Why drought matters for the global environment

STAP Information Note

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STAP SCIENTIFIC AND TECHNICAL ADVISORY PANEL

An independent group of scientists that advises the Global Environment Facility

gef

UN environment programme

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Table of Contents

1. What is the issue?

The United Nations General Assembly defines drought as a "naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems."[1]. With the intensification of climate change, drought is emerging as a critical global challenge. It is leading to ecosystem disturbances and biodiversity loss, greenhouse gas emissions, and water scarcity, threatening agricultural systems and food security, undermining livelihoods, and driving migration and conflicts[2]. Approximately 55 million people are affected by drought annually globally. The Intergovernmental Panel on Climate Change (IPCC) estimates that between 800 million and 3 billion people could experience water scarcity due to drought at 2°C warming[3].

Drought will be an important issue at the UNCCD's COP16 in December, at which increased support to drought-affected countries will be considered, including by "…shifting from crises management to drought preparedness and adaptation measures that significantly reduce vulnerability and exposure at all levels." [4]

"The Global Environment Facility (GEF) addresses drought in the land degradation focal area, including through drought-smart land management and drought mitigation in drylands[5]. Also, through the Least Climate Change Fund (LDCF) and Special Fund for Climate Change (SCCF), the GEF seeks to reduce vulnerability to drought by enhancing adaptive capacity to climate change and strengthening resilience[6].

This STAP information note presents background information on drought and its relevance to the work of the GEF. STAP has created this note to outline its preliminary thoughts on drought for its side event at COP16 and related discussions. It discusses drought as a global concern, summarizes the scientific evidence on drought, and details its implications for GEF's objectives. The note also highlights some actions to prevent or mitigate drought.

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[1] UNGA (1994) defined drought as a "naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems."

[2] UNCCD (n.d.).

[3] See IPCC (2022).

[4] See UNCCD (n.d.).

[5] GEF-8 programming supports drought management, particularly through the land degradation focal area. See GEF (2022).

[6] See UNFCCC (2024).

2. What does the science say: causes, trends, impacts, and solutions?

Drought occurs when there is a deficit in precipitation that subsequently can affect the water cycle – the movement and supply of water above and below ground (e.g. soils, aquifers, lakes, rivers, reservoirs, snow, ice)[7]. Drought is also influenced by vegetation, land and water management practices, and warmer temperatures.

Vegetation regulates the water cycle through evapotranspiration and influences soil-water retention and runoff, consequently affecting the likelihood of drought depending on the specific situation. Land and water use practices, such as irrigation, water harvesting and storage, and soil health practices (e.g., tillage system, cover cropping, mulching, and crop rotation), can also influence drought.

Higher temperature is the most significant cause of drought because it increases soil and surface water evaporation and dries out vegetation. Evidence shows that climate change increases the frequency and intensity of extreme weather events, such as droughts[8]. Record-breaking temperatures have been linked to more frequent and severe droughts worldwide[9]. The sixth IPCC assessment report[10] projects that warmer temperatures will lead to a decline in precipitation and an increase in drought in several parts of the world.

Based on data from the 2022 UNCCD reporting process, 1.84 billion people in 101 countries are affected by drought, with 4.7% facing severe or extreme drought conditions[11]. Eighty-five percent of those affected by droughts reside in low- or middle-income countries. Between 2016 and 2019, approximately 3.28 billion hectares (about 50% of the land area in reporting UNCCD countries) were impacted by drought.[12] Figure 1 illustrates an IPCC map highlighting areas (in orange) where drought severity is expected to increase due to climate change.

Figure 1. IPCC map showing where drought (orange areas) is expected to increase because of climate change. The drought pattern is similar regardless of the emissions scenario. However, the magnitude of change increases under higher emissions.[13]

[7] IPCC (2021).
[8] IPCC (2021).
[9] Moss et al. (2024) & Flores et al. (2024).
[10] IPCC (2021).
[11] UNCCD (2024).
[12] UNCCD (2024).
[13] IPCC (2021).

Impact of drought on the environment

Drought profoundly affects multiple environmental dimensions, including soil health, biodiversity, climate stability, and water availability.

Soil: drought can alter soil microbial activity and negatively impact soil organic matter formation, consequently reducing the soil's water-holding capacity. These processes can affect the resilience and productivity of terrestrial ecosystems.[14]

Climate change: Droughts can cause the soil to crack, exposing stored carbon to oxidation – that is, releasing carbon into the atmosphere.[15] The relationship between drought, soil cracking, and increased soil carbon emissions amplifies global warming (Figure 2).

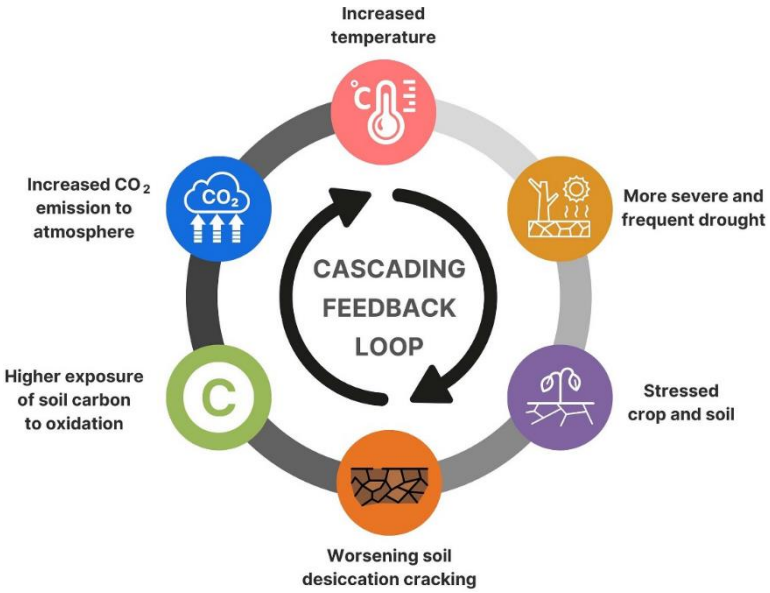

Figure 2. Feedback loop describing drought, soil desiccation cracking, and CO_2 emission relationships in a warming climate [16]

Biodiversity: Droughts can drive shifts in ecosystem structure and function, increasing the prevalence of fires and invasive species, altering plant-soil interactions, and impairing ecosystem services, such as nutrient cycling[17]. Exceptionally hot droughts are expected to become more common, creating conditions for wildfires, invasive species, and soil degradation, among other effects, which could trigger unfavorable ecosystem transitions[18]. Furthermore, drought can lead to pollinators decline due to a reduction in the number of available flowers.[19] Additionally, it limits food availability to animals, affecting their survival and breeding cycles, which could lead to species extinction.[20]

Water: During drought conditions, groundwater, as a more drought-resilient natural water resource compared to rivers and lakes, is likely to be extracted more to satisfy industrial, irrigation, and

[14]UNCCD (2024).

[15]Vahedifard et al. (2024) & Ke et al. (2024).

[16]Figure sourced from Vahedifard et al. (2024).

[17]Cook et al. (2020); Cook et al. (2022); Robinson et al. (2019) & Kaisermann et al. (2017).

[18]Flores et al. (2024) & Ke et AL. (2024).

[19] Descamps et al. (2021); Phillips et al. (2018) & Kuppler et al. (2021).

[20] Cahill et al. (2013); & Fonturbel et al. (2021).

community demands. This could lead to a significant decline in groundwater levels and accelerate groundwater depletion[21]. In addition, prolonged drought could lead to the deterioration of natural water quality (i.e., rivers and wetlands), potentially resulting in increased concentrations of pollutants and salinity in the water, eventually affecting the quantity and quality of drinking water resources for local communities[22].

Impact on food security and other socioeconomic issues

As aforementioned, droughts can impact soil and water, essential for agricultural (crop and livestock) productivity. It can also increase pest pressure by making plants more vulnerable to insects and fungi.[23] In the Horn of Africa, droughts have severely affected populations and ecosystems, causing food insecurity for millions of people[24]. This leads to income losses, especially in rural areas where women, children, indigenous and local communities are most vulnerable.

Most populations in less developed economies in Africa, Asia, and Latin America, are more vulnerable to drought[25]. They tend to have limited economic resources, potentially weak governance, increased population growth, and pressure on resources (land, water), and live in landscapes increasingly exposed to drought. Collectively, these factors limit opportunities to reduce exposure and sensitivity to drought.

Drought poses significant challenges to Indigenous People and local communities, threatening their livelihood and cultures[26]. For the foreseeable future, the dynamic interplay between climate change and socioeconomic development will likely magnify drought vulnerability and risk, especially to Indigenous Peoples and local communities [27].

Droughts have also been identified as one of the underlying causes of conflict, migration, and displacement[28]. Understanding the complex interactions between environmental, political, socioeconomic, and cultural factors is essential to accurately defining the challenges and responses influencing drought.

Addressing drought

Addressing drought requires a multifaceted approach that combines immediate relief efforts to mitigate impacts with long-term resilience strategies to help prepare for possible future occurrences. Investing in land, forests, and other natural capital that affects biodiversity, soils, and water availability is essential. Examples of interventions that can help prepare, mitigate, or respond to drought risks include:

- **Promoting drought-smart land management practices**, supporting drought mitigation efforts in arid regions, and assisting countries in line with the UNCCD's mandate to enhance resilience and sustainable land management in the face of drought challenges.

[21] Liu et al. (2022).

[22] European Climate and Health Observatory (2024).

[23] EPA (2024) & Skendiz et al. (2021).

[24] Kimutai, et al. (2023).

[25] Drysdale et al. (2020) & Juárez-Lucas et al. (2024).

[26] UNEP (2024).

[27] WEF (2024); UNEP (2024) & UN-DESA (n.d.).

[28] IPCC (2021) & Migration Data Portal, (2023).

- **Drought-resilient agriculture**, e.g., planting drought-resistant crop varieties and adopting agroecological practices such as agroforestry, silvopasture, permaculture, mulching, no-till farming, mixed cropping, and cover cropping[29] that can help improve soil organic matter and carbon content.
- **Sustainable urban planning and green infrastructure**, including using permeable pavements, green roofs, and stormwater management systems, can help cities store rainfall water.[30]
- **Implementing early warning systems for drought monitoring and prediction** to allow for early detection of drought conditions and proactive measures by communities and governments.
- **Biodiversity conservation as a measure for addressing drought**. The nexus between drought and biodiversity is critical for enhancing ecosystem resilience and mitigating impacts. Biodiversity conservation plays a crucial role in drought prevention by helping maintain healthy ecosystems that naturally regulate water cycles, improve soil moisture, and buffer against water scarcity. It helps buffer against drought by strengthening ecosystems' functional diversity and resilience, allowing landscapes to better withstand and recover from dry conditions. For example, protecting wetlands, rivers, and watersheds can help maintain natural water cycles and storage systems.[31] Similarly, avoiding deforestation or rehabilitating or restoring forests and grassland ecosystems through nature-based solutions can facilitate water cycle stabilization, improve rainfall, and enhance land water retention.[32] Diverse tree communities contribute to forest productivity through soil water partitioning, sustaining drought-sensitive species, and improving growth during dry spells.[33]

  Biodiversity conservation-aligned practices such as short-duration grazing in grasslands can improve resilience to water scarcity [34], while diverse decomposer communities maintain carbon and nitrogen retention, supporting essential ecosystem functions during dry periods[35]. Although biodiversity may not directly resist drought, it significantly aids recovery[36] and is linked to reduced negative impacts on rural incomes in developing countries. However, the role of biodiversity can vary by scale and biome; in boreal forests, mixed-species interactions may lead to soil moisture depletion[37].
- **Sustainable water managemen**t **and conservation practices,** including efficient irrigation techniques like drip irrigation and water storage infrastructure, e.g., reservoirs and dams, aquifer recharge, and rainwater harvesting systems.[38] Recognizing the critical role of green water (soil moisture) in mitigating drought impacts underscores the need for comprehensive water conservation plans. Protecting moist biodiversity habitats, such as floodplains and riparian areas, is vital for native plant survival during droughts.[39] Although efficient irrigation can alleviate shortages, it does not address the root causes of water scarcity. Implementing strategies like rainwater harvesting, water recycling, and improved irrigation practices is crucial to enhancing resilience[40]. Adopting a framework that integrates prevention, preparedness, and management—including aquifer recharge and effective water allocation—can help create a robust response to drought challenges and promote sustainable water management.

[29] For example, Caceres-Arteaga and Lane (2020); Altieri et al. (2015).; Maia et al. (2023) Paracchini et al. (2020).
[30] For example, Yang and Wang (2017); Ramyar et al. (2021); Liu and Bergen (2018).; Sturiale and Scuderi (2019).
[31] Bullock and Acreman (2003).
[32] Ellison et al. (2017).
[33] Hisano et al. (2024).
[34] Griffin Nolan et al. (2019) & Loeser et al. (2007).
[35] Luan et al. (2024).
[36] Van Ruijven and Berendse. (2023).
[37] Grossiord et al. (2014).
[38] For example, Knutson 2008; Kosmowski 2018; Ragab and Hamdy (2004); Chartzoulakis and Bertaki, (2015); Álvarez-Berríos et al. (2018) & Srivastav et al. (2021).
[39] McLaughlin et al. (2017).
[40] Zaveri et al. (2023).

- **Supportive policies, governance frameworks**, and incentives to encourage and enforce water conservation practices, regulate water allocation, and promote efficient water use. Policies supporting drought insurance or financial support could also help enhance adaptative capacity and reduce the economic impact on affected people and communities.
- **Engage in capacity development, education, and awareness-raising initiatives** to enhance drought preparedness, promote sustainable water management practices, and foster effective adaptation strategies.

3. Why is drought important to the GEF?

The GEF aims to support transformational change and deliver GEBs across its focal areas (biodiversity, climate change mitigation and adaptation, chemicals and waste, international waters, and land degradation) as well as through its Integrated Programs (IPs). Delivering socioeconomic benefits is also essential to the GEF.

Drought and its associated impacts could hamper the GEF from achieving its focal area objectives:

- Drought can reduce soil carbon sequestration capacity and trigger emissions (80% of terrestrial carbon is found in soils[41]), thereby ***impeding greenhouse gas mitigation*** efforts.
- It ***leads to land degradation***, which could consequently lead to more drought.
- Drought ***impairs biodiversity*** by limiting plant growth, increasing wildfires and outbreaks of pests, impairing ecosystem services, such as nutrient cycling, and threatening local species.
- It adversely impacts the water cycle and puts pressure on fresh- and groundwater, thereby increasing competition for water resources and ***adversely affecting the effort to manage international waters sustainably***.
- The impact of drought ***threatens the resilience of ecosystems and human communities***, leading to income losses, ***thereby increasing exposure and sensitivity to climate change impacts and reducing their adaptive capacity***.

Drought negatively impacts projects and programs that aim to maintain or improve forest cover and other natural capital. Several of the GEF's IPs fall under this consideration, including those on Food Systems, Ecosystem Restoration, Forest Biomes, Blue and Green Islands, Net-Zero Nature-Positive Accelerator, and Sustainable Cities – which aim to achieve GEBs in climate change mitigation, biodiversity conservation, and sustainable land management.

The interventions being implemented through GEF investments, including the IPs, can, however, help build resilience to drought and prevent future occurrences. These include for example, support for sustainable, regenerative, nature-positive agricultural production systems in the Food Systems IP; investments in conservation and effective governance to maintain the integrity of globally important and critical tropical primary forests in the Amazon, Congo, and Critical Forest Biome IP; the application of integrated approaches for restoring degraded ecosystems in the Ecosystem Restoration IP and support for SIDS in implementing nature-based solutions and to value ecosystem services and incorporate them into decision making in the Blue and Green Islands IP.[42]

STAP side event at the UNCCD COP16

At its side event at COP16, STAP will discuss drought as a significant driver affecting the global environment. STAP will rely on questions to guide the event discussion, such as:

[41] Lal, R. (2004).

[42] See GEF (2023), which highlights the integrated solutions being implemented across the 11 GEF-8 IPs.

- What actions can be taken to better manage the risks and impacts of drought on the global environment?
- What are some key lessons on drought? For example, what has worked, why, and under what context can we prevent, mitigate, and manage drought and reduce the population's vulnerabilities?
- Given that the causes and impacts of drought are complex and interrelated, producing local, regional, and global feedback affecting the health of the global environment:
    - what actions are necessary, from the local to the global level, to counteract further negative tipping points? And are there geographical areas where these actions are more necessary?
    - what are the knowledge gaps in understanding drought impacts on ecosystems, biodiversity, and climate change? What further support, including capacity building, do countries need to help address these gaps?
    - How can the attribution of drought, climate change, conflict, and migration be better understood to define responses accurately?

The side event's discussion outcomes will be shared with the GEF secretariat and STAP. The outcomes may also inform STAP insights on how drought could be relevant to GEF-9.

References

Adaawen, S., Rademacher-Schulz, C., Schraven, B., & Segadlo, N. (2019). Drought, migration, and conflict in sub-Saharan Africa: what are the links and policy options? Current directions in water scarcity research, 2, 15-31. https://doi.org/10.1016/B978-0-12-814820-4.00002-X.

Altieri, M. A., Nicholls, C. I., Henao, A., & Lana, M. A. (2015). Agroecology and the design of climate change-resilient farming systems. Agronomy for Sustainable Development, 35(3), 869–890. https://doi.org/10.1007/s13593-015-0285-2.

Álvarez-Berríos, N. L., Soto-Bayó, S., Holupchinski, E., Fain, S. J., & Gould, W. A. (2018). Correlating drought conservation practices and drought vulnerability in a tropical agricultural system. Renewable Agriculture and Food Systems, 33(3), 279–291. https://doi.org/10.1017/s174217051800011x.

Brottrager, M., Cuaresma, J. C., Kniveton, D., & Ali, S. H. (2023). Natural resources modulate the nexus between environmental shocks and human mobility. Nature Communications, 14(1). https://doi.org/10.1038/s41467-023-37074-y.

Bullock, A., & Acreman, M. (2003). The role of wetlands in the hydrological cycle. Hydrology and Earth System Sciences, 7(3), 358–389. https://doi.org/10.5194/hess-7-358-2003.

Cáceres-Arteaga, N., & Lane, K. M. D. (2020). Agroecological Practices as a Climate Change Adaptation Mechanism in Four Highland Communities in Ecuador. Journal of Latin American Geography, 19(3), 47–73. https://www.jstor.org/stable/48618951.

Cahill, A. E., Aiello-Lammens, M. E., Fisher-Reid, M. C., Hua, X., Karanewsky, C. J., Ryu, H. Y., Sbeglia, G. C., Spagnolo, F., Waldron, J. B., Warsi, O., & Wiens, J. J. (2012). How does climate change cause extinction? Proceedings of the Royal Society B Biological Sciences, 280(1750), 20121890. https://doi.org/10.1098/rspb.2012.1890.

Calmon, M. & Feltran-Barbieri, R. (2019). 4 Ways Farmers can adapt to climate change and generate income. World Resources Institute. https://www.wri.org/insights/4-ways-farmers-can-adapt-climate-change-and-generate-income.

Chartzoulakis, K., & Bertaki, M. (2015). Sustainable Water Management in Agriculture under Climate Change. Agriculture and Agricultural Science Procedia, 4, 88–98. https://doi.org/10.1016/j.aaspro.2015.03.011.

Clarke, B., Barnes, C., Rodrigues, R., Zachariah, M., Stewart, S., Raju, E., Baumgart, N., Heinrich, D., Libonati, R., Santos, D., Albuquerque, R., Alves, L., Pinto, I., Otto, F., Kimutai, J., Philip, S., Kew, S., & Bazo, J. (2024). Climate change, not El Niño, main driver of extreme drought in highly vulnerable Amazon River Basin. https://spiral.imperial.ac.uk/handle/10044/1/108761.

Cook, B. I., Mankin, J. S., Marvel, K., Williams, A. P., Smerdon, J. E., & Anchukaitis, K. J. (2020). Twenty-First century drought projections in the CMIP6 forcing scenarios. Earth S Future, 8(6). https://doi.org/10.1029/2019ef001461.

Cook, B. I., Smerdon, J. E., Cook, E. R., Williams, A. P., Anchukaitis, K. J., Mankin, J. S., Allen, K., Andreu-Hayles, L., Ault, T. R., Belmecheri, S., Coats, S., Coulthard, B., Fosu, B., Grierson, P., Griffin, D., Herrera, D. A., Ionita, M., Lehner, F., Leland, C., et al. (2022). Megadroughts in the Common Era and the Anthropocene. Nature Reviews Earth & Environment, 3(11), 741–757. https://doi.org/10.1038/s43017-022-00329-1.

Descamps, C., Quinet, M., & Jacquemart, A. (2020). The effects of drought on plant–pollinator interactions: What to expect? Environmental and Experimental Botany, 182, 104297. https://doi.org/10.1016/j.envexpbot.2020.104297.

Dinc, P., & Eklund, L. (2023). Syrian farmers in the midst of drought and conflict: the causes, patterns, and aftermath of land abandonment and migration. Climate and Development, 16(5), 349–362. https://doi.org/10.1080/17565529.2023.2223600.

Drysdale, R. E., Bob, U., & Moshabela, M. (2020). Coping through a drought: the association between child nutritional status and household food insecurity in the district of iLembe, South Africa. Public Health Nutrition, 24(5), 1052–1065. https://doi.org/10.1017/S1368980020000105.

Ellison, D., Morris, C. E., Locatelli, B., Sheil, D., Cohen, J., Murdiyarso, D., Gutierrez, V., Van Noordwijk, M., Creed, I. F., Pokorny, J., Gaveau, D., Spracklen, D. V., Tobella, A. B., Ilstedt, U., Teuling, A. J., Gebrehiwot, S. G., Sands, D. C., Muys, B., Verbist, B., et al. (2017). Trees,

forests and water: Cool insights for a hot world. Global Environmental Change, 43, 51–61. https://doi.org/10.1016/j.gloenvcha.2017.01.002.
EPA. (2024). Climate Impacts on Agriculture and Food Supply. United States Environmental Protection Agency. https://climatechange.chicago.gov/climate-impacts/climate-impacts-agriculture-and-food-supply.
European Climate and Health Observatory. (2024). Drought and water scarcity. (2024). European Climate and Health Observatory. https://climate-adapt.eea.europa.eu/en/observatory/evidence/health-effects/drought-and-water-scarcity.
European Commission, Joint Research Centre, Toreti, A., Bavera, D., Acosta Navarro, J., Acquafresca, L., Azas, K., Barbosa, P., De Jager, A., Ficchi, A., Fioravanti, G., Grimaldi, S., Hrast Essenfelder, A., Magni, D., Mazzeschi, M., Mccormick, N., Salamon, P., Santos Nunes, S. and Volpi, D., Global Drought Overview September 2024 – GDO Analytical Report, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/7511271, JRC139423.
Feron, S., Cordero, R. R., Damiani, A., MacDonell, S., Pizarro, J., Goubanova, K., Valenzuela, R., Wang, C., Rester, L., & Beaulieu, A. (2024). South America is becoming warmer, drier, and more flammable. Communications Earth & Environment, 5(1). https://doi.org/10.1038/s43247-024-01654-7.
Flores, B. M., Montoya, E., Sakschewski, B., Nascimento, N., Staal, A., Betts, R. A., Levis, C., Lapola, D. M., Esquível-Muelbert, A., Jakovac, C., Nobre, C. A., Oliveira, R. S., Borma, L. S., Nian, D., Boers, N., Hecht, S. B., Ter Steege, H., Arieira, J., Lucas, I. L., et al. (2024). Critical transitions in the Amazon forest system. Nature, 626(7999), 555–564. https://doi.org/10.1038/s41586-023-06970-0.
Fontúrbel, F. E., Nespolo, R. F., Amico, G. C., & Watson, D. M. (2021). Climate change can disrupt ecological interactions in mysterious ways: Using ecological generalists to forecast community-wide effects. Climate Change Ecology, 2, 100044. https://doi.org/10.1016/j.ecochg.2021.100044.
GEF. (2023). GEF-8: Moving Toward an Equitable, Nature-Positive, Carbon-Neutral, and Pollution-Free World. Global Environment Facility Secretariat. https://www.thegef.org/newsroom/publications/gef-8-moving-toward-equitable-nature-positive-carbon-neutral-and-pollution.
Global Migration Data Portal. (n.d.). Migration Data Portal. https://www.migrationdataportal.org/.
Griffin-Nolan, R. J., Blumenthal, D. M., Collins, S. L., Farkas, T. E., Hoffman, A. M., Mueller, K. E., Ocheltree, T. W., Smith, M. D., Whitney, K. D., & Knapp, A. K. (2019). Shifts in plant functional composition following long-term drought in grasslands. Journal of Ecology, 107(5), 2133–2148. https://doi.org/10.1111/1365-2745.13252.
Grossiord, C., Granier, A., Gessler, A., Jucker, T., & Bonal, D. (2013). Does drought influence the relationship between biodiversity and ecosystem functioning in boreal forests? Ecosystems, 17(3), 394–404. https://doi.org/10.1007/s10021-013-9729-1.
Hisano, M., Ghazoul, J., Chen, X., & Chen, H. Y. H. (2024). Functional diversity enhances dryland forest productivity under long-term climate change. Science Advances, 10(17). https://doi.org/10.1126/sciadv.adn4152.
IPCC. (2020). Climate Change 2022: Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. International Panel on Climate Change. Cambridge, UK. https://doi.org/10.1017/9781009325844.
IPCC. (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland. https://doi.org/10.59327/ipcc/ar6-9789291691647.
Juárez-Lucas, A., Perez, L. C., & Mizrav, H. C. (2024, April 9). A closer look at droughts in Latin America and the Caribbean. World Bank Blogs. https://blogs.worldbank.org/en/latinamerica/a-closer-look-at-droughts-in-latin-america-and-the-caribbean.
Kaisermann, A., De Vries, F. T., Griffiths, R. I., & Bardgett, R. D. (2017). Legacy effects of drought on plant–soil feedbacks and plant–plant interactions. New Phytologist, 215(4), 1413–1424. https://doi.org/10.1111/nph.14661.
Ke, P., Ciais, P., Sitch, S., Li, W., Bastos, A., Liu, Z., Xu, Y., Gui, X., Bian, J., Goll, D. S., Xi, Y., Li, W., O'Sullivan, M., De Souza, J. G., Friedlingstein, P., & Chevallier, F. (2024). Low latency carbon budget analysis reveals a large decline of the land carbon sink in 2023. National Science Review. https://doi.org/10.1093/nsr/nwae367.
Kimutai. J., Barnes. C., Zachariah, M., Philip, S., Kew, S., Pinto, I., Wolski, P., Koren, G., Vecchi. G., Yang, W., Li, S., Vahlberg. M., Heinrich, D., Arrighi, J., Marghidan, C. P., Thalheimer, L., Singh, R., Kane, C., Raju, E., Otto, F. E. (2024). Human-Induced Climate Change Increased 2021-2022 Drought Severity in Horn of Africa. Social Science Research Network. http://dx.doi.org/10.2139/ssrn.4701486.
Knutson, C. L. (2008). The role of water conservation in drought planning. Journal of Soil and Water Conservation, 63(5), 154A-160A. https://doi.org/10.2489/jswc.63.5.154a.
Kosmowski, F. (2018). Soil water management practices (terraces) helped to mitigate the 2015 drought in Ethiopia. Agricultural Water Management, 204, 11–16. https://doi.org/10.1016/j.agwat.2018.02.025.
Kuppler, J., Wieland, J., Junker, R. R., & Ayasse, M. (2021). Drought-induced reduction in flower size and abundance correlates with reduced flower visits by bumble bees. AoB Plants, 13(1). https://doi.org/10.1093/aobpla/plab001.
Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. Science, 304(5677), 1623–1627. https://doi.org/10.1126/science.1097396.
Lenton, T.M., Armstrong McKay, D.I., Loriani, S., Abrams, J.F., Lade, J.F., Donges, J.F., Milkoreit, M., Powell, T., Smith, S.R., Zimm, C., Bailey, E., Dyke, J.G., Ghadiali, A., & Laybourn, L. (2023). The Global Tipping Points Report 2023. University of Exeter, Exeter, UK. https://global-tipping-points.org/.
Liu, L., & Jensen, M. B. (2018). Green infrastructure for sustainable urban water management: Practices of five forerunner cities. Cities, 74, 126–133. https://doi.org/10.1016/j.cities.2017.11.013.
Liu, P., Famiglietti, J. S., Purdy, A. J., Adams, K. H., McEvoy, A. L., Reager, J. T., Bindlish, R., Wiese, D. N., David, C. H., & Rodell, M. (2022). Groundwater depletion in California's Central Valley accelerates during megadrought. Nature Communications, 13(1). https://doi.org/10.1038/s41467-022-35582-x.
Loeser, M. R. R., Sisk, T. D., & Crews, T. E. (2006). Impact of Grazing Intensity during Drought in an Arizona Grassland. Conservation Biology, 21(1), 87–97. https://doi.org/10.1111/j.1523-1739.2006.00606.x.
Luan, J., Li, S., Liu, S., Wang, Y., Ding, L., Lu, H., Chen, L., Zhang, J., Zhou, W., Han, S., Zhang, Y., & Hättenschwiler, S. (2024). Biodiversity mitigates drought effects in the decomposer system across biomes. Proceedings of the National Academy of Sciences, 121(13). https://doi.org/10.1073/pnas.2313334121.
Maia, S. M. F., De Oliveira Galvão, C., Abbruzzini, T. F., Campo, J., Orsini, J. a. M., Cerri, C. E. P., & De Oliveira, T. S. (2023). Managing drought stress in Agro-Ecosystems of Latin America and the Caribbean Region. In CRC Press eBooks (pp. 157–180). https://doi.org/10.1201/b22954-7.
Moss, W. E., Crausbay, S. D., Rangwala, I., Wason, J. W., Trauernicht, C., Stevens-Rumann, C. S., Sala, A., Rottler, C. M., Pederson, G. T., Miller, B. W., Magness, D. R., Littell, J. S., Frelich, L. E., Frazier, A. G., Davis, K. T., Coop, J. D., Cartwright, J. M., & Booth, R. K. (2024).

Drought as an emergent driver of ecological transformation in the twenty-first century. BioScience, 74(8), 524–538. https://doi.org/10.1093/biosci/biae050. McLaughlin, B. C., Ackerly, D. D., Klos, P. Z., Natali, J., Dawson, T. E., & Thompson, S. E. (2017). Hydrologic refugia, plants, and climate change. Global Change Biology, 23(8), 2941–2961. https://doi.org/10.1111/gcb.13629.

Paracchini, M. L., Justes, E., Wezel, A., Zingari, P. C., Kahane, R., Masden, S., Scopel, E., Héraut, A., Bhérer-Breton, P., Buckley, R., Colbert, E., Kapalla, D., Sorge, M., Asieduwaa, A., Kerr, R. B., Maes, O., & Nègre, T. (2020). Agroecological practices supporting food production and reducing food insecurity in developing countries. HAL (Le Centre Pour La Communication Scientifique Directe). https://doi.org/10.2760/82475.

Phillips, B. B., Shaw, R. F., Holland, M. J., Fry, E. L., Bardgett, R. D., Bullock, J. M., & Osborne, J. L. (2018). Drought reduces floral resources for pollinators. Global Change Biology, 24(7), 3226–3235. https://doi.org/10.1111/gcb.14130.

Ragab R.& Hamdy A. (2004). Water management strategies to combat drought in the semiarid regions. Water management for drought mitigation in the Mediterranean . Bari: CIHEAM, 2004. p. 47-112. https://om.ciheam.org/om/pdf/b47/05002266.pdf.

Ramyar, R., Ackerman, A., & Johnston, D. M. (2021). Adapting cities for climate change through urban green infrastructure planning. Cities, 117, 103316. https://doi.org/10.1016/j.cities.2021.103316.

Robinson, D. A., Hopmans, J. W., Filipovic, V., Van Der Ploeg, M., Lebron, I., Jones, S. B., Reinsch, S., Jarvis, N., & Tuller, M. (2019). Global environmental changes impact soil hydraulic functions through biophysical feedbacks. Global Change Biology, 25(6), 1895–1904. https://doi.org/10.1111/gcb.14626.

Skendžić, S., Zovko, M., Živković, I. P., Lešić, V., & Lemić, D. (2021). The impact of climate change on agricultural insect pests. Insects, 12(5), 440. https://doi.org/10.3390/insects12050440.

Srivastav, A. L., Dhyani, R., Ranjan, M., Madhav, S., & Sillanpää, M. (2021). Climate-resilient strategies for sustainable management of water resources and agriculture. Environmental Science and Pollution Research, 28(31), 41576–41595. https://doi.org/10.1007/s11356-021-14332-4.

Sturiale, N., & Scuderi, N. (2019). The role of green infrastructures in urban planning for climate change adaptation. Climate, 7(10), 119. https://doi.org/10.3390/cli7100119.

UNCCD. (2024). Proportion of total land area under drought. https://data.unccd.int/countries-affected-by-drought

UNCCD. (2024). Intergovernmental Working Group on Drought (2022-2024). United Nations Convention to Combat Desertification. https://www.unccd.int/convention/governance/intergovernmental-working-group-drought-2#:~:text=The%20most%20recent%20UNCCD%20Conference,and%20linking%20them%20to%20national.

UN-DESA. (2024). Climate Change. United Nations Department of Economic and Social Affairs: Indigenous Peoples. https://www.un.org/development/desa/indigenouspeoples/climate-change.html.

UNEP. (2024). As climate crisis alters their lands, Indigenous Peoples turn to the courts. United Nations Environmental Programme. https://www.unep.org/news-and-stories/story/climate-crisis-alters-their-lands-indigenous-peoples-turn-courts.

UNGA. (1994). Intergovernmental Negotiating Committee for the Elaboration of an International Convention to Combat Desertification in Those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa. United Nations General Assembly. A/AC.241/27. https://www.unccd.int/sites/default/files/relevant-links/2017-01/English_0.pdf.

USDA. (n.d.) Agriculture Adaptation Menu | USDA Climate Hubs. https://www.climatehubs.usda.gov/hubs/northern-forests/topic/agriculture-adaptation-menu.

Vahedifard, F., Goodman, C. C., Paul, V., & AghaKouchak, A. (2024). Amplifying feedback loop between drought, soil desiccation cracking, and greenhouse gas emissions. Environmental Research Letters, 19(3), 031005. https://doi.org/10.1088/1748-9326/ad2c23.

Van Ruijven, J., & Berendse, F. (2009). Diversity enhances community recovery, but not resistance, after drought. Journal of Ecology, 98(1), 81–86. https://doi.org/10.1111/j.1365-2745.2009.01603.x.

WEF (2024). Why Indigenous communities face climate displacement challenges. (2024, September 10). World Economic Forum. https://www.weforum.org/agenda/2024/02/indigenous-challenges-displacement-climate-change/.

Yang, J., & Wang, Z. (2017). Planning for a sustainable desert city: The potential water buffering capacity of urban green infrastructure. Landscape and Urban Planning, 167, 339–347. https://doi.org/10.1016/j.landurbplan.2017.07.014.

Zaveri., E., Damania., R. & Engle., N. (2023). Droughts and Deficits - Summary Evidence of the Global Impact on Economic Growth. World Bank Group. Washington, D.C. http://documents.worldbank.org/curated/en/099640306142317412/IDU03b9849a60d86404b600bc480bef6082a760a.