FRIEDRICH-SCHILLER-
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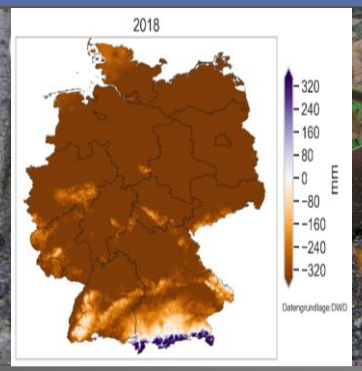
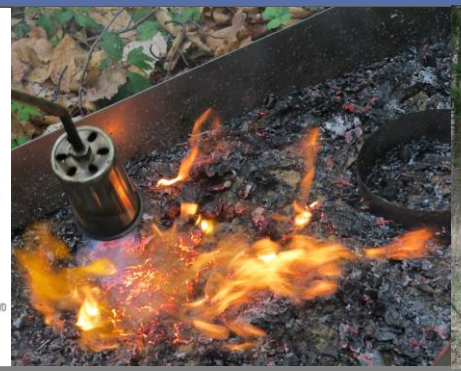
JENA

Ökosystemstörungen und Extremereignisse als Steuergrößen für Menge und Zusammensetzung der gelösten und partikulären organischen Substanz

Ecosystem disturbances and extrem events as key drivers for amount and quality of dissolved and particulate organic matter

Beate Michalzik, Kerstin Näthe, Karin Potthast, Alexander Tischer et al.




Introduction

- Disturbance is any relatively discrete event in time and space that disrupts the structure of populations, communities, and ecosystems and causes changes in resource availability or the physical environment. (Pickett & White, 1985; Chapin et al., 2002)

- The impact of disturbance on ecosystem processes depends on its type, size, frequency, timing, and severity/intensity. (Chapin et al., 2002 Principles of Terrestrial Ecosystem Ecology)

Generalisierte Definition Störungsereignis

Störungen sind zeitlich und räumlich diskrete Ereignisse, die zum Verlust von lebender Biomasse führen und die Verfügbarkeit von Ressourcen in Lebensgemeinschaften verändern.

(Wohlgemuth et al., 2019)

Introduction

Hot spots and hot moments

"Biogeochemical hot spots are areas (or patches) that show disproportionately high reaction rates relative to the surrounding area (or matrix).

Hot moments are short periods of time that show disproportionately high reaction rates relative to longer intervening time periods."

(McClain et al., 2003)

Introduction

Dissolved organic matter -DOM

- dissolved organic forms of carbon (DOC), nitrogen (DON), phosphorus (DOP) and sulfur (DOS) of < 0.45 µm in pore size

- consists of a continuum of organic substances ranging from defined small molecules to highly polymeric humic substances

- research started in the early 1980-ies and peaked in the mid to late 1990-ies focusing on DOM in forest soils

DOC is considered as the most important OC fraction that drives biogeochemical cycles and interaction between the bio-, hydro- and geosphere (Amon, 2002)

Introduction

Particulate organic matter – POM

However, the particulate fractions of organic matter (0.45 µm < POM < 500 µm), being mobile and transported in solution, are scarcely investigated.

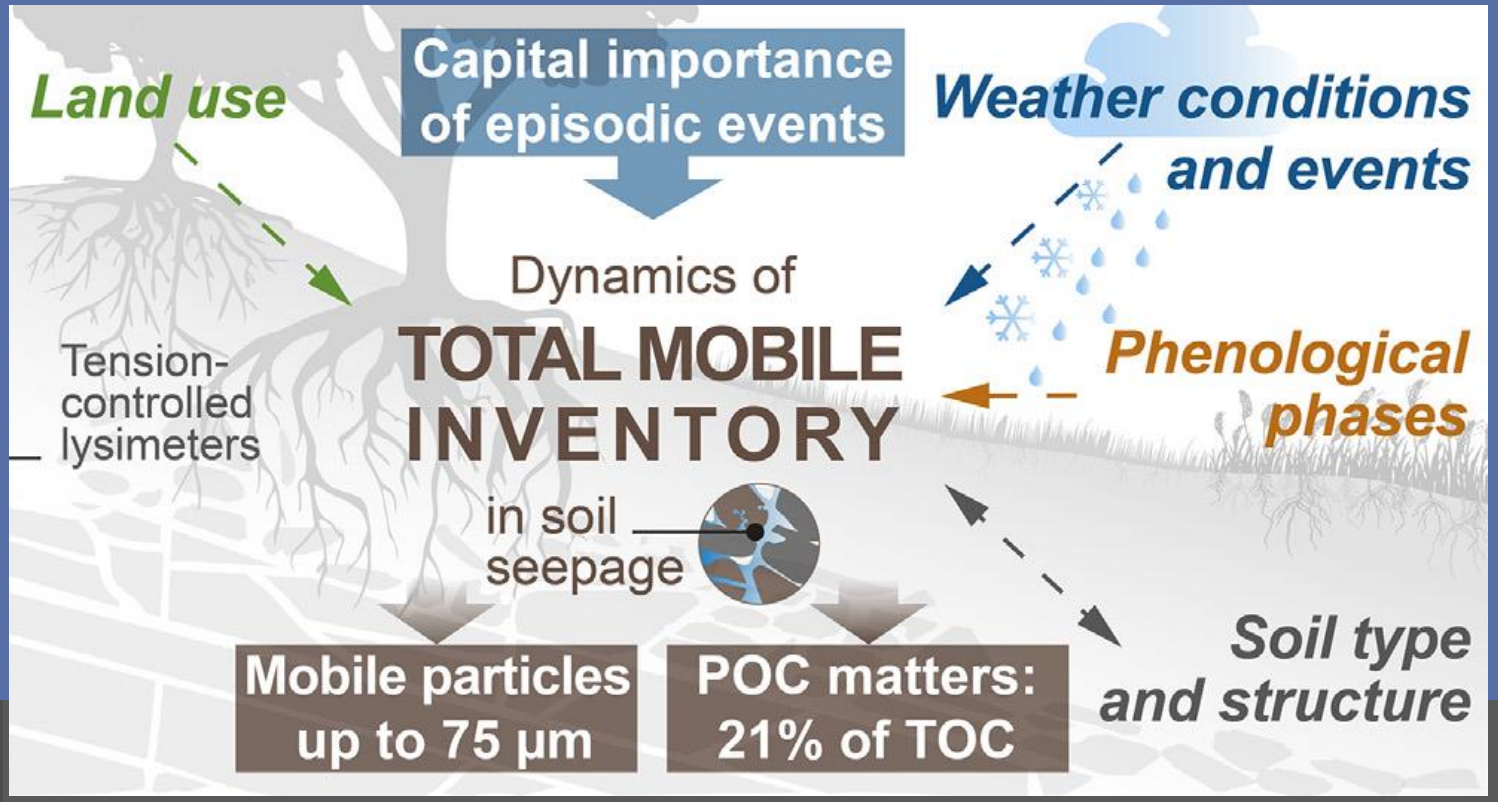
Indirectly determined as differences

TOC - DOC = POC (Particulate Organic Carbon)

TN - DN = PN (Particulate Nitrogen)

Introduction

New concepts



Lehmann et al., 2021 Science of the Total Environment 756 (2021)

Key findings

"In undisturbed soil, diverse mineral-, mineral-organic, organic, and bioparticles (microbial cells, biotic detritus) up to 75 µm was mobile"

"On average, a significant proportion of 21% of the mobile organic carbon belonged to the >0.45 µm fraction."

"Individual infiltration events during winter accounted for up to 80% of annual fluxes of particulate organic carbon."

How do ecosystem disturbances impact the amount and quality of DOM and POM?

Motivation

Effects of Climate Change on ecosystem processes til 2025 (2100)

„Increase in frequency of ecosystem disturbance by fire and insect pest (high confidence)“

William Hare in WBGU, 2003

“All assessed modelled pathways that limit warming to 2°C (>67%) or lower by 2100 include land-based mitigation and land-use change, with most including different combinations of reforestation, afforestation, reduced deforestation, and bioenergy. However, accumulated carbon in vegetation and soils is at risk from future loss (or sink reversal) triggered by climate change and disturbances such as flood, drought, fire, or pest outbreaks, or future poor management. (high confidence)”

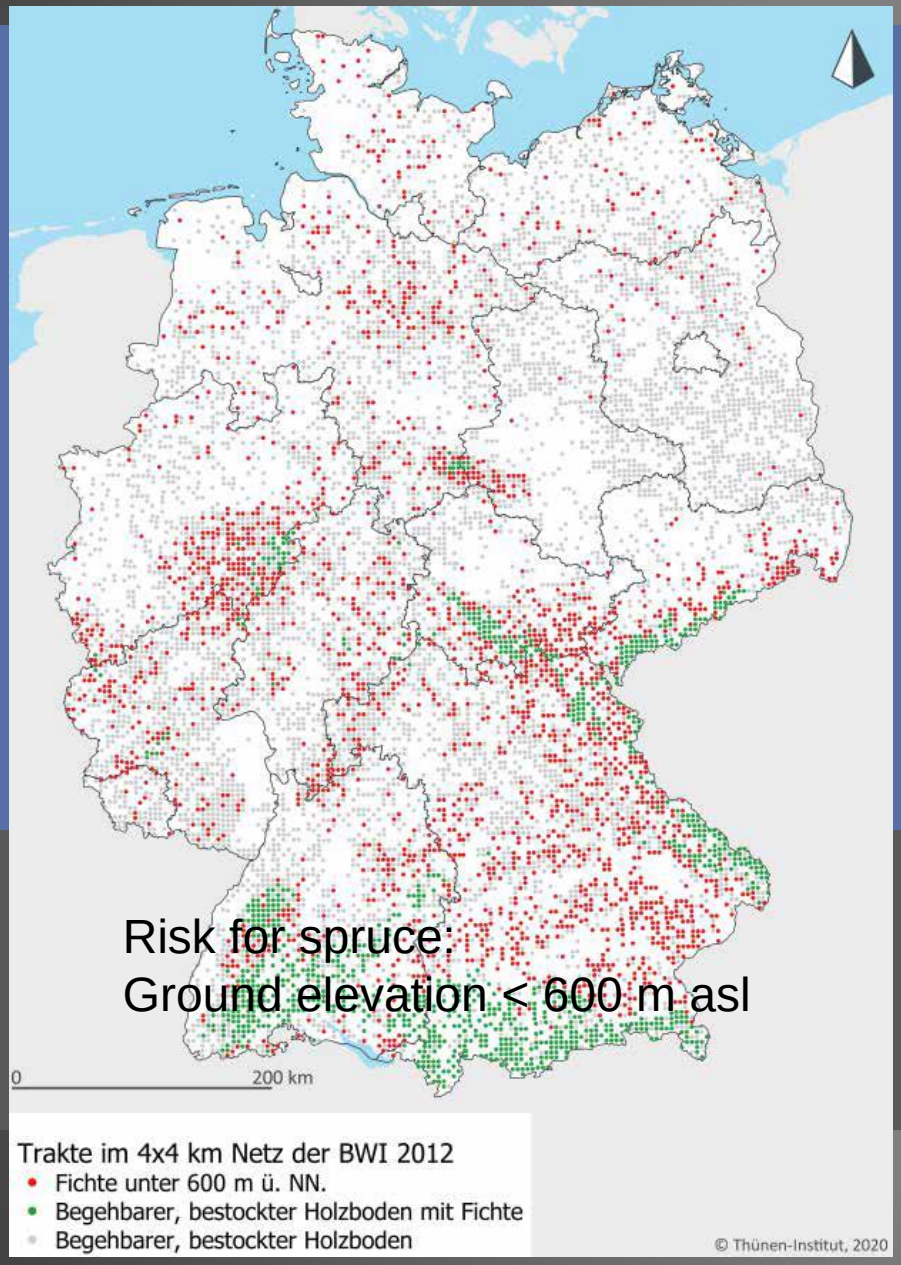
IPCC 2023, AR Synthesis Report

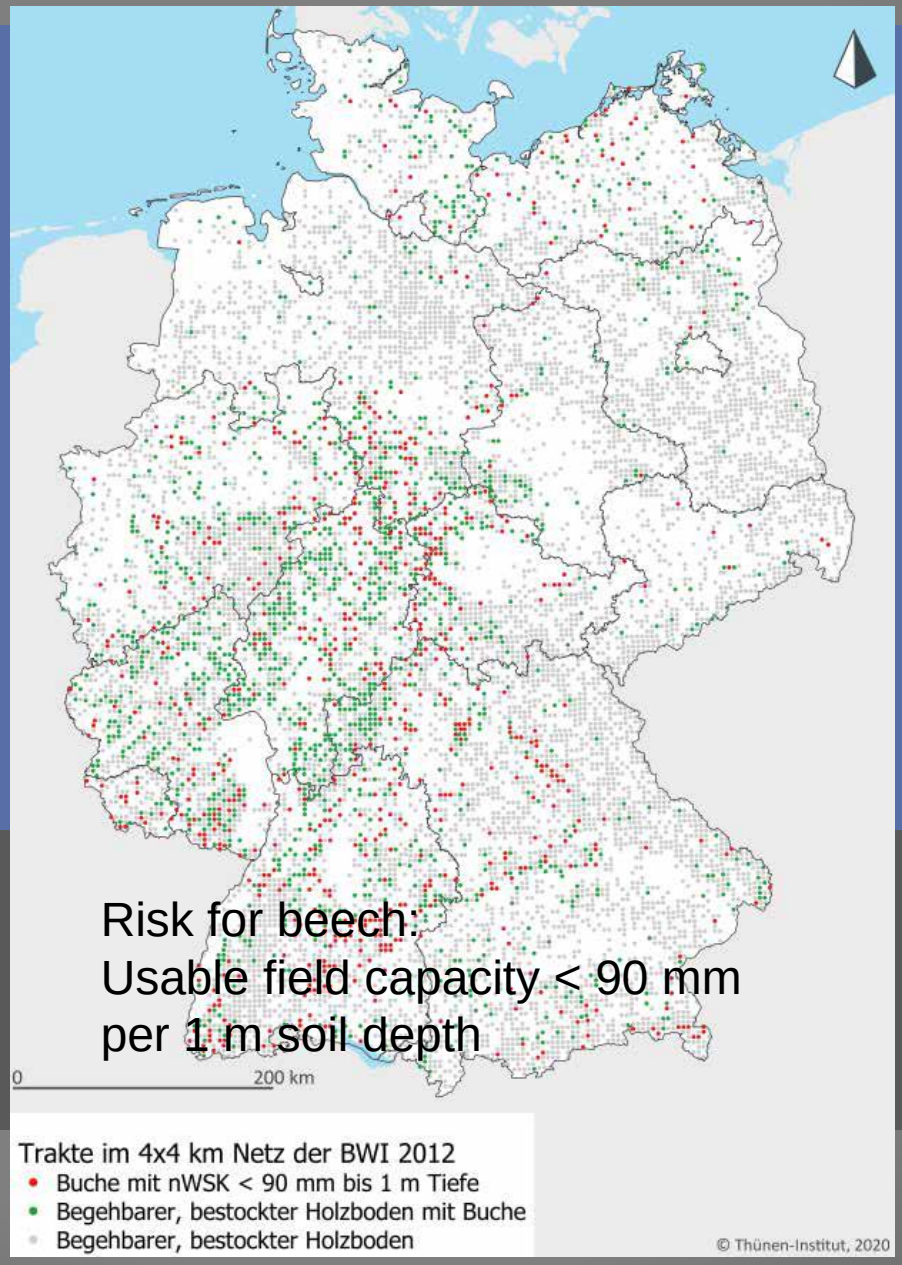
Motivation

Climate zone types future impact by Climate Change

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), 2015

Germany-wide projection approach to damage risk





Areas at risk for sites with spruce as dominating tree species or beech, respectively

Bolte et al., 2021, AFZ-Der Wald 4/21

Motivation

Effects of disturbances & stressors on forest ecosystem functions & services

- increasing pressure on forests by stressors such as droughts, forest fires, insect pests/plant pathogenes, N saturation and climate change

(Dale et al., 2001)

- changes in forest productivity, biodiversity, water, matter and nutrient cycling and carbon sequestration

(Brown et al., 2010; Gandhi and Herms, 2010; Sims et al., 2010; Swank et al., 1981)

- diminished recreational and cultural functions of landscapes

(Bastian, 2000)

Motivation

→ understand the impact of ecosystem disturbances on the magnitude of DOM and POM release dynamics and quality on the field scale

→ identify hot spots and hots moments in landscapes and their role for functions, processes and development of terrestrial ecosystems

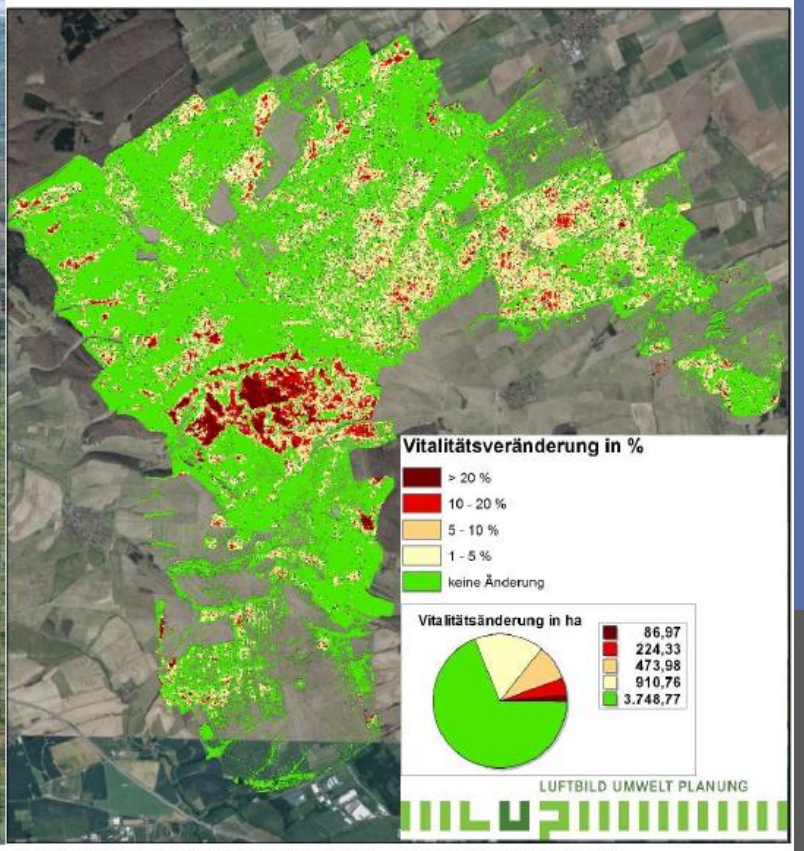
Results from field studies

Droughts

Drought year 2018 in the Hainich area, Thuringia

Vitalitätsänderungen der Waldflächen im NP Hainich zwischen Juli 2018 und Juli 2019

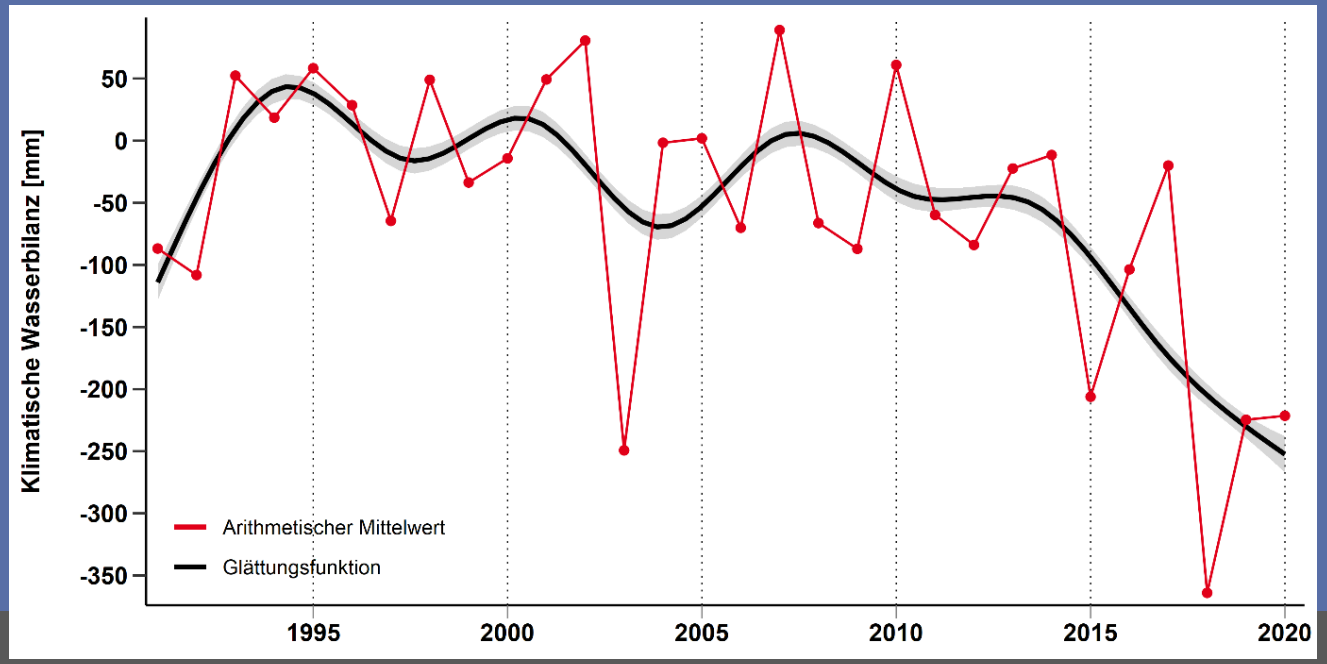
(berechnet auf Basis von Sentinel 2 Daten anhand des Disease Water Stress Index)



74 % der Fläche mit sehr starken Vitalitätsänderungen (> 20) betreffen Buchen

Drought effects on climate parameters

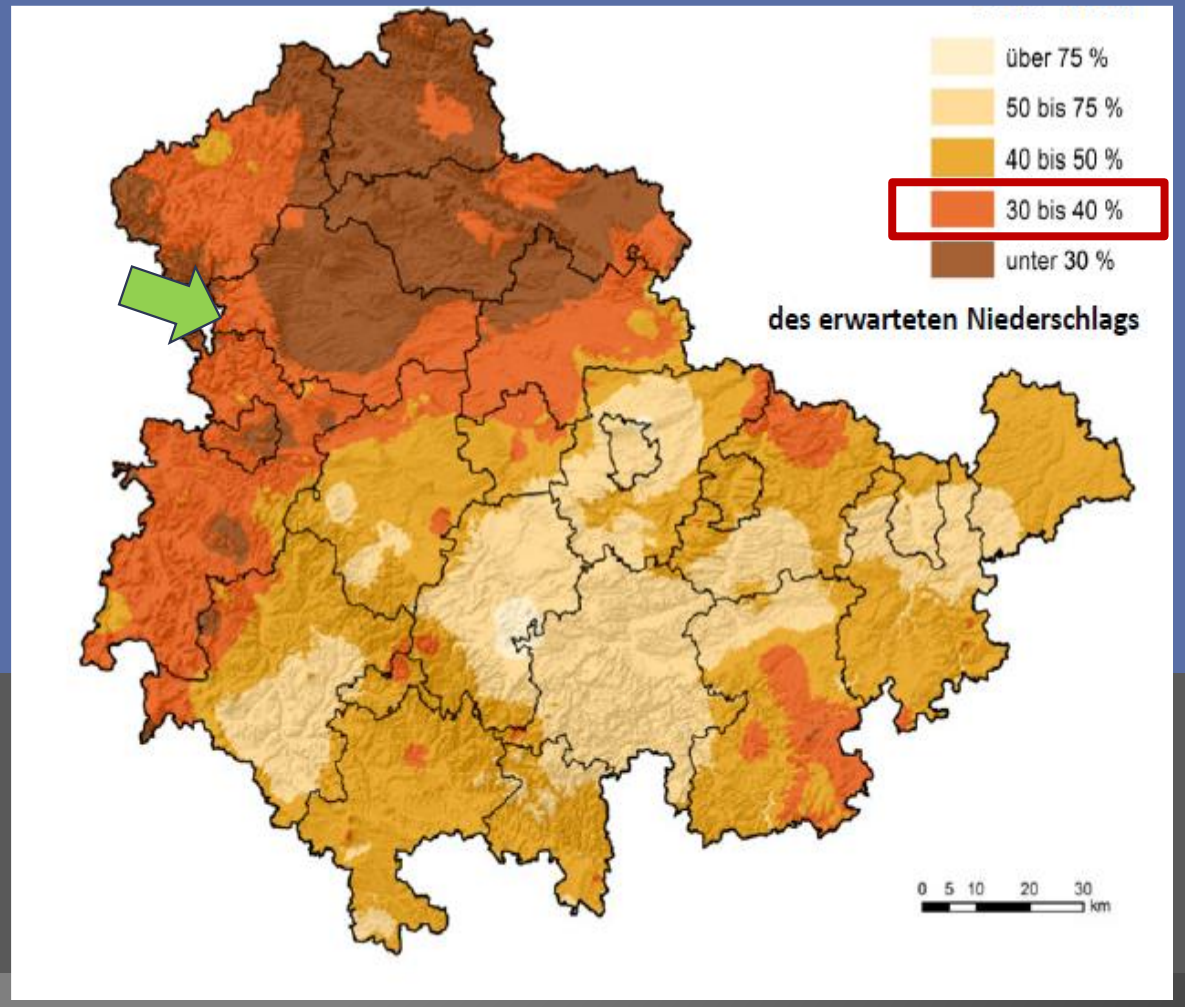
Climate water balance (416 sites of the forest condition assessment)



Adrian Danescu, Thünen-Institut

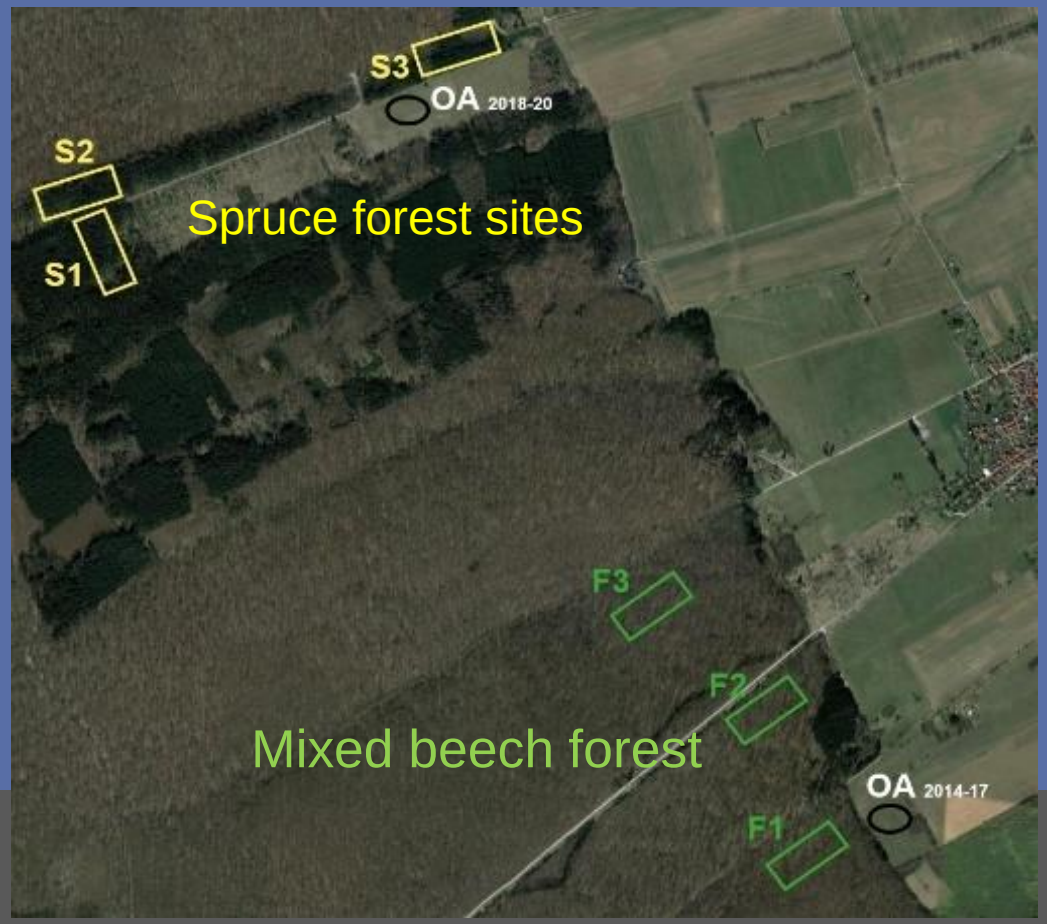
- Extrem years 2003, 2018 to 2020 clearly reflected by the forest condition assessment.
- Tree mortility rate peaks in 2020 to record levels (1.8% all tree species, spruce: 4.2%).

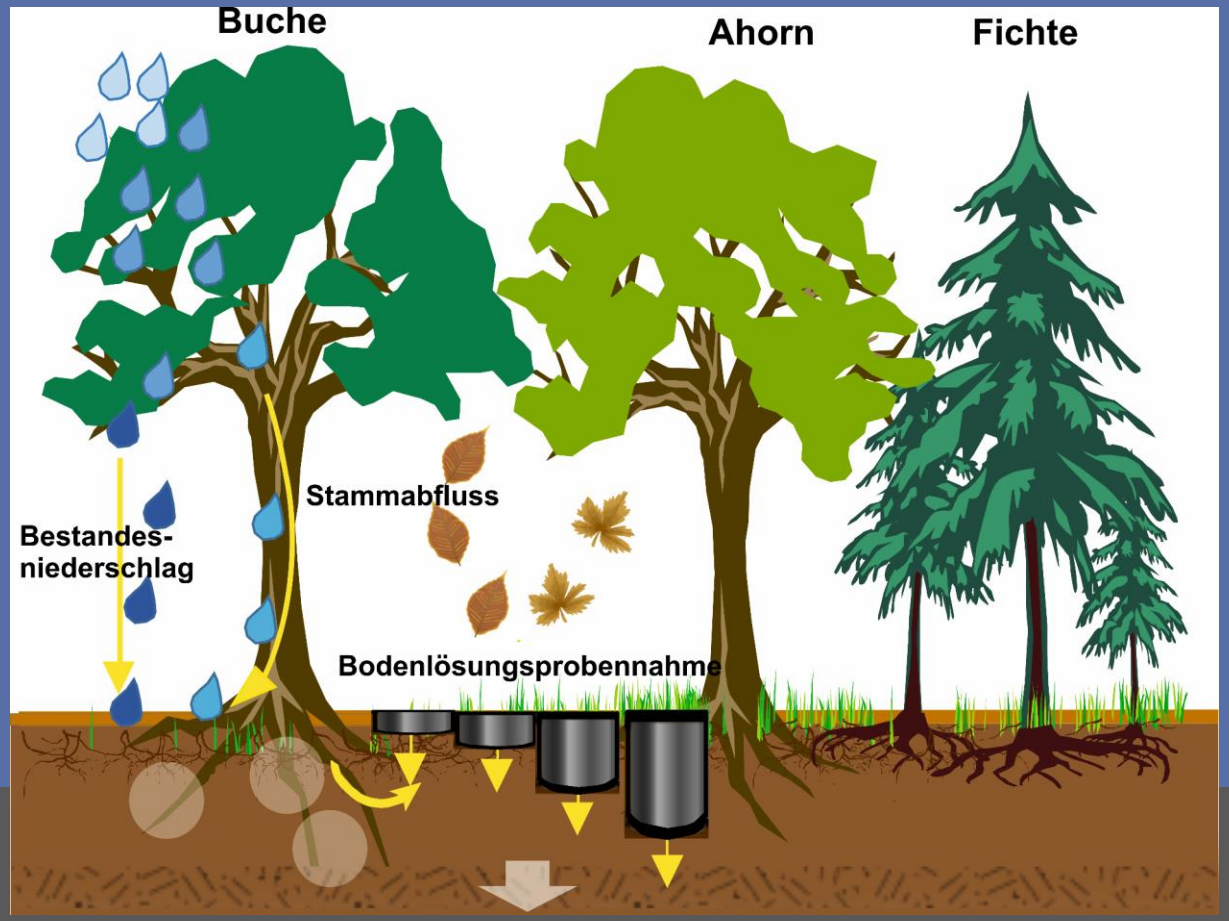
Rain amount in summer 2018 compared to 1961-90



TLUBN Klimaagentur

Collaborative research centre DFG-SFB 1076 „AquaDiva- Unterstanding the links between surface and subsurface biogeosphere“





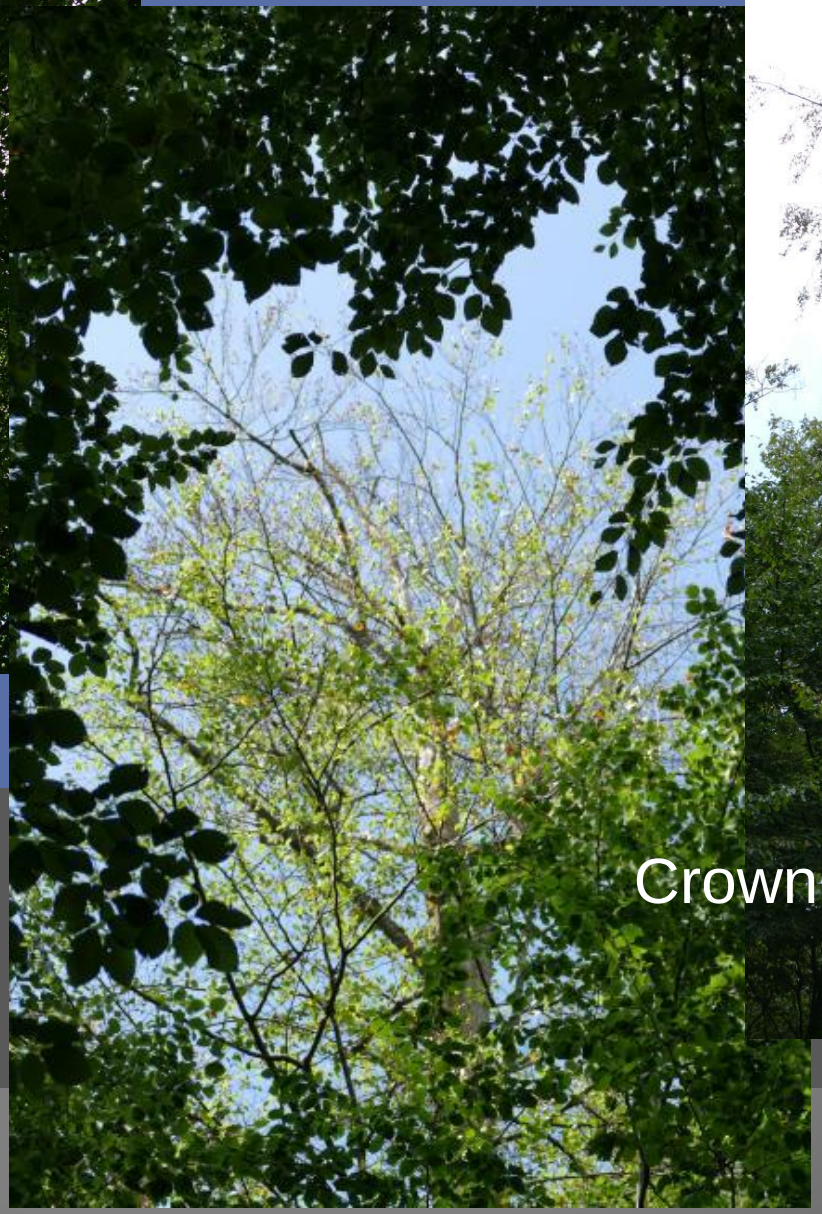
Parent material: Loess over Muschelkalk

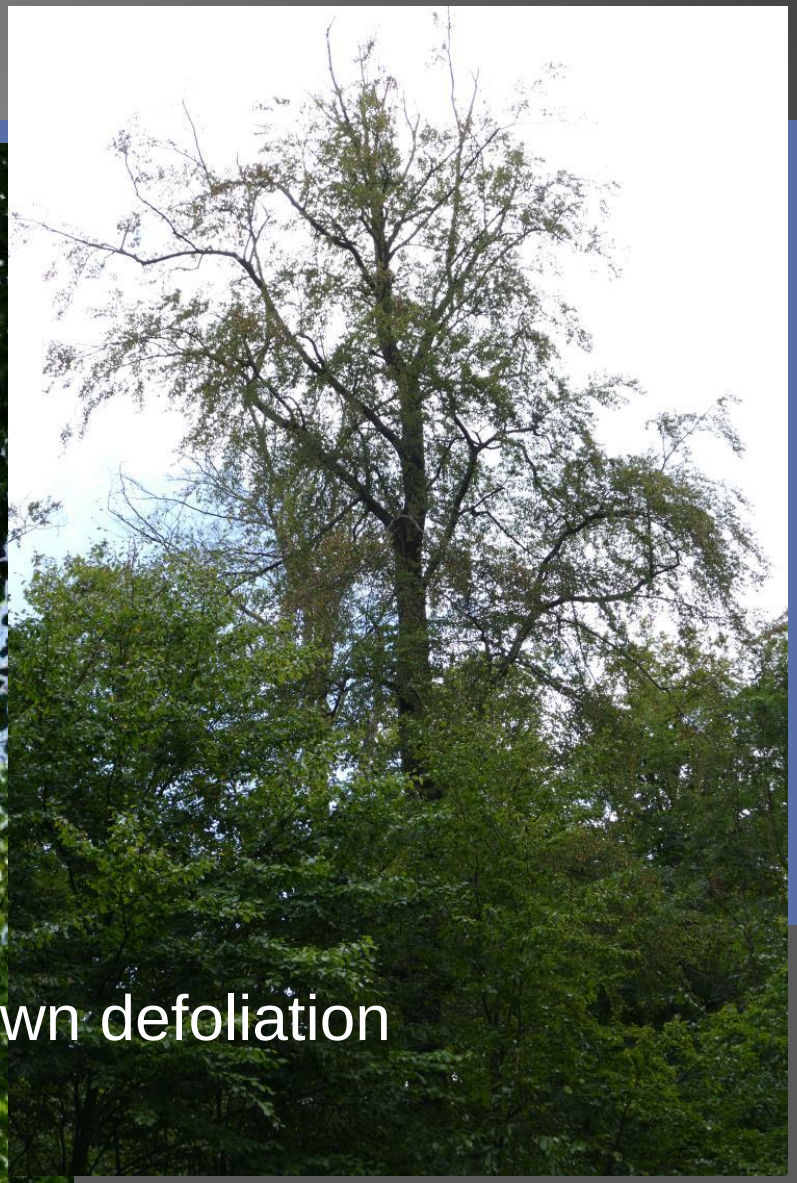
Soil type: Parabraunerde/ Luvisols

Soil depth: 30-40 cm

To characterize the input fluxes to the subsurface, water, matter and element fluxes were monitored from July 2018 to July 2020

Hainich August 2018- beech stand

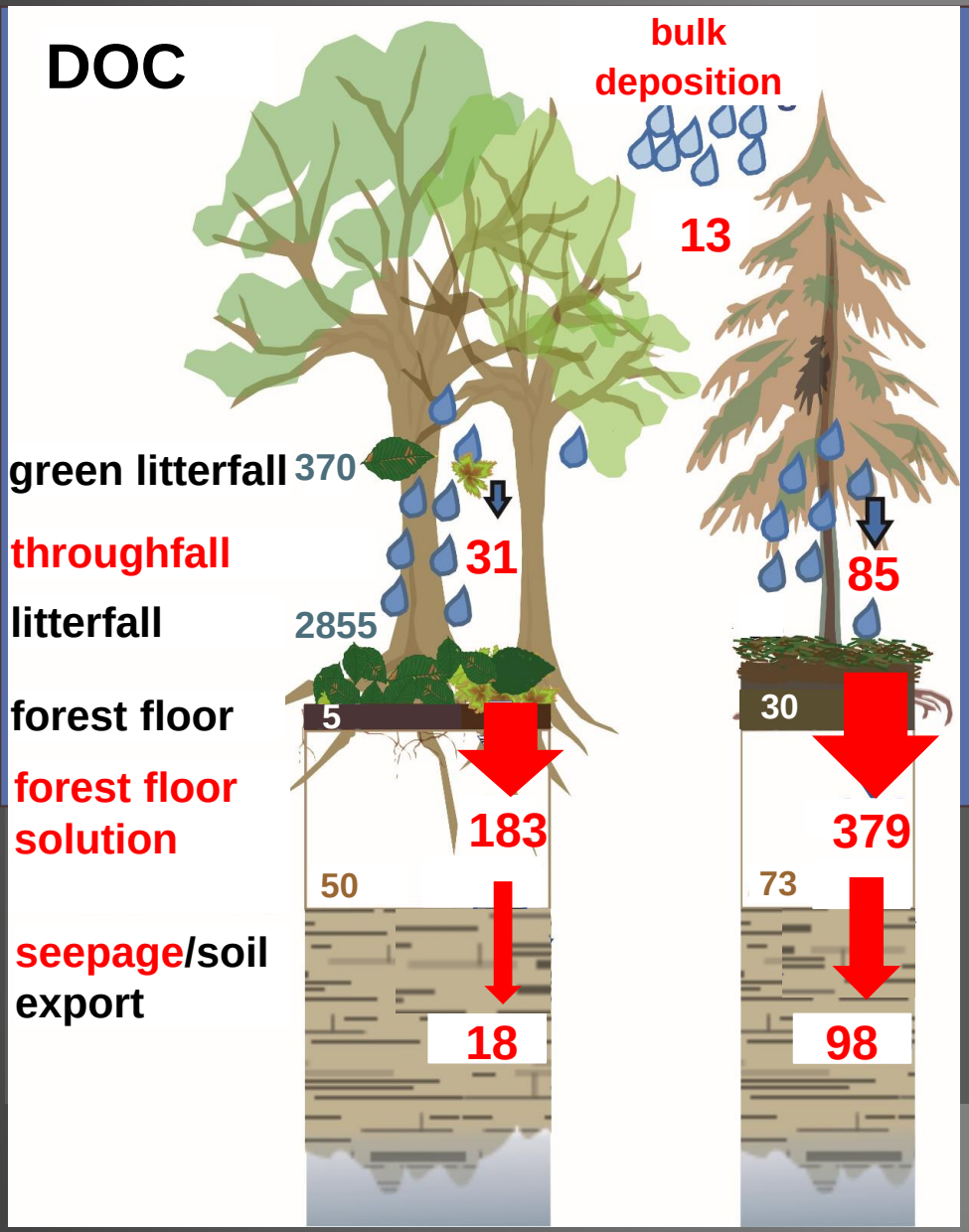


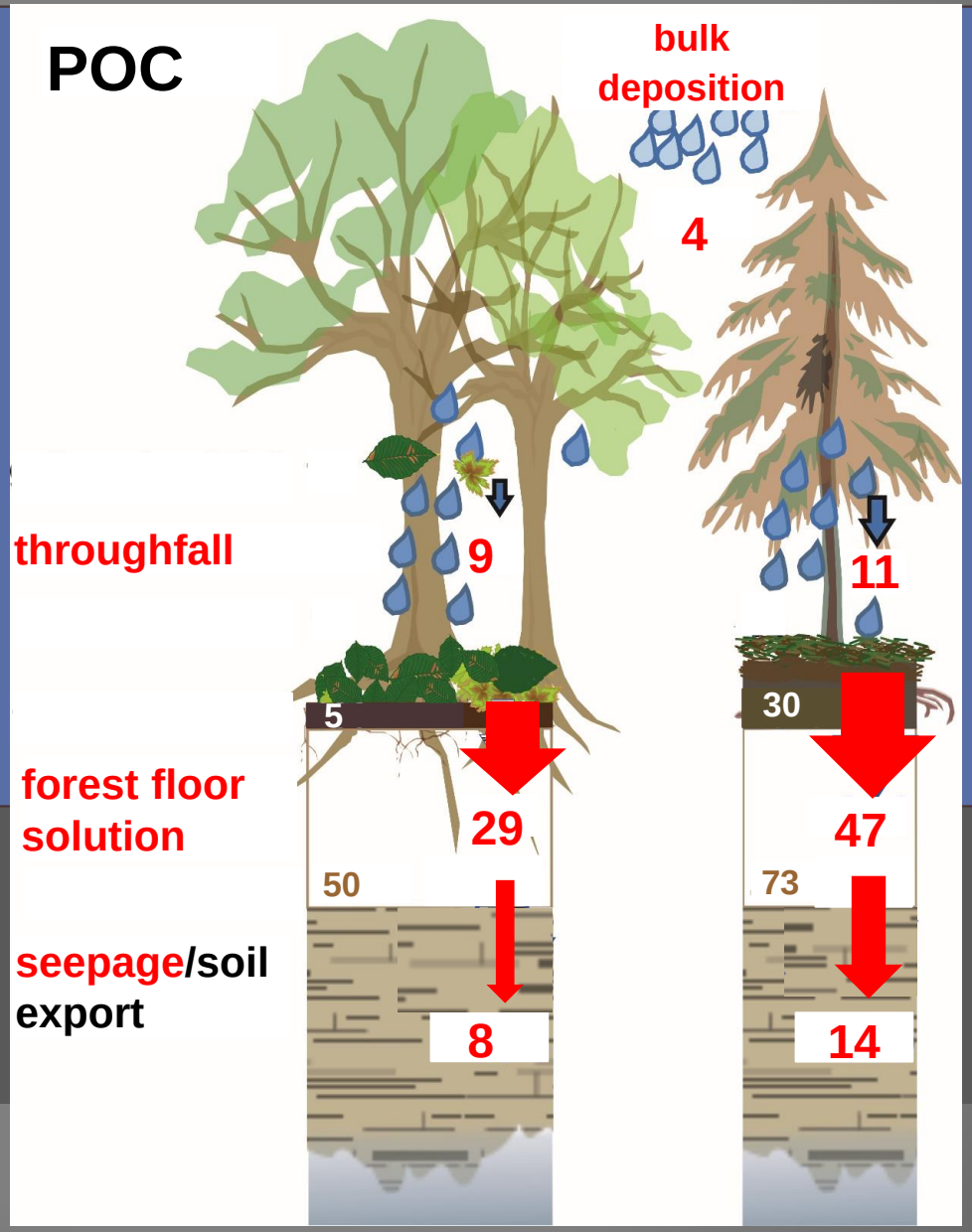


DOC (fraction < 0.45 µm) fluxes
[kg ha^{-1} a^{-1}] from 07/2018 – 07/2019

POC (fraction > 0.45 µm) fluxes
[kg ha^{-1} a^{-1}] from 07/2018 – 07/2019

Proportion of POC
in TOC fluxes [%]





Beech forest

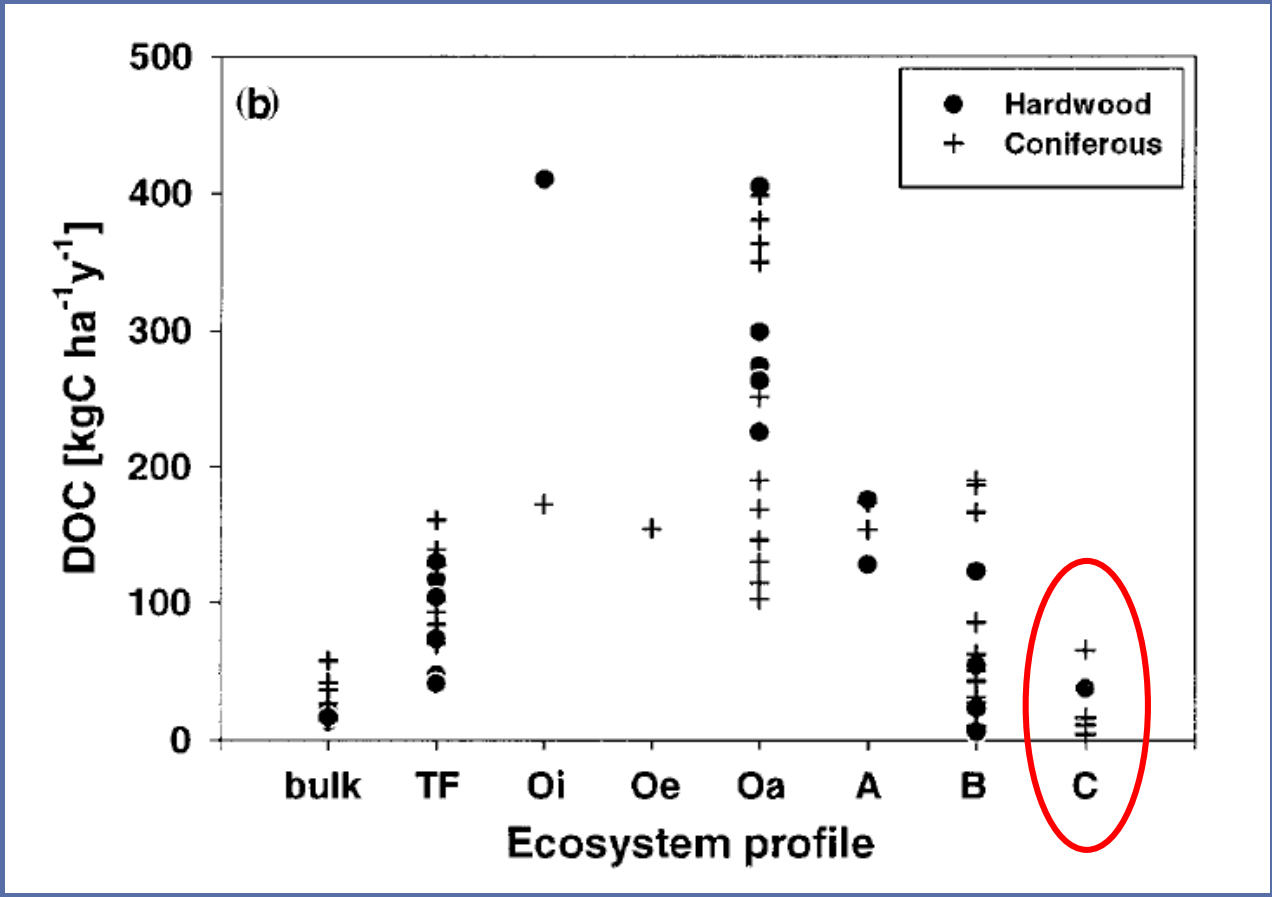
Comp.	TOC [kg ha^{-1} a^{-1}]	%POC
BD	17.4	25
TF	39.9	23
FF	212.0	14
Seepage	26.1	31

Spruce forest

Comp.	TOC [kg ha^{-1} a^{-1}]	%POC
BD	17.4	25
TF	96.2	12
FF	425.5	11
Seepage	112.0	12

Interim conclusion & comparison to other studies

Mean annual DOC fluxes in temperate forest ecosystems



Michalzik et al. 2001

- Drougth increased seepage DOC fluxes

→ especially for conifer sites

- Include POC in flux budgets

→ Share of POC in TOC in soil solutions up 30%

Temporal development - drought 2018 + subsequent bark beetle infestation

Interacting effects of disturbance agents and modifications of ground vegetation altered water distribution and nutrient fluxes at the surface

POM quality

Soil Biology and Biochemistry 154 (2021) 108153

Contents lists available at ScienceDirect

Soil Biology and Biochemistry

journal homepage: http://www.elsevier.com/locate/soilbio

Drought and rewetting events enhance nitrate leaching and seepage-mediated translocation of microbes from beech forest soils

Markus Krüger [a], Karin Potthast [b], Beate Michalzik [b,c], Alexander Tischer [b], Kirsten Küsel [a,c], Florian F.K. Deckner [a], Martina Herrmann [a,c,*]

[a] Institute of Biodiversity, Friedrich Schiller University Jena, Jena, Germany
[b] Department of Soil Science, Friedrich Schiller University Jena, Jena, Germany
[c] German Center for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany

"Bacterial cells contributed an estimated 17–34% to the export of particulate organic carbon (POC) and particulate nitrogen (PN) below the litter layer with the highest contribution after drought and rewetting."

"Predicted higher frequency of drought periods in temperate [...] regions may result in enhanced export of soil-derived microorganisms with implications for microbial community dynamics and metabolic potential in subsoils and subsurface environments.

Interim conclusion- drought

- Effects of Drought + subsequent bark beetle infestation accelerated N mineralization (and mobilized DOC in the subsoil under spruce)

- but: DN (and DOC) fluxes normalized over the following two years

→ Discrete event in time and space → hot spot and hot moment in the landscape

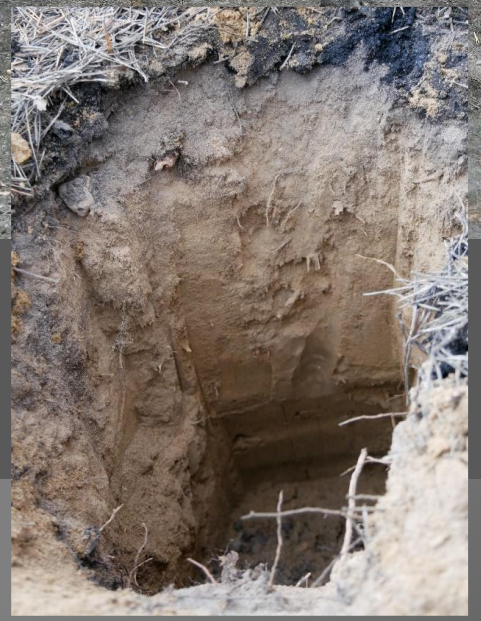
- Include particulate fractions of C and N in C and N budgets because they are quantitatively important

- drought/rewetting cycles enhance the export of soil-derived microorganisms

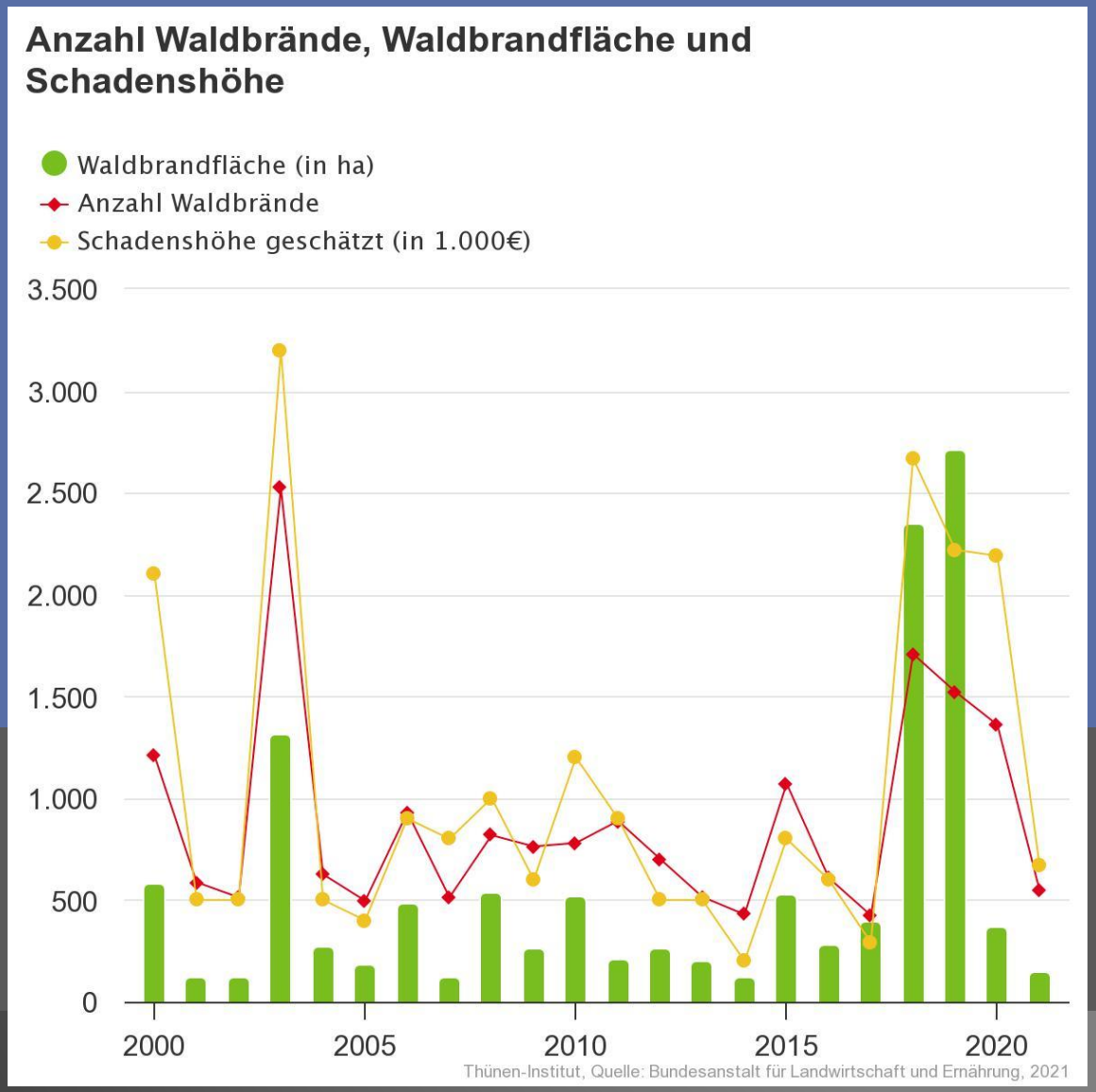
Fire disturbance

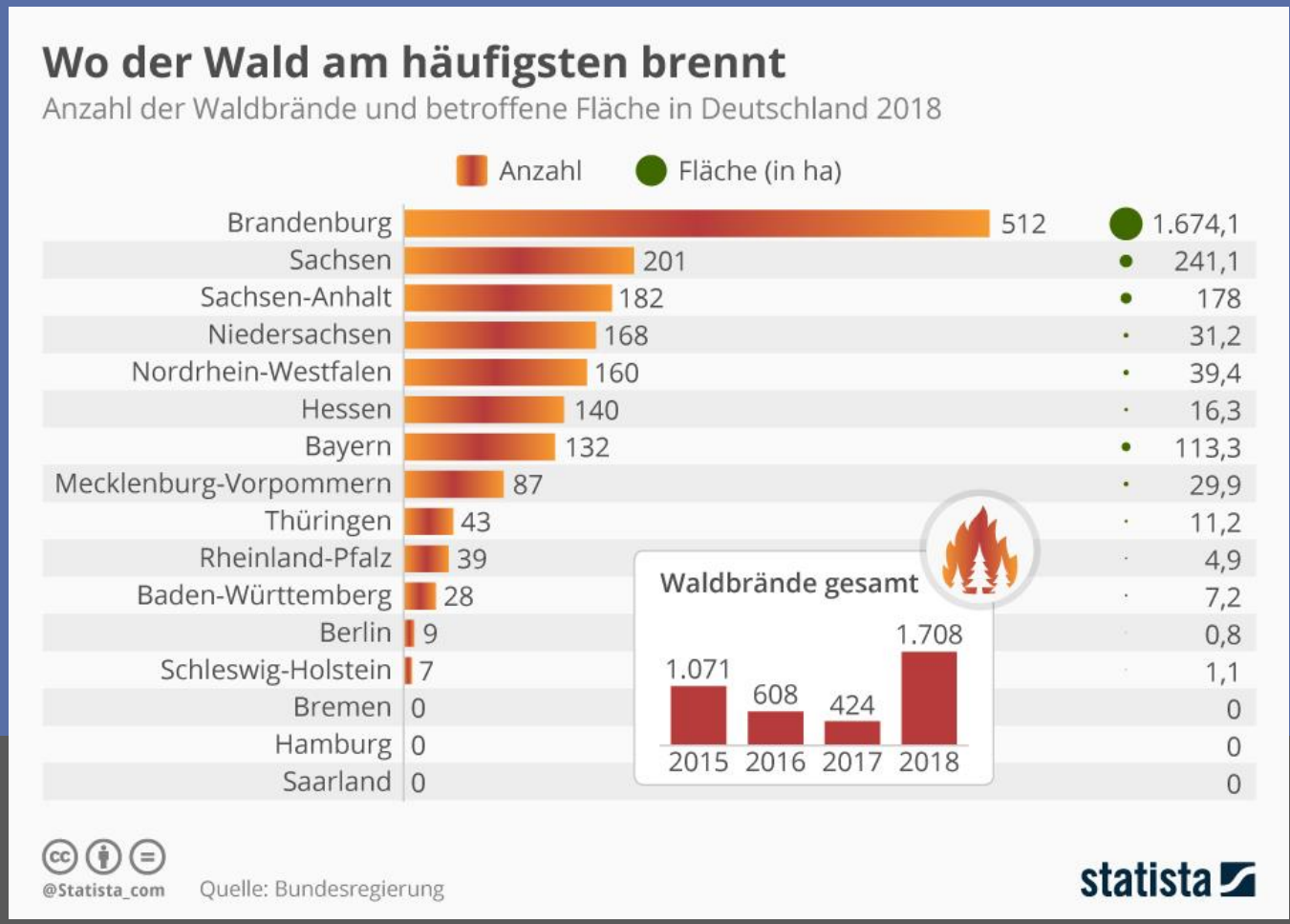
Forest fire in Treuenbrietzen/Brandenburg in August 2018
→ 330 ha of pine plantation burnt


20



Fire occurrence and extent in Germany





Field experiment with simulated low intensity ground fires

Catena 162 (2018) 360–375

Contents lists available at ScienceDirect

Catena

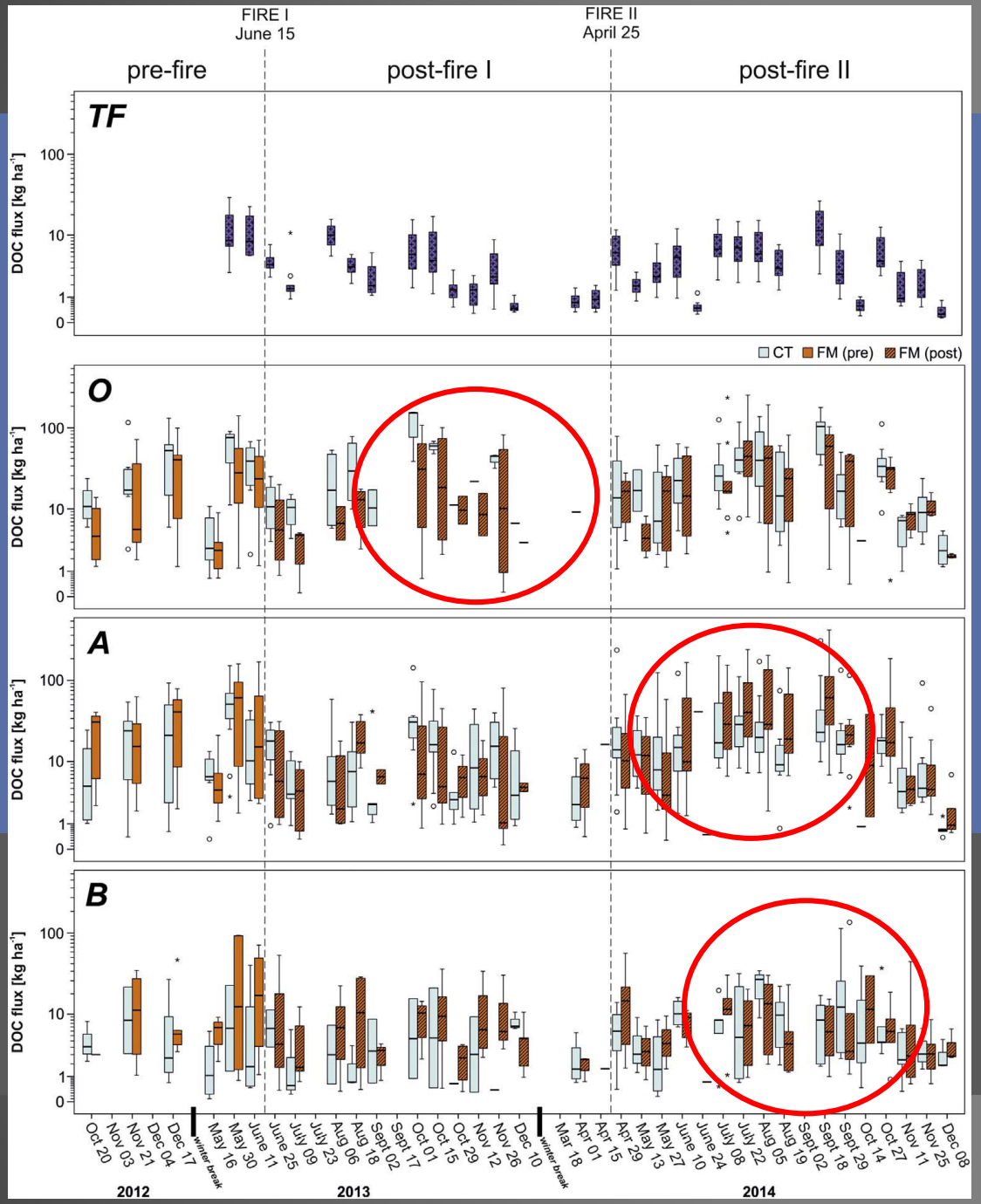
journal homepage: www.elsevier.com/locate/catena

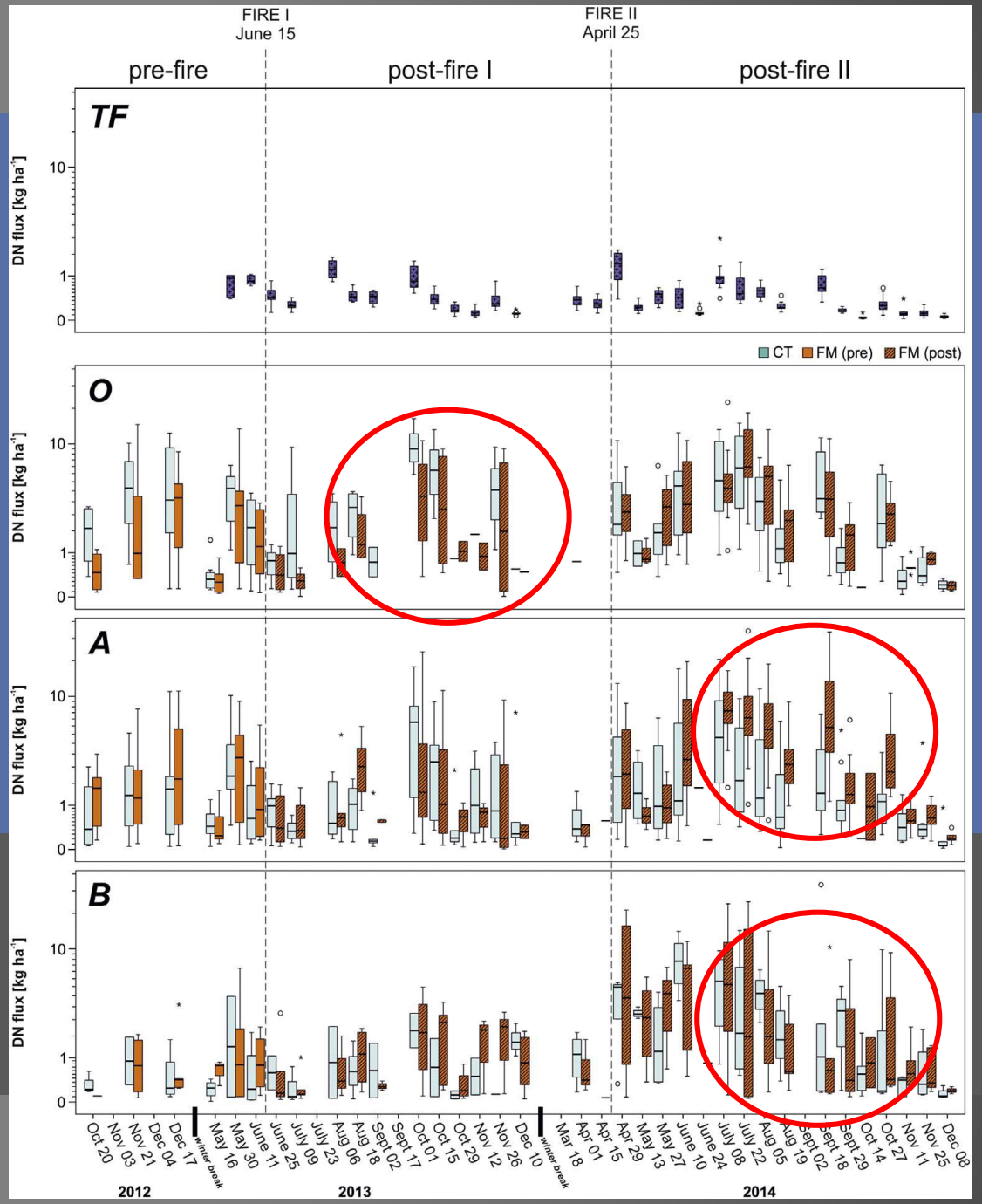
Low-intensity surface fire effects on carbon and nitrogen cycling in soil and soil solution of a Scots pine forest in central Germany

Kerstin Näthe[a,*], Delphis F. Levia[b], Alexander Tischer[a], Beate Michalzik[a]

[a] Soil Science, Institute of Geography, Friedrich Schiller University Jena, Germany
[b] Departments of Geography and Plant and Soil Sciences, University of Delaware, Newark, DE, USA

Parent material: Triassic Sandstone
Soil type: mosaic of Spodosols and dystric to spodic Cambisols
Soil texture: silty and sandy loam
Humus forms: moder to raw humus


FIRE I
June 15
FIRE II
April 25
pre-fire
post-fire I
post-fire II
TF
O
A
B
DOC flux [kg ha-1]
CT
FM (pre)
FM (post)
2012
2013
2014
winter break


FIRE I
June 15
FIRE II
April 25
pre-fire
post-fire I
post-fire II
TF
O
A
B
DN flux [kg ha-1]
CT
FM (pre)
FM (post)
2012
2013
2014
winter break

DOM and TOM flux dynamics

Linear mixed-effect modelling (LMM) revealed that low intensity fires

- reduced DOC (−64%) and DN (−11%) fluxes in the organic layer, but increased soil CO_2 fluxes (+7%).

- induce nutrient flush from the charred material into the A horizon,
→ as indicated by an enhanced solution pH and electrical conductivity (data not shown)
→ Which may have stimulated microbial activity,
→ leading to enhanced DOC (+47%) and DN (+202%) fluxes

- The B horizon was unaffected by the fire treatment and retained DOC and DN.

- POC and PN fluxes were less affected by the fire treatment and decoupled from those of dissolved organic matter (DOM).

Erosion and sediment transport

Enhanced soil erosion after severe wild fire due to reduced infiltration caused by increased soil hydrophobicity and a loss in vegetation cover

The variability of the soil erosion depends on the **fire intensities**:

→ 0,1 to 6 t / ha a (controlled fire)

→ **21 to > 110 t/ ha a (intensive fire)**

A strong decrease in erosion from the 1. to the 4. year after a fire event:

1. Year: 21- 49 t / ha a (soil cover of 28%)
2. Year: Decrease by 1-2 magnitudes 0.5 to 5 t/ha a (soil cover of 82%)
4. Year: no erosion

(Megahan & Molitor 1975; Noble & Lundeen 1971; Robichaud & Waldrop 1994; Robichaud & Brown 1999)

Interim conclusions

Depending on their intensity, forest fires

- significantly affect nutrient-poor soil systems by causing a short-term flush (“hot moment”) of DOM in the mineral A horizon (vertical “hot spot”) and by sorption in the mineral B horizon.

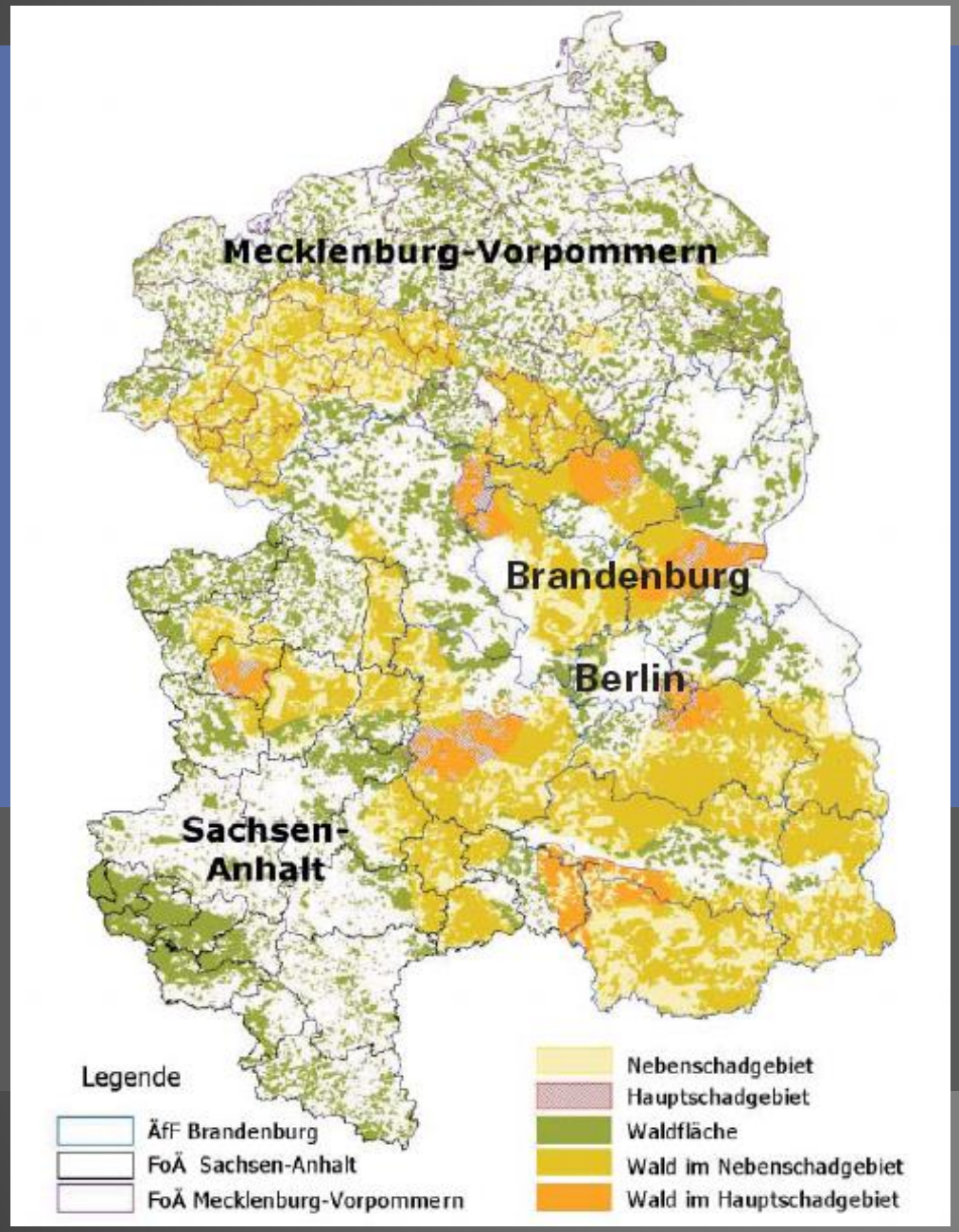
- enhance the rates of erosion and sediment transport by storm events.

Insect mass outbreaks

Pine forest

Pine lappet
(*Dendrolimus pini*)

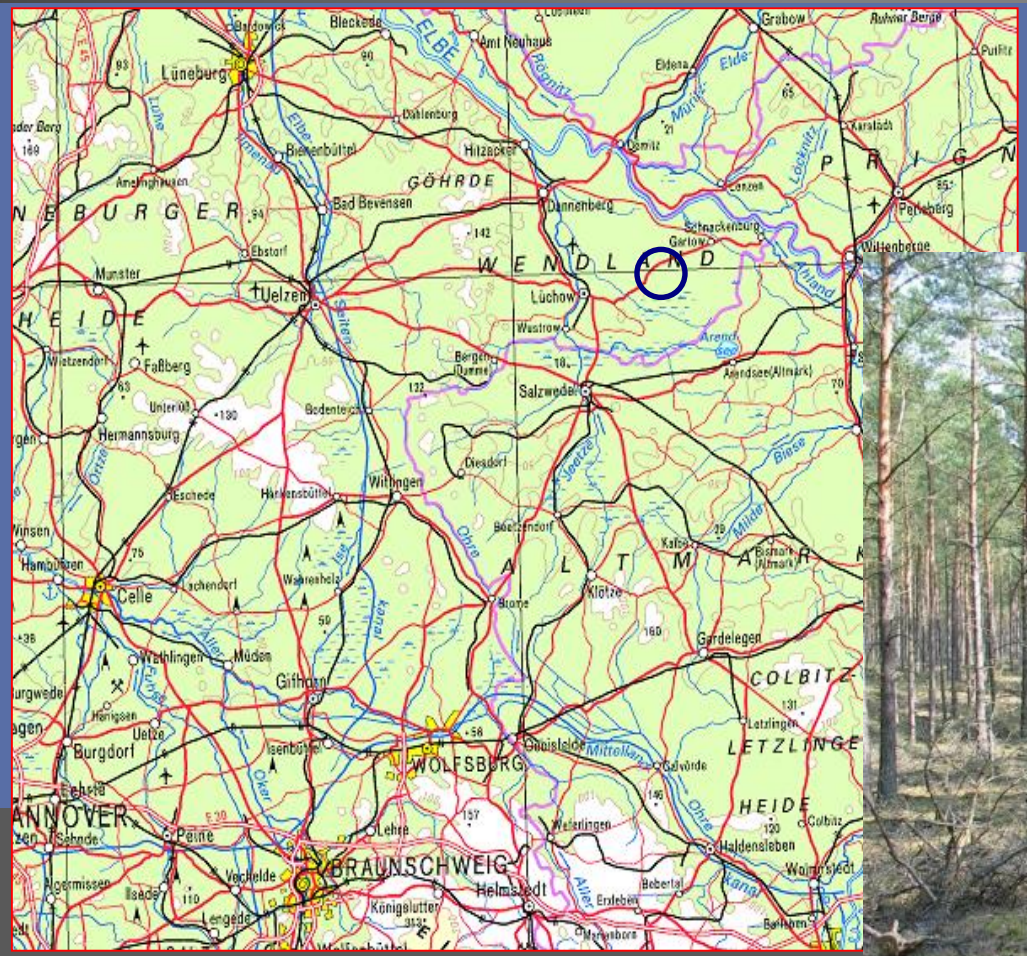
Main and secondary impact areas of the **Nun moth** (*Lymantria monacha*)



- 80% of the forest area in Brandenburg is planted by pine trees
- future areas of risk: ca. 150.000 ha

(Majunke et al., 2004)

Experimental site- Prezeller Pine Forest in the „Wendland“ area



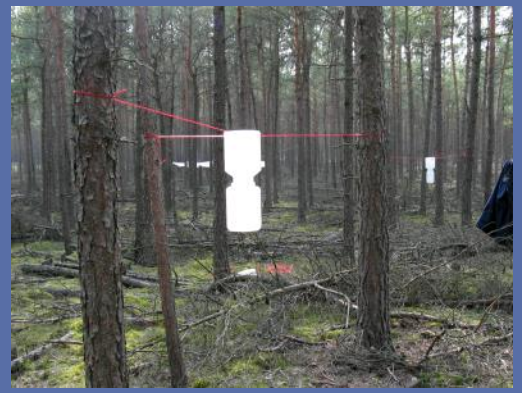
Forest floor:
61.50 t C ha^{-1}
1.88 t N ha^{-1}
pH (KCl) 3,05

ca. 60 year old pine forest on podsol soils over glacial aeolian sand deposits, mean annual precipitation: 550 mm, temperature: 8.6 °C

Methods – field instrumentation

ecosystem input

open field: bulk deposition sampling n = 2



transfer between canopy and soil

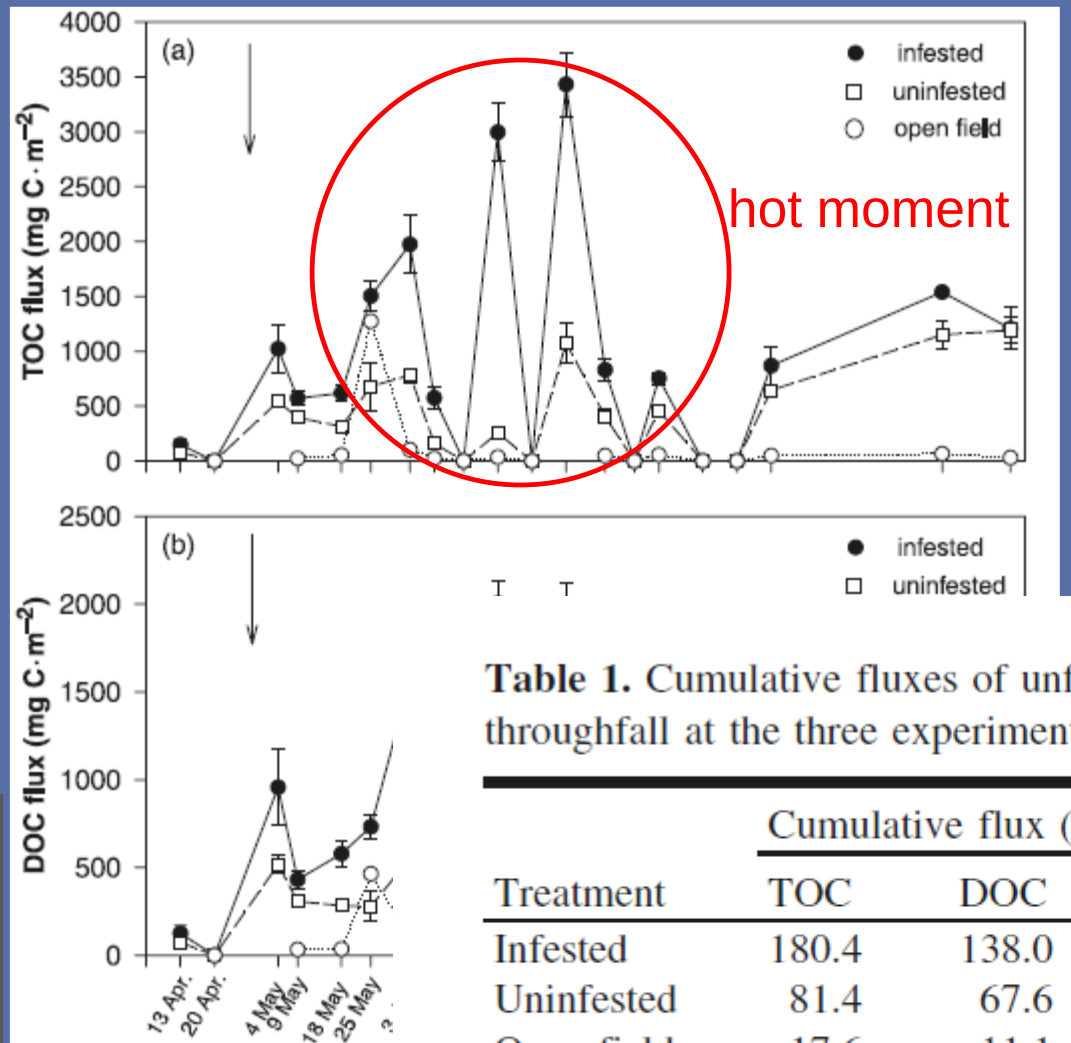
control and infested sites:
throughfall sampling n = 10 each

assessing faeces and frass inputs by

3 tree nets (net areas ca. 7 m^2 each)

→ in weekly sampling from April to October (6 months)

Carbon and nitrogen inputs with throughfall



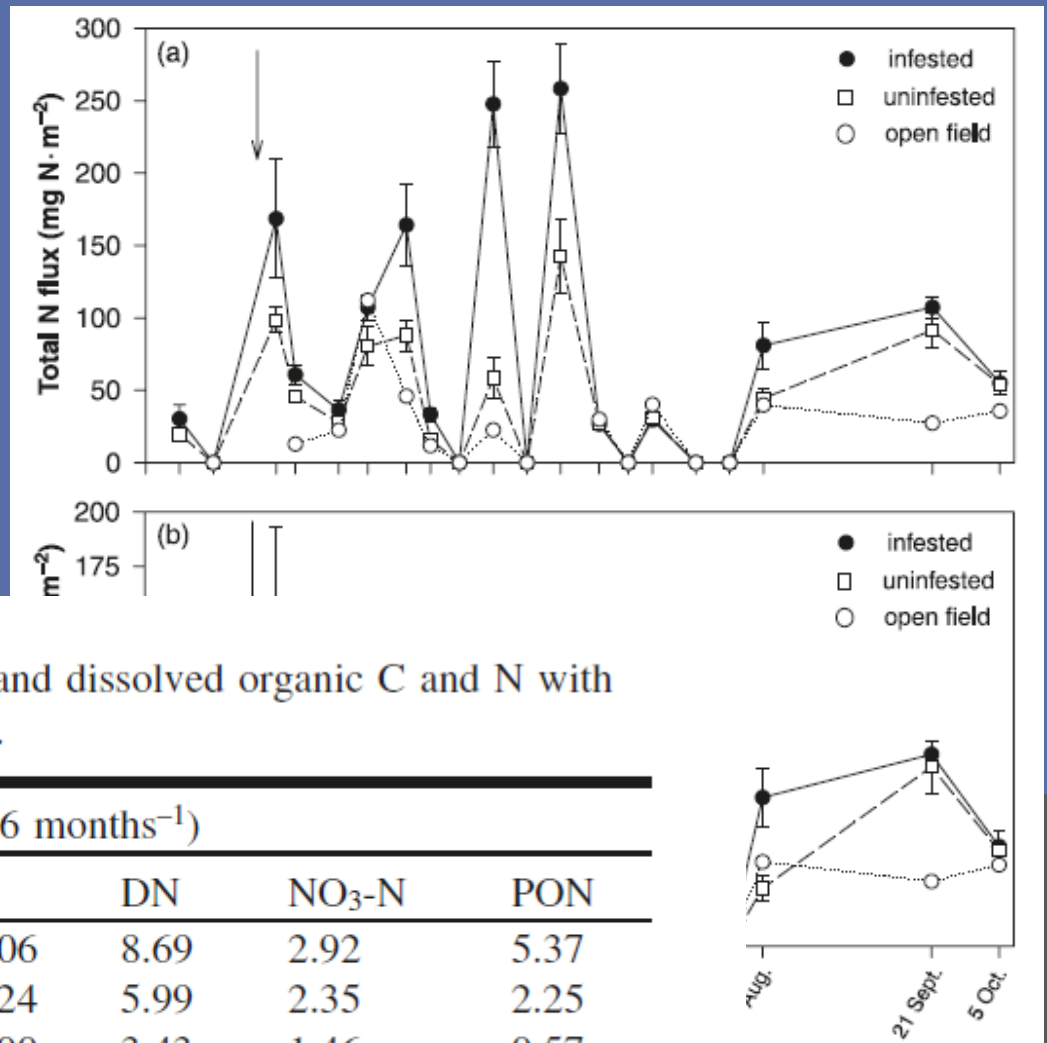


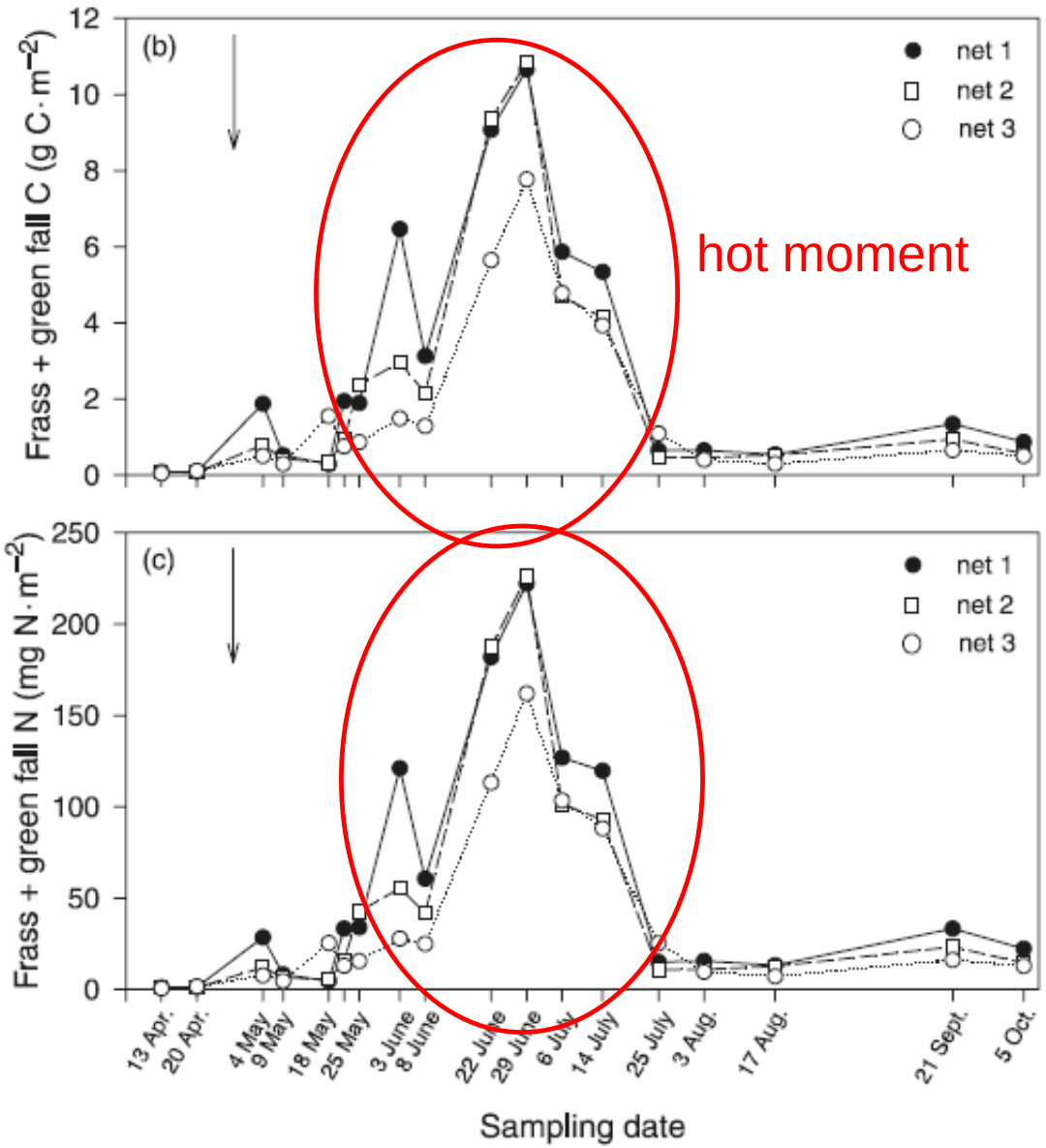
Table 1. Cumulative fluxes of unfiltered and dissolved organic C and N with throughfall at the three experimental sites.

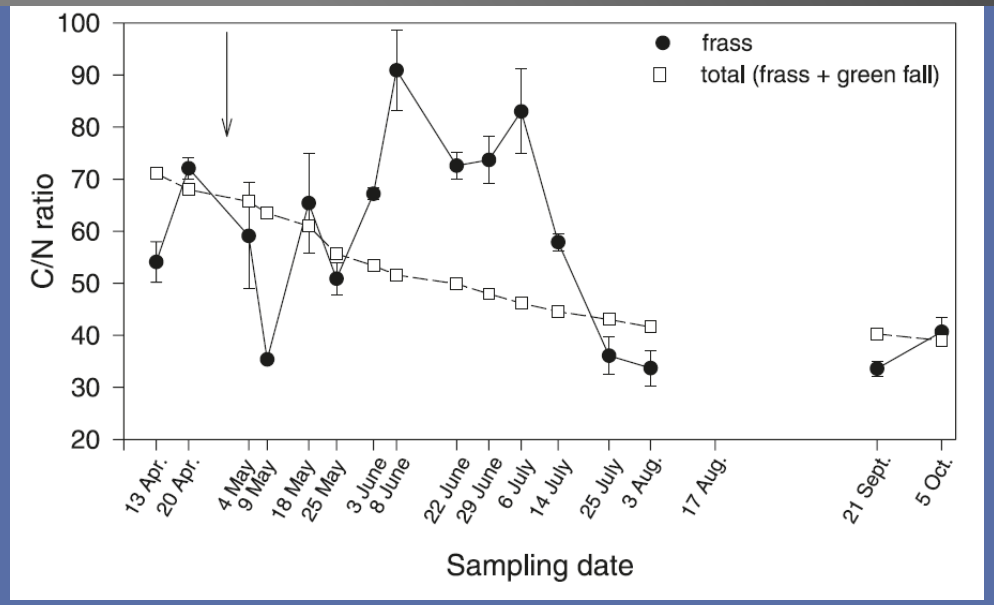
	Cumulative flux (kg·ha^{-1}·6 months^{-1})					
Treatment	TOC	DOC	TN	DN	NO_3-N	PON
Infested	180.4	138.0	14.06	8.69	2.92	5.37
Uninfested	81.4	67.6	8.24	5.99	2.35	2.25
Open field	17.6	11.1	4.00	3.43	1.46	0.57

Note: TOC, total organic C; DOC, dissolved organic C; TN, total N; DN, dissolved N; NO_3-N, nitrate N; PON, particulate organic N.

le Mellec & Michalzik (2008)

Carbon and nitrogen inputs with frass and green litterfall





C_{org} and N input via faeces and frass

up to 500 kg C (Ø 420) per ha

up to 12 kg N (Ø 9) per ha

Wide C:N ratios in frass material → low nitrogen contents – less degradable?

Interim conclusions

Insect mass outbreaks lead to

→ short-term massively magnified organic matter (DOM + POM) and nutrient inputs to the soil

→ creating “hot moments” during the vegetation period → altered timing of nutrient availability

→ chemically altered OM inputs (needle biomass ↔ faeces/ frass material)

Main conclusions

Conclusions

Drought, forest fires and insect mass outbreaks

- create „hot spots and hot moments“ of intensified DOM and nutrient fluxes in forested landscapes

- alter the quality of OM and the timing of availability

- promote the formation and mobilization of particulate (> 0.45 µm) fractions of organic C and N

- these form a significant part of the C and N cycling in forested ecosystems and should be involved in energy and element budgets

- bacterial cells contributed 17–34% to the export of POC and particulate nitrogen (PN)
- higher frequency of drought periods may result in enhanced export of soil-derived micro-organisms into the subsurface

Knowlegde gaps

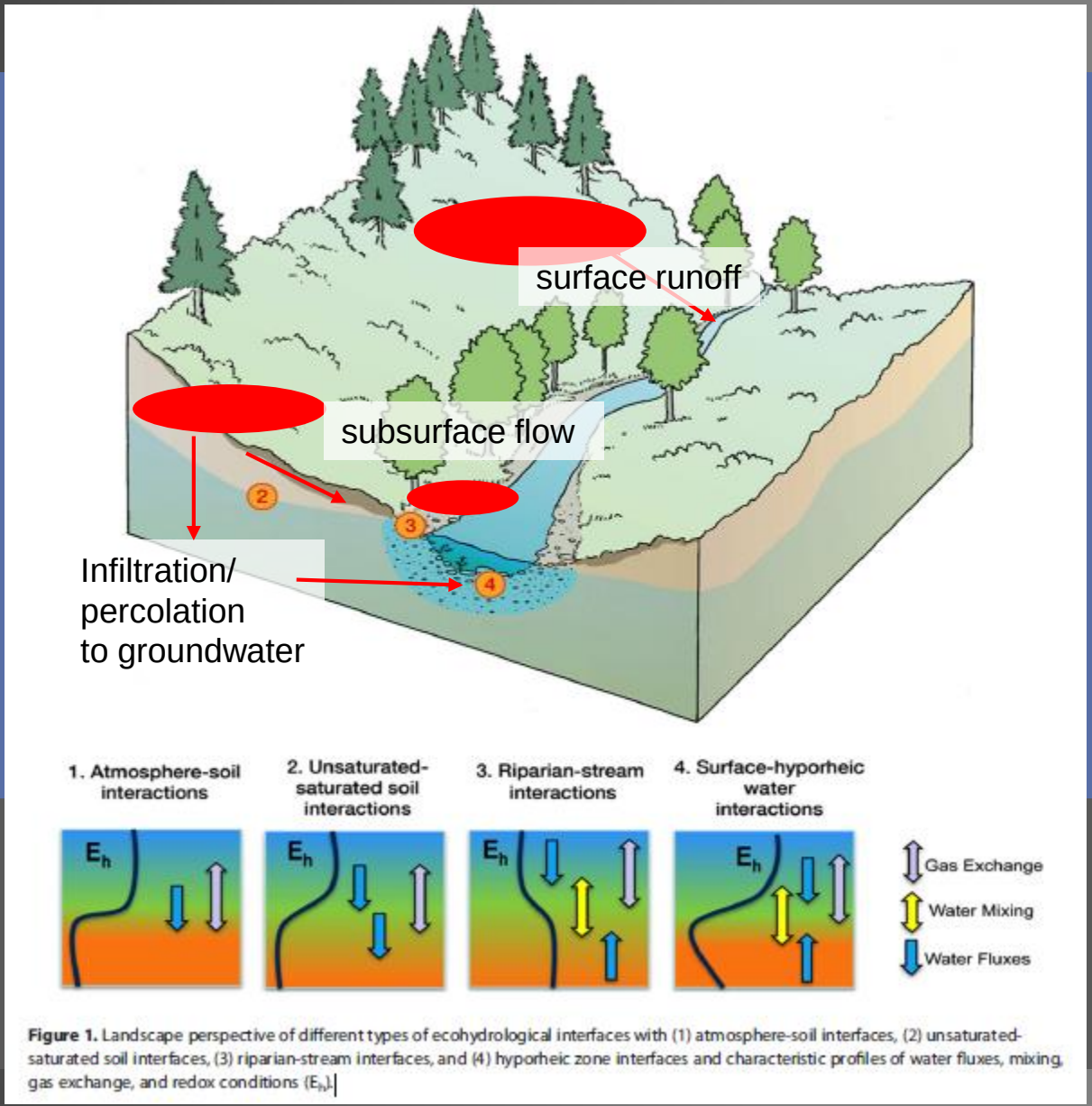


Figure 1. Landscape perspective of different types of ecohydrological interfaces with (1) atmosphere-soil interfaces, (2) unsaturated-saturated soil interfaces, (3) riparian-stream interfaces, and (4) hyporheic zone interfaces and characteristic profiles of water fluxes, mixing, gas exchange, and redox conditions (E_h).

- Effects of disturbance induced OM inputs on soil processes (*e.g.* mineralisation rates, soil nutrient storage and availability, nutrient losses),
-and ecosystem processes and stability (*e.g.* long and short-term feedback cycles)?

Impact of disturbance induced biogeochemical hot spots and moments in landscapes on the chemistry of surface waters.

- depending on its hydrologically connectivity
- landscape topography
- climate related extreme (rain storm) events

Modified Krause, S., et al. (2017), Ecohydrological interfaces as hot spots of ecosystem processes, Water Resour. Res., 53, 6359– 6376, doi:10.1002/2016WR019516.

Thank you!