ALPINE DROUGHT OBSERVATORY

Report on the drought impact assessment for the Alpine region (D.T3.2.1)

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INDEX

Aims and method of drought impact assessment

Drought impact assessments are often done locally as homogenized data is often not available from many locations over a large region such as the Alpine Space. The Alpine Drought Impact report Inventory $EDII_{ALPS}$ V1.0 and the updated V1.1. (Stephan et al., 2022 https://doi.org/10.6094/UNIFR/230219) archives more than 3200 drought impacts classified from text-reports from various sources. The database was built on the concept and including initial contents from the European Drought impact report Inventory, EDII (Stahl et al., 2016). **A comprehensive analysis of historical drought impacts based on the $EDII_{Alps}$ data allowed a first assessment of the impact of drought in space and time and therefore the risk that certain sectors face across the Alpine Space**. The **"reported impacts"** data can also be explored visually on the ADO platform on https://ado.eurac.edu.

As mentioned in the report to DT3.1.1, the overall numbers of the **$EDII_{ALPS}$ are biased to the search efforts and regional report availability** and should not be mistaken with a "proneness to drought" or with overall vulnerability to drought. But, relative fractions can be used for comparisons and therefore allow to **deduct recommendations for impact monitoring in the region in the future**.

The $EDII_{ALPS}$ data provided the opportunity to identify differences and similarities in time and space over the Alps for relevant sectors in a number of ways. The following sections summarize this analysis of impact data

(1) over time and per affected sector, including the characteristics of specific memorable drought events that happened in particular regions,

(2) spatially across the Alpine Space, in the ADO case study areas'NUTS-2 regions, and up- vs downstream in the major alpine river basins,

(3) seasonally, respectively the annual distribution of impact types and drought types.

Where possible we grouped the reported impacts to soil moisture and hydrological drought likely causing different impact types (Fig. 1).

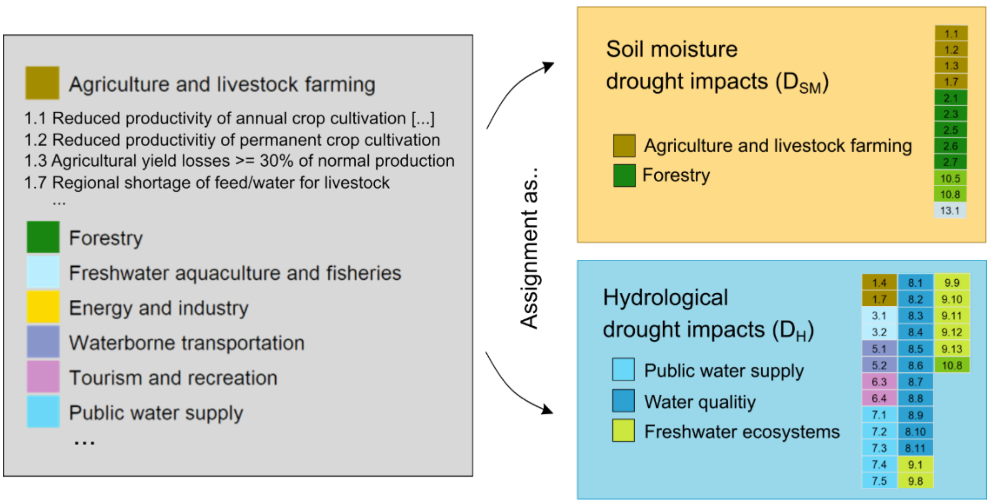

***Figure 1**. Framework for assignment of specific impact types, either to the group of soil moisture drought impacts (D_{SM}) with a majority from the sectors agriculture and livestock farming and forestry, or to the group of hydrological drought impacts (D_H) with a majority from the sectors public water supply, water quality and freshwater ecosystems. For details on impact categories and subtypes see Stahl et al., 2016 and Stephan et al., 2022.*

Assessment

Over time by sector

The count of reported impacts per year increased over time with substantially more archived impacts in the years 1976, 2003, 2015 and 2018 (Fig. 2). The increased report numbers of these years confirm memorable drought events that are also documented in the literature. Comparing these drought events shows that the relative dominance of the impact-category 'agriculture and livestock farming' present in the reports of 1976 decreased substantially in the later drought years of 2003, 2015, and 2018 in which, however, it is still one of the most affected sectors. Other sectors that emerged with frequent reports are public water supply, forestry, freshwater ecosystems and water quality. In the drought of 2003, high water temperatures and low oxygen levels were initially reported as impacts in the category water quality, but finally led to the great fish dieback reflected by the subtype 'Increased mortality of aquatic species' (9.1) of the category Freshwater ecosystems. The drought years of 2015 and 2018 showed a substantially increased number of reports related to Forestry. These impacts are known to be a response to the sequence of persistent dry and warm periods which accumulated the pressure from water deficit in soil moisture and groundwater. The increasing proportion of forestry impacts likely reflect that recurrent soil-moisture drought with delayed impacts.

Over the entire time period covered by the $EDII_{ALPS}$ impact record, the number of collected drought impacts increased, especially after 2000 and 2010 (Fig. 2). This trend is influenced by (1) general reporting behavior changes with digitization and online media availability, (2) accessibility to drought reports in the recent past being easier than access to historical information, and (3) awareness of the drought hazard having increased along with exacerbating climatic changes and recurring drought events. For the most recent droughts, reports are yet to be published. Thus, the decreasing number of reports for the most recent years is likely an effect of a delay in publishing and then collecting such text-based impact information. In summary, we conclude that while the time trend is biased, identifying major events and an overall tendency towards an increasing risk of drought impacts are robust and relevant observations. With substantially different report numbers from the baseline, the database clearly highlights and captures major drought years and contains the stories of their impacts.

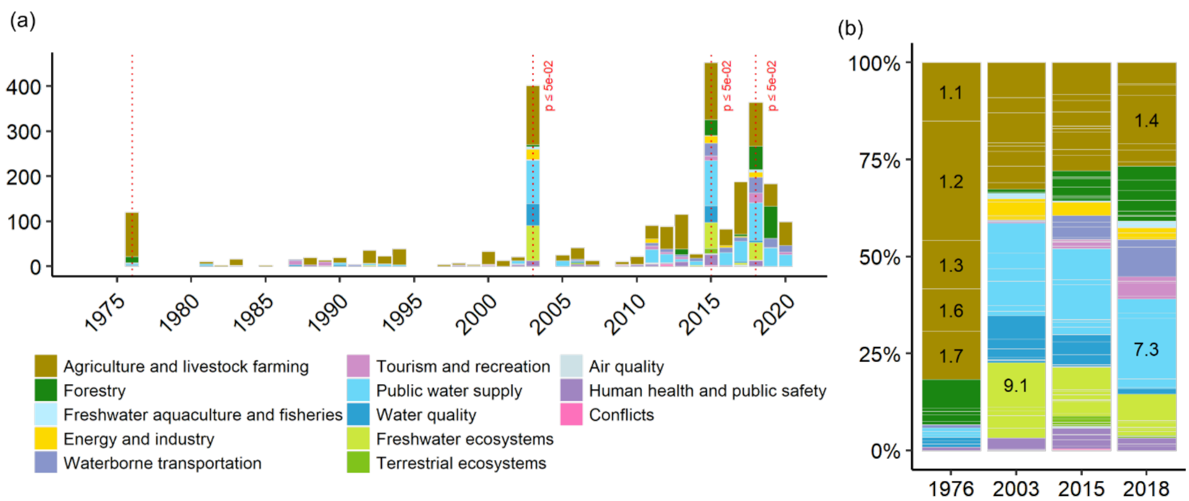

Figure 2. *Reported impacts by categories from 1975 to 2020. (a) Counts of reports per year, outstanding years marked with red dotted lines (details see Stephan et al., 2021). (b) Distributions by type and category for major drought years. Subtypes with a proportion ≥ 10 % per region are labeled.*

Spatial differences

The reported impacts are heterogeneously distributed across the Alpine Space (Deliverable D.T3.1.1, Fig. 3). Several spatial analyses were carried out and the main findings are summarized here. All the conducted spatial analyses used contrasting subregional pairs for comparison: northern region vs. southern region, pre-Alpine region vs. high-altitude region (details published in Stephan et al., 2021), in the ADO case study areas, as well up- and downstream parts of the major river basins of the Alps (details published in Dahlmann et al., 2022).

The number of reports and their contents differ between the main **subregions** (Fig. 3). Most reports in the database are geocoded to the northern region and hence in the Rhine and Danube river basins - again an effect of the data availability rather than an indicator of how strongly regions were affected. In the pre-Alpine region, the majority of impact reports are on agriculture, a fact that is well reflected by the preferred locations of areas with highest water demands for crop production (Fig. 3b). Specific for the high-altitude region are impacts on winter tourism as lack of snow and/or high temperatures impaired the preparation of ski slopes. In the dataset fewer reports are geocoded to the high-altitude region. The lower number of impacts in higher-elevation regions may reflect the rather specific impact types and an overall lower relevance of drought as a hazard due to overall low water demand and/or better water availability. Nevertheless, during summer and early autumn, bans on public water use (subtype 7.3) provide the largest proportion of impacts in both, the high-altitude region as well as the southern region. Drought conditions may deplete alpine tributaries as well as the largely fractured aquifers and their springs often used for drinking water supply, while downstream areas might indeed rely on the surface water from the alpine 'water towers', making both regions vulnerable and at-risk for water restrictions.

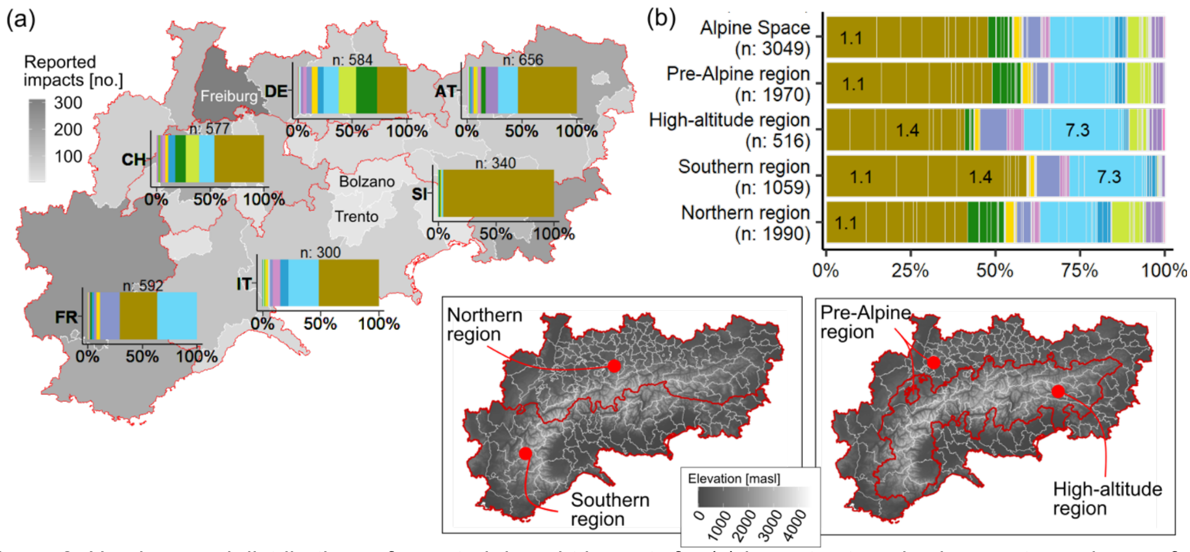

***Figure 3**. Numbers and distributions of reported drought impacts for (a) impact categories by country and map of NUTS 2 regions' impact totals; (b) impact categories and subtypes (types >10% are indicated) for different subregions (map inset). Colors as in Fig.2.*

The NUTS 2 regions that cover **the ADO case study regions** provide another option for regional comparisons based on the EDII$_{ALPS}$ impact data. It becomes apparent that reported impacts archived in this database differ substantially on this small regional scale (Fig. 4). Main differences between these specific NUTS 2 regions include different peak years apart from the common drought year of 2003. In particular the Italian and Slovenian case study regions differ regarding the drought years. Also different composition of the impact categories and types differs. While more diversified impacts were reported for the regions in Austria, France, Switzerland and Italy, the reports from the region in Slovenia primarily concern agriculture and livestock farming. This difference is influenced by the information sources used to compile the EDII$_{ALPS}$ data and the existence of previous and ongoing efforts on agricultural drought and impact monitoring in the region. A substantial proportion of the data stem from the bulletins of the Drought Mitigation Center for Southeastern Europe (DMCSEE), which informs the public and specifically farmers about drought situations. For more information on regional sources and resulting biases, see Stephan et.

al (2021). Agricultural vulnerability to drought, however, is a primary issue in all case study areas, as also the work in Task 5 of the ADO project has documented.

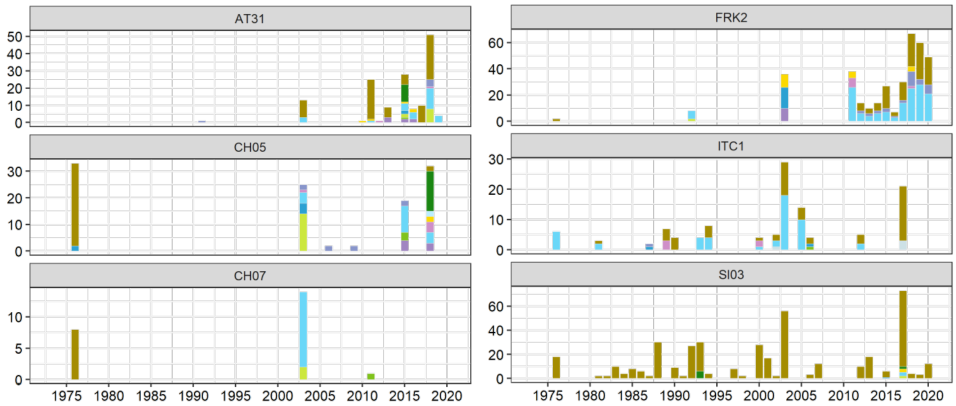

Figure 4. *Number of reported impacts by category between 1975 and 2020 for the NUTS 2 regions that cover the ADO case study regions: AT31 (Upper Austria), CH05 (Thurgau), CH07 (Ticino), FRK2 (Vercors), ITC1 (Orco valley), SI03 (Podravska). Colors as in Fig.2.*

The aim of another regional comparison was to investigate whether **upstream-downstream differences** in the distribution of drought impacts exist in the four major river basins of the European Alps - Rhine, Rhone, Po and Danube. As there is no scientific consensus, how to define up- and downstream, two approaches to classify up- and downstream regions were developed to compare regional impacts from the $EDII_{ALPS}$. The first classification is based on the distances to the main sink, and the second classification on human influence. Both approaches were applied on the Rhine, Po, Rhone and Danube basin within the Alpine Space (Fig. 5). The $EDII_{ALPS}$ database provided drought impact data to analyze the distribution patterns of reported drought impacts from 2000-2020. The results suggest a strong regional variability regarding the temporal and spatial distribution of drought impacts within the individual basins. But they support the general hypothesis: for both classifications the number of drought impacts per area (impact density) is higher in downstream regions. For the classification based on distances differences are statistically significant for the Rhine and Danube basin. The analysis by Dahlmann et al. (2022) further suggests that differences in the drought hazard's severity played a minor role for the impact asymmetries. Nevertheless, further studies will be necessary that link impacts and basin-specific drought hazard more directly than it could be done in this effort. The ADO platform combines all necessary data for such further analyses.

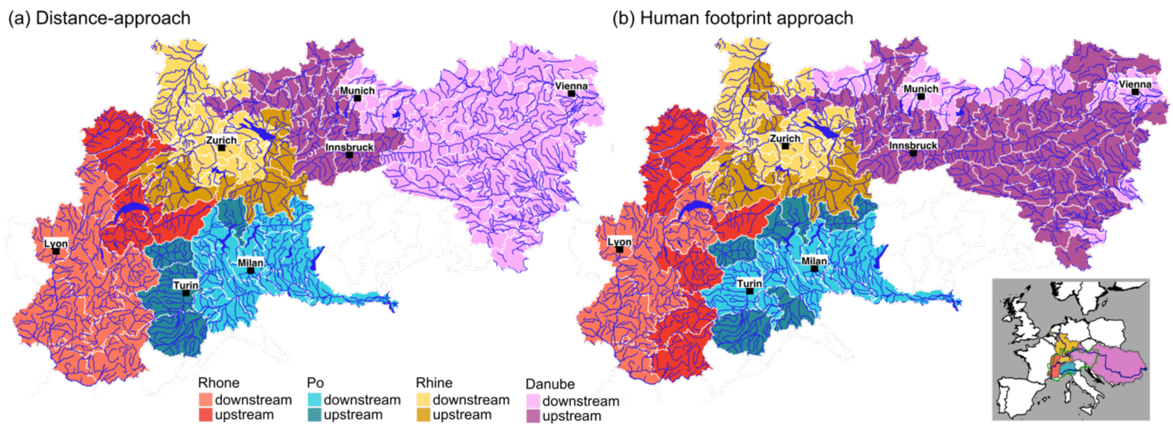

Figure 5*. NUTS 3 regions across the Alpine Space classified into up- and downstream parts of each river basin applying (a) the distance approach and (b) the human footprint approach. (from Dahlmann et al., 2022)*

Impact seasonality

The reported drought impacts occurred mostly in summer, followed by autumn and spring, and least in winter (Fig. 6). The dominance of the affected sectors agriculture and livestock farming and public water supply is present throughout the year and seasons with the highest frequencies in the months of June, July and August. This seasonality confirms the expectation that drought impacts occur mostly in summer. Additionally stressed by high air temperatures and evapotranspiration, this season has the highest water demands, and hence, higher potential water shortages occur despite a mostly balanced annual precipitation in the Northern and Western parts of the Alpine Space, as has previously been shown by Kruse et al. (2010). In early autumn natural soil and catchment water storages are depleted and exceptional conditions during that low flow season may therefore lead to drought impacts.

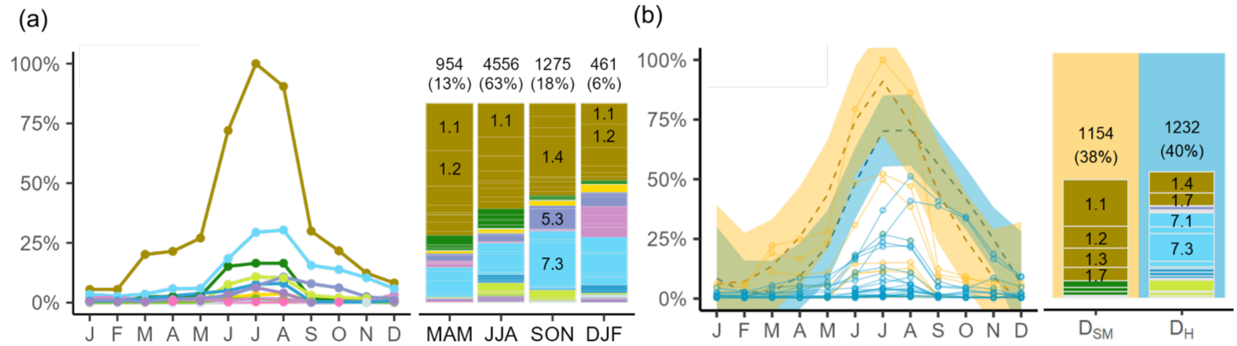

***Figure 6**. Annual distribution of reported impact with (a) by categories aggregated per month (line diagrams) and season (bar plots). Subtypes with a proportion ≥ 10 % per season are labeled. (b) by impact group and subtypes with D_{SM} (yellow) or D_H types (blue). Seasonal regimes for D_{SM} (yellow lines) and D_H impacts (blue lines) are loess curves with standard errors (dotted line with coloured symbol). Subtypes with a proportion ≥ 5 % are labeled. Monthly values in a) and b) are relative to frequency of the month with most impacts. Total counts of each season/each group are given on top of the bars, the proportion in brackets relates to the amount of impacts assigned to the season/group. Colors as in Fig. 2.*

Comparing the seasons in relative terms, the highest diversity of affected sectors is presented for autumn and winter. Whereas in summer, most reported impacts are about reduced productivity of annual crop cultivation (1.1) and other consequences in the agricultural sector, the most reported impact types in autumn are reduced availability of irrigation water (1.4), bans on domestic and public water use (7.3), and other impacts on waterborne transportation (5.3). This suggests that impacted water sectors shift from mostly the agricultural production in summer towards a number of water uses relying on surface and groundwater in autumn. With the aim to distinguish impacts with such similar causes, we grouped impact types as triggered by soil moisture drought (D_{SM}) with a majority from the sectors agriculture and livestock farming and forestry, and as triggered by hydrological drought (D_H) with a majority from the sectors public water supply, water quality and freshwater ecosystems (Fig. 1 and 3b). The annual distribution of the grouped D_{SM} impacts and D_H impacts shows that D_H impacts have a delayed seasonal start and later termination (Fig. 3b). Whereas D_{SM} impacts start to occur more frequently in spring, D_H impact start to occur more frequent in late spring (May) and early summer (June). Accordingly, the peak of D_{SM} impacts is in July, and of D_H impacts in August. And especially in autumn, when D_{SM} impacts decline quickly, D_H impacts still occur and more frequent than in spring. This delayed effect confirms the common understanding that drought types occur in a particular order and this analysis shows that the concept is reflected not only in hydro-meteorological indices but also in the wider impacts of drought. Nevertheless, the role of winter should not be neglected in driver-impact relations. Several studies have shown winter as an essential season relevant to the drought development, both, in winter directly, due to delayed effects from summer and autumn (drained natural stores) accumulating in winter and particularly in the following year, due to a lack of winter snow as a reserve and therefore a potential precursor for water deficits in following seasons (van Loon et al., 2010; Livneh and Badger, 2020).

Recommendations for impact monitoring and concluding remarks

This assessment confirmed that, similar to many regions in the world, in the Alpine Space region, agriculture and livestock farming is the sector that is impacted most frequently by drought. Based on the $EDII_{ALPS}$ data used for this assessment, (early) summer, i.e. the growing season, has emerged as the key season in which impacts occurred in the past. Local variations in this region with strongly varying terrain, however, might deviate. In order to understand the more specific regional risk of drought impacts on particular crops, grasslands, and in particular subregions, building a more systematically consistent impact database is recommended. Based on the core that the $EDII_{ALPS}$ now provides continued efforts of impact monitoring would be beneficial. One example how to proceed towards such desired systematic impact monitoring effort is already followed in Slovenia, through DMCSEE and as a result of the DriDanube project and by the Czech and Slovak observer networks for the platform Intersucho.cz. In the future, more detailed and systematic impact data might then have the required completeness and representativeness to be used for the validation of vulnerability and risk assessments (Deliverable D3.3.1) and to train impact-based prediction and forecasting (Deliverable D3.3.2).

Judging by the frequency of the analyzed reports, other water sectors have also emerged as relevant. Most important and ranking second in the list is the public water supply sector. The presented impact assessment based on the $EDII_{ALPS}$ has the strength to reveal this impact as relevant and to provide narratives of the diverse nature of such impacts. But the information coverage sourced from media and drought reports is insufficient to provide a systematic account of the overall status of water security during drought events. In the absence of a database that could be tapped for more systematic water-supply-impact data, impact monitoring for public water supply might also consider building a network of communities reporting their issues. In addition, locally relevant water sources for public water supply (groundwater, springs, surface water) might be mapped to direct a targeted selection of the most useful hazard index to monitor. (Late) Summer has emerged as the key season to expect impacts from drought in sectors that rely on surface and subsurface water (rather than soil moisture). Although direct winter drought impacts are rare in the $EDII_{ALPS}$, this season should not be neglected in monitoring and risk analysis as snowpack storage of water during winter is important. Overall, the seasonal and spatial patterns of drought impact occurrences follow the water availability and provide relevant information for a targeted monitoring to reduce the risk of such impacts happening.

The spatial and temporal analysis presented here and in the scientific publications referred to provide proof for the existence of drought impacts and an overview of major regional patterns. To extract local anecdotal knowledge, the impact reports with their categorization and descriptive texts can now be directly visualized on the ADO platform and users can therefore learn more about specific impacts that happened in their region and around. All data is also available for further local study and any other cross-regional comparisons that may inform setting priorities of measures for example. Readers and follow-up projects are encouraged to use the impact report data and expand this first regional analysis while at the same time carefully taking into account the biases due to the availability and collection efforts of drought impact reports.

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