Perspectives on stability and climate change

Ecological stability and temporal dynamics, and the interacting effects of land use and climate change, are emerging scientific perspectives of the Biodiversity Exploratories. These perspectives encourage research into **temporal** patterns of stability, responses to **perturbations** (e.g. by land use or experimental treatments) and climate change and underlying mechanisms, including those indicated by **functional traits** relevant to climate and land-use change. This document aims to summarize concepts and initial findings on stability patterns, mechanisms and climatic trends from research carried out in the Biodiversity Exploratories to date (Fig. 1).

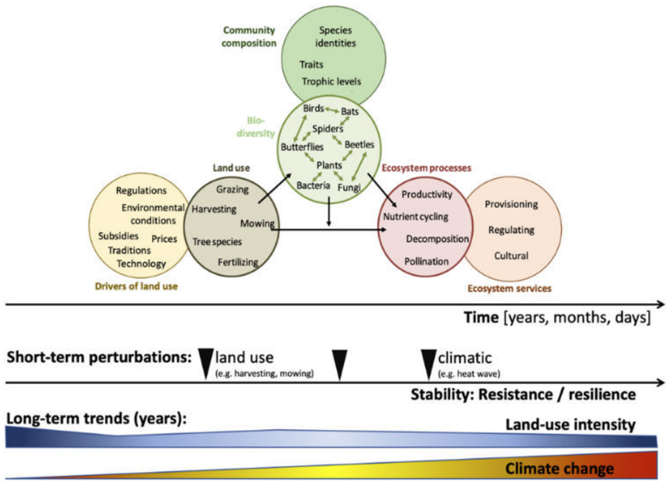

Fig. 1: The conceptual framework of the Biodiversity Exploratories with its main elements, land use, biodiversity and ecosystem processes and services, will be extended by open questions on temporal stability and climate change impacts as an important new perspective – affecting all main elements and their relationships at different time scales. Short-term perturbations include single management practices with machinery (mowing, fertilization, timber harvesting), whereas long-term effects include changes in the frequency of such perturbations and their quality, e.g., changes from extensive pastures to fertilized meadows (see Fig. 4). Important effects of climate change involve pulse perturbations (e.g., drought and heat waves) and their effects at short time scales (days, weeks) as well as long-term trends in temperature and precipitation over several years and decades. We will encourage new projects to contribute to temporal dynamics or climate responses of any relationship studied within the conceptual framework, but also to deepen the framework without explicitly addressing temporal changes.

1. Stability

Stability is a key topic in ecological research but also includes multiple facets, concepts and definitions. Several stability measures aim at temporal trends (Fig. 2), often at an interannual scale of populations and ecosystems. Responses to defined **perturbations** may also occur at much shorter time scales (Fig. 2c). Data for mid- and **long-term trends** of observations in the Biodiversity Exploratories exist, and include monitoring programmes conducted by the core projects and some contributing projects (Fig. 3), as well as trends in land use (Fig. 4) (e.g., Allan et al. 2014, Blüthgen et al. 2016, Seibold et al. 2019, Vogt et al. 2019, Junggebauer et al. 2024). Responses to **experimental** treatments (e.g., Sade, FOX, REX, LUX), to land use activities or environmental changes (e.g. microclimate, see below) may also be related to ecological stability concepts and underlying mechanisms (e.g. Schäfer et al. 2019). Research on stabilizing mechanisms may include well-defined **functional traits**, dynamic processes and **modeling**.

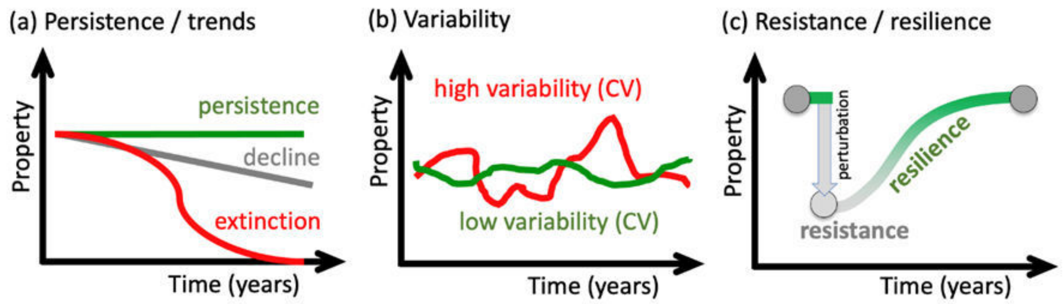

Fig. 2: Commonly used concepts of stability in ecology, focusing on (a) continuous trends (e.g declines) and extinctions, (b) fluctuations (measuring the CV, i.e., the coefficient of variability of a specific ecological property) and (c) dynamic responses to perturbations and subsequent recovery. Important ecosystem properties include population densities, biodiversity or process rates (see McCann 2000, Pimm et al. 2019, Van Meerbek et al. 2021). **Underlying stability definitions**: (a) **Persistence** of populations or processes suggests stability in contrast to declines and extinctions. (b) Low **variability** (CV) in population density or process over time suggests high stability. (c) **Resistance**: low degree of change after perturbation. **Resilience**: short return time to equilibrium (or original state) after perturbation.

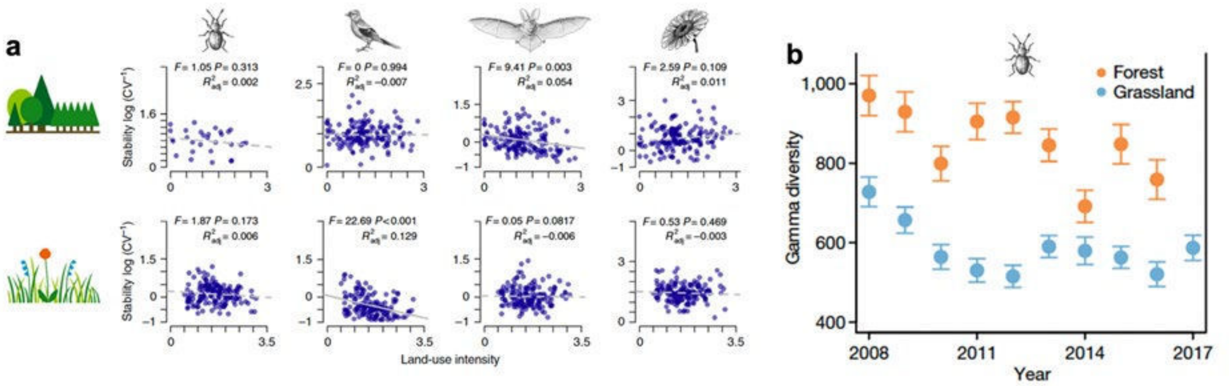

Fig. 3. Examples of interannual changes in the Biodiversity Exploratories: (a) variability in animal and plant species populations (inverse coefficient of variation over 7 years as a measure of stability) and changes in total number of arthropod species in each region for the first 10 years (a: Blüthgen et al. 2016, b: Seibold et al. 2019).

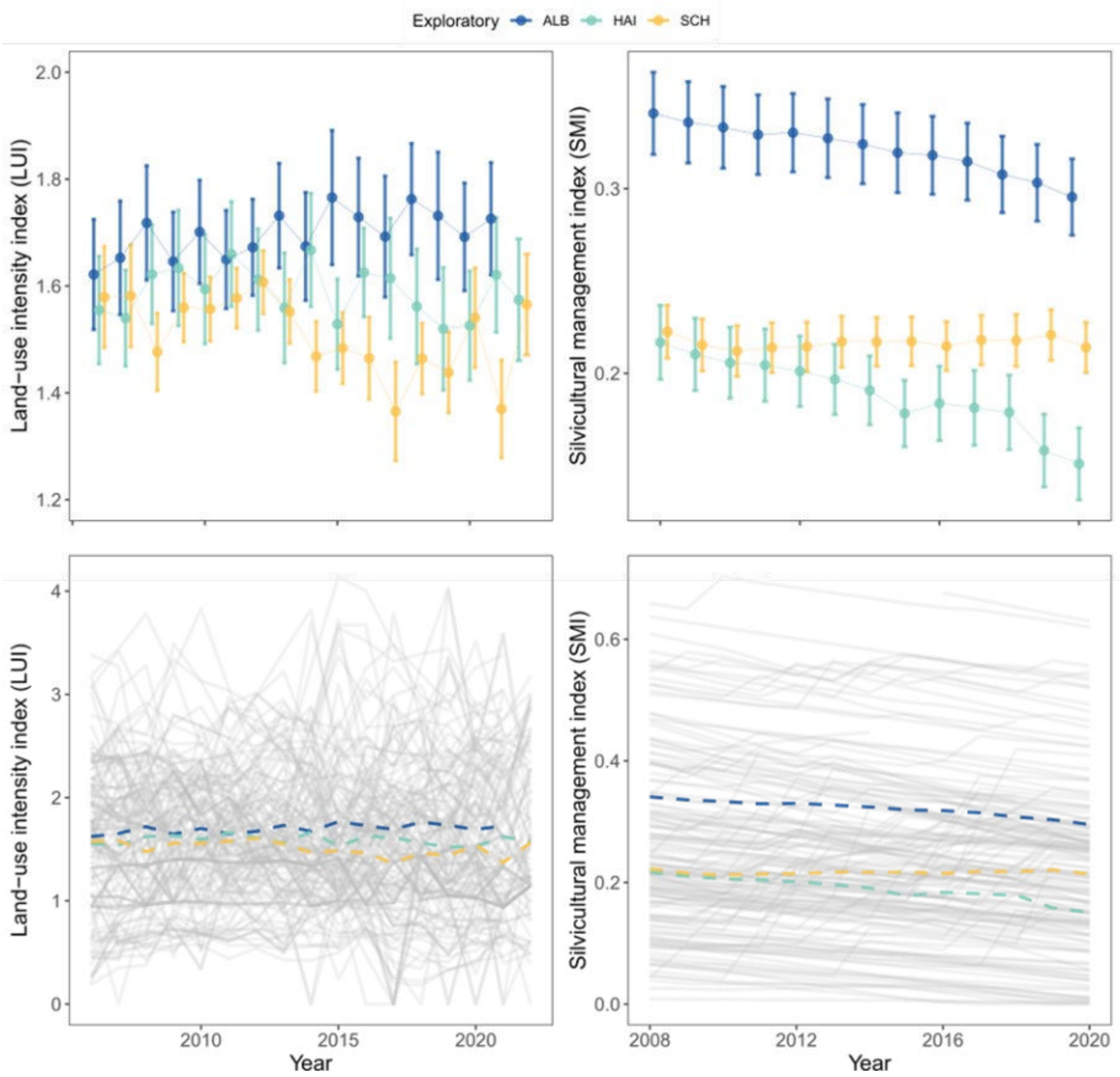

Fig. 4. Temporal change in land-use intensity LUI (left) for grasslands and forest management intensity SMI (right) for each of the 300 EPs (grey) and as an average for the three regions Schwäbische Alb (blue), Hainich-Dün (red) and Schorfheide-Chorin (green).

2. Interacting effects of climate change and land use

Signatures of anthropogenic climate change have become apparent in recent years, as temperature and precipitation showed consistent trends and an increasing number of anomalies in Central Europe. A key objective of the new phase will be to unravel the interacting effects of climate change and land use on biodiversity and ecosystem functions at more local scales.

Trends over 13 years measured by the 300 climate stations in the Biodiversity Exploratories showed an increase in the length of the vegetation period (growing degree days) and a reduction in precipitation, but also strong variation across regions, forest and grassland and plots (Fig. 5). The effect of land use on plot microclimate was pronounced. For instance, high land-use intensity in grasslands, consistent with frequent mowing or intensive grazing that reduces shading potential by the vegetation, increased the soil temperature in summer by ca. 2°C, with consistent effects in a normal and a particular warm year.

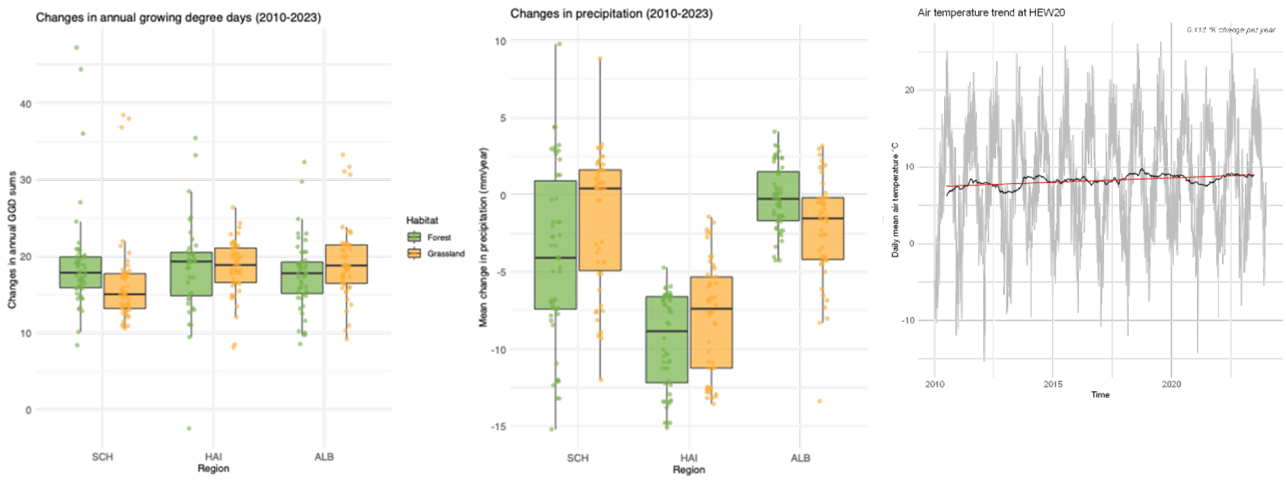

Fig. 5: Climatic trends between 2010 and 2023 in all forest and grassland plots recorded in climate stations. (a) Most sites showed an increase in the number of growing degree days per year, i.e. an increase in the effective duration of the growing season. (b) The change in annual precipitation was variable between sites, but more plots showed a decline in rainfall, particularly in the Hainich. See also Box 4 for additional results. Example: Daily mean air temperature observed at the forest plot HEW 20 in Hainich (gray) with a trend line derived from temporal decomposition (black line) to which a linear model was fitted (red line) to calculate the average trend in °K/year.

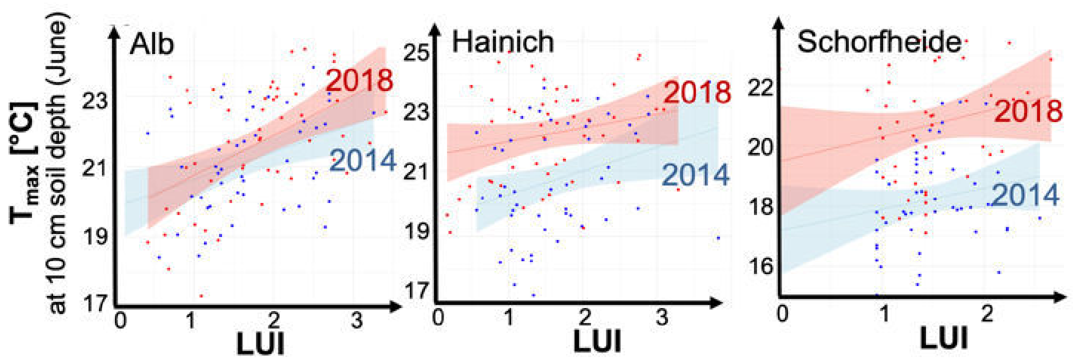

Fig. 6: Effect of land-use intensity (LUI) across 150 grassland plots on average daytime maxima in June at 10 cm soil depth. One relatively 'normal' year (2014) and a particularly warm year (2018) are shown.

Progress in our understanding of the relations between land-use, climate impacts, and stability of biodiversity and ecosystem properties may also be supported by the recently established joint **multi-site experiments** (REX, LUX, FOX), allowing to separate important land-use impacts, e.g. by mowing, fertilization or grazing in grasslands, and by canopy openness and amounts of deadwood and leaf litter in forests – and their interactions with surrounding biodiversity and microclimate (see link on REX, LUX, FOX). One experimental approach of microclimate manipulation is represented by **rain-out shelters** in the BEClimWood experiment (see link on BEClimWood).

All contributing projects can use the platform and **available data** on biodiversity, ecosystem processes and changes in land-use intensity available in BExIS, including time-series data. New research may also explore accessible data from previous phases and replicate previous surveys, while contributing new information, mechanisms, interpretation or modeling.

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