

8th Environment Action Programme

Drought impact on ecosystems in Europe



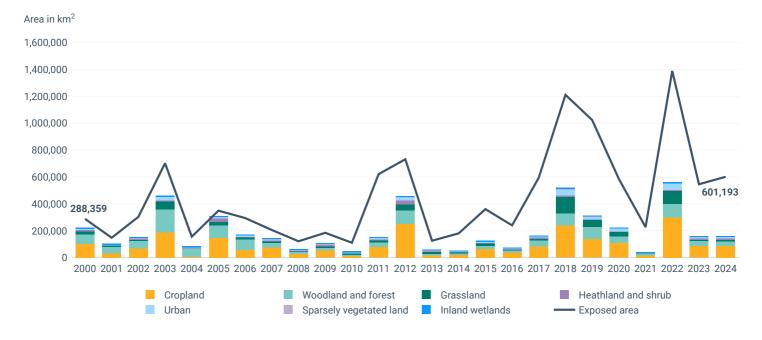


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Europe is facing more and stronger climate hazards, including heatwaves and prolonged droughts. Drought conditions were drier-than-average in eastern/south-eastern Europe during 2024. Around 600,000 km² of the European Union was exposed to below 2000-2020 average soil moisture levels. In response, vegetation productivity did not recover to the 2000-2020 baseline condition in almost 160,000km² of south-eastern Europe and Mediterranean regions. Without effective implementation of global climate mitigation as well as EU and national climate adaptation strategies and plans, the impacts of prolonged drought are likely to further increase.

Figure 1. Area of drought impact on vegetation productivity in the EU-27



Droughts **hinder carbon sequestration** by natural ecosystems, which leads to undermining the EU's climate mitigation goals (Climate Impact and Preparedness Portal). It compromises ecosystems' ability to reduce the impact of heat waves and increases the risk of wildfires. They also impact food production, resource management, and territorial development—core aims of the EU Common Agriculture Policy.

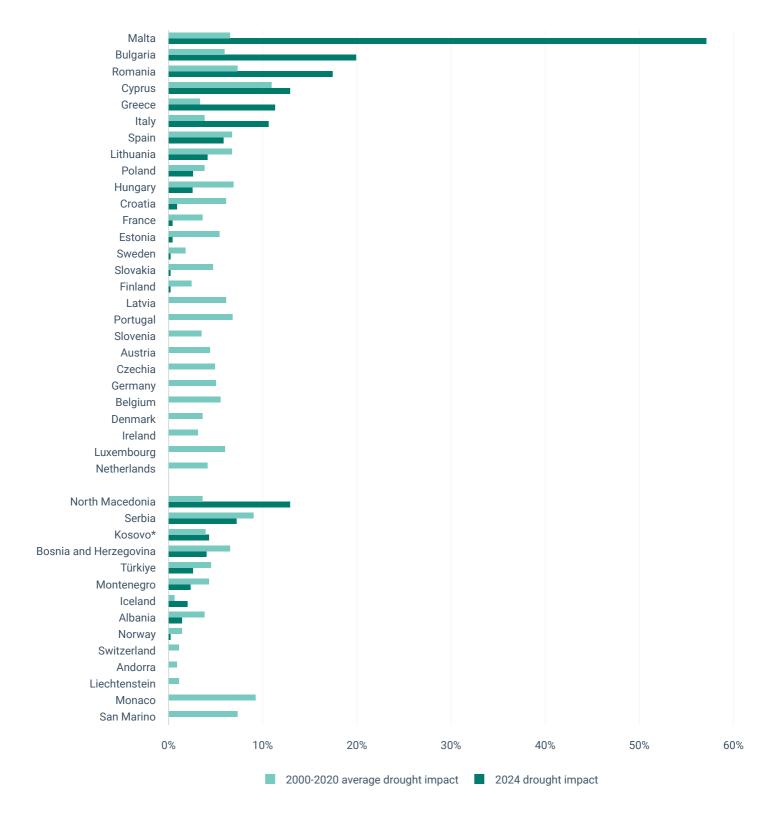
As set out in the European Water Resilience Strategy, droughts and water scarcity are increasingly challenging the EU, for both environment and society. Strengthening ecosystem resilience and reducing drought impacts require **urgent climate adaptation action** by the EU and Member States, alongside stronger global climate mitigation, to meet Paris Agreement targets (IPCC AR6, 2023).

In 2024, severe droughts exposed 601,193 km² across Europe, with vegetation productivity failing to recover to the baseline level of 156,703 km² — indicating **adaptation stress** (Figure 1). Since 2017, vegetation impact has consistently exceeded the 2000-2020 baseline level (approx. 152,000km²), except in 2021.

During 2024, 87,567 km² of EU-27 **cropland productivity** was below the 2000–2020 baseline. Heathlands and shrubs were affected across 9,866 km², while **forest productivity** was impacted over 33,518 km². This is below the 2000-2020 baseline, yet still a concern for carbon sequestration and the EU's 2050 climate goals. Grasslands and heathlands, among the EU's most biodiverse and carbon-rich ecosystems, were impacted on 24,056 km² in 2024—larger than the size of Slovenia. Only 222 km² of wetlands were affected in 2024, reflecting drought concentration in Southeast Europe where wetlands are rare.

By mid-century, heatwaves and droughts are expected to increase in frequency and in intensity across most of Europe, outpacing the global average (IPCC AR6). Between 2000 and 2024, 12 years saw **drought-affected areas** above the median, with eight occurring after 2010. Given the rising frequency and severity of droughts, impacted areas are unlikely to decline by 2030. Land and water management must become more sustainable which includes drought-tolerant crops, cover crops, and crop residues and the effective implementation of EU and national climate adaptation strategies are essential (Climate-ADAPT).

Figure 2. Drought impact area during 2024 in comparison to the 2000-2020 average for the EEA-38 regions



Strong regional differences can be seen in the **2024 drought impact** on Figure 2. The impacted area was much higher than the 2000-2020 average area for six EU Member States (eight in EEA member countries). In Malta, over 57% of the country's vegetation productivity could not recover to the 2000-2020 level. The same drought caused lower than baseline vegetation productivity in 20% of Bulgaria's and 17% of Romania's territory. Vegetation in Cyprus, Greece and Italy failed to recover in more than 10% of each country. In absolute terms, Romania suffered largest vegetation productivity impact from the drought (41,370km²), followed by Italy (31,856km²) and Spain (29,304km²).

For the non-EU region, drought impact in Macedonia was most concerning, where vegetation failed to recover across 13% of the country, 9.4 percentage points above the 2000-2020 baseline. The **largest area affected** by drought was seen in Türkiye (20,549km²).

Supporting information

Definition

The indicator only addresses droughts, hence the annual deficit in soil moisture due precipitation shortages. The indicator does not address hydrological droughts which occur when low water levels become evident in hydrological systems, especially in streams, reservoirs, and groundwater, usually after many months of meteorological drought. The indicator monitors anomalies and long-term trends in vegetation productivity based on remote sensing observed time series data of vegetation indices in areas that are under pressure from soil moisture deficit.

Drought pressure is computed as soil moisture deficit within the growing season, using the Soil Moisture Index (SMI)10 time series of the Copernicus EMS European Drought Observatory of the European Commission Joint Research Centre (EDO, 2019).

Drought impact during the growing season is indicated as a severe negative annual productivity anomaly in drought-pressured areas, i.e. areas with negative annual soil moisture anomalies. Detailed indicator specifications are described under 'Methodology'.

Methodology

Soil moisture deficit is calculated at the pixel level by deriving z-score anomalies from the Soil Moisture Index, such as:

SMA = SMI-SMIMN (2001-2020)/SMISD (2001-2020), (Equation 1)

Where SMA is Soil Moisture Anomaly, MN is the 2001-2020 average SMA and SD is the 2001-2020 standard deviation of the SMI. The calculated SMA values are then averaged within the growing season to derive the SMA(gs) time series.

The aggregation is performed by averaging the monthly SMA values extracted from the EDO within the vegetation growing season. The vegetation growing season was defined by using the start and the end date of the growing period (SOS or Start of Season and EOS or End Of Season, respectively) extracted from the Medium Resolution Vegetation Phenology and Productivity product of the Copernicus Land Monitoring Service. The SOS and EOS datasets can be explored and downloaded from EEA's data repository under sdi.eea.europa.eu. Direct links to the datasets:

SOS:

https://sdi.eea.europa.eu/catalogue/srv/eng/catalog.search#/metadata/a7b2369b-dd62-4d02-99e2-e5d74a8ec83a

EOS:

https://sdi.eea.europa.eu/catalogue/srv/eng/catalog.search#/metadata/a3cfb2c4-156a-413c-a73b-15ebbb016557

Annual drought pressure is derived at the pixel level and is simply defined as:

SMA(gs) < -1, (Equation 2).

Negative soil moisture anomalies indicate that the annual average availability of soil moisture for plants is lower than the long-term normal condition and drops to such a level that it might impact vegetation productivity.

To indicate **drought pressure area**, strong negative soil moisture anomalies are selected by setting a maximum value at -1 standard deviation (std). The drought pressure area is the sum of those grid cells within each analytical unit (see later), where the growing season aggregated SMA values are < -1. This threshold was selected to allow the monitoring of vegetation responses to only considerable soil moisture deficits. Choosing the threshold of -1 std follows the recommendations of the European Drought Observatory (EDO11) of the European Commission's Joint Research Centre. This approach is also followed in the EEA indicator addressing soil moisture deficit. By applying this threshold, drought impacts can better be distinguished from response in vegetation anomalies due to other environmental pressures such as e.g. wildfires, storms or insects infestations. As vegetation productivity decline may be also caused by anthropogenic impacts, pixels with land use change were excluded from the statistical population based on the Copernicus Corine Land Cover 2000-2018 accounting layers datasets.

The **drought pressure intensity** is defined as the annual, growing season aggregated SMA values where SMA < -1, where aggregation is performed by temporal and spatial averaging within analytical units (see later).

Annual drought impact is quantified as:

SMA(gs)<0 and LINTa<-0.5, (Equation 2),

where LINTa (ILarge Integral anomaly) refers to the 2000-2022 annual anomalies in growing season productivity derived from remote-sensing data and approximated using vegetation indices (see more explanation below).

The LINT anomalies were calculated as standard deviations from the long-term mean:

LINTa(year xi-n)=(LINT(xi)-LINT(LTA))/LINT(std)), (Equation 3).

Where xi-n indexes the time series (from i=2000 till n=2021), LINT(LTA) is the long term (using the background of 2000-2020) average of the LINT values and LINT(std) is the long term (using the background) standard deviation of the LINT values for the same period.

The threshold of a -0.5 standard deviation for the vegetation anomalies was selected to indicate small deviations from the long-term mean and to allow for moderate productivity levels under drought impact to be accounted for. In a Europe-wide study, this is a pragmatic solution that provides a wide overview of drought impact situations in Europe. However, local studies might consider setting a lower or higher threshold to reflect local conditions.

The drought impact area is the sum of those grid cells within each analytical unit (see below) where the growing season aggregated SMA values are < -1 and the LINT anomalies are < -0.5. The drought impact intensity is defined as the annual aggregated LINT anomalies where SMA < -1 and LINTa < -0.5. Aggregation is performed by temporal and spatial averaging within analytical units.

For the analytical units of this indicator the following datasets were combined:

- Administrative boundaries, aligned with the Corine Land Cover: https://sdi.eea.europa.eu/catalogue/srv/eng/catalog.search#/metadata/08c0e074-4a98-4545-bd85-f58fe3f74d82;
- Environmental Zones: https://sdi.eea.europa.eu/catalogue/srv/eng/catalog.search#/metadata/6ef007ab-1fcd-4c4f-bc96-14e8afbcb688;
- Corine Land Cover accounting layers 2000 and 2018: https://sdi.eea.europa.eu/catalogue/srv/eng/catalog.search#/metadata/fa9bd2f5-8006-42e7-8090-7b9f9b09bf29 and https://sdi.eea.europa.eu/catalogue/srv/eng/catalog.search#/metadata/5a5f43ca-1447-4ed0-b0a6-4bd2e17e4f4d.
- MAES ecosystem types derived from the Corine Land Cover as Look Up Tables (can be distributed upon request).
- Land cover flows: https://sdi.eea.europa.eu/catalogue/srv/eng/catalog.search#/metadata/835d25e0-b9dc-4fb9-a8b6-f9e5336fa357.

The combination of the above datasets resulted in analytical units with 2,700,000 records in the database, which is easy to handle with desktop computers.

Vegetation productivity: LINT, or Large Integral

In summary, vegetation productivity is derived from remote-sensing observed time series data of vegetation indices. The vegetation index used for the LINT index is the Plant Phenology Index (PPI) (Jin and Eklundh, 2014). The PPI is based on the MODIS Nadir BRDF-adjusted reflectance product (MODIS MCD43 NBAR). The product provides reflectance data for the MODIS 'land' bands (1-7), adjusted using a bidirectional reflectance distribution function. This function models values as if they were collected from a Nadir view to remove so-called cross-track illumination effects. The PPI is a new vegetation index optimised for the efficient monitoring of vegetation phenology. It is derived from radiative transfer solution using reflectance in the visible-red (RED) and near-infrared (NIR) spectral domains. The PPI is defined as having a linear relationship with the canopy green Leaf Area Index (LAI) and its temporal pattern is very similar to the temporal pattern of gross primary productivity (GPP) estimated by flux towers at ground reference stations. The PPI is less affected by the presence of snow than other commonly used vegetation indices such as the Normalized Difference Vegetation Index (NDVI) or the Enhanced Vegetation Index (EVI).

The product is distributed with a 500m pixel size (MODIS Sinusoidal Grid) with an 8-day compositing period. The large integral, or LINT, used in this indicator is the mathematical integral calculation of the smoothed and gap-filled PPI time series data between the start and end of the growing season points, being the SOS and EOS datasets described above.

All input data sets are derived with wall-to-wall coverage of the land surface of the EEA-38 region.

No gap filling was needed.

Policy/environmental relevance

The indicator is a headline indicator for monitoring progress towards the 8th Environment Action Programme. It contributes mainly to monitoring aspects of the 8th EAP priority objective Article 2.2.b that shall be met by 2030: 'continuous progress in enhancing and mainstreaming adaptive capacity, including on the basis of ecosystem approaches, strengthening resilience and adaptation and reducing the vulnerability of the environment, society and all sectors of the economy to climate change, while improving prevention of, and preparedness for, weather- and climate-related disasters' [1]. More specifically, and in accordance with the European Commission Communication on the 8th EAP monitoring framework, the indicator assesses whether the EU will 'decrease the area impacted by drought and loss of vegetation productivity' by 2030 [2].

Justification for indicator selection

Droughts are extreme climate events that are induced by temporary water deficits and may be related to a lack of precipitation, soil moisture, streamflow or any combination of the three taking place at the same time. Droughts can occur in most parts of the world, even in wet and humid regions, and can have profound impacts on agriculture, industry, tourism and ecosystems and the services they provide. In arid and semi-arid ecosystems (including the Mediterranean regions), limited water availability is a recurrent phenomenon and governs plant growth and phenology. On the other hand, in temperate and boreal regions, sporadic prolonged dry periods can lead to water-limited conditions and have far-reaching impacts on ecosystems' carbon balance and structure. The immediate impacts of droughts within the growing season (i.e. a few weeks in duration) are, for example, lead to decline in crop production, pasture growth and fodder supplies from crop residues. Prolonged water shortages (e.g. of several months) may, among other things, potentially increase wildfire occurrences.

The monitoring and assessment of drought impacts are complex because they vary in their severity and often depend on the different phases of the given drought event. Differences in the physiological response of vegetation to water deficits cause differences in the sensitivity and resilience of terrestrial ecosystems to drought, and ultimately influence the types of impacts that droughts have, i.e. slow growth or reduced greenness, that lead to loss of biomass or may even result in plant mortality. Consequently, significant changes in vegetation productivity provide an indication/early warning of imminent impacts on ecosystems' equilibrium states.

Context description

In June 2024, the EU adopted the Nature Restoration Law requiring member states to restore at least 30% of habitats covered by legislation from a poor to a good condition by 2030, increasing to 60% by 2040, and 90% by 2050.

Droughts have an impact on the condition of ecosystems covered by the Nature Restoration law such as forests and grasslands and wetlands and might hamper reaching the restoration targets.

The EU Strategy on Adaptation to Climate Change (COM(2021) 82 final) sets out important objectives around mainstreaming adaptation across different policy areas. It shows the importance of healthy soils in minimising impacts of floods and droughts. Droughts negatively affect the adaptative capacity of agricultural ecosystems, the resilience of forest ecosystems and in urban ecosystems droughts indirectly affect the ability of green urban spaces to protect people against heatwaves.

The EU legislation for LULUCF as part of the 2030 climate target sets clear targets for the LULUCF sector for each Member States. The capacity of forests and other land uses to store and remove carbon from the atmosphere will depend on management as well as a number of natural circumstances. The latter include variations in growing conditions and droughts, which can have an important effect on reaching the national carbon removal targets of Member States by impacting the amount of carbon storge in ecosystems.

Targets:

No specific targets.

Accuracy and uncertainties

Methodology uncertainty:

The approach cannot account for all land use or land cover changes that have occurred within a pixel in the whole period of analysis. For example, clear cuts within forest ecosystems or the use of irrigation systems as part of management processes in agricultural areas might increase or decrease vegetation productivity independently of drought occurrences. This can introduce noise to the data sets that might further bias the assumed pixel-based relationships between drought pressure and vegetation productivity.

Another source of uncertainty is related to the simplification of the drought impact model for its implementation in the operational setting. On one hand, the same thresholds for deviations in soil moisture and vegetation production imply similar impacts/impact severity in different sectors (agriculture, forestry, etc), which gives an acceptable approximation on the continental scale but might need to be adjusted to local conditions. Still, in some cases, the start, end, severity and spatial extent of a drought, as well as the propagation of its impacts through the whole land systems, might change as a result of additional climate and/or surrounding biophysical conditions, such as temperature, snowpack, albedo and soil's water-holding capacity.

Lastly, insect infestations, wildfires and land use change, in most extreme case soil sealing will also reduce vegetation productivity. For the latter the analytics has excluded those grid cells with known land use change processes. Data on insect infestation are not available on the EU scale and wildfires will be included in the next version of the indicator. However, the analytics of anomalies for every 500m grid cells only retained those events where soil moisture deficit and negative vegetation anomalies occurred the same time and place. As vegetation productivity and soil moisture deficit have been shown to show a strong correlation, we think that the method is appropriate to indicate drought impact to an acceptable certainty.

Data set uncertainty:

The datasets represent the average impact on the productivity of all terrestrial ecosystems within an area covered by a pixel of 500m×500m. Therefore, the indicator can be used at coarse resolution only, indicating drought impacts on main terrestrial ecosystems. As opposed to field measurements, remote-sensing products measure vegetation's light

absorption from a satellite at a height of several hundred kilometres, which might introduce bias due to atmospheric disturbances.

In some land use types like e.g. in forestry, land management practices like e.g. clearing and thinning are practices that affect the measurements of vegetation productivity derived from satellite data. These measures are not captured by CORINE land cover and could therefore affect the results. Furthermore, the short vegetation period in the Nordic countries and high degree of cloudiness may potentially affect the results regionally.

Rationale uncertainty:

No uncertainty has been identified.

Data sources and providers

- Vegetation productivity 2000-2024, European Environment Agency (EEA)
- EDO Soil Moisture Index (SMI) (version 3.0.1), European Drought Observatory, Joint Research Centre

✓ Metadata

DPSIR

Impact

Topics

Agriculture and food # Biodiversity # Climate change adaptation

Tags

#Biodiversity #Productivity #Land cover #8th EAP #LSI011 #Drought impact #Ecosystems

Temporal coverage

2000-2024

Geographic coverage

Albania Austria

Belgium Bosnia and Herzegovina

Bulgaria Croatia Cyprus Czechia Denmark Estonia Finland France Germany Greece Iceland Hungary Italy Ireland Kosovo (UNSCR 1244/99) Latvia Liechtenstein Lithuania Malta Luxembourg Netherlands Montenegro Norway

North Macedonia Norway
Poland Portugal
Romania Serbia
Slovakia Slovenia
Spain Sweden

Switzerland Türkiye

Typology

Descriptive indicator (Type A - What is happening to the environment and to humans?)

UN SDGs

SDG13: Climate action

Unit of measure

FIG1: Area of drought impact (km²)

FIG2: Percentage

Frequency of dissemination

Once a year

References and footnotes

- 1. EU, 2022, Decision (EU) 2022/591 of the European Parliament and of the Council of 6 April 2022 on a general Union environment action programme to 2030, OJ L 114, 12.4.2022, p. 22-36.
- 2. EC, 2022, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS on the monitoring framework for the 8th Environment Action Programme: Measuring progress towards the attainment of the Programme's 2030 and 2050 priority objectives COM/2022/357 final