"There is nothing so American as our national parks. The scenery and wildlife are native. The fundamental idea behind the parks is native. It is, in brief, that the country belongs to the people."

–PRESIDENT FRANKLIN DELANO ROOSEVELT, 1936

Salute to the National Parks

Forged in Fire and Brimstone: Yellowstone Fungi

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YELLOWSTONE! Our nation's first national park evokes images of Old Faithful blowing and bison, wolves and grizzly bears roaming across a dramatic landscape. Much of Yellowstone is a leftover supervolcano that last collapsed on itself 640,000 years ago creating a sunken crater or caldera; the whole park covers 2.2 million acres. The landscape bubbles, erupts, smokes, spits, and steams with geysers, fumaroles, hotsprings and mudpots that indicate thermal activity churning below. Stories like "Is Yellowstone going to blow" keep those of us who live near the park aware of the specter of another eruption. Then, in 1988, wildfires burned

Pisolithus, **Norris Geyser Basin, photo courtesy Noah Siegel.**

Astreus, Norris Geyser Basin, photo courtesy Noah Siegel.

over one third of the park, and while newscasters reported devastation, scientists predicted rejuvenation. Our oldest park is a stronghold for a natural bison herd, a genetically unique population of grizzly bears, and newly arrived wolves. Within these intense environs, fungi eke out a living in unusual habitats such as thermal soils, hot springs, burned ground, and the dung of Yellowstone's charismatic megafauna.

Brimstone Fungi

Geothermal areas of Yellowstone are famous, but the fungi that exist in these extreme environments mostly go unnoticed. The soil around hot springs is heated all winter; animals come to warm themselves and occasionally one falls in and boils itself. The soil is also acidic and conifers manage to survive in small shifting patches by attaching their roots to mycorrhizal fungi that tolerate these conditions. One is *Pisolithus arhizus* whose club-shaped reddish brown fruiting bodies are often camouflaged by red pine needles blanketing the ground. The tidy orbs deteriorate into strange-looking brown masses as they age, reflecting the apt designation "dog doo fungus" (one of the more polite names). Unlike powdery puffballs, internal peridioles (tiny chambers) contain the messy reddish brown spores that are gradually released, layer upon layer by weathering. This

is the famous fungus once called "P.T." used in reforestation of coal spoils in the eastern USA because it tolerates nasty conditions. Spores added to nursery seedlings can improve their survival in harsh conditions. Pigments from the fungus are used to add color to yarn. *Pisolithus* is a "gasteromycete" in the old sense as it produces spores internally, but phylogenetically it is more closely related to the boletes!

Astraeus hygrometricus is another mycorrhizal "gasteromycete" that inhabits thermal areas, looking for-all-the-world like a typical earthstar (*Geastrum*), but it too is related to the boletes. The outer layer (peridium) of the fruiting body, splits into rays which lift the round internal sac off the ground. The surface of the rays has a cracked checkered appearance and the rays themselves curl up in dry weather—hence the name *hygrometricus*—or indicator of water. In a fascinating quirk of evolution, its form parallels that of earthstars, but they are not closely related to each other nor do they have a common ancestor. In the wetter thermal areas, even in the dead of winter, tiny "hot spring fungi" such as species of *Coprinellus* can be observed on floating twigs and dead leaves as one soaks in thermal waters along with the local deer. The *Coprinellus* in the photo was taken in a thermal area of Banff in January (McIvor, 2016), but this genus has been reported in winter in Yellowstone hot springs as well.

An interesting asexual ascomycete called *Curvularia* (for the shape of its spores) lives inside the roots of certain grasses that thrive in thermal areas (Henson et al., 2005). *Dicanthelia lanuginosum*, dubbed "hot plants," not only need the fungus in order to survive in hot soils, but the fungus needs an internal virus to confer temperature tolerance to the plant (Marquez et al., 2007)! Who knew the complexity! Molecular aficionados might appreciate that Yellowstone is where Taq polymerase was discovered in the hot spring bacterium *Thermus aquaticus* in 1985. Its enzymes can copy DNA at hot temperatures and without this bacterial

Coprinellus, Banff, photo courtesy McIvor.

enzyme much of our molecular work on fungi would not be possible.

Fire Fungi

When I left Colorado for graduate school at Virginia Tech in 1989, I intended to study the fungi fruiting after the 1988 Yellowstone fires; mostly so I could return to the West each summer. It didn't work out, but I was able to periodically visit the aftermath. In 1988, over one third of Yellowstone burned; raging wildfires were so hot in some places that nothing was left but scorched earth and blackened tree spires. Over 80% of the park was, and is still, covered by lodgepole pine, a fire-adapted tree species. Lodgepole cones stay closed until fire melts the sap that glues them shut, and then seeds fly and seedlings are born by the thousands across newly opened ground. A year after the fire, began a rebirth of magnificent proportions.

In 1989, from firsthand accounts, burn morels (*Morchella* spp.) popped up like sponges covering an ocean floor. They

Pholiota

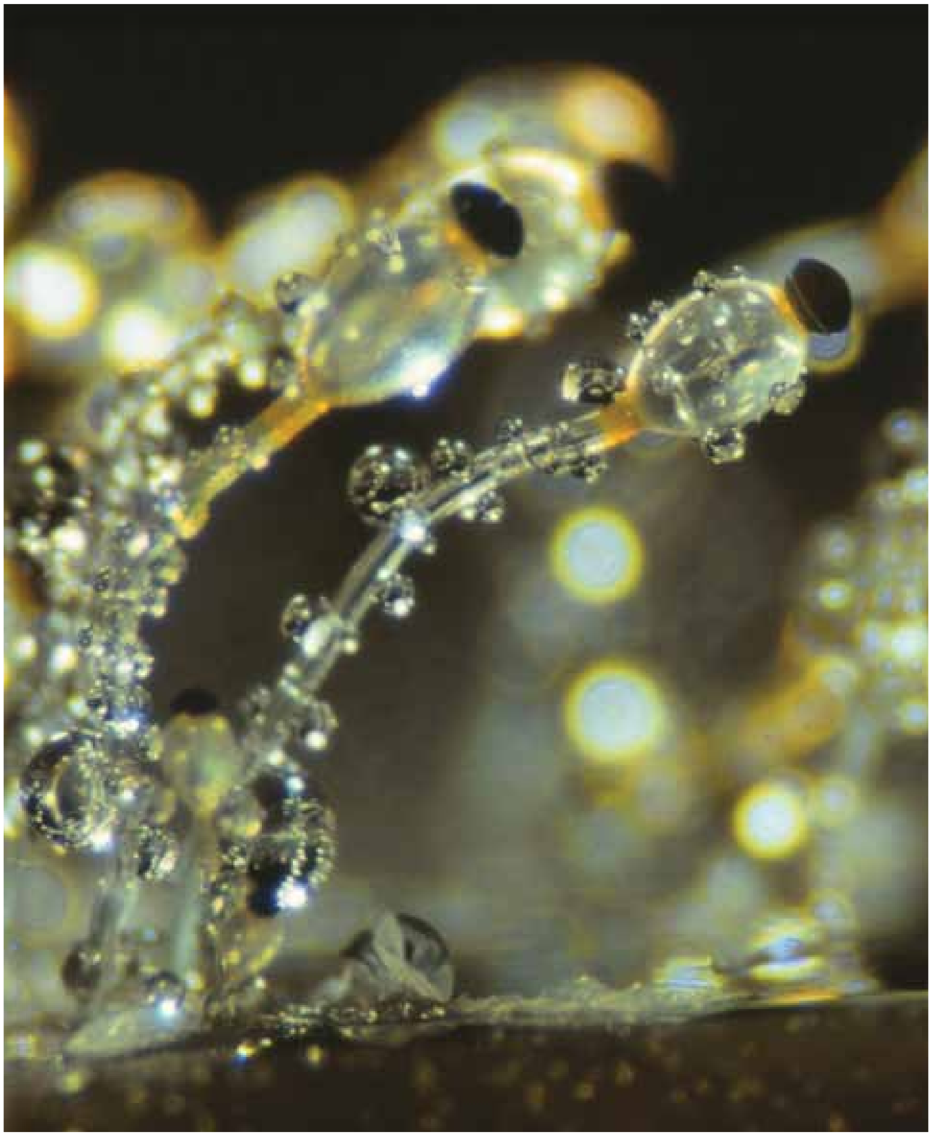
Psathyrella

Geopyxis

fruited along "edges" of the burn, in holes left by burned out roots of trees, on the moist side of charred logs, and in the lee of elk foot prints; they fanned out endlessly across burned soil, rising phoenix-like from the ashes. Biologist Roy Renkin was there and states that there was "a TREMENDOUS flush of morels in 1989," and after a later and smaller Yellowstone fire "you could have filled a dump truck with morels." The rule is that wild mushrooms can be picked in limited quantity in the park, but they also must be consumed in the park. There are reports of grizzly bears eating morels in burns (Quammen, 2016), so the competition can be fierce!

The ecology of burn morels is still a mystery. Do the spores need heat to germinate, or does the running mycelium crave open space or released nutrients? Close observation reveals delicate mycelium weaving together loose sooty soil, holding it on slopes and against rain. Burn morels are in the black morel clade, and we now know that there are several "burn species" difficult to distinguish by sight (Beug et al., 2014). All are considered edible, although I receive numerous reports of reactions to burn morels each spring. We have molecularly confirmed at least *Morchella sextelata* in the area (Cripps et al., 2016).

I have observed a fantastic array of burn fungi literally covering blackened soil in Yellowstone especially in spring. The burn Pholiotas are one of the most spectacular with their shiny flame-colored heads standing in relief to the black background. They are recognized by brown to orange brown spores that they drop on each other's heads, and a tiny white ring with scales below it on the stem. *Pholiota highlandensis* is the most common, but microscopic examination is necessary to sort out the others. *Psathyrella pennata* once called *P. carbonicola* has a more delicate bell-shaped cap and a slender stem; it gives a blackish spore print. It often seems to fruit from under burned logs. On a burn, purple, orange, yellow, red and brown cup fungi are sprinkled everywhere in shady nooks and crannies



Pilobolus kleinnii courtesy Michael Foos.

and many never occur except after fire. *Geopyxis carbonaria*, a bright orange burn cup with a white fringed margin and a significant stem often shows up just before the morels, and some say, it indicates areas where morels will fruit. I have watched over the years as the burn fungi died down and lodgepole seedlings grew up in the park. The pines first young mycorrhizal loves appeared to be *Suillus brevipes* and species of *Laccaria* and *Inocybe*, and perhaps *Coltricia perennis* if it is mycorrhizal. This cycle of lives punctuated by fire continues, and the park's recent "let-it-burn" policy fosters these fungi forged in fire.

Also in spring, another unusual set of fungi show up—the "snowbankers"—that depend on meltwater from late season snowbanks. There are extensive areas in Yellowstone where the forests melt in patches and the silvery to white *Clitocybe glacialis* (see cover image of *Fungi* vol.2, no.1) and *C. albirhiza* poke their heads up regularly through the snowbanks; spongy white *Tyromyces (Oligoporus) leucospongia* and the soft orange *Pycnoporellus alboluteus,* both polypores can cover logs over huge areas in spring where there is extensive downed timber (Cripps, 2009; Cripps et al., 2016).

Charismatic Megafauna and Mushrooms

There are numerous researchers for each charismatic mammal species in the park, but few to represent the hundreds of fungal inhabitants. Yet without fungi, the complex ecosystem that is Yellowstone would not be possible. Fungi foster and recycle plants and trees, the basis of the food chain; fungi fertilize and maintain the soil, soften trees for cavity nesters, process dung into nutrients, and provide food for animals. Fungi are linked to individual lives of animals in more intricate ways even on a landscape scale. Wolves were reintroduced to Yellowstone in 1995 after a 70-year absence—how could this possibly affect fungi? Well, the wolves caused a dip in the elk population which caused a resurgence of aspen and willow in the park, which meant more material for beavers to engineer more wetlands. As for the fungi, aspen and willows support their own private fungiflora of mutualists and decomposers. So wolves might be considered responsible for an uptick in orange cap boletes (*Leccinum* species) in the park because this genus loves aspen. Similarly the willow fungiflora would expand: *Tricholoma cingulatum*, one of the few ringed Tricholomas, and a strict willow associate, was found nestled on the edge of a beaver pond during the 2009 Bioblitz; it is a first report for Yellowstone.

As the great herds of bison, elk, deer and antelope spread across the great grasslands of Yellowstone, they also drop their dung. Piles would accrue if not for the industrious dung fungi. The "hat thrower" (*Pilobolus* species) covers the dung first with its minute fruiting bodies that look like tiny blown glass bubbles. Each shoots its "hat" (black spore packet) out of the "zone of repugnance" (grass in and around the dung heap) with great acceleration onto grass where it is eaten by passing grazers. Spores travel the digestive tract and are plopped out again ready to fruit and shoot, completing the cycle. A unique twist for Yellowstone is that even smaller creatures, lungworms, crawl up to hitch a ride on the spore packets and back into elk where they cause disease (Foos, 1997). Next small ascomycete dung-loving cups such as *Cheilymenia coprinaria (fimicola)*, spring up followed by basidiomycete mushrooms: the non-psychoative psilocybe *Deconica coprophila*, *Stropharia* cf *merdaria*, *Panaeolus semiovatus*, and various Conocybes and Coprinelli are common.

On the other end of the scale, sometimes weighing in at over 10 lb are the giant western puffballs (*Calvatia booniana*) which can dot the park's open grasslands like big white rocks—and yes, we have stopped the car for big white rocks. Some of these behemoths are over a foot across and if you pick one and are required to consume it in the park, you would be there for a while. The European and Scandinavian mycologists I took on a tour were astounded; they have nothing like it in their countries. This is our charismatic megafungus.

Bears once begged tourists for handouts in Yellowstone, but times have changed, and policy has rehabilitated bears back into creatures that fend for themselves. When I head up to the high elevation whitebark pine forests in the park (Dunraven Pass, Mount Washburn), I carry bear spray but so far encounters have been from a reasonable distance. Whitebark pine (*Pinus albicaulis*) is North America's only stone pine and it is dying by the hundreds in the park and elsewhere, mainly from mountain pine beetles, but also from blister rust. In fall,

Deconica coprophila

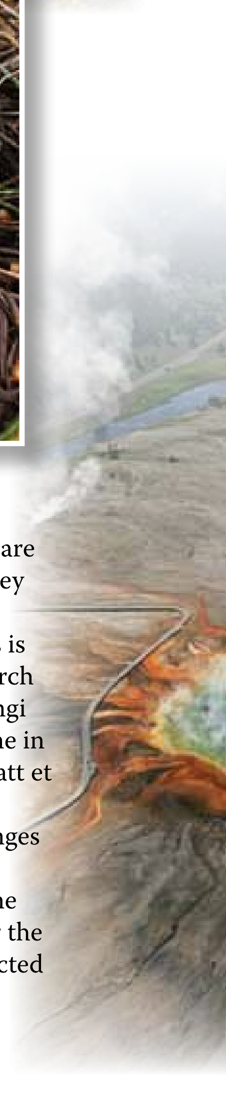
Rhizopogon evadens
courtesy C. Cripps

Suillus subalpinus courtesy C. Cripps

the living forests come alive with birds, bears, squirrels and mushrooms when the round purple cones mature on tree tops. Flocks of nutcrackers descend to incise out wingless seeds from cones that do not open. These "pine nuts" are transported and cached for winter, and seeds that are not retrieved by the birds germinate into baby pines. The birds are the main dispersal agent of the pine. Squirrels join the fray and clip whole branches to beat out the birds, dropping cones in clumps which they stash for winter. Later, grizzly bears raid the squirrel caches for food just before hibernation; the connections are endless. Some of the mycorrhizal fungi are specialized for 5-needle pines. *Suillus sibiricus* (aka *S. americanus*) is also found with other eastern and western pines, but *S. subalpinus*, first described by Meinhard Moser from Dunraven Pass and Grand Teton National Park (Moser, 1982), has only been found with whitebark pine; it has recently been proposed for the Fungal Red List due to decline of its host (Osmundson, 2016). Other myco-characters include *S. tomentosus* v. *discolor* (a 5-needle variety) and "pogies" such as *Rhizopogon evadens*. Squirrels, deer, elk, and bears (Mattson et al., 2002) nibble these fungi and spread their spores. I have observed numerous grizzly scats loaded with pogie spores under a microscope.

While whitebark pine forests are not unique to Yellowstone, they have received much scrutiny there because natural process is allowed to play out. My research has been to document the fungi associated with whitebark pine in the park. (Cripps, 2014; Mohatt et al., 2008).

I have witnessed many changes in Yellowstone National Park over a short span of time, some positive, some negative; as for the fungi, they too have been affected



Tricholoma cingulatum

Calvatia booniana courtesy C. Cripps

by changing park policy, we just haven't quite connected the dots yet.

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References

Beug, M. 2014. *Ascomycete Fungi of North America*. University of Texas Press, Austin.

Cripps, C.L. 2009. Snowbank Fungi revisited. *Fungi* 2(1): 47-53.

Cripps, C.L. 2011. "Fungi in Yellowstone National Park" Technical Report. 114 p. March 21, 2011.

Cripps, C.L. 2014. Underground connection: fungi and pines in peril. *American Forests* https://www.americanforests.org/our-programs/endangered-western-forests/underground-connection-fungi-and-pines-in-peril/

Cripps, C.L., and L.E. Eddington. 2012. What do we know about fungi in Yellowstone National Park? *Yellowstone Science* 20(1): 6-16.

Cripps, C.L., V.S. Evenson, and M. Kuo. 2016. *The Essential Guide to Rocky Mountain Mushrooms by Habitat.* University of Illinois Press, Chicago.

Foos, K.M. 1997. *Pilobolus* and lungworm disease affect elk in Yellowstone National Park. *Mycological Research* 101: 1535-1536.

Henson, J., Redman, R., Rodriguez, and R. Stout. 2005. Fungi in Yellowstone's geothermal soils and plants. *Yellowstone Science* 13: 25-30.

Mattson, D.J., S.R. Podruzny, and M.A. Haroldson. 2002. Consumption of fungal sporocarps by Yellowstone grizzly bears. *Ursus* 13: 95-103.

Marquez, L., R. Redman, R. Rodriquez, and M. Roossinck. 2007. A virus in a fungus in a plant: three-way symbiosis required for thermal tolerance. *Science* 315: 513-515.

McIvor, M. 2016. Mushrooms of winter. *Spore Print* 1(Winter Issue): 1-3.

McKnight, K. 1982. Checklist of Mushrooms and Other Fungi of Grand Teton and Yellowstone National Parks. Univ. of WY, NPS Research Center, Yellowstone Library and Museum Association.

Mohatt, K.R., C.L. Cripps, and M. Lavin. 2008. Ectomycorrhizal fungi of whitebark pine (a tree in peril) revealed by sporocarps and molecular analysis of mycorrhizae from treeline forests in the Greater Yellowstone Ecosystem. *Botany* 86: 14-25.

Moser, M. 1997. Contributions to the knowledge of North American species (Basidiomycota, Boletales). *Mycotaxon* 65: 391-402.

Osmundson, T.W. 2016. *Suillus subalpinus*. http://iucn.ekoo.se/iucn/species_view/442468

Quammen, D. 2016. The paradox of the park. *National Geographic* 229(5): 54-61.

Yellowstone: a Brief History

Yellowstone officially became a park in 1872. Before that it was frequented by fur trappers and was called Coulter's Hell after mountain man John Coulter. Amazingly, intrepid botanists followed soon after and the 1st recorded fungus for YNP was *Hymenochaete (Veluticeps) fimbriata,* found by Frank Tweedy in 1885; he was a botanist but collected fungi too (Cripps and Eddington, 2012). I know this because in 2009, after years of collecting in the park via scientific permits, I was commissioned to do a report on what is known about fungi in the park (Cripps, 2011). This meant gathering historical information that turned out to be interesting on a larger mycological scale because collecting patterns likely mirrored that of other areas of the West. A majority of the fungi officially collected (and vouchered) from 1885 up to the 1950s were rust fungi (mostly *Puccinia* species). This makes sense since the collectors were primarily botanists finding rusts on plant material that they pressed and dried.

Fast forward to the 1960s when mycologist Kent McKnight began collecting mushrooms in the park. Kent was at Brigham Young University and then the USDA in Beltsville; his communication with the park was painfully slow compared to our email exchanges today. In letters to park naturalists from 1963 to 1967, Kent tries to confirm the availability of housing for summer collecting. He asks if there will be electricity so he can use screens over a hotplate, but if necessary he can use a Coleman stove as the heat source. He is advised not to sleep outside as it is bear country but his three boys are allowed to sleep in a tent! Kent's small booklet *The Checklist of Mushrooms and Other Fungi of Grand Teton and Yellowstone National Parks* was published in 1982; it includes 474 species of (mostly) macrofungi, and 49 species of *Cortinarius.* The tiny line drawings are by his artist wife Vera. In the 1980s and 90s, Meinhard Moser of Austria and Joe Ammirati (University of Washington) continued the collecting in the park, adding more *Cortinarius* species to the known YNP mycoflora. Since this time, collecting by mycologists, myself included, has been more sporadic. A Bioblitz in 2009 netted 86 species of macrofungi, but unlike other parks which attract hundreds of people, we had only a dedicated crew of eight to scour the arid landscape demarcated for the foray.


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