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Don't Bust the Biological Soil Crust: Preserving and Restoring an Important Desert Resource

Sheltered from wind and scorching heat, a seedling takes root in mature biological soil crust (photo by Neal Herbert, National Park Service).

SUMMARY

Biological soil crusts are a complex of microscopic organisms growing on the soil surface in many arid and semi-arid ecosystems. These crusts perform the important role of stabilizing soil and reducing or eliminating water and wind erosion. One of the largest threats to biological soil crusts in the arid and semi-arid areas of the western United States is mechanical disturbance from vehicle traffic and grazing. The spread of the annual invasive cheatgrass has increased the fuel load in areas that previously would not carry a fire, posing a potentially widespread and new threat to this resource.

Recovery times for biological soil crusts are highly variable, and depend largely on the timing of disturbance and amount of moisture, with moisture hastening recolonization of crust organisms. Attempts to artificially restore biological soil crusts have been largely unsuccessful. However, crust organisms are airborne over short and long distances, and crusts can recover on their own when undisturbed and given time to reestablish.

Steve Warren has spent much of his career looking at the ground in arid areas of the world. A disturbance ecologist with the U.S. Forest Service Rocky Mountain Research Station, Steve has devoted over 35 years to closely examining something most people would trample over without ever noticing—small ecosystems on the soil surface in arid areas known as "biological soil crusts."

Biological soil crusts are found in every desert in the world, including the driest desert on Earth—the Atacama in Chile—where the rainfall can be less than 1 millimeter per year. Although soil crusts are variable in

Biological soil crusts fill in soil spaces not occupied by plants and can amount to 70 percent or more of the non-rocky ground cover (photo courtesy of U.S. Geological Survey, Canyonlands Research Station).

composition, they generally develop when microscopic algae and fungi, lichens, and mosses grow on and in the soil surface, entwining and adhering soil particles to form a matrix that helps to stabilize the soil.

Soil stabilization is especially important in arid areas where there are large expanses lacking plant cover. Dozens of studies have found that soil crusts reduce or completely eliminate erosion of soil by water and wind that would otherwise be widespread in these areas. Biological soil crusts also trap soil moisture, fix nitrogen from the atmosphere, and provide sheltered areas for plants to germinate and grow.

Because of the importance of soil crusts in arid ecosystems, managers need information on how to minimize impacts, the length of recovery time after a disturbance, and ways to speed up recovery through restoration practices. Warren, who is part of the Grassland, Shrubland, and Desert (GSD) Program at RMRS, and collaborators, including Larry St. Clair, a lichenologist at Brigham Young University, have spent several decades addressing these issues.

BIOLOGICAL SOILS CRUSTS ARE A BENEFICIAL COMBINATION OF ORGANISMS AND THEIR BY-PRODUCTS

To the trained eye, biological soil crusts are easy to see. "They have a certain color and a roughness, even in the early stages of colonization after a disturbance," says Warren. In the Great Basin and Colorado Plateau, one of the earliest soil crust species to colonize an area is the cyanobacterium *Microcoleus vaginatus*. This species secretes sticky substances that adhere to soil particles and act as a glue to help to stabilize arid soils. "I can take a knife and lift a piece of the crust and see the filaments of this cyanobacteria hanging down with sand particles stuck to them," Warren explains.

The thin filaments of cyanobacteria secrete sticky substances that bind soil particles in biological soil crusts, shown here at 90X magnification using a scanning electron microscope (photo by Neal Herbert, National Park Service).

Grassland, Shrubland, and Desert Program

Almost half of all lands managed by the U.S. Forest Service are treeless, especially in the Southwest and Intermountain Regions of the Forest Service. The Grassland, Shrubland, and Desert Program (GSD) at RMRS works on developing an understanding of the ecology and management approaches for these arid and semi-arid ecosystems. Scientists, professional technicians, and support staff with the GSD Program develop and deliver scientific knowledge, technology, and tools that will enable people to sustain and restore grasslands, shrublands, and deserts under increasing threats from human-related uses, invasive species, changing disturbance patterns, and climate change.

After the cyanobacteria colonize the soil surface, other organisms may join them. "As a general rule," says Warren, "the successional sequence of crust development in the Great Basin would be the cyanobacteria, then lichens, and then the mosses, although the earliest-colonizing organisms are there throughout." In the hotter, drier deserts such as the Mojave, cyanobacteria and algae remain the dominant components of the crusts, giving a relatively smoother appearance. In areas that are a little wetter and exposed to freezing and thawing—like the Great Basin and Colorado Plateau—the crust may take on a rougher appearance due to frost heaving and higher proportions of lichens and mosses that follow the cyanobacteria.

Biological soil crusts can cover large areas in arid ecosystems where plant cover is naturally limited by water availability. In some ecosystems, the biomass produced by soil crusts is even greater than that produced by vascular plants. The crusts add stability and erosion-resistance to soils, while performing other important ecological functions.

Cyanobacteria can capture nitrogen from the atmosphere and add it to the soil, so the nitrogen content of crust soils may be several times that of soils lacking crusts. In sandy soils, crusts reduce the rate that water trickles into soil during a rainstorm, which can allow water to accumulate around the base

Main Components of Soil Crusts

Cyanobacteria (also called "blue-green algae") are often the first soil crust organisms to colonize an area after a disturbance. These primitive bacteria are photosynthetic and can capture atmospheric nitrogen into a form that is available to vascular plants. Thin filaments of cyanobacteria secrete sticky substances that bind soil particles together. One of the most common cyanobacterium in the Colorado Plateau and Great Basin Desert (and also worldwide) is *Microcoleus vaginatus*, although other species may be more common in the hot deserts of the Southwestern United States.

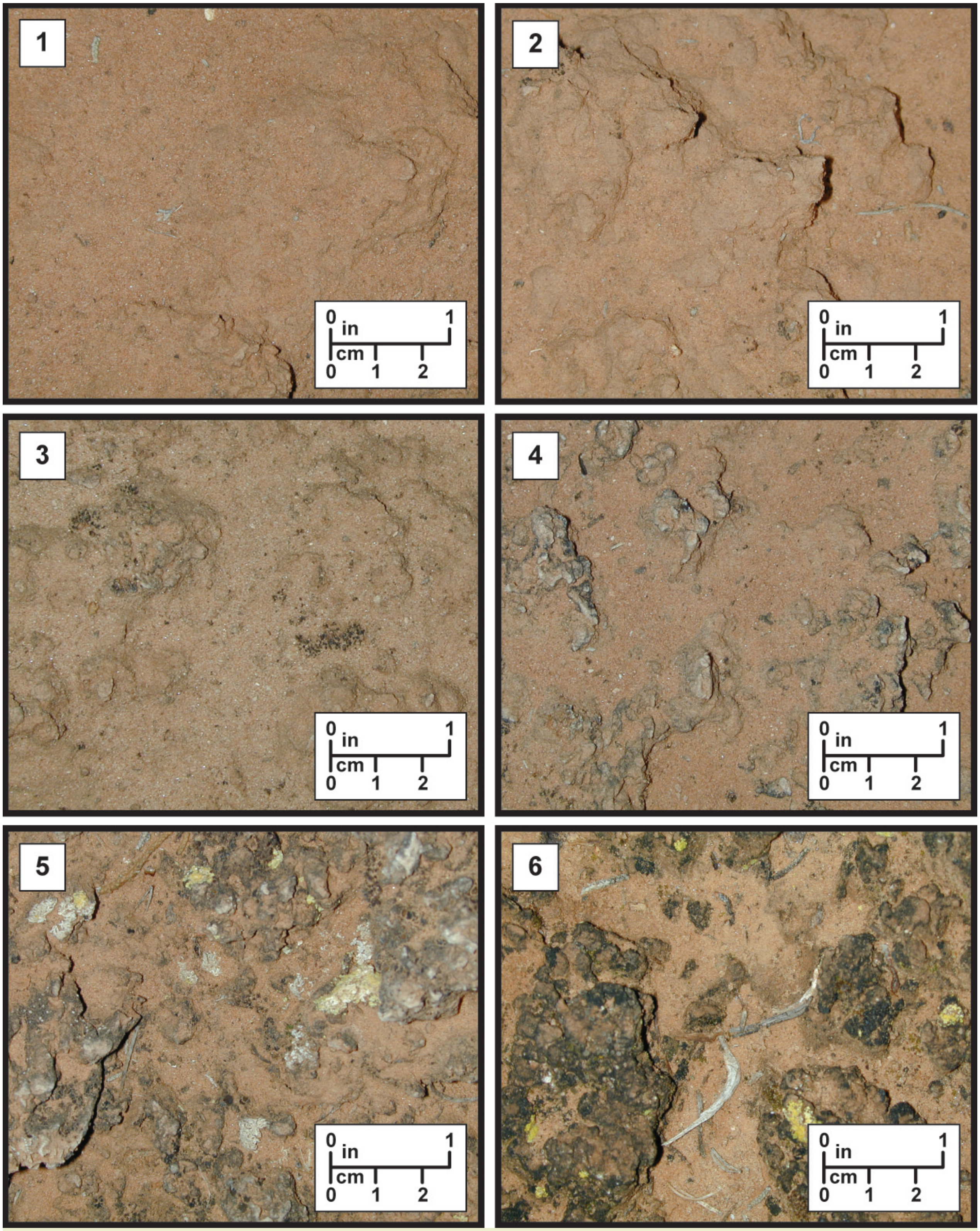
Green algae are light green to black photosynthetic organisms occurring as single cells or colonies. In biological soil crusts, they are found on or just below the soil surface. Green algae dry out and become dormant during dry times, but they "wake up" with even small amount of moisture. Unlike their aquatic counterparts, green algae in crusts are well adapted to living and reproducing in dry desert environments.

Fungi in biological soil crusts usually occur as free-living organisms, but they can also form symbiotic relationships with plant roots. Free-living fungi function as decomposers, feeding on organic material such as leaf litter, and contribute to the cycling of nutrients in the soil crust. Like the cyanobacteria, fungal filaments secrete substances that help bind soil particles together and increase soil stability.

Bryophytes are small, non-vascular plants known as mosses and liverworts, with mosses being more common in soil crust communities.

Lichen are a part of the living community that make up biological soil crust (photo by Neal Herbert, National Park Service).

Lichens are symbiotic systems involving a fungal partner and photosynthetic alga or cyanobacterium. The alga or cyanobacterium provide the fungal partner with food (carbohydrates), while the fungus provides a suitable environment by effectively regulating moisture and sunlight. Lichens come in a wide variety of shapes, sizes, and colors.



As biological soil crusts develop over time, they become rougher and darker (due to greater abundance of cyanobacteria with chlorophyll a in their cells). Highly developed soil crusts confer stability to soils (figure from Belnap, J.; et al. 2008. Journal of Arid Environments. 72: 1257–1264).

of shrubs and allow them to survive in areas that would otherwise be too dry. Once water has entered the soil, the crusts act as a barrier that reduces evaporation. Soil crusts can also provide places where plant seeds are sheltered from the weather extremes and have a greater chance of germinating.

GRAZING, VEHICLES, AND SOIL CRUSTS—HOW CAN THEY COEXIST?

The integrity of these fragile micro-ecosystems has been under assault for over a century, beginning with cattle grazing in the 19th century and continuing with mining operations. It is possible that 20 to 30 percent of rangelands have lost most of their soil crust, although, as Warren points out, "Some sites may still have crust, but it may not be in good condition."

When biological soil crusts are disturbed, they lose the capacity to perform their basic ecological functions. Warren believes that the biggest current threat to soil crusts comes from extensive and widespread mechanical disturbance from livestock and vehicles. Estimates of recovery times range from years to millennia depending on many factors including: the severity, extent, and type of disturbance, the underlying soil type, the time of year of the disturbance, proximity to established crust that can colonize disturbed areas, and the post-disturbance rainfall patterns.

MANAGEMENT IMPLICATIONS

- Soil crusts are crucial components of arid and semi-arid ecosystems, but they are fragile and sensitive to trampling and high-severity fires. Estimates on recovery times range from a couple of years to millennia, suggesting a conservative approach to management, such as limiting disturbances to discrete areas, and monitoring recovery after disturbance.
- Soil crusts can recover after low-severity fires that do not scorch the soil surface (such as cool-season burns in sagebrush or burns in young, less-dense juniper stands). Surviving crust organisms can then recolonize the burned area.
- Cheatgrass invasion is an emerging threat to biological soil crusts because it increases fuel loads and the likelihood of damage to soil crusts by wildfire.
- Passive restoration of soil crusts appears more viable than active restoration (such as transplanting soil crust from undisturbed areas). Passive restoration involves removing disturbance agents and allowing natural recovery, which will depend on colonization of crust organisms from nearby areas or the atmosphere and adequate moisture for establishment.

In most arid ecosystems, soil crusts evolved without large herds of grazing animals, and, obviously, without vehicle traffic. The damage caused by livestock trampling is proportional to how intense the impact is, which is related to the stocking rate, distance to water sources, season of use, and amount of time on the allotment. Rainfall also matters. In general, biological soil crusts recover slowly after disturbance in the driest deserts, and during the drier season in semi-arid areas.

St. Clair has observed how the timing of precipitation affects the speed of soil crust recovery following grazing. "People predict that it can be 200–400 years before these crusts recover, but I have seen an area that was grazed and heavily impacted for 50–60 years recover in a few years when the timing of grazing removal happened to coincide with a wet period in the early 1980s," he recalled.

Vehicle traffic causes similar impacts as grazing, except that people are potentially more wide-ranging than livestock. Warren stresses the importance of keeping vehicle traffic in discrete areas—not everywhere—to protect biological soil crust communities. "It's OK to drive in these areas, or to graze them, but only in small proportions of them," he says.

Concentrating recreational use in arid areas to particular locations can help prevent widespread soil crust damage. It may also be helpful to restrict use of these areas during the dry season when the crusts are more vulnerable to damage.

FIRE AS A LESS WELL-UNDERSTOOD THREAT TO BIOLOGICAL SOIL CRUSTS

Wildfire, according to both Warren and St. Clair, is emerging as a new, significant threat to biological soil

Compaction from trails and roads destroys biological crusts, which can take several years to millennia to regrow (photo by Jason Hollinger, Flickr/Creative Commons license).

crusts. "It used to be that a desert wouldn't carry much of a wildfire, because the space between the shrubs simply didn't provide enough fuel," explains St. Clair, "Now with the invasion of non-native annual grasses you have the fuel to carry substantial and intense fire across hundreds and thousands of acres, which decimates both the native plant and biological soil crust communities."

So what changed? Invasive annual grasses like cheatgrass have spread into well-developed biological crust communities of the Great Basin and Colorado Plateau. Cheatgrass can grow directly on top of the crusts and fill in disturbed areas between patches of crust. Ecosystems invaded by cheatgrass have higher and more continuous fuel loads, setting the stage for larger and more severe wildfires. Some research suggests that higher levels of grazing are related to both lower cover of soil crust and higher cover of annual grasses, but more research is needed to determine the potential relationship between these factors and wildfire.

How about the impact of prescribed burning on slow-growing soil crusts? Research by Warren, St. Clair, and collaborators suggests that low-severity fires pose less of a risk to biological soil crusts than high-severity fires. Low-intensity, cool-season fires in sagebrush ecosystem do not cause serious soil crust damage, nor do fires in younger and less-dense juniper stands. Fire usually cannot burn the soil surface in spaces between shrubs, so crusts in unburned areas remain mostly intact and can eventually recolonize the burned areas. However, more severe fires in older and denser juniper stands can burn soil crust and reduce the likelihood of postfire recovery.

Cheatgrass is an invasive annual grass that has infested tens of millions of acres of arid and semi-arid ecosystems across the western United States (photo by John M. Randall, The Nature Conservancy, Bugwood.org).

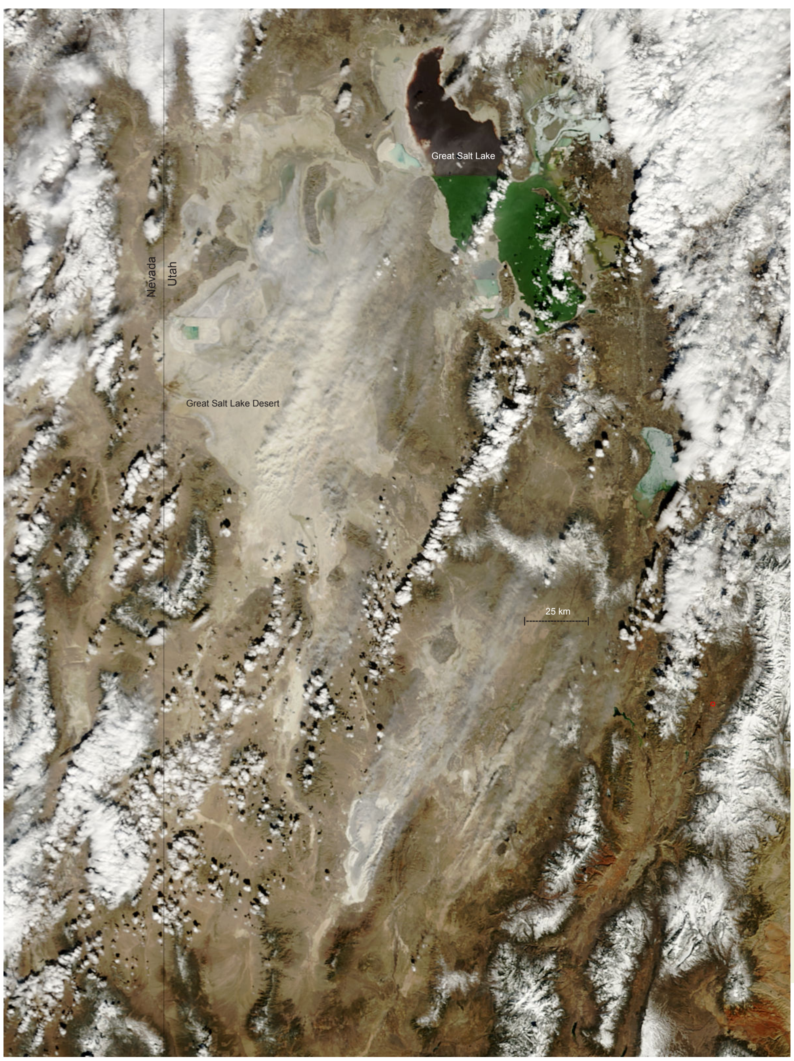
KEY FINDINGS

- Biological soil crusts—consisting of microscopic cyanobacteria, algae, fungi, lichens, mosses, and their by-products—occur in all deserts and perform important ecosystem functions such as nutrient cycling, nitrogen fixation, and soil stabilization
- Soil crusts are fragile and have relatively slow recovery times. The main threats to crust integrity include heavy livestock grazing, high-severity fires, and mechanical disturbance such as off-road vehicle traffic, especially when occurring during or followed by a dry period.
- The speed of recovery of soil crusts after disturbance is variable and depends on the extent and type of disturbance, how long the disturbance agent was present, proximity to established crust that can colonize disturbed areas, and rainfall after the disturbance agent is removed.
- Soil crusts can recover relatively quickly from low-severity fire if followed by a good rain year.
- Fragments and propagules of biological soil crusts are present in the atmosphere and can be carried far distances by dust storms, potentially acting as a source for "passive restoration" of soil crusts.

PASSIVE RESTORATION—THE UPSIDES OF LETTING IT BE

Given the long recovery time after disturbances, researchers have looked into the viability of restoring soil crust artificially. One method attempted by Warren and St. Clair earlier in their careers was a crust "transplant." The researchers harvested biological soil crust from one place, made it into a slurry, and applied this slurry to damaged sites. According to St. Clair, "We had pretty good success with that, but it's like 'robbing Peter to pay Paul', and not really viable for large-scale applications."

Other methods have focused on reintroducing the cyanobacterial component of the crust. An approach used by Warren, St. Clair, and others involved laboratory-grown cyanobacteria pellets that could be applied to the soil surface, with the idea that cyanobacteria would establish in place and start to stabilize the soil. Unfortunately such efforts were not successful. Cyanobacteria had poor survivorship in the pellets, and UV



Dust storms that travel over large arid areas, like this one in northern Utah on March 4, 2009, might be one of the prime long-distance conveyances of airborne soil crust components (photo courtesy of NASA).

radiation hitting the soil surface might have killed cyanobacteria in the field.

Given the high cost and high failure rate of artificial crust restoration projects, Warren and St. Clair have turned their attention to passive restoration. "The idea is that we don't need to apply crust organisms to the soil because they and their propagules are blowing around in the air and atmosphere," Warren points out. The premise of passive restoration is that crust organisms land on the soil surface and reestablish themselves naturally when there is enough moisture and time free from disturbance.

Currently, Warren and St. Clair are working on a review of this topic, where they explain that most components of biological soil crusts have in fact been detected in the atmosphere. Dust storms might be one of the primary means that soil crust components hitch-hike over large arid areas, while on a smaller scale, "dust devils" can lift dust into the atmosphere and transport it several miles away.

Whether soil crust organisms are applied artificially or colonize from the air, the key to recovery is that the area receives adequate moisture to hasten the process. Warren explains, "If you have a large area that is badly disturbed, you can just lay off of it. It may take 20 years to recover, depending on how much it rains, but the organisms will colonize the area from the air."

FURTHER READING

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MANAGING AREAS FOR BIOLOGICAL SOIL CRUST INTEGRITY

The reality of managing biological soil crusts is that the tools are limited. Protection of existing crust is the most effective method, but whether or not this requires the complete removal of grazing and recreation is unclear given the many variables that factor into how quickly an area recovers.

Warren has some simple recommendations for managers looking to minimize impacts to soil crusts or to enhance their recovery from physical disturbance: "First, limit disturbances to discrete areas, and in areas being impacted, let the area recover by removing the disturbance agent. Then, know that the speed of recovery will depend largely on how much precipitation falls."

Education and awareness is the first step in helping recreators reduce their impact on biological soil crust (image courtesy of the National Park Service)

The scientific understanding of biological soil crusts has come a long way in the past few decades, and so has awareness in the management community. According-to St. Clair, "Some time ago, many of federal and state land management agencies in the West were not aware of biological soil crusts at all. They have really come onto the managers' radar in the past ten or fifteen years."

St. Clair thinks one of the most important ways to protect soil crusts is awareness and advocacy within land management agencies. He explains, "We need to continue to communicate to the land managers and people with 'boots on the ground' that these crusts are there and that they are ecologically significant, and to have them act as advocates for and protectors of these areas."

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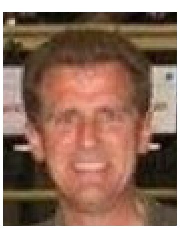

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