Heeding the heat: Desert regions may better inform the future of global temperate zones driven by climate change

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Satellite imagery shows the landscape in Denmark in a typical July in contrast to the dry, hot conditions with little vegetation in July 2018. Credit: Jose Gruenzweig, The Hebrew University of Jerusalem, European Space Agency; CC BY-SA 3.0 IGO

When it comes to the world's climate, in the past decade, Earth keeps sending us its summer siren's call.

Annually, it's mostly been a case of heeding the heat, and repeat. According to NASA, nineteen of the hottest years have occurred since 2000, with 2016 and 2020 tied for the hottest ever on record. This summer is already making worldwide headlines, with the UK scorching beyond 40 degrees Celsius (104.5 Fahrenheit) for the first time ever.

More climate extremes are occurring. Earlier snowmelts affect the high-altitude areas, severe forest fires are increasing, while rain pulses, followed by dry periods, are becoming the norm. But if heat waves and severe droughts are trends that will continue to hold across the globe, what will the future bring to temperate forest and cropland regions of the world?

Scientists are looking at the unique adaptations of desert life, which function by their own set of rules long considered to be unique to dry areas. Now, new research by an international team of scientists suggests that climate change is causing these "dryland mechanisms" to increasingly affect earth's wetter areas, such as temperate regions' croplands and forests.

To better predict how the world's wetter areas will operate in the future, the scientific team recommends that we can begin to apply the lessons learned from how life works in arid regions, according to new research published in the journal *Nature Ecology and Evolution*. The study was led by Jose Grünzweig of The Hebrew University of Jerusalem and co-authored by Arizona State University's Heather Throop.

"The new insights can contribute to advancing our adaptive capacity to withstand climate extremes and lessen their impacts on nature and people," said Throop, a professor with a joint appointment in ASU's School of Earth and Space Exploration and School of Life Sciences.

Spurred by a recent meeting of the European Ecological Federation, the team compiled a list of the unique rules of life driving dryland ecosystems. Currently, more than a third of the Earth's land area is drylands. Many of these key processes have been considered relevant only to arid regions, including:

- rapid cycling between wet and dry conditions that influence plant and animal activity,
- redistribution of water in soils by plant roots,
- and formation of living crusts on soil surfaces by microscopic organisms.

Overall, the team identified a dozen different dryland mechanisms affecting multiple processes, including vegetation distribution, plant growth, water flow, energy budget, carbon and nutrient cycling, and decomposition of dead material.

"These dryland mechanisms are controlled by environmental factors, such as intense solar radiation, high temperatures, large bare patches between plants, and inconsistent availability of water," said Throop.

The mechanisms were also categorized as either more likely to be fast-responding—those that we might expect to see occurring from short-term drought (e.g., dry-wet cycles, heat and sunlight breaking down dead material) and slow-responding—those that would happen after decades of dry conditions (e.g., formation of living crust on soils) as a result of changes in plant distribution.

Corn in Denmark during the July 2018 heatwave. Credit: Janne Hansen; CC BY-NC 4.0

"In the paper we present these 12 different dryland mechanisms that are really routine processes in drylands but aren't commonly found in wet systems," said Throop. "And then we categorized them in the paper based on how likely it is that these are going to happen in wetter systems in the future. What sort of changes would be required for us to start seeing those in wetter systems?"

What's clear to the researchers is that a new, unprecedented pattern is emerging, one that was considered absent or insignificant in most biomes on Earth. These dryland mechanisms are now, with increasing frequency, occurring in temperate regions. In the future, these also will likely increase in frequency and become more relevant due to warmer, drier conditions from climate change.

For example, much of Europe experienced a severe drought and heat wave in summer 2018. As a result, the low plant cover in agricultural fields during this time likely led to desert-like biological processes occurring in these usually wet locations (see Denmark aerial image).

"A lot of the corn and irrigated agriculture suffered," said Throop. "There was dramatically decreased plant growth in those systems, which leads to more exposure of bare soil on the surface that's not covered by plants."

To better understand potential future ramifications of dryland mechanisms on things like vegetation distribution and decomposition of dead material, the team took its drylands' data and modeled it to show how the forces driving drylands will increasingly apply to temperate regions under future climate conditions.

"We can use mathematical models to predict how systems will behave under drier or hotter conditions, but we usually assume that the operating rules will stay the same even if the climate changes," said Throop. "But right now, what our models don't really take into account is what if the rules by the which the system works change?"

What happened when they fully took their dozen dryland mechanisms into account? The results, first and long-term consequences were stunning. For example, their models predict that the total non-dryland area with average topsoil temperature of >40 C (>104 F) is estimated to increase by about 17 million km^2 (approximately equal to the total land area of the U.S. and Brazil) by the end of the century.

"Breaking down dead material is important in ecosystems since it releases nutrients for new plant growth," said Throop. "Typically, in wet systems this decomposition is driven by organisms such as bacteria that consume the dead material. In dry systems the rules are different—we have a lot more influence of sunlight and high temperatures breaking down material that's sitting on the surface."

"So, instead of having biology driving that decay, we have physical processes driving it," said Throop. "One of the big differences with dry systems is that because you don't have many plants there's a lot of open space and you have a lot of redistribution, with things like dead leaves blowing around on the soil surface and accumulating unevenly. Where in wet systems, those things are staying in place, and you have a much more even distribution of resources."

Dry soil conditions will cause the emergence of some dryland mechanisms, such as redistribution of soil water via plant roots. Other mechanisms will respond to changes in vegetation, with more sparsely distributed vegetation increasing the prevalence of microorganisms forming soil surface crusts and increasing the role of sunlight in breaking down dead leaves.

"What's also clear is that some of these projected changes will occur in regions with large human populations, and, thus, will significantly affect the well-being of society in these regions," said Throop. "We will need continued research and monitoring on ecosystem functioning under increasing frequency and severity of droughts and heatwaves in order to improve our understanding of the underlying emergent processes."

Ultimately, the researchers hope that a better understanding of these uniquely adapted desert systems will lead society to set realistic expectations for the future of historically temperate and wetter areas—before it's too late to heed Mother Nature's call.

More information: José Grünzweig, Dryland mechanisms could widely control ecosystem functioning in a drier and warmer world, *Nature Ecology & Evolution* (2022). DOI: 10.1038/s41559-022-01779-y. www.nature.com/articles/s41559-022-01779-y

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