European Environment Agency

8th Environment Action Programme

Drought impact on ecosystems in Europe

8TH EAP HEADLINE INDICATOR, 2024

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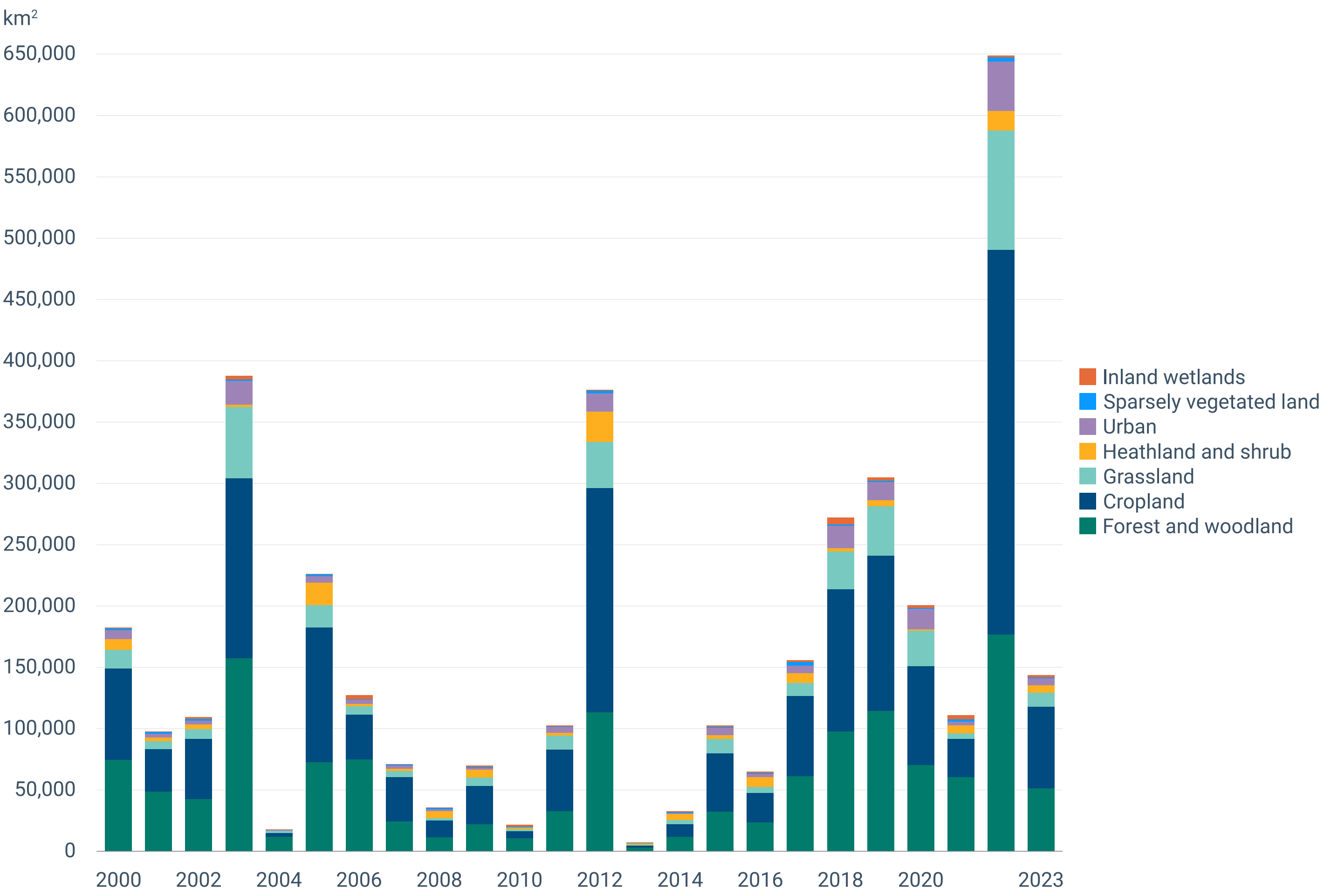
The EEA's European Climate Risk Assessment concludes that Europe is the fastest-warming continent in the world. Monitoring impacts of meteorological droughts supports policy measures, targeting greenhouse gas removals and the adaptation of ecosystems to climate change. In 2023 drought impact on European ecosystems eased after the devastating previous year. The European Union aggregated drought impact area was 143,513 km^2, larger than the 2000-2020 long-term average drought impact. If global mitigation and EU and national adaptation strategies are not effectively implemented, drought impacts will increase.

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



Droughts **hamper** nature's ability to deliver a wide range of environmental, social and economic benefits. They impact the EU's ability to achieve its climate change mitigation objective, influence adaptation and implement the EU biodiversity and soil strategies. Viable food production, sustainable management of natural resources and balanced territorial development, long-term objectives of the EU common agriculture policy, are also affected by drought.

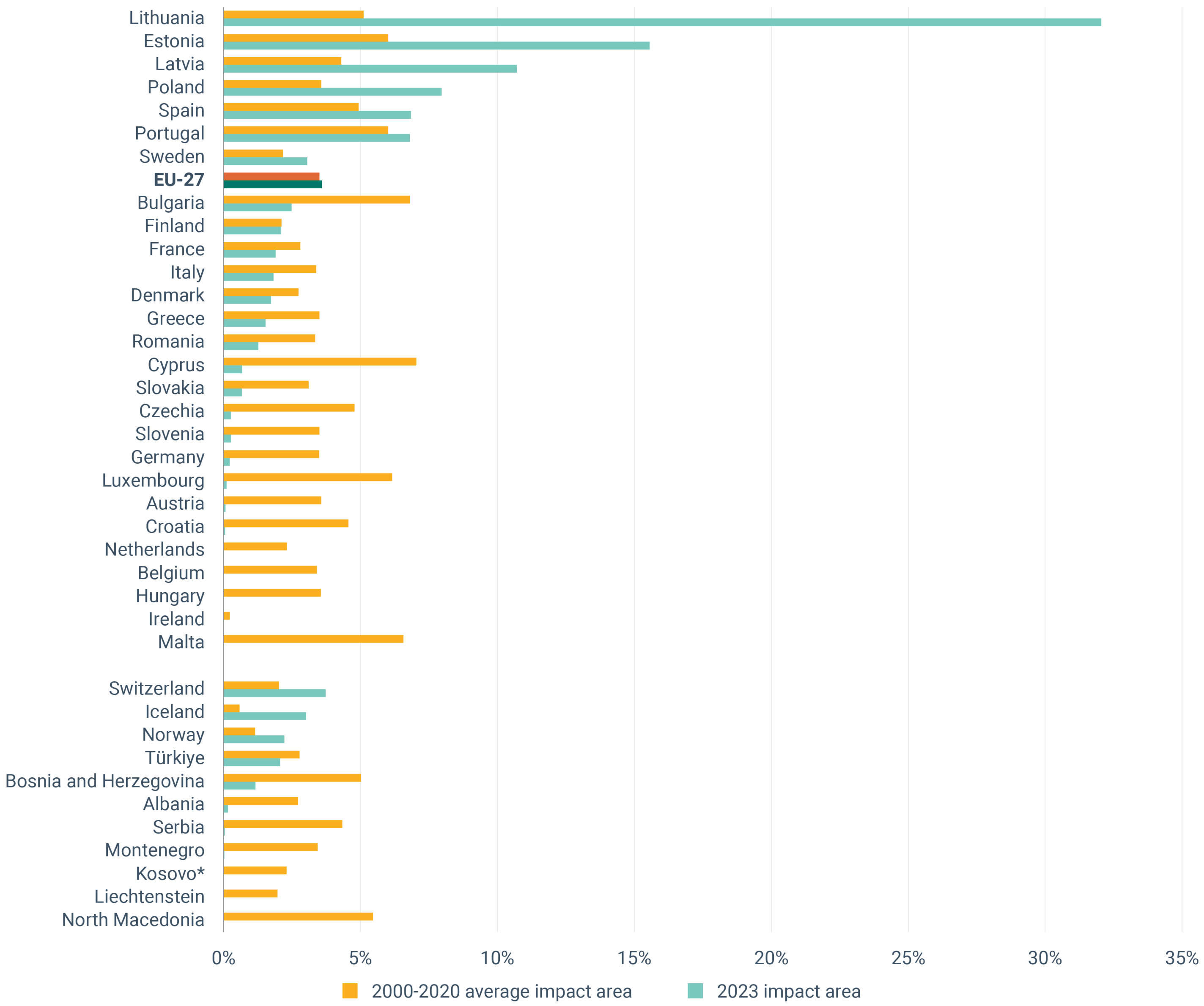
After the devasting drought in 2022, **drought impact** on European ecosystems eased in 2023. Excess precipitation at the end of summer counterbalanced the effects of soil moisture deficit and heatwaves over the spring and summer in many places[1]. The 2023 drought impacted area was 143,000 km^2. This is slightly above the average annual impact in the period 2000-2020 when ca. 141,229km^2 (3.5%) of EU land was affected by droughts. The annual extent of intense drought impacts in the EU shows an increasing trend (Figure 1) despite the 2023 recovery year.

EU-27 cropland area with lower-than-average vegetation productivity was almost 66,500 km^2 in 2023, hence above the 2000-2020 average impact (59,000 km^2, ca 4% of croplands). The drought impact of other land cover types was around or slightly lower than their 2000-2020 average impact, making **croplands** the main contributor for the 2023 drought impact. Forest vegetation productivity suffered with over 52,000km^2, larger than the area of Slovakia. Forests and woodlands sequester large amounts of carbon, but drought conditions slow this process that may jeopardise the EU's ambition of becoming climate neutral by 2050.

Grasslands and heathlands are among the **most biodiverse areas** in the EU, storing a large amount of carbon in the below ground biomass pool[2]. These two land cover types combined were impacted over an area of 18,000km^2 in 2023, just below the size of Slovenia. In absolute values, the 2023 impacted wetland area was only around 3% of the EU wetlands. Slightly more than the average, as well as the 2022 impacted area, and hence an increasing trend can also be observed here (dashboard).

By mid-century, the frequency and intensity of heatwaves and drought are **projected to increase** over most parts of Europe[3]. During 2000-2023, eight years showed above average drought impacted area, where five years were in the last 10 year period (dashboard). Based on the recurrent and increasingly strong drought events during the 24 year period, drought impacted areas may not decrease by 2030. It is therefore important that land management practices are adequately adjusted in a timely manner and that the EU and national adaptation strategies [4] are effectively implemented.

Figure 2. Drought impact area during 2023 in comparison to the 2000-2020 average for the EEA-38 regions



Drought impacted **area** in most of the EU member countries remained much lower than or equal to the 2000-2020 average impacted area (Figure 2). The 2023 impact in the Baltic states is much larger than previous drought conditions in the EU region.

The most striking result was found in Lithuania, where 32% of the country endured less than average **vegetation productivity** compared to 5% of the country being impacted during 2000-2020. Drought impacted 16% of Estonia and 10% of Latvia in 2023. Both countries' long-term average impact was less than 10% of the territory. Northern Poland and the southern part of Portugal and Spain drought impact was also above the long-term average impacted area, yet remained below 10% of their territories.

When considering the **absolute impacted** areas in 2023, Spain had the largest territory under drought (34,000km^2), followed by Poland (24,000km^2) and Lithuania (20,000km^2). From the non-EU countries, Norway and Switzerland experienced drought impact in 2023 that exceeded the long-term average impact, yet in both cases, it was less than 4% of the territory. Turkiye was most affected by drought accounting for 16,000km^2.

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:

$SMA = SMI - SMI_{MN\ (2001-2020)} / SMI_{SD\ (2001-2020)}$, (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 (EDO[11]) of the European Commission's Joint Research Centre. This approach is also followed in the EEA indicator addressing soil moisture deficit (EEA, 2021). 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 (lLarge 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:

1. Administrative boundaries, aligned with the Corine Land Cover: https://sdi.eea.europa.eu/catalogue/srv/eng/catalog.search#/metadata/08c0e074-4a98-4545-bd85-f58fe3f74d82

2. Environmental Zones:

3. https://sdi.eea.europa.eu/catalogue/srv/eng/catalog.search#/metadata/6ef007ab-1fcd-4c4f-bc96-14e8afbcb688

4. 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.

1. MAES ecosystem types derived from the Corine Land Cover as Look Up Tables (can be distributed upon request).

2. 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' [5]. 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 [6].

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 (3) which requires 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

- Medium Resolution Vegetation Phenology and Productivity: Large integral (raster 500m), Oct. 2022, European Environment Agency (EEA)
- EDO Soil Moisture Index (SMI) (version 2.1.3), European Drought Observatory (JRC)

Metadata

DPSIR

Impact

Topics

 # Agriculture and food **# Biodiversity** **# Climate change adaptation**

Tags

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

Temporal coverage

2000-2023

Geographic coverage

Albania
Austria
Belgium
Bosnia and Herzegovina
Bulgaria
Croatia
Cyprus
Czechia
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Iceland
Ireland
Italy
Kosovo (UNSCR 1244/99)
Latvia
Liechtenstein
Lithuania
Luxembourg
Malta
Montenegro
Netherlands
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 (km^2)

FIG2: Percentage

Frequency of dissemination

Once a year

References and footnotes

1. European Commission. Joint Research Centre., 2023, *Drought in Europe: August 2023 : GDO analytical report.*, Publications Office, LU.
↵
2. Global assessment of soil carbon in grasslands, 2023, FAO.
↵

3. 231031_EUCRA_TechnicalReport_comments_compiled.xlsx, (https://eea1.sharepoint.com/:x:/r/teams/2.3.1EU-wideclimateriskassessment/_layouts/15/Doc.aspx?sourcedoc=%7B3E971390-BA99-42DD-B4C6-235D3AB3D370%7D&file=231031_EUCRA_TechnicalReport_comments_compiled.xlsx&action=default&m accessed November 24, 2023.
↵

4. EEA, 2023, 'National climate change adaptation planning and strategies [2023] Article 19(1) Implementing Regulation 2020/1208, Annex I — Reportnet 3', *European Environment Agency* (https://reportnet.europa.eu/public/dataflow/895) accessed May 9, 2023.
↵

5. 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.
↵

6. 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
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