

# Grasshoppers under siege: Here's how climate change depletes insect populations and threatens the global food supply

It's tough out there for a hungry grasshopper on the Kansas prairie. Oh, there's plenty of grass to eat, but this century's grass isn't what it used to be. It's less nutritious, deficient in minerals like iron, potassium and calcium.



Partly due to that nutrient-deficient diet, there's been a

[huge decline in grasshopper numbers](#) of late, by about one-third over two decades, according to a 2020 study. The prairie's not hoppin' like it used to — and a major culprit is carbon dioxide, says study author Michael Kaspari, an ecologist at the University of Oklahoma in Norman.

Atmospheric carbon dioxide is at its [highest in human history](#). That's probably fine for plants like the grasses the hoppers munch. They can turn that atmospheric carbon into carbohydrates and build more plant — in fact, plant biologists once thought all that extra carbon dioxide would simply mean better crop yields. But experiments in crops exposed to high carbon dioxide levels indicate that many food plants contain less of other nutrients than under carbon dioxide concentrations of the past. Several studies find that plants' levels of nitrogen, for example, have fallen, indicating lower plant protein content. And some studies suggest that plants may also be deficient in phosphorus and other trace elements.

The idea that plants grown in today's carbon dioxide-rich era will contain less of certain other elements — a concept Kaspari categorizes as nutrient dilution — has been well-studied in crop plants. Nutrient dilution in natural ecosystems is less-studied, but scientists have observed it happening in several places, from the [woods of Europe](#) to the [kelp forests off Southern California](#). Now researchers like Kaspari are starting to examine the knock-on effects — to see whether herbivores that eat those plants, such as grasshoppers and grazing mammals, are affected.

The scant data already present suggest nutrient dilution could cause widespread problems. “I think we are in canary-in-a-coal mine territory,” Kaspari says.

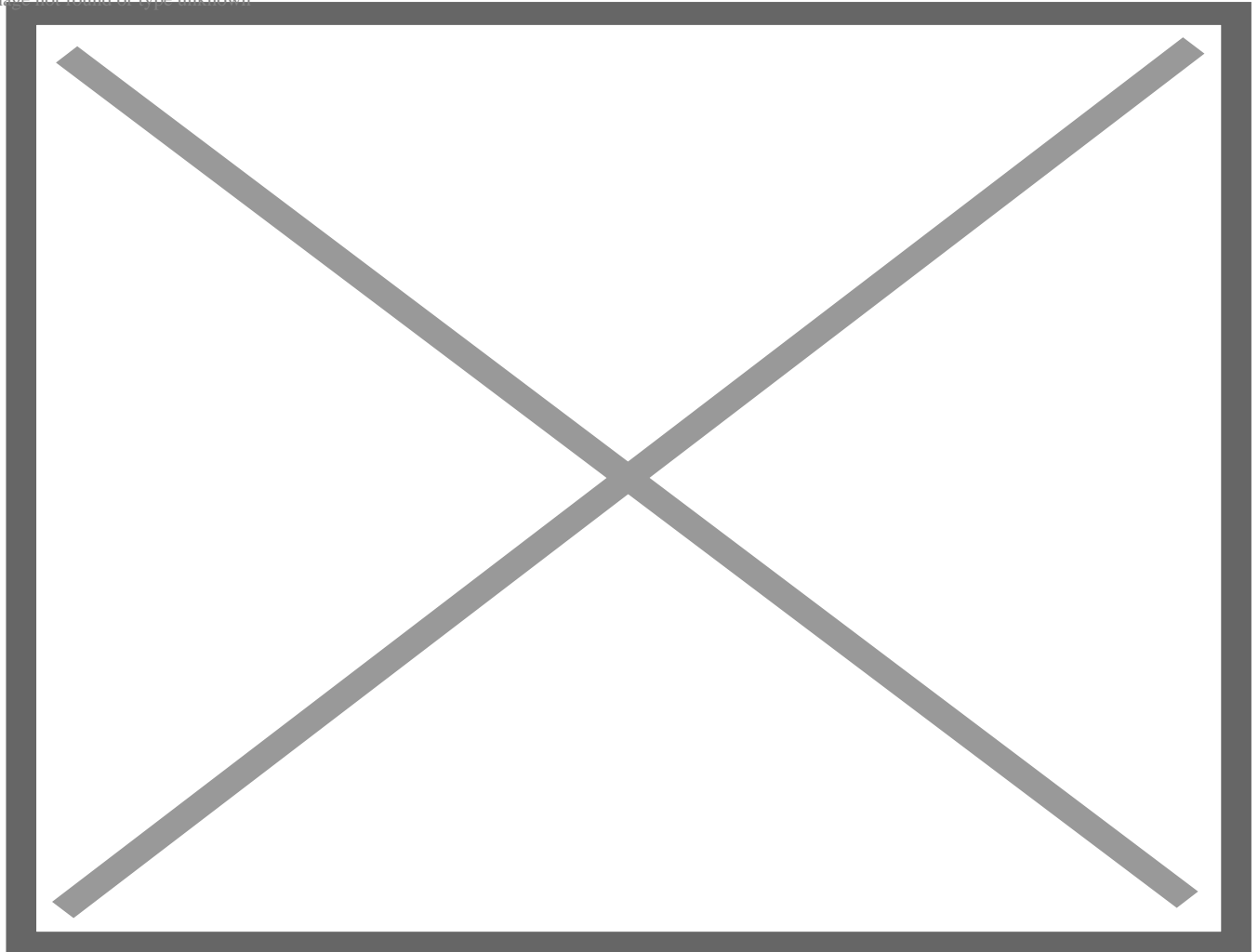
## Lower-quality food?

It's clear that rising carbon dioxide levels change plant makeup in a variety of ways. Scientists have done years-long studies in which they pump carbon dioxide over crops to artificially raise their exposure to the gas, then test the plants for nutrient content. One large analysis found that raising carbon dioxide by about 200 parts per million [boosted plant mass](#) by about 18 percent, but often reduced levels of nitrogen, protein, zinc and iron.

Vegetables like lettuce and tomatoes [may be sweeter and tastier](#) due to added carbon-rich sugars, but lose out on some 10 percent to 20 percent of the protein, nitrate, magnesium, iron and [zinc](#) that they have

in lower-carbon conditions, according to another large study. On average, plants may [lose about 8 percent of their mineral content](#) in conditions of elevated carbon dioxide. Kaspari likens the effect to trading a nourishing kale salad for a bowl of low-nutrient iceberg lettuce.

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When vegetables are grown under elevated levels of carbon dioxide, they typically get bigger and sweeter and may have more of some minerals, such as calcium, an analysis of several different studies found. But quantities of other minerals, including zinc and iron, can go down.

Scientists don't yet know exactly how extra carbon dioxide leads to changes in all these other nutrients. Kaspari, who discussed the importance of [micronutrients such as calcium and iron in ecosystems](#) in the 2021 *Annual Review of Ecology, Evolution and Systematics*, suggests it's a simple issue of ratios: Carbon goes up but everything else stays the same.

Lewis Ziska, a plant physiologist at the Columbia University Mailman School of Public Health in New York City, thinks it's more complicated than just ratios. For example, in the vegetable study, elevated carbon dioxide increased the concentration of certain nutrients, such as calcium, even as it limited levels of others.

One contributing factor could be plants' little openings, called stomata, through which they take up the

carbon dioxide they use to make sugars and the rest of their structures. If there's plenty of carbon dioxide around, they don't need to open the stomata as often, or for as long. That means plants lose less moisture via evaporation from those openings. The result could be less liquid moving up the stem from the roots, and since that liquid carries elements such as metals from soil, less of those trace elements would reach the stems and leaves.

Scientists have also posited that when carbon dioxide is high, plants are [less efficient at taking up minerals](#) and other elements because the root molecules that normally pull in these elements are acting at a lower capacity. There are probably multiple processes at play, says Ziska. "It's not a one-size-fits-all mechanism."

Whatever is going on in these well-studied crops, the same thing is presumably occurring in trees and weeds and other non-agricultural species, says Kaspari. "If it's happening to the human food supply, it's happening to everybody else."

Free Air Carbon dioxide Enrichment (FACE) studies pump extra carbon dioxide over plants so scientists can see how they respond. Many FACE studies have focused on crop plants; this University of Birmingham project is studying the effects of elevated carbon dioxide on a large patch of forest in Staffordshire, England. Credit: University of Birmingham

Several studies suggest that Kaspari is right. For example, even though farmers add nitrogen fertilizer to croplands and that nitrogen then washes into neighboring waterways or wildlands, nitrogen availability is [on the decline](#) in a variety of non-agricultural ecosystems. In one analysis, researchers examined nitrogen levels in more than 43,000 leaf samples, collected in various studies between 1980 and 2017. Atmospheric carbon dioxide levels rose by nearly 20 percent during that period, and nitrogen concentrations in the leaves [decreased by 9 percent](#). Mineral concentrations are also affected: Scientists who studied trees in Europe between 1992 and 2009 observed a [drop in several](#), including calcium, magnesium and potassium, in at least some of their leaf samples.

Scientists can also examine museum and herbaria samples to study how plant nutrient content has changed as planetary carbon dioxide levels have risen. Ziska and colleagues did so for goldenrod, a key food source for bees. Using collections from the Smithsonian Institution's natural history museum in Washington, DC, they analyzed pollen from as far back as 1842, just before the American Industrial Revolution. At that time, the carbon dioxide levels were 280 parts per million, compared to just over 420 today.

Pollen protein content, and thus nutrition level, decreased over time by about one-third, the scientists found. Ziska's modern experiments with goldenrod grown under carbon dioxide levels as high as 500 parts per million confirmed that [more carbon dioxide yields protein-deficient pollen](#). Though it's not clear yet what this means for bees, it's probably not good, Ziska says.

The results are striking, particularly compared with crop studies that don't draw on large historical datasets, says Samuel Myers, a principal research scientist at the Harvard T.H. Chan School of Public Health who has investigated the link between the [health of pollinators](#) and [human nutrition](#).

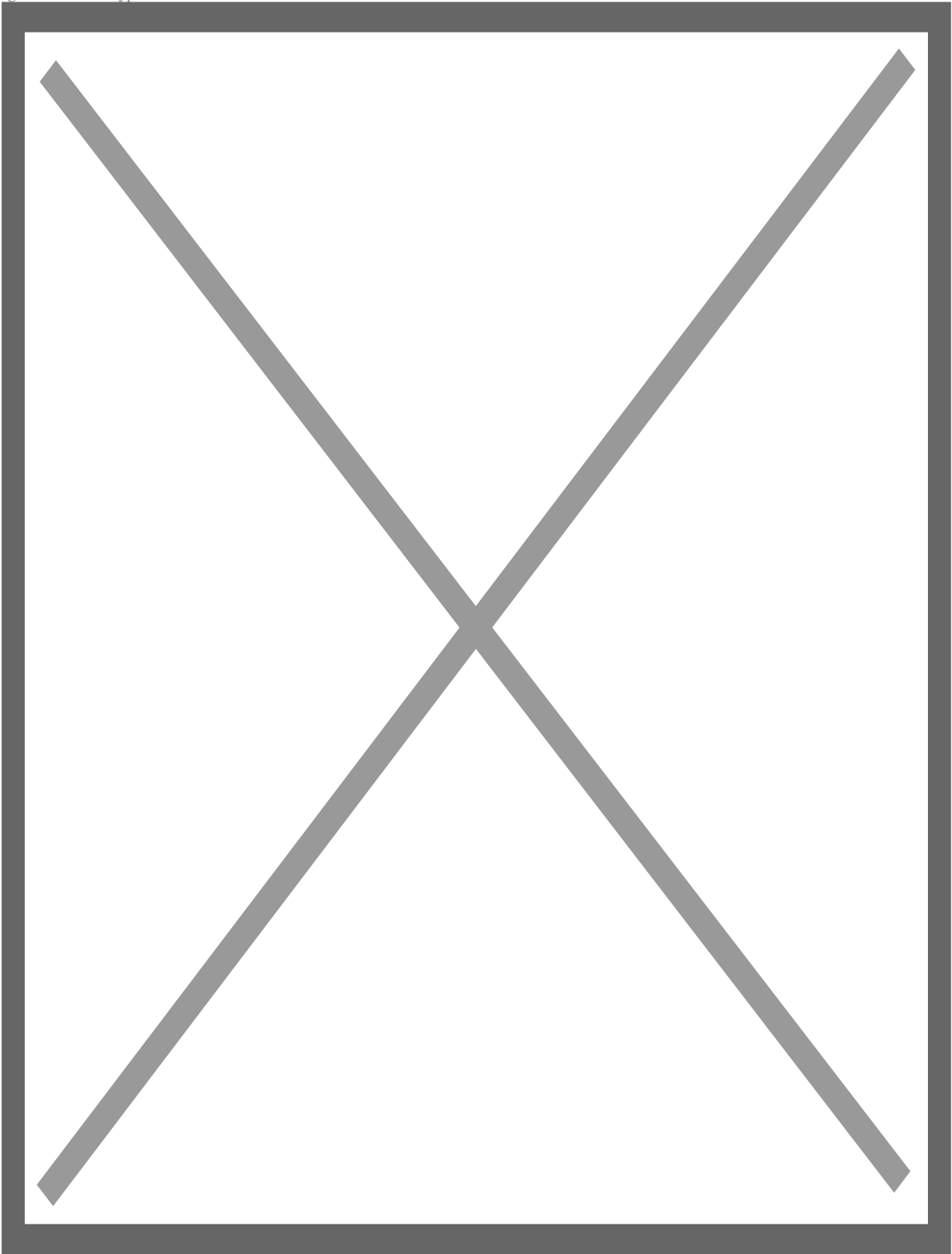
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## **Lush grasslands, empty calories**

Animals such as bees need more than protein from their diet; they also need micronutrients. Certain minerals, like sodium, are more important for animals than for plants, Kaspari notes. Many plants are fine with no sodium at all, but animals require sodium for brains and muscles to work properly. (That's why deer visit salt licks and athletes chug Gatorade.) Many plants seem to survive without iodine, but animals depend on it for thyroid function.

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Plants take up many elements from the soil, some of which are needed by both plants and animals, others only by animals.

Nutrient dilution, then, could affect herbivores in all kinds of ways, and could be contributing to a reported, though controversial, drop in insect numbers that's sometimes referred to as the "insect apocalypse," says Andrew Elmore, an ecologist at the University of Maryland Center for Environmental Science in Frostburg. "When insects are nutritionally stressed, they don't grow as quickly, and therefore they don't reach maturity as quickly, they don't reproduce as rapidly, and so population size can decline," Elmore says.

Kaspari's study on Kansas grasshoppers, published in 2020, was the first to [link nutrient dilution in plants to a conspicuous decline in an insect population](#). It focused on the Konza Prairie, a natural area in northeastern Kansas that's been set aside to research the tallgrass prairie ecosystem. Konza features shrubs and trees alongside grasses, and is home to rodents, birds, lizards and deer.

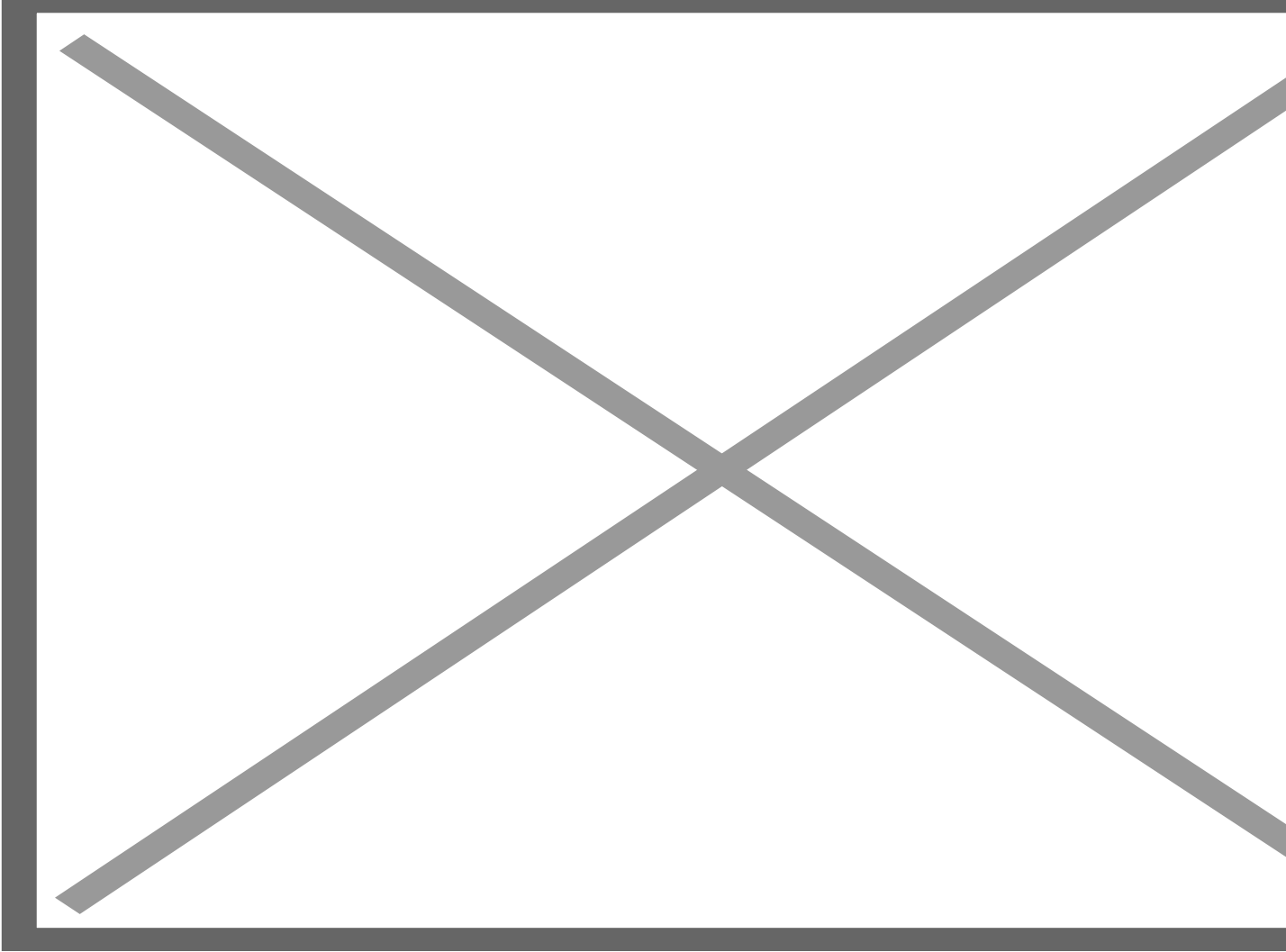
Kaspari and colleagues accessed more than three decades' worth of data on the prairie's plant life and grasshopper populations — more than 93,000 of the insects had been sampled. Plant biomass went up, mostly due to a doubling of grass biomass, from the mid-1980s through 2016. That sounds like a big buffet for grasshoppers, but their populations declined by more than 2 percent every year, the researchers found. Kaspari and colleagues think the reason lies in the grasses: Within them, several elements that grasshoppers need — nitrogen, phosphorus, potassium and sodium — waned over the same time period.

While other aspects of climate and weather no doubt played a role in grasshopper numbers, the researchers estimated that nutrient dilution was responsible for about one-quarter of the grasshopper decline.

There are hints that creatures higher up the food chain — grasshopper predators — might be affected too. Alice Boyle, an avian ecologist at Kansas State University in Manhattan, says that her as-yet-unpublished data from the Konza Prairie show that when researchers counted territorial male grasshopper sparrows in specific areas over time, the birds' population dropped from about 65 in 1980 to fewer than 20 in 2021. The species could disappear from the prairie within 100 years, she says.

Grasshoppers are major chompers of grass in grasslands like Konza, but so are bigger animals that graze the prairie. Little is known about the effects of nutrient dilution on large herbivores such as deer, but for evidence of what might be going on, Kaspari points to their "urban cousins" — cattle.

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Nitrogen is a critical element of plant proteins. When nitrogen levels decline in leaves, the insects and animals that get protein from those leaves may grow more slowly and have fewer offspring.

To investigate possible nutrient dilution in cattle diets, Elmore and colleagues took advantage of a long-term dataset on cow dung from Texas A&M Agrilife Research in Temple. There, rangeland ecologist Jay Angerer, now with the US Department of Agriculture, helped ranchers concerned about their animals' nutrition by analyzing cow patties — a practice that has given him more than 36,000 measurements covering more than 22 years. The researchers found that since 1994, when carbon dioxide levels were about 360 parts per million, the concentration of crude protein in the cowpat samples [dropped by almost 10 percent](#).

These studies paint a picture of American grasslands that have become green deserts, stacked with lush plant life that offers empty calories. How the interwoven effects of high carbon dioxide, plants, and the animals that eat the plants will play out in other ecosystems remains to be seen. Studies aiming to clarify what's going on are underway: For example, a large collaboration [called the Nutrient Network](#) is busy

analyzing grassland nutrient budgets and herbivore populations around the world, in order to better understand the links between plant production and diversity and the influence of grazers. And the Cedar Creek Ecosystem Science Reserve, at the University of Minnesota, has been [analyzing how ecosystems are responding to environmental change](#), including high carbon dioxide, for more than four decades.

The diverse effects of climate change on natural ecosystems make it hard to know how concerned to be. Some organisms could gain an advantage while others lose out. For example, the grasshoppers Kaspari studied appear to be taking a hit, yet other grasshoppers — specifically, [crop-damaging locusts](#) — seem to [benefit from a diet that's less nutrient-rich](#).

“That’s what keeps me up at night, is the complexity of the global experiment that we’re now running on the ecosystem,” says Myers, who is director of the [Planetary Health Alliance](#), a consortium investigating the impacts of environmental degradation on human health. “We don’t have any idea what the implications are.”

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