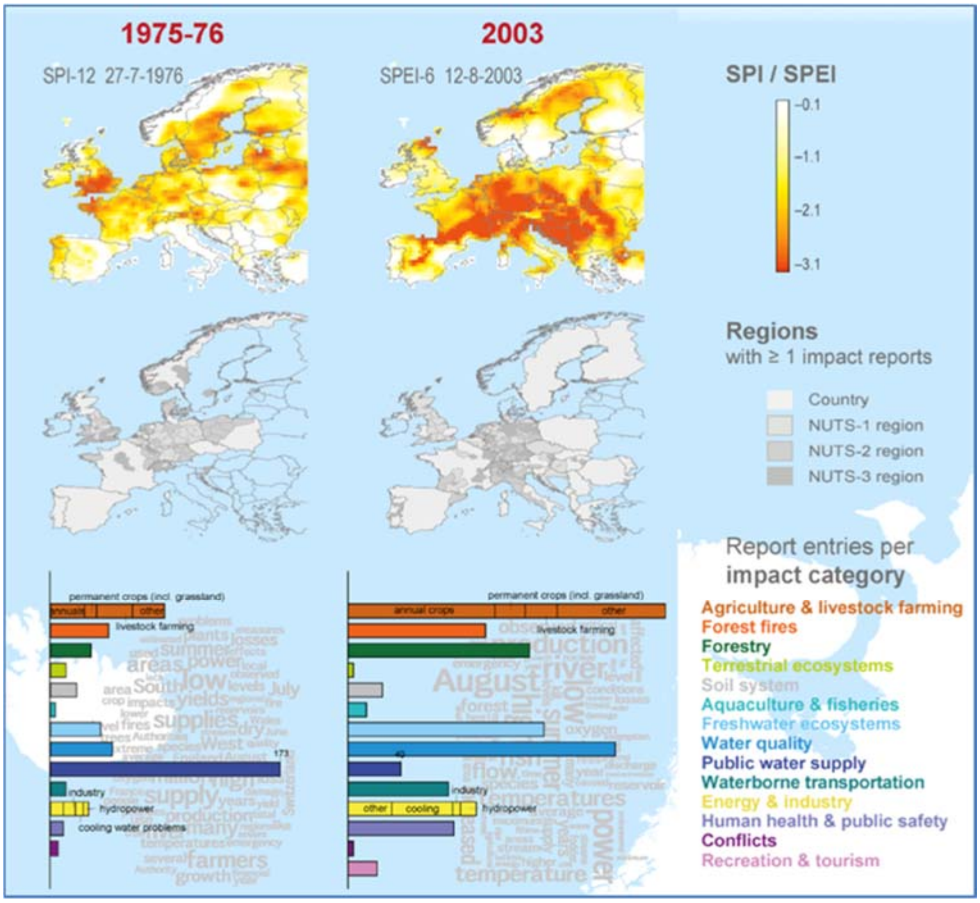
Technical Report No. 28

RECOMMENDATIONS FOR INDICATORS FOR MONITORING AND EARLY-WARNING CONSIDERING DIFFERENT SENSITIVITIES: PAN-EUROPEAN SCALE



Author names: Kerstin Stahl, James H. Stagge, Sophie Bachmair, Veit Blauhut, Francisco. C. Rego, Lucia De Stefano, Susana Dias, Lukas Gudmundsson, Larissa Gunst, Irene Kohn, Henny A.J. Van Lanen, Julia Urquijo Reguera, Lena M. Tallaksen

Date: 30 March 2015

DROUGHT-R&SPI (Fostering European Drought Research and Science-Policy Interfacing) is a Collaborative Project funded by the European Commission under the FP7 Cooperation Work Programme 2011, Theme 6: Environment (including Climate Change, ENV.2011.1.3.2-2: Vulnerability and increased drought risk in Europe (Grant agreement no: 282769). The DROUGHT-R&SPI project started 01/10/2011 and will continue for 3 years.

Title:	Recommendations for indicators for monitoring and early-warning considering different sensitivities: pan-European scale
Authors:	Kerstin Stahl, James H. Stagge, Sophie Bachmair, Veit Blauhut, Francisco. C. Rego, Lucia De Stefano, Susana Dias, Lukas Gudmundsson, Larissa Gunst, Irene Kohn, Henny A.J. Van Lanen, Julia Urquijo Reguera, Lena M. Tallaksen
Organisations:	- Albert-Ludwigs-Universität Freiburg, Germany (ALU-FR) - Universitetet i Oslo, Norway (UiO) - Instituto Superior de Agronomia, Portugal (ISA-CEABN) - University Complutense of Madrid, Spain (UCM) - Eidgenössische Technische Hochschule Zürich, ETH - Wageningen Universiteit, The Netherlands (WU)
Submission date:	30 March 2015
Function:	e.g. This report is an output from Work Package 3; Task 3.4
Deliverable	DROUGHT-R&SPI Deliverable 3.6: Recommendations for indicators for monitoring and early warning considering different sensitivities.

Cover: Maps of drought indicators SPI-12 and SPEI-6 corresponding best to spatial distribution of drought impact reports in Europe (from Kohn et al., 2014; edc.uio.no/droughtdb)

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1. Summary & Recommendations

Drought monitoring and early warning (DMEW) can help to prepare for a drought and to manage an emerging or ongoing drought. DMEW will be most useful for decision-making if the indicators of drought used within a DMEW system are chosen specific to the vulnerability and potential impacts of the region or river basin. At the pan-European scale, DMEW mainly benefits transboundary communication in its current state. However, it could become an important tool for policy choices (e.g. drought declaration, aid and compensation etc.) and risk management decisions at the national and multi-national scale, if it was linked more specifically to drought impacts.

To explore the potential for a more specific impact and sensitivity targeted DMEW system, the DROUGHT R&SPI Work Package 3 empirically investigated the impact-relevance of commonly used hydrometeorological drought indicators. For this purpose, researchers collected and evaluated new qualitative and quantitative impact data representing different drought-affected sectors. Methods employed ranged from visualization, correlation, to logistic regression models predicting impact occurrence and the analysis of the output of large-scale hydrological model ensembles. The results of this work lead to a number of key findings that are recounted in the next sections of this report, and to the following consequent recommendations regarding application and further development of drought indicators for DMEW at a pan-European scale:

Recommendations

1. Hydrometeorological drought indicators used in pan-European DMEW must consider short (2-6 months) as well as long-term (≥9 months) precipitation and climatic water deficits due to their varying relevance to different impacts (sectors) and climatic regions.
2. In addition to monitoring accumulated precipitation deficits as drought indicators (e.g. SPI), long-term water deficits should also be monitored. Ideally, water deficit indices should be based directly on hydrological variables (soil moisture, river flow, lakes, reservoir and groundwater levels). However, these are often heavily influenced by human regulations and therefore may not be directly linked to temporal occurrence of climatic water deficits. Both hydrological variables and human regulations (e.g. abstractions) need to be monitored and made freely available.
3. Drought impacts should be monitored systematically and at a detailed spatial and temporal resolution in addition to the commonly used drought hazard indicators. The impact information should be used routinely to test the validity and usefulness of drought indicators, particularly when new indicators are developed.
4. Development efforts towards impact/sector-specific DMEW with a pan-European coverage should be intensified. Impact-specific indicators must be developed based on adequate data. Options include impact-specific composite indicators or a menu of individual indicators together with guidance on their links to impacts and underlying vulnerability.
5. For the purpose of pan-European overview, DMEW appears most promising for a resolution at the scale of countries (for small countries) or regions (ca. NUTS-2), which also has the benefit of targeting specific sectors and is more readily understood by stakeholders.

2. Motivation for research on impact-relevant indicators

Drought monitoring and early warning (DMEW) can help prepare water users and regulators for drought and help manage water resources during the drought event. DMEW is thus an important prerequisite for risk reduction and a more drought resilient society. In order to be useful decision tools and effective triggers for measures and mitigation actions, the indicators of drought used in DMEW should be linked to the specific vulnerability of a region, i.e. to particular drought impacts.

The details of drought impacts, however, are often not known as they are not monitored in the same way as hydrometeorological variables and the impacts vary widely across regions and affected sectors. Lackstrom et al. (2013) therefore described the impacts as the “missing piece” in DMEW. Completing the piece of the puzzle, however, is difficult. Drought impacts are less straightforward to quantify compared to impacts of other natural hazards (Logar & van den Bergh, 2013). For example, flood impacts produce mostly structural damages, which have a corresponding economic value that can be estimated or insured. Drought impacts are, on the other hand, more diverse and a direct and exclusive link to the drought hazard is often difficult to make (Ding et al., 2011).

The overarching question for the DROUGHT R&SPI project (WP3) was whether and how it was possible to consider this diversity of drought impacts across Europe when selecting drought monitoring and early warning indicators at the pan-European scale. This scale is much larger than the local occurrence of particular impacts that may be known to local water users or managers. Therefore, it was necessary to develop new approaches to investigate impact-relevant indicators. In particular, there was a need to collect impact data at a pan-European scale covering different sectors and regions.

3. The DROUGHT-R&SPI approach to linking indicators to impacts

Work package 3, “Drought sensitive areas in Europe: impacts, vulnerabilities & risks”, has addressed this need for investigating the diversity of impacts across different European countries and geoclimatic regions using three approaches: (1) participatory techniques (stakeholder involvement), (2) categorized data on drought impacts derived from a variety of text sources, (3) and quantitative drought impact data reported by member states, such as reported and modeled annual crop yields, and area-burned by forest fire (Stahl et al., 2015). Investigations of impact-relevant indicators at the larger national or regional scales used mainly the second and third type of data.

The European Drought Impact report Inventory (EDII) (Stahl et al., 2012) is a database that now contains close to 5000 entries of reported impacts and is available online, also allowing entries from the community (http://www.geo.uio.no/edc/droughtdb). Textual impact reports from reliable sources are classified into 15 impact categories representing different sectors and related sub-types. The derived impact entries to the EDII database are referenced in time and space and, where available, recorded supplementary information on associated costs or drought response measures is included. The summary texts on the reported impacts have served to construct narratives for major European drought events assembled in the European Drought Reference (EDR) database (Stagge et al., 2013; www.geo.uio.no/edc/droughtdb).

The EDII employs a clear definition of impact by which there a *negative consequence for environment, society or economy resulting from drought*. Quantitative impact data, such as crop production or losses, or forest fire area-burned, do not necessarily make this direct link a priory. Yet, the benefit of quantitative impact data is that it can be directly correlated with time series of drought indices, such as the Standardized Precipitation Index (SPI) or with hydrometeorological variables in general. This was demonstrated by Lenferink et al. (2014; 2015) and Gunst et al. (2015), who correlated soil moisture, evapotranspiration and SPI to crop yields.

Unlike quantitative impact data, the negative consequences of drought collected in the EDII are archived as a categorized occurrence of an event. Analysis methods therefore need to consider binary occurrence or frequencies. In a first assessment of the link between hydrometeorological drought indicators and the impact reports collected, Kohn et al. (2014, Figure A1.1, Annex) visualized the spatial distribution of reported impacts for particular drought events to find matches of SPI/SPEI based on the European Drought Reference database (EDR) (Stagge et al., 2013; edc.uio.no/droughtdb). Several specific studies have then expanded this methodological challenge towards more objective approaches and used the qualitative EDII impact data to determine impact-related index thresholds. Common to these is first, to extract time series of impact occurrence from the archived impact reports. Figure 1 shows schematically how these 'impact onsets or occurrences' can then be related to different drought hazard indicators following three main approaches:

1. Measures of the distribution of the drought index in months or years with impact occurrence (e.g. Bachmair et al., 2014; De Stefano et al., 2015)
2. Frequencies of occurrence will provide a numerical variable (given ample data availability) that can be correlated to the drought index (e.g. Bachmair et al., 2014)
3. Logistic regression models to describe the likelihood of impact occurrence by one or many drought indices as predictors (Gudmundsson et al., 2014a; Blauhut et al., 2015; Blauhut and Stahl, 2015; Stagge et al., 2015; Stagge et al., in revision)

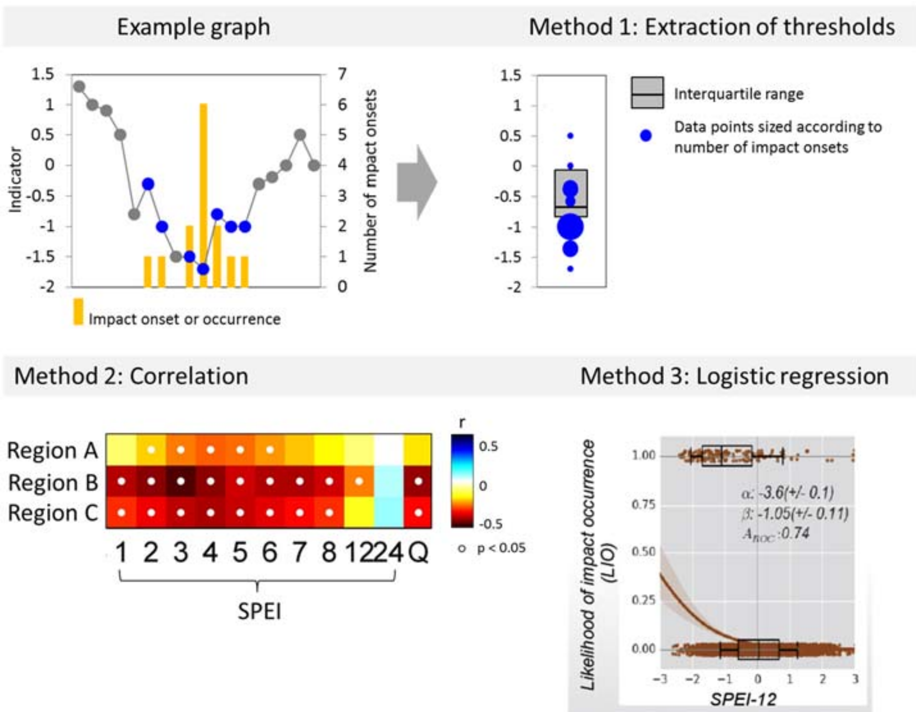

Figure 1 Scheme of the three approaches to investigate impact-related drought index values (based on Bachmair et al., 2014 and Blauhut et al., 2015).

The first method directly provides a a drought index value that can be interpreted as a threshold below which an impact occurred. The other methods allow an assessment of indicator-relevance by statistically testing the strength or significance of the relation between different indicator variables and the derived impact variable.

Section 4.1 presents a pan-European application of Method 1. A variation of this method was also employed to describe the pan-European exposure to drought, i.e. one out of many components of drought vulnerability, by De Stefano et al. (2015). Section 4.2 then summarizes the findings of the various studies within DROUGHT-R&SPI that investigated impact-relevant drought indicators at the national or regional scale, significantly larger than case studies' scale to allow comparison and contrasting.

4. Results: indicators linked to past impact occurrence

4.1 Indicator thresholds pan-European scale

Applying Method 1 as described above to all NUTS-2 regions as described above allows to derive impact-related thresholds of selected drought indices, i.e. the Standardized precipitation index (SPI) (McKee, et al. 1993) and the Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente Serrano et al., 2010). SPI and SPEI were derived from the E-OBS (version 9) following the recommendations by Gudmundsson and Stagge (2014) and Stagge et al. (2015). Specifically, for each NUTS-2 region, the annual minima of four drought indicators (SPI-6, SPEI-6, SPI-12 and SPEI-12) were derived for all years with impact occurrence. Figure 2 shows maps of the medians of all extracted values per region.

Impacts occurred at negative SPI/SPEI values in all regions, and mostly below -1 to -1.5, i.e. more than one standard deviation below the mean of the standardized precipitation or climatic water deficit. This threshold is often classified as moderately dry and denotes a frequency of 1 in 10 years to 1 in 20 years (McKee et al., 1993; WMO, 2012). Spatial patterns are not very strong, though lower thresholds appear to be more predominant in the latitudinal range of northern Portugal and Spain, Southern France, Northern Italy and Southeastern Europe. A comparison between the two indices for different accumulation periods shows that less severe values were associated with impacts for the 12-month accumulation period. For specific impact categories, impact reports are more scarce at the NUTS-2 resolution and are only available at country scale. Therefore category-specific thresholds cannot be extracted at this scale, except for the category "Agriculture and livestock farming", which shows similar patterns as displayed in Figure 2.

Kohn et al. (2014) merged information from different spatial units for an assessment of major drought events in Europe in the last decades. This analysis indicates that the hotspots, where most impacts occurred, matched SPI or SPEI accumulation periods between 6 and 12 months and values below -2. The indicator with the best-matching spatial distribution to the impact occurrence in the drought-region varied from event to event.

The standardized drought indices successfully normalize widely varying climates across Europe, which allows for direct comparisons of impact thresholds. However, the relatively similar impact thresholds found suggest that the normalized drought indices cannot distinguish between regions.

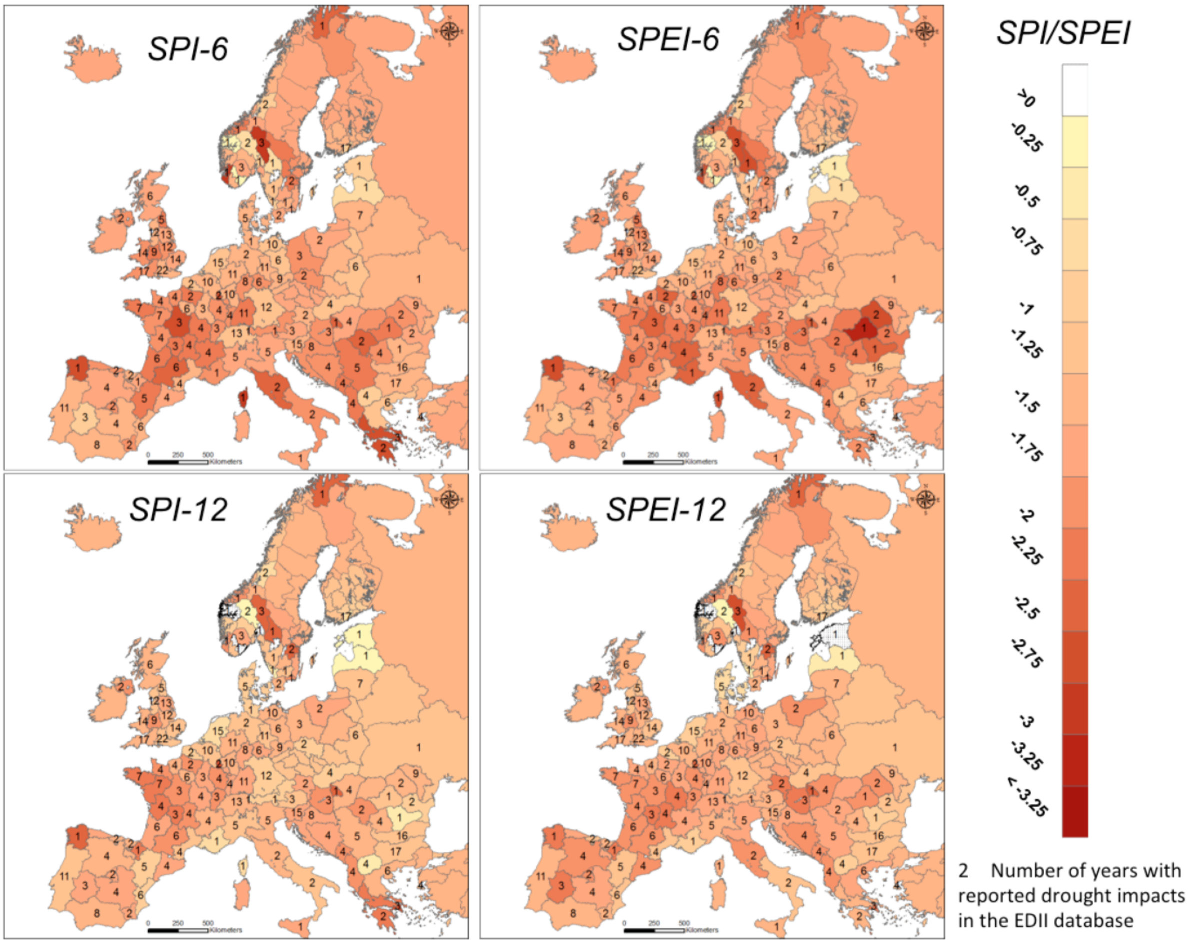

Figure 2. Impact-related SPI and SPEI values for all NUTS-2 regions with impact reports in any category. Index value for regions with no data is interpolated from neighboring regions.

4.2 Findings of regional to multi-national studies

The impact data inventory is more populated for some regions than for others. Furthermore, quantitative impact data such as crop yields or areas burned by wildfires was available for specific regions only. Therefore, on smaller regional to multi-national scales within Europe, such data allowed more detailed analyses. The best indicators by region and by impact type or sector found in the regional studies that were carried out within the project are summarized briefly in Table A1.1. (Annex). Key findings can be summarized as follows.

General Findings

- Drought indicators showing the best link to drought impacts varied regionally at spatial scales smaller than the national or continental scale. The scale difference between impacts reported for administrative units (NUTS) and the river basin scale used for hydrological monitoring complicates analyses.
- SPEI showed closer links to impacts than SPI, which is also in line with other studies assessing the correlation between SPI (or SPEI) and different hydrological, agricultural, and ecological response variables.
- Best predictive indicators for particular drought impacts depend on sector and on sectorial management practices:

- For rainfed agriculture, predominantly short to intermediate accumulation periods of SPI or SPEI (about 2-6 months) are better linked to impact occurrence, confirming other studies' findings.
- For irrigated agriculture, water supply, energy and industry, generally longer accumulation times of SPI and SPEI or combination of short and long accumulation periods are better linked to the impacts, with the optimal choices varying. Water management practices may affect the link between meteorological drought and impacts, e.g depending on the type of water use (groundwater vs surface water) or modified by reservoir storage that increases the resilience and hence the relevant index accumulation time. To fully account for these practices, more information and complex models and/or hydrological indices will be necessary.

- Different drought impacts occur during different seasons, highlighting the need for a season-specific analysis, indicator or to otherwise account for this. Unfortunately many impact reports only allow to determine the year of occurrence, not the month or season.
- The link between drought indicators and impacts is often non-linear and affected by competing influences (e.g. fuel availability for wildfires; positive effects of drought-related weather during particular phases of crop growing or for particular crops) that can be revealed through analysis with well-chosen indicators.
- Little information is available for the onset, duration and end of impacts, making it difficult to analyse impacts over prolonged droughts as they have occurred in the Mediterranean and in the UK, and thus to select specific indicators that take into account the severity and duration of these long droughts.

The studies have revealed important issues that complicate analyses. For instance, the spatial differences of impact reporting at administrative regional levels that is often too coarse to associate it to other relevant units such as river basins, and thus prevents the use of hydrological indicators. Hydrological indicators are also more difficult to obtain, as no EU wide observation based data product exist that is freely accessible which could support a suitable analysis at the pan-European level. Commonly, large-scale models do not account for the important human alterations to river flow in the necessary detail.

Scale issues also concern the multi-scalar temporal nature of drought and its impacts. Large-scale European droughts have lasted over rather different regions and time periods from seasons to multiple years (Stagge et al., 2013; Stahl et al., 2012, www.edc.uio.no/db). The European Drought reference database developed narratives for the evolution of impacts during a drought, but more data are needed both for impacts as well as the progression of the natural hazard characteristics over time.

The studies have also shown that underlying vulnerability and previous measures taken to build resilience varies across Europe (De Stefano et al., 2015). Hence, factors such as the presence of drought management plans, ecological status of water bodies, level of regulation of water resources, and others can hence also affect the relevant indicators that will provide the best monitoring and early warning for drought. As illustrated by Blauhut and Stahl (2015) vulnerability indicators can strongly alter drought risk in terms of the likelihood of impact occurrence.

5. Conclusions and Recommendations for DMEW at the Pan-European Scale

The analyses undertaken have implications for the choice and development of impact-relevant drought indicators for drought monitoring and early-warning. The highly varying temporal scales of drought have caused much debate in the project and some of the research aimed to establish the specific time lags of accumulations of precipitation or climatic water deficits that were linked to certain impacts. For this purpose the indices most commonly used in DMEW, standardized precipitation and climatic water deficit, were used. Although the best indicators appear to vary with impact type, region, and drought event, some commonalities have emerged.

> Recommendation 1 is therefore: drought indicators used in Pan-European DMEW need to consider short (3-6 months) as well as long-term (>12 months) water deficits due to their varying relevance to different impacts (sectors) and climatic regions.

Overall, hydro-meteorological drought indicators were used due to their availability at the pan-European scale. However, the collection of impact data shows a similarly high number of reports on water resources-related impacts as on agriculture, suggesting that precipitation and soil moisture based indicators currently used in many of the continental to global scale monitoring and early warning systems should be complemented by indicators that use observations and forecasts of surface and groundwater quantity (river discharge, lake level, snow water equivalent, groundwater levels, etc.).

> Recommendation 2 is therefore: in addition to monitoring accumulated precipitation deficits as drought indicators (e.g. SPI), long-term water deficits should also be monitored. Ideally, water deficit indices should be based directly on hydrological variables (soil moisture, river flow, lakes, reservoir and groundwater levels). However, these are often heavily influenced by human regulations and therefore may not be directly linked to temporal occurrence of climatic water deficits. Both hydrological variables and human regulations (e.g. abstractions) need to be monitored and made freely available.

Prior reports have described the choice of drought indicator as a trade-off between the monitoring objective and the availability of data (D1.4 Gudmundsson et al. 2014b). Through analyses of impact-relevant drought indicators, DROUGHT-R&SPI found that it is feasible to include impact-relevance into the monitoring objectives. The large variety of impact types and the varying relevance of particular impacts found across Europe supports the often-repeated concern that one drought index will not be sufficiently useful. EDII data, but also data from various EU data portals helped to show this at the pan-European scale. Such a database is absolutely crucial to improve existing DMEW towards more impact-specific and regionally differentiated tools.

> Recommendation 3 is therefore: drought impacts should be monitored systematically and at detailed spatial and temporal resolution in addition to the commonly used drought hazard indicators. The impact information should be used routinely to test the validity and usefulness of drought indicators, particularly when new indicators are developed.

For easier communication but also for local cases of complex multipurpose water use, composite indicators have been developed previously. One reason is that standardized indices are sometimes found too difficult to communicate to non-scientists with little background on statistics. Simplified (e.g. interpreted and categorized “yellow-orange-red” warning levels) indicators based on composites of multiple individual indicators allow to safely communicating triggers for particular drought response and mitigation actions.

> Recommendation 4 is therefore: intensify the development efforts towards impact/sector-specific DMEW with a pan-European coverage. Impact-specific indicators must be developed

based on adequate and freely available data. Options include impact-specific composite indicators or a menu of a set of individual indicators together with guidance on their links to impacts and underlying vulnerability.

During DROUGHT-R&SPI, debates over spatial and temporal scales have been a dominant issue both with stakeholders and among researchers. With a focus on awareness, communication, and policy relevance, DMEW at the pan-European scale has somewhat different objectives than local water managers have for DMEW. Need and usefulness of pan-European DMEW may hence be more difficult to understand and communicate.

Recommendation 5 is that for the purpose of pan-European overview, DMEW appears most promising for a resolution at the scale of countries (for small countries) or regions (ca. NUTS-2), which also has the benefit of targeting specific sectors and is more readily understood by stakeholders.

At the scale of Europe, indices for a consistent cross-comparison will always remain in conflict with usefulness 'on the ground'. The analyses on pan-European drought impacts, however, elucidate some of the patterns and may thus help the decisions for the standardization of various sets of indices that perhaps have a wider relevance than locally, while still allowing inter-comparisons at EU level.

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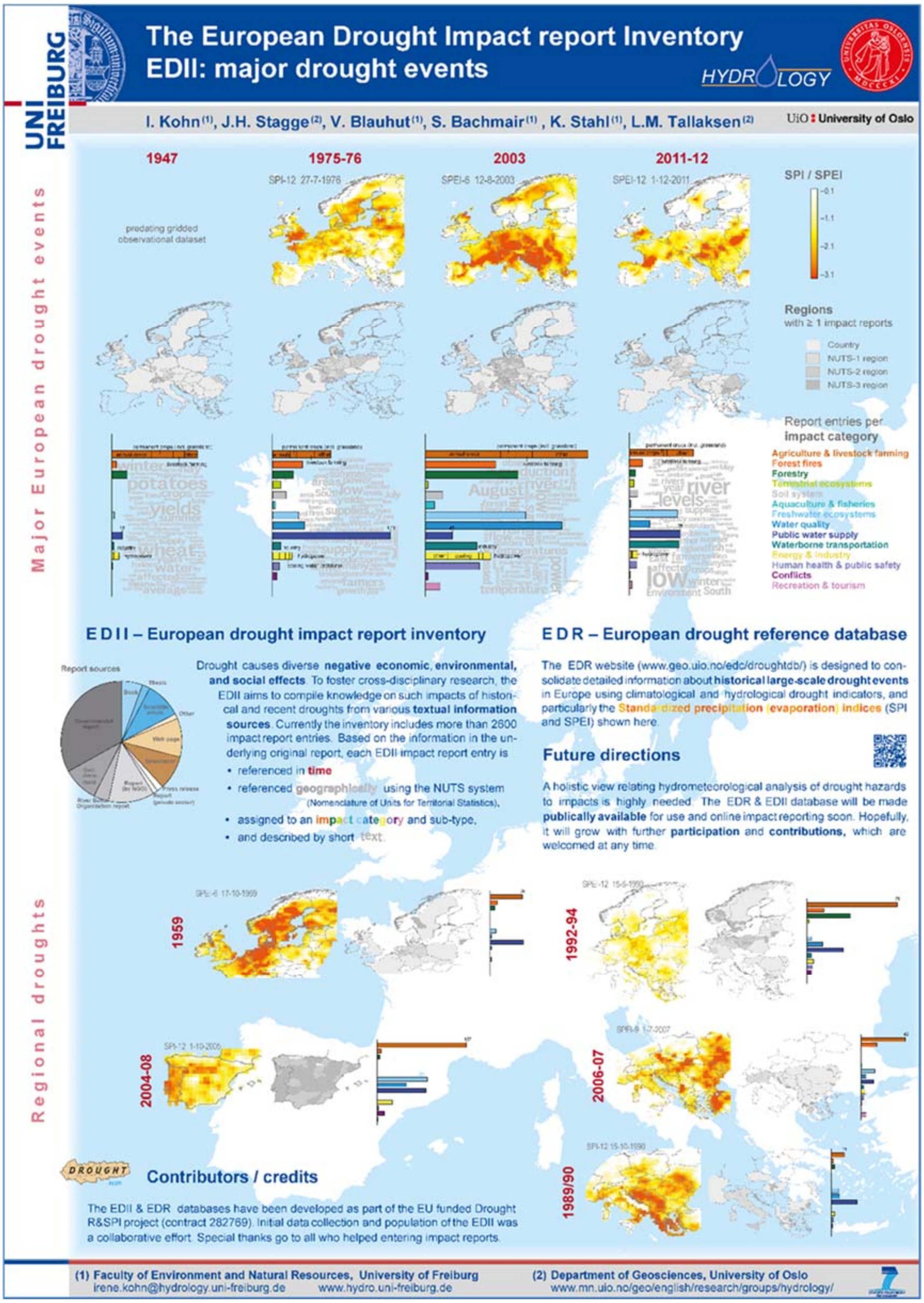

Figure A.1 Visual investigation of drought indicators (SPI and SPEI) and reported drought impacts for selected drought events (Poster by Kohn et al., presented at the EGU Leonardo conference, Nov. 2014)

Table A1.1. Overview of methods and results of regional to multi-national ational studies linking drought indicators and impacts

Study/Reference	Region	Impact data & Method	Best indicator: per region	Best indicator: per specific type of impact or sector
Stagge et al (in revision)	Germany, UK, Slovenia, Norway, Bulgaria: country scale	Four impact categories, source: EDII Logistic regression on monthly impact occurrence with multiple predictors	SPEI or relation SPI to SPEI more often significant than SPI; Longest accumulation periods relevant in UK (12, 24 months); Medium/long acc. period for specific countries assumed to be related to differences in water management practices (use of irrigation, reservoir storage) and hydrological regimes (seasonality)	Agricultural and energy/industry impacts are best explained by a single drought index & seasonality; SPEI with shortest acc. periods for agriculture generally, longest acc. periods (related to hydrological deficits & reservoir storage) consistently for energy/industry impacts; Best indicators for public water supply and freshwater ecosystem impacts to indices are more complex with both a short (1-3 month) and a medium to long (6-24 month) accumulation period relevant.
Bachmair at al. (2014)	Germany: NUTS1 regions	All impact categories, source EDII Correlation and extraction of indicator thresholds associated with monthly impact onset	Generally intermediate timescales of SPI and SPEI (3-5 months) showed highest correlation with impacts; SPEI better correlated than SPI, streamflow percentiles similar to SPI in some NUTS1 regions; Less negative SPI and SPEI thresholds occur in north-eastern Germany, more negative thresholds in the South	Not investigated
Bachmair et al. (in preparation)* **in collaboration Belmont Forum project DrIVER*	Germany and UK: NUTS1 regions	All impact categories, source EDII Correlation of indicators with no. of impact occurrences	UK: Long SPI and SPEI timescales are best explanatory variables in the southern regions, while in the central/northern regions intermediate SPI and SPEI timescales show highest correlation	UK: Short to intermediate SPI or SPEI timescales for agriculture, longer timescales (12 or 24 months) for water supply, intermediate to long timescales for impacts on ecology, intermediate timescales for water quality; DE: similar, except that intermediate accumulation periods of SPI or SPEI for Germany best correlate with e.g. impacts on water supply or waterborne transportation (long accumulation periods >12 months are not correlated to any impact type)
Gudmundsson et al. (2014)	Southern Europe with sub-regions: Iberian Peninsula, South Italy & Greece	Forest Fire (area burned), source EFFIS Logistic regression on above-normal wildfire activity with multiple predictors (SPI)	For the Iberian Peninsula, SPI with longer accumulation times (4 to 5 months) In South Italy & Greece, SPI values with short accumulation times (2 months)	The probability of above normal wildfire activity in large geo-climatic regions in southern Europe is significantly related to meteorological drought as measured by SPI with varying accumulation periods. Potential for forecasting with lead time of 1-5 months.
Stagge et al. (in preparation)	Pan-European using NUTS2 regions	EFFIS wildfire area burned Logistic regression on percent area burned using SPI, SPEI, and a seasonal component	SPEI provides slightly better models of wildfire extent than SPI. The most important explanatory factor is negative 1-3 month SPEI values (drought). A common secondary factor is a wet period (positive SPI6 /	Not investigated.

			SPEI6) lagged 3-6 months prior to the fire. Seasonal terms show a single, distinct summer peak in southern latitudes, dual peaks in the spring and late summer for mid-latitudes, and a flat, single peak outside the snow period for high latitudes.	
Gunst et al. (2015)	Pan-European (up- scaled from NUTS2 regions) and three main climate regions (Atlantic, Continental and Mediterranean)	Correlation in statistical models	SPEI and SPI give similar results Accumulation period did not differ per region, but per crop type (see right column) The three climate regions and European scale did not give the same relations concerning phases of the growing season, but in general correlations in the sowing and harvesting period are negative and in the flowering season positive.	Best indicators for different crops: Barley and wheat: SPI/SPEI-3 Potato, maize and sugar beet: SPI/SPEI-1&2 (shorter timescales)