Technical Report No. 12

A EUROPEAN DROUGHT REFERENCE (EDR) DATABASE: DESIGN AND ONLINE IMPLEMENTATION

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Acknowledgement/Preface

The European Drought Reference (EDR) database is a key deliverable of Work Package 1 (WP1). It contains consolidated information on major large-scale droughts in Europe, their characteristics, climatological course and major impacts building upon common data sources. Currently, the database contains information for 12 major European events. The physical characteristics (including both climatological and hydrological drought indices) were derived as part of WP1. The impacts have been obtained from the European Drought Impact Report Inventory (EDII; developed as part of WP3) and the authors would like to thank all contributors to EDII for making this information available through the impact database (see DROUGHT-R&SPI Technical Report no. 3 for further details).

The design and structure of the EDR database was developed and implemented by James H. Stagge, whereas other co-authors have contributed with methodology, derivation of indices and gathering of information for specific drought events. A synthesis of information from EDII for each event was facilitated by Irene Kohn.

This first version of the EDR database provides the basis for a comprehensive and unique European reference database for major historical drought events that is not limited by national boundaries. The database is a dynamic site that will be continuously improved and updated until the end of the project (and hopefully thereafter), including standard assessments for a more complete set of events and other information of interest for the drought community as it is generated within the project. The EDR database will become available to the public at the end of the project, providing a valuable tool and source of information for the user against which existing (observational as well as model based) studies can be compared. Hopefully, it will also inspire new studies and raise the awareness of the drought hazard to the larger science and user community, including water managers and policy makers.

Lena M. Tallaksen
(Work Package 1 leader), Oslo, 27 September 2013

Abstract

This report presents the structure and status of the online European Drought Reference (EDR) database. This website provides detailed historical information regarding major historical European drought events. Each drought event is summarized using climatological drought indices, hydrological drought indices, and user-generated drought impacts. The database currently highlights 11 drought events, from 1959 to 2007. In addition, an online tool is provided to query and view climatological drought indices for any day in the available historical record. The EDR database is tool designed to compile drought statistics in a usable manner and will continually improve as more data becomes available. It is our hope that the EDR database can become a standard reference tool which improve public awareness of drought issues and stimulate data collection, sharing, and analysis.

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1. Introduction

Drought is an extreme, but temporary water shortage relative to the average (natural) condition of a region. It can be defined as a “a sustained and regional extensive occurrence of below average natural water availability” (Tallaksen & van Lanen, 2004). Deviations or anomalies are part of the natural variability in the climatic system on various spatial and temporal scales. Accordingly, drought can occur in any hydroclimatological region and at any time of the year, and its characteristics and impacts may vary considerably between regions in Europe depending on climate as well as properties of the land surface.

The climate in the middle and north of Europe is influenced by the Westerlies of the mid-latitudes during the whole year, whereas the Mediterranean region lies in a transitional climate zone, influenced by the Subtropical High Pressure Belt during summer and the mid-latitude Westerlies during winter. Hence, three main climate regions can be distinguished: a temperate climate with a dry summer season in the Mediterranean, and a temperate and a cold climate without any dry season in the middle and north of Europe, respectively. The climate of these regions is further modified by numerous other factors such as soil moisture content, oceanic currents and topography. In the Mediterranean region, with its seasonal climate, severe droughts can for instance be caused by longer than usual influence of the subtropical high-pressure belt. Droughts can accordingly last several weeks or even months. In the more humid mid-latitudes of western and northern Europe, “atmospheric blockings” are the major atmospheric anomalies causing extended dry weather periods. Here already a few weeks or months with low rainfall may constitute a severe drought. The blocking high-pressure system (anticyclones) diverts the moisture bringing pressure systems of the Westerlies away from the affected region to either lower or higher latitudes.

The primary cause of a drought is the lack of precipitation over a large area and for an extensive period of time, called a meteorological drought (Tallaksen & van Lanen, 2004). The water deficit propagates through the hydrological cycle and gives rise to different types of drought. Combined with high evaporation rates a soil water deficiency may cause a soil moisture drought to develop. Subsequently, groundwater recharge and streamflow will be reduced and a hydrological drought may develop. A reduced recharge leads to lower groundwater heads and storage and finally to low river flows or even dried up river. Thus, drought has a wide range of impacts depending on the scale of the event and which components of the hydrological cycle are most severely affected. These include major social, economic and environmental impacts as listed by Stahl et al. (2012), who classify the impacts into nine categories and corresponding types.

A suite of drought indicators is normally recommended for drought studies given the diversity of the studied phenomenon. Commonly, the deviation from a long-term (hydroclimatological) statistics is being used, expressed as e.g. a value from the empirical (percentile-based index) or fitted distribution. This includes indices like the Standardized Precipitation Index (SPI), the SPEI, soil moisture percentiles or runoff anomalies for different time resolutions. As drought is a slowly developing phenomenon, both the onset and recovery of a drought event are considered, accounting for varying persistence (memory) in the natural system. Different parts of the terrestrial system will impacted by the drought depending on the duration of the drought event and the persistence of the system, e.g. agricultural drought (typically months) or hydropower drought (typically years).

A prerequisite to mitigate the wide range of drought impacts is to establish a good understanding of the drought generating mechanisms from their initiation as a meteorological drought through to their development as agricultural (soil moisture) and hydrological drought. Droughts are regional by nature, typically covering large areas, and should preferably be studied at the pan-European scale to consistently address the dynamic nature of drought (i.e. spatial and temporal characteristics) and drought-generating processes across Europe. In particular, potential links to climate drivers and studies of large-scale impacts such as heat waves, forest fires and vegetation stress, require a large-scale approach. On the other hand, the high spatial variability found within a drought-affected region is caused by a combination of catchment and land surface properties, together with small-scale climate variability, thus local-scale studies should be seen as a complementary and necessary part of any large-scale assessment for the purpose of local mitigation strategies and risk assessments.

2. Objective and Organization

The online European Drought Reference (EDR) database was created as part of the Drought R&SPI Task 1.1, to create "a concise reference dataset of historical droughts, their climatological cause and major impacts…". The EDR database introduced in this document achieves this goal, consolidating information on major large-scale droughts in Europe in a single location available to the public online through the European Drought Centre (EDC) website. The EDC website is already an active European drought resource, with over 275 members representing 55 countries, and provides a useful platform to launch this new drought reference database.

The EDC website will also house the European Drought Impact Report Inventory (EDII), which is part of Deliverable 3.2 and is outlined in Stahl et al. (2012). Housing the EDR database and the EDII database within the same website provides the public with a simple, yet comprehensive location to learn about droughts. Additionally, it allows for direct links between the databases. Within each detailed drought event summary in the EDR database is a reported drought impact section, which presents all relevant impacts from the EDII. The summary of reported drought impacts is updated automatically, meaning that its data and coverage will improve throughout the course of the project as the EDII grows and improves.

European researchers have significant information and expertise regarding droughts; however, this expertise is distributed across many countries and too often is not combined. The EDR database has great potential to consolidate this knowledge on droughts into a single resource, analogous to the US Drought Monitor. It is our hope that the EDR database can become a standard reference tool which will grow with time and stimulate data collection, sharing, and analysis.

3. Data and Methods

3.1 Historical climate

All historical climate estimates in the EDR database were based on the Watch Forcing Dataset (WFD), a gridded historical climate dataset based on ERA-40 reanalysis with 0.5° x 0.5° resolution (Weedon et al., 2010). The WFD consists of subdaily forcing data spanning the time period 1/1/1958 to 12/31/2001 and employs bias-correction for temperature and precipitation based on CRU-TS2.1 and GPCCv4 observations. For the purpose of this research, the European extent is defined as the region between 34°-72° N latitude and -13°-32° E longitude, resulting in 3,950 land grid cells that follow the CRU land surface mask. Climate variables used for climatological drought indices include rainfall, snowfall, temperature, and wind speed. Climatic indices are always based on precipitation, calculated as the sum of rainfall and snowfall.

The Watch Forcing Dataset – ERA-Interim (WFDEI) was used to extend climatic coverage to include events which occurred after 2001. This climate set was prepared using nearly identical procedures as the WFD, although using an updated re-analysis model (ERA-Interim, Dee et al. 2011) and updated observations for bias-correction (CRU-TS3.1, Mitchell & Jones, 2005 and GPCCv5, Rudolf et al., 2011). For the purposes of the online EDR database, it is assumed that the WFDEI and WFD form a continuous time series, with no detectable bias between the two datasets. This is currently being confirmed by the creators of the climate data and initial results have shown that this is a reasonable assumption when compiling summary statistics over a large area, such as Europe (Weedon, personal communication).

3.2 Historical modelled runoff

Historical gridded runoff was simulated using a suite of nine large-scale models at the same 0.5° x 0.5° resolution and forced by the WFD to maintain consistency (Haddeland et al 2011a). Technical details of the hydrologic models are summarized in Table 1 and described in great detail by several methodology and validation studies (Haddeland et al. 2011a, Gudmundsson 2012a, Gudmundsson 2012b). Simulated runoff was available for the period 1963-2001, as the first 5 years of the WFD were used as a model spin-up period. Despite large differences in how runoff is calculated, all models simulate Qs (water leaving the surface of a grid cell) and Qsb (water leaving the grid cell below the surface), allowing Qtot, the total amount of water discharged by a cell to be calculated as Qs + Qsb. All models assume ‘‘naturalized’’ conditions, ignoring direct anthropogenic effects such as dams and water abstraction. The large-scale hydrological models have not simulated runoff using the WFDEI and therefore no hydrological drought statistics are available for major drought events after 2001.

Comparison of the nine large-scale models with observations suggests that the multi-model ensemble mean is a more consistent predictor of runoff than any single large-scale model (Gudmundsson 2012b) . Given this finding, all estimates of hydrologic drought within the drought event database were based on the multi-model ensemble (MME). To calculate the MME, each model was processed and normalized individually and combined when calculating summary statistics. More detail is provided in Section 3.4 – Hydrological Drought Indices.

Table 1: Overview of the large-scale hydrological models, adapted from Haddeland et al. 2011a and Gudmundsson et al. 2012a.

Model name	Runoff Scheme	Energy Balance	Evapo-Transpiration	Reference(s)
GWAVA	Saturation excess/beta function	No	Penman-Monteith	Meigh et al. 1999
H08	Saturation excess/beta function	Yes	Bulk approach	Hanasaki et al. 2008
HTESSEL	Infiltration excess/Darcy	Yes	Penman-Monteith	Balsamo et al. 2009
JULES	Infiltration excess/Darcy	Yes	Penman-Monteith	Cox et al. 1999 ; Essery et al. 2003
LPJmL	Saturation excess	No	Preistley-Taylor	Bondeau et al. 2007 ; Rost et al. 2008
MATSIRO	Infiltration and saturation excess/groundwater	Yes	Bulk approach	Takata et al. 2003; Koirala 2010
MPI-HM	Saturation excess/beta function	No	Thornthwaite	Hagemann and Gates 2003; Hagemann and Dümenil 1998
ORCHIDEE	Saturation excess	Yes	Bulk approach	De Rosnay and Polcher 1998
WaterGAP	Beta function	No	Preistley-Taylor	Alcamo et al. 2003

3.3 Climatological Drought Indices – SPI and SPEI

Within the EDR database, the Standardized Precipitation Index (SPI) and the Standardized Precipitation-Evapotranspiration Index (SPEI) were used to objectively quantify and compare drought severity, duration, and extent across the varied climatic regions in Europe. SPI is recommended as a key meteorological drought indictor by the World Meteorological Organization (WMO, 2006) and the Lincoln Declaration on Drought (Hayes et al., 2011). The newer SPEI was developed to incorporate other climatic factors such as temperature and wind speed, which affect evapotranspiration and thereby water balance, while maintaining the same understandable statistical methodology as the SPI (Vicente-Serrano et al. 2010). Because SPEI includes climatological factors other than precipitation, the term "climatological drought" is used for the remainder of this study, rather than "meteorological drought".

SPI is typically computed by summing precipitation over k months, termed accumulation periods, and fitting these accumulated precipitation values to a parametric statistical distribution from which non-exceedance probabilities are transformed to the standard normal distribution ($\mu=0$, $\sigma=1$) (Guttman, 1999; Lloyd-Hughes & Saunders, 2002; McKee et al., 1993). SPEI is calculated in a similar fashion, but instead uses accumulated climatic water balance, defined as the difference between precipitation and PET (Vicente-Serrano et al. 2010). In this way, SPI and SPEI values are easily statistically interpretable, representing the number of standard deviations from typical accumulated precipitation, or climatic water balance, for a given location and time of year.

For the drought event database, SPI and SPEI were calculated at a daily temporal resolution. Accumulation periods considered in this study are the commonly used periods: 1, 2, 3, 6, 9, 12, and 24 months, which are considered equivalent to 31, 61, 91, 183, 274, 365, and 730 days, respectively. All normalization was performed relative to the reference period 1970-1999, in accordance with WMO standard reference periods. Selection of a common reference period allows for consistency with hydrological drought indices and provides a consistent baseline as new data becomes available in the future. SPI was normalized using the 2-parameter gamma distribution, while SPEI was normalized using the Generalized Extreme Value distribution, in accordance with recommendations from Stagge et al.

(2013a, b). SPI and SPEI values were limited to the range between -3 and 3 to ensure reasonableness (Stagge et al. 2013a).

When calculating SPEI, potential evapotranspiration was calculated using the Penman-Montieth equation with the Hargreaves-Samani modification (Hargreaves and Samani, 1985) as described in the FAO-56 (Allen et al., 1998) and as recommended by Stagge et al. (2014). The Penman-Montieth equation is the standard for accurately calculating PET and is recommended by both the WMO (WMO, 2006) and the FAO-UN (Allen et al., 1998). The modified form of the Penman-Montieth equation uses the daily difference between Tmax and Tmin as a proxy to estimate net radiation (Hargreaves & Samani, 1985), which retains the physical foundation of the Penman-Montieth equation, while also largely avoiding concerns with mixing bias corrected WFD temperature and precipitation with non-bias corrected radiation (Haddeland et al., 2011b).

For the purpose of the EDR database, a grid cell was considered to be in climatological drought when the given index (SPI or SPEI) for the cell was below the 20% nonexceedance percentile, calculated from the reference period (1970-1999). In the context of SPI and SPEI, this percentile is equivalent to an SPI/SPEI of -0.842. Climatological drought extent was estimated using the SPI-6, a normalized measure of accumulated precipitation during the previous 6 months. This accumulation period was chosen as a reasonable measure of medium-duration, seasonal drought typical of Europe (Van Loon and Van Lanen 2012) and is correlated with hydrological droughts in both headwaters and downstream reaches (López-Moreno et al. 2013). Drought extent was calculated as the percent area with SPI-6 below -0.842, or the 20th percentile.

3.4 Hydrological Drought Indices

Hydrological droughts were defined using a threshold method (Zelenhasic and Salvai 1987), similar to that used for SPI and SPEI. For each grid cell and each of the nine hydrologic models, total runoff was derived as the sum of subsurface and surface runoff. Flows were then smoothed, using a five day moving average, to remove the effect of transient storm events and focus on baseflow as recommended by Tallaksen et al. (1997). Using the five day smoothed flows, daily varying drought thresholds were calculated using the 20% nonexceedance frequency, as in the SPI and SPEI analysis. For consistency, these thresholds were calculated using the same 30 year reference period (1970-1999).

Thresholds and daily percentiles were calculated separately for each of the hydrologic models and then combined to determine the daily mean ensemble flow percentile. Droughts were then defined as any day when this mean ensemble percentile fell below the 20th percentile. Hydrological drought index availability is limited to the period 1963-2001 because these models were not run for the WFDEI climate forcing data.

3.5 Selection of Major Drought Events

In total, 11 major European drought events within the European region were chosen to be detailed in the EDR database. Dates and location of these events are summarized in Table 2. Selection of these events was primarily based on those years with the highest mean annual hydrological drought extents. This preliminary list was updated based on meteorological drought indices to include drought events outside the hydrological data range (prior to 1963 and after 2001). Major drought events were then confirmed through drought impact reports submitted to the drought impact inventory.

Table 2: Major European drought events during the period 1958-2009.

Year	Location	Duration (approximate)
1959	Northern Europe	5/1959 - 2/1960
1972	Northern/Eastern Europe	12/1971 - 7/1972
1973	Central Europe	1/1973 - 7/1973
1975-1976	Europe	11/1975 - 2/1977
1989-1990	Mediterranean	2/1989 - 10/1990
1991-1995	Mediterranean	2/1992 - 10/1994
1996-1997	Northern Europe	4/1995 - 7/1996
2000	East/Southeastern Europe	1/2001 - 3/2001
2003	Europe	4/2003 - 11/2003
2004-2007	Iberian Peninsula	7/2004 - 6/2007
2007	Eastern Europe	2/2007 - 8/2007

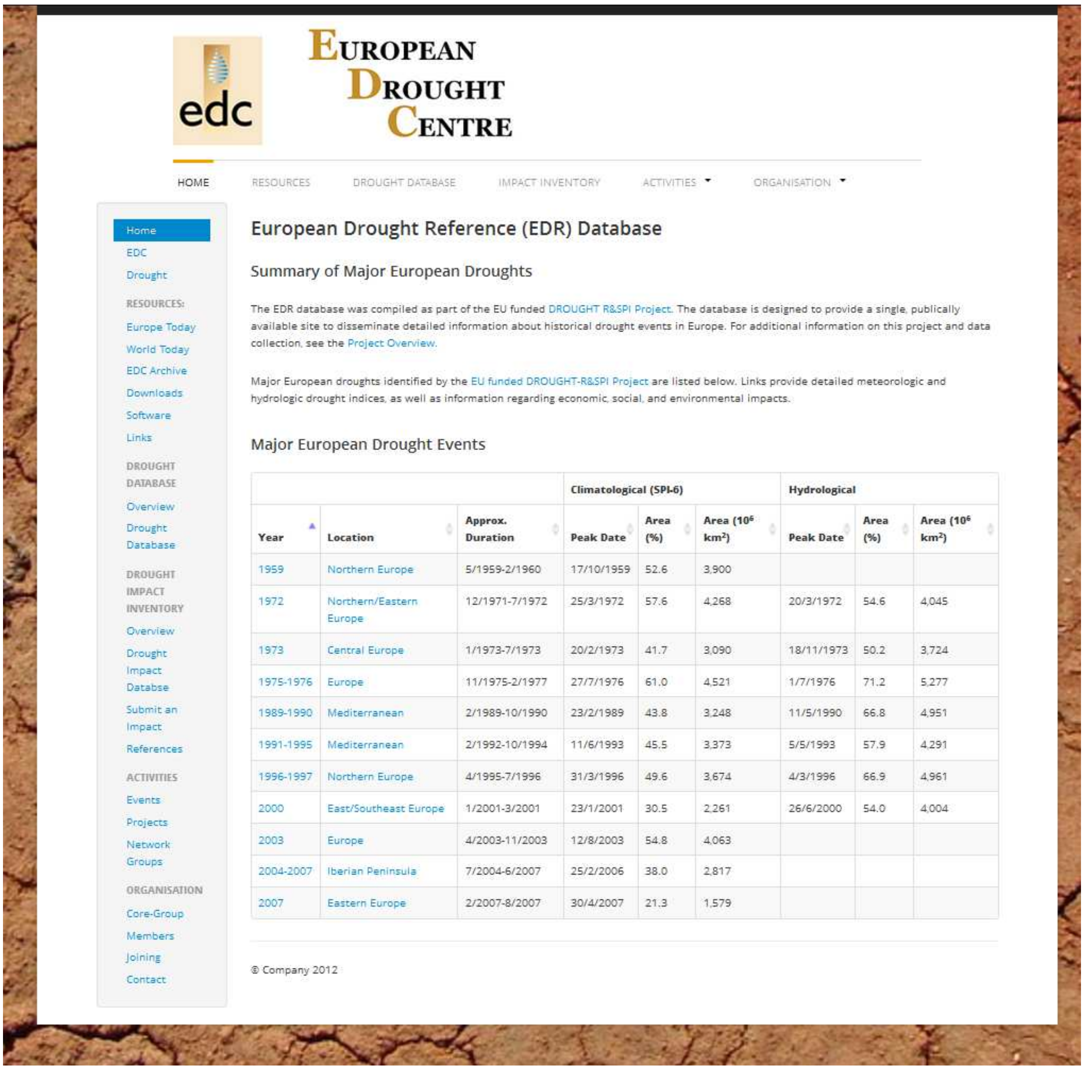
4. Structure and Status

The online drought event database is organized into three sections: an overview of major drought events, individual drought event pages with greater detail, and an application that allows the user to query drought conditions (SPI-6) on any day in the available historical record. Each of these sections are outlined in this report, using the 1975-1976 drought event as an example. Individual drought event pages for all 11 events are provided in Annex 1.

4.1 Major Drought Event Overview

The drought event overview page (Figure 1) is the starting page for investigating the major drought events included in the drought event database. This page provides a short outline of the purpose and content of the drought event database, while also providing a link to this document for additional detail regarding the underlying data and calculation methods.

The primary feature of the drought event overview page is a sortable table with summary statistics of the 11 major drought events identified in Table 2. Apart from the year and a subjective description of the region affected, the table provides an approximate duration for each event. Start and end dates for the drought duration are determined based on the date when total area in drought exceeds 30% and remains as such. A 2 month buffer is applied to both the start and end dates in this definition to account for drought development and decline.



European Drought Reference (EDR) Database

Summary of Major European Droughts

The EDR database was compiled as part of the EU funded DROUGHT R&SPI Project. The database is designed to provide a single, publically available site to disseminate detailed information about historical drought events in Europe. For additional information on this project and data collection, see the Project Overview.

Major European droughts identified by the EU funded DROUGHT-R&SPI Project are listed below. Links provide detailed meteorologic and hydrologic drought indices, as well as information regarding economic, social, and environmental impacts.

Major European Drought Events

			Climatological (SPI-6)			Hydrological		
Year	Location	Approx. Duration	Peak Date	Area (%)	Area (10^6 km^2)	Peak Date	Area (%)	Area (10^6 km^2)
1959	Northern Europe	5/1959-2/1960	17/10/1959	52.6	3,900			
1972	Northern/Eastern Europe	12/1971-7/1972	25/3/1972	57.6	4,268	20/3/1972	54.6	4,045
1973	Central Europe	1/1973-7/1973	20/2/1973	41.7	3,090	18/11/1973	50.2	3,724
1975-1976	Europe	11/1975-2/1977	27/7/1976	61.0	4,521	1/7/1976	71.2	5,277
1989-1990	Mediterranean	2/1989-10/1990	23/2/1989	43.8	3,248	11/5/1990	66.8	4,951
1991-1995	Mediterranean	2/1992-10/1994	11/6/1993	45.5	3,373	5/5/1993	57.9	4,291
1996-1997	Northern Europe	4/1995-7/1996	31/3/1996	49.6	3,674	4/3/1996	66.9	4,961
2000	East/Southeast Europe	1/2001-3/2001	23/1/2001	30.5	2,261	26/6/2000	54.0	4,004
2003	Europe	4/2003-11/2003	12/8/2003	54.8	4,063			
2004-2007	Iberian Peninsula	7/2004-6/2007	25/2/2006	38.0	2,817			
2007	Eastern Europe	2/2007-8/2007	30/4/2007	21.3	1,579			

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Figure 1: Screenshot of the major drought event overview page.

In addition, the date of peak drought extent and the associated maximum drought area (percent and absolute area) are presented for both climatological and hydrological drought. As described in Sections 3.3 and 3.4, measures of meteorological and hydrological drought extent are based on the 20% nonexceedance percentile for SPI-6 and the multi-model ensemble mean, respectively. Hydrological drought statistics are not provided for the 1959 (Northern Europe), 2003 (Europe), 2004-2007 (Iberian Peninsula), and 2007 (Europe) events because output is not available from the nine hydrological models outside the original WFD timescale.

The drought event overview table is completely sortable, allowing the online user to easily rank drought events by maximum areal extent, either based on climatological or hydrological droughts. The table also allows a quick comparison within each event with regard to hydrological and climatological drought. Each event in the table is clickable and the hyperlink connects directly to the detailed individual drought event page described in Section 4.2.

4.2 Individual Drought Event Details

The individual drought event pages are accessible via the drought event overview page and provide greater detail and context for each of the 11 major drought events. Each drought event page contains an event summary, climatological drought data, hydrological drought data, and information regarding available drought impact reports.

4.2.1 Drought Event Summary and Background

The drought event summary (Figure 2) consists of a text overview, describing in detail how the drought event began, developed, and eventually returned to normal climatic conditions. Within this summary is information regarding large-scale climatic drivers, drought impacts, mitigation efforts, and all other pertinent data. Wherever applicable, these statements are cited, with a list of references provided at the bottom of the web page. Each drought event also includes a summary box, mirroring the information provided in the drought overview page.

Figure 2: Screenshot of the drought event summary and background section for the 1975-1976 drought event.

4.2.2 Climatological Droughts

The climatological drought section (Figure 3) displays details regarding the progression, location and severity of the particularly drought event with respect to the climatological drought index, SPI-6. Each climatological drought section contains a text overview, highlighting important climatological features of the drought event and briefly describing large-scale climatic drivers that control the drought when this information is available.

Two figures are also presented for each drought event, showing: (1) daily snapshots of SPI-6 severity and (2) the percent area in climatological drought by date. The first figure, presenting the daily spatial distribution of SPI-6 indices, shows abnormally dry regions (negative SPI-6) in progressive shades of red and abnormally wet regions (positive SPI-6) in shades of blue. This figure is interactive, allowing the user to view the progression of climatological drought as a movie, to select individual dates within the drought event, or to scroll through the event manually. The second figure shows the progression of the entire drought event, plotting percent area in drought against time. This figure clearly shows the speed of onset, progression, and end of the event, while also highlighting the maximum drought extent. The 1975-1976 drought event (Fig. 3) was a distinct, singular event, but this figure is also useful for identifying secondary peaks or temporary recover periods, which could otherwise be overlooked in summary statistics.

Currently the climatological drought section only presents information regarding the SPI-6 for ease of understanding and readability. However, data and figures have been generated for all major accumulation periods (1, 2, 3, 6, 9, 12, and 24 months) of the SPI and SPEI, but have not been uploaded to the site. This information may be added to the climatological drought section in the future if it improves understanding of each event.

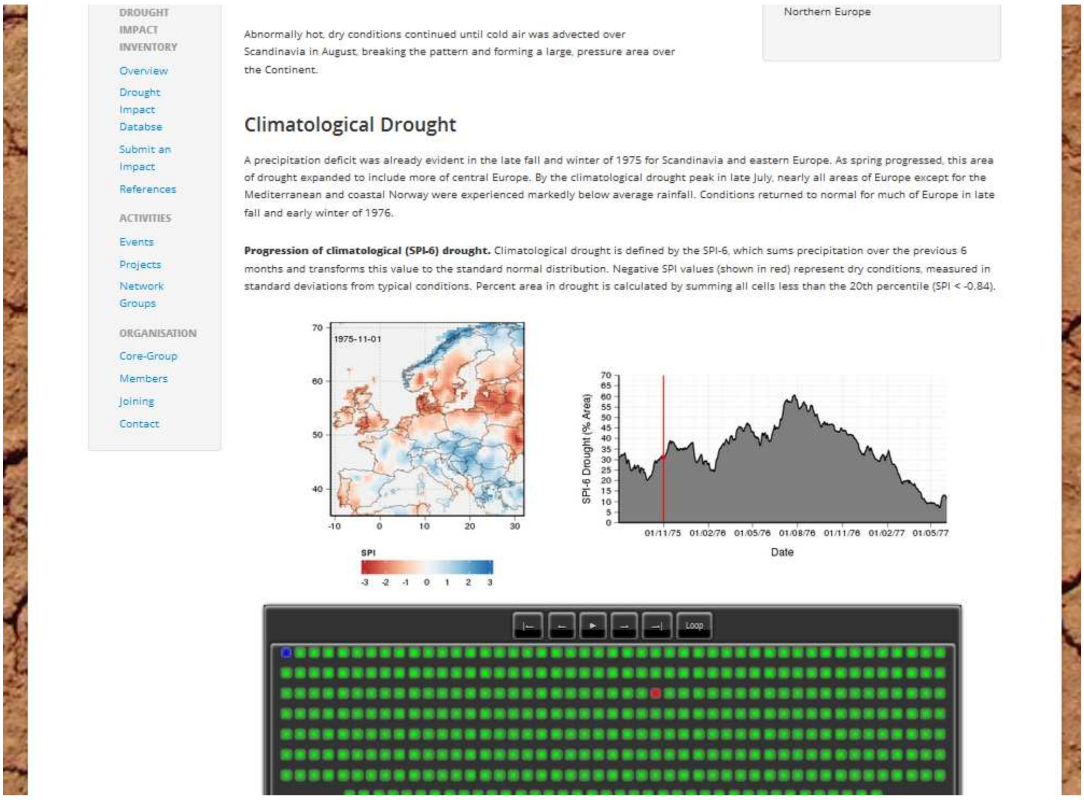


Figure 3: Screenshot of the climatological drought section for the 1975-1976 drought event.

4.2.3 Hydrological Droughts

The hydrological drought section of the online EDR database (Figure 4) focuses entirely on hydrological drought as estimated by the nine large-scale hydrological models. Each hydrological drought section contains a text summary of low flow patterns in addition to two figures showing the spatial pattern of drought at the hydrological drought peak and the corresponding location of the drought centre for each of the hydrological models. The hydrological drought section is not available for drought events outside the WFD coverage (1959, 2003, 2004-2007, and 2007).

The spatial figure showing hydrological drought is based on the MME mean flow percentile, as described in Section 3.4. All grid cells with runoff (surface + subsurface) below the 20% nonexceedance percentile is shaded as a location in drought. Conditions at the hydrological drought peak are shown as a static figure, but may be improved to an interactive figure, similar to the climatological drought section as the website is improved. The second, drought centre figure displays the drought centroid and indicates the drought area by a circle scaled to the total area covered on the particular day. This allows plotting all models and the ensemble median (grey colour) in one map for comparison.

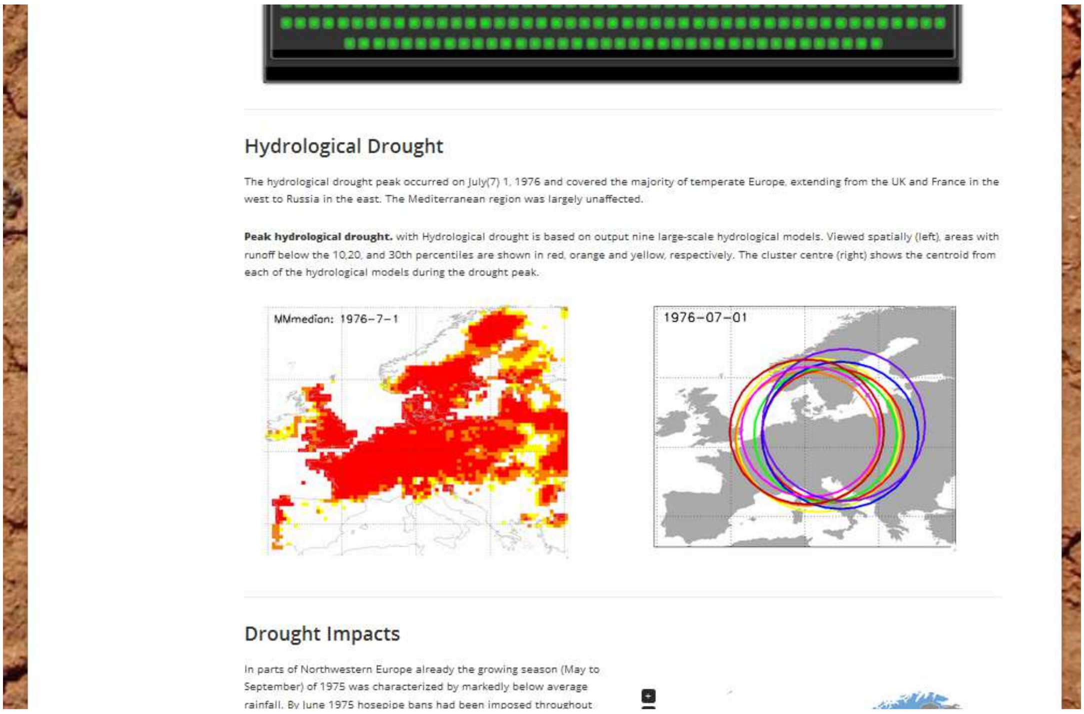


Figure 4: Screenshot of the hydrological drought section for the 1975-1976 drought event.

4.2.4 Reported Drought Impacts

For all major droughts, the drought impact section (Figure 5) lists those drought impacts reported in the European Drought Impact Report Inventory (EDII) outlined in Stahl et al. (2012). This database is housed online and is queried automatically each time the page is loaded. Therefore, the reported drought impact section will improve throughout the course of this project and following its completion as the EDII increases in scope and detail. Currently, the EDII has differing levels of coverage, both spatially throughout Europe and temporally, with more attention focussed on the most recent drought events. The drought impact section consists of a text summary, an interactive map showing the location of all relevant drought impact reports, and a sortable table listing all pertinent details for the drought reports.

The drought impact map shows all drought impacts at the country level, with increasingly darker colors representing greater numbers of reported drought impacts in the EDII. Drought impact reports with exact locations (latitude/longitude) are shown as unique points. Online users can scroll over each country to access a short summary, showing the name of the country, number of impacts, and description of impact in the case of point reports. The map can also be zoomed and moved to show greater detail.

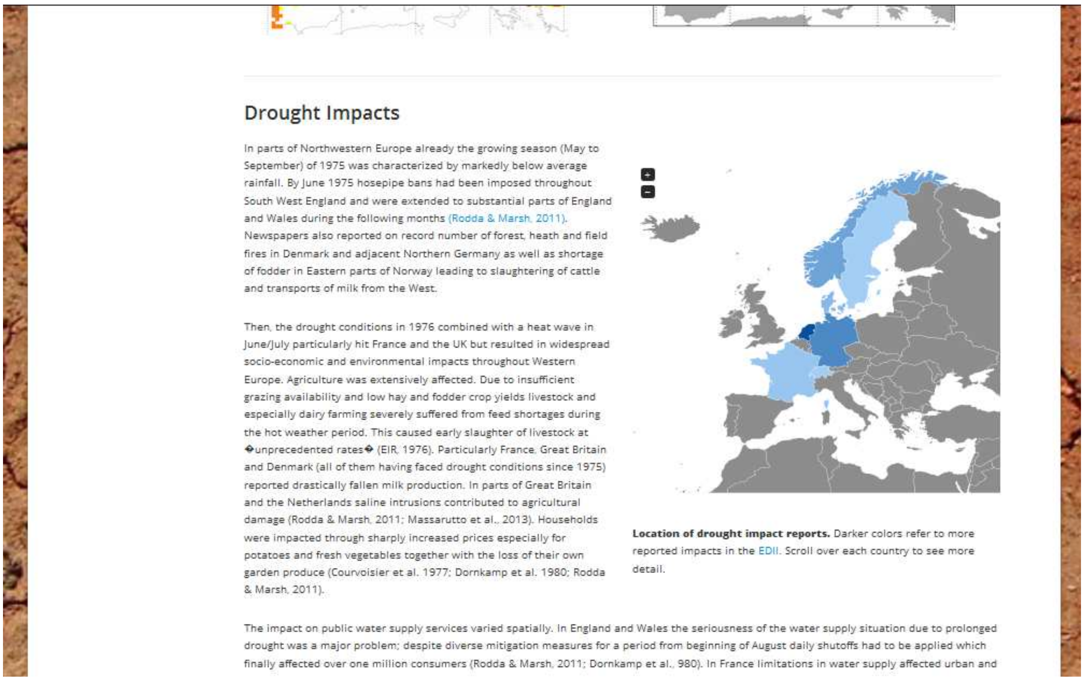
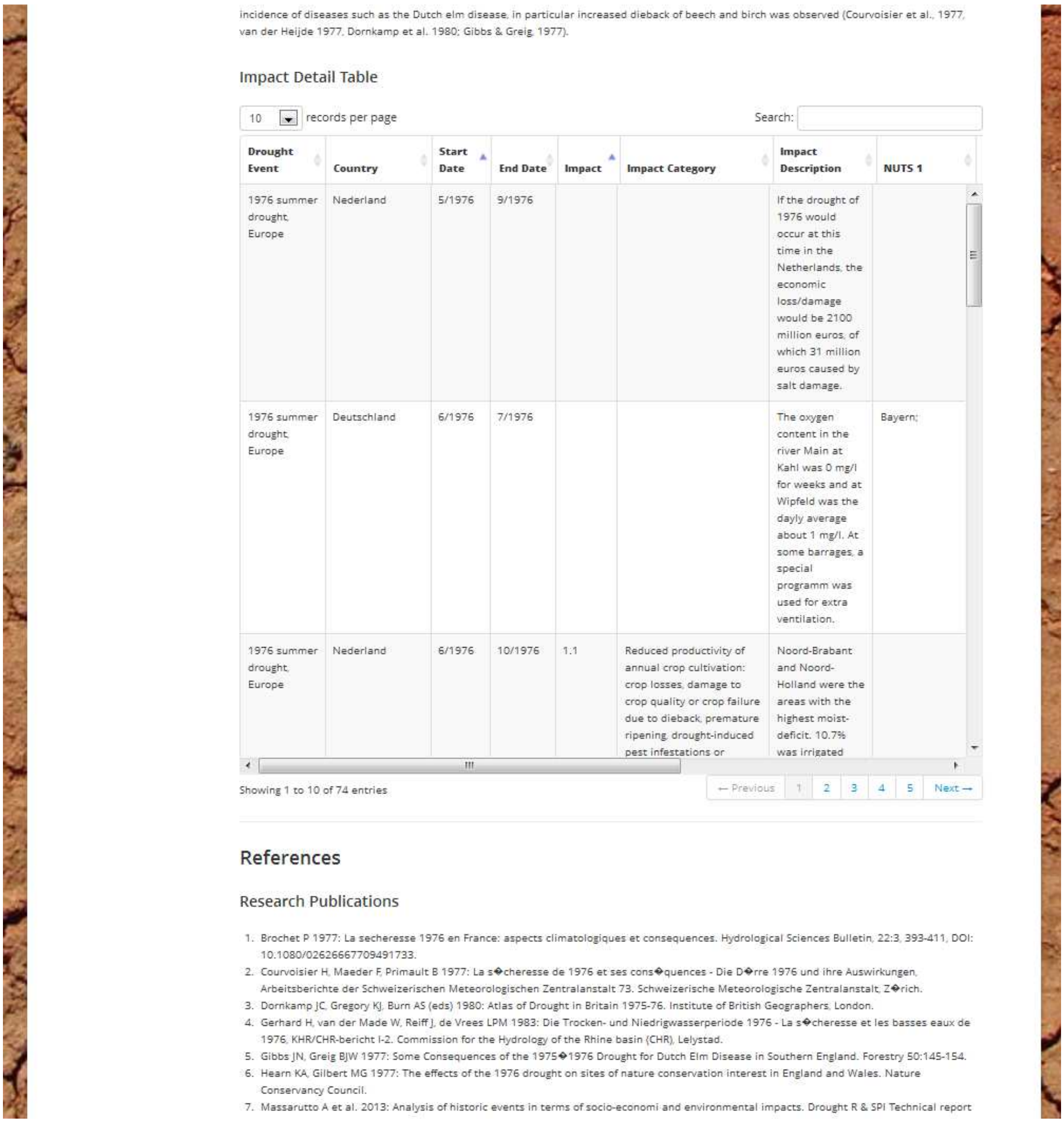


Figure 5: Screenshot of the reported drought impacts section, showing the text summary and impact locations for the 1975-1976 drought event.

The drought impact table provides complete details on all drought impact reports shown in the impact map. This includes location (country and NUTS region), start and end dates, impact category and description, and the reference for the provided information. All information in this table follows the format provided in Stahl et al. (2013) including impact types and categories. The table is interactive, allowing the user to sort by any column, to increase the number of records shown per page or to do a text search within the records. The search function is particularly useful if the user wishes only to see a particular impact type or particular region. References with URLs are shown as clickable links, which will take the user directly to the drought impact reference.



incidence of diseases such as the Dutch elm disease, in particular increased dieback of beech and birch was observed (Courvoisier et al., 1977, van der Heijde 1977, Dornkamp et al. 1980; Gibbs & Greig, 1977).

Impact Detail Table

10 records per page   Search:

Drought Event	Country	Start Date	End Date	Impact	Impact Category	Impact Description	NUTS 1
1976 summer drought, Europe	Nederland	5/1976	9/1976			If the drought of 1976 would occur at this time in the Netherlands, the economic loss/damage would be 2100 million euros, of which 31 million euros caused by salt damage.	
1976 summer drought, Europe	Deutschland	6/1976	7/1976			The oxygen content in the river Main at Kahl was 0 mg/l for weeks and at Wipfeld was the dayly average about 1 mg/l. At some barrages, a special programm was used for extra ventilation.	Bayern;
1976 summer drought, Europe	Nederland	6/1976	10/1976	1.1	Reduced productivity of annual crop cultivation: crop losses, damage to crop quality or crop failure due to dieback, premature ripening, drought-induced pest infestations or	Noord-Brabant and Noord-Holland were the areas with the highest moist-deficit. 10.7% was irrigated	

Showing 1 to 10 of 74 entries   ← Previous 1 2 3 4 5 Next →

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Figure 6: Screenshot of the reported drought impacts section, showing the impact table and references for the 1975-1976 drought event.

4.3 Climatological Drought (SPI) By Date

In addition to information on the 11 major drought events, the EDR database allows the user to query the SPI database for any available date range (1959-2009) and view its progression as an interactive movie (Figure 7). Currently this page only provides data for SPI-6, as used in all major drought events, but the data exists to extend this functionality to any available drought index. The period from 2001 to 2009 is based on the WFDEI dataset and is considered experimental data subject to verification.

The generated SPI maps follow an identical format to those presented in the climatological drought section of the individual drought event pages and contain the same functionality. SPI figures may be viewed as a movie, scrolled frame-by-frame manually, or paused to view an individual date in the historical record.

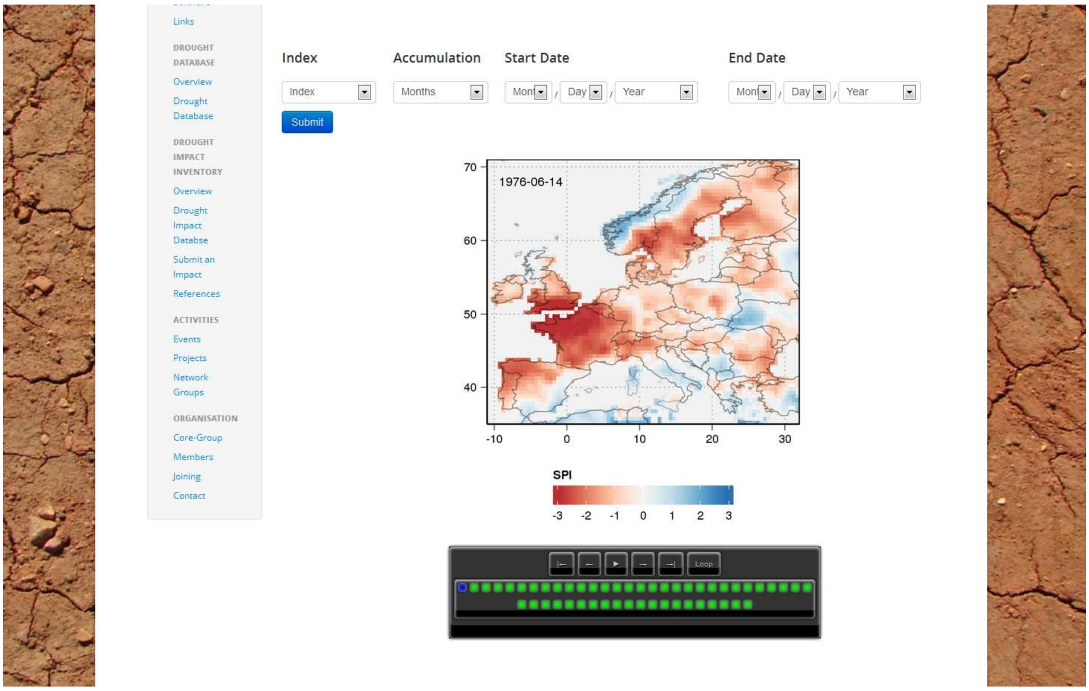

Figure 7: Screenshot of the climatological drought query by date.

5. Availability and Proposed Improvements

The online EDR database is fully functional, but will continue to improve throughout the Drought R&SPI project. As of September 2013, it is only accessible to Drought R&SPI project members for internal testing and feedback. It will be made available to a larger test audience, i.e. the EDC members by November 2013, and made completely public in June 2014. The reason for this stepwise procedure is to insure ample testing with continual improvements to the site and its data. The content and formatting of the website will be continuously updated with additional tools and findings added as they become available.

One such anticipated improvement is the inclusion of a large-scale climate driver section for each drought event. Research on the climate drivers of drought is ongoing within the Drought R&SPI project (Kingston et al. 2013) and is tied to deliverable Task 1.3 (MS 15). As results from climate driver studies become available, summary statistics and figures will be included in this section. Figure 8 shows the mean geopotential height anomaly preceding the drought of 1976 and is typical of what would be included in this section.

Additionally, the WFDEI is being updated on a regular basis. The newest set of climate data will be released within the year and will include the years 2010-2012. This data will be incorporated into the EDR database to expand the temporal coverage. There is potential to add simulated runoff from future model runs (large-scale model ensemble forced by the WFDEI) once provided by the modelling community.

Technical improvements to the online EDR database are also proposed. Most notably, these improvements include expanding the SPI search functionality to include SPEI and hydrological drought snapshots. Similarly, the hydrological drought section will be improved to include an interactive daily drought progression, similar to those for climatological drought (SPI-6).

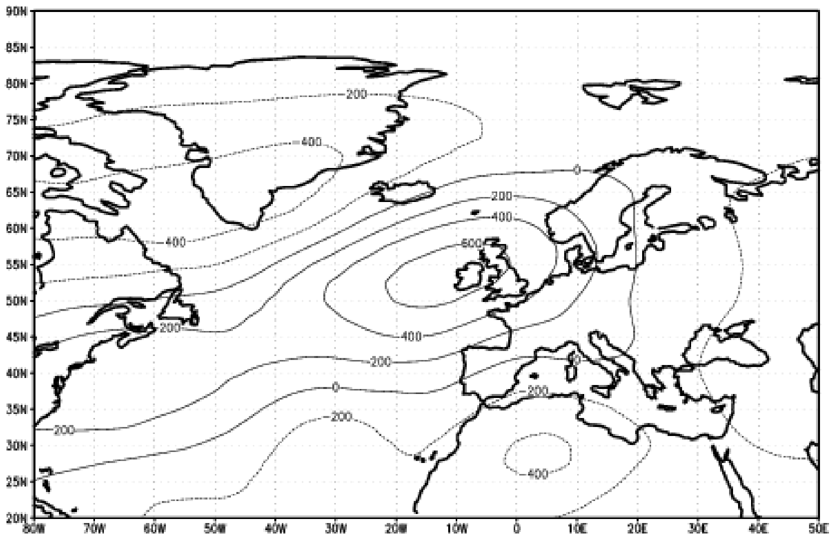

Figure 8: Mean geopotential height anomaly prior to the drought of 1976. Reproduced from Kingston et al (2013).

6. Conclusions

The EDR database was designed to provide a single, publically available site to disseminate detailed information about historical drought events in Europe. The current site provides the user with comparisons between events, in the form of an overview table, and detailed information about each of the 11 identified major European drought events in individual pages. In addition, an application is provided that allows the user to view meteorological drought conditions on any date in the available historical record.

This website is a first step towards creating a repository where drought information can be compiled and easily distributed throughout Europe. It has great potential to increase awareness of European droughts as well as provide a platform for future study. In its current state, the EDR database is an effective tool, but it is designed to be flexible, improving as new information is made available. Along with the EDII, this site will improve throughout the Drought R&SPI project and hopefully continue to provide important drought information after the project is complete.

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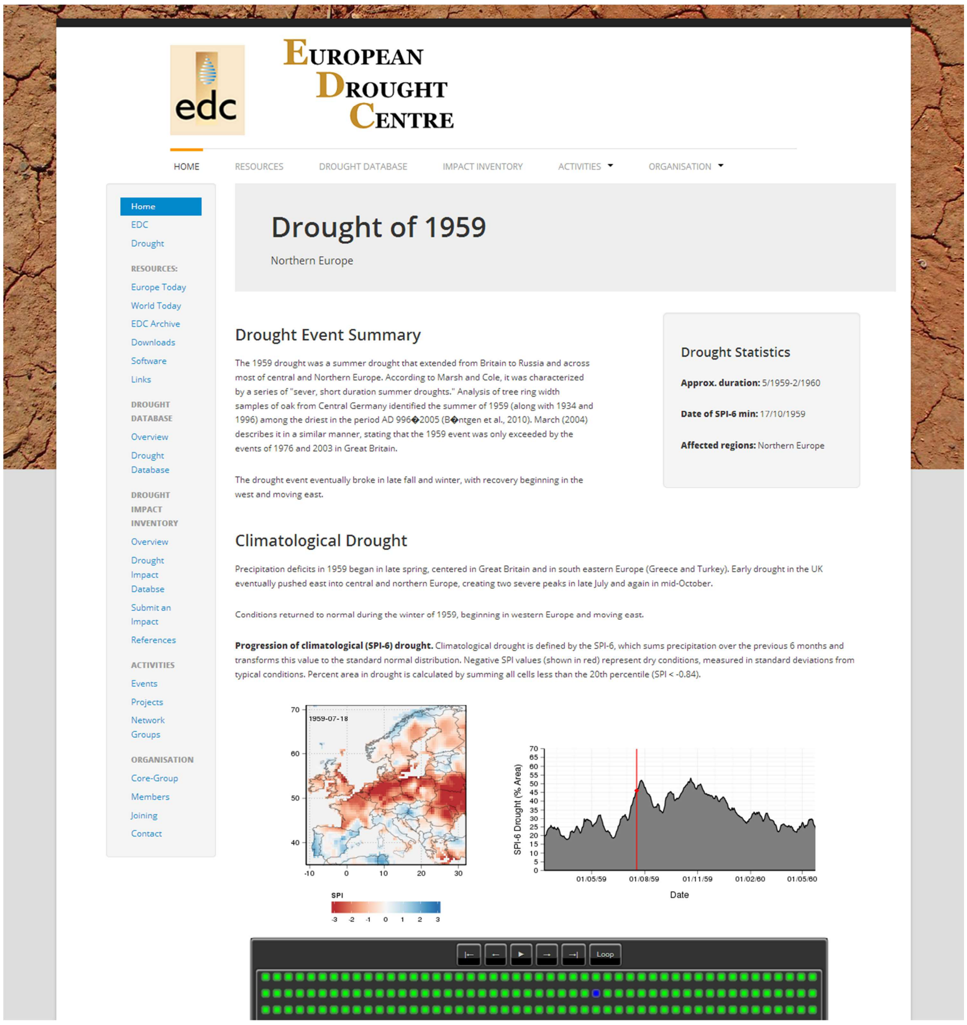
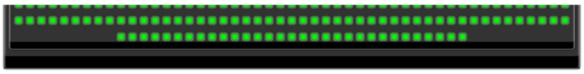
Annex 1 Major Drought Event Screenshots

1959 Drought Event





Drought Impacts

Analysis of tree ring width samples of oak from Central Germany identified the summer of 1959 (with 1934 and 1996) among the driest in the period AD 996�2005 (B�ntgen et al., 2010). In consequence of the dry and hot summer Western Germany suffered from severe water supply shortages in late 1959. Particularly affected were the industrial and (emerging) agglomeration areas, taken into account that water demands were rapidly rising at that time (time of the �Wirtschaftswunder�). Due to extreme low stream flows and depleted reservoirs used for public supply (e.g., in the Harz Mountains) many people were affected by hosepipe bans and water rationing (SPIEGEL, Nov 1959). Also in England and Wales ten million consumers were affected by hosepipe bans and drought orders because of extreme low flows and a serious depletion of reservoirs (Marsh et al., 2007), while the impact on groundwater had been rather limited (Cole & Marsh, 2006). Other reported impacts of the 1959 drought in Northern/Central Europe are: the occurrence of forest fires in Norway (Direktoratet for samfunnssikkerhet og beredskap etter oppdrag fra Justis- og politidepartementet, 2008) and huge economic losses for the waterborne transportation sector in the Netherlands (RIZA, 2005).

Location of drought impact reports. Darker colors refer to more reported impacts in the EDII. Scroll over each country to see more detail.

Impact Detail Table

10 records per page Search:

Drought Event	Country	Start Date	End Date	Impact	Impact Category	Impact Description	NUTS 1	NUT
1959 Scandinavia	Norge	1959	1959	12.1	Increased burned area	150 ha of productiv forest burnt down in Deset, Rendalen. Total area affected was much larger.	Norge	Hedı og O
1959 Scandinavia	Norge	1959	1959	12.1	Increased burned area	500 ha productiv forest burnt down in Tingstadlia, Rendalen. Total area affected was much larger.	Norge	Hedı og O

Showing 1 to 2 of 2 entries ← Previous 1 Next →

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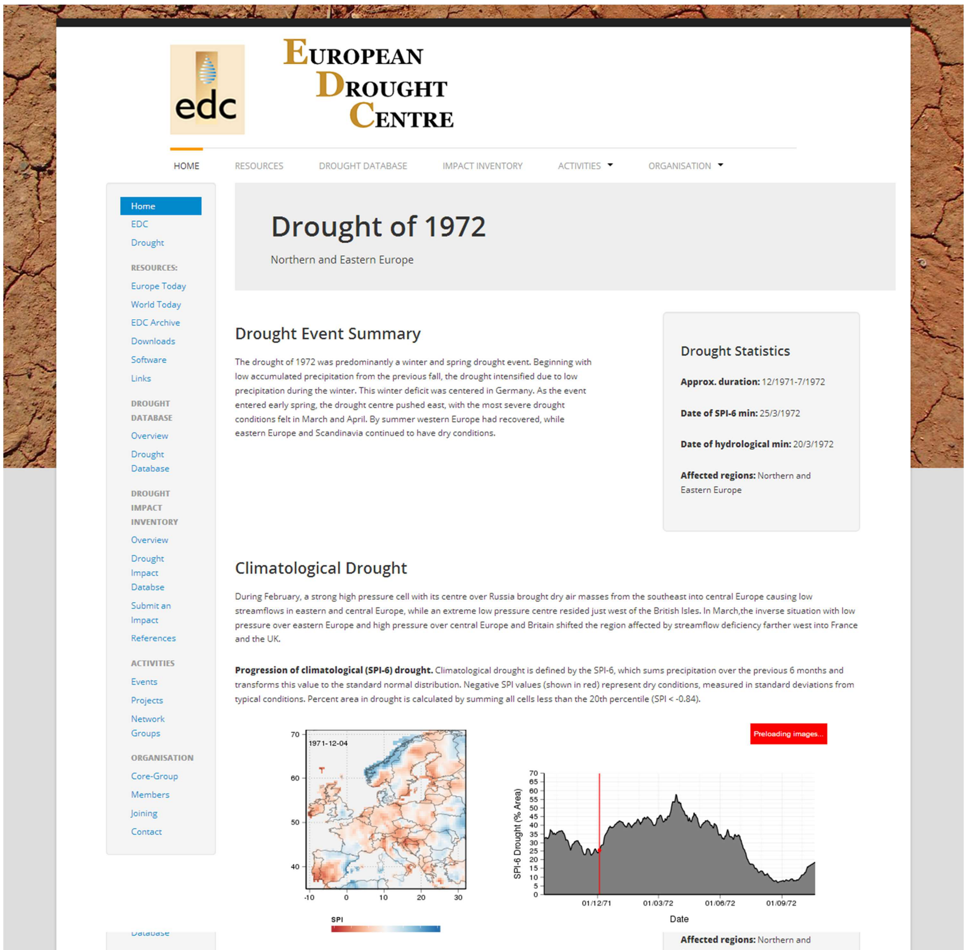
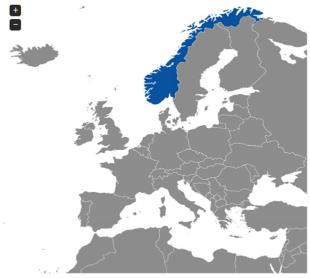
1972 Drought Event



Drought Impacts

According to Bradford (2000) drought in 1972 affected particularly the USSR with extreme low river levels. �lesund and other areas in Norway were affected by water use restrictions because of water shortage in 1972 (Aftenposten 1972-03-07). According to Cole & Marsh (2006) drought conditions from summer 1972 to late 1973 affected the most of England and Wales but became not critical in most areas; notable deficiencies were observed for spring-fed rivers and aquifers and streams in Chalk areas but summer flows were mostly not extreme. (No documentary evidence of impact could be found by Cole & Marsh).



Location of drought impact reports. Darker colors refer to more reported impacts in the EDII. Scroll over each country to see more detail.

Impact Detail Table

10 records per page Search:

Drought Event	Country	Start Date	End Date	Impact	Impact Category	Impact Description	N 1
1972 Norway	Norge	1/1972		7.99	Drying up of reservoirs	Water shortage due to nearly no precipitation for months. Wateruse restrictions for Ålesund, but also affecting other areas.	N

Showing 1 to 1 of 1 entries ← Previous 1 Next →

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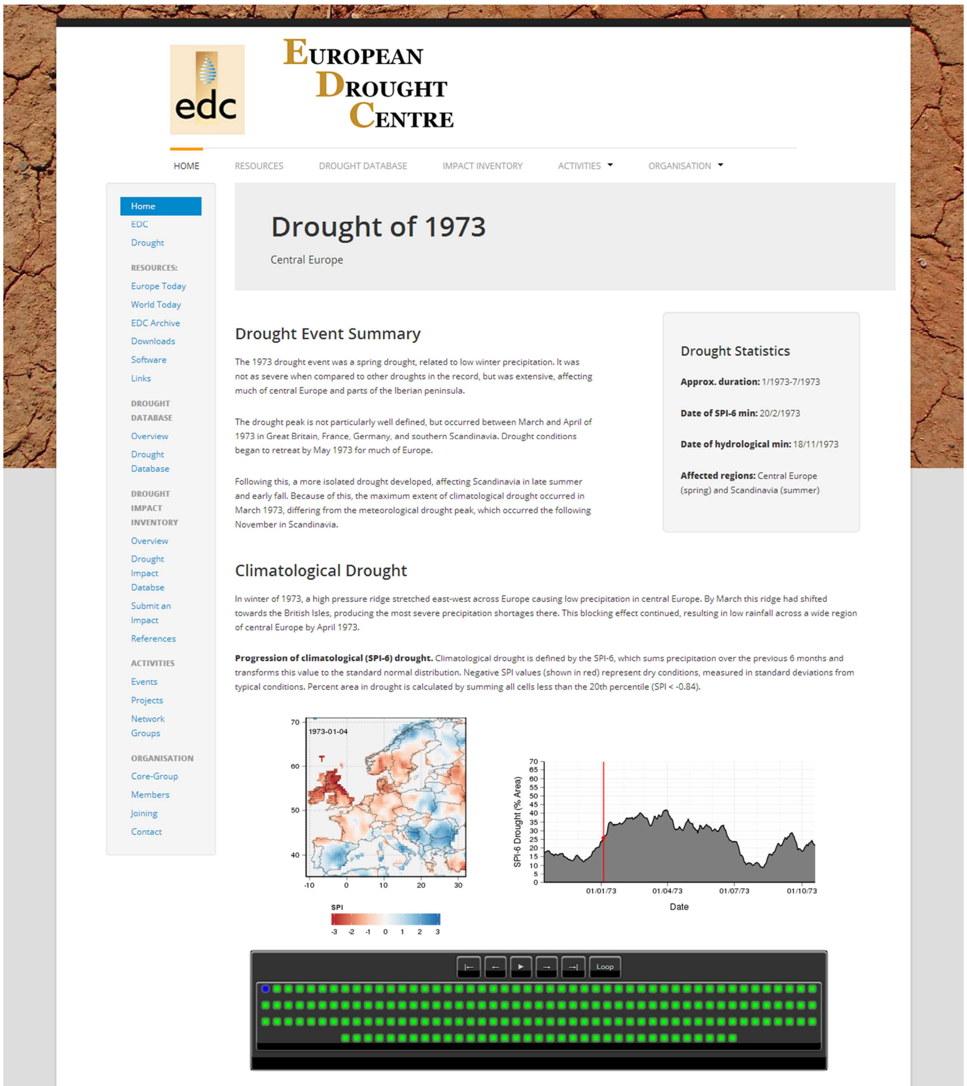
3. Cole GA, Marsh T 2006: The impact of climate change on severe droughts Major droughts in England and Wales from 1800 and evidence of impact. Science Report: SC040068/SR1. Environmental Agency, Bristol.

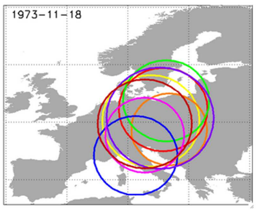
1973 Drought Event



Hydrological Drought

Peak hydrological drought. with Hydrological drought is based on output nine large-scale hydrological models. Viewed spatially (left), areas with runoff below the 10,20, and 30th percentiles are shown in red, orange and yellow, respectively. The cluster centre (right) shows the centroid from each of the hydrological models during the drought peak.

The hydrological drought peak occured in November, significantly later than the meteorological drought peak. This fall hydrological drought was centered in Scandinavia and eastern Europe.



Drought Impacts

According to Bradford (2000), in 1973 countries in North and Central Europe (UK, Austria, Germany and Czechoslovakia) were affected by drought conditions. �lesund and other areas in Norway were affected by water use restrictions because of water shortage in 1972 (Aftenposten 1972-03-07). According to Cole & Marsh (2006) drought conditions from summer 1972 to late 1973 affected the most of England and Wales but became not critical in most areas; notable deficiencies were observed for spring-fed rivers and aquifers and streams in Chalk areas but summer flows were mostly not extreme. (No documentary evidence of impact could be found by Cole & Marsh).

Location of drought impact reports. Darker colors refer to more reported impacts in the EDII. Scroll over each country to see more detail.

Impact Detail Table

10 records per page Search:

Drought Event	Country	Start Date	End Date	Impact	Impact Category	Impact Description	N
No data available in table							

Showing 0 to 0 of 0 entries ← Previous Next →

References

1. Aftenposten 1972-03-07, http://eavis.aftenposten.no/aftenposten/46449/11/
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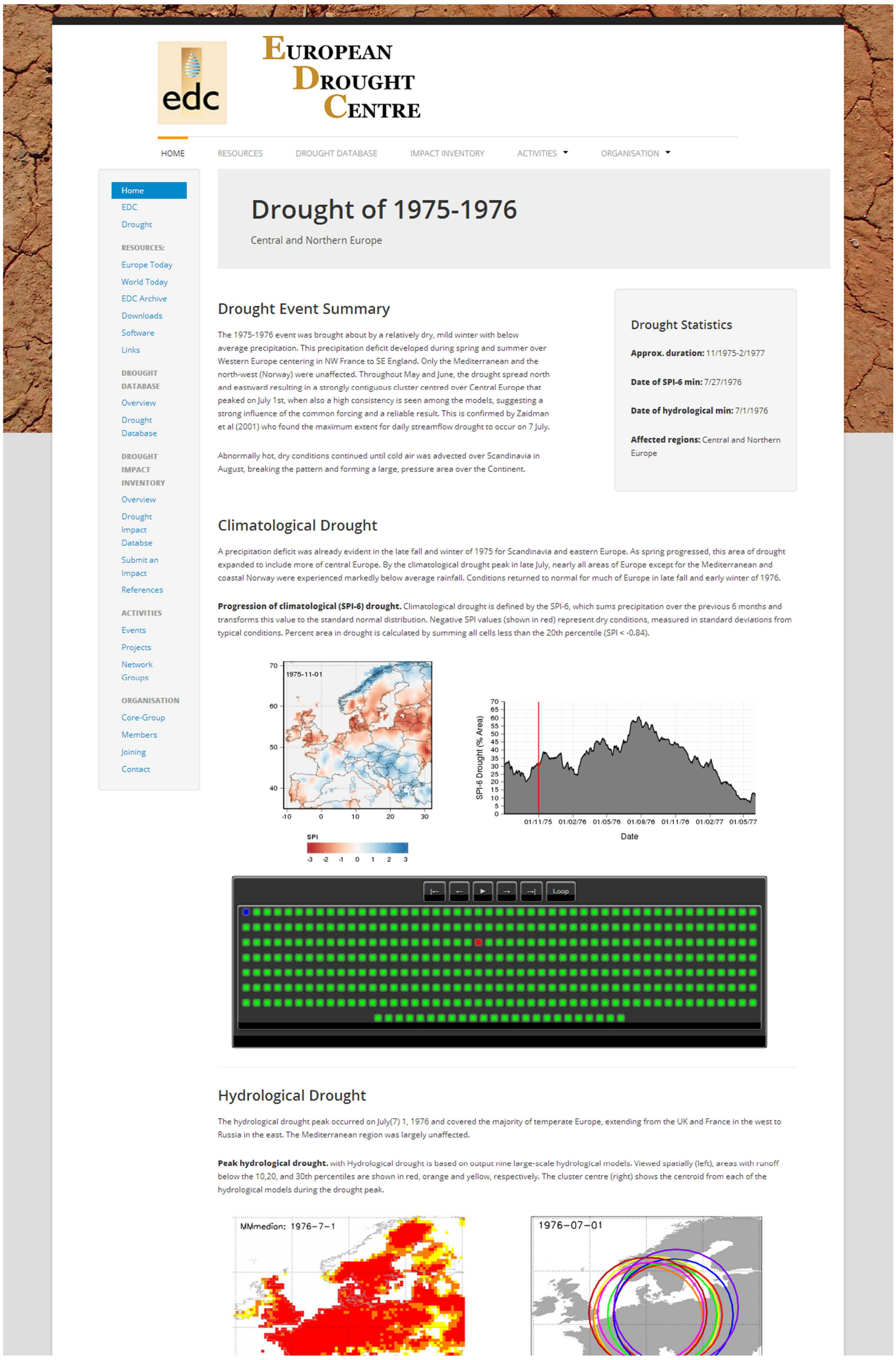
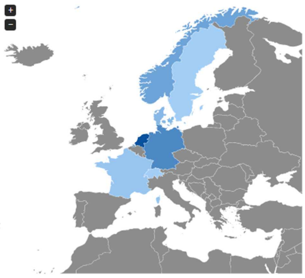
1975-1976 Drought Event



Drought Impacts

In parts of Northwestern Europe already the growing season (May to September) of 1975 was characterized by markedly below average rainfall. By June 1975 hosepipe bans had been imposed throughout South West England and were extended to substantial parts of England and Wales during the following months (Rodda & Marsh, 2011). Newspapers also reported on record number of forest, heath and field fires in Denmark and adjacent Northern Germany as well as shortage of fodder in Eastern parts of Norway leading to slaughtering of cattle and transports of milk from the West.

Then, the drought conditions in 1976 combined with a heat wave in June/July particularly hit France and the UK but resulted in widespread socio-economic and environmental impacts throughout Western Europe. Agriculture was extensively affected. Due to insufficient grazing availability and low hay and fodder crop yields livestock and especially dairy farming severely suffered from feed shortages during the hot weather period. This caused early slaughter of livestock at �unprecedented rates� (EIR, 1976). Particularly France, Great Britain and Denmark (all of them having faced drought conditions since 1975) reported drastically fallen milk production. In parts of Great Britain and the Netherlands saline intrusions contributed to agricultural damage (Rodda & Marsh, 2011; Massarutto et al., 2013). Households were impacted through sharply increased prices especially for potatoes and fresh vegetables together with the loss of their own garden produce (Courvoisier et al. 1977; Dornkamp et al. 1980; Rodda & Marsh, 2011).



Location of drought impact reports. Darker colors refer to more reported impacts in the EDII. Scroll over each country to see more detail.

The impact on public water supply services varied spatially. In England and Wales the seriousness of the water supply situation due to prolonged drought was a major problem; despite diverse mitigation measures for a period from beginning of August daily shutoffs had to be applied which finally affected over one million consumers (Rodda & Marsh, 2011; Dornkamp et al., 980). In France limitations in water supply affected urban and rural areas in particular in the East, in Brittany and in touristic areas at the West coast yet were less severe than expected at the beginning of the summer (Brochet, 1977). While the need for a reduction in demand, including sometimes also outdoor water use restrictions (hosepipe bans), was given also in large parts of the Rhine basin, critical regional water shortages and failures of supply remained limited mainly to rural areas where in some cases emergency supply had to be realized by trucks and even helicopters (Gerhard et al. 1983).

Because of low stream flows reduced hydropower production and impaired production of thermal and nuclear power plants were common problems for the energy sector. Further, inland navigation on the Rhine and other important transport routes was heavily impaired sometimes until into 1977 (van der Heijde, 1978; Gerhard et al. 1983; RIZA, 2005). According to RIZA (2005) 1976 belongs to the top five years of largest economic loss for the navigation sector in the Netherlands (ranked fifth after the years 1921, 1949, 1949 and 1959). Across much of Southern and Eastern England land subsidence was experienced on a scale not previously recorded leading to substantial property damage (Dornkamp et al., 1980).

Among the reported environmental impacts of the drought and heat wave in 1976 are impacts on freshwater ecosystems, i.e. the temporary deterioration of (surface) water quality (mainly eutrophication phenomena), algal blooms, extreme water temperatures, depletion of dissolved oxygen to critical levels, massive proportions of sewage effluent, saline incursions, fish kill events (sometimes related to excessive withdrawals for agricultural irrigation), drying up of stream sections with effects on aquatic species and especially migratory fish (Dornkamp et al. 19890; Gerhard et al., 1983; Rodda & Marsh, 2011). In the Dutch delta area an outbreak of avian botulism (over 60 000 cadavers counted) was attributed to the prevailing low water levels, water quality problems combined with the high temperatures during summer (Gerhard et al., 1983). The considerable fall of groundwater levels had a particular impact on oligotrophic wetland habitats in the Netherlands (van der Heijde, 1978; Sykora, 1979). Noted (detrimental) effects of the drought on sites of nature conservation interest in Britain were documented by Hearn & Gilbert (1977 in Dornkamp et al., 1980). Devastating wildfires were widespread in the summer of 1976, again Southern England (up to 40 fold number of fires than in 1974, Dornkamp et al., 1980) and regions in Northern France (three fold area burnt compared to a reference year, Brochet et al., 1977) were severely affected. Besides direct fire damage, European woodlands and forests suffered from the prolonged drought stress and increased incidence of diseases such as the Dutch elm disease, in particular increased dieback of beech and birch was observed (Courvoisier et al., 1977, van der Heijde 1977, Dornkamp et al. 1980; Gibbs & Greig, 1977).

Impact Detail Table

10 records per page Search:

Drought Event	Country	Start Date	End Date	Impact	Impact Category	Impact Description	NUTS 1
1976 summer drought, Europe	Nederland	5/1976	9/1976			If the drought of 1976 would occur at this time in the Netherlands, the economic loss/damage would be 2100 million euros, of which 31 million euros caused by salt damage.	
1976 summer drought, Europe	Deutschland	6/1976	7/1976			The oxygen content in the river Main at Kahl was 0 mg/l for weeks and at Wipfeld was the dayly average about 1 mg/l. At some barrages, a special programm was used for extra ventilation.	Bayern;
1976 summer drought, Europe	Nederland	6/1976	10/1976	1.1	Reduced productivity of annual crop cultivation: crop losses, damage to crop quality or crop failure due to dieback, premature ripening, drought-induced pest infestations or diseases etc.	Noord-Brabant and Noord-Holland were the areas with the highest moist-deficit. 10.7% was irrigated area; 56% surface water was used, 44% groundwater. Crop losses were highest in sandy areas; 40-50%. In polder areas 20-30%. Areas that were not irrigated even had 10 to 20% higher loss.	
1976 summer drought, Europe	Nederland	5/1976	10/1976	1.9	Increased costs/economic losses	Estimated is a total loss due to the drought in the agricultural sector of around 1780 million euros. The loss in a drought year is often	

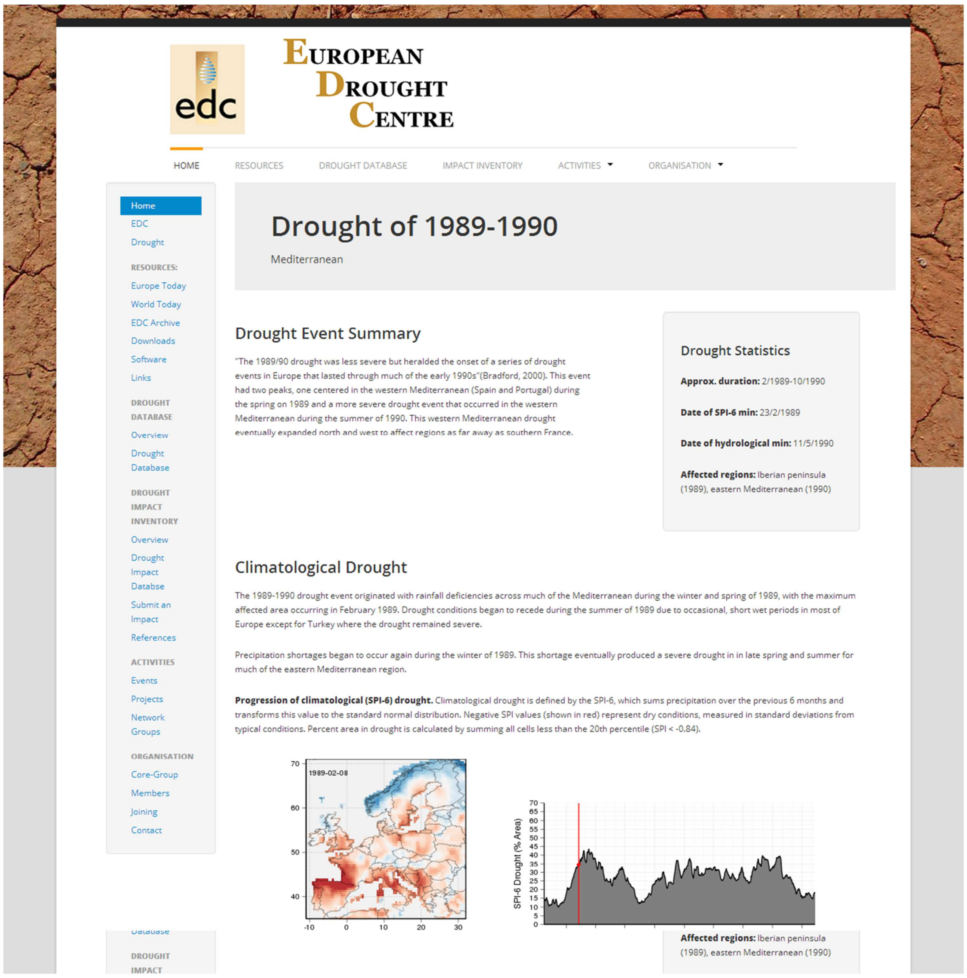
Showing 1 to 10 of 74 entries

← Previous 1 2 3 4 5 Next →

References

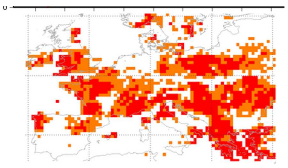
Research Publications

1989-1990 Drought Event



the winter and the hydrological drought peaked in May when it affected most of southern and central Europe.

By late summer, the drought centre had shifted back towards southeastern Europe. Drought conditions remained in the eastern Mediterranean for several months, while streamflow returned to normal in central Europe.



Peak hydrological drought. with Hydrological drought is based on output nine large-scale hydrological models. Viewed spatially (above), areas with runoff below the 10,20, and 30th percentiles are shown in red, orange and yellow, respectively.

Drought Impacts

Two consecutive years with low precipitation impacted the eastern Mediterranean most severely. In Greece, there were reductions in agricultural production as well as shortages of ground and surface water. Water reservoirs which supplied Athens reached dangerously low levels in October 1990.

Location of drought impact reports. Darker colors refer to more reported impacts in the EDII. Scroll over each country to see more detail.

Impact Detail Table

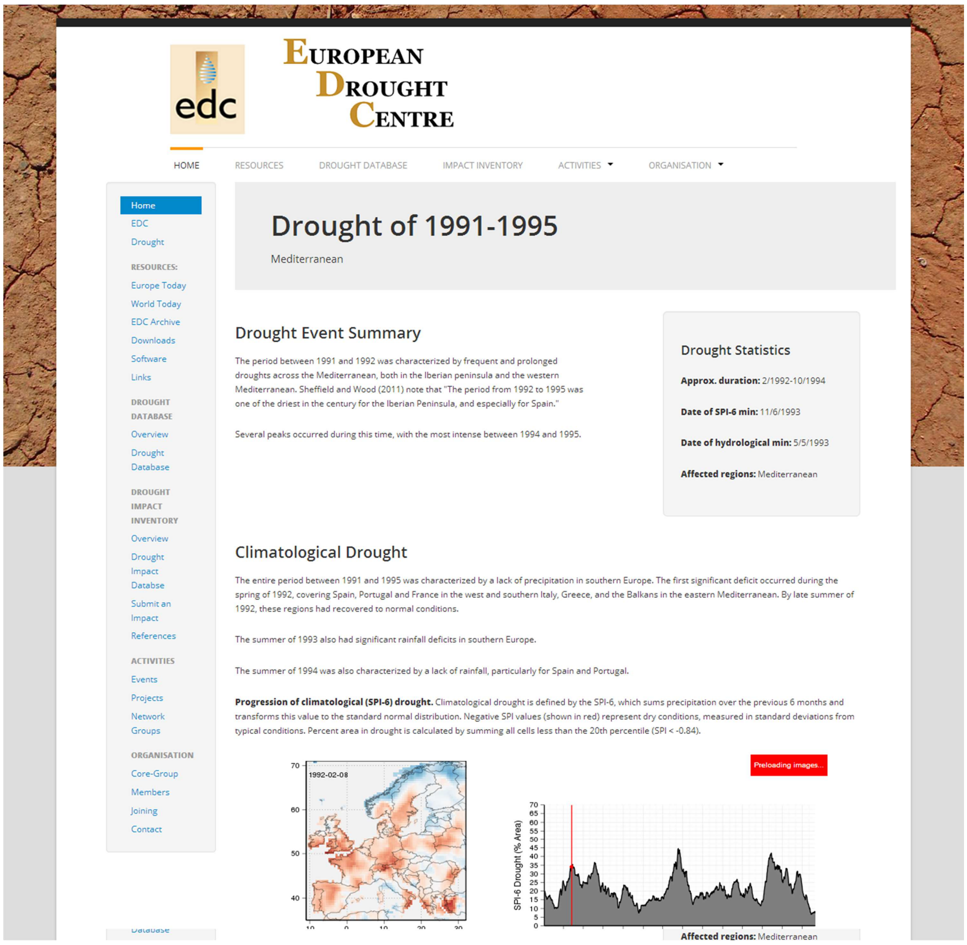
10 records per page   Search:

Drought Event	Country	Start Date	End Date	Impact	Impact Category	Impact Description
1989 Norway	Norge	1989	1989			Summer drought has been a significant stress facto for Norways ce in southeast Norway during the 14 years of forest monitoring. Dry and warm summers were followed by increases in defoliation,discolouration of foliage, cone formation and mortality. The cause hanisms are discussed. M likely, defoliation resulted from increased needlefal the autumn after dry summers.During the monitori periode 1988-2001, southeast Norway was repeate affected by summer drought, in particulary in the early 1990s.
1989, Greece	Ellada	1989	1990	1.3	Reduced productivity of permanent crop cultivation	Reduction in agricultural production and in irrigated area.
1989, Greece	Ellada	1989	1990	1.4	Reduction of cultivated areas due to a lack of irrigation water	Reduction in agricultural production and in irrigated area.
1989, Greece	Ellada	1989	1990	7.2	Regional/region-wide water supply shortage/problems (drying up of springs/wells, reservoirs, streams)	Shortage of groundwater and surface water. Water flow in Pineios river and its tributaries was significantly reduced. Water supply from lake Plasti for irrigation was reduced by 70%. The area irrigate with surface water was reduced by 90%.
1990, Greece	Ellada	1989		7.2	Regional/region-wide water supply shortage/problems (drying up of springs/wells,	Decline of water levels in the supplying reservoirs. Indicative case: On October, 1990, Athens had wate for only 56 days.

Showing 1 to 5 of 5 entries   ← Previous 1 Next →

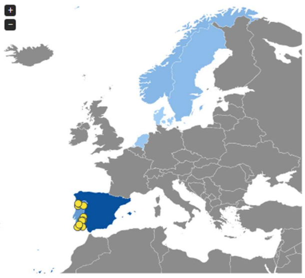
References

1991-1995 Drought Event



Drought Impacts

The severe drought episode in the early 1990s (peaking in 1995) affected nearly the whole Iberian Peninsula but had by far the largest social impact in its Southern part, i.e. in the Guadalquivir basin in Andalusia and in the Portuguese Alentejo region. Millions of domestic consumers in the South-Western corner of Spain including especially urban areas such as those of Seville, Cadiz and Palma di Mallorca suffered water cuts and water quality problems. In autumn of 1995, just before the abrupt end of the drought event, 15% of the Spanish population was experiencing water shortages and another 15% was facing reduced water supply (Garrido & G�mez-Ramos, 2000; Llamas, 2000; Mestre, 2010). Also most municipalities located in the Alentejo region of Portugal experienced reduced water supply and interruptions for more than 12 hours a day (Santos, 1998 in Massarutto et al., 2013). Overall the water shortage situation led to conflicts. In particular water transfers and general management issues in the transboundary basin of the Tagus river initiated renewed �water hostilities� between several Spanish Autonomous Communities, but were also again the cause of political tension between Spain and Portugal (Llamas, 2000; see also L�pez-Moreno et al., 2009). In 2000 a new bilateral agreement (termed Albufeira Convention) regulating the management of waters shared by both Iberian countries came into force.



Location of drought impact reports. Darker colors refer to more reported impacts in the EDII. Scroll over each country to see more detail.

A large part of economic losses due to the drought is attributable to agricultural damage which affected both, rain-fed and irrigated farming, but losses were far more remarkable in the latter one and especially dramatic in the case of the Guadalquivir basin (Garrido & G�mez-Ramos, 2000; Iglesias et al., 2003): here, where normally irrigation had counted for 75% of gross regional water use, about 500 000 ha of irrigated land were affected by water shortages, in fact virtually no water was available for irrigation allotments during the growing seasons of 1994 and 1995. This resulted in total economic losses over 3 billion Euros according to farmers� representatives. Further 20,000 jobs were lost in agriculture due to the fallowing of the irrigated area (EMASESA, 1997 in Iglesias, 2003). Generally, across Spain strong restrictions had to be placed on irrigation during the drought period resulting in significant decreases in the total national production of corn, cotton and rice and from 1994 onwards permanent crops, i.e. vineyards, olives and citrus fruits were increasingly affected as well (Mestre, 2010). Within Portugal horticulture throughout the Algarve region was particularly hit (Massarutto et al., 2013). In both countries hydropower production was notably reduced during the drought. According to EC (2007) Spain estimated the incurred costs in the agriculture and the energy production sector at about 1,800 and 210 million, respectively (period 1990-95), while Portugal reported costs of 241 million Euros in agriculture and costs of 426 million Euros for energy production. According to EurAqua (2004) the minimum economic costs of the drought in Spain were 3,700 million Euros. The international disaster database EM-DAT registered the drought disaster in Spain with an estimated damage of 4,500 billion US Dollars.

The situation in 1992 had forced the Spanish Authorities to adopt a set of emergency measures which aimed at reducing water consumption and exploitation of new water resources by providing extraordinary credits as well as (simultaneously) mitigating the drought effects on the agricultural sector (Mestre, 2010); according to Llamas (2000) the total cost of these various emergency measures to the Spanish treasury amounted to about 600 million Euros. Structural measures, which were financially promoted and contracts awarded following urgent procedure during the drought, included desalination plants, well drillings and water carriers. However, apparently hardly any of these projects began to supply water before the end of the drought (Garrido & G�mez-Ramos, 2000). In consequence of the severe restrictions in the supply of Seville a plan for building a new dam had emerged which became an extremely controversial issue once the drought finished (Garrido & G�mez-Ramos, 2000). Also the National Water Authority of Portugal had decided to construct a new reservoir in the Alentejo region (completed in 1999).

Regarding the impact the drought had on ecosystems and habitats there is little quantitative documentation (through detailed surveys etc.) available, yet increased mortality was observed for fish in dam reservoirs and birds in the interior wetlands. The water shortage situation especially in agricultural production led to strongly increased exploitation of groundwater resources, thus overexploitation resulted in saltwater intrusion in coastal aquifers in the South East and adverse effects on wetlands in the Centre of Spain (Mestre, 2010). Besides a significant increase of forest fires, the prolonged drought damaged the forested areas in Southern and Central Spain (Pe�uelas et al., 2001; Mestre, 2010; Carnicer et al., 2011).

Impact Detail Table

10 records per page Search:

Drought Event	Country	Start Date	End Date	Impact	Impact Category	Impact Description	NUTS 1	NUTS 2
1992 drought, Scandinavia	Danmark	5/1992	7/1992			Late spring and first half of summer of 1992 Denmark experienced its longest drought episode since nationwide measurements began in 1874. Combined with incredible sunny weather and relatively strong dry winds must this drought described as the longest and the worst ever.	Danmark	
1992 drought, Scandinavia	Sverige	5/1992	7/1992	1.1	Reduced productivity of annual crop cultivation: crop losses, damage to crop quality or crop failure due to dieback, premature ripening, drought-induced pest infestations or diseases etc.	Perhaps the most difficult case of early summer drought in Sweden over the last 100 years in 1992. In parts of Götaland was no or insignificant with rain during the time May 13 to July 11. Ungskär in southeastern Blekinge received no measurable rainfall at all during this 60-day period. The vegetation was inhibited strongly and parts of Götaland received only normal harvest of spring-sown crops. Many smaller streams in the southeastern parts of the country dried out. In the severe drought had several major forest fires. Although the drought was alleviated somewhat in mid-July rainfall in south-eastern Götaland far too small for it to be any significant	Sverige	

Showing 1 to 10 of 64 entries

← Previous 1 2 3 4 5 Next →

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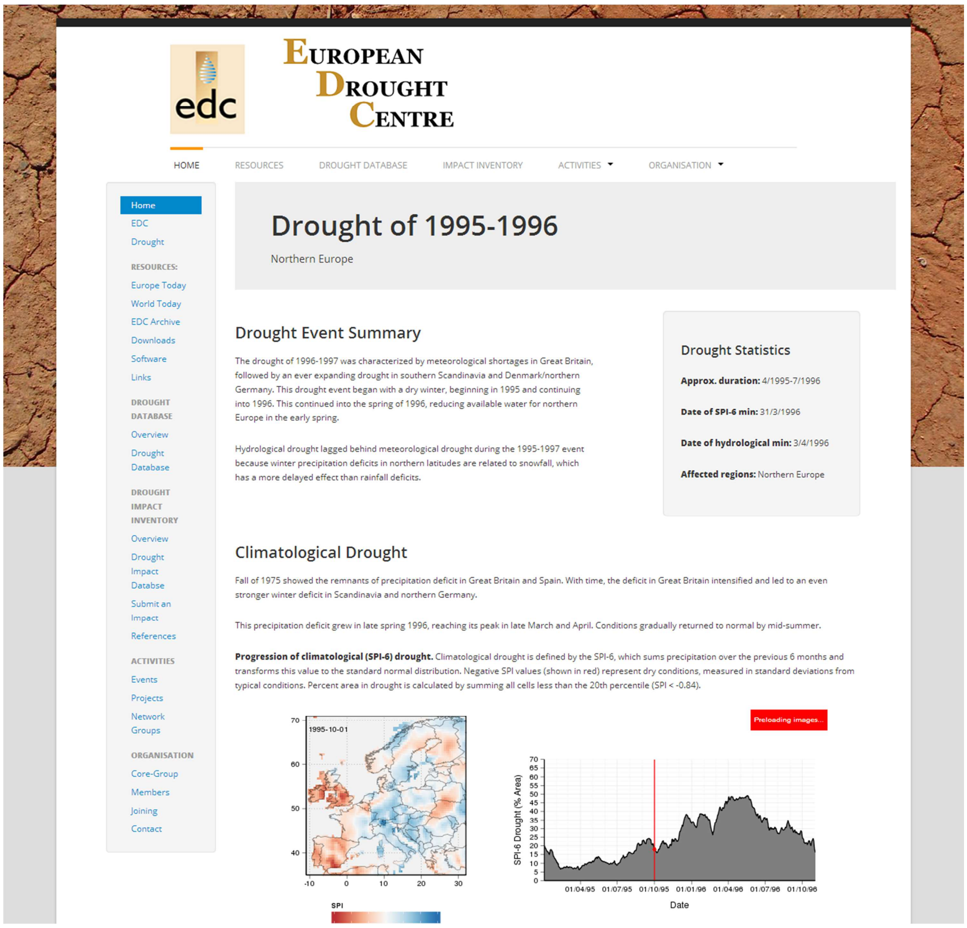
1995-1996 Drought Event



Later in 1996 and 1997 drought impacts were reported concerning hydropower production, navigation, decreased grassland yields for livestock farmers and forest and heath fires for Netherlands, Belgium and the Scandinavian countries. Historically low groundwater levels were recorded across the Netherlands threatening 200 plant species according to a newspaper article in April. Analysis of tree ring width samples of oak from Central Germany identified the summer (growing season) of 1996 (with 1934 and 1959) among the driest in the period AD 996-2005 (B�ntgen et al., 2010). The effect of 1996 and other dry seasons in the 1990s is also visible in forest monitoring data for spruce forests in Norway (Solberg, 2004).

Location of drought impact reports. Darker colors refer to more reported impacts in the EDII. Scroll over each country to see more detail.

Impact Detail Table

10 records per page

Search:

Drought Event	Country	Start Date	End Date	Impact	Impact Category	Impact Description
1996 drought scandinavia	Sverige	1/1996	10/1996			Inflow to the hydropower system in the Nordic countries was overall 7.8% lower than normal in 2002. By comparison, the total inflow in the Nordic countries were 21.3% lower than normal in 1996. What makes 2002 a special year, was extremely low inflow in the second half, and that the inflow was a record low in all the Nordic countries simultaneousl In weeks 31-52, total inflow to the Nordic countries only 50% of the average for the past 20 years. Historically, there has been a positive correlation in the inflow, but an extreme year in one country has nevertheless often been partially offset by less extreme inflow in the other. Based on the profile of the historical material (including 2002), we estimate probability of getting as low as or lower inflows in th weeks 31-52 for Norway isolated to 1.0%. The probability of getting as low or lower inflow in the same period in the Nordic countries, we estimate to be less than 0.5%.
1996 drought scandinavia	Norge	1/1996	10/1996			Inflow to the hydropower system in the Nordic countries was overall 7.8% lower than normal in 2002. By comparison, the total inflow in the Nordic countries were 21.3% lower than normal in 1996. What makes 2002 a special year, was extremely low inflow in the second half, and that the inflow was a record low in all the Nordic countries simultaneousl In weeks 31-52, total inflow to the Nordic countries only 50% of the average for the past 20 years. Historically, there has been a positive correlation in the inflow, but an extreme year in one country has nevertheless often been partially offset by less extreme inflow in the other. Based on the profile of the historical material (including 2002), we estimate

Showing 1 to 10 of 33 entries

← Previous 1 2 3 4 Next →

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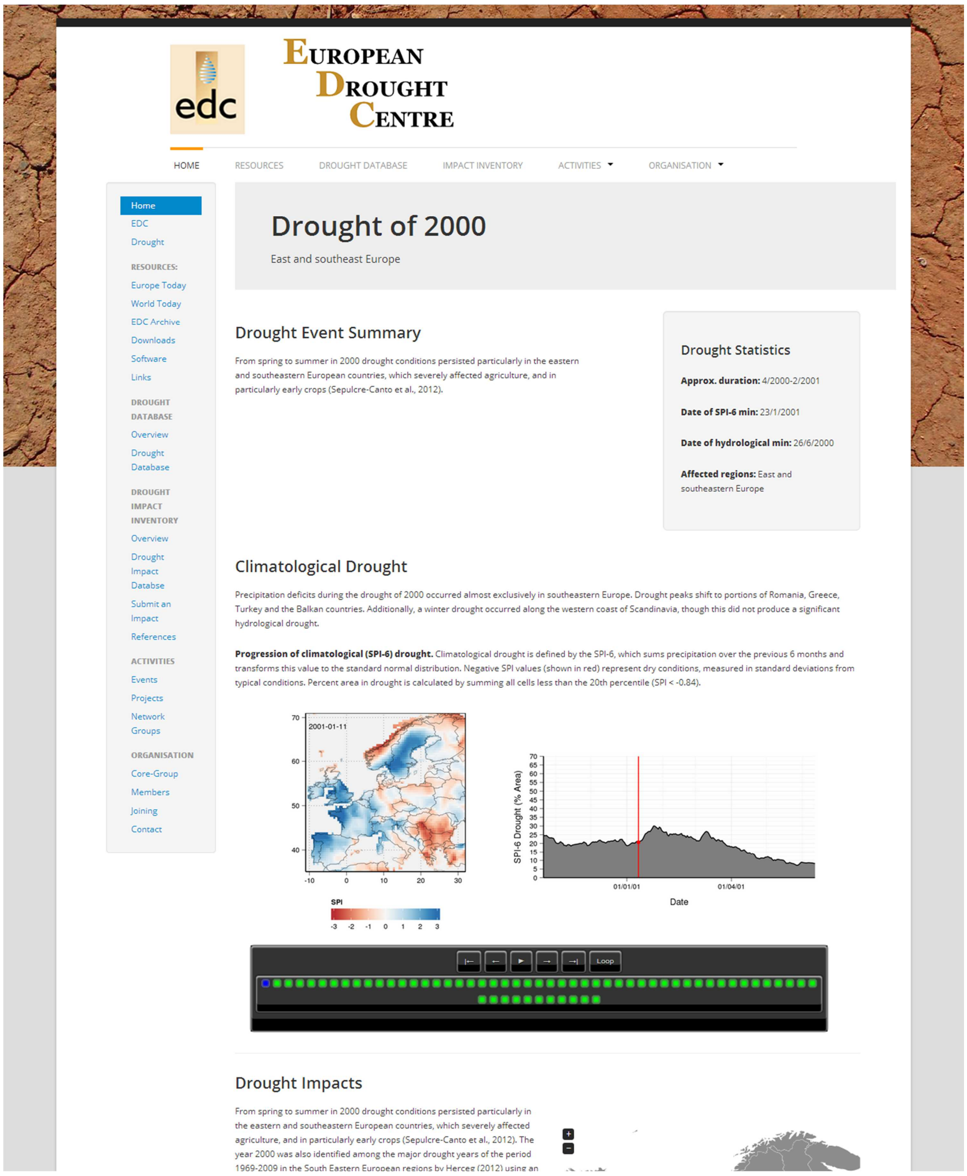
2000 Drought Event



Drought Impacts

From spring to summer in 2000 drought conditions persisted particularly in the eastern and southeastern European countries, which severely affected agriculture, and in particularly early crops (Sepulcre-Canto et al., 2012). The year 2000 was also identified among the major drought years of the period 1969-2009 in the South Eastern European regions by Herceg (2012) using an adapted Palfai-Index (Hungarian agricultural drought index). Romania was most affected according to Glinni et al. (2001 in Sepulcre-Canto et al., 2012).

Drought disasters were registered by EM-DAT in Romania, Moldova and in Bosnia-Hercegovnia. Other regions affected include Bulgaria, Czech Republic, Eastern Germany, Greece, Hungary, Poland, Romania, Turkey, Slovenia and the Western Balkans (Demuth, 2009, AUA, 2011). A large area was affected by forest fires in Bulgaria. Natural disaster was declared in many regions of Croatia reporting problems to fresh water fishery, hydropower production and tourism as well as dried up streams and wells (AUA, 2011). However more detailed information particularly on non-agricultural drought impacts is needed.

Location of drought impact reports. Darker colors refer to more reported impacts in the EDII. Scroll over each country to see more detail.

Impact Detail Table

10 records per page Search:

Drought Event	Country	Start Date	End Date	Impact	Impact Category	Impact Description	NUTS 1	NUTS 2
1999-2002 Greece	Ellada	2000		1.1	Reduced productivity of annual crop cultivation: crop losses, damage to crop quality or crop failure due to dieback, premature ripening, drought-induced pest infestations or diseases etc.	Reduction in crop productivity of grains	Voreia Ellada;	Kentriki Makedonia;
2000 drought, Germany	Deutschland	2000		1.1	Reduced productivity of annual crop cultivation: crop losses, damage to crop quality or crop failure due to dieback, premature ripening, drought-induced pest infestations or diseases etc.	An extreme drought in 2000 leads especially in eastern, Germany and East-Lower Saxony to crop damage. The most affected crops were com and potatoes. The economic loss was about 326 mio. € and affected 1 mio. ha land.		
2000 drought, Germany	Deutschland	2000		1.1	Reduced productivity of annual crop cultivation: crop losses, damage to crop quality or	, losses by drought for crops, corn and potatoes	Brandenburg; Mecklenburg-Vorpommern; Niedersachsen; Sachsen;	

Showing 1 to 9 of 9 entries ← Previous 1 Next →

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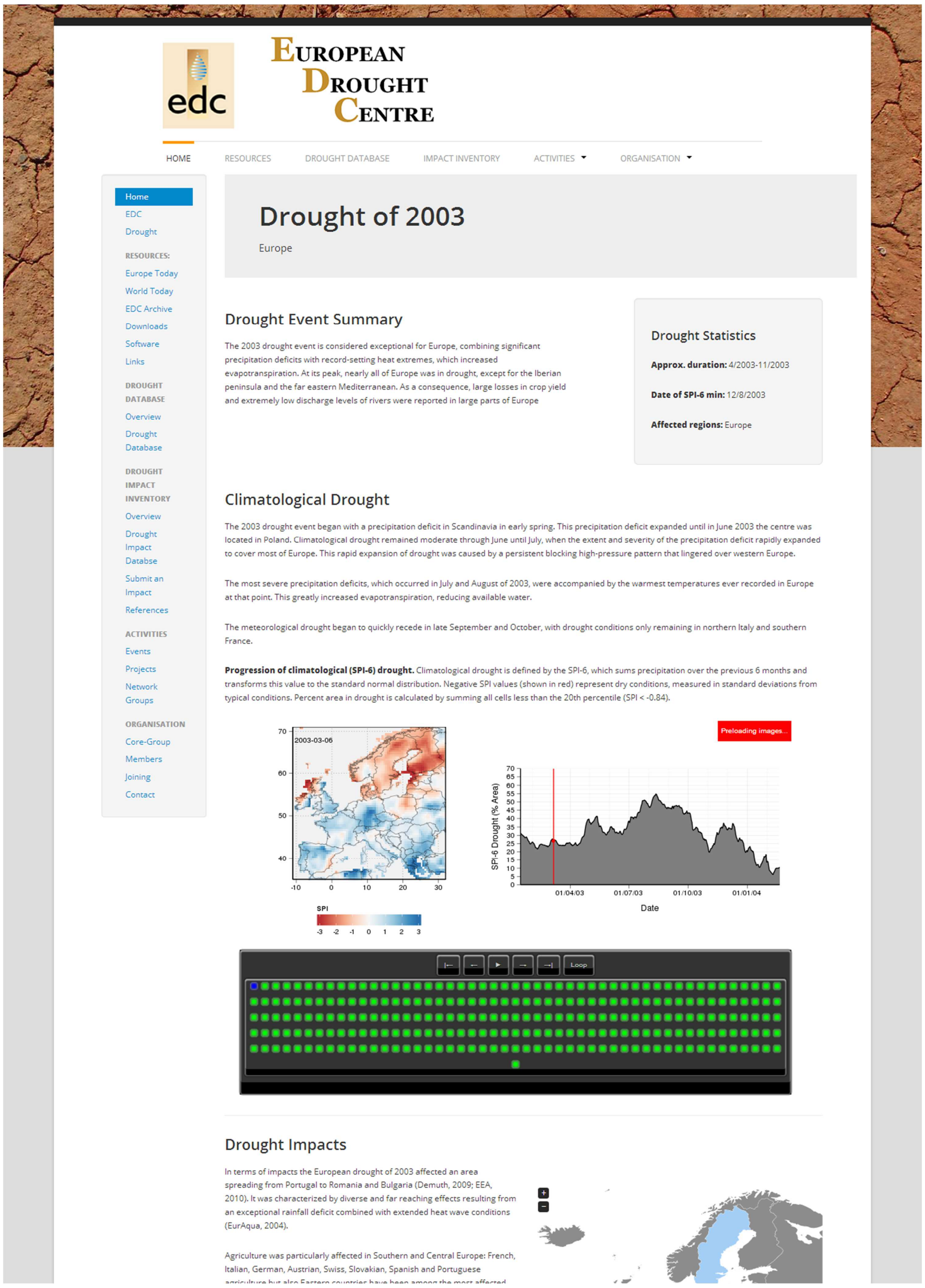
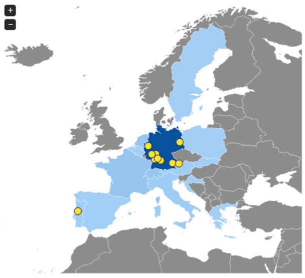
2003 Drought Event



Drought Impacts

In terms of impacts the European drought of 2003 affected an area spreading from Portugal to Romania and Bulgaria (Demuth, 2009; EEA, 2010). It was characterized by diverse and far reaching effects resulting from an exceptional rainfall deficit combined with extended heat wave conditions (EurAqua, 2004).

Agriculture was particularly affected in Southern and Central Europe: French, Italian, German, Austrian, Swiss, Slovakian, Spanish and Portuguese agriculture but also Eastern countries have been among the most affected by the drought and the heat wave in 2003 (COPA-COGECA, 2004; Swiss Re, 2004). In many countries of the South-Eastern European region, like Hungary, Slovenia, Croatia, Serbia and Montenegro 2003 was among the major agricultural droughts in recent years (AUA, 2011). The International Disaster Database EM-DAT registered drought disasters in 2003 in Bosnia-Herzegovina, Croatia and Hungary. Significant decreases in yields compared to previous years were common, however with big variations per region. According to COPA-COGECA (2004), European livestock farmers were worst hit due to the big impact on green fodder supply. Agricultural losses were estimated to amount to more than 10 billion Euros (COPA-COGECA, 2004, Swiss Re, 2004). Governmental measures to mitigate the effects for the farmers were taken in several countries and also by the European Commission.



Location of drought impact reports. Darker colors refer to more reported impacts in the EDII. Scroll over each country to see more detail.

Local limitations and serious shortage problems in public water supply were reported for some rural mountainous areas in Italy, Austria, Switzerland, France and Germany. A few communities and single farms, which had depended exclusively on the use of local spring waters (or traditional private wells), had to be supplied by emergency actions. However, immense demands during the hot summer period, restrictions on water use and abstraction and a strong overall depletion of resources, i.e. dried up springs and boreholes, extremely low groundwater levels and reservoir stocks, were common across Europe. In Eastern Austria authorities initiated the construction of additional (large scale) water supply networks (EurAqua, 2004, see also Bogner, 2004).

At most rivers extreme low flows and, during the heat wave, also extremely high water temperatures were recorded. Thus, the energy sector was challenged by a reduced potential of hydropower production, widespread problems with cooling of nuclear and thermal power plants as well as unusually high demands. Thermal and nuclear power plants throughout Europe had to operate at reduced capacities or even shut down due to the high river water temperatures. In August emergency exemptions from environmental legislation were granted for several power plants in France, the Netherlands and Germany in order to ensure security of supply (avoid disruptions). The situations of power supply in Italy (Cassardo et al. 2007; IReR, 2007) and France (e.g., EC, 2007; UNEP, 2004; Poumad�re et al. 2005) were probably the most stressed ones. A series of vulnerabilities was revealed when the national French supplier EDF during the heat wave episode requested temporary exemptions for one third of its nuclear park (Poumad�re et al. 2005). Already at the beginning of June there were some unexpected (sometimes long-lasting) blackouts in Italy, due to the increase of electric energy demand above the threshold of productivity, which caused several inconveniences and knock-on losses in industrial activities, e.g. steel production (Cassardo et al., 2007; IReR, 2007).

For months inland navigation was heavily impaired by extreme low flows and water levels of most large rivers in 2003. That affected rivers like the Po, the Elbe or the Oder, where navigation sometimes even ceased completely, but in particular the major European transport routes in the Danube and Rhine basins (EurAqua, 2004; EC/CCR, 2005; Jonkeren et al., 2007; ICPDR; AUA, 2011; Massarutto et al., 2013).

In France, the Netherlands and in Southern England structural damage due to soil shrinkage and subsidence caused considerable costs (EurAqua, 2004; Marsh et al., 2004; Corti et al., 2009). Specifically the collapse of two peat dikes confronted the Netherlands with a new drought phenomenon which raised safety concerns (Ministerie van Verkeer en Waterstaat, 2004; Massarutto et al., 2013).

Freshwater ecosystems were put under exceptional stress, with increased risk to biodiversity loss during 2003 (EurAqua, 2004). Reports on dried up stream sections, extreme water temperatures, violation of minimum flow requirements, temporary water quality deterioration and eutrophication, limited to critical dissolved oxygen concentrations, increased pollution loads, increased mortality and mass kill of fish were widespread (e.g., Massarutto et al., 2013; ICPR, 2004; Lange, 2009; Marsh et al., 2004; BUWAL et al., 2004; EC, 2007). Also several hundreds of death diving ducks in the Netherlands (RIZA et al., 2005) and mass kill of invasive mussel species in German rivers (ICPR, 2004; LfU, 2004) were among the spectacular events attributed to the drought in 2003. In many regions of Switzerland as well as in parts of Southern Germany the authorities released bans on water abstraction from small streams for irrigation purposes during the low flow period in 2003 which sometimes led to conflicts with farmers as well as illegal abstractions (Massarutto et al., 2013; BUWAL et al., 2004; LfU, 2004; LfW, 2004).

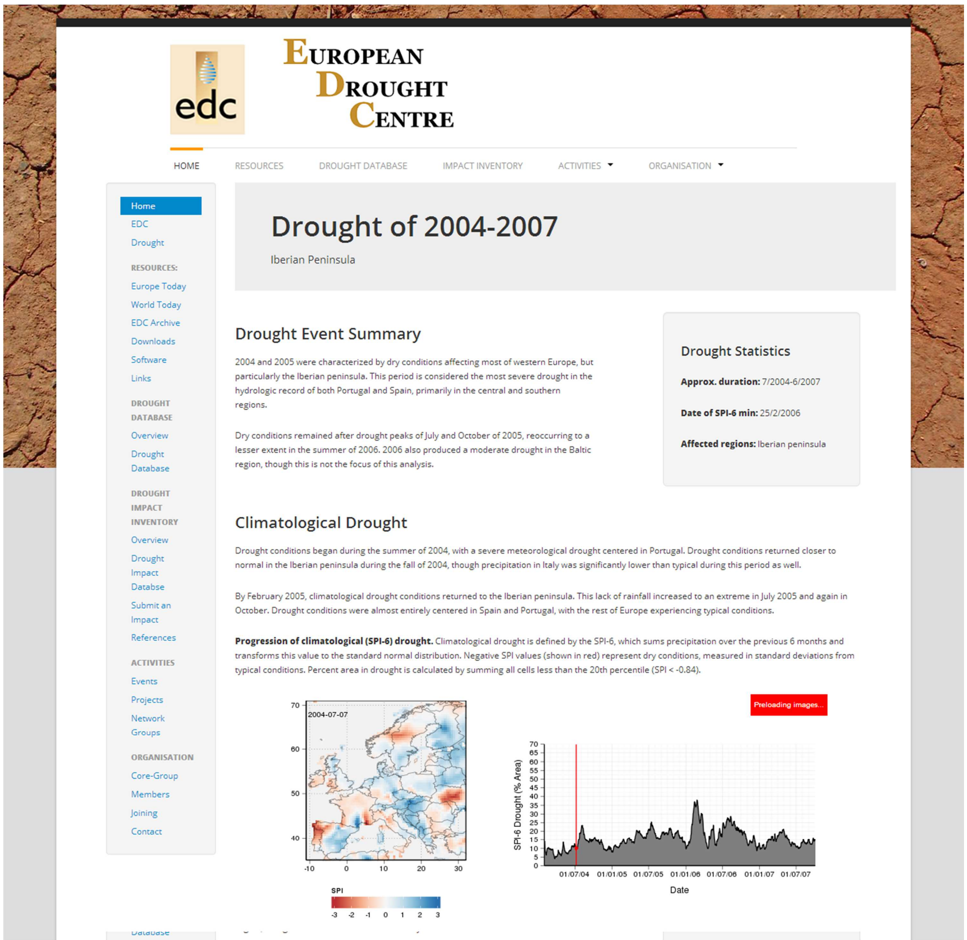
Drought stress to forest ecosystems in 2003 is considered to be a major explanation for the increased defoliation of broadleaved species observed in 2004 especially in Central Europe and particularly pronounced for common beech (UNECE, 2005). Increased dieback and susceptibility to pest infestations were also frequently reported (Rouault et al., 2006). In Southern Europe the summer of 2003 was one of the most severe forest fire seasons experienced during the last decades with the greatest severity mostly concentrated in Portugal and France (EC, 2004). In total the exceptionally dry and warm conditions resulted in over 25,000 reported heath and forest fires from Portugal to Ireland and Finland (EurAqua, 2004).

Impact Detail Table

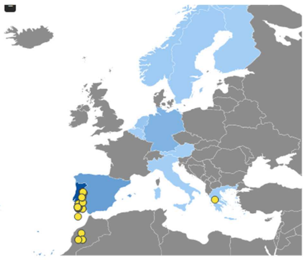
10 records per page Search:

Drought Event	Country	Start Date	End Date	Impact	Impact Category	Impact Description	NUTS 1
2003 summer drought, Europe	Deutschland	7/2003	2003			Critical oxygen conditions (deceeding 4 mg/l) occured in the Saar, which is a river characterized by a general quite high organic pollution. Instable oxygen conditions are a regular problem in the Saar and a concept for mitigation measures had already been established before the year 2003. However, while there seemed to be a declining trend of both the occurrence of critical situations and the volume of mitigation efforts in the preceeding years, the situation worsened again in 2003. At Mettlach the oxygen concentration was repeatedly close to and upstream of the weir deceeded the fish critical concentration (4 mg/l). The absolute minimum was 1.7 mg/l.	Rheinland-Pfalz
2003 summer drought, Europe	France	8/2003				Special stream ecological monitoring in the context of the emergency excemption for the power plant La Maxe from environmental legislation	Est

2004-2007 Drought Event



Yet, for Portugal and Spain this drought episode, evolving from the winter of 2004/2005 onwards, is considered to be one of the worst events in recent times that caused major socioeconomic impacts particularly regarding hydropower and crop production (Garc�a-Herrera et al., 2007; Massarutto et al., 2013; EC, 2006; EC, 2007). In 2005 Portugal declared a calamity status at national level and a temporary "Drought Commission" (Comiss�o para a seca) was established on governmental initiative (Massarutto et al., 2013). According to EM-DAT the drought disaster from 2004-2005 in Portugal had an estimated economic cost of more than 1.3 billion US-Dollars.



Location of drought impact reports. Darker colors refer to more reported impacts in the EDII. Scroll over each country to see more detail.

Due to the exceptional dry conditions in the hydrological year 2004-05 agriculture suffered from extreme yield losses and even complete failure for virtually all kind of crops, but especially in rain-fed farming (Comiss�o para a seca, 2005; USDA-Foreign Agricultural Service, 2005, Garc�a-Herrera et al., 2007; Gouveia et al., 2009). Cereal production (of both Iberian countries) dropped to only 60% of average (Garc�a-Herrera et al., 2007) and, in particular there was a severe shortage of wheat (Gouveia et al., 2009). In Portugal vegetation in the South was most affected by drought stress in 2005 � in a region, which due to its semi-arid characteristics is generally dominated by rainfed agriculture, and with the Alentejo region alone being responsible for more than 80% of the total of wheat production in Portugal (Gouveia et al., 2009). Extremely poor pasture conditions, premature cutting and problems with availability of water in the field threatened livestock farmers. This was also evident in an increased number of abortions of ruminants in Portugal in 2005 (Comiss�o para a seca, 2005). The costs incurred due to drought impacts in the agricultural sector in 2004-2005 in Portugal and Spain were quantified to 0.5 billion and 2-3 billion Euros, respectively in EC (2007). In both countries rather strict restrictions of irrigation water use became effective in many regions during the growing season in 2005 and also in following years. In many areas the (irrigated) cultivation area was considerably reduced. On the other hand, the prolonged drought episode apparently increased incentives for drilling (illegal) boreholes to access ground water for irrigation in Spain (WWF, 2008).

Due to low stream flows throughout the Iberian Peninsula many of the (multi-functional) surface water reservoirs had been heavily depleted at the end of the summer in 2005; this fact increased tension in water management and led to large political and social unrest (Garc�a-Herrera et al., 2007). The low water availability was also a major problem for terrestrial and aerial firefighting when Portugal faced again devastating wildfires: regardless of efforts, the summer of 2005 was the second worst (after 2003) in recorded wildfire history with 325,000 ha burned (Massarutto et al., 2013). In terms of water resources, Algarve was at that time the most affected region in Portugal, with two important dams below usable capacity levels as well as significant saline intrusion in its most important aquifer (EC, 2006; Comiss�o para a seca, 2005). In late August about 100,000 people in municipalities across Portugal were affected by limitations in water supply (Comiss�o para a seca, 2005; EC, 2006). There was a suspect that a remarkable number of Hepatitis A and Salmonellosis cases had been related to the use of alternative (emergency) water supply systems (Comiss�o para a seca, 2005). Portugal spent in total 23 million Euros on drought mitigation measures regarding only water supply (EC, 2007). Also 118 small villages in the Pyrenees suffered strong water restrictions during the summer of 2005 and supply by cistern trucks was necessary for 60 villages (Ministerio de Medio Ambiente, Medio Rural y Marino, 2008) as well as for several cities within the Douro basin in Central Spain (Confederaci�n Hidrogr�fica del Duero, 2007).

The extremely low river flows between December 2004 and June 2005 directly affected Iberian hydropower production which in 2005 decreased to only 40% of the average and both countries were forced to massive imports of fossil fuel resources to compensate this by thermoelectric production (Garc�a-Herrera et al., 2007). Portugal had to use additional fossil fuel worth 182 million Euros with another expense of about 28 million Euros for annual CO2 emissions licenses in 2005 (EEA, 2010). Due to drought impacts in the Energy sector in 2004-2005 Portugal and Spain incurred costs of 261 and 713 million Euros, respectively (in EC, 2007).

Reported impacts on ecosystems in Portugal include deterioration of water quality, increased algal bloom and eutrophication of surface waters, and increased salinity of groundwater including significant saltwater intrusion in the Algarve region (Massarutto et al., 2013). In some streams, fish populations were severely depleted due to extreme low flow conditions prevailing in the severe drought year of 2005 (Comiss�o para a seca, 2005). In particular, increased mortality and likely local extinction of an endangered and endemic freshwater fish species from Guadiana river basin was observed (Cardoso & Carrapato, 2007 in Massarutto et al., 2013). Fish kill was also observed in Spain (Ministerio de Medio Ambiente, Medio Rural y Marino, 2008). It seems that the reduced freshwater flows also had effects on estuarine fish species (Dolbeth et al 2008, Martinho et al 2007). Further, there are some indications of adverse effects on grassland and wetland bird species (Massarutto et al., 2013). Carnicer et al. (2011) studied increasing defoliation and tree mortality trends observed for Southern Iberian forests over the last two decades in relation to the two severe drought episodes (1990-1995 and 2005-06).

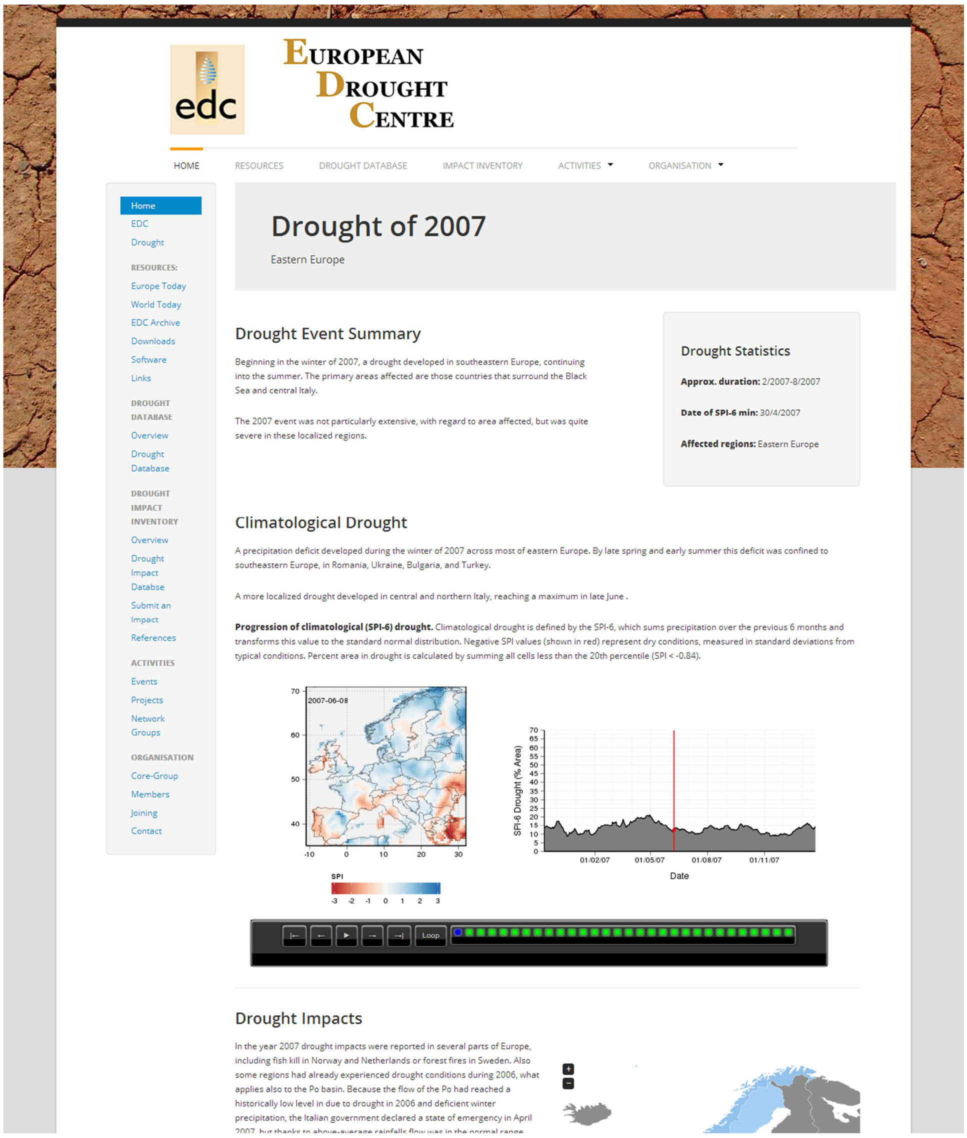
Corresponding to the clear peak of the climatological drought in the summer of 2005 , the great majority of recorded impact reports in the inventory refers specifically to 2005. However, a few notable incidents in the following years were reported. Those concern mostly water management issues and drought impacts on freshwater ecosystems in different regions of Spain (see Ministerio de Medio Ambiente, Medio Rural y Marino, 2007), like e.g. fish kill and hosepipe bans, but also local cuts in domestic supply. Due to the sustained drought conditions the important Entrepe�as�Buend�a reservoir system in the Tagus basin (constructed for hyperannual management) was neither in 2005 nor in 2006 able to satisfy demand, thus managers were obligated to reduce flow to both the Tagus River and the depended water transfer system to the J�car and Segura basins; this, like in previous droughts, resulted in conflicts and political ramifications at the national level (Lorenzo-Lacruz et al., 2010). Finally, just before rains in spring 2008 brought significant relief for most of the country, Barcelona had taken the unprecedented step of importing a tanker of emergency water from Marseilles (WWF, 2008; Demuth, 2009; EEA, 2010). In addition, this emergency situation prompted the construction of a new water transfer scheme from the Ebro river to Barcelona (WWF, 2008).

Impact Detail Table

10 records per page   Search:

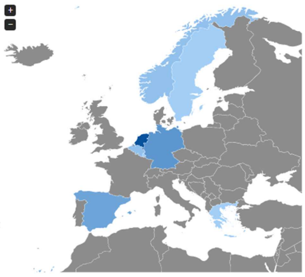
Drought Event	Country	Start Date	End Date	Impact	Impact Category	Impact Description	NU1
2004 -2007 Iberian Peninsula	España	1/2005	10/2005			Increased of 20% of the number of forestfires compare to the average of last decada((8.571 out of 7.156). Forestry area burned affected 161.155 ha, 43% more than the average of the previous decada (112.680 ha burned)	
2004 -2007 Iberian Peninsula	España	10/2005				In the river Corbones 500 kg of dead fish were found in october 2005	S
2004 -2007 Iberian Peninsula	España	10/2005				In the river Guadalete more than 1000 dead fish were found in october 2005	S

2007 Drought Event



Drought Impacts

In the year 2007 drought impacts were reported in several parts of Europe, including fish kill in Norway and Netherlands or forest fires in Sweden. Also some regions had already experienced drought conditions during 2006, what applies also to the Po basin. Because the flow of the Po had reached a historically low level in due to drought in 2006 and deficient winter precipitation, the Italian government declared a state of emergency in April 2007, but thanks to above-average rainfalls flow was in the normal range again in June (R&SPI Po basin Case study flyer; Sepulcre-Canto et al., 2012). However, like with the 2000 event, the South-Eastern European region seems particularly hit by the drought in 2007 with estimated economic costs of at least 1.5 billion Euros (Demuth, 2009). The year 2007 was also identified as one of the major drought years in the period 1969-2009 in the South Eastern European regions by Herceg (2012) using an adapted Palfai-Index (Hungarian agricultural drought index). A drought disaster was declared particularly for Moldova by EM-DAT. Specific non-agricultural drought impacts reported: Hydropower production of the Fierza plant, being the second largest hydropower plant in Albania, was only 33% of average production and in Croatia inland navigation ceased completely (AUA, 2011).



Location of drought impact reports. Darker colors refer to more reported impacts in the EDII. Scroll over each country to see more detail.

Impact Detail Table

10 records per page Search:

Drought Event	Country	Start Date	End Date	Impact	Impact Category	Impact Description	NUTS 1
2004 -2007 Iberian Peninsula	España	1/2007	2007			Consortium supply system to Bilbao-Vizcaya, that supplies water to 90% of Vizcaya inhabitants, were below 40% of its capacity so some restriction in use were registered	Nores
2006 summer drought, northern Europe	Nederland	7/2007	8/2007	1.1	Reduced productivity of annual crop cultivation: crop losses, damage to crop quality or crop failure due to dieback, premature ripening, drought-induced pest infestations or diseases etc.	The potato yield in Sout-East Drenthe is damaged by the drought. At least 25% of the yield is lost, but this might become more if the drought continues. Potatoes are very sensitive for heat.	Noord Neder
2007 drought, Europe	Deutschland	4/2007		1.1	Reduced productivity of annual crop cultivation: crop losses, damage to crop quality or crop failure due to dieback, premature ripening, drought-induced pest infestations or diseases etc.	An extreme drought in april 2007 leads especially in northwestern and northeastern Germany to damage at crops and oil-bearing seed. One reason was the low amount of Precipitation (4 mm/m^2 average of Germany). The economic loss was about 450 mio. € and affected 1.3 mio ha land.	
2007 drought, Europe	Nederland	5/2007	5/2007	1.1	Reduced productivity of annual crop cultivation: crop losses, damage to crop quality or crop failure due to dieback, premature ripening, drought-induced pest infestations or	Some fields have to be sown again because the seeds did not survive teh drought. Especially the onions are sensitive for drought, also the wheat remains small this year.	Oost-N

Showing 1 to 10 of 26 entries ← Previous 1 2 3 Next →

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