GfÖ Workshop

Impacts of the severe 2018 summer drought on the functioning of temperate forests and other terrestrial ecosystems

June 4th 2019

University of Basel, Switzerland
Lecture Hall of the Botanical Institute
Schönbeinstrasse 6
Basel

Directions:
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Programme

08:30 – 08:40 **Welcome**

Kahmen A (University of Basel, Switzerland)

08:40 – 09:00 **The 2018 drought effects on 12 temperate tree species within the IDENT diversity field experiment**

Hajek P, Nock C, Bauhus J, Paquette A, Scherer-Lorenzen M, Messier C, Rose L (University of Freiburg, Germany)

09:00 – 09:20 **Three examples of trees death by natural and experimental drought**

Grams T (TU Munich, Germany)

09:20 – 09:40 **Hydraulic response of European beech, Norway spruce and Douglas fir during an exceptionally dry summer**

Schumann K, Leuschner C, Fischer M, Schuldt B (University of Würzburg, Germany; University of Göttingen, Germany)

09:40 – 10:00 **Physiological causes of tree damages and mortality in European tree species during the extreme summer drought 2018**

Arend M, Patthey R, Hoch G, Schuldt B, Link R, Kahmen A (University of Basel, Switzerland; University of Würzburg, Germany)

10:00 – 10:30 **Coffee break/Poster**

10:30 – 10:50 **Impact of drought on forest dynamics – learning from extreme drought years**

Rigling A et al. (WSL, Switzerland)

10:50 – 11:10 **Mid-term effects of summer drought 2018 on beech individuals (Fagus sylvatica) with early leaf senescence**

Aymon C, Kistler M, Vitasse Y, Gessler A, Gossner M, Hagedorn F, Rigling A, Wasem U, Wohlgemuth T, (WSL, Switzerland)

11:10 – 11:30 **Drought impact on gas exchange, water relations and VOC emissions of a Pinus sylvestris stand in southern Germany in 2018**

Werner C, Grün M, Kreuzwieser J, Bergner N, Christen A (University of Freiburg, Germany)

11:30 – 11:50 **Effect of the 2018 extreme summer on CO_2 and H_2O fluxes of two contrasting forests in Switzerland**

Gharun M, Hörtnagl L, Paul-Limoges E, Eugster W, Meier P, Baur T, Burri S, Buchmann N (ETH Zurich, Switzerland)

11:50 – 12:10 **The European 2018 drought impact on functioning of Swiss temperate forests: Insights from observations and a 3D tomography approach**

Damm A, Paul-Limoges E, Kükenbrink D, Morsdorf F (University of Zurich,

Switzerland; Eawag, Switzerland)

12:10 – 12:30 **Quantifying impacts of the drought 2018 on European ecosystems in comparison to 2003**

Buras A, Rammig A, Zang CS (TU Munich, Germany)

12:30 – 13:30 **Lunch break**

13:30– 15:00 **Workshop**

15:00 – 15:30 **Coffee break/Poster**

15:30 – 17:00 **Workshop**

17:00 – 17:30 **Summary and closing remarks**

The 2018 drought effects on 12 temperate tree species within the IDENT diversity field experiment

Hajek P, Nock C, Bauhus J, Paquette A, Scherer-Lorenzen M, Messier C, Rose L

University of Freiburg, Germany

In 2018, central Europe was subject to the most severe drought episode ever recorded with drastic consequences for the European forest ecosystems. A high level of tree diversity may buffer forest ecosystems against declines in their functioning according to the insurance hypothesis. The Freiburg IDENT (International Diversity *Experiment* Network with Trees) site (Freiburg, Germany) allows to test whether more diverse forests are potentially more resistant to the risks of drought under field conditions.

The fourfold replicated block design with 408 plots includes monocultures as well as 2, 4 and 6 species mixtures of six Northern American and six European tree species resulting in a gradient in species richness (SR) and functional diversity (FD). Forty-nine trees were planted per plot in 2013 with a distance of 0.45 m. We measured leaf area index (LAI), canopy damage and mortality rates of all tree species (20,000 individual trees in total) and compare pre-drought (May) and drought (July-October) conditions.

The leaf area index peaked in July 2018 and continuously declined about 20-65% during the following three months of drought. The minimum LAI was measured within the last two weeks of August (week 34 and 35) for the most drought affected genera *Betula* and *Larix*. A slight increase in LAI of the respective species after week 36 indicates a recovery phase with the sprout of new leaves subsequent to the first rain event (31.08.2018, 30 mm). The onset of the final leaf fall in autumn started during week 40. The LAI in mixed plots was generally higher than in monocultures, however species mixture did not consistently reduce leaf loss. Tree canopy damage (leaf coloration) became obvious for *Betula* and *Larix* already during the first week of July, whereas the maximum extent of premature leaf senescence in *Pinus* and *Quercus* was observed ten weeks later. *Acer* and *Picea* species were less affected by leaf damage, with the notable exception that some plots of *Picea* were subject to bark beetle attacks. In plots with high species richness, trees were not systematically resistant to premature leaf senescence. The whole-tree mortality of conifers was higher in mixtures with *Acer platanus* and *Quercus rubra*. The most drought-sensitive species were *Betula papyfera* and *Larix laricina* (30 % and 60 % mortality, respectively).

The diversity-insurance-hypothesis cannot be generalized for all species combinations in European forest ecosystems, i.e. higher diversity not necessarily provides resistance to drought predicted for the future. The mechanism behind species richness and mixture effects are state of our current investigations.

Three examples of trees death by natural and experimental drought

Grams T
TU Munich, Germany

I will give three brief examples related to the death of European beech (*Fagus sylvatica*) and, in particular, Norway spruce (*Picea abies*) under drought.

Example 1 – Comparing tree death in 2018 in pure and mixed stands
Data come from five sites along a natural precipitation gradient across Bavaria, Germany. The sites range from dry, northern Bavaria (Franconia) to the south-east close to the Alps with much higher precipitation. At each site three plots have been established in 2013 with (a) pure beech, (b) pure spruce and (c) beech/spruce mixed stands of 60-100 year old trees. Focus is on tree performance and death of trees in 2018 growing in mixed compared to pure stands.

Example 2 – Drought stressed spruce trees dying from bark beetle attack
Findings come from a throughfall-exclusion experiment in Kranzberg Forest (k.roof), southern Germany. Successful bark beetle attack was limited to drought-stressed spruce trees with significantly reduced stem diameter growth in previous years. Other parameters such as pre-dawn water potential, NSC concentration or sap flow did not relate to infestation and subsequent tree death by bark beetles.

Example 3 – Spruce trees dying from drought
The throughfall-exclusion experiment (TEE) at Kranzberg Forest with about 70 trees readily accessible via canopy crane allows for detailed assessments of leaf physiological processes in drought stressed trees. Experimental summer drought started in 2014 and was repeated throughout 2018, resulting in significant drought effects in both species. For example, pre-dawn twig water potentials reached values as low as -2.5 MPa, related to reductions in photosynthesis and stem diameter growth by up to 80% under drought, in particular in spruce. Spruce trees, apparently dying from drought, did not show differences in NSC concentrations or water transport capacities compared to surviving spruce under drought.

Hydraulic response of European beech, Norway spruce and Douglas fir during an exceptionally dry summer

Schumann K, Leuschner C, Fischer M, Schuldt B

University of Würzburg, Germany

University of Göttingen, Germany

Central European forests are increasingly affected by severe drought events, highlighting the need for adaptive forest management strategies. Norway Spruce, the commercially most important but potentially drought-sensitive species, might widely be replaced by Douglas fir in future forests. To confirm the species' higher drought-stress resistance, branch hydraulic and foliar characteristics of mature trees of the two conifers were related to stomatal regulation patterns, leaf water potential and sap flux density during the extreme summer drought of 2018, and compared to European beech. Although the three species differed in branch specific hydraulic conductivity, no species differences in embolism resistance and turgor loss point were observed. Douglas fir had the smallest hydraulic safety margin. Unexpectedly, sap flow in Douglas fir reached zero flux already in early August, while flux continuously declined in beech and spruce until mid of September. In beech, this was accompanied by a steady leaf water potential decline, indicating an anisohydric stomatal control strategy, while potentials remained constant at either high (spruce) or low (Douglas fir) level in the conifers. Stomatal conductance was sensitively regulated in response to air humidity in beech and spruce, but not in Douglas fir, which showed signs of an isohydric behaviour. This raises questions about the drought tolerance of this species.

Physiological causes of tree damages and mortality in European tree species during the extreme summer drought 2018

Arend M, Patthey R, Hoch G, Schuldt B, Link R, Kahmen A

University of Basel, Switzerland

University of Würzburg, Germany

In 2018, an exceptionally severe summer drought affected forest ecosystems in wide parts of Northern and central Europe, causing striking leaf and canopy damages and tree mortality. At the recently established Swiss Canopy Crane II research site, we investigated the effect of this severe drought stress event on the water and carbon sta- tus of adult individuals of nine European tree species (*Fagus sylvatica, Quercus petraea, Acer pseudoplatanus, Carpinus betulus, Fraxinus excelsior, Sorbus torminalis, Picea abies, Abies alba, Pinus sylvestris*). Mid-day twig water potentials, measured bi-weekly throughout the season, reached very low values in summer and early autumn, coming close to, or even exceeding, the xylem pressure at 50% loss of hydraulic conductance (P50 value). Mea- surements of diurnal stem diameter variations revealed long-lasting stem shrinkages, indicating the development of sustained tree water deficits. Stomatal conductance was strongly reduced in P. abies, A. alba and F. sylvatica, while the other tree species maintained much higher values. Among the observed tree species, only F. sylvatica and P. abies developed visible drought stress symptoms, with strong leaf browning and necrosis in F. sylvatica (but no mortality) and canopy die-back and subsequent tree death in P. abies. The canopy die-back in P. abies was accompanied by a sudden decline of mid-day water potentials to exceptionally low values and a complete loss of xylem hydraulic conductivity, suggesting desiccation and hydraulic failure as the main cause of drought-induced mortality of P. abies. Still, the analysis of non-structural carbohydrates is underway to explore the effect of the exceptionally severe summer drought in 2018 on the carbon status of the investigated tree species. Taken together, our observations show the particular sensitivity of P. abies and F. sylvatica to drought, and these tree species may therefore be considered at high risk of decline under the conditions of a future climate with more frequent and intense droughts.

Impact of drought on forest dynamics – learning from extreme drought years

Rigling A et al.

WSL, Switzerland

Climate change is taking on striking proportions in Switzerland and extreme weather events such as winter storms, late frosts and drought years have increasingly left their mark on our forests in recent years. It must be assumed that periods of heat and drought will become even more frequent in the future. What does this mean for our forests? The extreme hot and dry year of the past decades and specifically the year 2018 offer unique opportunities to learn about the resistance and resilience of our forest ecosystems to extraordinary drought. I will present newest results on different scales in space and time from long-term monitoring programs and from new short-term initiatives of the Swiss Federal Research Institute WSL. The focus will be on Norway spruce, Scots pine and European beech. Our data show that the sensitivities vary considerably depending on the tree species and location. The future development of our forests will depend on the combination and timing of weather extremes. Forests can cope with a single dry year, but several successive hot and dry years combined with storms, pests and diseases will lead to massive changes in the growth dynamics and ultimately the tree species composition of our forests.

Mid-term effects of summer drought 2018 on beech individuals (*Fagus sylvatica*) with early leaf senescence

Aymon C, Kistler M, Vitasse Y, Gessler A, Gossner M, Hagedorn F, Rigling A, Wasem U, Wohlgemuth T

WSL, Switzerland

The summer drought of 2018 was the longest and most severe drought in several regions of Switzerland since the beginning of weather stations records. i.e. since 1864. In addition, this summer was particularly warm and ranked as the warmest since 1864 when accounting for the period from April to September, even warmer than the exceptional summer 2003. During the hottest period (July/August) of this drought, early leaf senescence and leaf fall was recognized for various broadleaved tree species in the driest regions of Switzerland, especially for beech. In August and September 2018, the WSL launched an initiative to monitor how these beeches will perform in the future. In particular, the purpose of this study is to look at the impact of the summer drought 2018 on beech individuals over the course of two years (2018-2020).

A total of 825 beech individuals showing early leaf senescence (test trees) were marked and assessed in the four cantons of Basel, Schaffhausen, Zürich and Aargau. Another 139 trees showing no premature leaf senescence were also selected in the vicinity of the affected trees to serve as control trees. After the first assessment during the summer 2018, a second visit of all 964 trees was carried out in April 2019, focusing on phenology and vitality signs such as the crown mortality, the presence of bark exudation or the state of the bark. Bud break and leaf out was monitored for a subset of 118 selected trees (48 control trees and 70 test trees).

Preliminary results show that roughly 45% of the marked trees have more than 10% crown mortality during the spring 2019, with an overall crown mortality of 13%. However, the impact of the drought depends on the region. Trees in Basel and Schaffhausen tend to be more affected than those in Zürich, in agreement with the geographically variable severity of the 2018-drought. Looking at pathogens, ~15% of all the trees show signs of bark exudation to various extent. The phenology of the affected trees was also impacted with, in some cases, slower bud development rate.

During the summer 2019, a third assessment of the 964 trees is planned in order to measure new parameters such as the degree of defoliation, crown closure or soil conditions. As drought will occur more frequently in the future, such monitoring and quantification of the damages will be increasingly needed to allow an in-depth information of policy makers and foresters and support decisions in forestry.

Drought impact on gas exchange, water relations and VOC emissions of a *Pinus sylvestris* stand in southern Germany in 2018

Werner C, Grün M, Kreuzwieser J, Bergner N, Christen A

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We investigated the impact of the 2018 drought and heat spell in a 50 year old Scots pine (*Pinus sylvestris* L.) forest at the meteorological site at Hartheim in the upper Rhine valley (South-West Germany). Compared to other regions of Germany, the orographic location results in low precipitation in this region with mean annual precipitation of 642 mm. 2018 was the driest (409 mm) and the second warmest year (12.6°) in Hartheim since establishment of the research site in 1978. In terms of solar irradiance 2018 was the year with second highest rates (4,63 GJ m^{-2} y^{-1}) since 1978 and soil moisture decreased significantly and from 2004 to 2017. Moreover, annual total longwave outgoing radiation (thermal emittance of the canopy) increased during the last 10 years, which might be an indication of canopy dye-back with higher ratio of dead needles and lower transpirational cooling – which is in line with observation of spars canopies structures and a high amount of senescence needles.

The 2018 drought strongly impacted the pine tree ecophysiology with marked decline of assimilation rates, leaf water potentials, and biogenic volatile organic compound (BVOC) emissions. The water scarcity resulted in strong decline of predawn and midday leaf water potentials (> -6 MPa) and net carbon dioxide assimilation (≤ 0). Furthermore, a depletion of storage pools for BVOC-emissions occurred. The Hartheim pine forest is currently characterised by high tree mortality. Therefore, repeated drought events, like the one in 2018, can have detrimental effect on this pine forest in the near future.

Effect of the 2018 extreme summer on CO_2 and H_2O fluxes of two contrasting forests in Switzerland

Gharun M, Hörtnagl L, Paul-Limoges E, Eugster W, Meier P, Baur T, Burri S, Buchmann N

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Forest ecosystems play a major role in the global cycles of carbon and water. This exchange of carbon and water is strongly affected by drought events and heat waves. Focusing on direct measurements, this study uses recent eddy covariance measurements to assess the impact of the 2018 extreme summer on the CO_2 and H_2O fluxes of two contrasting forest types in Switzerland. The ICOS Candidate Class 1 Ecosystem site Davos (CH-DAV) is a sub-alpine coniferous forest dominated by Norway spruce (*Picea abies* (L.) Karst) and is located at 1639 m elevation in the eastern part of the Swiss Alps. The Lägeren forest (CH-LAE) is a mixed deciduous forest with a high species diversity, dominated by beech (*Fagus sylvatica*), and located at 689 m elevation in the easternmost outcrop of the Jura mountain range. We aim to address three main research questions in this study: 1) How did the summer 2018 affect the net ecosystem exchange of carbon (NEE) and the total fluxes of water vapor (i.e. evapotranspiration)? 2) How did the extreme summer affect the contributions of gross primary productivity (GPP) and ecosystem respiration (R_{eco}) to NEE, compared to previous years? 3) Did water use efficiency increase in both forests in 2018 in response to drier atmospheric conditions?

The European 2018 drought impact on functioning of Swiss temperate forests: Insights from observations and a 3D tomography approach

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Photosynthesis and related processes including net CO_2 assimilation and transpiration (T) are sensitive indicators of environmental change. With ongoing climate change, weather extremes are expected to occur more frequently. Associated increases in temperatures and drought events will alter ecosystems, but the severity and direction of these changes remain unclear. In order to advance our understanding of these vegetation response dynamics and inform models, sensitive multi-sensor measurements are needed at ecosystem-level.

We complemented the well-instrumented mixed deciduous forest Lageren site in Switzerland with a novel remote sensing (RS) instrument, the fluorescence spectrometer (FloX), to observe sun-induced chlorophyll fluorescence (SIF) besides eddy covariance (EC) based carbon and water flux measurements. We developed a novel approach using concurrent below and above canopy EC measurements to partition water vapour fluxes into evaporation and T, based on the coupling of the layers and on the origin of the water vapour sources. We then explored the mechanistic link between T and SIF derived from continuous tower-based measurements, as well as their link to stomatal conductance, water stress, and other environmental factors. We also collected all relevant information to create a virtual scene of the canopy and provide a tomographic perspective on the gas exchange of a forest canopy based on 3D radiative transfer models, ecohydrological models, in-situ RS and micrometeorological observations.

The European drought in 2018 substantially impacted the functioning of ecosystems across Europe and provides an interesting case to evaluate the sensitivity of our new approaches. We found that, in our mixed forest, mid-afternoon reductions in T occur during periods of high vapour pressure deficit in summer. T and SIF similarly declined during the drought of the 2018 summer, due to the water stress imposed on the trees. We observe changing vertical profiles of gas exchange in dependency on the drought. Our results contribute to a better understanding of gas exchange dynamics during drought conditions and the sensitivity of RS for such ecosystem responses. Provided insight will guide further developments of RS (including SIF) informed modelling approaches to estimate T across spatial scales. Our findings provide substantial insights to facilitate the harmonization of remote sensing and in situ gas exchange measurements.

Quantifying impacts of the drought 2018 on European ecosystems in comparison to 2003

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In recent decades an increasing persistence of atmospheric circulation patterns has been observed. In the course of the associated long-lasting anticyclonic summer circulations, heat waves and drought spells often coincide leading to so-called hotter droughts. Previous hotter droughts caused a decrease in agricultural yields and increase in tree mortality, and thus, had a remarkable effect on carbon budgets and negative economic impacts. Consequently, a better understanding of ecosystem responses to hotter droughts and the underlying mechanisms is crucial. In this context, the European hotter droughts of the years 2003 and 2018 may be considered as key events. As a first step towards the quantification of their causes and consequences, we here assess anomalies of atmospheric circulation patterns, temperature loads, and climatic water balance as potential drivers of ecosystem responses as quantified with the MODIS enhanced vegetation index (EVI). Our assessment indicates the climatic properties of 2018 to locally supersede those of the European drought in 2003. In contrast to 2003, 2018 was characterized by a climatic dipole, featuring hot and dry weather conditions north of the Alps but comparably cool and moist conditions across large parts of the Mediterranean. Analyzing ecosystem response of five dominant land-cover classes, we generally observed significant positive effects of April-July climatic water balance on ecosystem productivity which appeared to affect a larger area and be significantly stronger in 2018 compared to 2003. Moreover, we found a significantly higher sensitivity of pastures and arable land to climatic water balance compared to forests. Frequently observed legacy effects of forest ecosystems may add to the complexity of this picture at a later stage. In conclusion, this study provides valuable insights into the heterogeneous responses of European ecosystems to extreme drought, which is of particular importance due to the anticipated increasing frequency of hotter droughts in the 21st century.