Joint Fire Science Program
Fire Science Brief
RESEARCH SUPPORTING SOUND DECISIONS

Juniper trees burning during the prescribed burn at the SageSTEP Onaqui Utah Juniper study site, October 2006.
Onaqui sites are located on and adjacent to the Onaqui mountains in Rush Valley, UT.
Credit: Summer Olsen, SageSTEP.

Biological Soil Crusts: A Crucial Component of Arid Ecosystems

Summary

Biological soil crusts are a complex community of primitive organisms that thrive worldwide in harsh, arid and semi-arid regions where other vegetation such as trees, shrubs, and grasses is sparse. These crusts play a key role in stabilizing bare soil, stemming erosion from wind and rain, trapping moisture, fixing carbon and nitrogen in the soil, and providing shelter for the seeds of vascular plants. Together, the species that make up soil crusts—cyanobacteria or blue green algae, green algae, fungi, lichens, and mosses—have developed synergistic communities critical to these dry ecosystems. In the semi-arid Great Basin, juniper has encroached into areas once dominated by soil crusts, sagebrush, and native grasses. The lack of fire has led to dense juniper stands and even-aged stands of older sagebrush more prone to carry intense wildfire than mixed-aged stands. Researchers are exploring the use of fire to reverse juniper encroachment and foster a healthier mix of sagebrush stands. There is little information, however, on the effects of fire on fragile soil crusts. A recent study explored the effects of a controlled burn on crusts at a site in the foothills of the Onaqui Mountains in Utah. The results indicate that low-intensity fire has few long-term adverse effects. The study also documented the baseline condition of biological soil crusts in a fairly healthy system. This information may help guide restoration of soil crusts in other, more impaired, ecosystems.

Key Findings

- Low-intensity fire resulted in nearly 100 percent mortality of early successional juniper but was unlikely to carry into mid- to late-successional stands.
- The fire was spotty in the interspaces between juniper and sagebrush dominated areas and had few long-term adverse effects on soil crusts.
- Regeneration of juniper from seed may take 10 years or more. In the meantime, pioneer species from the existing crusts may provide a gateway for the complex mix of organisms characteristic of soil crusts to re-establish.
- In general, vegetative species diversity was very low in juniper stands and somewhat richer in sagebrush communities.
- Recovery of soil crusts in a good rain year after a light fire was fairly quick.

Pioneer organisms

Biological soil crusts are composed of some of the most primitive organisms on Earth, but they are far from simple. In evolutionary history, about 2 billion years ago cyanobacteria evolved the means to produce nutrients from sunlight through photosynthesis, releasing oxygen as a byproduct of the reaction. This development radically altered the harsh atmosphere in which only anaerobic bacteria could survive, paving the way for the nonvascular plants, including those that comprise soil crusts, followed by vascular plants such as ferns, grasses, and trees. "The components of biological soil crusts appeared long before vascular plants," says Steven D. Warren, a supervisory biologist with the Forest Service's Rocky Mountain Research Station in Fort Collins, Colorado.

A well developed soil crust. Credit: Larry St. Clair.

Today, cyanobacteria continue to serve as pioneer organisms in harsh environments and work in concert with green algae, fungi, lichens, and bryophytes, to form biological soil crusts. To the casual observer, however, soil crusts may seem like inert material. "Most people don't have a sense of it," says Larry St. Clair, a professor of Biology at Brigham Young University. "To many it's just dirt, just soil." These crusts, however, are a prominent feature on the landscape in many western arid to semi-arid environments, from the Mohave Desert to the Great Basin, and perform a variety of essential ecological services.

Components of soil crusts

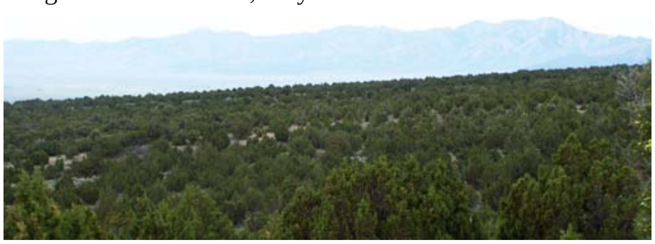
- **Cyanobacteria.** These primitive, single-celled, filamentous or small colonial bacteria, which are too small to be seen by the naked eye, can be carried by the wind and are often the first organisms to inhabit harsh environments such as bare or rocky soils. Formerly termed *blue-green algae*, cyanobacteria often form thin filaments that secrete sticky polysaccharides that bind soil particles, thus reducing the effects of erosion and runoff from precipitation. They lack chloroplasts but are able to photosynthesize and fix atmospheric nitrogen, providing nutrients for other organisms.
- **Green algae.** These single-celled to colonial algae contain chloroplasts and perform photosynthesis. The green algae in biological soil crusts are found at or just beneath the soil surface, and unlike their aquatic counterparts, are highly adapted to arid environments, lying dormant during long periods of dry weather, and rebounding with even very small amounts of moisture. In evolutionary succession, they are the precursors of the bryophytes.
- **Fungi.** Fungi occur in a wide range of ecosystems. They occupy a Kingdom of their own, distinct from the animals and plants, and do not photosynthesize; rather they get their nutrients directly from various organic sources, as they decompose organic matter such as leaf litter and contribute to nutrient cycling in soils. Fungi that contribute to soil crusts are generally free-living and filamentous. Like filamentous cyanobacteria they secrete polysaccharides and help bind soil particles together.
- **Bryophytes.** These small, non-vascular plants include the mosses, hornworts, and liverworts. Bryophytes can reproduce either sexually via spores or asexually. The bryophytes in biological soil crusts are adapted to dry environments due to their ability to reproduce asexually. Like the cyanobacteria, they are considered pioneer species because they can thrive on barren soil or rocks. They are resistant to drastic changes in precipitation.
- **Lichens.** Lichens are symbiotic systems consisting of a combination of organisms. Fungi alone cannot perform photosynthesis, but get their nutrients from their symbiotic partners, either green algae or cyanobacteria, or both. In return, they act as a sort of greenhouse for the algae, protecting them from drying out in arid environments.

Soil lichen. Credit: Larry St. Clair.

Threats to crusts

Mature soil crusts can take from a few to hundreds of years to fully develop, and they are sensitive to disturbances such as trampling by livestock, compaction by off road vehicles, and intense fire. When the settlers arrived in the Great Basin in the mid 19th century, human population was sparse and relatively nomadic, and there were no large herds of cattle or sheep. "The indigenous foraging animals such as elk, deer, and antelope typically form small units and tend to migrate to the mountains in summer, when crusts are most vulnerable," says St. Clair. By the late 19th and early 20th centuries, heavy grazing, coupled with the invasion of exotic plants, altered the frequency and severity of wildfire, thus impairing the health of soil crusts.

More recently, the rise in popularity of off road vehicles—and to a lesser extent, trampling by recreationists—has been added to the list of threats to soil. On some federal lands, heavy equipment used in military training operations can damage crusts. An added threat is encroachment by woody species such as juniper, which began its expansion in the late 19th century, likely due to a number of factors including livestock grazing, unusually wet weather patterns, and a longer fire return interval. "Historically, juniper was present only in swales where fire did not occur very often in the past," says Warren, but it is now encroaching into the open spaces once dominated by biological crusts and native grasses. "In the past 100 years, there has been a shift to infrequent, high intensity fire that is not good for soil crusts," says Warren. "That is not natural."

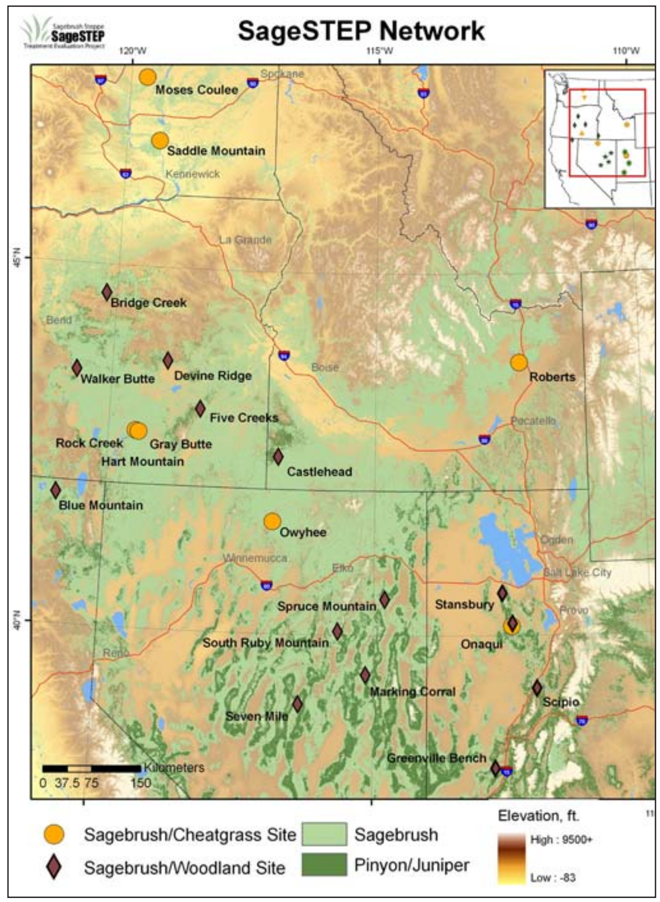


Utah juniper and pinyon pine woodland adjacent to Onaqui study plots, June 2009. Credit: Summer Olsen, SageSTEP.

Deviations from the historic fire return interval have also resulted in even-aged stands of highly flammable native sagebrush that produce more intense wildfire than mixed-aged stands. In much of the Great Basin, non-native cheatgrass has also added to the fuel load. "With the spread of invasives like cheatgrass, a lightning strike can burn thousands of acres," says St. Clair.

Sagebrush rangeland adjacent to Onaqui study plots, June 2009. Credit: Summer Olsen, SageSTEP.

Little information has been gathered on the effects of fire on biological soil crusts, and until recently nothing was known about the effects of fire in the juniper/pinyon woodlands. With funding from the Joint Fire Science Program, Warren and St. Clair have investigated the effects of fire on biological soil crusts on a Bureau of Land Management research site in western Utah.



Fire effects in a juniper/sagebrush community

The study area is located in the foothills of the Onaqui Mountains and is one of several research sites in six Great Basin states managed by the Sagebrush Steppe Treatment Evaluation Project. SageSTEP is an organization comprised of multiple federal agencies, several universities in the Great Basin, and The Nature Conservancy. SageSTEP, which is also supported by the Joint Fire Science Program, was launched in 2005. Its goal is to evaluate methods to restore the sagebrush steppe community of the Great Basin and determine the best land management practices to achieve that goal. The research focuses on two sagebrush communities, the Cheatgrass Network and the Woodland Network, reflecting two of the greatest threats to the sagebrush-steppe ecosystem in the Great Basin: the invasion of non-native cheatgrass and the encroachment of woody species such as juniper and pinyon on the landscape.

This collaborative study took place on a burn site in the Woodland Network in a juniper dominated area of the foothills of the Onaqui Mountains at an elevation of 5,500 feet (1,700 meters). This semi-arid area receives on average 18 inches (45 centimeters) of precipitation annually, most of it in the cool fall and winter months. Originally, the burns were planned for summer 2006, the dry season. That summer, however, due to a very active wildfire season in the western states, the burn was delayed until October. Cooler temperatures, higher humidity and precipitation, and calm winds produced a low-intensity burn that did not carry into the mid- to late-successional juniper stands.

In addition to the dominant species, Utah juniper (*Juniperus osteosperma*), other vegetation included Wyoming big sagebrush (*Artemisia tridentata* var. *wyomingensis*), bluebunch wheatgrass (*Pseudoroegneria spicata*), Indian ricegrass (*Achnatherum hymenoides*), and an exotic annual forb, bur buttercup (*Ceratocephala testiculata*).

The area had been sparsely grazed prior to the study, and livestock have been excluded for the duration of the SageSTEP experiments. The soil crusts in the open spaces between stands of juniper and sagebrush were in relatively good health. “This is a typical Great Basin soil community in good condition, well formed, with a diversity of species and relatively unaffected by soil disturbance,” says St. Clair. The data collected on the site, therefore, represents an invaluable resource as a baseline to understand healthy soil crust communities and guide restoration efforts in what is a fairly new area of research. “Remediation efforts should target as closely as possible the background patterns,” he says.

Sagebrush rangeland with encroaching juniper trees adjacent to Onaqui study plots. A few cattle graze outside the study area.

The area was divided into 10 sets of small plots, 1.5 by 1.5 feet (0.5 by 0.5 meters), in each of the three vegetation types: juniper understory, sagebrush understory, and the biological soil crusts in the interspaces. Aluminum tags were set in the middle of each plot to determine fire intensity. After the fire a duplicate set of plots was established as an unburned control.

The research team collected data after the burn in October 2006 to determine the immediate effects of the fire, and again in September 2007 and June 2008 to track the recovery dynamics of crusts and other vegetation following the burn. Samples were taken of vascular plants such as grasses and forbs, and soil crust components—mosses and lichens. Biomass of the chlorophyll-bearing organisms, green algae and cyanobacteria, was determined using a common laboratory technique that measures the amount of chlorophyll α present in the soil, and the density and number of species present were recorded. Soil samples were also examined to determine the rates of nitrogen fixation before and after the burn.

In the juniper plots, the fires were of low intensity, but were hot enough to scorch the canopy and achieve 100 percent mortality of the early successional trees without carrying into the mid to late successional juniper, which is difficult to burn, though when it does, it burns at high intensity. In the sagebrush plots, there was also 100 percent mortality of the shrubs.

Sagebrush burning during the prescribed burn at the SageSTEP Onaqui sagebrush site, October 2006. Credit: Summer Olsen, SageSTEP.

Overall, the researchers found very little botanical or plant diversity under the juniper. “When juniper matures it creates a closed canopy where few plants can survive,” says Warren. In addition, the trees are prolific shedders of needles and branchlets, creating a thick layer of organic matter, six or eight inches deep. Species diversity under sagebrush was slightly more diverse.

Grasses were present in all three vegetation types. In the juniper plots, grasses were completely consumed and did not recover during the three years of measurement. In the sagebrush plots, grass was completely consumed, but rebounded in years two and three of the study. In the interspaces, grass cover was significantly, but not entirely, reduced and recovered after one year and remained steady at the second year.

Forbs were scarce in the juniper, sagebrush, and interspace vegetation types. In the juniper and sagebrush plots, forb cover increased in the second year after the burn, and in the interspaces forb cover was lower in the first year, but recovered in the second and third years.

Mosses were rare in the juniper understory, and were therefore not significantly affected by the burn. Mosses, which were present in the sagebrush and interspaces, declined in both the burned and unburned control immediately after the fire and continued to decline in the following two years. Lichens, uncommon in both juniper and sagebrush understory, were reduced by fire but were not significantly affected in the interspaces due to the spotty nature of the fire there.

Biomass and density of green algae and cyanobacteria were significantly reduced under the juniper and sagebrush but not in the interspaces. Rates of nitrogen fixation under juniper and sagebrush were likewise negatively affected, but remained unchanged in the interspaces.

Overall, the research revealed that low-intensity, cool-season fire used to remove early successional juniper and control sagebrush has few adverse effects on the healthy biological soil crusts in the open spaces.

Overall, the research revealed that low-intensity, cool-season fire used to remove early successional juniper and control sagebrush has few adverse effects on the healthy biological soil crusts in the open spaces. The “pioneer species” such as algae and cyanobacteria, which survived the spotty fires, may serve as inoculants, paving the way for the other components of biological soil crusts to spread from the open spaces into the areas cleared of shrub and woody species.

The science of biological soil crusts is relatively young. In fact, scientists are still characterizing many of the basic components of crusts, and much more research, basic and applied, is needed. For example, considering the widespread invasion of cheatgrass in the Great Basin, St. Clair suggests that the effects of this non-native grass on biologic soil crusts should be explored. “Cheatgrass germinates early in the spring, and extracts water and soil resources from the soil,” he says. A heavy infestation of cheatgrass may also crowd out the crusts directly, interfering with the light necessary for photosynthesis. Moreover, cheatgrass can carry intense fire across hundreds and thousands of acres. “Before the arrival of modern humans, fire in this ecosystem was a relatively low impact event,” says St. Clair.

Biological soil crusts are an important part of the landscape and need to be a part of any management plan. “It is important that land managers understand the importance of this component of the landscape and raise the public profile through education,” he says. “I have heard managers say, ‘I had no idea these things were here!’”

Management Implications

- If the goal is to get rid of juniper without adversely affecting biological soil crusts, low-intensity fire should be applied in the early successional stage.
- Intense fire in juniper and sagebrush vegetation communities should be avoided because of the increased likelihood that fire may spread into the interspaces and adversely affect soil crusts.
- Mechanical removal, such as clear cutting or herbicides may be necessary to reduce mid to late successional juniper. Burning at the early successional stage is likely a better use of limited resources to halt encroachment of juniper.
- Land managers need to understand the function of crusts and help raise public awareness of the complex and essential role of biological soil crusts to the health of the ecosystem.

Utah juniper tree skeleton at Onaqui woodland study site about one month after the burn, November 2006. Credit: Summer Olsen, SageSTEP.

Further Information: Publications and Web Resources

Arkle, Robert S., David S. Pilliod, and Katherine Strickler. Biological Soil Crusts Web Site: http://www.soilcrust.org/

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Scientist Profiles

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