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## A Critical Zone Observatory for detecting ecosystem transition: the constructed catchment Chicken Creek (Germany)

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### Abstract

The constructed catchment Chicken Creek was established in 2005 as an experimental landscape laboratory for ecosystem research. The 6 ha area with clearly defined horizontal as well as vertical boundary conditions was left for natural primary succession. All Critical Zone elements are represented at this site, which allows the study of most processes occurring at the interface of bio-, pedo-, geo- and hydrosphere. It provides outstanding opportunities for investigating interactions and feedbacks between different co-evolving compartments. The catchment has been extensively instrumented since 2005. Data are recorded with a high spatial and temporal resolution and include hydrological, geomorphological, pedological, limnological as well as biological parameters in order to detect transition states of the ecosystem. In contrast to other Critical Zone Observatories, this site offers the unique situation of an early stage ecosystem with highly dynamic properties. The first years of development were characterized by a fast formation of geomorphological structures due to massive erosion of the initially non-vegetated surface. Hydrological processes led to the establishment of a local groundwater body within 5 years. In the following years the influence of biological structures like vegetation patterns gained increasing importance. Feedbacks between developing vegetation and e.g. hydrological features became more and more apparent. As a result, different phases of ecosystem development have been distinguished.

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## 1. Introduction

Ecosystems may rapidly change state when certain thresholds, tipping-points or break-points are exceeded<sup>1,2</sup>. Therefore, the identification and quantification of such thresholds is urgently needed<sup>3</sup>. Most Critical Zone Observatories (CZO), however, represent mature ecosystems. In contrast, the Chicken Creek CZO (Germany) is an initial, fast developing ecosystem which allows for the observation of ecosystem transition. The evolution of such initial ecosystems is rapid and highly dynamic so that short-term feedback processes and changes of ecosystem behavior can be studied directly. The main focus of the Chicken Creek experiment is on the multidisciplinary study of ecosystem and landscape functioning<sup>4</sup>. It is based on an artificially created watershed left to natural primary succession. Watersheds as the only landscape unit with naturally defined boundaries are often used in interdisciplinary ecological research for very different purposes and at different scales. Usually these sites are naturally developed catchments kept under observation to understand the ecological response to disturbances and manipulations. CZOs based on artificial watersheds are rather rare. The Landscape Evolution Observatory (LEO) in Arizona, USA<sup>5</sup> is the most prominent example which is run under completely controlled environmental conditions. The constructed catchment Chicken Creek, however, offers the opportunity to investigate linkages between abiotic site development and biotic responses and vice versa in a well-defined system at the landscape scale and under real environmental conditions.

## 2. Constructed catchment

The Chicken Creek catchment was constructed as part of the post-mining landscape of the Lusatian lignite mine Welzow-Süd in the State of Brandenburg, in Northeast Germany, about 150 km southeast from Berlin (Fig. 1). The site was built as the headwater of a small stream (*Hühnerwasser*) representing the initial ecosystem development phase of the prevailing Pleistocene landscape conditions. It consists of an area with clear boundary conditions at the surface and in the underground and has both terrestrial and aquatic parts. Detailed descriptions of its internal structures and also of the construction works are summarized in previous publications<sup>6,7</sup>. Generally, the site is constructed as a two-layer system with a clay layer as the aquiclude and an overlying sandy layer as the aquifer. The watershed covers an area of 6 ha. As a unique feature this site was left to natural and unmanaged succession after the construction work was completed in 2005. Floral and faunal patterns are allowed to evolve unrestrictedly. The site is completely fenced off to avoid disturbances by human visitors or the abundant game animals.

## 3. Monitoring program

The Chicken Creek catchment is equipped with a comprehensive ecological monitoring network observing hydrological, pedological, limnological and biological parameters and processes (Fig. 1). Time series of geomorphology, hydrology, soil and water chemistry as well as biotic parameters have been recorded in high temporal and spatial resolution. Immediately after completion of catchment construction in autumn 2005, ecological monitoring techniques were applied to track the development of newly emerging structures. With the surface of the site made as homogeneous as possible, monitoring installations were oriented along a regular 20 m x 20 m grid. As the first phase of soil sampling proved the local Quaternary substrate to be relatively homogenous all further work was undertaken along the same basic grid. Meteorological data are registered by three weather stations in the catchment and groundwater levels are recorded at numerous locations within the catchment, most of them equipped with automatically registering pressure transducers. Two main weirs were installed during catchment construction in order to measure water fluxes. Flumes have been implemented in two main erosion gullies to register continuous base flow from groundwater discharge and episodic run-off events. Both the weirs and one of the flumes are equipped with automated water sampling units taking daily samples for water quality analyses. In addition, soil solution is sampled continuously from four soil pits that were excavated down to the saturated layer. In these pits, boron silicate glass suction plates were installed into the soil. Automated TDR probes and tensiometers are used to measure soil moisture throughout the catchment. Aerial images taken regularly by a micro-drone equipped with a digital camera allow for monitoring of changes in surface structures. Further, the developing vegetation of the study site has been recorded since 2005 once a year at assessment plots along the regular grid.

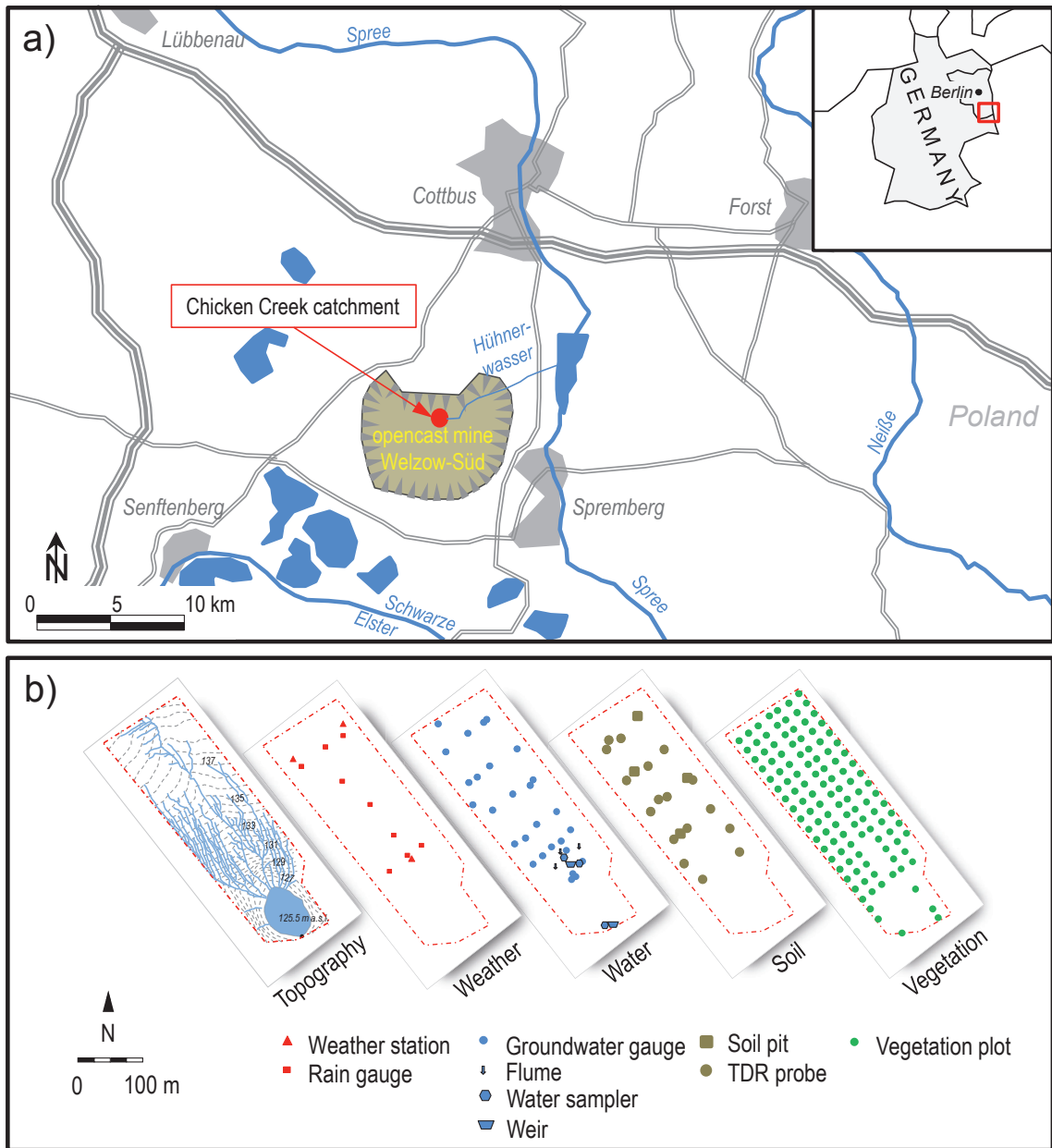


Fig. 1. (a) Location of the Chicken Creek CZO and (b) overview of monitoring instrumentation: Installed devices for meteorological, hydrological and pedological measurements as well as permanent plots for botanical investigations

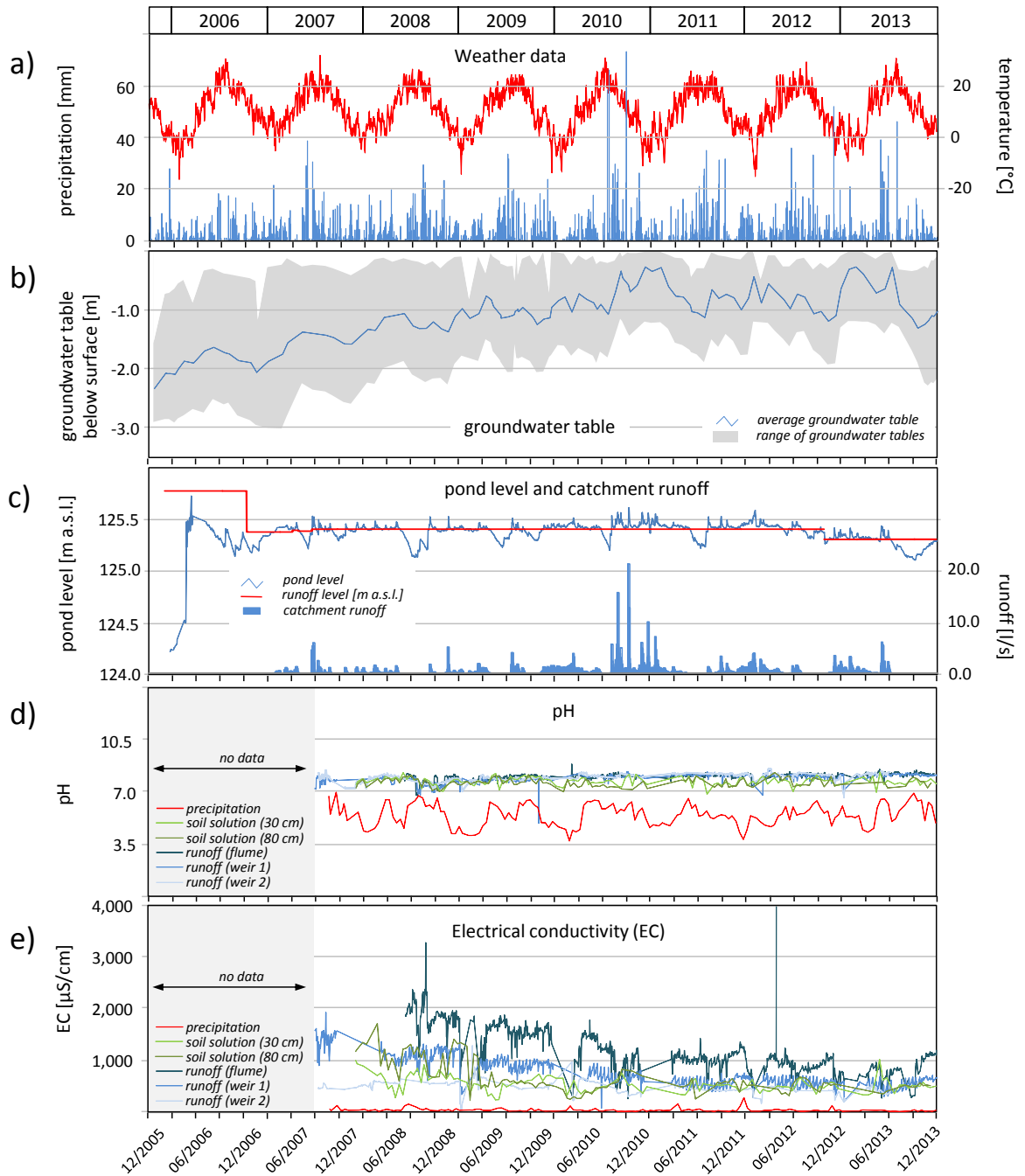


Fig. 2. Time series of the abiotic development of the Chicken Creek CZO: a) measured temperature and precipitation 2005-2013, b) groundwater levels (average and range) below measured 2005-2013, c) pond level (with marked runoff level) and runoff from the catchment, d) acidity of soil solution and surface waters compared to pH of rain water, e) electrical conductivity of soil solution and surface waters compared to rain water.

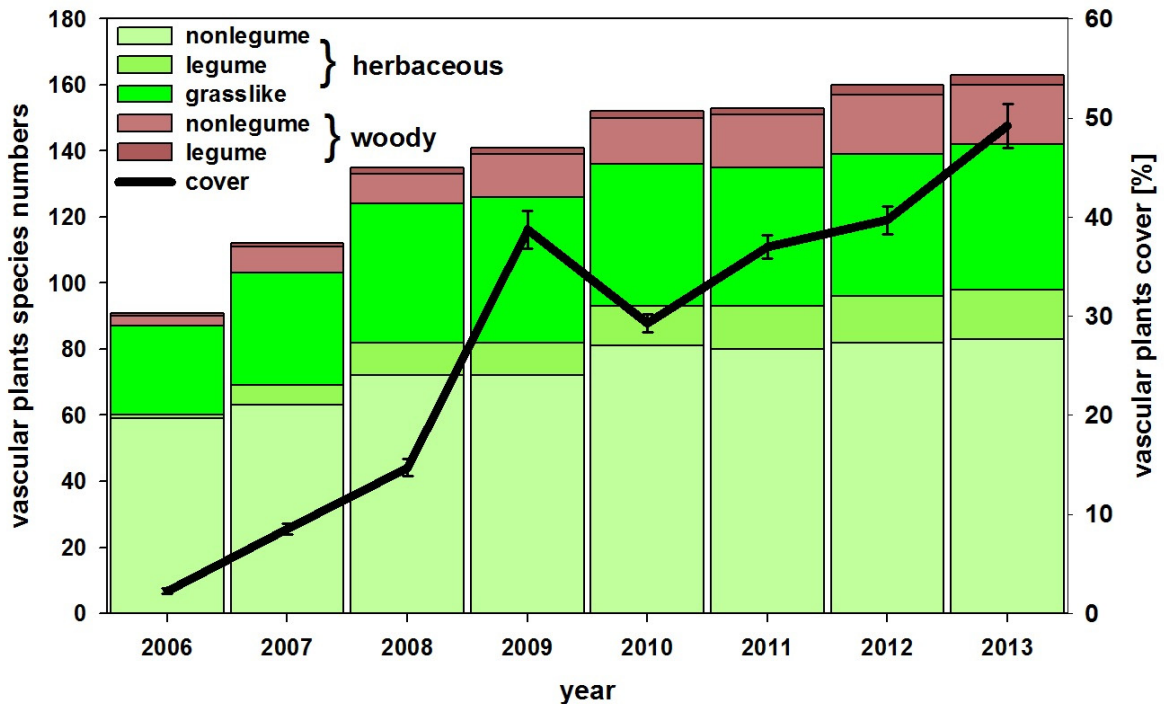


Fig. 3. Time series of the biotic development of the Chicken Creek CZO: Annual number of vascular plant species and total cover of vascular plants (2005-2013)

#### 4. Critical Zone observation at the Chicken Creek catchment

The registered time series (Fig. 2 and 3) demonstrate the dynamic evolution of the system as well as the occurrence of first feedback processes<sup>8</sup>. During the first two years (up to 2007), development of the Chicken Creek catchment was dominated by intensive surface runoff processes, e.g. after episodic heavy rain events or snow melt, resulting in severe sheet and gully erosion causing considerable changes to the initial surface structure. Sediment relocation and the emergence of erosional and depositional structures resulted in rapid surface differentiation. With the development of biological soil crusts<sup>9</sup> and increasingly denser vegetation, the growth of the rill length and stream bed area was disrupted. The saturation of the substrate's pore volume and the establishment of a groundwater body above the clay layer proceeded over several years. Groundwater filling was completed in 2009 when the overall increasing trend of the groundwater table ended and only seasonal fluctuations remained (Fig. 2b) and the runoff from the pond became more pronounced and continuous (Fig. 2c). The again decreasing groundwater tables in 2013 probably indicate the growing influence of vegetation on the hydrology of the catchment.

The pond at the lower end of the catchment integrates most of the hydrological processes occurring within the catchment. A close relationship between the temporal patterns of rainfall and discharge at the pond weir indicates the still initial conditions of the catchment. Due to the carbonate content of the substrates, mean pH values (Fig. 2d) varied between 7.0 and 8.4 in all water and soil solution samples. The decreasing electrical conductivity (EC) of water samples (Fig. 2e) reflects the elution of easily soluble compounds (e.g.  $\text{CaSO}_4$ ) from the sandy substrate. With increasing vegetation cover (Fig. 3) and litter input to the soil, carbonate weathering increased as indicated by higher inorganic carbon (TIC) concentrations in soil solution (increase from <25 mg/l in 2007 to >50 mg/l in 2011 and following years)<sup>4</sup>. Further, during the first years a remarkable differentiation in plant species composition occurred, mainly related to the catchment areas consisting of slightly different substrates. The percentage of woody plants is rapidly increasing (Fig. 3).

## 5. Ecosystem transition and phases of ecosystem development

Considerable changes were observed within the Chicken Creek catchment during the first years of observation. Both internal and external factors could be identified as driving forces of new structures and patterns<sup>10</sup>. Previous hypotheses suggest that the very first phase of ecosystem development is characterized by a still more or less abiotic system developing under the influence of existing structures and external drivers followed by later phases with growing influence of biota<sup>11</sup>. This is in good accordance with the observed phases of ecosystem development in the Chicken Creek catchment<sup>4</sup>: Phase I (2005-2007) was characterized by a very rapid alteration of surface structures due to geomorphic processes. Simultaneously, pioneering biota invaded the site forming early, irregular patterns of scattered populations. This first phase was short in time and highly dependent on initial structures. The following phase II (2007-2009) was defined by a growing importance of hydrologic processes. These processes depend on infiltration of precipitation water. The continued plant colonization caused a significant decline of geomorphic processes as the surface became progressively stabilized by vegetation including biological crusts. Finally, phase III (after 2009) was marked by the gradually growing importance of soil forming processes as well as of biotic interactions and groundwater discharge. Both the interactions between flora and fauna as well as the impacts on their abiotic environment will very likely gain larger influence in the near future.

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