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Spatial variation in determinants of agricultural land abandonment in Europe

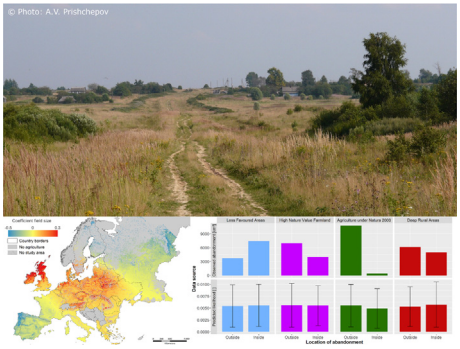
Christian Levers [a,*], Max Schneider [a,b], Alexander V. Prishchepov [c,d,e], Stephan Estel [a,f], Tobias Kuemmerle [a,g]

[a] Geography Department, Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany
[b] Department of Statistics, University of Washington, Box 354322, Seattle, WA 98195-4322, USA
[c] Section of Geography, Department of Geosciences and Natural Resource Management, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark
[d] Institute of Environmental Sciences, Kazan Federal University, Tovarisheskaya str. 5, Kazan 420097, Russia
[e] Institute of Steppe of the Ural Branch of the Russian Academy of Sciences, Pionerskaya str.11, Orenburg 460000, Russia
[f] Department of Earth & Environment, Boston University, 685 Commonwealth Avenue, Boston, MA 02215, USA
[g] Integrative Research Institute on Transformations of Human-Environment Systems (IRI THESys), Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany

HIGHLIGHTS

- Agricultural abandonment is a common land-use trend in many regions worldwide.
- We identified the leading spatial determiants of abandonment patterns in Europe.
- We used model-based boosting that accounts for spatial variation in the data.
- Abandonment mainly explained by climate, farm management, and socioeconomic setting.
- Context-specific, regionalised policies needed to mitigate abandonment outcomes.

GRAPHICAL ABSTRACT



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ABSTRACT

Agricultural abandonment is widespread and growing in many regions worldwide, often because of agricultural intensification on productive lands, conservation policies, or the spatial decoupling of agricultural production from consumption. Abandonment has major environmental and social impacts, which differ starkly depending on the geographical context, as does its potential to serve as a land reservoir for recultivation. Understanding determinants of abandonment patterns, and especially how their influence varies across broad geographic extents, is therefore important. Using a pan-European map of agricultural abandonment derived from MODIS NDVI time series between 2001 and 2012, we quantified the importance of farm management, climatic, environmental, and socio-economic variables in explaining abandonment patterns. We chose a machine learning modelling framework that accounts for spatial variation in the relationship between abandonment and its determinants. We predicted abandonment probability as well as determinant coefficients for the entire study area and summarised them for regions under selected EU support schemes. Our results highlight that agricultural abandonment was mainly explained by climate conditions suboptimal for agriculture (i.e., low/high growing degrees days). Determinants related to farm management (smaller field size, lower yields) and socio-economic conditions (high unemployment, negative migration balance) also contributed to describing agricultural abandonment patterns in Europe. Several determinants influenced abandonment in strongly non-linear ways and we found substantial spatial non-stationarity effects, although abandonment patterns were equally well-explained by predictors

* Corresponding author.
E-mail addresses: christian.levers@geo.hu-berlin.de (C. Levers), maxs15@uw.edu (M. Schneider), alpr@ign.ku.dk (A.V. Prishchepov), estelste@bu.edu (S. Estel), tobias.kuemmerle@hu-berlin.de (T. Kuemmerle).

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specified with spatially constant and varying effects. Predicted abandonment probability was similar inside and outside EU support or conservation zones, whereas observed MODIS-based abandonment was generally higher outside these zones, suggesting that schemes such as Natura 2000 or High Nature Value Farmland likely influence abandonment patterns. Our work highlights the potential value of spatial boosting for gaining insights into land-use change processes and their outcomes, which should increase the ability of such models to inform context-specific, regionalised decision making.

1. Introduction

Agriculture is the dominant land use on Earth, currently covering approximately 40% of the terrestrial surface (Ramankutty et al., 2008). As the global demand for agricultural products will increase over the next decades (Garnett et al., 2013; Tilman et al., 2002), assessing how to achieve these increases while minimising agriculture's environmental impacts has become a central challenge (Tscharntke et al., 2012; Tilman et al., 2011; Godfray et al., 2010).

Despite the rising demand for agricultural products and an increasing scarcity of land suited for cropland expansion, there is also a strong trend of agricultural abandonment globally, particularly in developed countries (Cramer et al., 2008; Ellis et al., 2013). Agricultural abandonment can generally be described as the ceasing of agricultural activities on croplands and grasslands with subsequent natural vegetation recovery (Prishchepov et al., 2012b; MacDonald et al., 2000; Keenleyside and Tucker, 2010), with potential restoration of forests in temperate and boreal regions (Stanturf and Madsen, 2002), grasslands in steppe-like environments (Brinkert et al., 2016), and shrubby vegetation in the Mediterranean (Rey-Benayas et al., 2010). Estimates of abandoned agricultural area range between 385 and 472 Mha for the period 1700 to 2000 CE, of which the predominant majority occurred during the second half of the 20th century (Campbell et al., 2008; Cramer et al., 2008), with approximately 120 Mha of abandonment in Europe since 1990 (FAOSTAT, 2017).

Agricultural abandonment can have positive and negative impacts. It improves non-provisioning ecosystem services such as increased carbon storage (Schierhorn et al., 2013; Kuemmerle et al., 2011; Kurganova et al., 2015), soil recovery, and water regulation (Rey Benayas et al., 2007). Moreover, agricultural abandonment can increase biodiversity or the recreational value of landscapes (Navarro and Pereira, 2012; Ceauşu et al., 2015). However, agricultural abandonment can also lead to the loss of farmland biodiversity and cultural landscapes (Fischer et al., 2012; Beilin et al., 2014; Plieninger et al., 2014) as well as to soil erosion (Stanchi et al., 2012) and increased fire frequency and intensity (Dubinin et al., 2011; Rey Benayas et al., 2007). As these impacts vary across geographical regions, a sound understanding of where and why agricultural abandonment occurs is needed to assess the recultivation potential of those abandoned areas, especially where they may limit or provide recultivation options. For example, where abandonment happened in areas of good agro-ecological conditions, such as in parts of the former Soviet Union after the collapse of communism in 1991 (Baumann et al., 2011), recultivation of some of those areas may help to address the future demands for agricultural products (Schierhorn et al., 2013; Saraykin et al., 2017).

Recently, substantial progress has been made to map agricultural abandonment using remote sensing (Estel et al., 2015; Alcantara et al., 2013; Löw et al., 2015). Moreover, many case studies exist that investigated and identified determinants of agricultural abandonment, often relying on regression analyses. Some studies emphasised that farm management variables, such as inputs, yields, or farm structure, determine abandonment patterns, for example in Romania (Müller et al., 2013) or European Russia (Prishchepov et al., 2013; Ioffe et al., 2004). Other studies highlight the importance of environmental variables, such as soil quality, precipitation, or temperature, to explain abandonment patterns, both at broader and finer scales. While broad-scale climatic determinants, such as water limitations, explained abandonment patterns in Southern and Eastern Europe (Arnaez et al., 2011; Gellrich et al., 2007; Hatna and Bakker, 2011), abandonment patterns were also explained by local environmental variables, such as rugged terrain in Albania and Romania (Müller et al., 2013) and poor soils in the Swiss mountains (Gellrich and Zimmermann, 2007). In contrast, several studies accentuated that socio-economic conditions determine abandonment patterns, for instance rural depopulation in Spain (Stellmes et al., 2013) or limited market accessibility in European Russia (Prishchepov et al., 2013, Ioffe et al., 2004).

A key problem for synthesising from the rich case study evidence is that their results are often contradictory at broader scales, impeding the transferability of results from one area to another. Meta-analyses can address this issue of generalisability (Rey Benayas et al., 2007; van Vliet et al., 2015) and recent studies found that factors reducing the profitability of farming, such as limiting agro-environmental site conditions (e.g., poor soils) and economic settings (e.g., commodity prices, support payments), were most important to explain abandonment in Europe. In contrast, location factors (e.g., elevation, remoteness), institutional setting (e.g., land ownership, tax regimes), and farm(er) characteristics (e.g., farm income, land mismanagement) were less important (Keenleyside and Tucker, 2010; van Vliet et al., 2015; Rey Benayas et al., 2007). External factors, such as migration and public policies, act as triggers for abandonment in Europe, while internal causes, such as agro-ecological and socio-economic conditions, control abandonment patterns and extent (Lasanta et al., 2017).

Notwithstanding the importance of meta-analyses for generalisation, they cannot overcome limitations of the study design of individual case studies. Land-use change in general, and agricultural abandonment in particular, are complex spatial processes. These processes are often characterised by non-linear predictor effects on the target variable (i.e., local minima/maxima or potential thresholds that are characterised by steep and quick changes in the relationship between predictor and target variable; e.g., Levers et al., 2014), spatial autocorrelation of the target variable (i.e., neighbourhood effects and self-reinforcing phenomena; e.g., Overmars et al., 2003), or spatial variability of predictor effects (i.e., relationships between target variable and predictors that change across space; e.g., Fotheringham, 1997, Brunsdon et al., 1998). All of these complicate modelling, as an independent target process cannot be assumed. Several methods exist to address these spatial characteristics, such as generalised linear mixed models (spatial autocorrelation; Bolker et al., 2009), geographically weighted (ridge) regression (spatial non-stationarity; Brunsdon et al., 1998, Wheeler, 2007), or decision tree based models (non-linearity; Elith et al., 2008). Unfortunately, existing case studies often neglect one or more of these important spatial data features (Hothorn et al., 2011) and meta-analyses thus cannot control for them in retrospect. Generalisation via meta-studies is furthermore hindered by the diverse spatial and temporal resolutions and/or extents over which case studies were carried out. Both could describe diverging explanations for abandonment often found in case studies and this leaves a clear knowledge gap regarding our understanding of abandonment. What is needed are consistent, spatially explicit studies of abandonment across large spatial extents.

Here, we addressed this knowledge gap by modelling agricultural abandonment using a model-based boosting approach that allows the use of spatially constant and varying coefficients (hereafter referred to