New Global Biodiversity Atlas Reveals the Secrets of Soil

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A water-beaded springtail, a kind of wingless hexapod (six-legged). Fast movers and good jumpers, the 8500 known species of hexapods live everywhere from Antarctica to rainforests and warm beaches. An average square meter of soil in a temperate grassland can yield as many as 40,000 individuals. Image credit: Andy Murray

Peer inside a hunk of moss-covered soil, and you'll find an alien world. Microscopic animals called tardigrades—nicknamed "water bears" and "moss piglets"—amble about on eight clawed legs, their sharp round mouths piercing the moss to get a meal. Some tardigrade species are predators, gobbling up other tiny soil inhabitants, like rotifers—glassy tube-like creatures as slight as a hair, with hard jaws. Rotifers, in turn, are hunting bacteria or other microorganisms in the capillaries of water that form between soil particles. Meanwhile, some of those bacteria may be chomping up dead organisms and other organic matter, shooting out nutrients that feed the moss and other plants.

After a tardigrade molts, it leaves behind the remains of its exoskeleton, which is often filled with eggs that develop within. Image credit: David Robson

When you hear the word "biodiversity," soil might not be the first thing that pops into your mind. After all, scenes from lush rainforests or colorful tropical reefs are immediately more recognizable as hosting diverse organisms. In reality, though, tardigrades and rotifers are just two examples of many in a world teeming with life: Soil holds an estimated quarter of biodiversity worldwide.

On Monday, May 23, the Global Soil Biodiversity Initiative and the European Commission Joint Research Centre will publish a new report highlighting this diversity. (You can download the report for free here beginning Monday.) The report is billed as the first global biodiversity atlas, and it pulls together information on how soils form; global maps of soil types and biodiversity; major threats to soil; where certain soils exist, like the iron-rich reds in tropical regions of Africa and the silky marbled browns of the Russian Arctic; and the latest soil science. It's the first time all of this information has been available in one place.

Most intriguing, though, is the dizzying menagerie of wildlife that live inside soil. Much of it, particularly microorganisms that are hard to grow and study in the lab, has only been discovered in recent years thanks to advances in genetic screening.

Why does the air smell like soil after it rains? Thank the phylum Actinobacteria, with various species cultivated here on artificial substrates made with jelly-like substances and nutrients such as oatmeal. Members of one genus, *Streptomyces*, are capable of producing a wide variety of antibiotics with numerous properties: antibacterial, antifungal, antiviral, antitumor, antiparasitic, insecticide, and weed controlling. Image credit: Paola Turconi // Fondazione Istituto Insubrico di Ricerca per la Vita

The 300,000 known soil types worldwide are home to an estimated one million species of bacteria; 1.5 to 5.1 million fungi species; tens of thousands of different insects and worms; and many moles and other burrowing mammals. There are also uncountable lesser-known soil creatures such as coneheads, nematodes, pseudoscorpions, springtails, and stramenopiles.

Less than a single teaspoon of soil may contain billions of individual microbes representing tens of thousands of species—more organisms than there are humans on the planet—and yet scientists estimate that they've only identified around 1 percent of the microbes that live in soil.

The pseudoscorpion is a tiny arachnid that lacks the elongated postabdomen and venomous sting of a real scorpion. Considering its size—usually less that 5 mm long—it's surprisingly long lived, surviving up to four years. Image credit: Andy Murray

Nematodes, or roundworms, are soil microfauna. There are 20,000–25,000 known species, but scientists estimate there may be as many as 10,000,000 species in this phylum. Image credit: David Robson

Entwined myriapods. The sub-phylum myriapoda includes millipedes, centipedes, and other terrestrial arthropods. Image credit: Lady Dragonfly via Flickr

Soil is by far the most biologically diverse part of the Earth, with a mix of living organisms interacting with one another and with plants and small animals, forming a web of biological activity. Many of the 14,000 known ant species are among them. Image credit: Valentin Gutekunst via Flickr

According to the atlas, the known soil biodiversity across the world correlates closely with the biodiversity aboveground, including plants and animals. But soil is more than a habitat for hidden flora and fauna. It's also a vital natural resource, just like water and air. “Soil is the living, breathing skin of our planet,” the authors note.

In addition to living organisms, it's made of organic matter, minerals, and water. It's a major carbon sink, storing carbon dioxide that could contribute to climate change if it were to escape. The living things within it each play a role. Microbes, for example, eat organic matter and spit out vital nutrients that help plants grow, while the paths of wriggling invertebrates like insects and worms let air and water circulate. Plant roots help hold the soil in place, preventing erosion, and provide niche ecosystems where countless species thrive.

Without soil, our planet wouldn't function, and neither would we: An estimated 99 percent of our food comes from terrestrial agriculture. “We can't eat and we can't have clean air unless we have plants in soil,” says Diana Wall, a soil scientist at Colorado State University and the scientific chair of the Global Soil Biodiversity Initiative. “And soils have to be healthy to grow these trees and forests, and the food we eat.”

Soil also isn't easy to regenerate. Depending on the climate and the type, it can take a hundred to thousands of years to form mere centimeters. “Within our lifetime, [soil] is a nonrenewable resource,” says Valerie Behan-Pelletier, an acrologist and emeritus research associate with the Canadian National Collection of Insects and Arachnids, as well as an atlas author. “Our food, our fresh water—the quality of so many things in life is dependent on soil.”

One in five animals on Earth is thought to be a nematode. These transparent aquatic organisms are classified into five groups based on their morphology and the shape and size of their mouthparts: bacterivores, fungivores, omnivores, plant parasites, and predators. Predaceous nematodes like this one have one or more large teeth or a pointed spear that they use to attack and ingest small animals such as enchytraeids, tardigrades, rotifers, protists—and other nematodes. Image credit: H. van Megen and J.H. Helder // Wageningen University

The naked mole-rat is one of only two soil-inhabiting mammals known to be eusocial, meaning they live in colonies with a division of labor more often seen in bees, with a reproductive queen and nonreproductive workers. It may not be pretty, but it is enduring: a naked mole-rat can live for up to 31 years. Image credit: Smithsonian National Zoo via Flickr

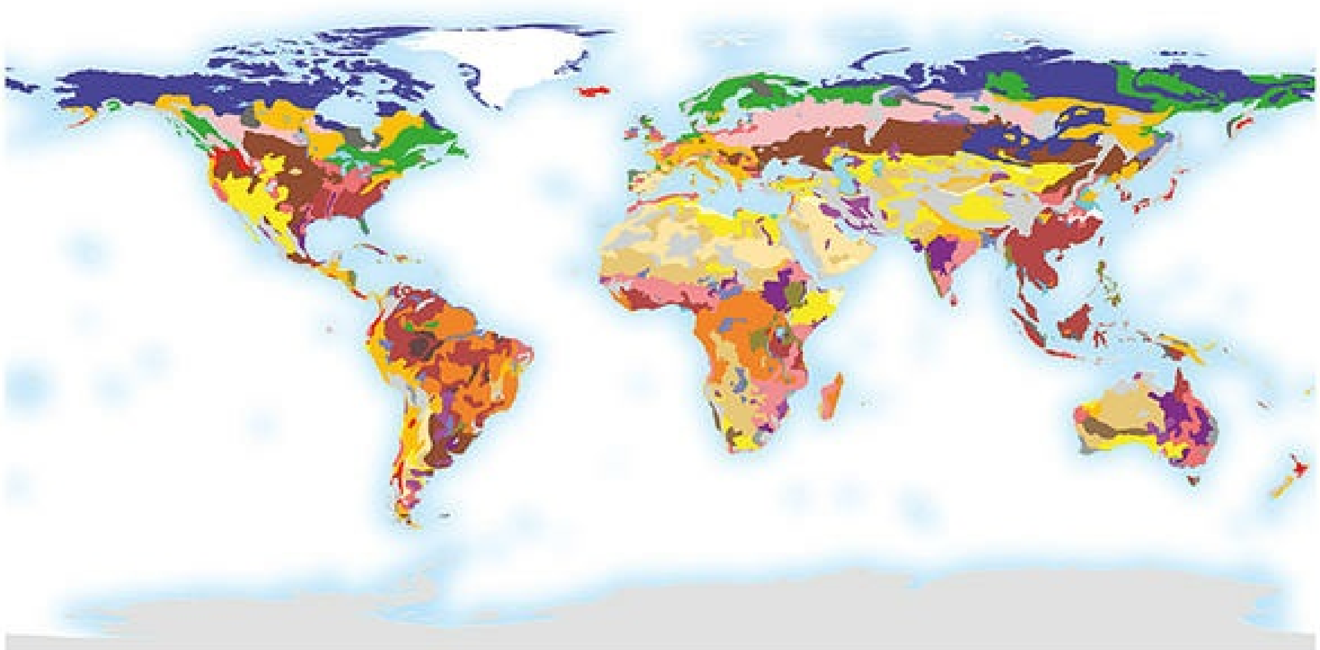
With its fearsome jaws, the multicolored, iridescent Japanese tiger beetle (*Cicindela japonica*) is strikingly beautiful —and probably terrifying if you're an ant or another prey species roaming the soil. Image credit: Yoshichika Awoki

Since soil is such a vital resource, the new biodiversity atlas was originally intended for policymakers, Wall says, to help guide decisions on agriculture policy, biodiversity initiatives, and any other regulations that might affect soil.

But the project soon became a potential resource for scientists from other areas of study, Wall adds. That's not surprising considering the construction of the atlas: It took three years and a multidisciplinary team of 121 scientists, which made it easy for other researchers to hear about the work.

“One of the problems we have is that the other disciplines do not quite perhaps realize the importance of soils—the global issues as they relate to science,” says Rattan Lal, a soil scientist at the Ohio State University, who wasn't involved with the atlas. “Soil science is a kind of synthesis of lots of disciplines: biology, chemistry, physics, hydrology, microbiology. We need other disciplines to study processes of soil.”

The atlas is important, Lal adds, because it is “bringing a scientific issue to a broader audience.”



Global distribution of the main soil types, from lime-rich calcisols (bright yellow) and peat-rich histosols (dark gray) to andosols (bright red)—the result of volcanic ejections—and nutrient-poor ferralsols (deep orange). Because climate plays an important role in soil formation, soils generally differ from one major climatic zone to another. Image credit: Joint Research Centre

In addition to showing where soils are and what lives in them, the atlas lists soil's biggest threats. These include agriculture, climate change, soil erosion, certain invasive species, pollution, and loss of diversity of plants and other aboveground life. These pressures may increase as the global population grows and demands for food and fiber rise.

There are hotspots of plant species loss in Brazil and India, for example, as well as trends toward plant loss in areas where we grow food and build homes, which likely corresponds to drops in soil biodiversity. Agriculture is one of the most intense ways we use soil, and it currently takes up more than 40 percent of our land, according to the atlas; the more we work the land, the more it may reduce certain soil invertebrates. And everyday byproducts of modern civilization, including oil, pesticides, and heavy metals, can change the distribution of organisms living in the soil in both immediate and long-lasting ways. Heavy metals, for example, can alter the metabolism of plants and soil microbes, while certain pesticides don't discriminate between beneficial species and pathogens or pests (although soil communities may be able to bounce back or build resistance if pesticides are managed well).

Enchytraeidae are a family of annelida (class oligochaeta), resembling small white earthworms that are found both on land and in water. They can only be identified when alive because the taxonomy uses external and internal structures, which can be clearly seen only through the living transparent body. Image credit: Andy Murray

Research pinpointing current soil biodiversity on farms could set a baseline for the future, to monitor how that biodiversity changes in soils that grow food and support livestock. It may also point to ways to keep the soil healthy.

But an even more important feature of the atlas may be what it doesn't show, says Noah Fierer, one of the authors as well as a microbial ecologist at the University of Colorado Boulder. "One of the values is that it highlights what we don't know, and that's oftentimes more than what we do know." Understanding those knowledge gaps, Fierer adds, helps point scientists to where more work needs to be done.

The maps in the atlas are far from complete, and scientists don't understand the roles that the vast majority of soil organisms play in soil. Consider the rotifers that are dodging hungry water bears in your hunk of mossy soil. Although scientists have identified 2030 rotifer species, know their peculiar asexual mating habits, and have figured out that the critters can spend long periods of time in suspended animation, their role in the soil food web is mostly a mystery.

Rotifers are minute multicellular organisms 0.05 to 3 mm long with mostly transparent bodies subdivided into a head, trunk, and a foot. Across species, they're sexually dimorphic, and the females are always larger. One class, Bdelloidea, evolved entirely without sexual reproduction and are assumed to have reproduced without sex (parthenogenetically) for many millions of years. There are no male Bdelloids. Image credit: Hendrik Segers

If scientists can't get a better handle on soil communities as they exist today, certain biodiversity could be lost forever. "One thing at stake is you don't know what you're missing until it's gone," says Penny Hirsch, a soil microbiologist at Rothamsted Research, who wasn't on the atlas team. The working hypothesis on soil has been that its inhabitants may have overlapping functions, which means losing one might not necessarily hurt the overall health of the ecosystem. For example, if multiple species feed on the same type of fungi and keep it in check, and one of those species is wiped out, the others may be able to pick up the slack. Still, says Hirsch, "the implications of not knowing are perhaps that we aren't sure what to look for if things go wrong."

The next step for the Global Soil Biodiversity Initiative is to get a more precise snapshot of the soil in specific countries, says Wall. This will provide data on current biodiversity, historical and possible future trends, and overall health. It could also help inform decisions on soil management.

In the meantime, the scientists hope soil gets more popular with policymakers, the public, and budding researchers.

"There are new things to discover in the soil, right here on Earth. You don't have to go to Mars or the moon to find something you don't know," says Nancy Johnson, a soil ecologist at Northern Arizona University one of the authors of the atlas. "My gosh. It's right under our feet."

There are 40,000 known mite species and perhaps twice as many in existence. Image credit: Andy Murray

All images via Global Soil Biodiversity Initiative

Editor's note: An earlier version of this story said that soil has more biodiversity along the equator. That's only the case for the diversity of termites, as compared to other regions.