Impact of the European drought 2018 on tree health and mortality in Swiss forest ecosystems

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Introduction

The ongoing warming of Earth's climate is accompanied by an intensified frequency of extreme events. Changes to both the global water and carbon cycles in which forest ecosystems play a crucial role can have impacts on the environment and humans.

The summer of 2018 was one of the driest summers in Switzerland (Fig. 1) in recent history. Reduced leaf water content, leaf discoloration and tree mortality were observed among many forests. We took advantage of the naturally occurring sequence of pre-drought, drought, and post-drought conditions between 2017 and 2019 to analyze:

- How much of the Swiss forest was strongly affected by the 2018 drought?
- How do the drought impacts depend on environmental factors?

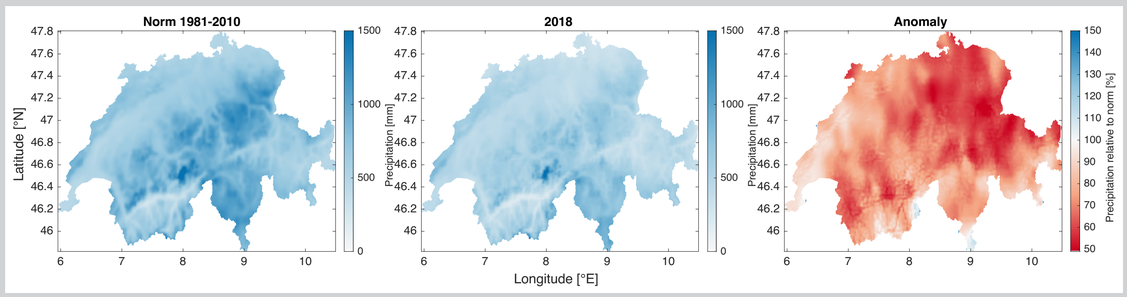

Fig. 1: Accumulated total precipitation for the periods of March to August of the norm 1981-2010, 2018, and the precipitation anomaly of 2018 relative to the norm (Data provided by MeteoSwiss).

Data & Methods

We analysed Sentinel-2 bottom of atmosphere reflectance imagery from August 2017, 2018, and 2019 at a 10x10 m spatial resolution. The normalised difference water index (NDWI) [1] was taken as a proxy for drought effects on forests. The NDWI is sensitive to leaf water content, an early response to drought conditions, and is stable over challenging topography, like in Switzerland.

- Resistance (NDWI change between 2017-2018)
- Recovery (NDWI change between 2018-2019)
- Resilience (NDWI change between 2017-2019)

We used linear regression analysis to assess the relationship between the percentage of negatively affected forest pixels (decrease of NDWI of >10%) for the canton of Zürich and following individual environmental variables:

Climate drivers:
- Precipitation, Temperature

Topographic modifiers:
- Elevation, slope, aspect, potential direct incident radiation, exposition

Forest stand characteristics:
- Distance to forest edge, heterogeneity within forest stand, tree type (coniferous/broadleaf)

Results

We observe a non-spatially clustered distribution of forest resilience (NDWI difference between 2017-2019) and we find that in similar regions of the canton there are both areas with increases and decreases in NDWI (Fig. 2). This implies that not large fractions of the forest are being lost but rather effects of the drought are scattered but generalized.

We find that different drivers are associated with forest resistance, recovery and resilience (Fig. 3). Nonetheless, topography is generally important for all the phases and effects of the drought, while climate and forest stand properties seem more relevant for resistance.

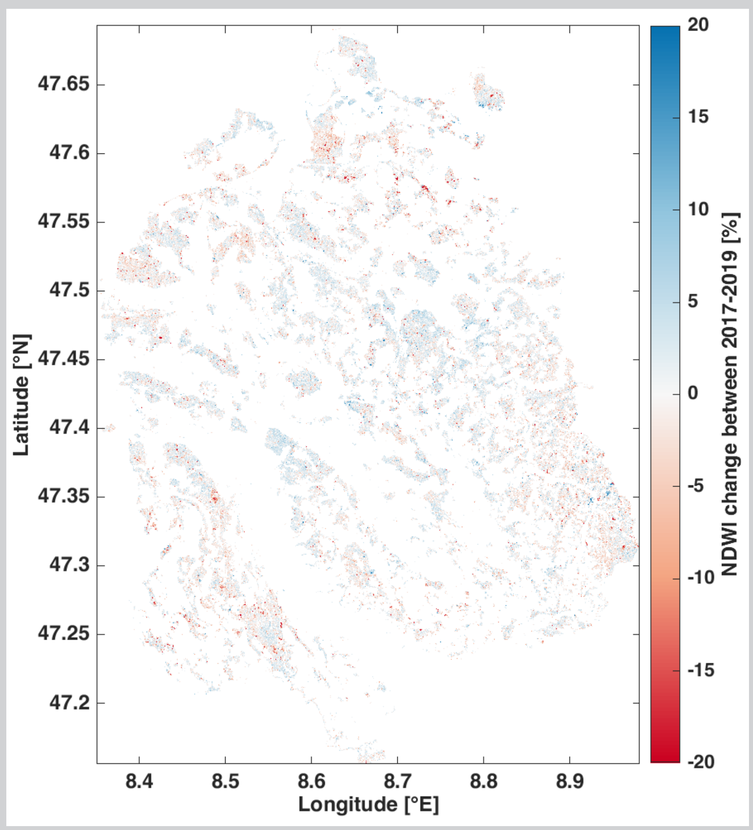

Fig. 2: Resilience (NDWI change between 2017 and 2019) for forested areas for the canton of Zürich (northern Switzerland) in red to blue colors, non-forested areas are white. Small patches in dark red represent damaged forest area.

		Resistance (2017-2018)	Recovery (2018-2019)	Resilience (2017-2019)
Heavily affected pixels		1.36%	0.2%	0.47%
Climate	Drier	↗	→	↗
	Hotter	↗	→	↗
Topography	Higher elevation	↘	→	→
	Steeper slopes	↘	→	↘
	South facing slope	→	→	→
	Higher potential incident radiation	↗	→	↗
	More exposed position	↘	→	↗
Forest stand	Closer to forest edge	↗	→	↗
	More heterogenous	↘	→	→
	More coniferous trees	→	→	→

Slope of the normalised regression line: ≥ 10, 0, ≤ -10

R-square: 0, 0.2, 0.4, 0.6, 0.8, 1

Fig. 3: Environmental factors and their correlation with negative NDWI change (i.e forested area damaged by the 2018 summer drought or as consequence in the successive year) for the canton of Zürich. The slopes of the regressions between the proportion of forest areas with negative NDWI changes and the modifying environmental factor are indicated by the direction of the arrows.

On the positive side, recovery seems less affected by the drivers with the exception of south facing slopes - usually associated with more stressful conditions for forests.

Finally, resilience is greatly affected by topographic factors, suggesting that in the topographical variable Swiss forests, predicted droughts may strongly affect forest persistence.

Discussion

Based on decreses in NDWI values from the pre-drought year 2017 to the drought year 2018, we estimated that 1.36% of the forest area in the canton Zürich was not resistant to the drought event of 2018. This number is low compared to nation-wide field assessments [2], reporting substantial crown defoliation (>60%) for 5.9% of Norway spruce (*Picea abies*) and for 2.8% of European beech (*Fagus sylvatica*) or 4.7% and 1.2% of trees dying after the drought event, respectively.

Reported extents of affected areas are the highest on record for Switzerland and they are even considerably larger than the second highest mortality rates recorded in 1994.

Forest resilience in the canton of Zürich was strongly related to topographic site characteristics, followed by forest stand variables and climate variables being only weak predictors.

- Topographically exposed locations were the most vulnerable due to lower buffering capacity for soil water availability in uphill positions.
- Flatter areas as well as slopes with a high potential incident radiation showed low resilience values likely because of high input energy and thus high evapotranspirative demands.
- Higher vulnerability to water stress was found at forest edges, possibly due to less favorable micro-climatic conditions like higher surface temperatures that also determine a higher evapotranspirative demand and thus accelerate soil water stress.

Conclusion & Outlook

We have shown the suitability of satellite data to assess the impact of extreme events such as droughts on the structure and functioning of forest ecosystems on a regional scale and across large contiguous areas such as entire Switzerland [3].

Further research will focus on non-linear relationships and interactions between environmental modifiers on drought-induced impacts on forest ecosystems.

References & Acknowledgments

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