AZ Wildfire Initiative
Northern Arizona University
School of Forestry
Southwest Fire Science Consortium
FireScience.gov
Research Supporting Sound Decisions

MEET THE SOIL MICROINVERTEBRATES

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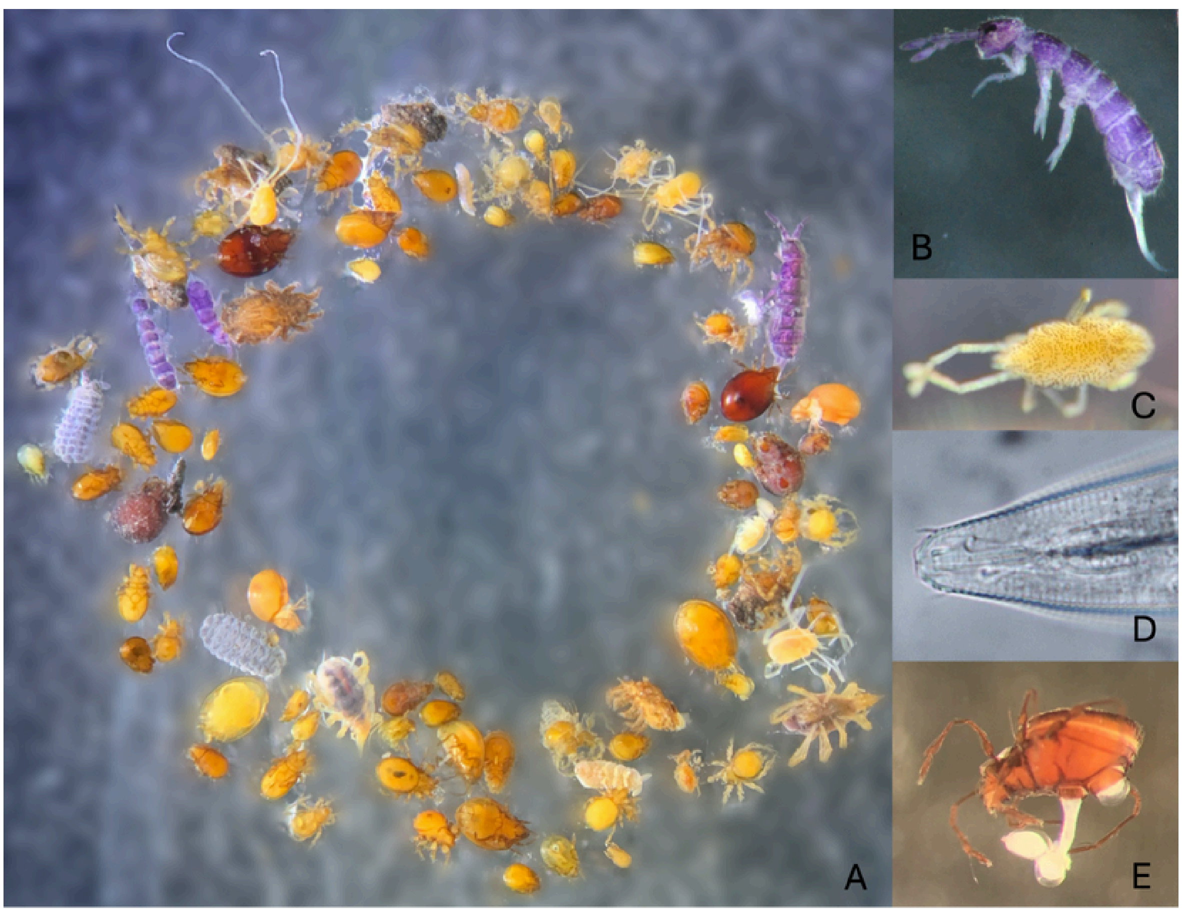
THE KINGS AND QUEENS OF THE SOIL JUNGLE

Did you know that most multicellular animals in forests are tiny soil and litter dwelling invertebrates that are barely visible or invisible to the naked eye? We call these minute critters “microinvertebrates” (in contrast to “macroinvertebrates,” which are larger, more easily observable invertebrates like earthworms). A square meter of forest floor is typically home to millions of nematodes (also known as roundworms) and tens to hundreds of thousands of mites (tiny arachnids) and springtails (six-legged creatures that evolved before insects, named for an appendage which enables many species to jump) (Figure 1). Other less common soil microinvertebrates in Southwest forests include tardigrades (water bears or moss piglets), rotifers, proturans (coneheads), diplurans (two-pronged bristletails), symphylans (pseudocentipedes that are far smaller than true centipedes), and pauropods. Although under-appreciated, these dazzlingly diverse animals are key components of forest soil food webs. They perform important ecological functions and have been evolutionarily intertwined with plants, microbes, and each other for an extremely long time—in many cases, since plants first colonized land.



ITS A NEMATODE WORLD

One square meter of forest floor has millions of nematodes. If that seems like a lot, it is: nematodes are so abundant that they are thought to comprise ~80% of all multicellular animals on Earth.

In the words of E.O. Wilson, “We live in a nematode world.”

Photos by Kara Gibson

Figure 1. Microinvertebrates collected from Southwest US forests, viewed under a microscope. A) Mites and springtails; B) springtail with eponymous appendage in view; C) prostigmatid mite; D) head of a bacterial feeding nematode; and E) oribatid mite laying eggs.

WHY SHOULD WE CARE ABOUT THEM?

They make the wood go round

Most soil microinvertebrate species consume bacteria, fungi, protists, lichens, algae, decaying plant material, or other microinvertebrates (living or dead). Some species specialize on one of these food sources, while others are omnivores. A small minority are parasites of plants or animals. Through their feeding activities and movement, soil microinvertebrates can increase the availability of plant nutrients like nitrogen, influence decomposition and carbon cycling, transport otherwise immobile fungi and bacteria throughout the soil, and regulate populations of the organisms they eat, including parasites and pathogens.

They are food

Microinvertebrates are on the menu for many larger animals including insects, spiders, and amphibians like New Mexico's endangered endemic Jemez Mountains salamander.* In addition to providing energy, microinvertebrate meals can be critical sources of calcium (e.g., some oribatid mites), omega-3 fatty acids (nematodes), and even defensive compounds (mites are likely a major source of the potent alkaloids found in poison dart frogs). Microinvertebrates are also sometimes indirectly "eaten" by trees: predatory fungal symbionts of some tree species paralyze soil fauna, extract nitrogen from their bodies, and then trade that nitrogen for carbon from their tree hosts.

*Although small microinvertebrates like nematodes are too tiny to be prey for amphibians, larger ones (especially mites) are commonly consumed.

They are ecological resilience

Globally, there are approximately 27,000 described species of nematodes, 40,000 species of mites, and 9,000 species of springtails (the most diverse groups of soil microinvertebrates). There are likely many more undescribed species because soil microinvertebrates have received far less attention from taxonomists than macroscopic animal groups. However, the alpha-diversity (the number of species in one spot) of soil microinvertebrates is often exceptionally high—so high that it has long perplexed ecologists, who refer to this phenomenon as "the enigma of soil animal diversity". This diversity can help increase ecological resilience to wildfire, drought, and rising temperatures. When some microinvertebrate species are lost, a diverse baseline community increases the probability that remaining species can "pick up the slack" if they have similar functional roles to lost species (this is called "functional redundancy").

WORLD RECORD HOLDERS

Oldest: a nematode that woke up after spending ~46,000 years in suspended animation within permafrost.

Strongest: a mite that can withstand crushing pressures of up to 560,000 times its body's weight, roughly equivalent to a human supporting the weight of the Titanic.

Fastest (runner): a mite that can run up to 323 body lengths per second—equivalent to 1,300 miles per hour for a human-sized creature—while executing hairpin turns.

Highest thermal tolerance: the same mite as above can survive body temperatures of up to 60 °C (140 °F) for one hour.

Best adapted for space travel: tardigrades in a dormant "tun" state can survive the vacuum of space.

Most acrobatic: some springtails can right themselves midair in under 20 milliseconds (faster than any other animal measured), allowing them to land on their feet after performing hundreds of somersaults.

They are innovative

The adaptations possessed by these diverse microinvertebrate species have the potential to catalyze scientific advances in fields ranging from medicine and physiology to materials science and robotics. Microinvertebrates in some taxonomic groups produce a dizzying array of chemical secretions, including antimicrobial compounds, most of which have yet to be characterized.

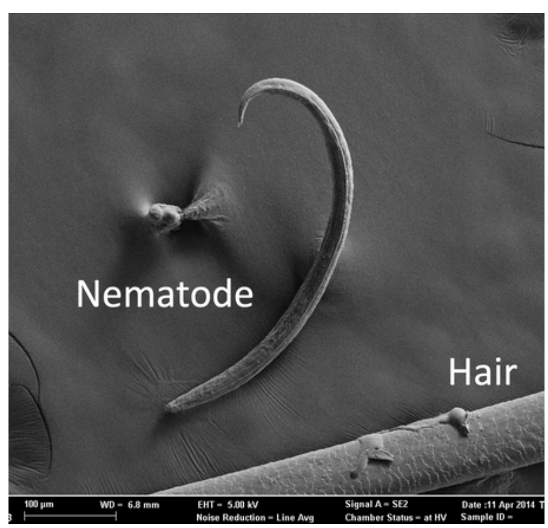
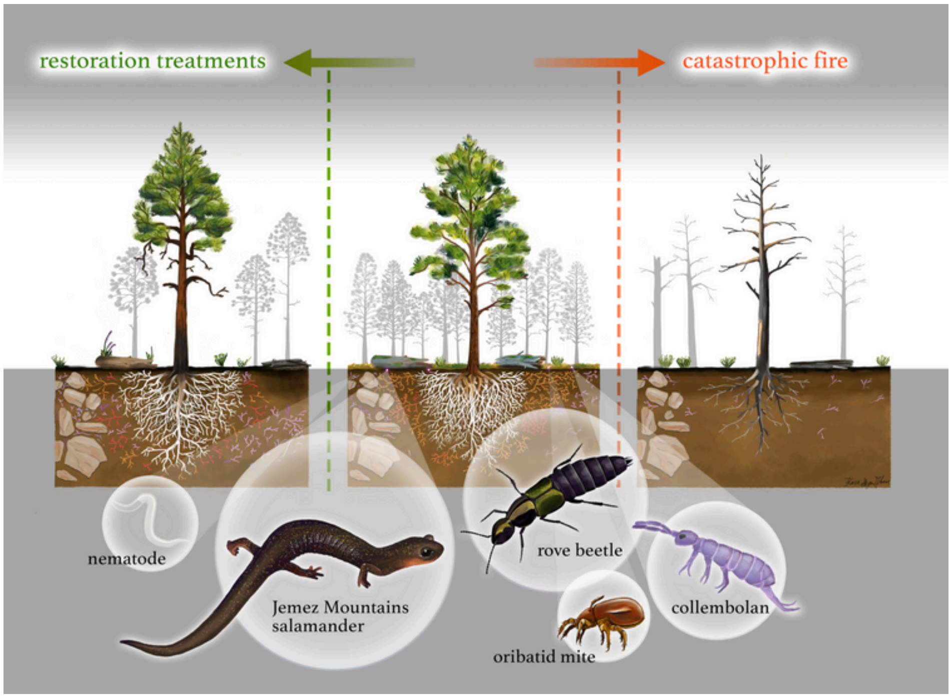


Image taken by a scanning electron microscope that shows, by comparison, the size of a nematode. Photo by Kara Gibson



LEFT: *Soil habitat physical characteristics and microbial communities differ in the three scenarios (treated, unburned & crowded, and post high severity fire) pictured here. The effects of these differences on soil microinvertebrates, and on the larger animals that eat them, are still poorly understood. Land managers can partner with researchers by taking some easy steps to monitor the effects of treatments on soils and their microinvertebrate communities. Informative data can be gathered using even very rudimentary equipment: for example, with a ruler, some simple soil sampling equipment, an oven, pH strips, and a scale, one can measure litter depth and soil bulk density, moisture, and pH.*

Illustration by Kara Gibson.

HOW CAN WE PROTECT MICROINVERTEBRATES WHILE MANAGING FORESTS?

Historically, many forests (e.g., ponderosa pine, dry mixed conifer) in the Southwest experienced frequent, low severity fires; however, due to a legacy of overgrazing, overharvesting, and fire suppression, these forests now have higher fuel loads than were historically typical and are prone to burning with high severity—especially as climate change increases temperatures and reduces precipitation in the region. **High severity wildfires can decimate soil microinvertebrate communities** by exposing animals to lethal soil temperatures and destroying soil organic matter, which provides critical habitat and food resources for microinvertebrates and microbes and helps soil retain water. (Soil moisture is especially important to nematodes, rotifers, and tardigrades because these animals are technically aquatic, relying on thin films of water in the soil—although many can weather dry periods in an inactive state called anhydrobiosis.) **Treatment strategies such as thinning and low severity prescribed fire can help protect microinvertebrates** from catastrophic wildfire and restore historic habitat features, but with an important caveat: while better than the effects of high severity fire, these treatments also carry the potential for negative and long-lasting impacts on soil microinvertebrates if not implemented carefully.

Thinning operations with heavy machinery

Compaction and other soil disturbance from heavy logging machinery often used in thinning operations can kill microinvertebrates during treatments, reduce the rate at which water infiltrates the soil, and increase erosion of important topsoil habitat. Because most microinvertebrate species are too small to shift soil particles and are therefore reliant on existing pores and channels, compaction can additionally limit their ability to access food and avoid hot, dry surface conditions by moving deeper in the soil. Compaction also increases the thermal conductivity of soils, allowing heat to penetrate more deeply. In combination, these effects could increase the vulnerability of soil microinvertebrates to climate change. Depending on the depth affected, soils can take years to decades to recover from compaction.*

Prescribed fire

While prescribed burning is often a viable strategy to prevent high severity wildfire, it may still carry risks to microinvertebrates that exceed those of historic fires. Although we lack true reference systems that would allow us to compare the effects of historic fires and prescribed fires on soils, microinvertebrates are probably more likely to experience lethal soil heating during today's prescribed fires than during low severity fires of the past due to the presence of thinning residues and heavy litter accumulation. (Of course, many microinvertebrates will also be present within these unnaturally deep litter layers, and they will perish when the litter burns unless they can escape to safe depths.) Heat might also penetrate more deeply into soils during prescribed fires than historic fires, especially if compaction occurred during prior thinning or if burning is conducted when soils are relatively moist, as is common to minimize the risk of uncontrolled wildfire. (The thermal conductivity of soils also increases with water content.) Many soil microinvertebrates appear to have relatively low heat tolerance; for example, significant mortality of soil mites, springtails, and proturans is likely to occur after 15-60 minutes at 38-48 °C (100-118 °F). Other microinvertebrates—e.g., many nematodes capable of entering anhydrobiosis—can withstand high temperatures only when conditions are dry. Thus prescribed fires may kill many microinvertebrates even if soil heating is modest compared to high severity wildfires.

*Recovery time increases with depth. Unfortunately, deep soil compaction has been called an "insidious threat" because it can occur in the absence of detectable surface compaction. While surface compaction results from high contact stress and can therefore be avoided by spreading the weight of heavy equipment out over wider tracks or tires, soil stress becomes more dependent on total equipment weight with increasing depth.

WHAT CAN YOU DO?

Although more research is needed on these topics, negative impacts of restoration treatments on soil microinvertebrates can likely be mitigated—and recovery hastened—by following these best management practices:

- *Minimize soil compaction*: Use the lightest adequate machinery when thinning, minimize the area driven upon, treat only when soil is dry or frozen, consider driving on slash mats, and follow any specific recommendations developed for the soil type and topography of your treatment area. If possible, also test for soil compaction at multiple depths before treating a large area to ensure that mitigation measures are adequate.
- *Create refugia*: Maintain small undisturbed areas from which soil microinvertebrates can recolonize the surrounding landscape. These refugia should be especially beneficial to microinvertebrates with long generation times, low reproductive output, and low dispersal ability (traits that make them slow to recolonize large areas); however, they will likely speed recovery of the entire microinvertebrate community. Refugia are provided naturally during low-severity fires that burn heterogeneously, leaving some areas unscathed, but maintaining tiny "islands" that are neither thinned nor burned may also be helpful (and provides a point of comparison to evaluate treatment effects on soil microinvertebrates and other organisms).

Citation Gibson, K. S., Johnson, N. C., Laturno, C., Parmenter, R. R., & Antoninka, A. (2022). Abundance of mites, but not of collembolans or nematodes, is reduced by restoration of a Pinus ponderosa forest with thinning, mastication, and prescribed fire. *Trees, Forests and People*, 100190.

Use this QR code to find references and download PDFs of this fact sheet.

*The **Southwest Fire Science Consortium** (SWFSC) is a regional organization that facilitates knowledge exchange and disseminates wildland fire research and information across agency, administrative, and state boundaries in the Southwest. The SWFSC is one of 15 Fire Science Exchange Networks funded by the Joint Fire Science Program.*

*The **Arizona Wildfire Initiative** (AZWI) at the Northern Arizona University's School of Forestry supports Arizona's wildland fire needs by enhancing workforce development and education, communicating science, and increasing resilience to Arizona's communities. AZWI is funded by the state of Arizona.*