

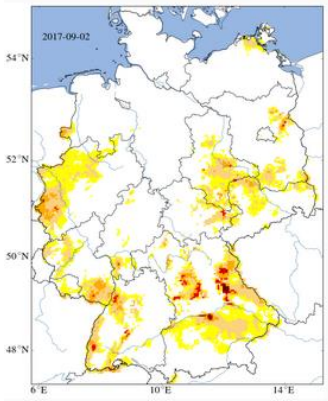




# Drought Monitoring & Early Warning Systems (DMEWS)

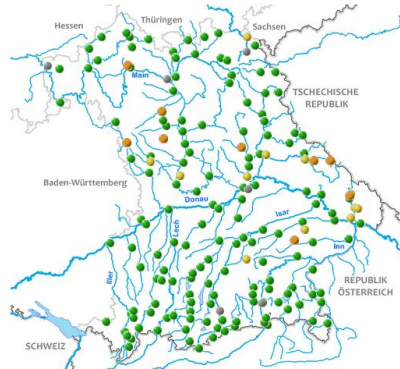
Total soil column (~1.8m)

German Drought Monitor, UFZ;  
[www.ufz.de](http://www.ufz.de)



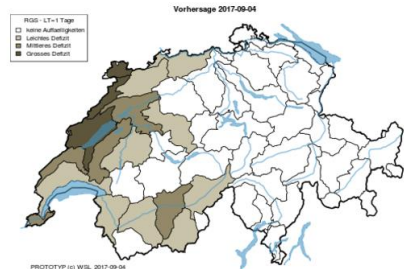
Niedrigwasserinformationsdienst  
 LfU Bayern; <http://nid.bayern.de/>

Niedrigwasserabflüsse vom: << Mo, 04.09.2017 >>

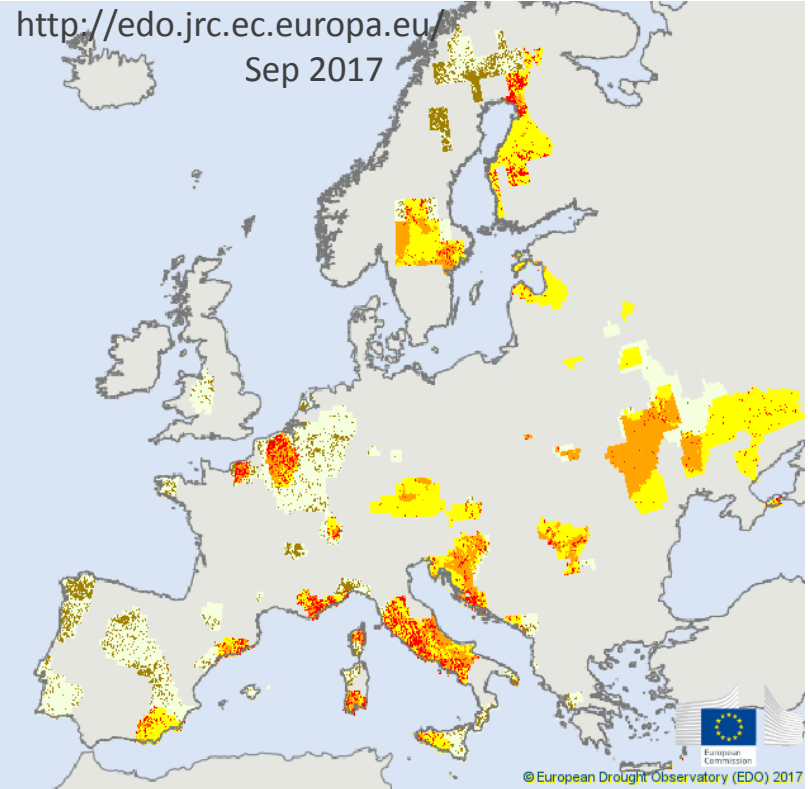


## Abfluss

- In den kommenden Tagen besteht ein leicht zunehmendes Abflussdefizit im Wallis



drought.ch – Informationsplattform  
[www.drought.ch](http://www.drought.ch)



European Drought Observatory, JRC

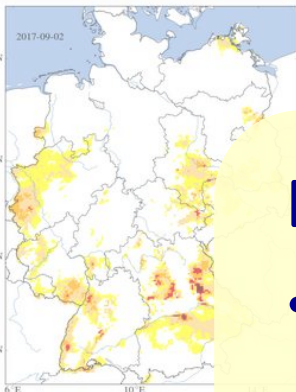
Total soil column (~1.8m)

German Drought Monitor, UFZ;  
www.ufz.de

<http://edo.jrc.ec.europa.eu/>  
Sep 2017

## Drought hazard definition

- based on **physical variables**: precipitation, soil moisture,..
- differing metrics (indices)



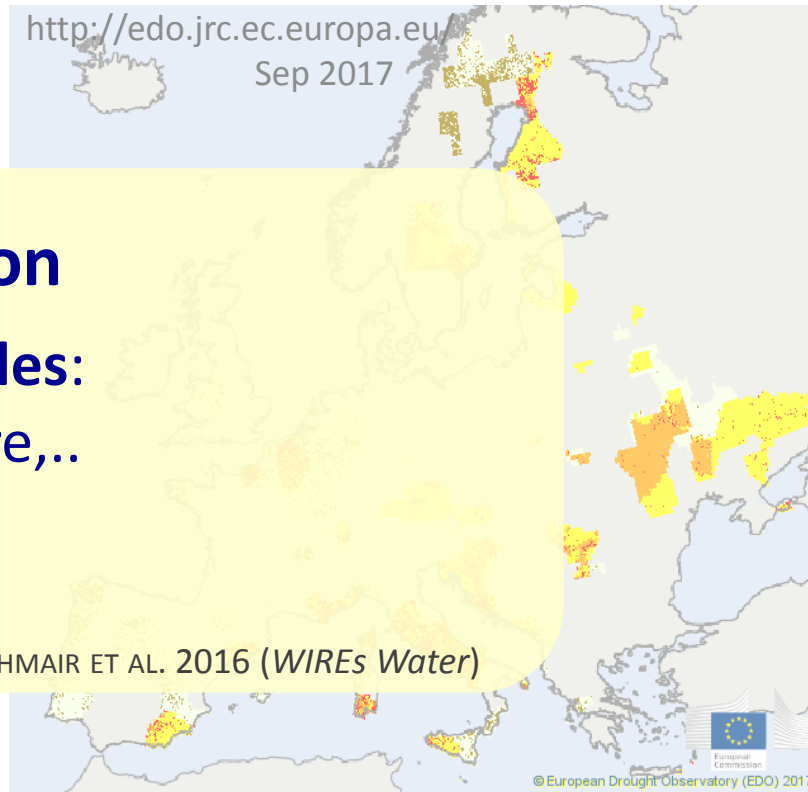
Abfluss

• In den kommenden Tagen



drought.ch – Informationsplattform  
www.drought.ch

e.g. BACHMAIR ET AL. 2016 (*WIRES Water*)



European Drought Observatory, JRC

# What's your picture of drought?



## Stakeholders' drought definition/perception

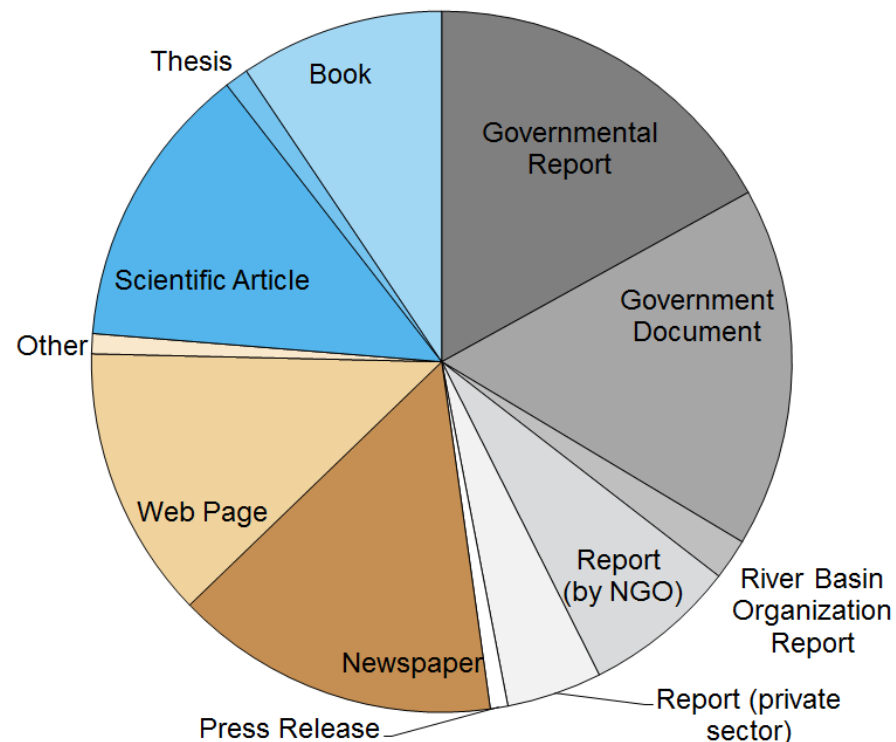
- experience of drought **impacts**
- context dependent

- EDII – How does it work ?
  - design & structure
  - current contents
  
- How to exploit the EDII data ?
  - examples of possible applications & analyses



## Reported drought impacts across Europe

- **negative environmental, economic, or social effects** experienced under drought conditions
- as reported in various **text information sources**



EDII information source types (July 2018)



16. August 2015  
 Leserservice 08 00/222 42 24 02 - www.der-sonntag.de

## Der Sonntag in Freiburg

### Water Supply

*At the waterworks "Ebnet" well site, groundwater levels have dropped below the threshold for abstraction (...) therefore water is now pumped from the "Hausen" wells to Freiburg (...)*

### Ecosystems

*(...) trees shed leaves (...)*

## Die Folgen der Dürre

Wochenlang Hitze und kaum Regen: Südbaden kämpft mit der **TROCKENHEIT**

Landwirte beklagen Ernteaufschläge, Förster warnen vor Waldbränden und die Wasserversorger haben alle Hände voll zu tun. Auch wenn die Hitzewelle in Südbaden vorerst beendet ist: Ihre Auswirkungen werden noch lange zu spüren sein.

Das Schlimmste, was passieren kann, ist Kalk in den Kochtöpfen. Mit dieser Botschaft wandten sich die Stadtwerke Müllheim-Staufen diese Woche an ihre Trinkwasserkunden. Denn die wochenlange Trockenheit bereitet dem kommunalen Versorger Probleme: Die höher gelegenen Quellen geben nicht mehr genug Wasser her. Deshalb setzen die Stadtwerke stärker auf die Tiefbrunnen in der Rheinebene. „Wir haben kein Mengenproblem, weil wir an einem der größten Grundwasserspeicher Europas leben“, sagt der technische Leiter der Stadtwerke, Michael Sattler. Allerdings werde das Wasser härter, was zu Kalkablagerungen führen kann. Das Rheintalgrundwasser ist mineralienreicher als das weiche Quellwasser aus dem Schwarzwald.

Auch in Freiburg sind die Auswirkungen der Dürre zu spüren. „Unsere Wassermeister haben derzeit sehr viel zu tun“, sagt Yvonne Schweickhardt, Sprecherin des Regionalversorgers Badenova. Beim Wasserverkäufer sei der Grundwasserspiegel so weit gesunken, „dass wir ihn nicht ohne Not weiter absenken wollen“, sagt Schweickhardt. „Deshalb pumpen wir mehr Wasser aus Hausen nach Freiburg.“

Hitze und Trockenheit führen zum einen dazu, dass Wasser fehlt. Kleinere Flüsse trocknen aus. Der Neumagen, der normalerweise von Münnstertal nach Bad Krozingen fließt, ist nur noch ein Kiesbett. Zum anderen wird mehr Wasser verbraucht. Vor allem durch Gartenbesitzer und Landwirte. Anfang Juli hat Badenova einen neuen Rekord-



Ausgetrocknet: die Dreisam bei March.

FOTO: SEGER (DPA)

verbrauch festgestellt. „Wir haben an einem Tag 71 000 Kubikmeter Wasser nach Freiburg gepumpt, so viel wie noch nie“, sagt Unternehmenssprecherin. Schweickhardt. Die durchschnittliche Tagesförderung betrage etwa 48 000 Kubikmeter.

#### Landwirte unterschiedlich stark betroffen

Als Werner Rappke, Präsident des Bauernverbandes BLHV vom Kaiserstuhl, in dieser Woche nach Freiburg kam, wanderte er sich über den „starken Blätterabwurf der Zierbäume wie im Herbst“. Die Bäume werfen einen Teil ihrer Blätter aus Wassermangel ab, um die übrigen ausrei-

chend versorgen zu können. Sie retten sich quasi damit selbst. Für viele Landwirte hat die Trockenheit dagegen kostspielige Auswirkungen. Etwa in der Weidewirtschaft. Die dritte Mahl seit dieses Jahr fast komplett ausgefallen, sagt Rappke. Erste Betriebe denken darüber nach, ihren Viehbestand zu reduzieren, um Kosten für den Futtermittelzukauf zu sparen. In Stuttgart hat der BLHV zudem angefragt, ob die Greeningflächen – also die fünf Prozent ökologischen Ausgleichsflächen – zur Futtergewinnung gemäht werden dürfen. Eine Antwort aus dem Ministerium steht noch aus.

Die Betroffenheit ist sehr unterschiedlich: Landwirtschaften mit sandigen, wenig speicherfähigen Böden haben massive Probleme. Andere, mit ausreichend Humus, erleben einen zwar heißen, aber doch einigermaßen normalen Sommer. Am meisten betroffen ist der Maisanbau. Auf tiefen Feldern in der Rheinebene haben die Pflanzen nicht einmal Kolben ausgebildet. In Schwanau bei Lahr haben Landwirte ihre Maisfelder jetzt als Futter für Biogasanlagen abgeerntet, um wenigstens noch etwas zu verdienen. „Die Ernte“, sagt BLHV-Kreisvorsitzender Karl Silberer, „ist der Jahreslohn der Landwirte.“ Besser sieht's dagegen beim Getreide in Südbaden aus. Die vielen Niederschläge im Frühjahr haben die Ernte gerettet. In Nordbaden seien die Landwirte nicht so glimpflich davongekommen, sagt Silberer.

Auch die Forstwirtschaft muss mit Einbußen rechnen. „Die anhaltende Trockenheit lag in der Hauptwachstumszeit“, sagt Südbadens Forstpräsident Meinrad Joos. „Das Jahr 2015 wird an den Bäumen in hundert Jahren noch ablesbar sein.“ An den Jahresringen. „Aber dieser wirtschaftliche Schaden ist in der langfristigen Denke der Forstwirtschaft zu verkraften.“

Problematisch könne allerdings noch der Borkenkäfer werden. Bernhard Schirmer, neuer Forstdirektor in Bad Säckingen, erklärt, warum: „Bohrt sich der Schädling in den Baum, schüttet der zur Abwehr Harz aus und ertränkt damit den Käfer. Konnten sie sich vorher in den Monaten vorher nicht ausreichend mit Wasserversorgern, produzieren sie zu wenig Harz.“ Da es im Winter und im Frühling viel geregnet hat, ging bis jetzt alles gut. „Der Borkenkäfer hat sich viel weniger ausgebreitet, als ich befürchtete habe. Das kann aber noch kommen“, sagt Schirmer.

Forstpräsident Joos warnt außerdem vor der hohen Waldbrandgefahr. „Anfang März ging es schon in die Richtung, grundsätzlich Rauchverbot im Wald. Das einzuhalten, ist dieses Jahr besonders wichtig.“

### Livestock farming

*(...) Failure of the third cut of grass; emergency cattle sales necessary for some farmers(...)*

### Agriculture

*(...) corn crops are most heavily affected. On many fields plants have not produced cobs(...)*

### Forestry

*(...) Effects in growth reduction expected (...)*

*(...) high forest fire danger...*

## Information Source



Information Source

Region Location

**SCHRIFFTENREIHE UMWELT NR. 369**

**Gewässerschutz**

**Auswirkungen des Hitzesommers 2003 auf die Gewässer**

**Dokumentation**

**4.1.1 Bachberkung**

In den Langbach-Bereichen (siehe Karte Wasser und Land) fließen unterhalb des Bachlaufes, während die Uferbereiche, insbesondere die Flußufer und alluviale Böden, in Sommermonaten, auf Grund Anstiege der Wasserstände, ausgetrocknet sind und die Ufer mit Fein- und Mittelsanden bedeckt. Diese die Uferbereiche exponierten Bereiche sind in der Karte dargestellt.

Im Folgenden wird der Frage nachgegangen, welche Wirkungen sich bei steigenden Wasserständen und bei Anstiegen der Wasserstände im Sommer 2003 in den Langbach-Bereichen zeigen. In der Karte sind die betroffenen Bereiche dargestellt. Diese sind in der Karte dargestellt. In der Karte sind die betroffenen Bereiche dargestellt. Diese sind in der Karte dargestellt.

**Abb. 11**

Langbach-Bereiche im Sommer 2003. Die Karte zeigt die betroffenen Bereiche. Diese sind in der Karte dargestellt. In der Karte sind die betroffenen Bereiche dargestellt. Diese sind in der Karte dargestellt.

**Nach: P. F. F. F.**



NUTS geocode, location, streams

Nomenclature des Unités Territoriales Statistiques



Eurostat 2007 edition

Information Source



Region Location



NUTS geocode, location, streams

Time of Occurrence



year, month or season

Impact Categorisation



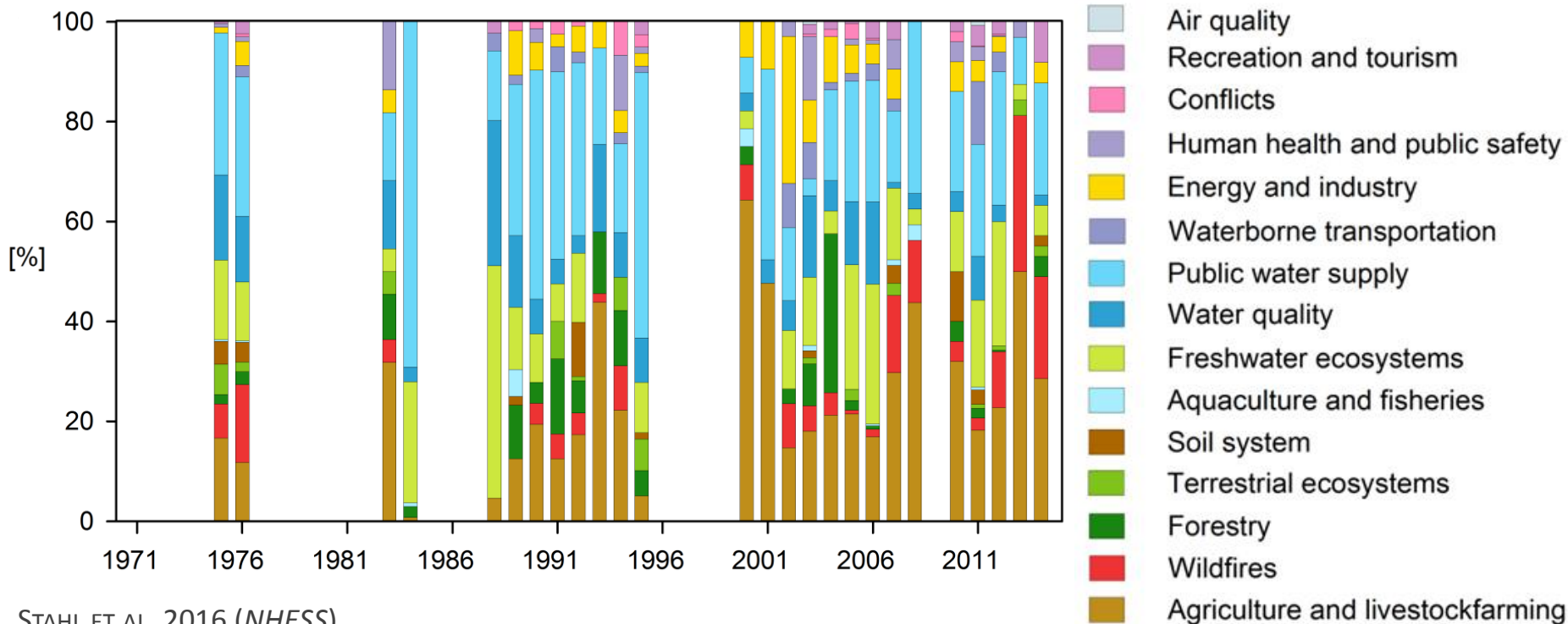
# Archiving impact reports: impacts categories

Information Source

Region Location

Time of Occurrence

Impact Categorisation



# Archiving impact reports: impact category subtypes

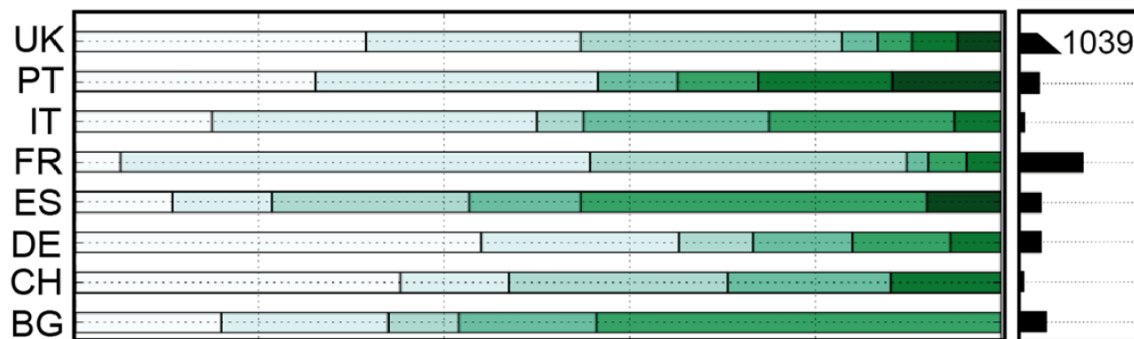
Information  
Source

Region  
Location

Time of  
Occurrence

Impact  
Categorisation

## Public water supply



- Local water supply shortage / problems
- Regional water supply shortage/problems
- Bans on domestic and public water use
- Limitations in water supply to households in rural areas
- Limitations in water supply to households in urban areas
- other
- Increased costs/economic losses

Information Source



Region Location



NUTS geocode, location, streams

Time of Occurrence



year, month or season

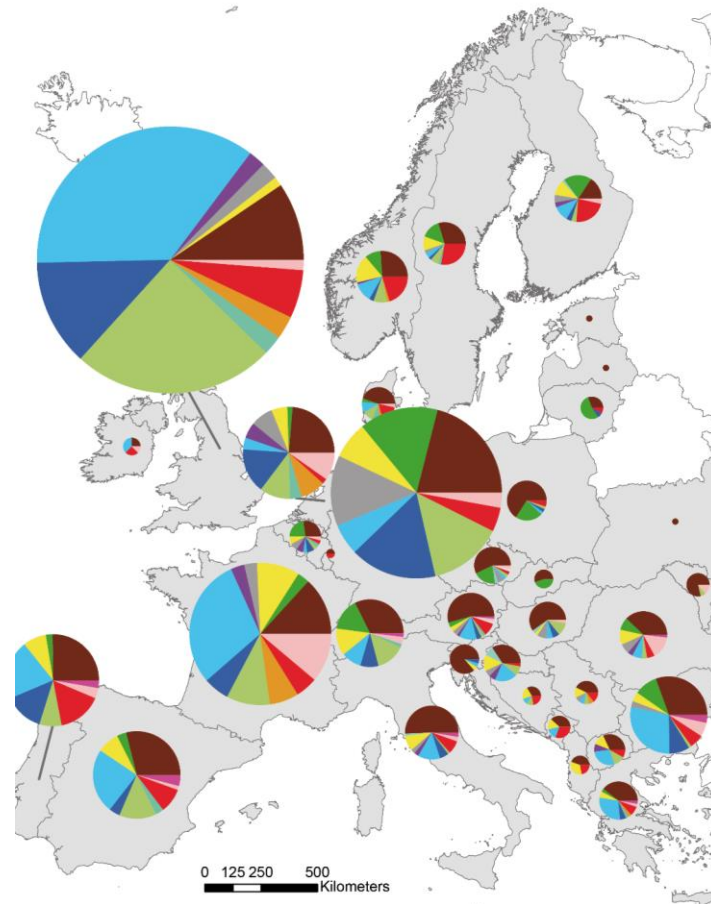
Impact Categorisation



EDII Archive

ID	Location	Country	NUTS 1	NUTS 2
bf_1		Switzerland	Switzerland	Espace Mittellan
ik_1		Switzerland	Switzerland	Nordwes
NUTS 3		Location		
bf_1	Bern	nuclear power plant Mühleberg in Mühleberg		
	Aargau	nuclear power plant Beznau in Döttingen (Zurzach)		
	Bern/Luzern;	several parts of		
Impact details				
YYYY	categ.	type	description	
2003	4	4.2;	Due to a lack of cooli were needed to redu	
2003	4	4.2;	Due to a lack of cooli were needed to redu and August 2003.	
	7	7.3;7 .4	Limitations and bans the lawn, filling of po actions were necessa	

- **5389** impact report **entries** with ~ 8000 impact types
- for **38 countries**
- far from being exhaustive and with biased coverages yet still a unique resource





- EDII – How does it work ?
  - design & structure
  - current state/contents



- How to exploit the EDII data ?
  - examples of possible applications & analyses



- as text-based archive – anecdotal evidence, narratives

see **E**uropean **D**rought **R**eference database

[www.geo.uio.no/edc/droughtdb](http://www.geo.uio.no/edc/droughtdb)



### 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 harvest bans had been imposed throughout South West England and were extended to substantial parts of England and Wales during the following months (Ridda & 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 (ER, 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 (Ridda & 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 (Couvourel et al. 1977; Dornkamp et al., 1980; Ridda & Marsh, 2011).

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 rations had to be applied which finally affected over one million consumers (Ridda & Marsh, 2011; Dornkamp et al., 1980). In France limitations in water supply affected urban and rural areas in particular in the East. In Brittany and in tourist areas at the West coast yet were less severe than expected by the beginning of the summer (Brochet, 1977). While the need for a reduction in demand, including sometimes also outdoor water use restrictions (swimming 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 (Gerhardt 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 Heide, 1978; Gerhardt 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 (started after the years 1921, 1949, 1969 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 energy efficient, saline intrusions. 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. 1980; Gerhardt et al., 1983; Ridda & Marsh, 2011). In the Dutch delta area an outbreak of axian bloaters (over 60 000 cadavers counted) was attributed to the prevailing low water levels, water quality problems combined with the high temperatures during summer (Gerhardt et al., 1983). The considerable fall of groundwater levels had a particular impact on oligotrophic wetland habitats in the Netherlands (van der Heide, 1978; Štorka, 1979). Noted (detrital) 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 top 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 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 (Couvourel et al., 1977, van der Heide 1977; Dornkamp et al. 1980; Gibb & Greg, 1977).

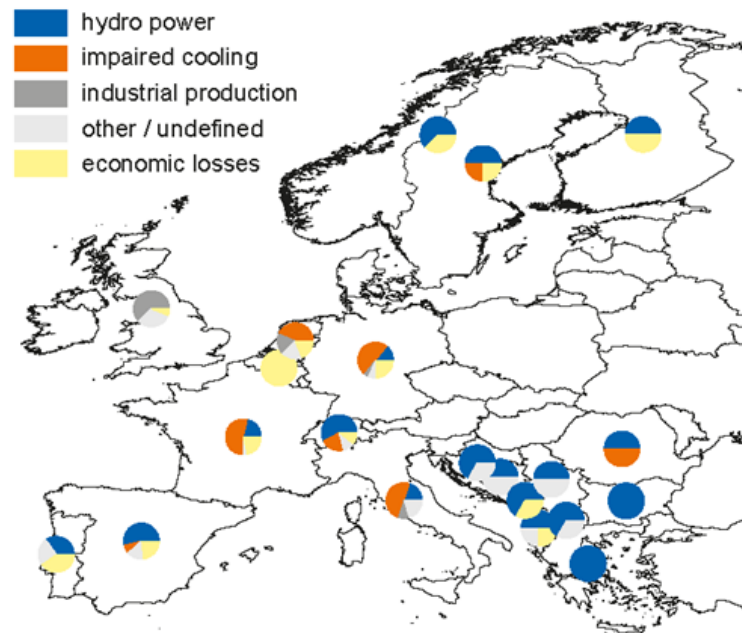
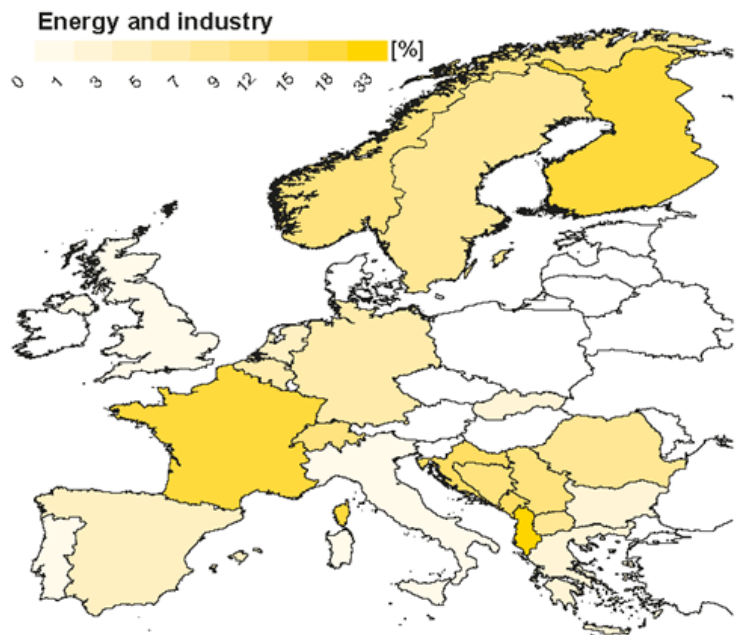
### Impact Detail Table

10 records per page

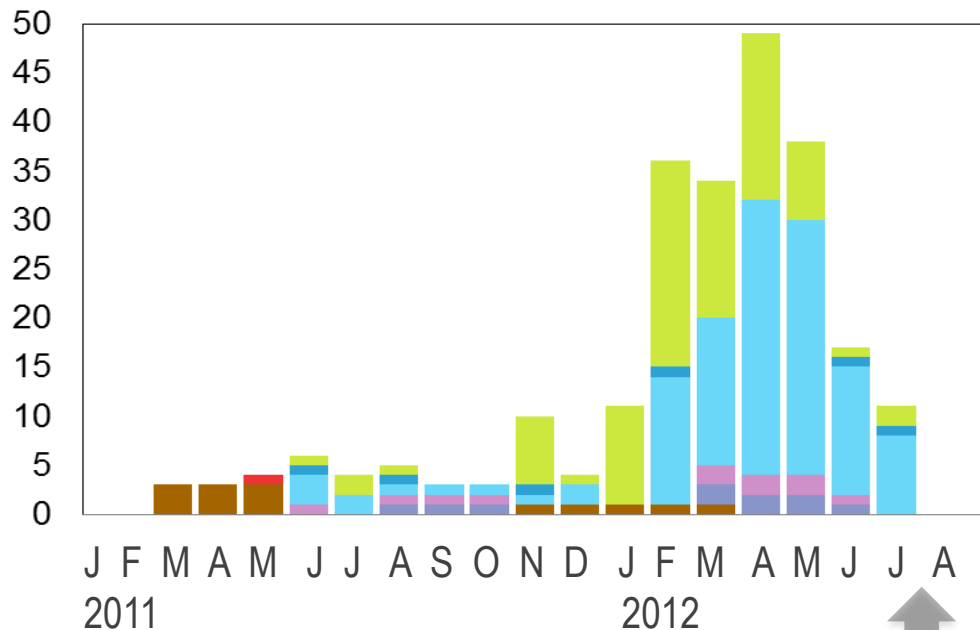
Drought Event	Country	Start Date	End Date	Impact	Impact Category	Impact Description	NUTS 1	NUTS 2
1975-76 Europe	United Kingdom	7/1976	7/1976	4.3	Restriction/Disruption of industrial production processes (due to a lack of process water and/or environmental legislation/restrictions for discharges into streams)	Rotacans in SW Wales - many there was severe limitations on all industrial users in Blaenau Gwent for four weeks.	Wales	West Wales and Valleys
1975-76 Europe	United Kingdom	7/1976	8/1976	4.3	Restriction/Disruption of industrial production process (due to a lack of process water and/or environmental legislation/restrictions for discharges into streams)	There were severe limitations for industrial water users lasting 4 weeks from mid-July.	Wales;	West Wales and Valleys;
1975-76 Europe	United Kingdom	7/1976	9/1976	4.3	Restriction/Disruption of industrial production process (due to a lack of process water and/or environmental legislation/restrictions for discharges into streams)	Shortages in water supplies led to reduced industrial productions in some districts, from mid-July, lasting 10 weeks.	Wales;	
1975-76 Europe	United Kingdom	9/1976	9/1976	4.3	Restriction/Disruption of industrial production process (due to a lack of process water and/or environmental legislation/restrictions for	Some factories had to reduce their working staff, from mid-July, lasting 10 weeks.		

Showing 51 to 60 of 1,447 entries

- as text-based archive – **anecdotal evidence, narratives**
- **visualisation**, impact/vulnerability assessment, impact profiles



## Reported impacts in SE England 2011–2012



*Olympics in London* ↑



**Freshwater ecosystems**

- **Jan/Feb 2012: Fish deaths and distress** in River Meon and a lake in Hampshire. 30 mature sea trout and 6 salmon reported dead.



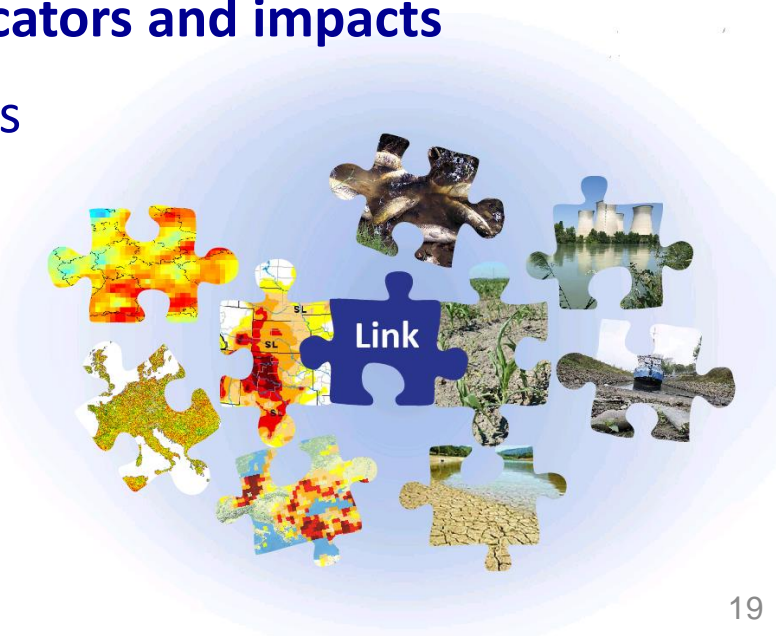
**Public water supply**

- **Mar 2012:** In some regions in the east and south east of England **several domestic wells dried up.**
- **Apr 2012:** 7 water companies in the south and east of England imposed **temporary water use bans on 20 million customers.**

- as text-based archive – **anecdotal evidence, narratives**
- **visualisation**, impact/vulnerability assessment, impact profiles
- analysing the **link between drought indicators and impacts**

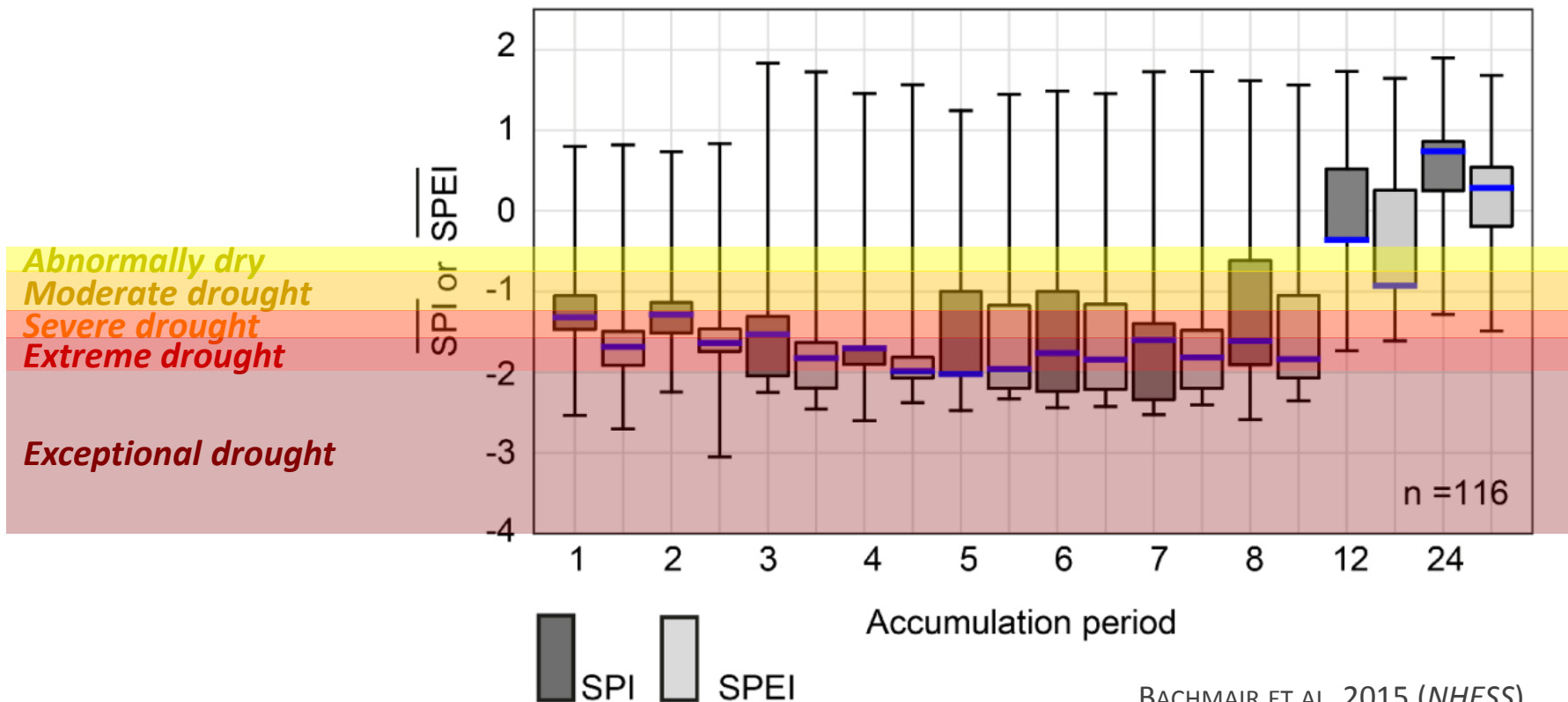
text-based drought impact information as

- ground-truth to **evaluate** indicators and trigger values used in **DMEWS**
- proxy for vulnerability / damage to **model drought risk**



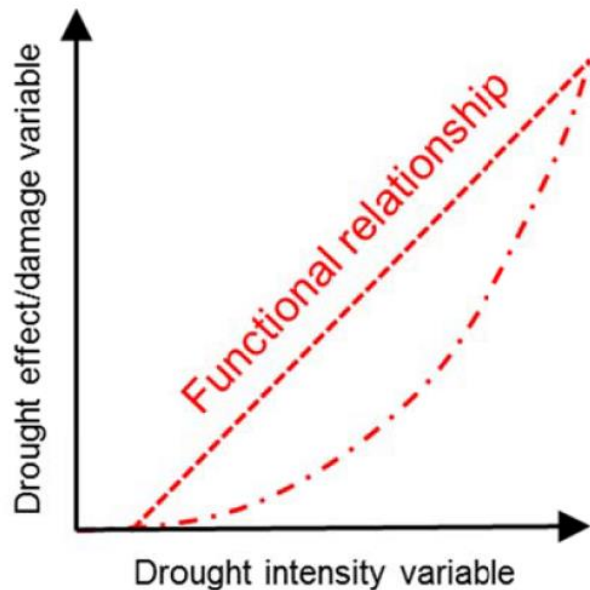
# Are applied thresholds meaningful for impact occurrence?

Indicator values concurrent with impact onset in Baden-Württemberg

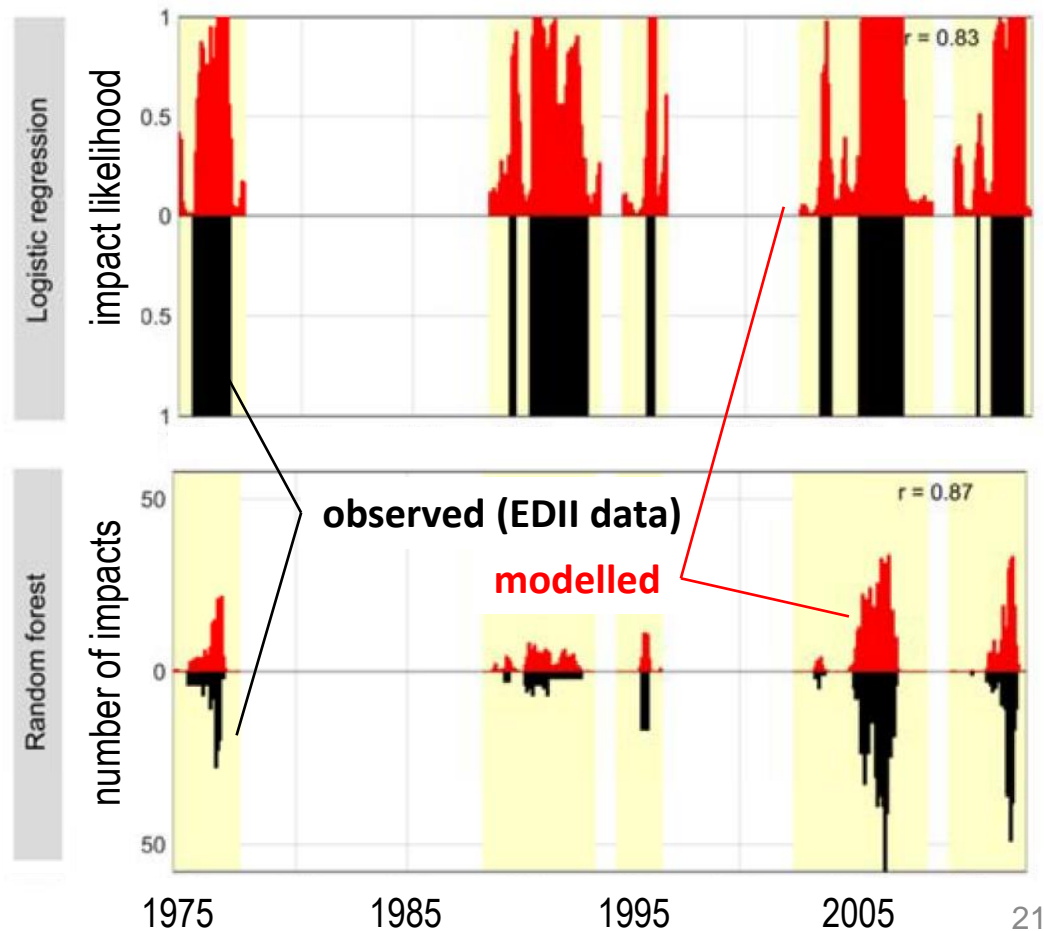


# Developing quantitative drought impact functions

BACHMAIR ET AL. (*NHESS Discussion, in review*)



see also previous studies by  
BLAUHUT ET AL., STAGGE ET AL., and BACHMAIR ET AL.



# Extracting low flow impacts

in the Rhine basin

for the 2003, 2011, and 2015  
events



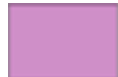


# Spatially referencing low flow impacts



## Energy and industry

- .. emergency exemption from environ. legislation .. **at power plant Nijmegen...**



## Recreation and tourism

- .. passenger ship stranded **in the Rhine near St. Goarshausen**, 45 pass. hurt...



## Freshwater ecosystems

- ..mass kill of the invasive mussel *Corbicula fluminea* **in the Rhine at Mainz and further downstream...**
- ... **sections of several streams in the Upper Rhine region** completely dried...

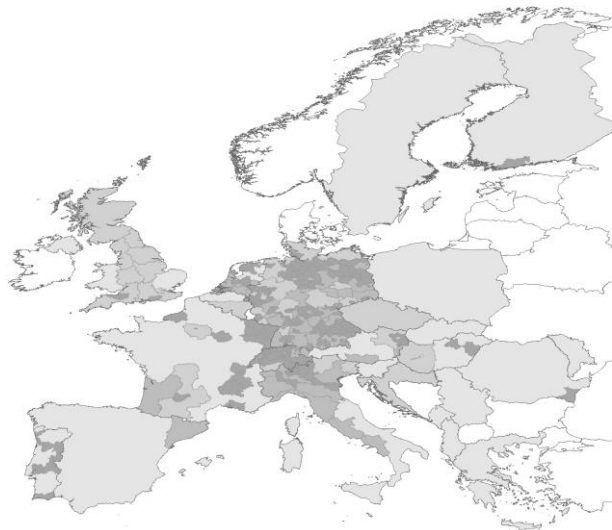


## Waterborne transportation

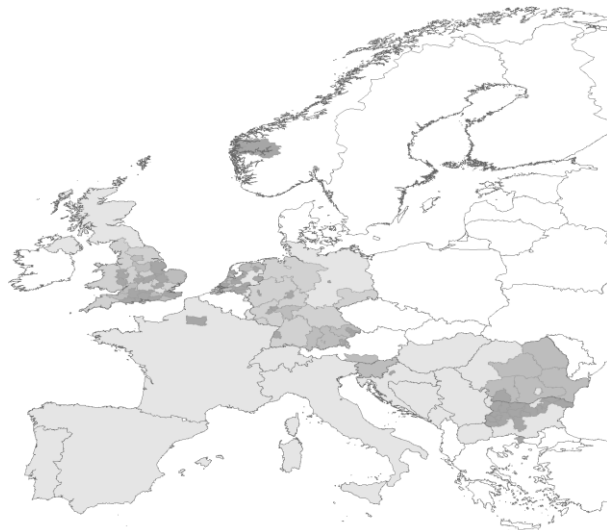
- ...ships **at the harbour Bonn** were asked to ...
- ... **Upper Rhine** able to load only ... similar problems .. **at the Lower Rhine...**
- ... in 2003 the economic loss **in the Kaub-related Rhine market** amounted to..
- ...impaired navigation **on the River Rhine** ..lower quantities of coal delivered by ship transport due to low water levels and resulting load restrictions, **thermal power plants in the Ruhr region** faced a shortage of coal and were forced to pay higher prices for ship loadings...



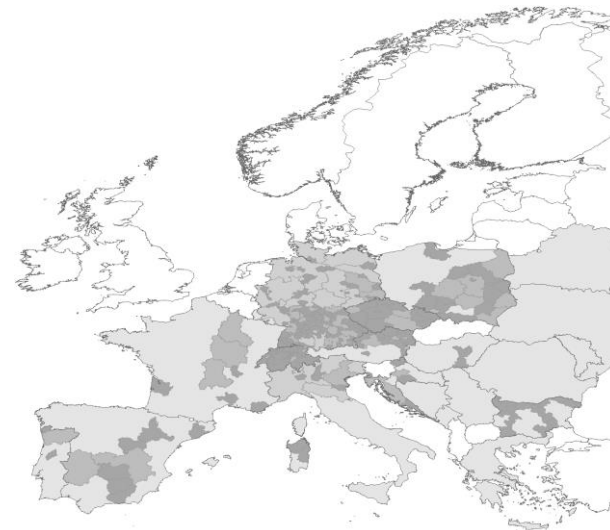
2003



2011/12



2015

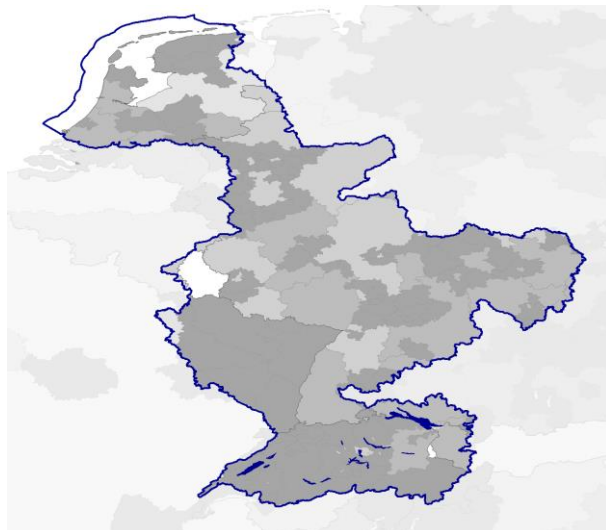


Countries & 
  NUTS – 1, 
  NUTS – 2, and 
  NUTS – 3 regions

with  $\geq 1$  drought impact reports



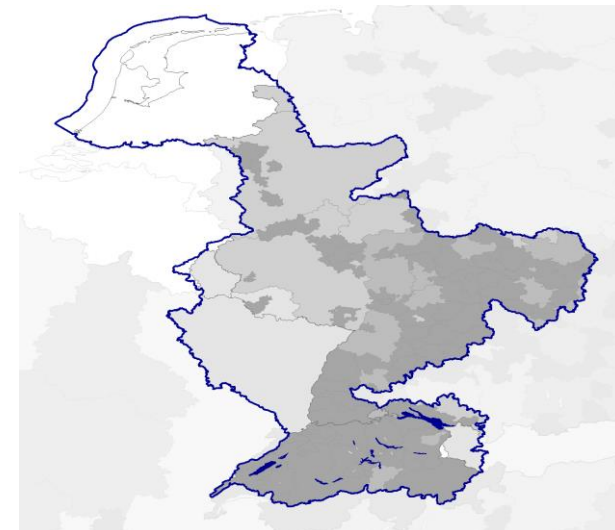
**2003**



**2011/12**



**2015**



Countries & 
  NUTS – 1, 
  NUTS – 2, 
  NUTS – 3 regions

with  $\geq 1$  drought impact reports

# ... which specified affected surface waters



2003



2011/12



2015



# Most frequently used words of their free text descriptions

2003

addition algal concentrations conditions cooling **critical**  
 $^{\circ}\text{C}$  discharge eels emergency energy  
 environmental exceeded exemption **fish** flow higher  
 increased kill **level** maximum measures mg nuclear  
 oxygen power **power** **plant** previous  
 problems production reduced **river**  
 ship site situation species stream summer  
**temperature** value

2011/12

able allowed average **capacity** carry **channel** cm content  
 costs depth fall full Germany goods **increase** inland landing  
**level** load longer lower means measured navigation  
 needed Netherlands normal open overcome period ports  
 problems reduced **river** salt salt intrusion  
**ships** sluices tankers transportation

2015

already B a d ban boats brown concentration costs critical dead  
 decreased died dried dying extremely **fish** found  
 hydropower **increased** irrigation K a u b lake **level**  
 load losses month number order **oxygen**  
 production **reduced** rescued resettled rivers  
 sections ships **streams** supply temperatures  
 trouts week

# Most frequently used words of their free text descriptions

2003

addition algal concentrations conditions cooling **critical**  
 °C discharge eels emergency energy  
 environmental exceeded exemption **fish** flow higher  
 increased kill **level** maximum measures mg nuclear  
 oxygen power **power plant** previous  
 problems **production** reduced **river**  
 ship site situation **species** stream summer  
**temperature** value

2011/12

able capacity channel  
 level load longer lower  
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2015

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 load losses month number order oxygen  
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 sections ships **streams** supply temperatures  
 trouts week

scaled ~ number of impact entries:

- **A unique resource** with great **potential** esp. for large-scale drought indicator–impact analyses in Europe
- Data **limitations** and **challenges** to be addressed
- **Collaborative efforts** needed:  
more participation in data collection, sharing, and analysis

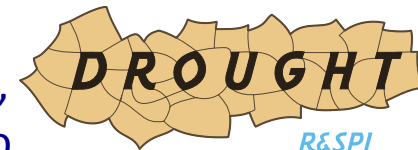
@hydro.uni-freiburg.de

[www.geo.uio.no/edc/droughtdb/](http://www.geo.uio.no/edc/droughtdb/)



- Near future: **Disaster Risk Management Knowledge Centre**  
as new hosting platform for the EDII !?

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Drought Impacts and Vulnerability thresholds in  
monitoring and Early warning Research



## EDII database, guidelines document, paper

- [www.geo.uio.no/edc/droughtdb/](http://www.geo.uio.no/edc/droughtdb/)
- [http://www.geo.uio.no/edc/droughtdb/img/Guidelines\\_EDII\\_Webversion.pdf](http://www.geo.uio.no/edc/droughtdb/img/Guidelines_EDII_Webversion.pdf)
- Stahl et al. (2016) Impacts of European drought events: insights from an international database of text-based reports. *Nat. Hazards Earth Syst. Sci.* 16, 801–809. doi:10.5194/nhessd-3-5453-2015

## Applications of EDII data

Bachmair S., Kohn I., Stahl K. (2015): Exploring the link between drought indicators and impacts, *Nat. Hazards Earth Syst. Sci.*, 15, 1381-1397, doi:10.5194/nhess-15-1381-2015.

Bachmair S., Svensson C., Hannaford J., Barker L. J., Stahl K. (2016): A quantitative analysis to objectively appraise drought indicators and model drought impacts. *Hydrol. Earth Syst. Sci.*, 20(7), 2589–2609, doi: 10.5194/hess-20-2589-2016, 2016.

Blauhut V., Gudmundsson L., Stahl K. (2015): Towards pan-European drought risk maps: quantifying the link between drought indices and reported drought impacts. *Environ. Res. Lett.* 10, 014008, doi: 10.1088/1748-9326/10/1/014008

Blauhut V., Stahl K., Stagge J. H., Tallaksen L. M., De Stefano L., Vogt J (2016): Estimating drought risk across Europe from reported drought impacts, drought indices, and vulnerability factors. *Hydrol. Earth Syst. Sci.* 20, 2779–2800

Stagge J.H., Kohn I., Tallaksen L.M., Stahl K. (2015): Modeling drought impact occurrence based on meteorological drought indices in Europe. *Journal of Hydrology* 530, 37–50. doi: 10.1016/j.jhydrol.2015.09.039

Bachmair S., Svensson C., Prosdocimi I., Hannaford J., Stahl K. (in review): Developing drought impact functions for drought risk management, *Nat. Hazards Earth Syst. Sci. Discuss.*, <https://doi.org/10.5194/nhess-2017-187>.