

Space-for-time substitution can predict grassland biodiversity dynamics

We showed the robustness of space-for-time substitutions in approximating temporal biodiversity responses of German grasslands to land-use intensification, which is a major driver of biodiversity decline. Our research calls for more standardized temporal data to fine-tune approximated biodiversity trends.

This is a summary of:

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The problem

Land-use intensification is one of the most important drivers of biodiversity decline and is putting around 15% (about 1 million) of the world's species at risk of extinction¹. Although the scientific community agrees that biodiversity is declining at the global scale, a debate remains active about the extent of biodiversity declines at regional and local scales, as different approaches to estimating biodiversity decline show different patterns^{2–4}. Ideally, biodiversity trends should be derived from observations in permanent plots over time. However, as biodiversity time series are rare, the most common approach is to infer temporal trends from spatial gradients: the so-called space-for-time-substitution approach. Comparing biodiversity responses to major drivers such as land-use intensification from time series and space-for-time approaches has rarely been attempted but could help to resolve the ongoing debate and deal with problems inherent to both approaches.

The observation

We tested whether space-for-time substitution and time-series approaches revealed the same responses of plant and arthropod biodiversity to land-use intensification. We used 11-year time series from 150 German grasslands surveyed in the [Biodiversity Exploratories](#) project. Such large-scale biodiversity projects that have operated for several years provide a unique opportunity to analyse spatial and temporal trends in the same plots. Space-for-time approaches infer land-use effects on biodiversity by comparing grasslands that differ in overall land-use intensity (that is, they use spatial variation in land use)⁵. Given substantial changes in land use across 11 years of monitoring (2008–2018), we were also able to test whether biodiversity responds similarly to temporal changes in land use within these grasslands and to spatial variation in land use between grasslands.

We show that land-use intensification across both space and time resulted in a decline in plant and arthropod biodiversity. The shape and direction of biodiversity response both in space and time was generally similar (Fig. 1), which supports the value of spatial data for estimating changes in biodiversity following land-use intensification. However, we found that the magnitude of biodiversity response was smaller with changes in

time than with changes in space (Fig. 1). This difference probably arises because temporal changes in land use were smaller than spatial ones, and because the effect of temporal changes on biodiversity may take several years to show up. Our research highlights the robustness of using space-for-time approaches to estimate temporal trends in biodiversity, but also calls for more standardized temporal data to capture delayed biodiversity responses and reliably measure biodiversity changes over time.

The implications

We found overall agreement between space-for-time substitution and time-series approaches in the direction and shape of land-use intensification effects on the diversity of plants and arthropods. The agreement we found, even using short time series, is promising as it indicates that commonly available spatial datasets can be used to identify drivers of past biodiversity changes and to predict future changes. Although similar studies on other habitats, landscapes, regions and taxa would be required to generalize our results to other systems, our findings should be relevant to most European grassland systems.

In contrast to the direction of biodiversity responses, the magnitude of biodiversity responses differed considerably in space and time, possibly owing to differences in the studied length of land-use gradients but also because of lagged biodiversity responses to land-use intensification in time. These two potential reasons for mismatch in the magnitude of biodiversity responses makes it challenging to assess whether the land-use effects that we find across space accurately represent the degree of diversity loss that has occurred following the green revolution. Properly assessing this question requires a more in-depth analysis of temporal biodiversity dynamics, with larger environmental gradients and longer-term population dynamics.

The next step will be to assess the congruence of spatiotemporal changes of biodiversity in response to multiple drivers (including climate change) and their interactions across a wide range of taxa, from bacteria to vertebrates, in grasslands and other ecosystems.

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EXPERT OPINION

"This study provides a valuable comparison of insights into the biodiversity impacts of land-use intensification that are detectable over space and time. I agree with the authors that such comparisons are conducted very

rarely and could be extremely useful for establishing the reliability of inferences gained via space for time substitution."
Ally Phillimore, University of Edinburgh, Edinburgh, UK.

FIGURE

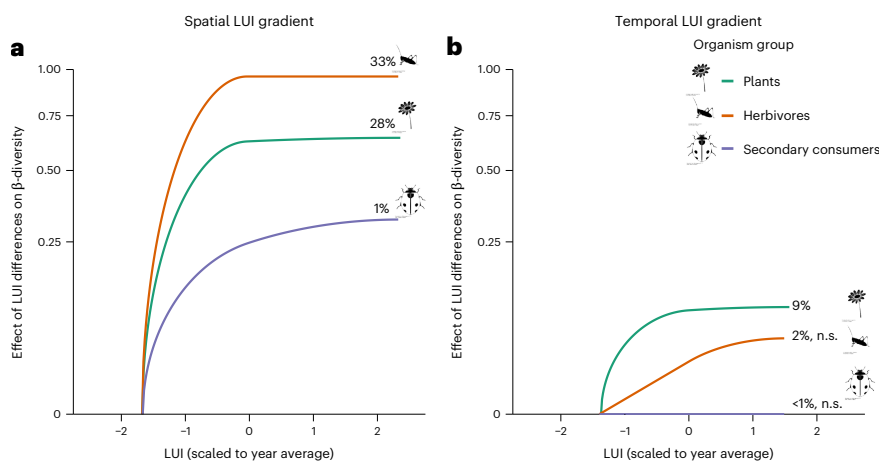


Fig. 1 | Spatial and temporal biodiversity responses to land-use intensity. a,b. Line graphs from the generalized dissimilarity models show the cumulative effects of differences in spatial (a) and temporal (b) land-use intensity (LUI) on species beta-diversity (y axis) along the LUI gradient (x axis). Spline maxima represent the total effect size of LUI variation on beta-diversity. Percentages of deviance uniquely explained by LUI in proportion to the total explained variation by LUI and year or spatial distance between plots are shown on the top of each line. n.s., not significant. Icons © Noun Project artists (CC BY 3.0): Farra Nugraha (flower); Alum Design (grasshopper); N.C. Srirangara (ladybird). © 2025, Neuenkamp, L. et al.

BEHIND THE PAPER

This study is synthesis work of the large-scale, long-term biodiversity project 'Biodiversity Exploratories' funded by the German Research Foundation. When we started this study, in 2020, spatially well-replicated biodiversity time-series of 10–11 years were available with accompanying land-use information. What a great opportunity to look into temporal dynamics and validate the many studies on spatial biodiversity dynamics and drivers

coming from this and other projects. During the visit of M. Gossner, a collaborator in the project and co-author of the present study, the idea emerged to investigate these things by comparing the spatial patterns of land-use effects on biodiversity he had found⁵ to the corresponding temporal ones. And so, our journey began by learning the complex and very useful tool of general dissimilarity modelling and applying it across trophic groups. **L.N.**

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This article presents an example of large-scale multitrophic biodiversity decline due to land-use intensification using space-for-time substitution, and was the starting point of the present study.

FROM THE EDITOR

"The reliability of space-for-time substitution approaches as compared with time series has been and still is heavily debated in ecology. Here, the authors test this using multitrophic data from the Biodiversity Exploratories project in Germany. The debate on space-for-time versus temporal approaches is of broad interest and this analysis is a rigorous take on it." **Editorial Team, Nature Ecology & Evolution.**