Now is a critical time to deepen both the research designs and modes of evaluation to determine the degree to which engagement in ecological restoration reciprocally benefits human health, including, for example, the health of youth participants in the Borderlands Earth Care Youth Institute's programs. The Microbiome Rewilding Hypothesis and the Psycho-Evolutionary Restoration Hypothesis are two such modes of evaluation. They are part of a larger toolbox of partial solutions to the degradation of ecosystem health and integrity and human health. The urgency with which we must act to restore ecosystems puts special emphasis on these two approaches, even though knowledge gaps exist, because they are building strong research foundations. The toolbox needs many more tools and approaches.

We recommend monitoring the soil microbiome, plant diversity, water quality, and human health impacts of restoration projects over relevant timescales, especially where costly infectious disease epidemics are becoming more prevalent. If executed properly, we may arrive at cost and co-benefit estimates of restoration work across a spectrum of cultures and ecosystem types that could help direct more investments from the health sector to this form of preventive, nature-based "medicine."

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