True Nature

Packed to the Hilt

The winter landscape can appear essentially barren of wildlife, but a surprising array of life thrives above, within, and beneath blankets of snow.

By Jeff Hull

A long-tailed weasel pokes its head out of a burrow. The predator, whose brown coat turns to camouflaging white in winter, prowls the subnivean world looking for voles, mice, and shrews.

MICHAEL QUINTON/MINDEN PICTURES/NATIONAL GEOGRAPHIC STOCK

Snow is the most transforming element. It changes everything. Winter's first covered landscape seems a different place than the world just a few hours earlier—softer, quieter, held more still. Its whiteness glints clean, sparkling in bright sunlight like a million tiny diamonds brought to a boil. Later, blue shadows pooling in subtle hollows enforce the impression of coolness.

But snow affects more than just the way the world looks. It alters the lives of creatures living in and beneath it. And on a level that is at once minute and massive, its arrival triggers a myriad of lifecycles that, until the past decade, nobody knew existed. The role of microbial life beneath the snow, it turns out, may have serious ramifications for how we measure and gauge the effects of global warming.

Although we think of snow as cold, it is in fact an excellent insulator, says Jim Halfpenny, as he shovels out a roughly four-foot-by-four-foot snow pit, one of many he digs every winter, on a slope in Yellowstone National Park one early April day. Author of several books, Halfpenny is a renowned naturalist and winter ecology expert who teaches classes in winter ecology, tracking, and the natural history of wolves, cougars, and bears at his Gardiner, Montana, facility on the park's northern boundary.

Early April in Yellowstone is not spring by more civilized standards. The land sloping toward the Lamar River lies beneath a frozen sea of white, though a bright sun softens the snow, rounds the drifts. But a quick look at the layers exposed by his shovel tells Halfpenny that spring has definitely arrived here. The snowpack, which has accumulated over several months, is now only 26½ inches thick and has decayed into four layers—in midwinter it might be twice as deep, with many distinct layers. Standing thigh-deep in his snow pit, Halfpenny measures the depth and temperature of each. He sprinkles crystals—mostly granules now—onto his tongue to gauge their size, pushes his hand against the snow to assess each layer's hardness, then removes samples and weighs them to determine the snow's water content.

Water content, or density, is critical to determining snow's insulating properties. Denser snow—like this pack—is wetter and provides less insulation. Cold, dry snow consists of billions of crystals separated by tiny air pockets. Six to eight inches at a relatively dry density of, say, 10 percent water content is enough to protect ground-level life from bitter nighttime temperatures. (In the high Rocky Mountains, seven percent density is common for new snow; closer to the coasts, 20 percent is typical.)

Fresh-fallen snow is a near mirror for short-wave radiation—sunlight and starlight—something skiers and mountaineers who get snowburn around the edges of their goggles and sunglasses can attest to. Older, dirtier snow may reflect only 40 percent to 50 percent of short-wave radiation.

Snow itself is almost black to long-wave radiation; it absorbs the heat emanating from basically everything that's not a sun. Where snow lies against any object—a rock, a tree trunk—long-wave radiation melts it, creating soft spots or spaces that small mammals can move through. Once an insulating layer covers the land, temperatures in the interstice between snow and the ground stabilize near 32 degrees Fahrenheit. Gaps open. Warmed by radiant heat from the earth, ground soil thaws, providing an abundant supply of that most important element of life, water.

In this subnivean space, sheltered from temperature flux, shrews devour insect eggs and pupae every day, mice eat seeds, and voles graze on grass. Some rodents live more communally, clustering in dens for warmth, excavating latrine caves to isolate the scent of their feces and urine from their living quarters. When small mammals do surface—sometimes to seek new food sources—they ascend and descend the snowpack in tunnels where radiant heat has thawed the snow along tree trunks and shrubs.

Halfpenny points to a glade of pine trees down the slope. Predators will come along and check every tree trunk, he says. "To a certain extent the same thing is going on with coyotes. But the key predators are martins and most of all weasels, because they go up and down along the tree trunks, too."

The snow conceals mice and voles from many of their summertime avian predators—owls, hawks, and kestrels—and at certain depths and hardnesses, shields them from foxes, coyotes, and bobcats. Weasels move in subnivean space almost as easily as their prey, but their long thin bodies are not efficient for heat storage, so they line their own subnivean dens with fur plucked from their victims to create more warmth for resting.

Sizing up the hole he's dug and data he's collected, Halfpenny knows right away that the snowpack on this day in Yellowstone is isothermal—it's headed for a meltdown. Thawing has progressed enough so that water percolates down through the pack and temperatures are nearly uniform throughout, within a tenth of a degree of freezing. The snow can no longer recover its winter characteristics.

Earlier in the winter, depth hoar—fragile crystals with minute spaces between them—dominates the snowpack. Deer mice, voles, shrews, and weasels can move freely beneath and within it. Grouse often submerge themselves in soft snow as shelter from nighttime cold.

But spring's isothermal conditions are dangerous for mammals below. Because the snow is water-saturated, it's lost many of its insulating properties. A string of too-cold or too-warm days could be disastrous. "Should a real cold front move in, a cross section of snow could freeze and the animals could be trapped in there," Halfpenny says. This late in the winter, food supplies are grazed over. Being trapped in one place by an ice layer could limit the animals' ability to forage, which could be fatal.

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A sudden, sustained rise in temperature is equally dangerous. "Since water is percolating down, everything [at ground level] is pretty wet," Halfpenny says. "In a real heavy melt, small mammals can get wet and get hypothermic—or, worse yet, drown. This can be a delicate time of the year for small mammals."

Plants are in a different position, as late winter and early spring's wetter snow transmits more short-wave radiation to the ground. Snowbank buttercups blossom through the drifts, and some grasses begin growing long before the snow melts away. Research suggests that chemical signals in growing grasses trigger reproductive activity in voles, so that they start bearing offspring beneath the snow's protective layer. Halfpenny says the years in which this happens account for significant pulses in vole populations—subnivean litters may survive in conditions of reduced predation and mature to breed in greater numbers, flooding the land with voles.

While many insects either die off in winter or enter a state of suspended animation, some, including snow flies and crab spiders, breed under the snow, feeding on springtails, tiny creatures that appear in such hordes they may make the snow's surface appear coated in soot. Insects that don't remain active survive in a number of ways, including by burrowing into the leaf litter or by "supercooling" their bodies. They pump glycerol into their cells to inhibit ice formation, which would rupture cell walls. Each cell also shrinks when the moisture in it moves toward the ice crystals that form between cells, allowing supercooled creatures to survive in sub-zero environs.

What's happening under the snow among even smaller organisms is far less understood, although in the past decade scientists have made remarkable and important discoveries. When Paul Brooks, now a professor in the department of hydrology and water resources at the University of Arizona, gave his first presentation to the American Geophysical Union in San Francisco in 1993, he summarized two years of research indicating that in midwinter, the ground beneath the snow was thriving with living, breathing, eating, growing microbes.

Afterward, Brooks says, the hall full of scientists was silent. Nobody believed him. "Nobody asked any questions," he says. "One person said I was incompetent, that I clearly didn't know how to measure this stuff. Another person said we all know there isn't life at temperatures that low."

Brooks pressed on and today is a pioneer of subnivean microbial biochemistry. He and others have found that the subnivean world seethes with microbial life—vast mats of fungi and bacterial colonies—many of which were not even known to science 20 years ago.

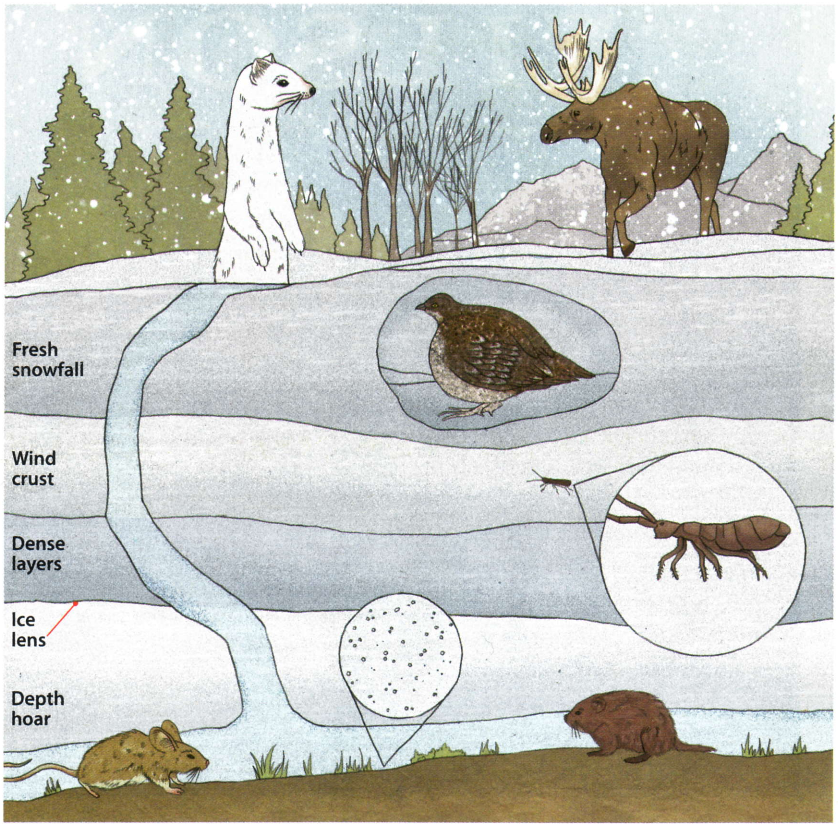
Steve Schmidt, a University of Colorado microbiologist, investigates many of these microbes. Employing techniques akin to those used on TV shows like *CSI*, Schmidt uses DNA sequencing to identify organisms in the soil. "We've found thousands and thousands of new things," he says. "We can't characterize a lot of them yet beyond their DNA, but we know they're there and we know they're different than anything else we've seen."

These subnivean microbes—which Schmidt says can be quite beautiful, some forming coral-like shapes and ranging from orange to grayish-blue—are distinguished by highly specialized eating preferences and grow rapidly in what were long considered inhospitable conditions.

Brooks himself thought nothing of subnivean microbial life when, while a graduate student of Schmidt's, he was working on an offshoot of acid rain problems—acidification caused by atmospheric nitrogen brought to earth by falling snow.

"We get out in winter and dig our snow pits, and we're standing there in two or three meters of snow, and we look down at the ground and see the ground isn't frozen," Brooks recalls. "It had been frozen in October, but it's not [in midwinter]. We found microorganisms were growing and holding on to the nitrogen, not just from the snowpack but also the nitrogen that was in the soil before snow started to fall. It was one of those surprising things where you think, 'Hey, wow! I wonder what's going on here?' "

To find out, they traveled to New Mexico, Colorado, Wyoming, and Alaska, taking



Snow Castle For many animals that don't migrate or hibernate, snowpack provides shelter and food throughout the winter. The snow world, or nivean environment, is divided into three regions: supranivean (above the snow), intranivean (within the snowpack), and subnivean (beneath the snow). Birds such as grouse may cover themselves in powder near the surface to stay warm, while deeper snow shields mice and voles from birds of prey and foxes, coyotes, and bobcats. Tunnels that form along tree trunks and shrubs allow weasels and other small mammals to move throughout the layers. In the subnivean space, near the warmer earth, rodents such as mice and shrews graze on grass or insect eggs. And at the ground surface, fungi and bacteria communities thrive, a source of carbon dioxide that's been recognized only in the past decade.

samples in a wide range of altitudes and ecosystems (coniferous and deciduous forests, meadows, treeless alpine slopes). Brooks found—and others confirmed—that winter is a time of great biological activity that produces massive amounts of carbon dioxide.

Brooks's latest data indicate that how much carbon microbes release is closely tied to when snow falls. A cold snap that occurs before a blanket of snow insulates the ground will freeze at least part of the plant and microbial life that has been growing all spring and summer. When plants and other organisms freeze, ice crystals can rupture cells and break down the tissues, which microbes and other scavengers that remain unfrozen can then use as food when they thaw.

Brooks found that when all other conditions remain similar, a delay in snowfall creates a huge difference in the amount of CO_2 respired into the atmosphere. To a point, the more severe the freeze, the more dead plants and microorganisms are frozen—and the more ice crystals rend open tissues. As a result, more microbe colonies may thrive when it warms under the snow cover, yielding 25 percent to 200 percent more CO_2 into the air. "Up to half the carbon that plants take up in summer is released back into the atmosphere by microbes in winter," Brooks says, a fact nobody knew until a few years ago. This means estimates of how much carbon seasonally snow-covered forests absorb must be recalibrated to account for the carbon collectively released by the respiration of billions of tiny creatures. If a warmer world means the delayed arrival of the snowpack, even more carbon could be released in the future.

There is a tipping point. If snowfall arrives too late, the ground remains bare and frozen too long, and ice sublimates into the air. Think of freezer burn: Leave a piece of fruit in a plastic bag in the freezer too long and ice crystals form inside the bag. Water that was in the fruit has sublimated, then condensed on the bag, forming ice. The same thing happens in bare soil, only there's no bag to trap the water vapor, which dissipates into the air. The ground grows dry. As a result, though there's plenty of food for microbes, without water their growth is retarded.

Fewer, smaller microbe colonies means less carbon respired into the atmosphere—which would seem like a boon for the climate except that it has another serious repercussion. Subnivean microbes, it turns out, provide much of the nitrogen that plants need to grow in the spring. They absorb nitrogen from the snow and from decomposing plants in the soil. As snow melts in the spring and these organisms die, nitrogen is freed at precisely the time plants emerging from winter need it to grow. The microbes provide a critical nitrogen banking service for vegetation in seasonally snow-covered ecosystems.

There's more: If a lack of nitrogen stunts vegetative growth, the amount of carbon that grasses, shrubs, and trees can remove from the atmosphere in spring and summer is also diminished. Essentially, that means less climate-change-causing carbon is pulled from the atmosphere and stored in plants. "There seems to be a very, very delicate balance," Brooks says, "a situation where a little change in just the timing of the snowpack could cause tremendous changes in how these systems function, both summer and winter."

Animals like voles and deer mice survive under the snow at the mercy of conditions. Their success in any given year drives ecosystem health. Populations of animals from snowy owls to grizzly bears are, in part, regulated by the number of rodents that survive beneath the snow. The more voles, shrews, and mice there are, the more predators there will be.

The smaller, microbial life that flourishes under the snow is just beginning to be understood, and it, too, prospers according to the whims of weather. But the lifecycles of subnivean microbes seem to have even further-reaching ramifications than local population dynamics. We see snow as a transformative element, brilliantly whitening our vision. But beneath its still surface, these tiniest of life-forms ebb and surge, ravaging secret winter feasts. Their tiny subnivean lives and deaths alter the composition of our atmosphere—and may affect the entire planet's health. ■

Jeff Hull's *most recent* Audubon *article was on wolverines (January-February 2008).*

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